Implantable self-powered detector for on-line determination of neutron flux in patients during NCT treatment

M.E. Miller[a], *L.E.Mariani*[b], *M.L.Sztejnberg Gonçalves-Carralves*[b], *M.Skumanic*[b], *S.I. Thorp*[a]

a) Instrumentation & Control Department, National Atomic Energy Commission, ARGENTINA.

b) Facultad de Ingeniería y Ciencias Exactas y Naturales, Universidad Favaloro, ARGENTINA.

Summary

- A novel method to measure on-line thermal neutron flux in patients is presented.

- The method is based on the use of a special self-powered detector (SPND).

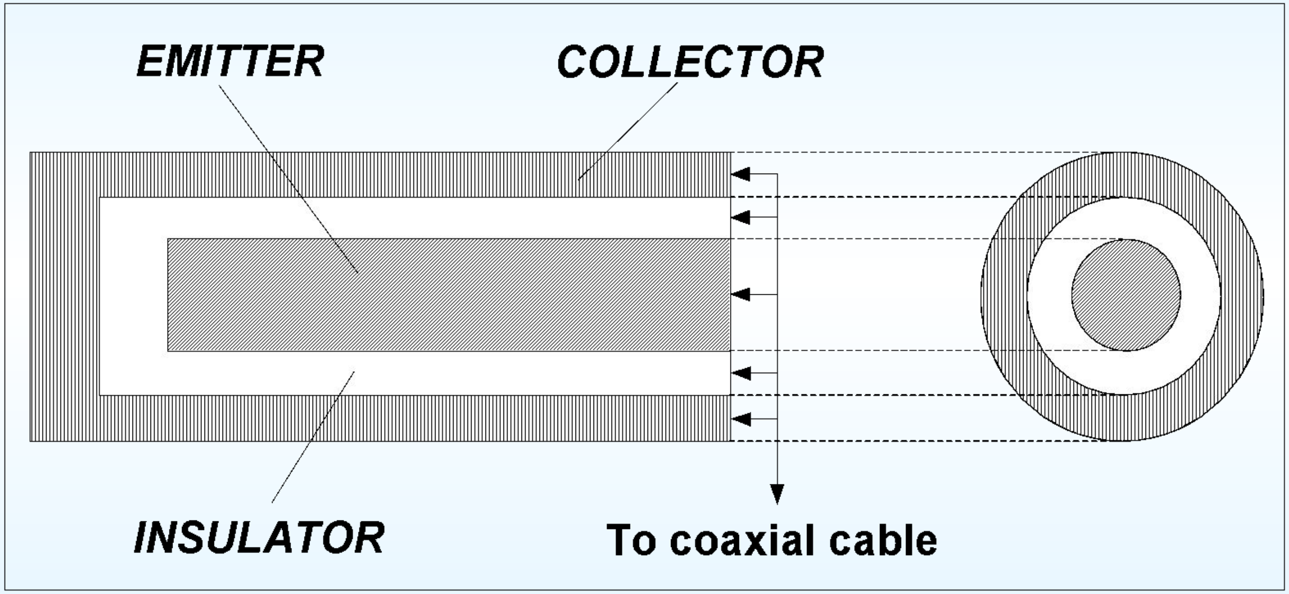
- It can be placed on or inside the patient owing to its small size and biocompatibility (for example, under the skin or inside the brain).

Introduction

- **NCT treatment optimization.**
  - **Importance of NCT Flux measurements.**
    - **In present, off-line activation methods.**
    - **Recently, on-line scintillation methods.**
    - ***In this work, an implantable SPND-based on-line method.***

Introduction

SPND



- **Neutron response**
- **Gamma response**

Introduction

Advantages

- Small-sized.
- No high voltage is required.
- Design allows to reduce gamma response (Z, m)

Consideration

- Depression of the flux around the detector

Materials and methods

Emitter material : high thermal cross section as possible (to obtain a meassurable signal with very small mass)

^{103}**Rh** :

- thermal capture cross section 134 barns (11 barns)
- Beta decay half life 42.8 s (4.4 min)

Materials and methods

Insulator material : **Acrylic**

- Tissue equivalent material for neutrons
- Used in detectors for medical applications
- No significant degradation

Materials and methods

Collector material : no toxic, sterilizeable, very low capture cross section, low residual radioactivity.

- **Graphite**: offers the possibility to obtain very thin conductive layers, but it is a water-soluble material.

- **Zircaloy-4**: zirconium-based alloy. Zirconium is a biocompatible metal, usable in biological prosthesis. No possibility of obtaining conductive layers as thin as graphite ones.

Materials and methods

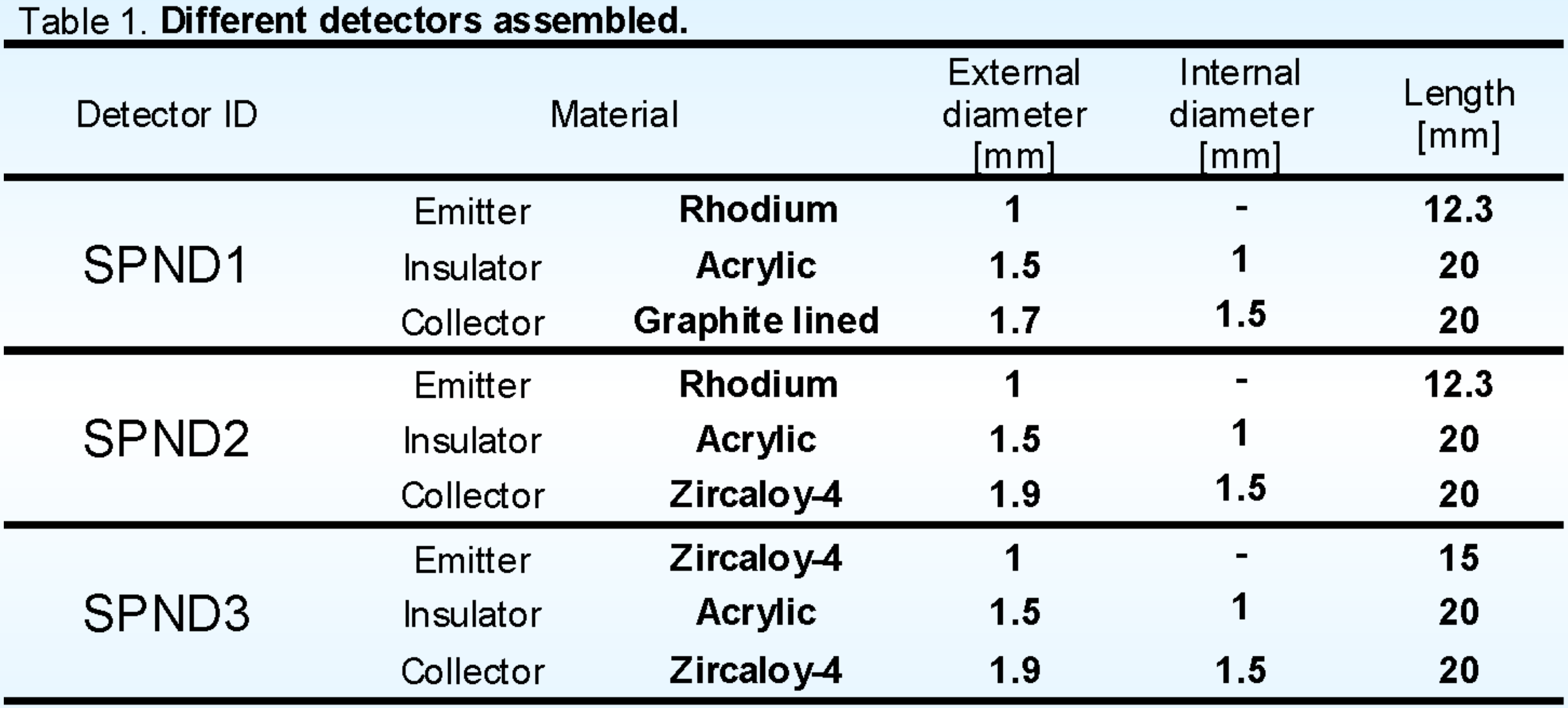
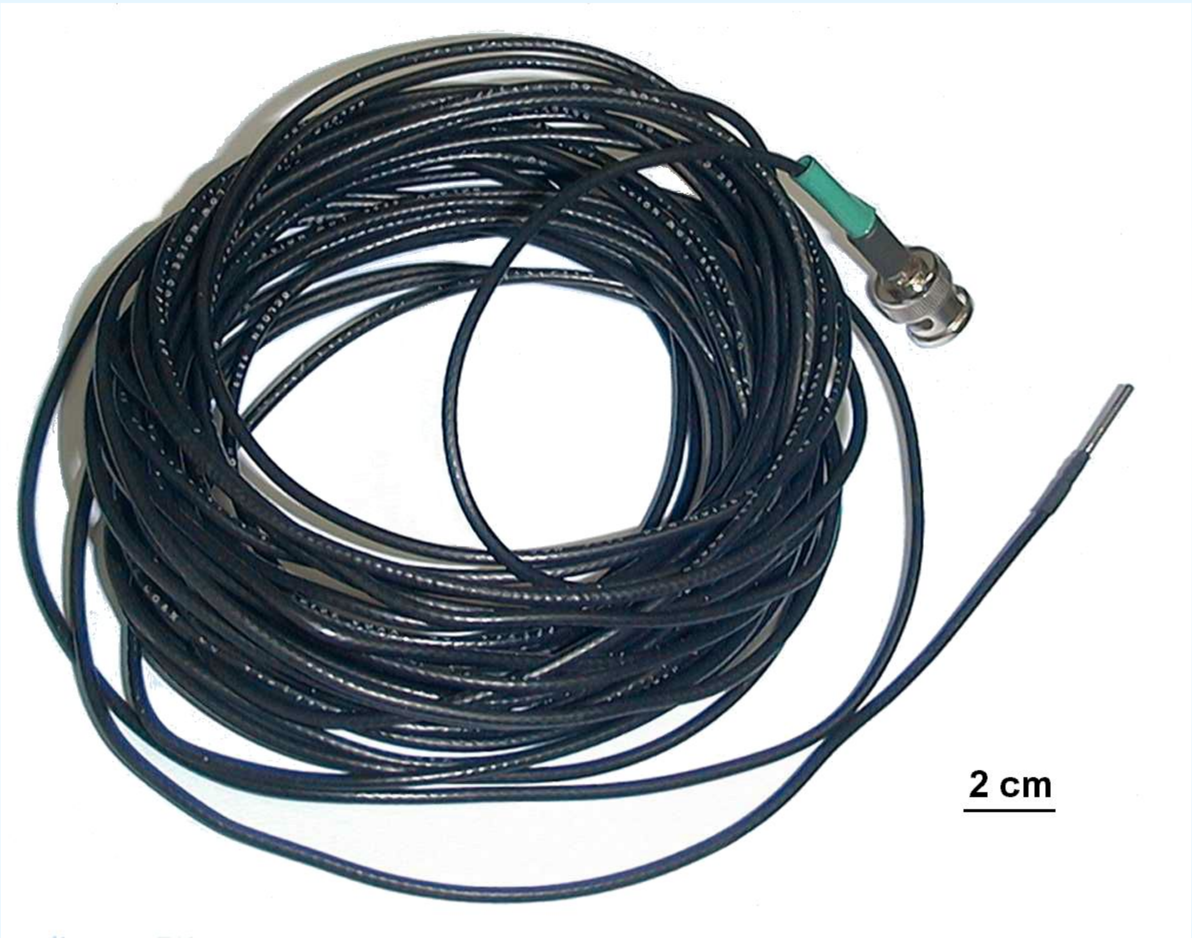


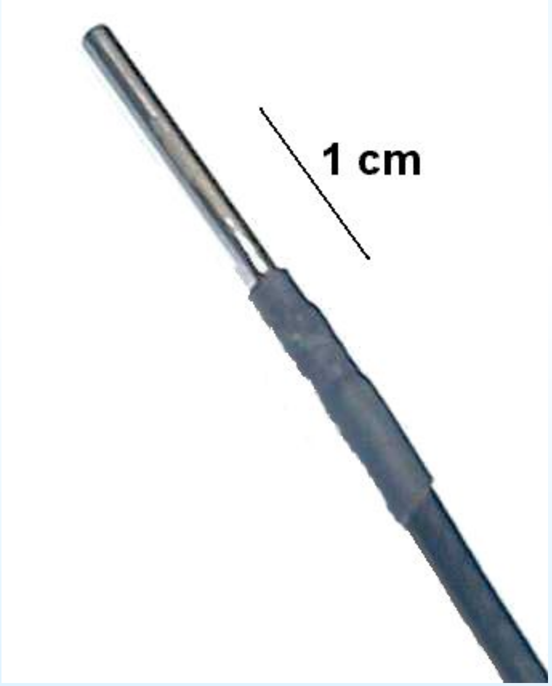
Table 1. **Different detectors assembled.**

Detector ID	Material		External diameter [mm]	Internal diameter [mm]	Length [mm]
SPND1	Emitter	**Rhodium**	**1**	**-**	**12.3**
	Insulator	**Acrylic**	**1.5**	**1**	**20**
	Collector	**Graphite lined**	**1.7**	**1.5**	**20**
SPND2	Emitter	**Rhodium**	**1**	**-**	**12.3**
	Insulator	**Acrylic**	**1.5**	**1**	**20**
	Collector	**Zircaloy-4**	**1.9**	**1.5**	**20**
SPND3	Emitter	**Zircaloy-4**	**1**	**-**	**15**
	Insulator	**Acrylic**	**1.5**	**1**	**20**
	Collector	**Zircaloy-4**	**1.9**	**1.5**	**20**

- SPND1 and SPND2: gamma response evaluation
- SPND2 and SPND3: neutron response evaluation

Materials and methods





Materials and methods

- **Gamma characterization:**
  ^{60}Co beam at 1.5 mGys^{-1}.

- **Neutron characterization:**
  thermal beam of RA-1 at 1.6 10^{8} ncm^{-2}s^{-1}.

- Detectors were connected to a low-noise coaxial cable (L=15 m, φ=2.5 mm).

- Electrometer: resolution of 1 fA, very stable reading.

- Characterization included: measurement of leakage current and the current under the corresponding irradiation field; and assessment of the corresponding sensitivities.

Materials and methods

- To estimate flux depression, three simple MCNP models based on SPND2 were implemented and compared.

- Coaxial arrangement of three cylinders, with SPND2 diameters, immersed in water and irradiated by a thermal neutron flux.

- MODEL1, cylinders are filled with SPND2 materials.
- MODEL2 rhodium is replaced by water.
- MODEL3 has water as sole material (unperturbed flux and basis for comparison).

Results

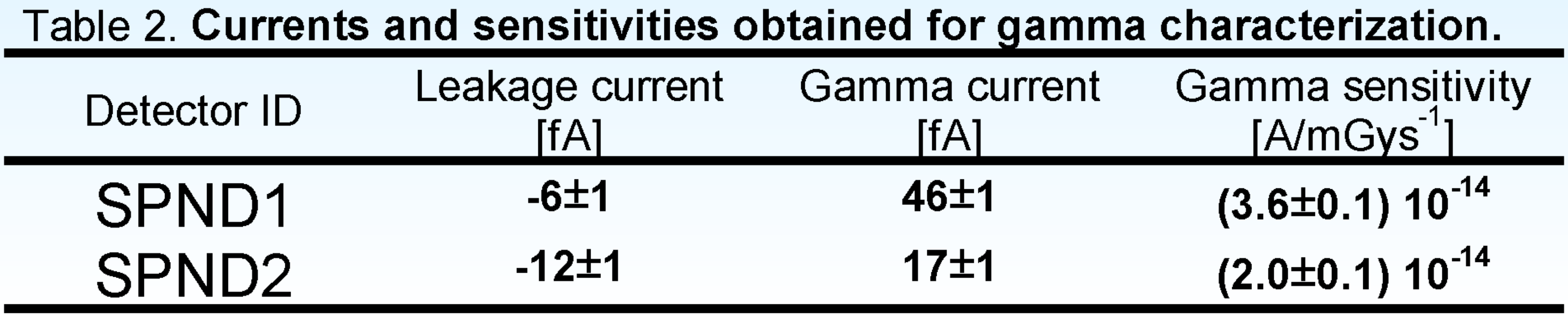


Table 2. **Currents and sensitivities obtained for gamma characterization.**

Detector ID	Leakage current [fA]	Gamma current [fA]	Gamma sensitivity [$A/mGys^{-1}$]
SPND1	**-6±1**	**46±1**	**$(3.6\pm0.1)\ 10^{-14}$**
SPND2	**-12±1**	**17±1**	**$(2.0\pm0.1)\ 10^{-14}$**

- SPND2 has a lower gamma response than SPND1 (about a 50%). In SPND1 current from sheath to emitter is lower than in SPND2 because both Z and total mass employed are lower for graphite than for Zircaloy-4, producing in SPND2 a better electronic compensation between emitter and sheath. Zircaloy-4 was then adopted as sheath material.

Results

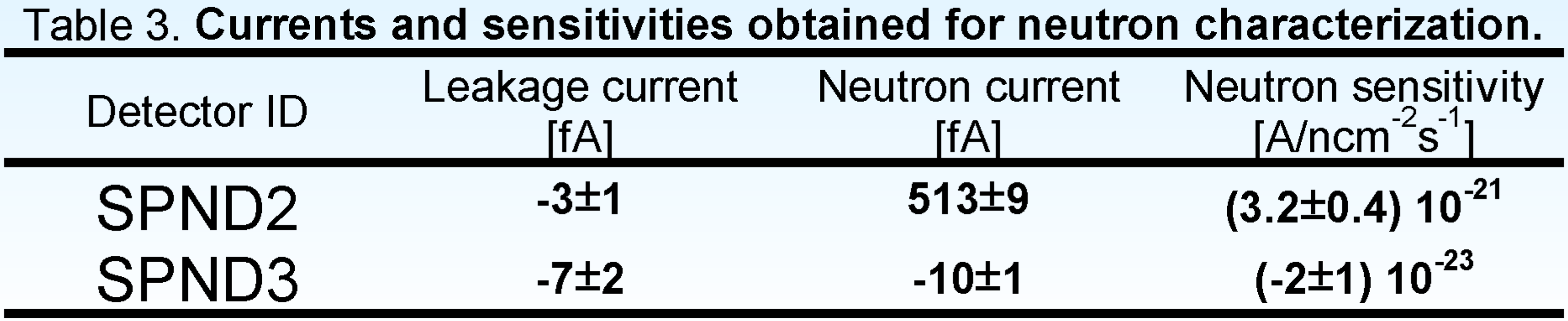


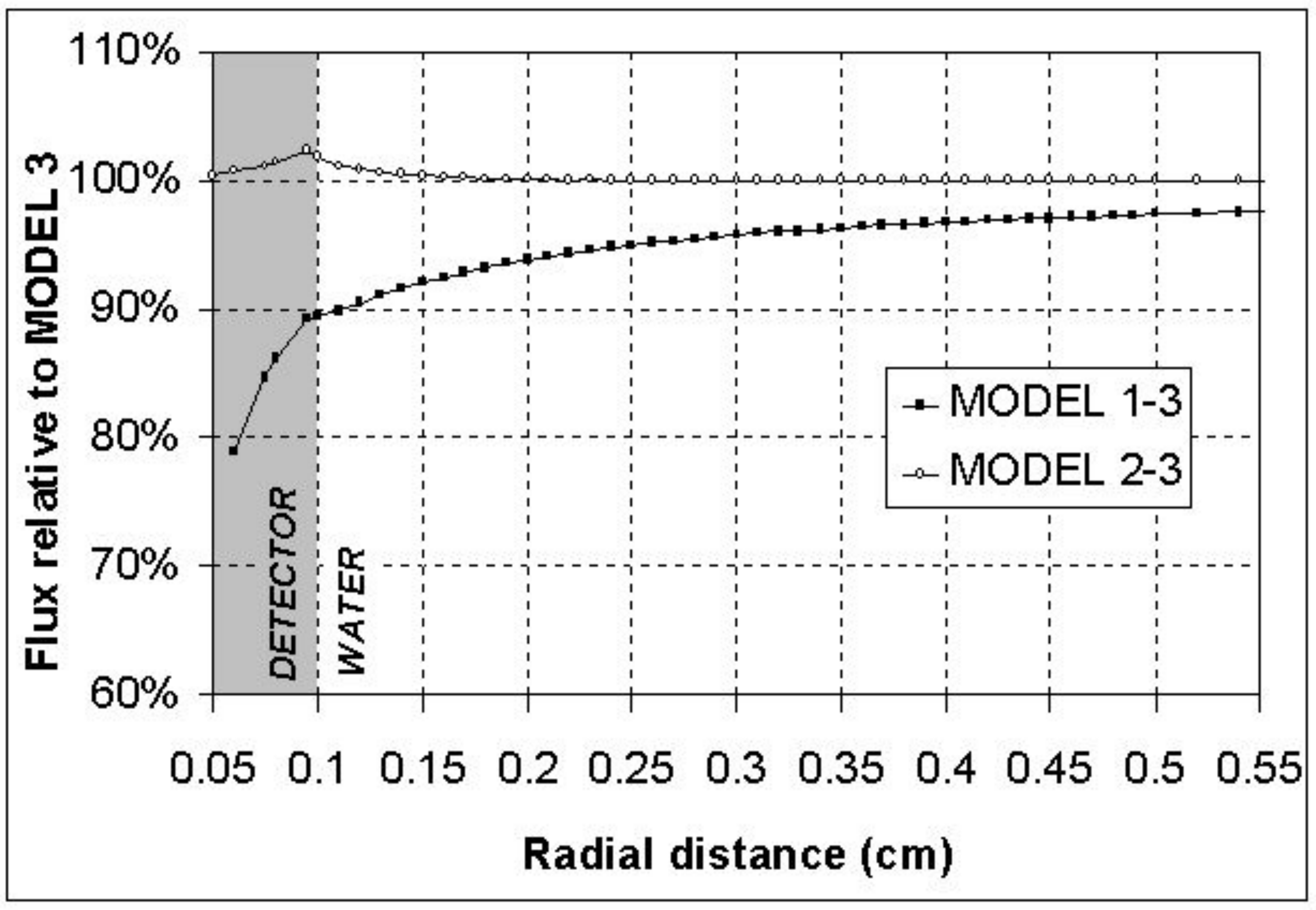
Table 3. **Currents and sensitivities obtained for neutron characterization.**

Detector ID	Leakage current [fA]	Neutron current [fA]	Neutron sensitivity [$A/ncm^{-2}s^{-1}$]
SPND2	**-3±1**	**513±9**	**$(3.2\pm0.4)\ 10^{-21}$**
SPND3	**-7±2**	**-10±1**	**$(-2\pm1)\ 10^{-23}$**

- SPND2 presented an adequate neutron response. Its comparison with SPND3 response leads to the conclusion that that most of the signal was originated in the interaction between neutrons and rhodium.

- SPND2 system leakage current level was less than 1% of the neutron one, which is low enough to be considered negligible.

Results



- Flux depression around 10% on detector surface.
- Flux depressions lower than 5% for more than 1.5mm from detector surface.

Discussion

- Values expected using SPND2 for typical NCT flux levels are: 3 pA ($\phi_{th} \approx 10^9$ ncm^{-2}s^{-1}) and 0.02 pA (1 mGys^{-1}) for neutron and gamma currents, respectively. In this case gamma contribution would be less than 1%.

- In order to improve spatial resolution it would be possible to reduce emitter length. Around 4 mm would produce an acceptable response.

- Depresion flux due to detector should be taken into account to determine its most convenient positions and its influence on treatment parameters.

Conclusion

An implantable SPND-based system was developed in compliance with all design requirements (materials, dimensions and sensitivity). It can be used to obtain on-line thermal neutron doses delivered to patients, and to recalculate treatment parameters for their optimization and correction during irradiation.

The End

Thanks for your attention

M.E. Miller, L.E.Mariani, M.L.Sztejnberg Gonçalves-Carralves,
M.Skumanic, S.I. Thorp

miller@cae.cnea.gov.ar