In-Pile Sub-Miniature Fission Chambers Qualification Under PWR Conditions

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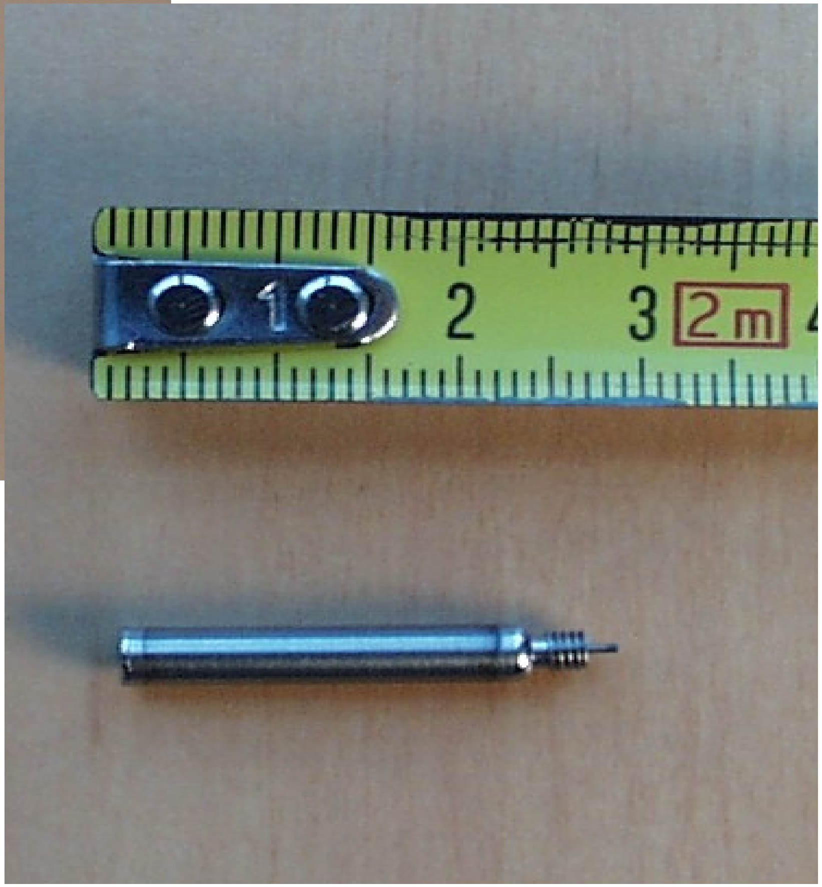
The in-core instrumentation Lab at CEA/Cad

- **At the Cadarache CEA center, there is a laboratory involved in the <u>development</u> (design, qualification) and <u>manufacturing</u> of special miniature Fission Chambers for Research and Power Reactor needs :**
  - **Cylindrical 4mm and 8mm FC with various fissile deposits (^{232}Th ^{233}U, ^{235}U, ^{238}U, ^{237}Np ,^{238}Pu, ^{239}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am, etc.)**
  - **Special geometries : e.g. back-to-back or triple-body FC**
  -  **: 1.5mm in diameter**

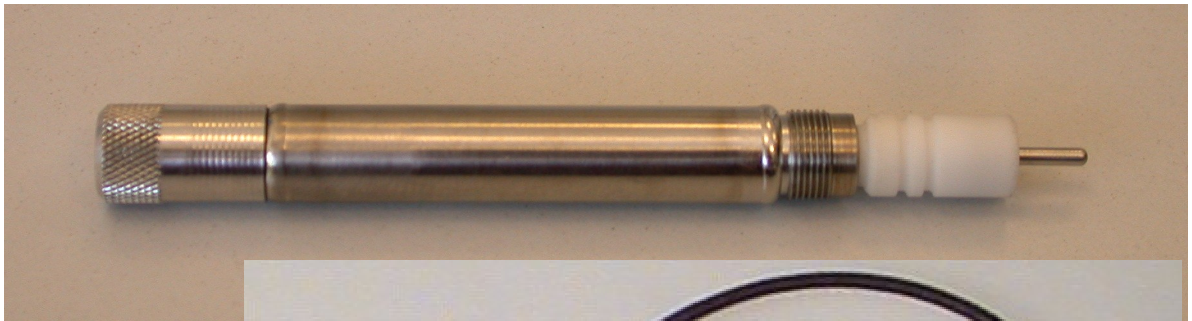
Actinide deposit by electrolysis in a glovebox

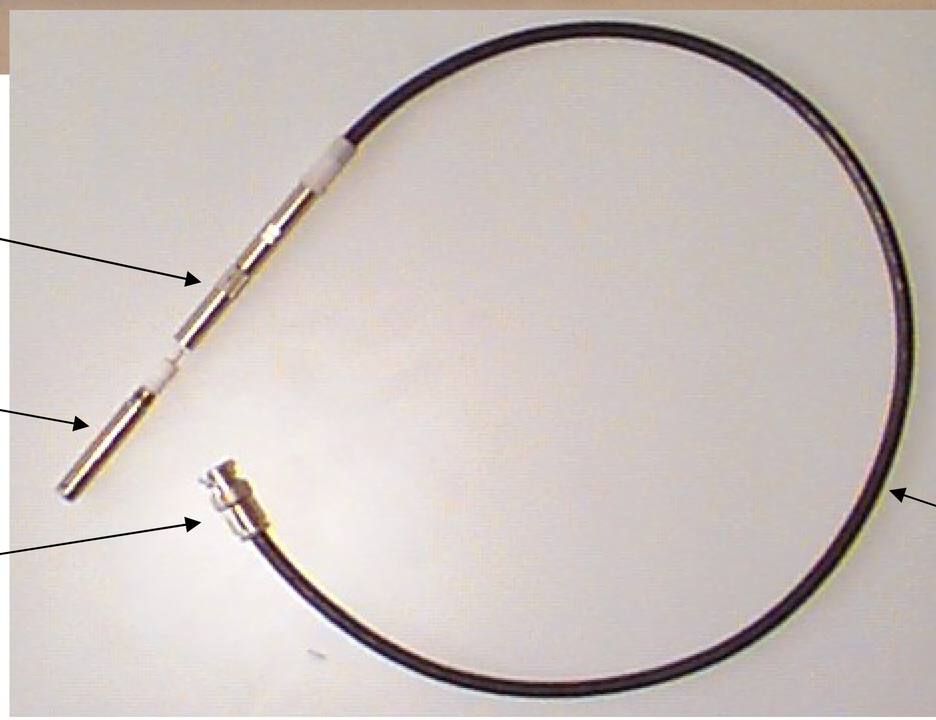
FC with special actinide coatings for critical facilities (1)



Ø4mm fission chamber
(pulse mode)

FC with special actinide coatings for critical facilities (2)





Special connector

8 mm-FC

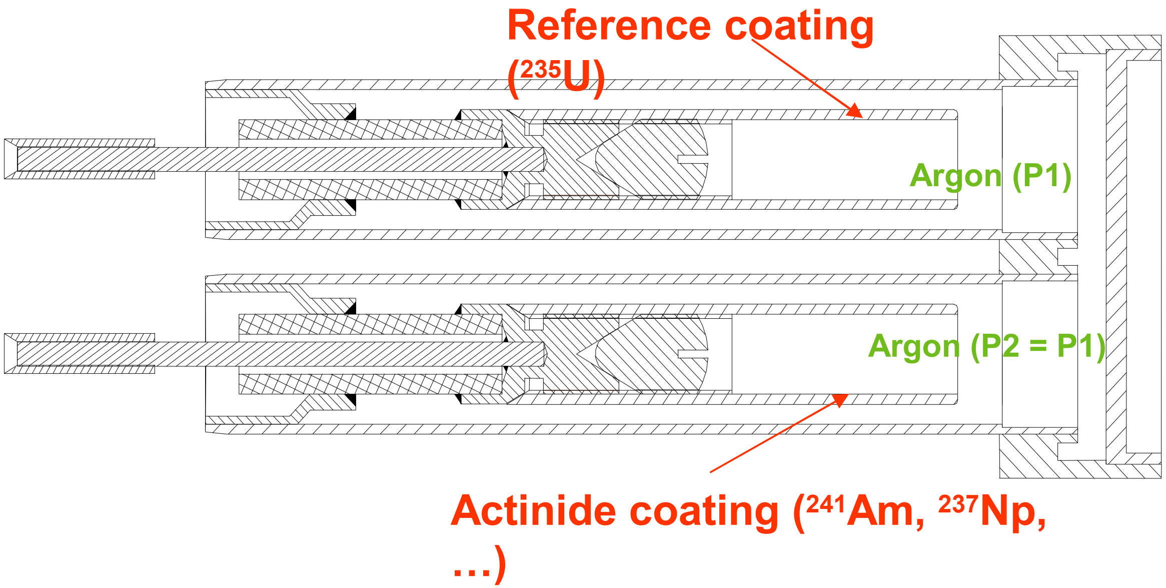
BNC connector

Organic cable

Ø8mm fission chamber (pulse mode)

Special geometries: multiple bodies (same filling gas)

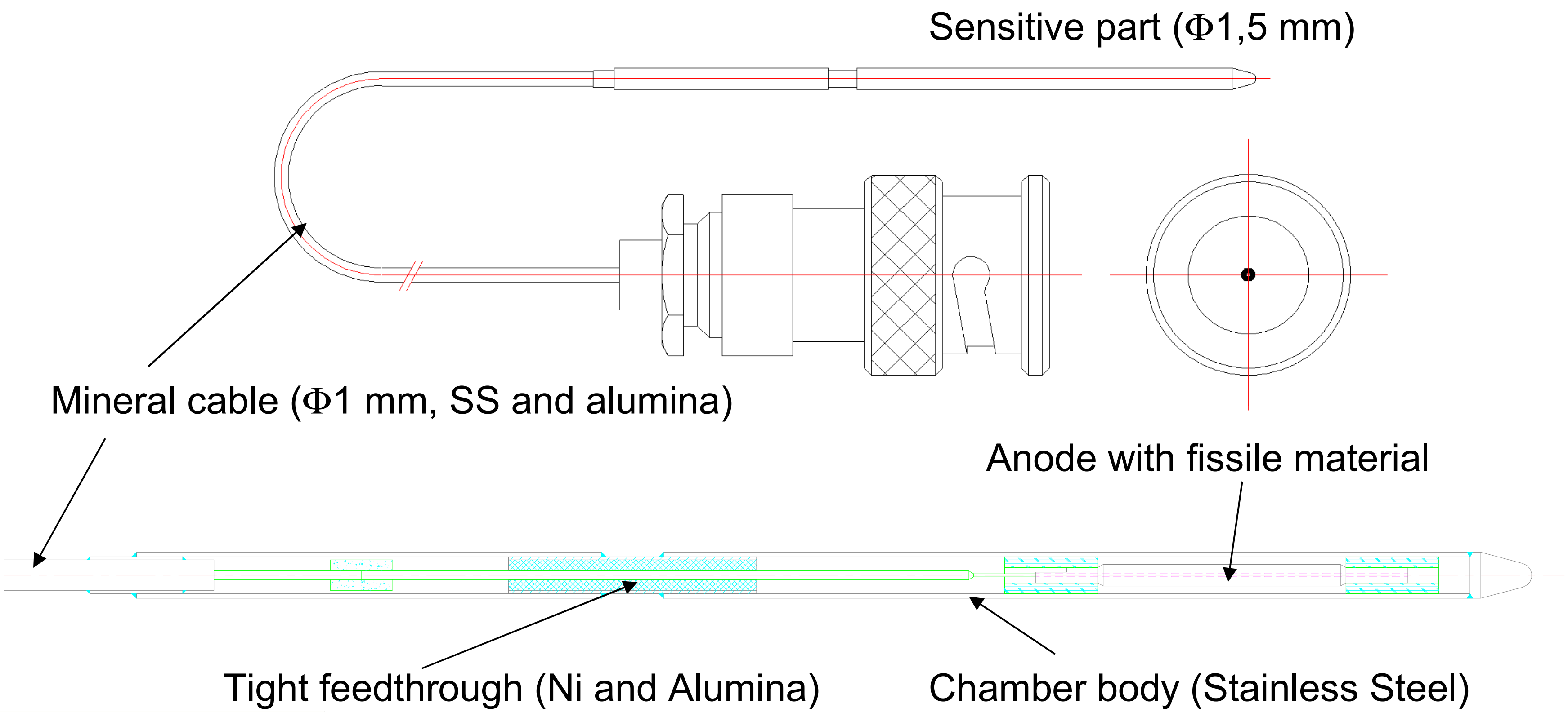
“Back-to-back” FC:
Actinide + reference



“Triple-body” FC:
Actinide + reference
+ no coating (gamma)

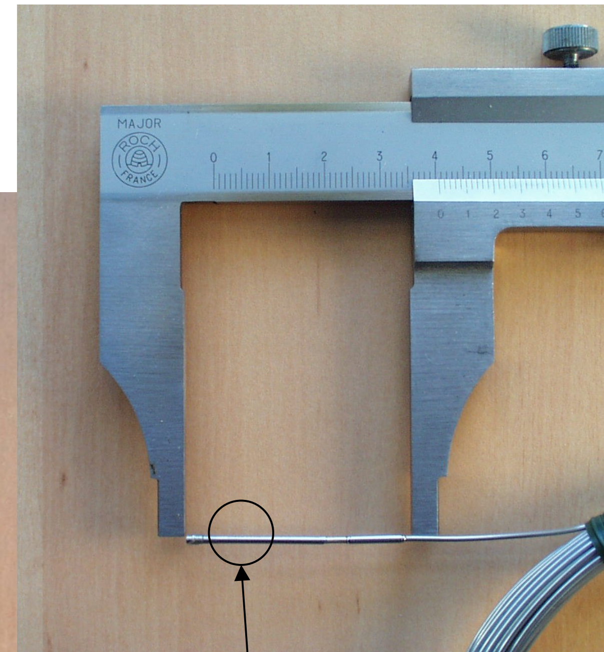
Ø1.5mm "Sub-Miniature" Fission Chambers (SMFC)

•**Detector dedicated for « high neutron flux » measurements (in-core) :** Current mode operation



Ø1.5mm Sub-Miniature Fission Chambers (SMFC)

Mineral cable (Φ1 mm, SS and alumina)



Sensitive part
(Φ1,5 mm ; L = 12 mm)

SCK/CEA "FICTIONS" program of SMFC development and qualification

•FICTIONS experiments in the BR2 reactor:

- **FICTIONS = FIssion Chamber Testing in Ordinary Neutron Spectra**
- **SCK/CEA collaboration for the SMFC development and qualification in the BR2 reactor (SCK-Mol)**

•Two qualification programs :

- **FICTIONS 1, 3, 5, 7 (odd numbers as "235"):**
  - ^{235}U SMFC for **thermal** flux measurement
- **FICTIONS 2, 4, 6, etc. (even numbers as "242"):**
  - ^{242}Pu SMFC for **fast** flux measurement

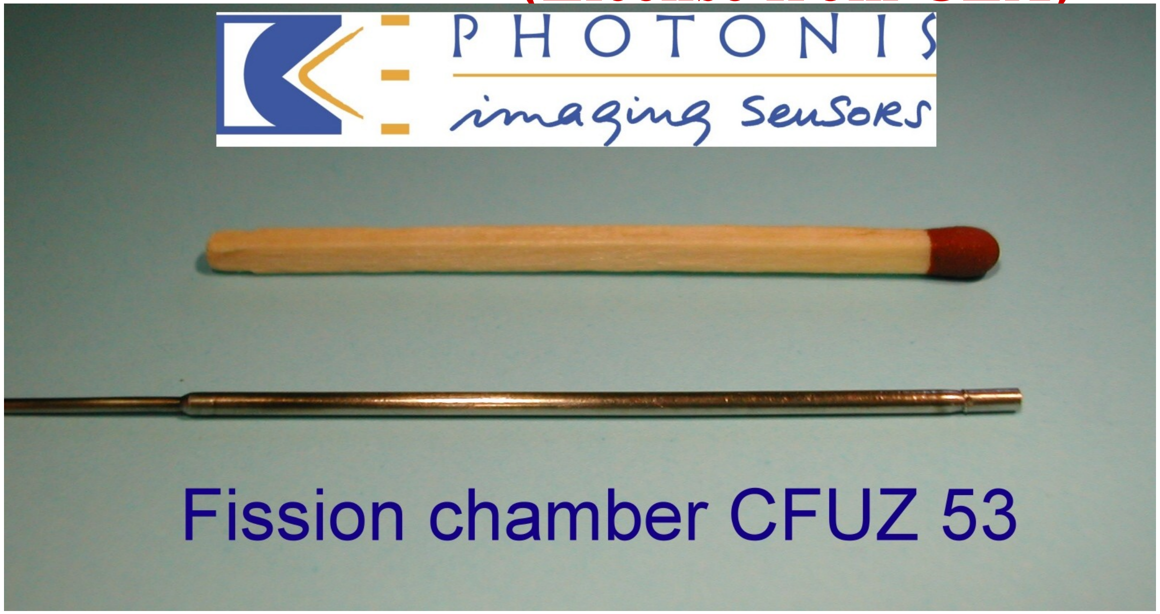
Qualification of ^{235}U SMFC for thermal flux measurement

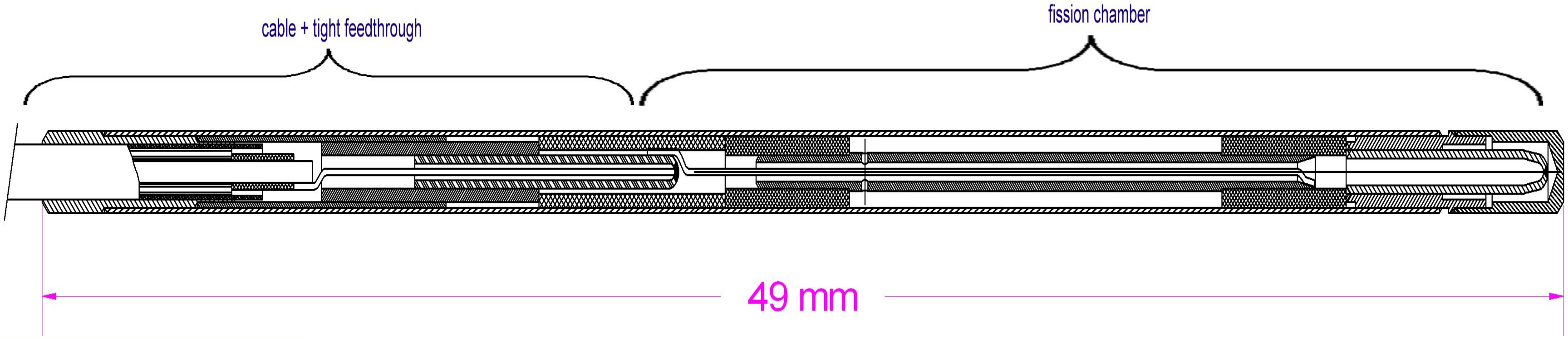
- **FICTIONS 1 experiment (2001-2002):**
  - **Qualification of CEA prototypes in the BR2 poll water**
    - T = 40 – 80°C, thermal fluence ≈ 3×10^{21} n/cm^2
- **FICTIONS 3 experiment (2003-2004):**
  - **Qualification of CEA prototypes under PWR conditions (CALLISTO loop)**
    - T = 300°C, P = 155 bar, thermal fluence ≈ 10^{21} n/cm^2

- **FICTIONS 5 experiment (2005):**
  - **Qualification of industrialized PHOTONIS prototypes (CFUZ53) under PWR conditions**

- **FICTIONS 7 experiment (2006-2007):**
  - **Long term qualification of CFUZ53 under PWR conditions**
    - 10 BR2 cycles ≈ 4 PWR cycles

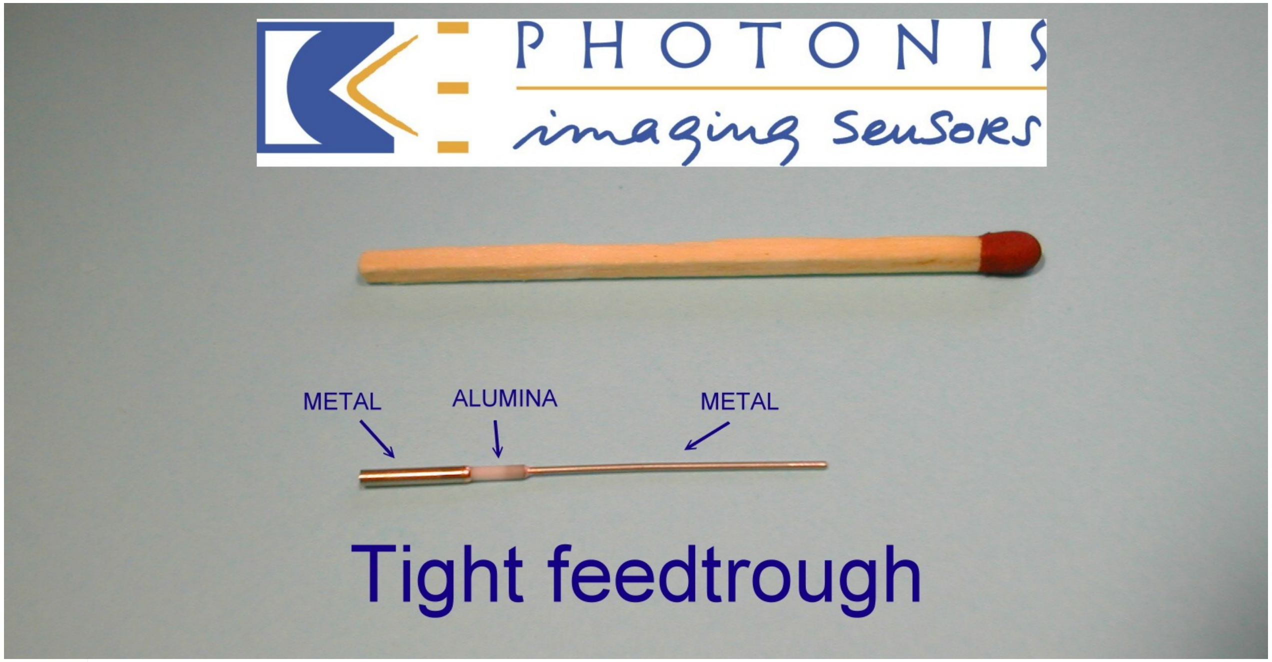
CFUZ53 : ^{235}U SMFC industrialized by PHOTONIS (License from CEA)





Sub-miniature CFUZ53 manufacturing

- **Industrialization process carried out by PHOTONIS:**
  - Miniature tight feedthrough manufacturing : metal/ceramic/metal brazing
  - Uranium deposit on an electrode as small as 0.7mm in diameter
  - Assembly and TIG soldering of very small parts



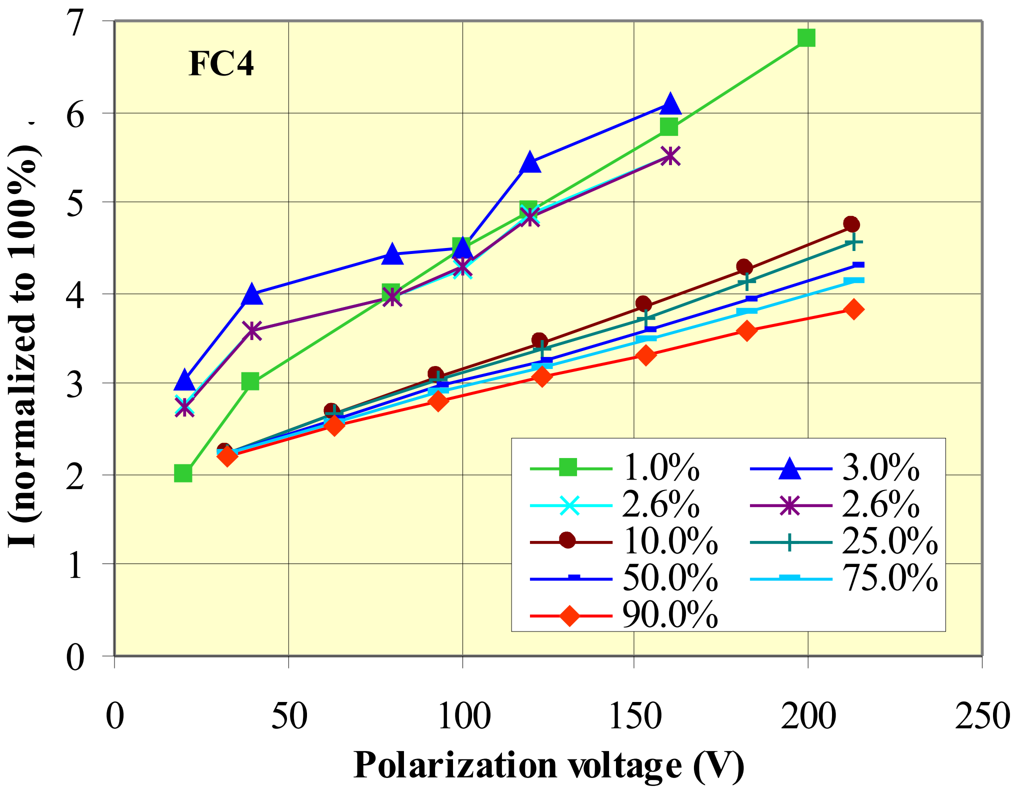
FICTIONS 5 experimental conditions

- **Experimental device**
  - 2 CFUZ53, 50µg $_{235}$U, P=1.1 bar (argon) : FC5 & FC6
  - 1 CFUZ53 without fissile deposit, P=1.1 bar (argon) : FC4
  - 1 Rh-SPND
  - 1 gamma thermometer
  - 1 K-type thermocouple
- **CALLISTO loop : PWR conditions (P, T, water chemistry)**
  - 260°C – 300°C
  - 155 bars
- **Irradiation conditions (56 MW full power, T=290°C)**
  - Thermal neutron: 6E13 nv0(at 2200 m/s), 1.1E14 n/cm²/s real (SPND measurement)
  - Epithermal neutron: 6E12 n/cm²/s (calculated)
  - Fast neutron : 5E13 n/cm²/s (calculated)
  - Gamma: 1.2 W/g (gamma thermometer measurement)

FIC5 Results (1) : noise measurements

•CFUZ53 without fissile coating :

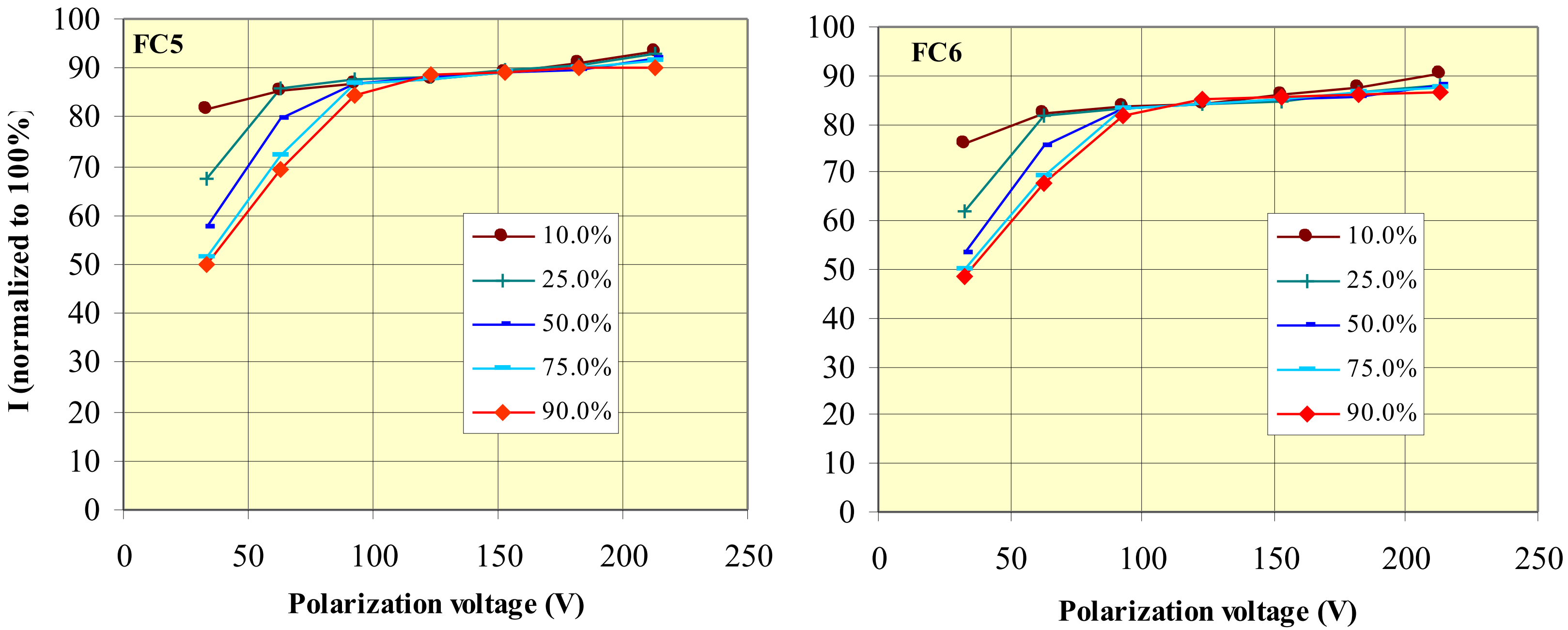
- **Gamma sensitivity (Iγ proportional to reactor power)**
- **Cable contribution Ic (isolation resistance)**



Iγ ≈ 2 µA @100%PN

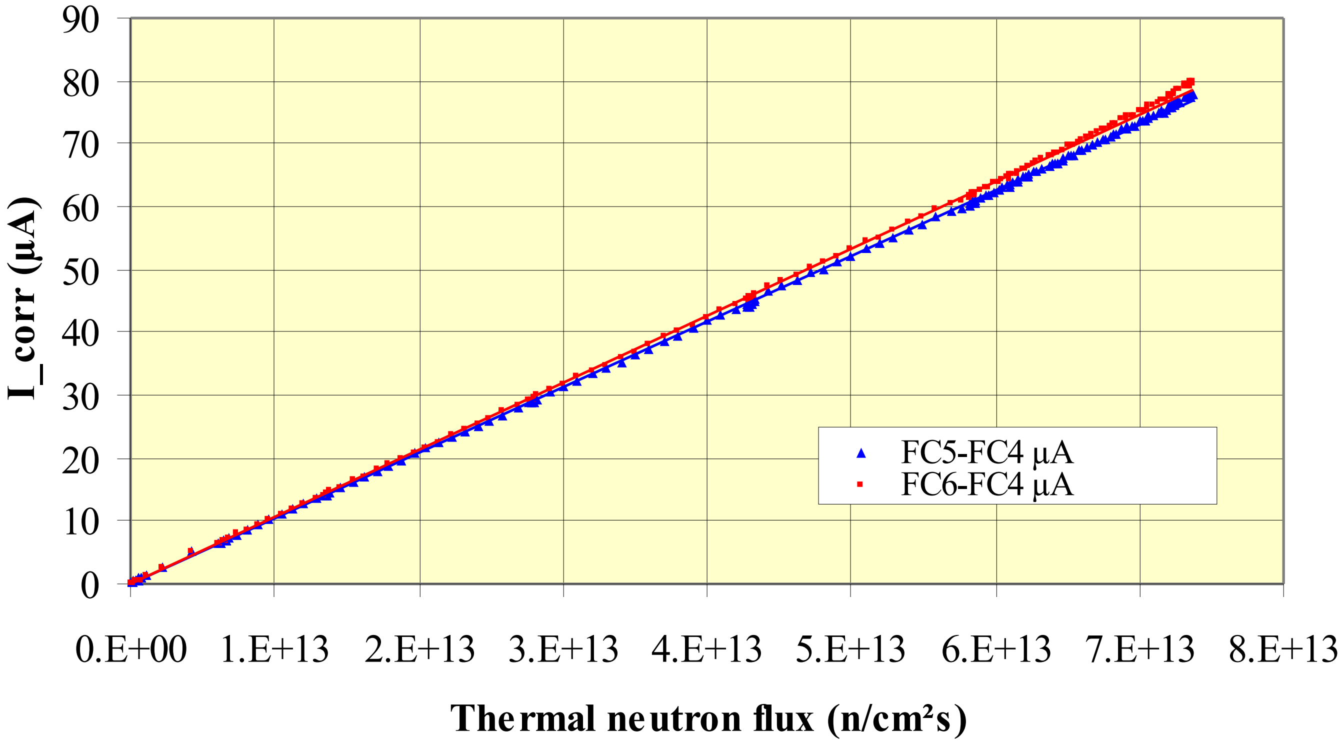
Ic ≈ from 8.5 nA/V (0.13GΩ @90%PN)
to 25 nA/V (4G Ω @1%PN)

FIC5 Results (2) : Saturation curves



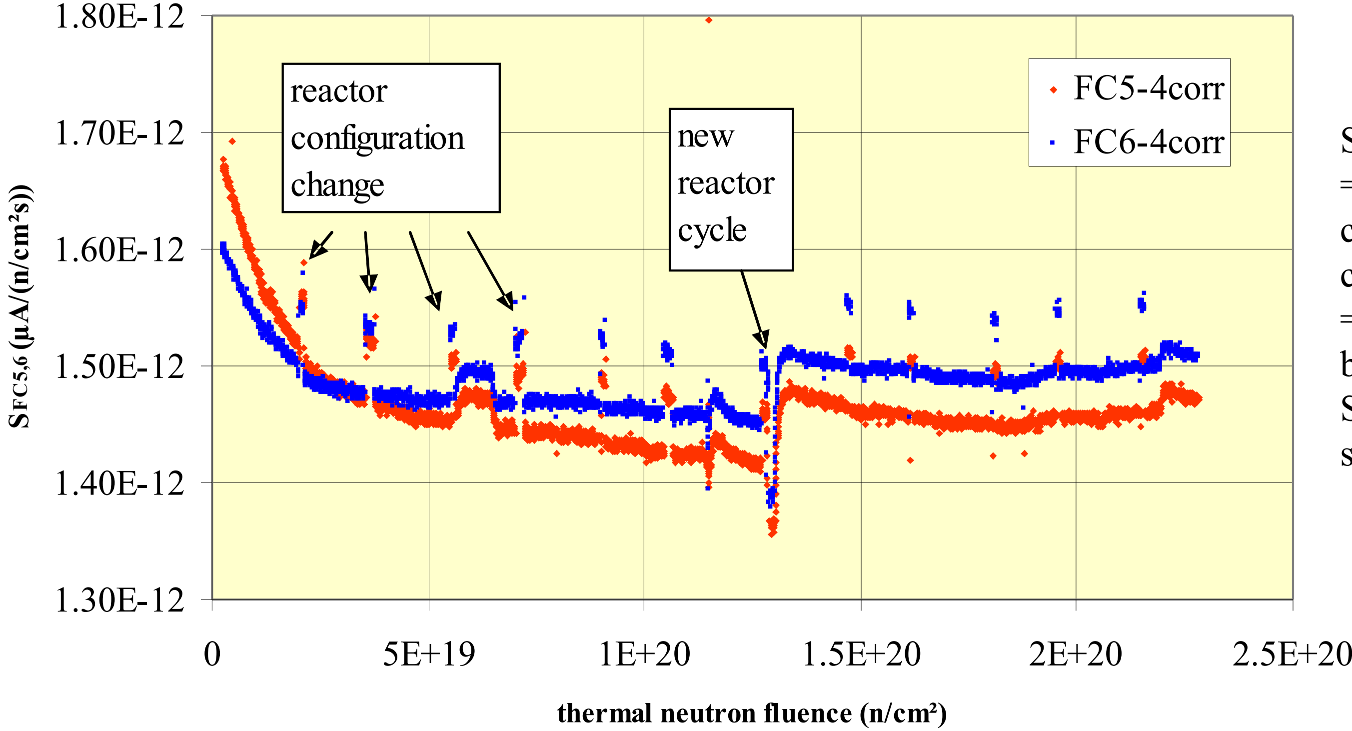
- Nice saturation plateaus
- Good reproducibility between FC5 & FC6
- Excellent linearity with reactor power in the middle of the plateau
- Chosen polarization voltage = 140 V

Results (3) : linearity of CFUZ53 response with the flux



- **Excellent linearity with the thermal flux**
  - **$I\_corr = I_{FC5,6} - I_{FC4}$**
  - **Thermal flux = conventional flux $nv_0 = \varphi_0 = f(I_{SPND})$**

FIC5 Results (4) : Evolution of the sensitivity with time



Short deviations = reactor configuration changes = discrepancy between FC and SPND responses to spectrum variations

- **Scorr = [I_corr / φ_0(SPND)] / exp(- σ_a.ϕt)**
  - **Small decrease (to be further analyzed) and then stabilization**
  - **Long term evolution consistent with the fissile deposit depletion**

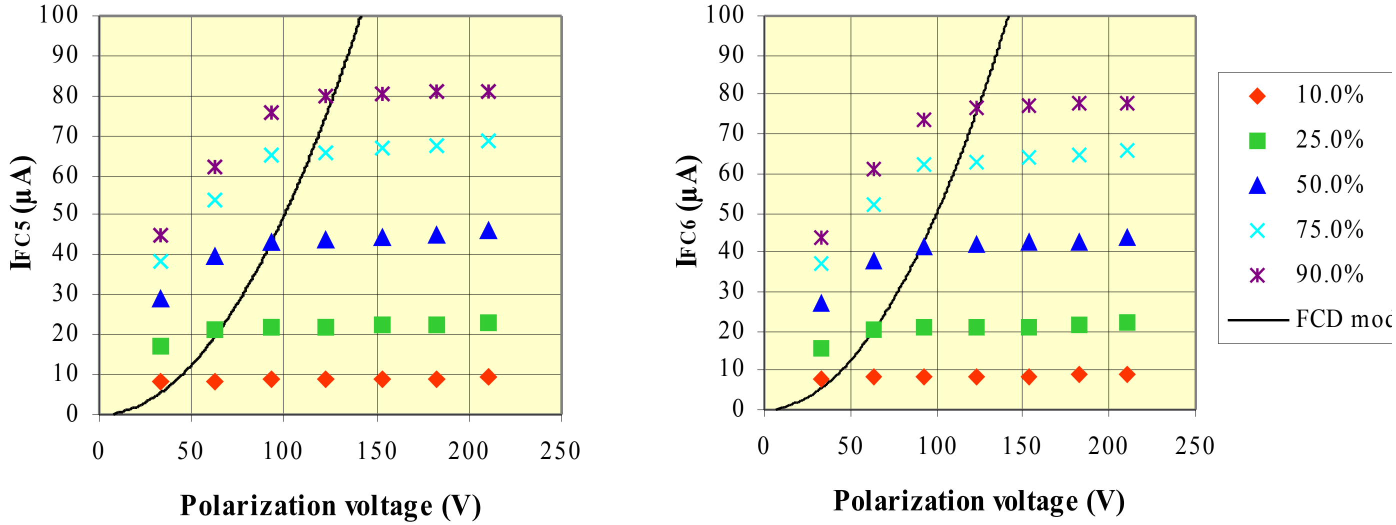
Results (5) : Calculation / measurement comparison

- **FCD computer code : numerical simulation of FC in current mode**
- **Sensitivity : good agreement**

$$S = 2\pi e L I_o p N_A \frac{\mu_s}{M} \sigma_{eff} r_a r_c \left[E\left(\frac{r_a}{r_c}\right) - \frac{r_a}{r_c} \right] = 1.58\times10^{-18}\,\mathrm{A/nv}$$

$$E(k) = \int_0^{\frac{\pi}{2}} \sqrt{1-k^2 \sin^2 x}\,dx$$

- **beginning of the saturation plateau : well predicted**



Conclusions on the first irradiation experiment for CFUZ53 qualification

•Many positive preliminary results:

- **Good reproducibility between the 2 similar CFUZ53**
- **Nice saturation plateaus**
- **Excellent linearity with reactor power and thermal flux**
- **Sensitivity well predictable:**
  - Value consistent with the calculation result from our FC model
  - Long term evolution consistent with the fissile deposit depletion

•Objectives of further analysis:

- **To understand the small short term sensitivity variation at the beginning**

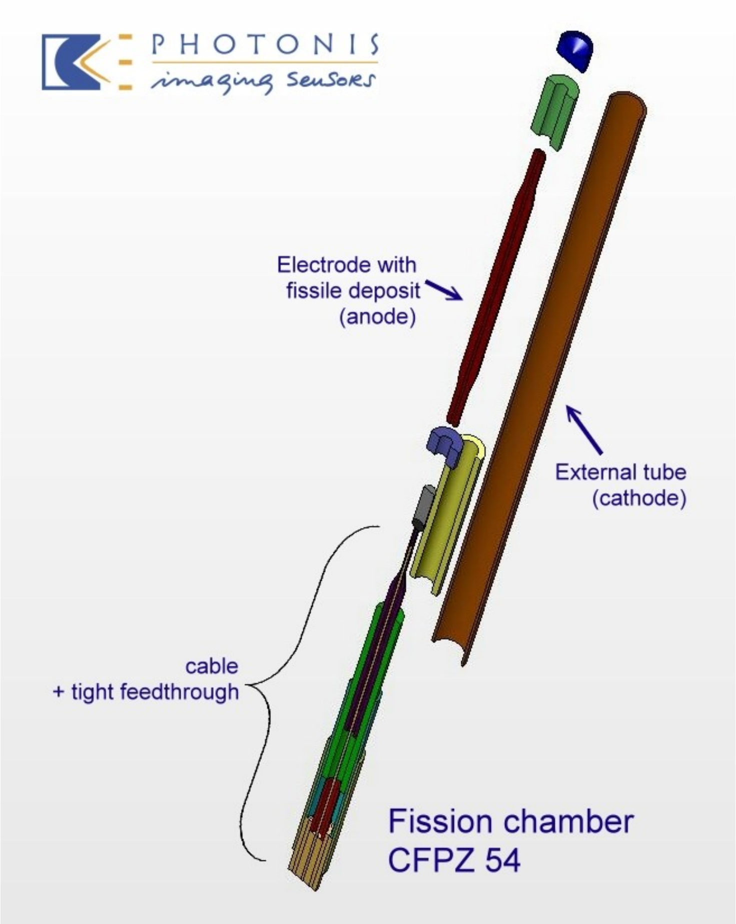
•Next qualification step (FICTIONS 7 experiment)

- **Long term irradiation experiment in BR2 (10 cycles, 5000 h, equivalent to 4 PWR cycles)**
  - 3 CFUZ53, 100µg ^{235}U, P = 1.1bar
  - PWR conditions (idem FICTIONS 5)
  - Beginning : April 2006

SMFC Perspectives : development of the CFPZ detector for fast flux measurement (> 1MeV)

•Concept:

- **Same geometry as CFUZ53 (1.5mm)**
- **Pu242 fissile coating**
- **Thermal neutron shielding (B_4C)**
- **50 Ω ∅1.3mm mineral cable for pulse/Campbelling modes**
  - Low signal
  - Neutron / gamma discrimination
- **Wide range electronics : 3 modes available (CEA development)**
- **Online calculation of the sensitivity (fissile deposit evolution code)**



•Qualification programme :

- **Technological validation in OSIRIS (end 2005)**
- **Physical validation in BR2 (2006 and after)**