# Self-powered neutron detectors: a simulation study with Monte Carlo codes

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# Overview

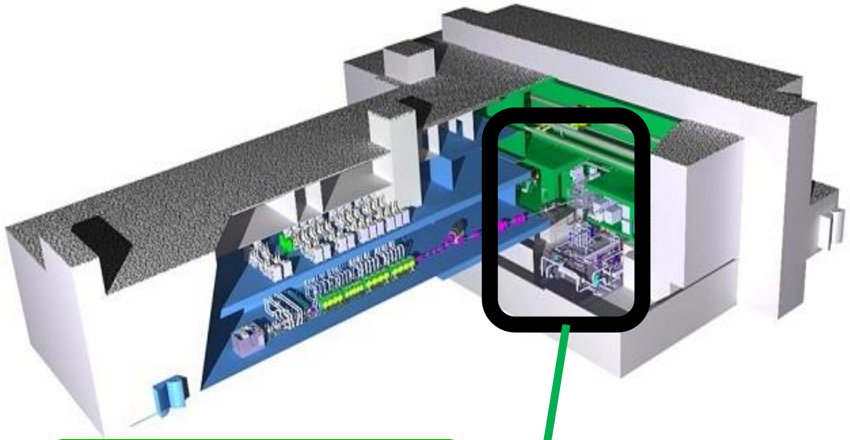
- Introduction of IFMIF-DONES
- Self-powered neutron detector
- Our work
- Monte Carlo codes
- Preliminary results
- Conclusions and future work
- References

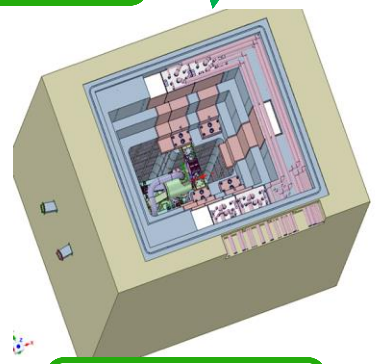
# IFMIF-DONES

International Fusion Materials Irradiation Facility – Demo Oriented NEutron Source

It is a scientific facility to generate a neutron source (up to 14 MeV) for the study and **licensing of materials** to be used in future fusion reactors as DEMO

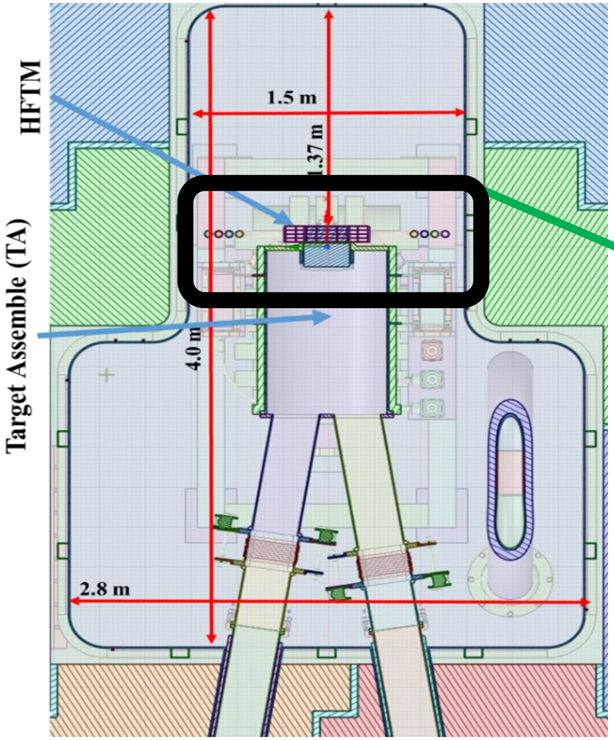
To analyze the specimen material after irradiation is necessary to **measure the neutron and photon fluxes** generated during its operation mode



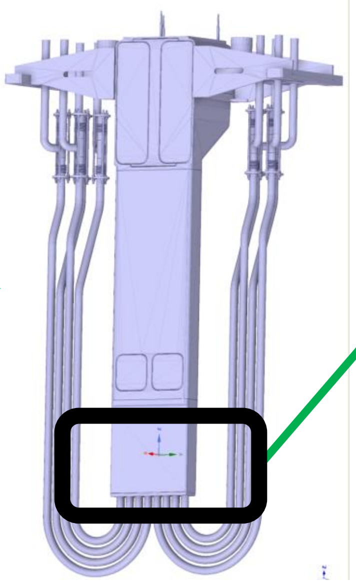



# IFMIF-DONES

Test Cell




STUMM
(Start-up and
Monitoring Module)



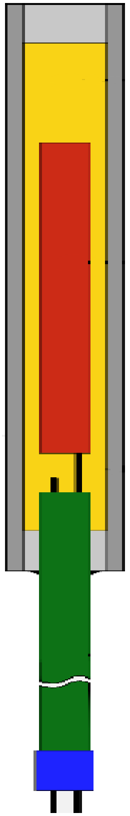
Detectors

HFTM
(High Flux Test
Module)

| Types of detectors |
|---|
| • Ionization Chamber (IC)<br>• Fission Chamber (FC)<br>• Self-powered neutron detector (SPND) |

# Self-powered neutron detectors

| | |
|---|---|
| SPND | Device which measures neutron and photon flux |
| | Online detector |
| | Gives an electrical signal in proportion to the incident fluxes of neutron and/or photon |
| | A combination of these signals is used to create a spatial map of the neutron and photon fluxes in the core |



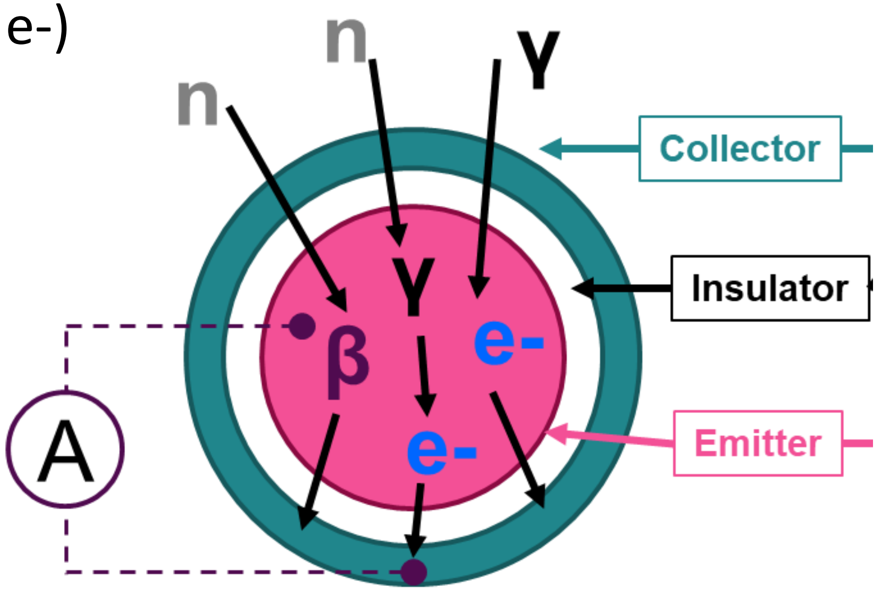
# SPNDs Morphology

Parts multi-layered design

- **Emitter** (active part) → high cross-section material of interaction with the target particle
- **Insulator** → provide electrical insulation and slow down electrons, create a potential difference measured as a direct current
- **Collector** → to stop the electron coming from emitter

Three main nuclear processes in the emitter to create current

- (n, β-)
- (n, γ, e-)
- (γ, e-)



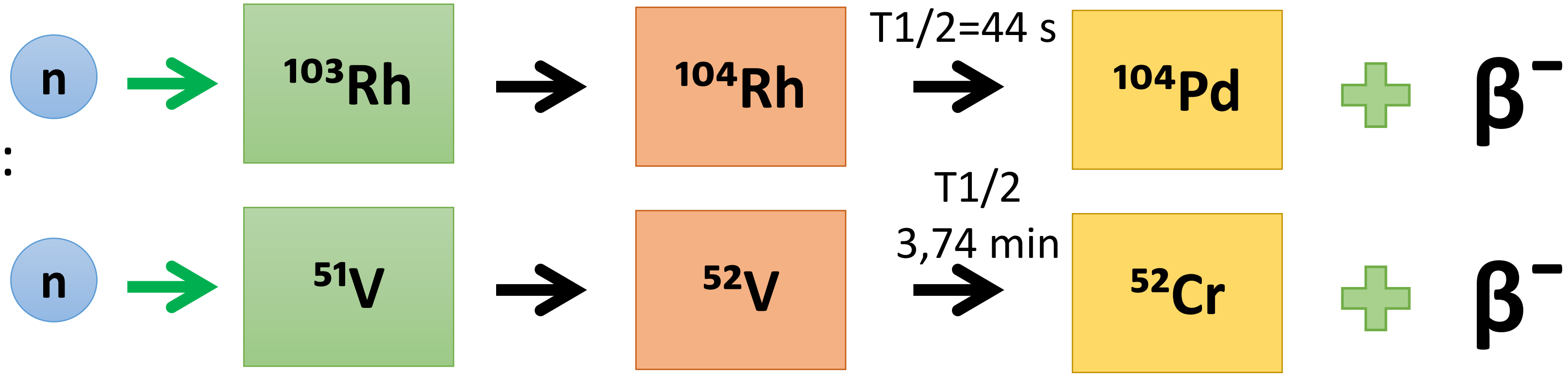
# Types of SPNDs

Both vary linearly with incident flux, independently

| Prompt component | Delayed component |
|---|---|
| • The part which varies immediately with a change in the incident flux<br>• The (n, γ, e−) and (γ, e−) are the common processes behind this component<br>• Photoelectric effect and Compton scattering | • It is the part of the signal which mostly arises due to (n, β−) process<br>• A characteristic half-life (T1/2)<br>• Neutronic capture |

# Types of SPNDs

- SPND based on delayed signal by neutronic capture (n, β–)
  - Rhodium:
  - Vanadium:




- SPGD based on prompt signal (n, γ, e–) (γ, e–)
  - $^{52}Cr$
  - $^{59}Co$
  - $^{209}Bi$
  - $^{92}Zr$
  - Inconel 600 (Ni, Cr, Fe alloy)

# Types of SPNDs

| Material | Cross-section at 14 MeV neutron (barn) | Burn-up (%/month) | Response |
|---|---|---|---|
| $^{103}Rh$ | 4,3 | 0,34 | Delayed |
| $^{51}V$ | 2,4 | 0,12 | |
| $^{52}Cr$ | 2,41 | - | Prompt |
| $^{59}Co$ | 2,7 | 0,09 | |
| Inconel 600 | 4 | 0,03 | |
| $^{209}Bi$ | 5 | - | |
| $^{92}Zr$ | 4 | - | |

A balance between a high cross-section and a low burn-up rate is needed in order to have a stable signal

# Advantages and Drawbacks of SPNDs

Solid

Rugged and robust design
- Temperature
- Flux

Small size
- 3 mm diameter
- 8-10 cm length

Operate without a bias voltage supply

Online information

Low level signal
- picoampere (pA)

Time of response
- (n, β–) based

Sensitivity changes
- Decreases non-linearly with emitter material consumption

# Our work

Knowing what the SPNDs are like and their behaviour

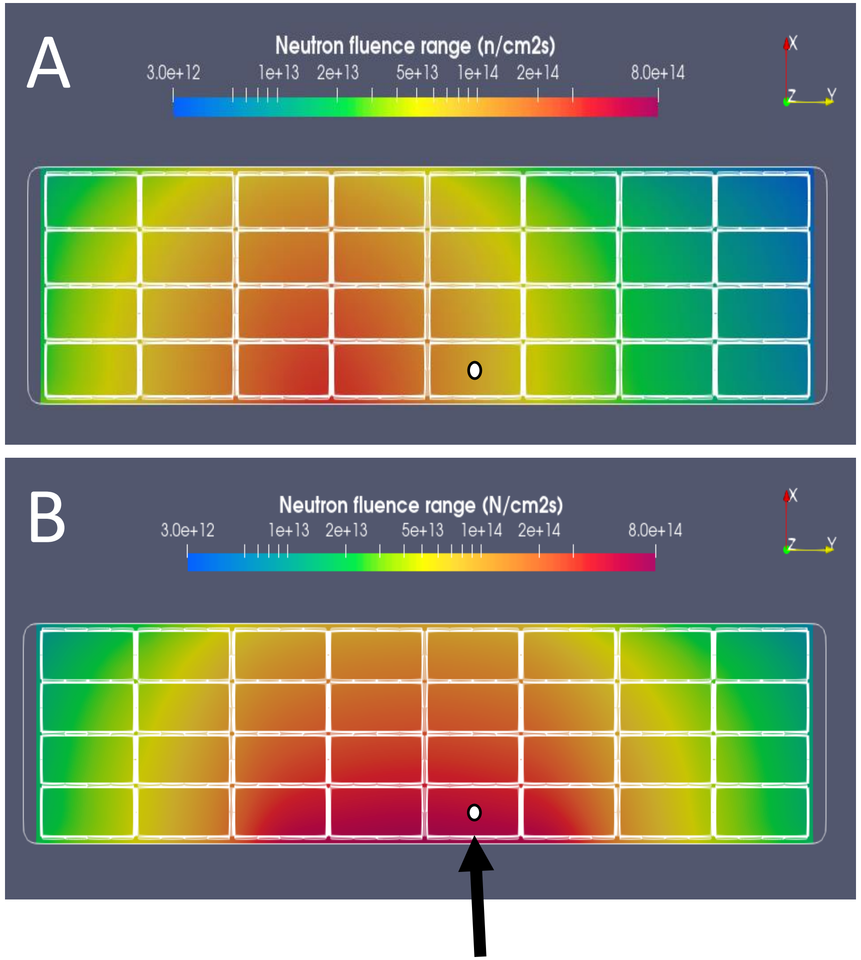
We replicate the  geometry of one of the SPNDs with simulation codes

# Monte Carlo Codes

- Monte Carlo N-Particle (**MCNP**) code can be used for general-purpose transport of many particles including neutrons, photons, electrons, ions, and many other elementary particles

- PENetration and Energy LOss of Positrons and Electrons (**PENELOPE**) code system can simulate the transport of electrons and photons

# SPND based on β decay

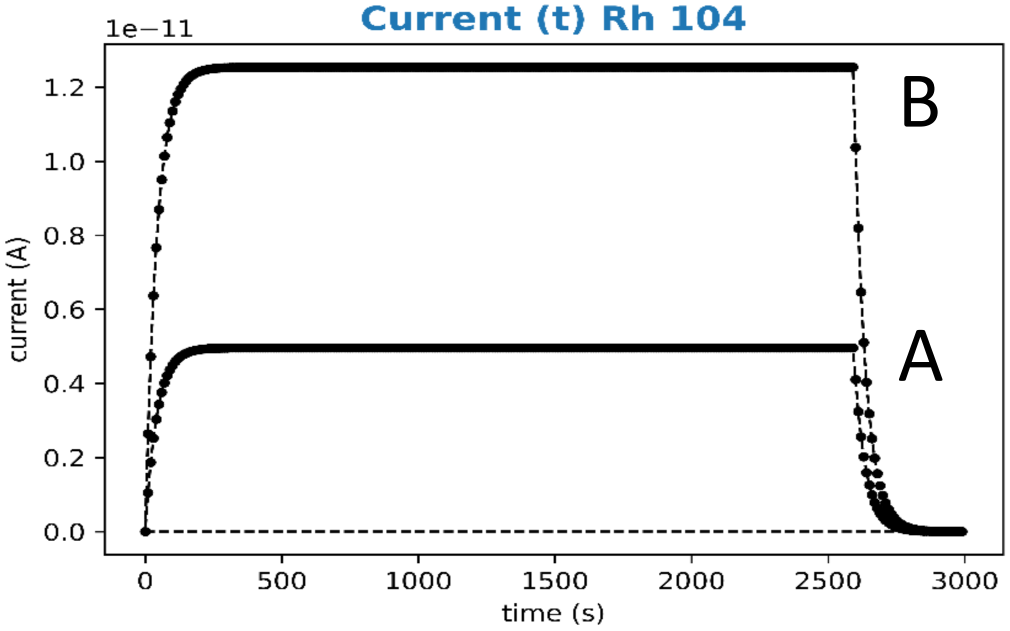



SPND

$^{1}n + {}^{103}Rh \rightarrow {}^{104}Rh \rightarrow {}^{104}Pd + \beta$

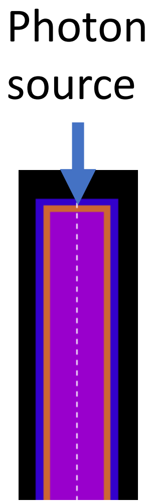
$$\begin{cases} A(t) = A_0\left(1 - e^{-\lambda t}\right) & t \leq t_{irrad} \\ A(t) = A_{(t_{irrad})} e^{-\lambda(t - t_{irrad})} & t > t_{irrad} \end{cases}$$

$$\begin{cases} \lambda = \dfrac{\log(2)}{42.3\ s} \\ t_{irrad} = 2592 \end{cases}$$



# SPND based on γ reactions

- Photon source energy: 1.25 MeV ($^{60}Co$ source)
- From the top of the spnd
- Energy deposition (MeV)
  - Emitter : $^{52}Cr$ (Z=24), $^{90}Zr$ (Z=40), $^{103}Rh$ (Z=45), $^{209}Bi$ (Z=83)
  - Collector: Inconel 600
- Using PENELOPE




| | Energy deposition (MeV) | |
|---|---|---|
| Z | Emitter | Collector |
| 24 | 0.57903(15) | 0.01183(5) |
| 40 | 0.5706(4) | 0.01184(13) |
| 45 | 0.6462(2) | 0.01119(6) |
| 83 | 0.75777(24) | 0.01096(6) |

# SPND based on γ reactions

- Photon source energy:
  - 1.25 MeV ($^{60}Co$ source)
  - 3 MeV
  - 6 MeV
  - 9 MeV
- From the top of the spnd
- Energy deposition (MeV)
  - Emitter : $^{90}Zr$
  - Collector: Inconel 600
- Using PENELOPE

| | Energy deposition (MeV) | |
|---|---|---|
| **Source energy (MeV)** | **Emitter** | **Collector** |
| 1.25 | 0.5706(4) | 0.01184(13) |
| 3 | 1.3324(5) | 0.08371(19) |
| 6 | 2.068(3) | 0.3185(11) |
| 9 | 2.638(4) | 0.4636(15) |

# CONCLUSIONS AND FUTURE WORK

- A SPND based on beta decay has a high electric current when the neutron fluence rate is higher
- A SPND based on gamma reactions has high energy deposition in the emitter:
  - At higher Z of the material used
  - At a higher energy of the source

➢ Study and analyse how the energy deposited in the SPND emitter is related to the measured electric current.

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THANK YOU FOR YOUR ATTENTION- QUESTIONS?