Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

Istituto Nazionale di Fisica Nucleare

On-target neutron flux monitoring with Self Powered Neutron Detectors at n_TOF

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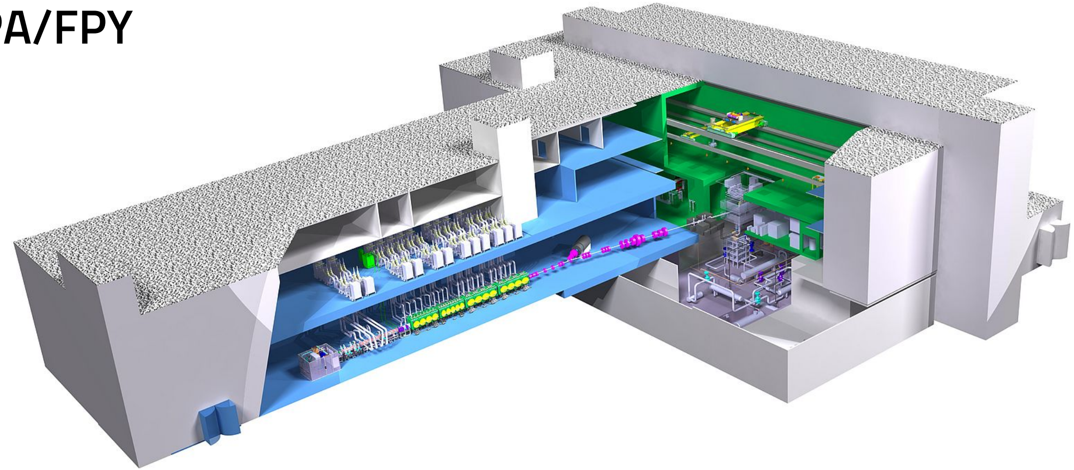
Prologue: DONES Demo Oriented NEutron Source

In order to evaluate the damage to structural materials for the DEMO reactor, the next step to commercial fusion electricity after ITER, the **Roadmap to Fusion Energy** has foreseen a **dedicated accelerator based test facility: IFMIF-DONES**

Plasma-facing materials radiation hardness will be tested under realistic fusion irradiation conditions and validated to be used in the harsh conditions of a fusion power plant. **Goal: 15 DPA/FPY**



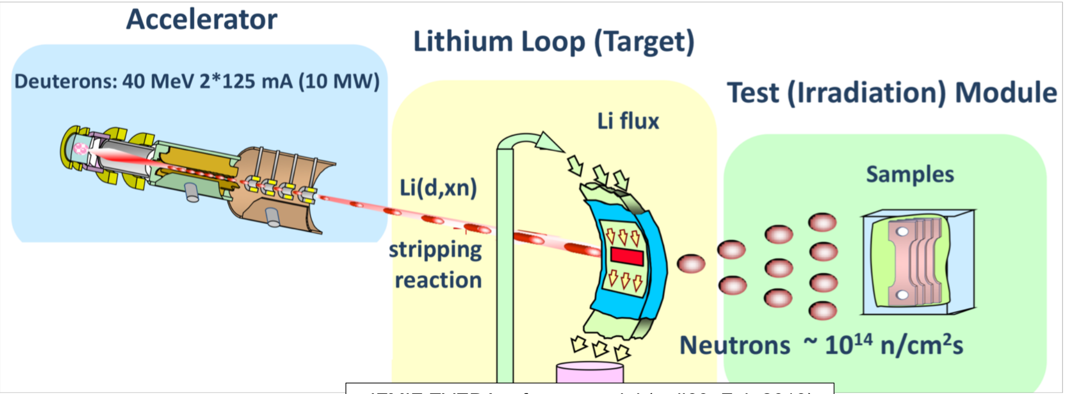
DONES to be built in Granada

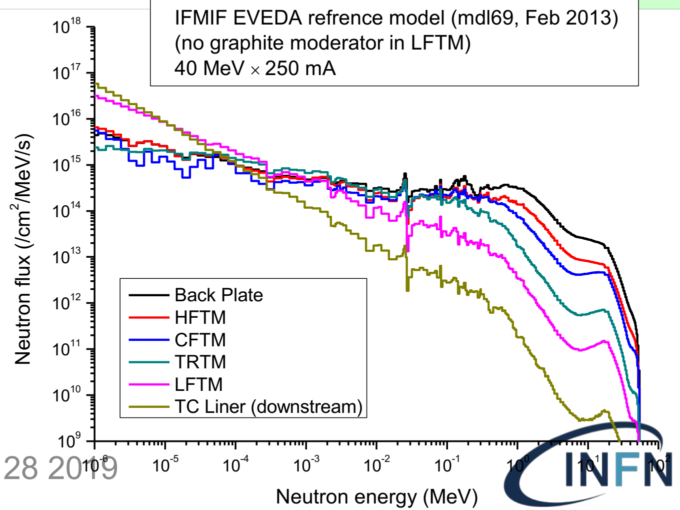
In 2018 the site **for the construction of DONES** has been chosen in Escuzar, 30 km from **Granada** (Spain)

DONES: 10^{14} n/cm^{2}s production by D-Li stripping

IFMIF-DONES is based on a **40 MeV, 125 mA in continuous wave mode (CW) deuteron accelerator** (5 MW beam average power) hitting with a rectangular beam size (approx. 20 cm x 5 cm) a **liquid Li screen target** flowing at 15 m/s to dissipate the beam power

and generating a flux of **neutrons of 10^{14} cm^{-2} s^{-1}** with a broad peak at 14 MeV through stripping nuclear reactions, close to the expected conditions of fusion power plants.



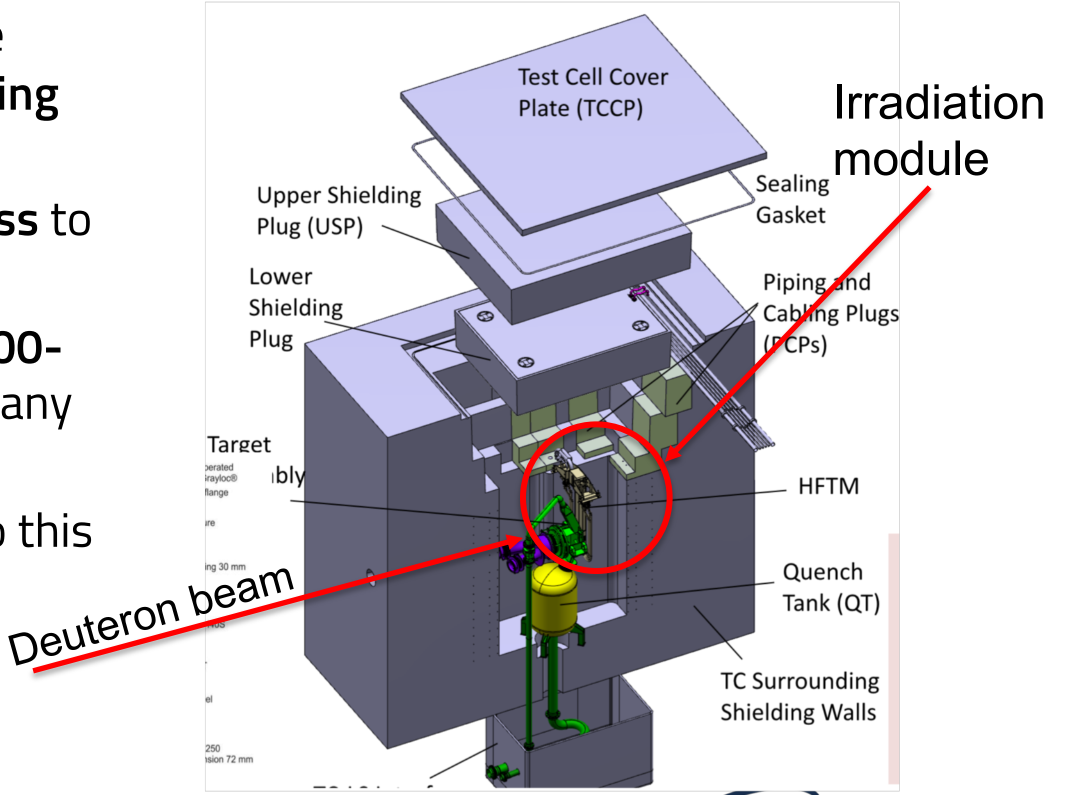


Neutron flux in the DONES Test Cell

Monitoring the neutron flux during the irradiation in the Test Cell is a **challenging** task:

- **year-long irradiations with no access** to the cell are foreseen
- **10^{14} n/cm^{2}s** on the samples with **200-400° C** pose a seriuos challenge for any kind of detector

New detectors should be developed to this pourpose

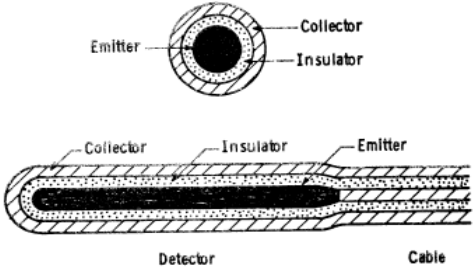


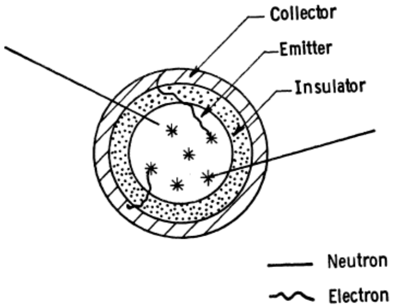
Self Powered Neutron Detectors for Fast Neutrons

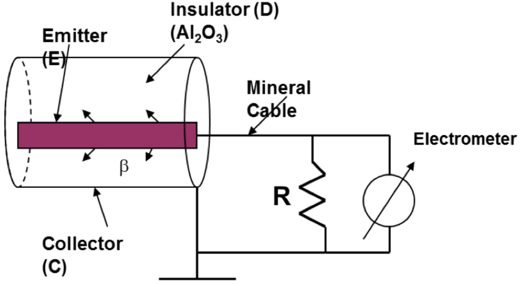
Self Powered (Neutron) Detectors (SPNDs) are **rugged miniature** devices used for **fixed in-core reactor monitoring** both for safety purposes and neutron and gamma flux mapping.

operate **without any bias voltage**

usually constructed in a **coaxial configuration** with a **central emitter characteristic of each device** type. The other electrode or metallic sheath is called collector and the two are separated by a coaxial insulator. Typical **diameter is 3mm**



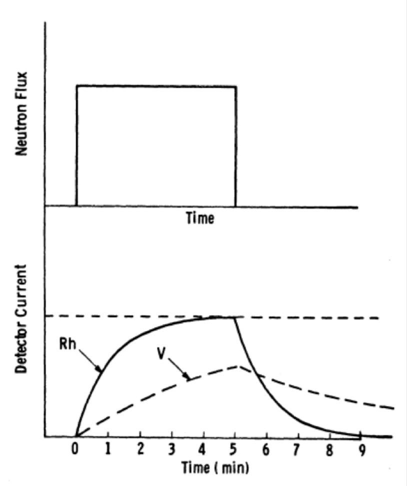




V, Co, Rh are common elements used as emitter in the thermal neutron SPNDs. Their sensitivity for fast neutron is rather low due to limited cross section of these elements. Alternative materials should be used to cover fast neutron energy range.

Contributions to signal formation

Different reactions can take place in the electrodes and the insulator, inducing a current through the emission of electrons



- (n,γ,β): the nuclei of the emitter are activated by a neutron capture and decay with β electron emission
  $\rightarrow$ **delayed response to neutrons**
- (n,γ): photons from a radiative capture interact through Compton and photoelectric effect
  $\rightarrow$ **prompt response to neutrons**
- (γ,e^-): external photons interact through Compton and photoelectric effect
  $\rightarrow$ **prompt response to photons**

Note that electrons coming from the emitter that stop in the collector give a **positive** signal; electrons coming from the collector that stop in the emitter give a **negative** signal

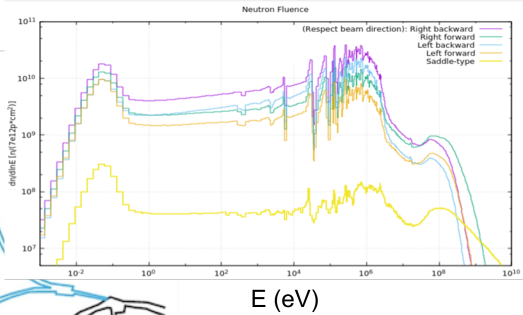
$\rightarrow$ The **net current is the algebraic sum of all the contributions**

Test environment for DONES candidate SPND: CERN nTOF

Working environment on DONES Target for the SPND:

mixed neutron and gamma field, wide energy range neutron spectrum up to 40 MeV

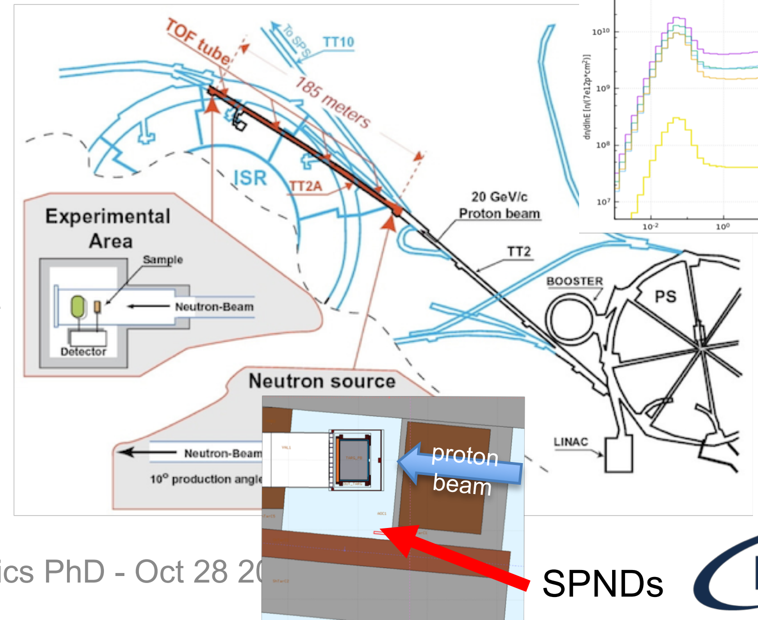
Looked for a **Particle accelerator facility with beam-on-target neutron production to face with similar conditions** including background (particle and EMI)



The **nTOF experiment at CERN**

exploits the 20 GeV PS proton beam interaction with a **lead target**, to produce neutrons by **spallation**.

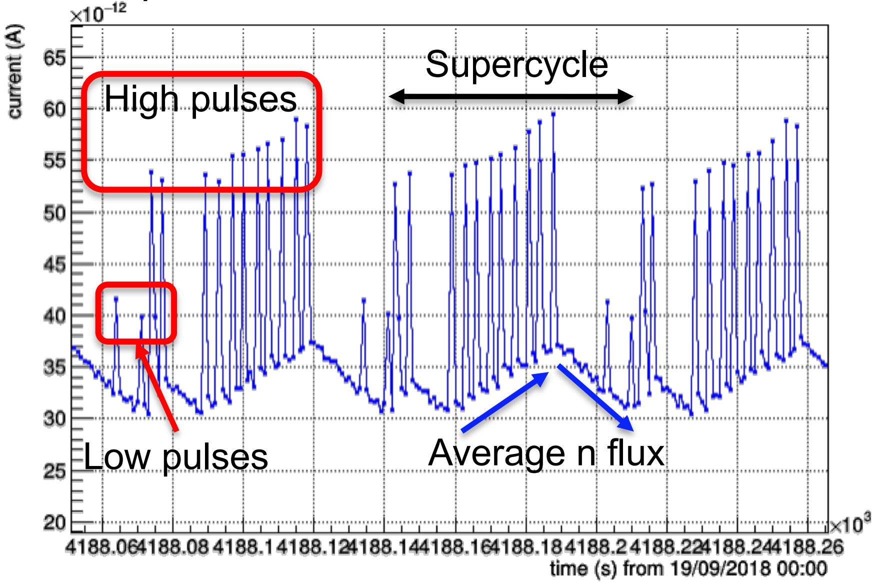
Neutron spectrum close to the target has a wide **energy spectrum up to hundred MeV** and a long tail down to thermal neutrons

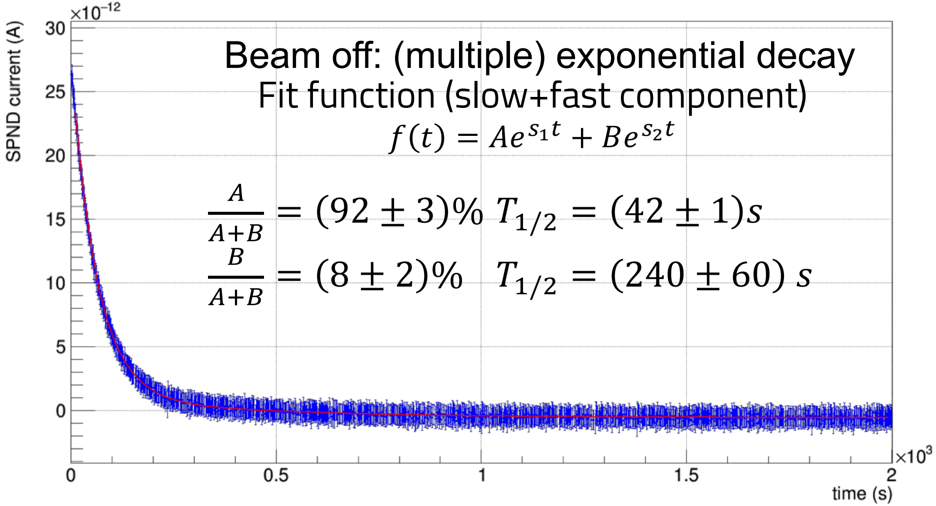


SPND signal on n_TOF target

Proton bunches hit target **every 1.2 s or multiple -> discrimination between prompt and delayed signal possible**

Rh SPND response has a sharp peak due to prompt target emission, proportional to pulse intensity, and a **slow drift of the baseline due to neutron activation** of the emitter





consistent with the expected values of the half life of ^{104}Rh and ^{104m}Rh

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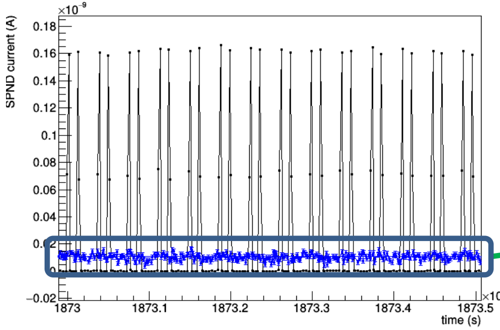
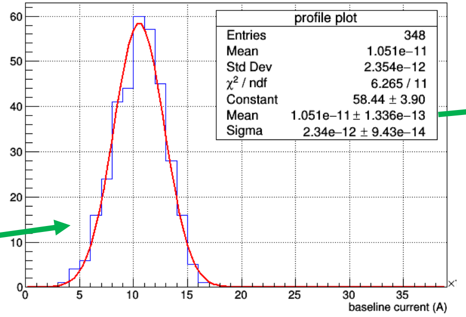
Rh SPND baseline signal linearity

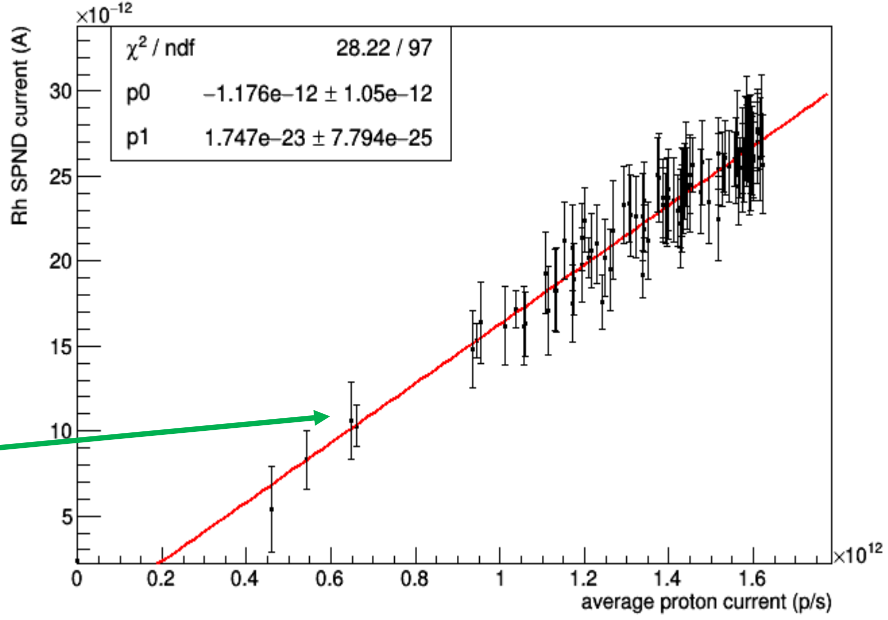
The intensity of the baseline current of Rh SPND is proportional to the average proton current on target → it's **proportional to the neutron flux** on the detector



baseline is isolated from the prompt signal



profile plot is fit with gaussian function and central value is added to the linearity plot



Consistent also with Warren analytical model which predicts 10^{-11} A in this flux range

n_TOF target monitoring with SPND:

Experiment at n_TOF with SPNDs has **successfully taken data across almost 50 days**

- ✓ **SPND response tested under several operation conditions** including variable neutron flux, flux interruptions from minutes to days, all in severe, real-life hadron accelerator EMI conditions. Average neutron flux of 10^{10} n/cm^{2}s
- ✓ Very **low noise** considering detectors position and cable length
- ✓ **Rh SPND** delayed signal consistent with model and linear with average neutron flux
- ✓ Rh SPND decay time consistent with expected activation processes
- ✓ **Rh SPND prompt signal also proportional to to prompt target emission**

Second test in GELINA photoproduction neutron facility (JRC Geel, Belgium): first experiment on the modified target moderator arm, thanks to JRC colleagues

- ✓ simulated neutron flux fully consistent with measured one
- ✓ Al SPND signal proportional to beam intensity in hard n flux

Future activities

The performances of the SPNDs and the experience of the first on-target experiment at nTOF and GELINA opened new scenarios:

- SPNDs **will be installed in the new nTOF Target#3 assembly to monitor the secondary particle production during next 10 years operation**

- **New tests of** SPND prototypes with different emitter materials are foreseen in research reactors and beam target facilities

- **Detailed signal generation Monte Carlo models** are needed to fully understand the response in such mixed fields: **comparisons and new development are foreseen**

PhD theses: possible activities

Within this project **several activities** could be argument for a **PhD thesis**:

- **Design of new SPNDs for n_TOF** target: dimensions and active materials
- **Installation and commissioning** of the new set of SPNDs on **n_TOF target at CERN**
- Development of **novel integrated radiation transport and electromagnetic model** for SPND signal formation

Experimental activities will be performed **within the n_TOF collaboration**: possibility to **participate in data taking at CERN** for **short and long term stays**, inclusion in the list of authors for **publications.**

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Thank you

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