Nuclear Physics Capabilities of the IFMIF-DONES Neutron Source

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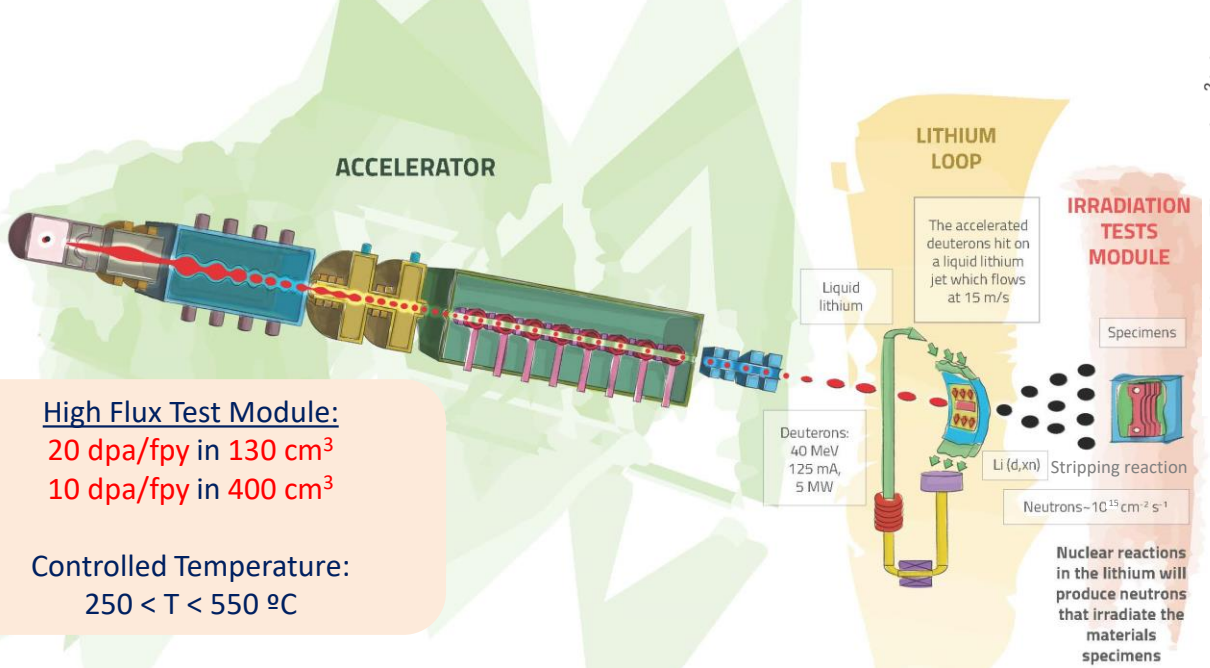
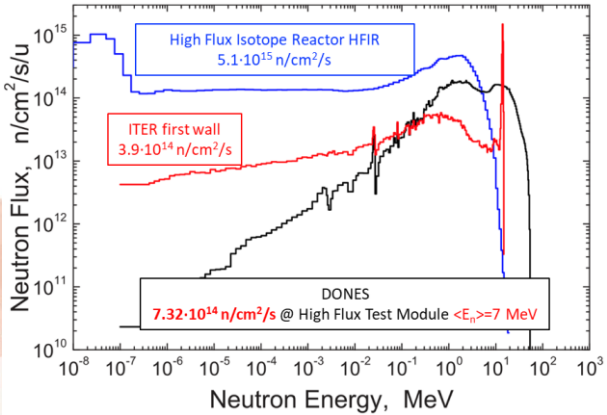
Outline

- **What is IFMIF-DONES**
- **IFMIF-DONES for Nuclear Physics**

What is IFMIF-DONES?

An accelerator based fusion-like neutron source to be used for the qualification of the materials to be used in the DEMO Reactor





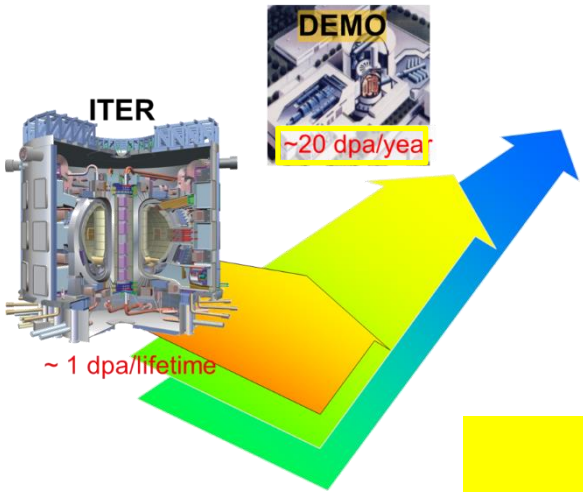
High Flux Test Module:
20 dpa/fpy in 130 cm^3
10 dpa/fpy in 400 cm^3

Controlled Temperature:
250 < T < 550 ºC

A neutron flux of ~ 10^{15} $n/cm^2/s$ is generated with a neutron spectrum up to 55 MeV energy

Why DONES ?

One of the main differences between ITER and DEMO is the radiation dose: at DEMO more than two orders of magnitude higher

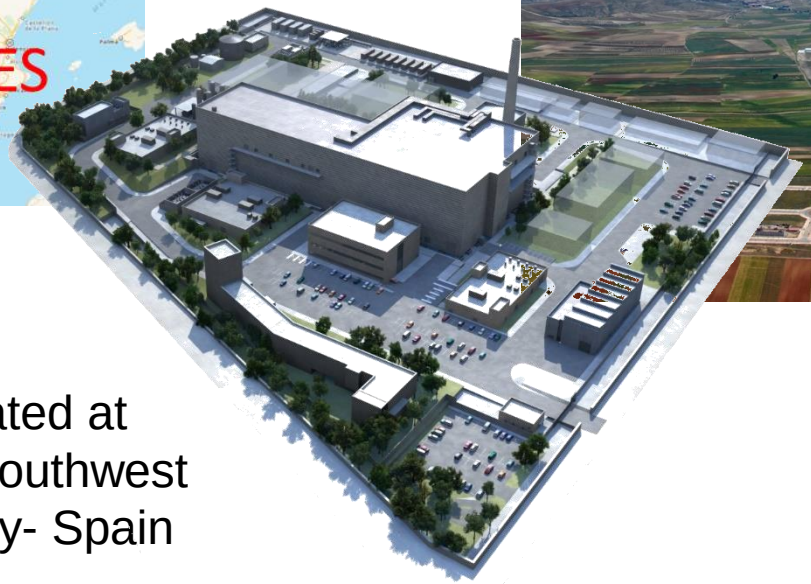


- Selection and qualification of candidate materials for fusion reactors
- Generation of engineering data for design, licensing and safe operation of DEMO up to end-of-life
- Completion, calibration and validation of databases (mainly generated from fission reactors research)
- Material testing and simulation carried out simultaneously to correlated fundamental understanding of radiation response of materials

But also of interest in other scientific areas (nuclear physics, medical and industrial applications,…) due to its unique characteristics

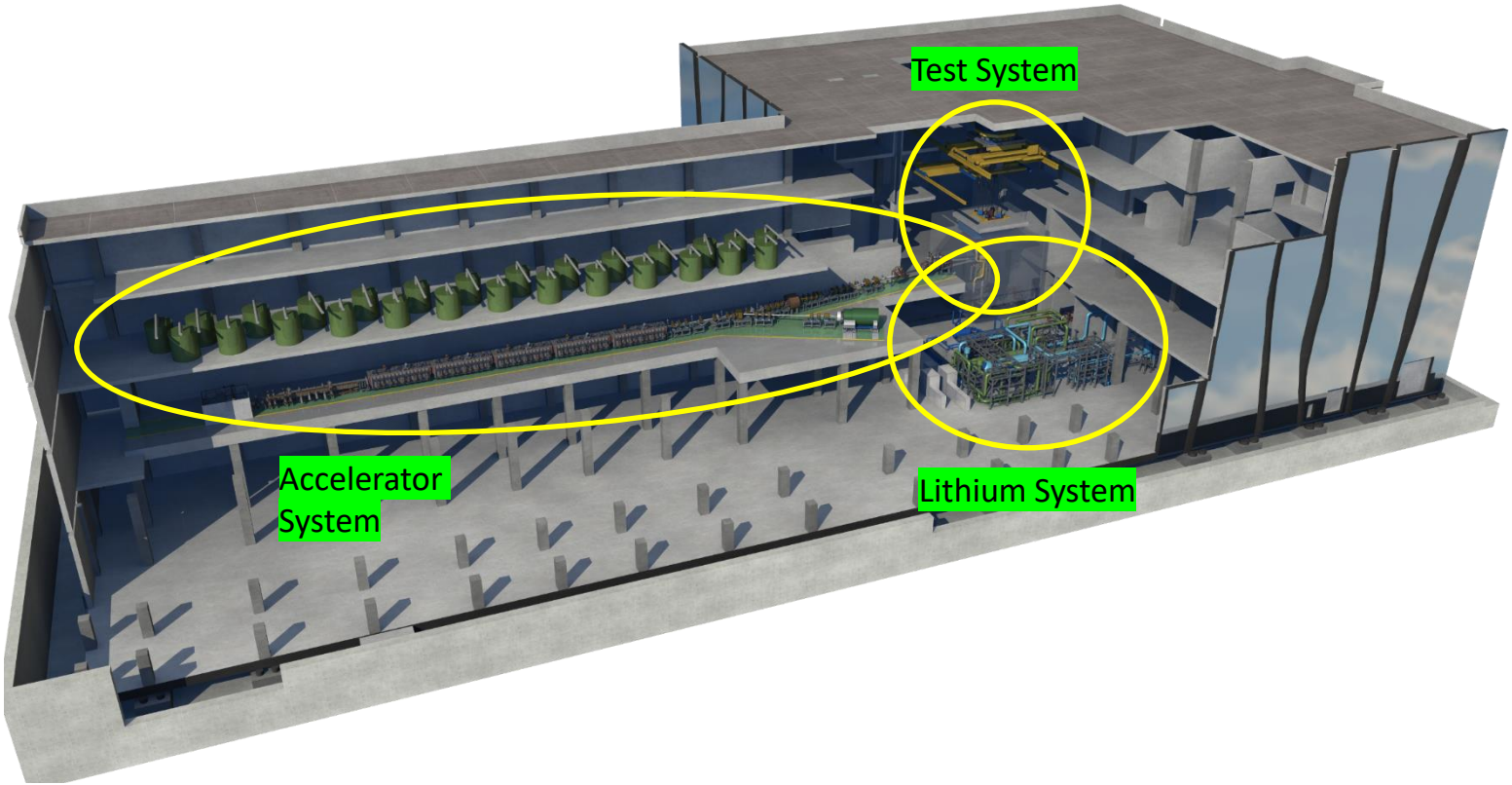
Identified as high priority in the EU Fusion Roadmap
Included in the ESFRI Roadmap as a EU strategic facility

IFMIF-DONES Facility



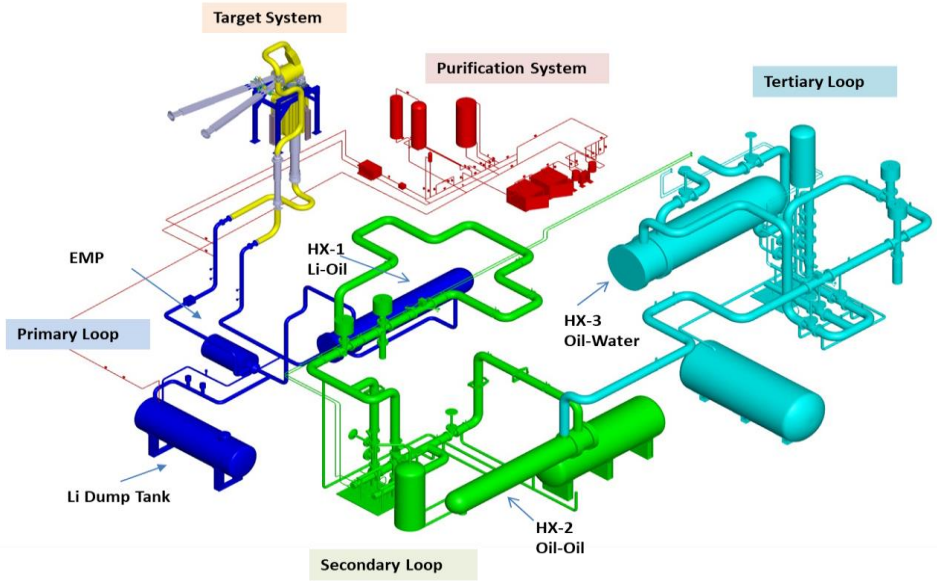
The site is located at Escúzar -18 km southwest from Granada city- Spain

IFMIF-DONES Plant



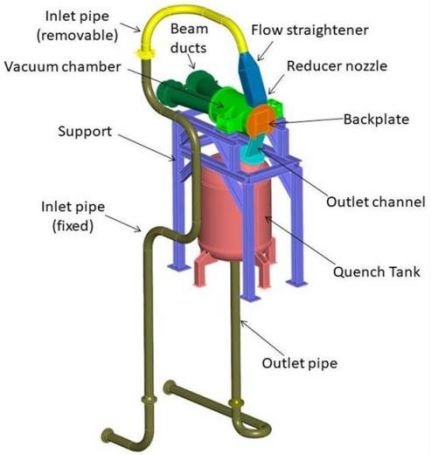
Lithium System

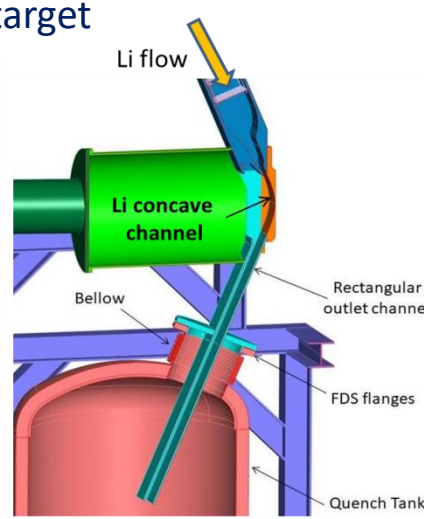
5 MW power handling, 15 m/s Li velocity, remote handling
Main requirements: Li flow stability and Li impurities control



Li volume ~14 m^3
Li flow rate ~100 l/s
Li temperature (cold side) ~300 °C

Lithium target





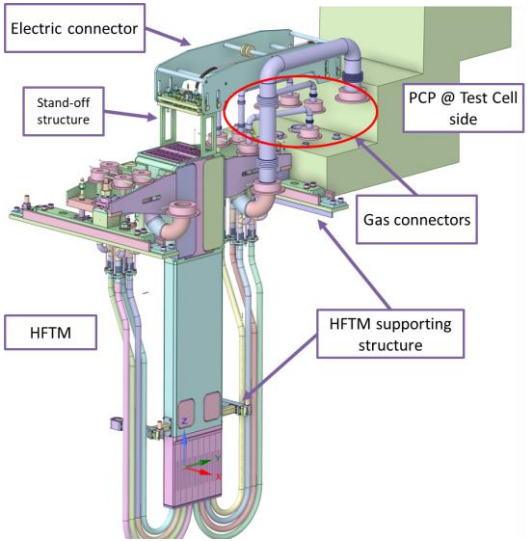
Jet thickness: 25±1 mm
Chamber pressure: 10^{-3} Pa
Li flow velocity: 15 m/s
Heat flux: 500 MW/m^2

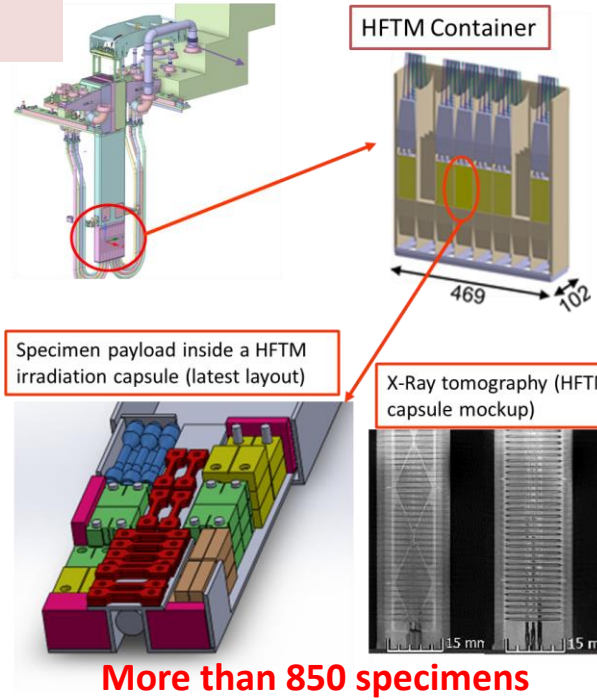
Test Systems

Main characteristics driven by the presence of neutrons and Li

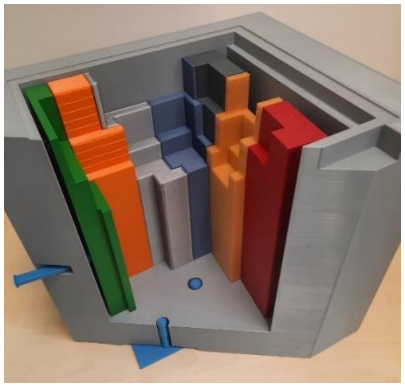
- **Internal components cooling by He**
- **Remote Maintenance required**

HFTM upper part



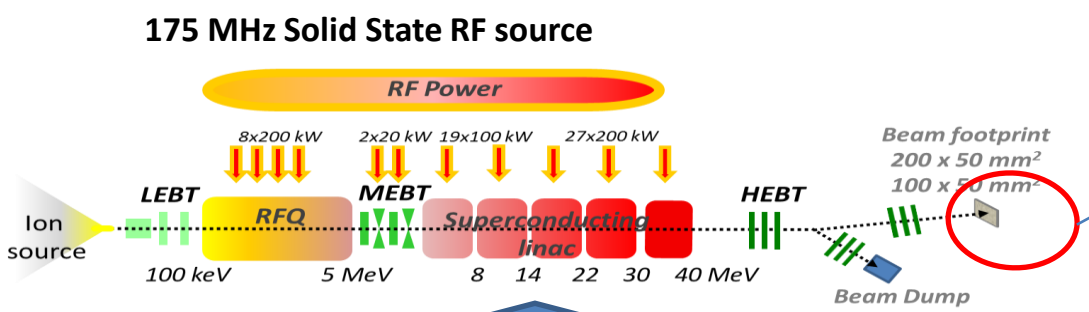


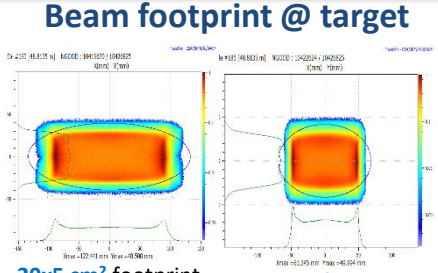
More than 850 specimens can be hold in the HFTM !!



Test Cell Removable Shielding Blocks (Maintainability and minimizing neutron streaming)

IFMIF-DONES: Accelerator





Auxiliaries

Vacuum, Cryogenics, Water cooling, Gas and electric distribution…

D+ CW 175 MHz SC LINAC
125 mA / 40 MeV → **5 MW**
Total length of ~**100 m**
Windowless liquid **Li target**
Hands-on **maintenance (<1 W/m)**

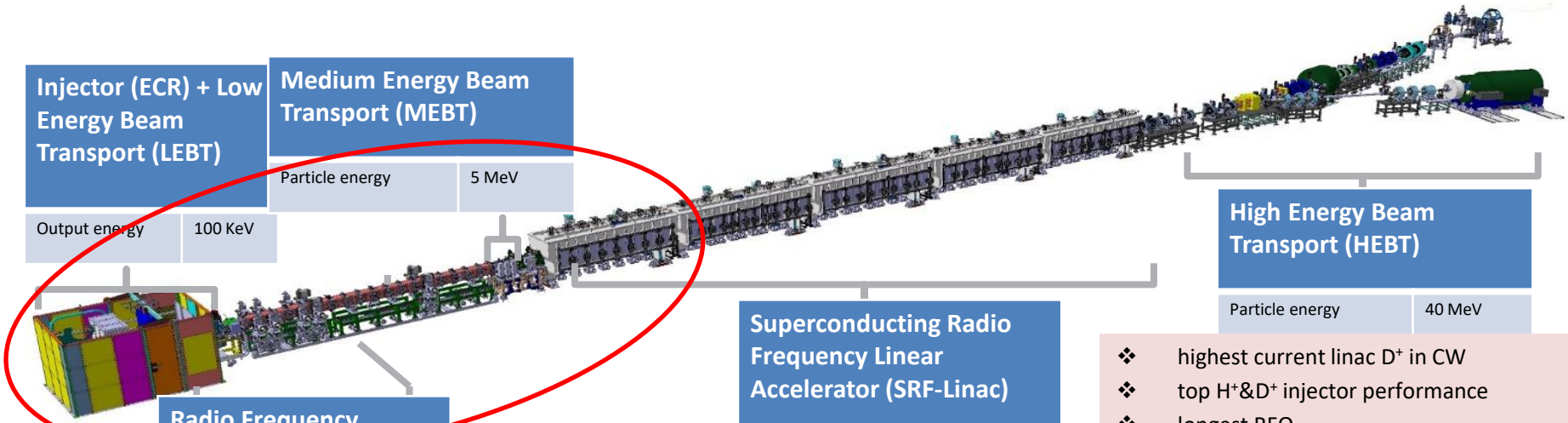
Staged comissioning in five years (Injector CW / RFQ @10-20% /SRF LINAC @ 1% / HEBT@ Target)

CW operation with an availability target of 87%

Accelerator systems summary

175 MHz, 5MW, 125 mA, CW, high availability: One of the more powerful accelerators in the world

Waiting for validation results from IFMIF-EVEDA: LIPAc Prototype (Rokkasho)



Injector (ECR) + Low Energy Beam Transport (LEBT)

Output energy	100 KeV

Medium Energy Beam Transport (MEBT)

Particle energy	5 MeV

Radio Frequency Quadrupole (RFQ)

Output energy	5 MeV

Superconducting Radio Frequency Linear Accelerator (SRF-Linac)

Output energy	40 MeV

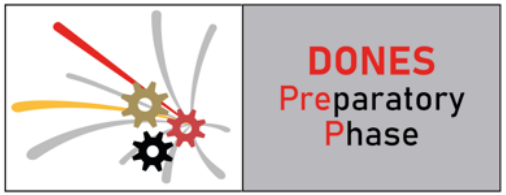
High Energy Beam Transport (HEBT)

Particle energy	40 MeV

- highest current linac D^+ in CW
- top H^+&D^+ injector performance
- longest RFQ
- record of light hadrons current through SC cavities
- highest beam perveance

The key mission of the facility is linked to the materials issue of the future fusion reactors but it has unique characteristics thatmust be available for other scientific problems

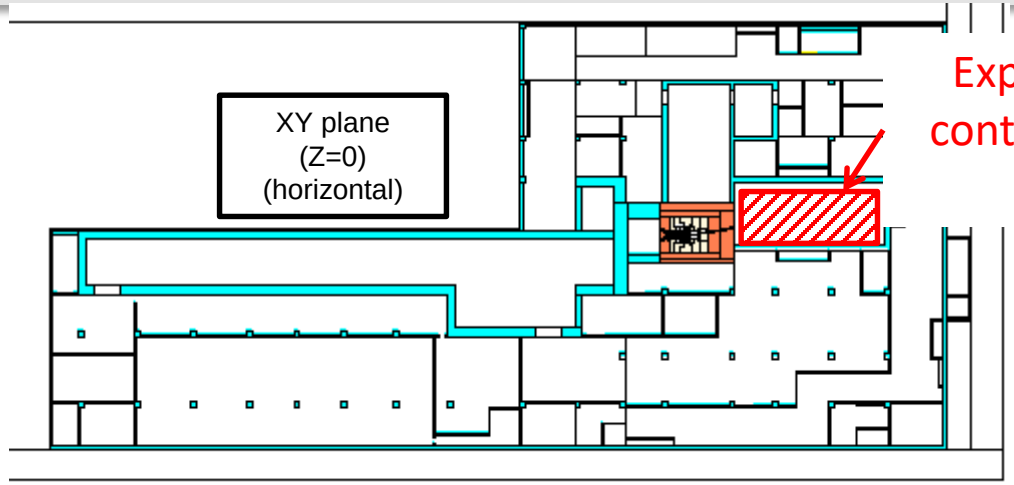
A systematic effort is being developed to analice the posible different ideas and to integrate them in the facility engineering design



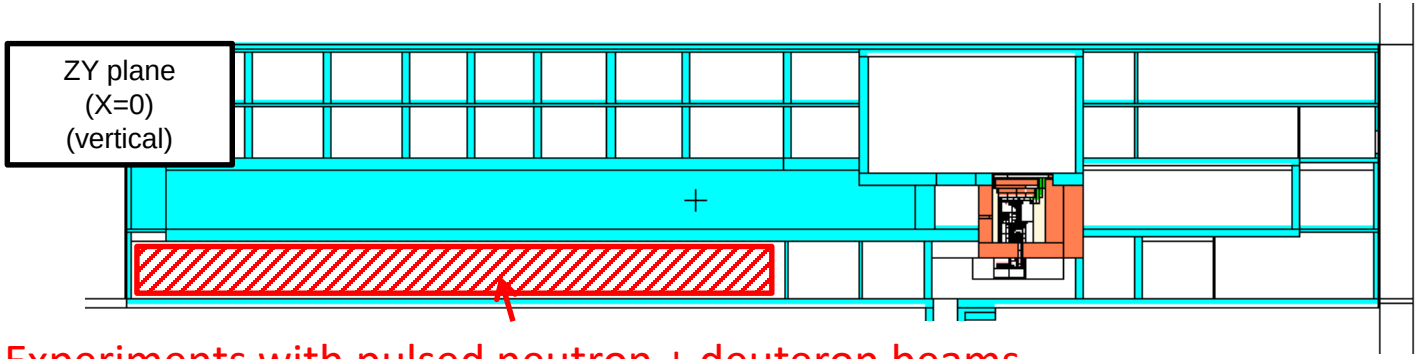
WP8 in the DONES-Prep Project coordinated by A. Maj (IPJ-PAN)

Coordinated by D. Cano (CIEMAT) and A.M. Lallena (UGR)

Additional experimental areas

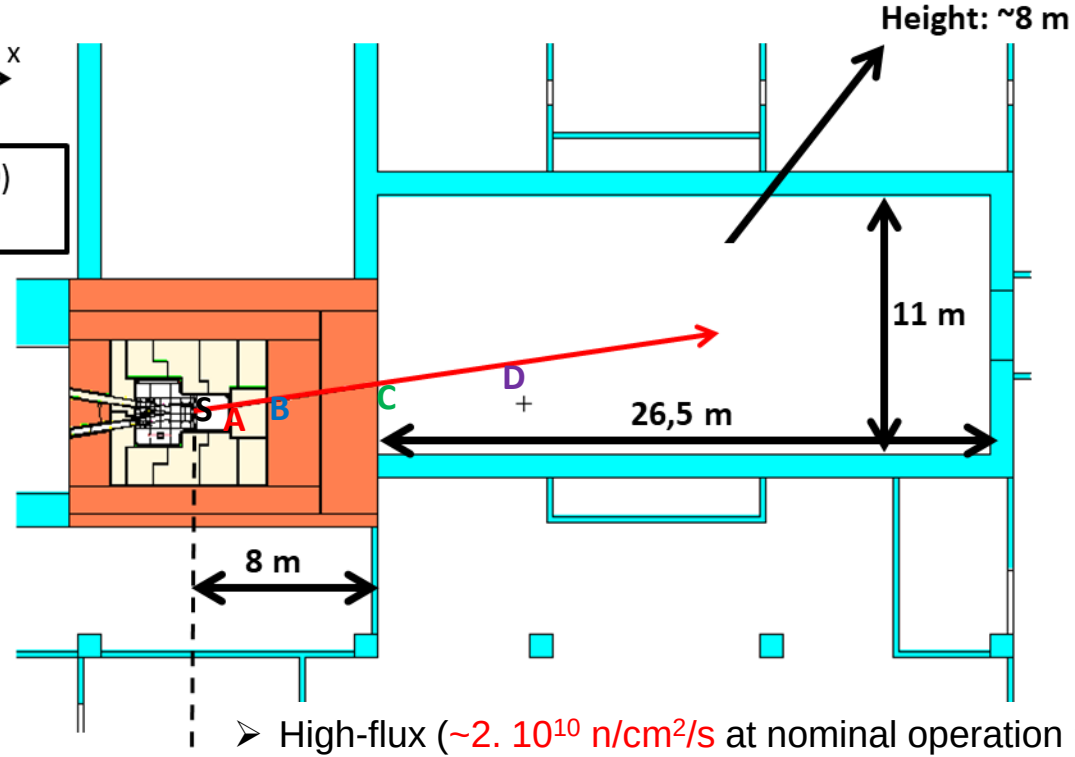


Experiments with continuous neutron beams

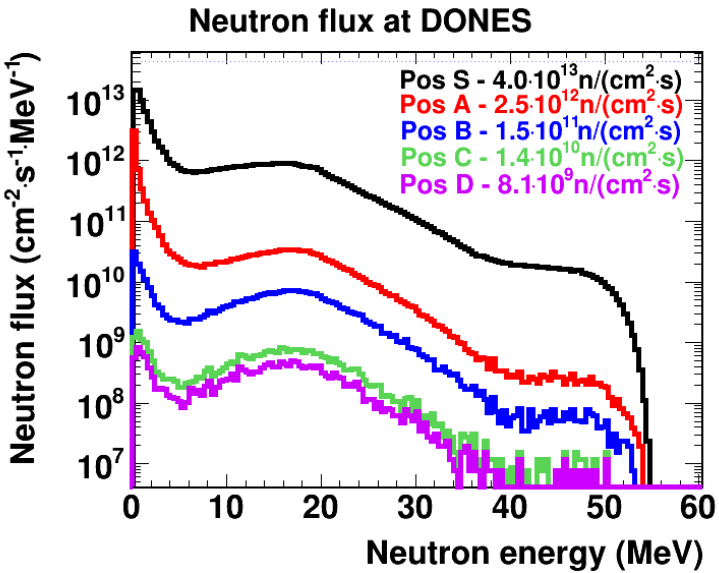


Experiments with pulsed neutron + deuteron beams

Continuous neutron beam experimental area



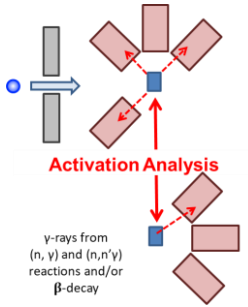
Very high neutron flux at very high energies!!!



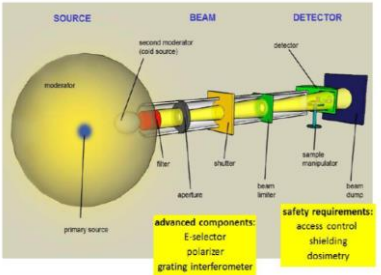
- High-flux (~2. 10^{10} n/cm^2/s at nominal operation 125 mA deuteron beam, covering a large energy range
- Collimated neutron beam (~98% of the neutrons with θ < 1°)

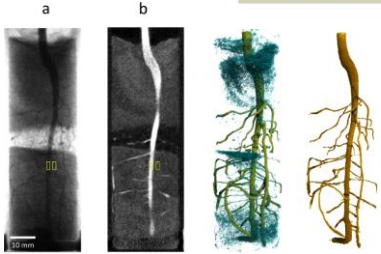
Potential experiments with neutrons

- **Nuclear physics studies with moderated and unmoderated neutrons**
  - Analysis of neutron-rich isotopes production by neutron induced fission
  - Spectroscopy of very exotic and short lived nuclei
  - Maxwellian-averaged capture cross-section for some stellar nuclear reactions by activation techniques with neutrons
  - Analysis of radioisotope production routes by nuclear decay induced reactions

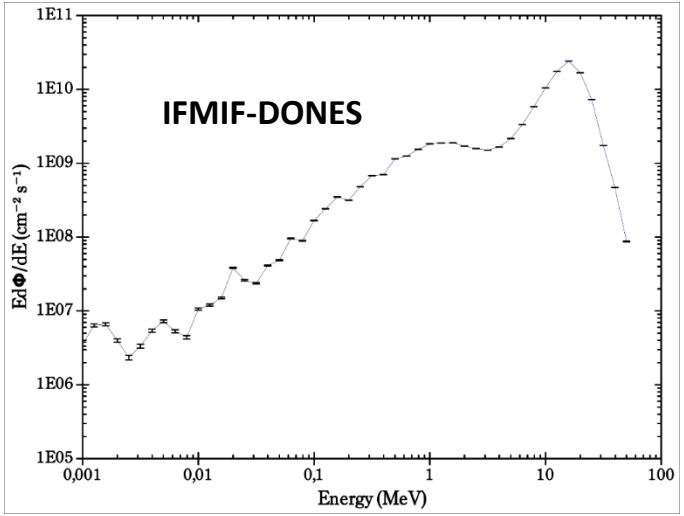


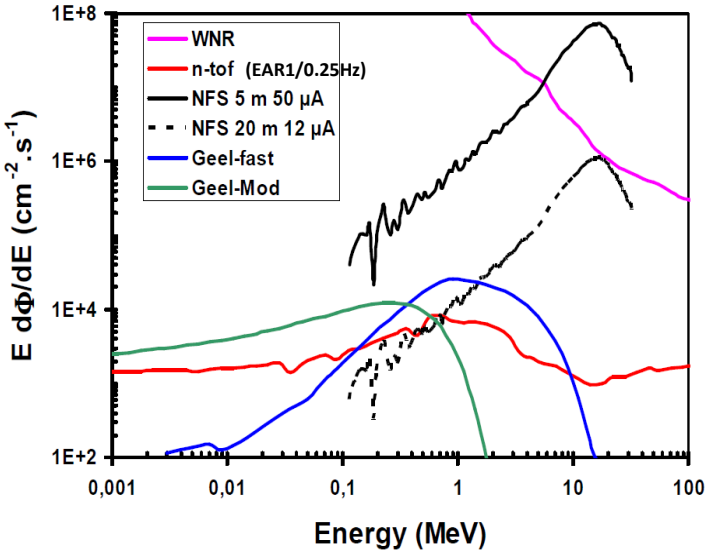
- **Others**
  - Neutron scatering with moderated neutron beams (biological matter)
  - Characterization of materials by radiation analysis (for medicine, chemistry, biology, forensics,…)
  - Materials doping
  - Imaging techniques with neutrons
  - Radioisotope producción for medical applications (e.g. 99Mo)
  - Fast neutron irradiation of components, devices or bio-simples
  - Superconductive materials under fast neutron irradiation





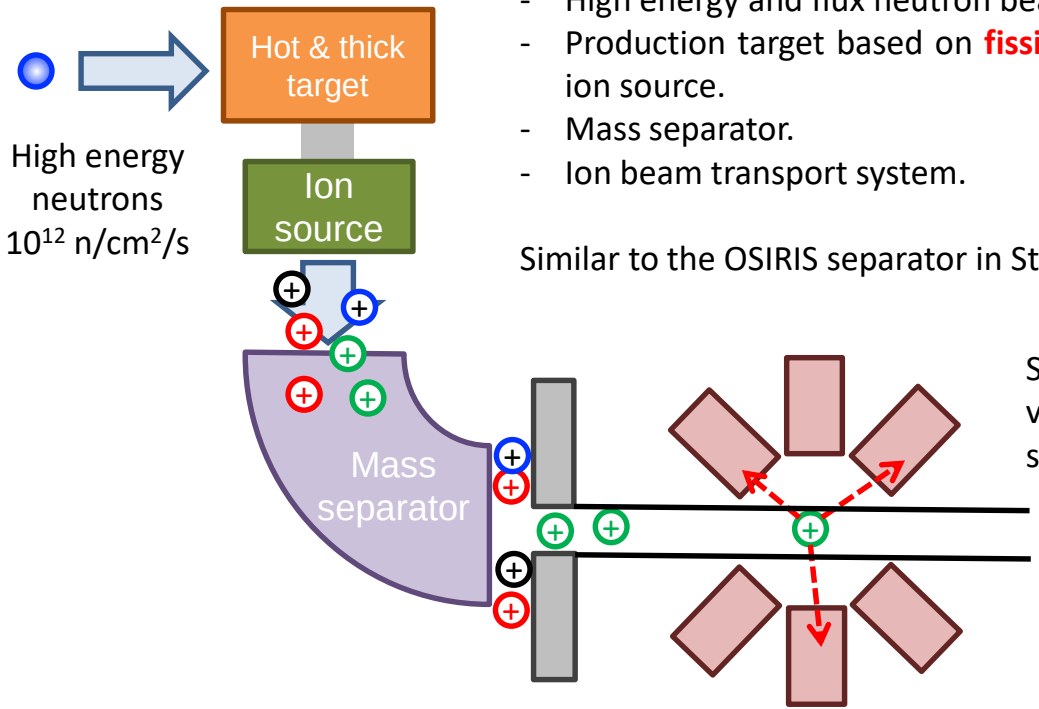
Unmoderated neutron beam





- IFMIF-DONES has higher neutron flux than TOF facilities
- but, No TOF technique to select neutron energy
- High flux for radioisotope production by (n,x) reaction

DOMISOL: DONES Magnetic Isotope Separation On Line



The DOMISOL consists of:

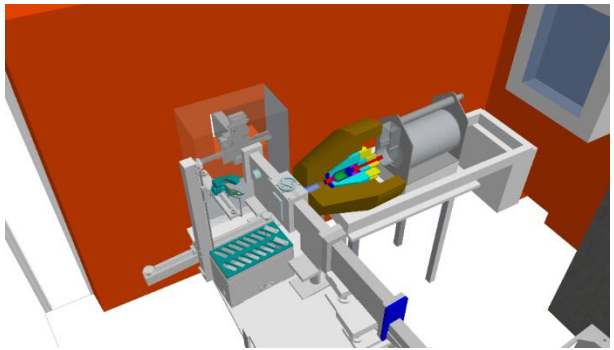
- High energy and flux neutron beam.
- Production target based on **fission** reactions and ion source.
- Mass separator.
- Ion beam transport system.

Similar to the OSIRIS separator in Studsvik.

Spectroscopy of very exotic and short lived nuclei.

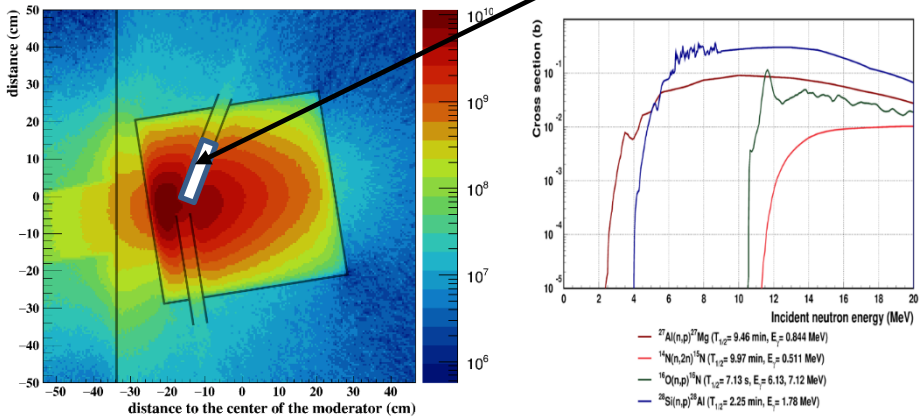
Neutron Activation Analysis

- Non-destructive method to determine the elemental composition of materials
  - with thermal Neutrons (NAA and Prompt Gamma AA)
  - with Fast Neutrons (FNAA and FPGAA).
- Neutron flux is a key ingredient:
  - ~$10^{12\text{-}14}$ n/cm^2/s for NAA ; ~10^{8} n/cm^2/s for PGAA,
  - ~10^{8} n/cm^2/s for FNAA



PGAA station @Budapest Neutron Center

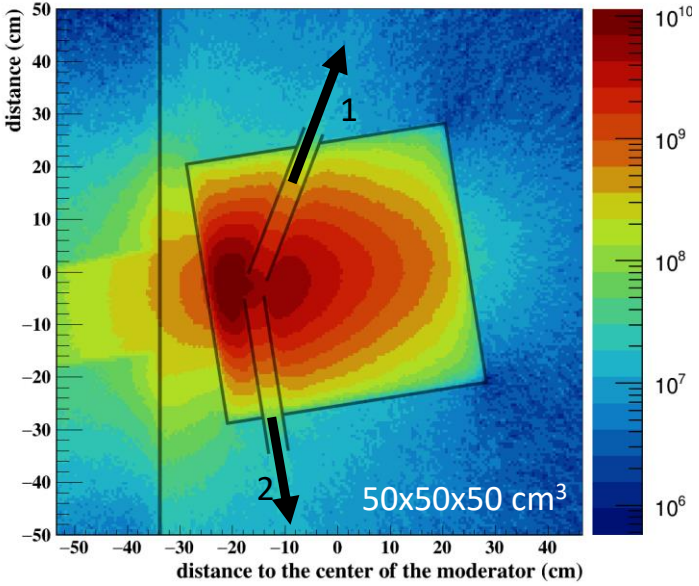
Irradiated sample to be analyzed

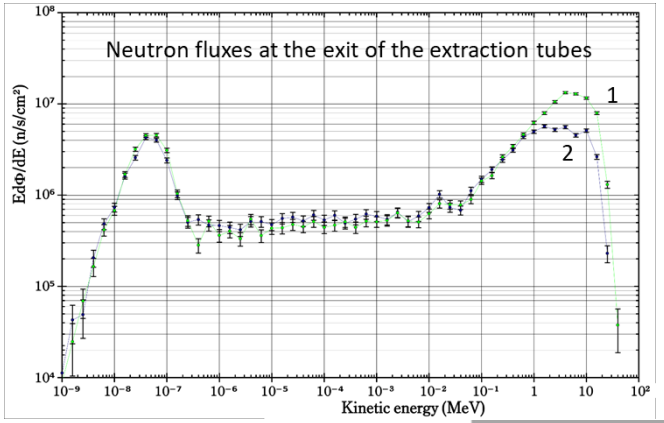


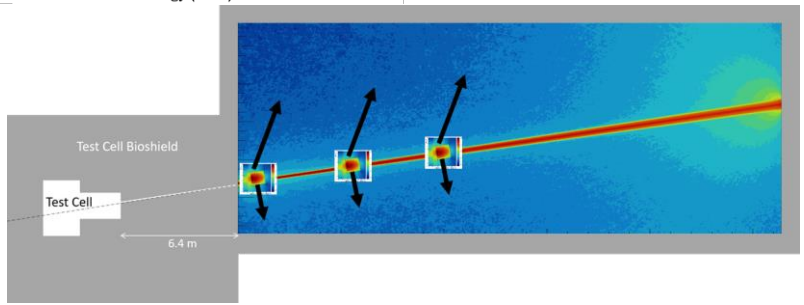
Fast Neutron Activation Analysis

➢ The IFMIF-DONES has the advantage to provide both thermal and fast neutrons and is competitive for FNAA and PGAA

Moderated neutrons







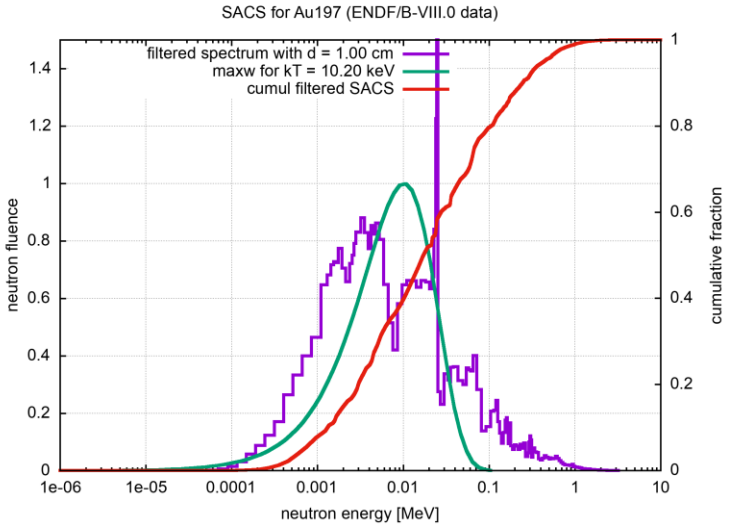
- At the exit of the tubes, the thermal neutron flux is ~ 10^7 n/cm^2/s below 400 meV but with a large fast neutron contamination (~ 7 10^7 n/cm^2/s)
- Offer the possibility to put moderators in cascade (Fishbone configuration)

Activation cross section measurements for astrophysics, and other applications

Experience acquired at the new n_TOF NEAR station (6 meters flight path). Produce a neutron flux which mimics Maxwellian spectra:

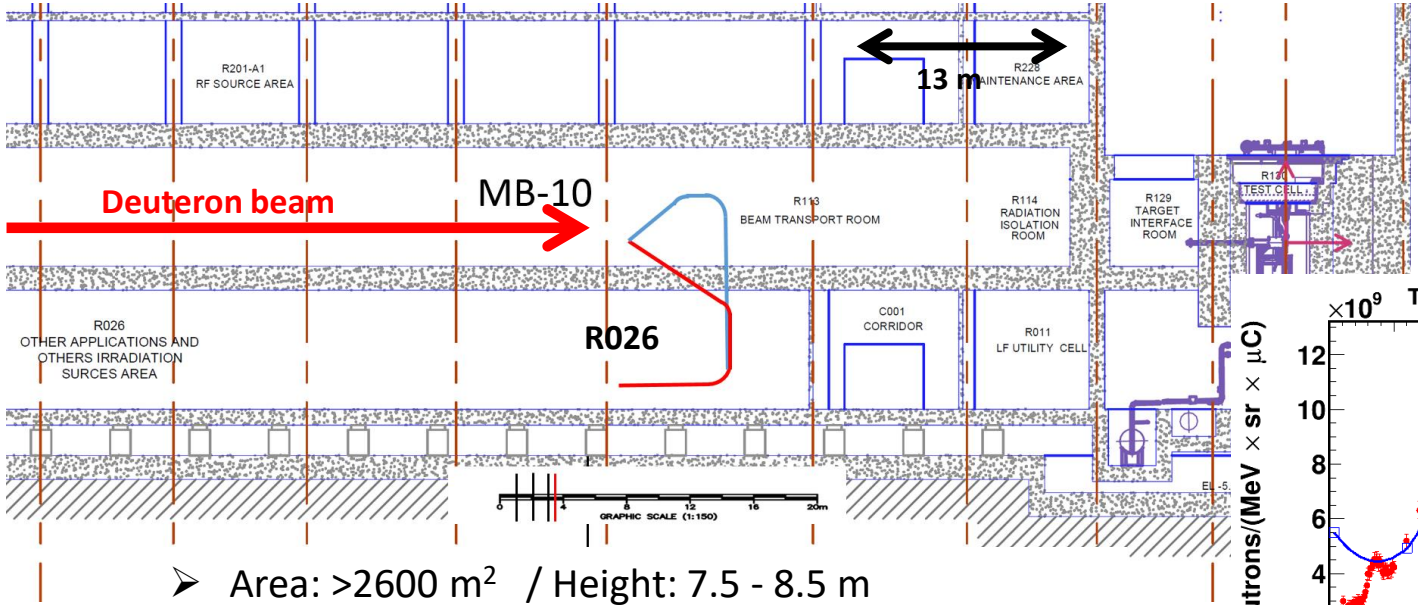
- Activation at high energies: (n,xn), (n,γ)
- (n,γ) at stellar temperatures (i.e. *k*T = 5 to 90 keV)
- (n,γ) at energies relevant for fast nuclear reactors.

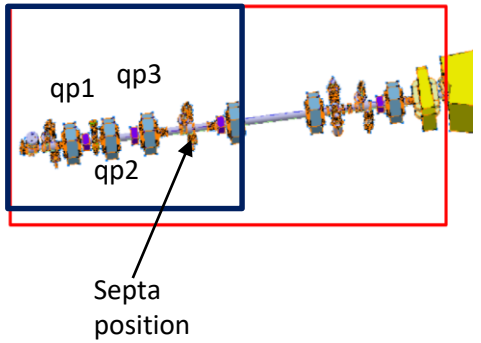
Unique Maxwellian averaged cross section measurements on very small masses (nanograms) and short half-lives (days) for some isotopes (e.g. ^{134,137}Cs, ^{85}Kr, ^{154}Eu, ...) of key relevance.

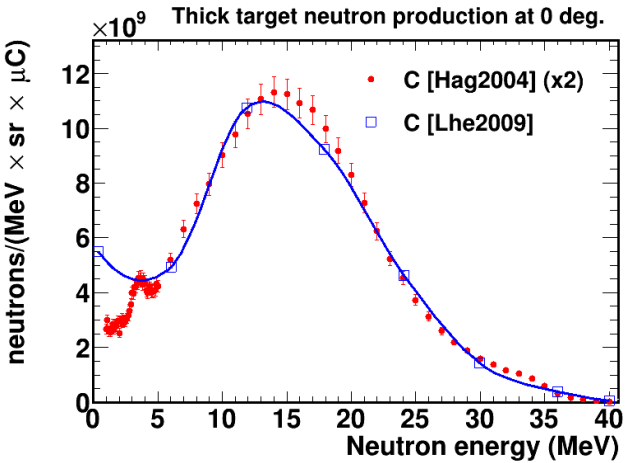


Pulsed beam experimental area

fast chopper at 40 MeV, at the end of the linac, able to extract one single bunch (over 10 000) and deviate it through an electrostatic meander followed by a magnetic septum into a dedicated transfer line





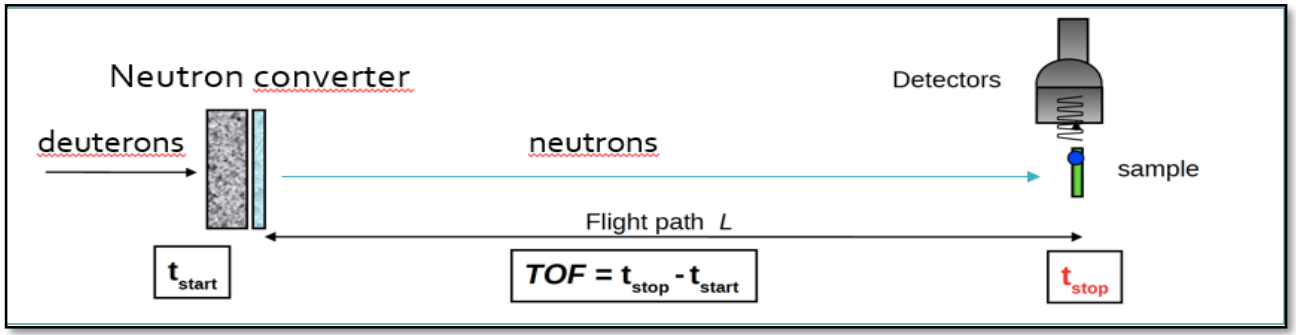


- Area: >2600 m^2 / Height: 7.5 - 8.5 m
- Extraction of the 40 MeV deuterons with kicker (1/1000 duty cycle or less)

Potential experiments with pulsed beams

- **With deuterons**
  - Production of radionuclides with a high intense deuteron beam
  - Deuteron induced reactions
    - (d,n) reactions
    - (d, charged particles) reactions
  - Half-life measurements of long-lived (10^5-10^7 years) isotopes

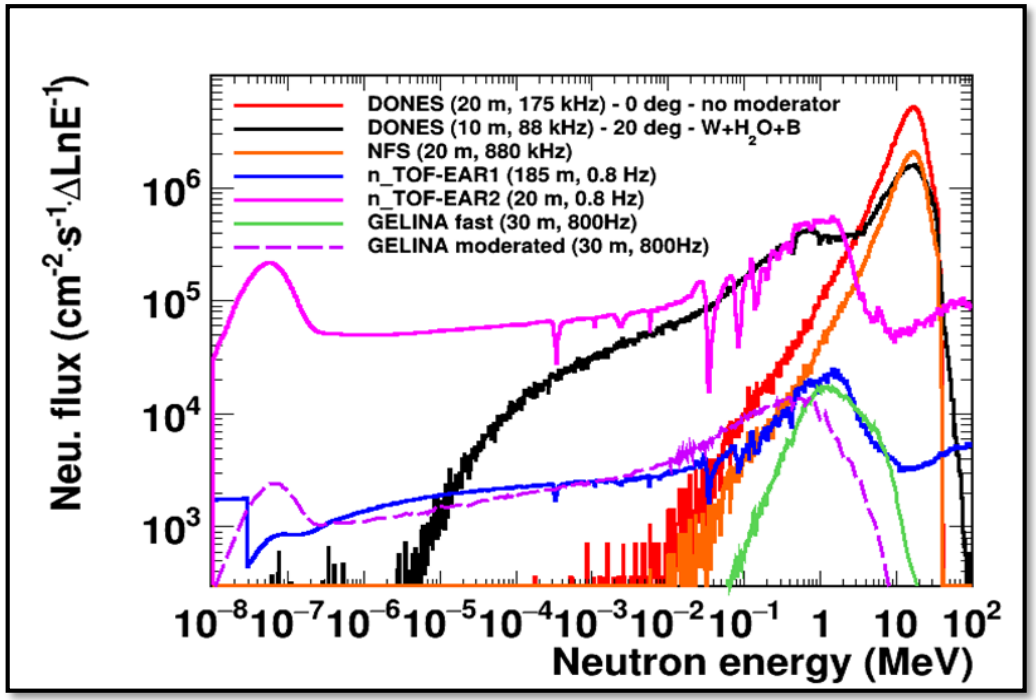
- **With pulsed neutron beam (ToF-DONES facility)→ with a** neutron production target
  - Neutron cross section measurements
  - Gamma-spectroscopy of nuclei produced in fast-neutron-induced fission reaction
  - Investigation of pygmy dipole resonances (PDRs) via (n, n'γ) reaction
  - Deuteron-induced proton transfer reactions (d,n)



Neutron time-of-flight facility (n_TOF)

TOF DONES

TOF DONES would be world's highest intensity TOF neutron source



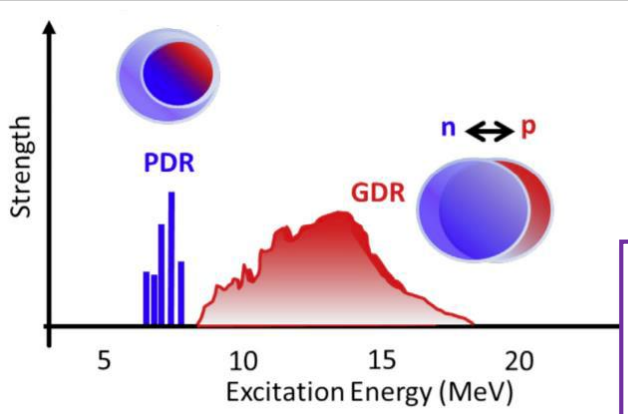
Broad experimental program on neutron induced reaction cross section measurements for nuclear technologies, astrophysics, fusion, particle and astro-particle physics

- (n,el) - elastic
- (n,γ) - capture
- (n,n'γ) -inelastic
- (n,xn) – neutron multiplication
- (n,f) - fission
- (n,p), (n,d), (n,t), (n,α)… - charged particle production
- Reaction studies with pulsed deuteron beam: cross sections, radiobiology, isotope production…

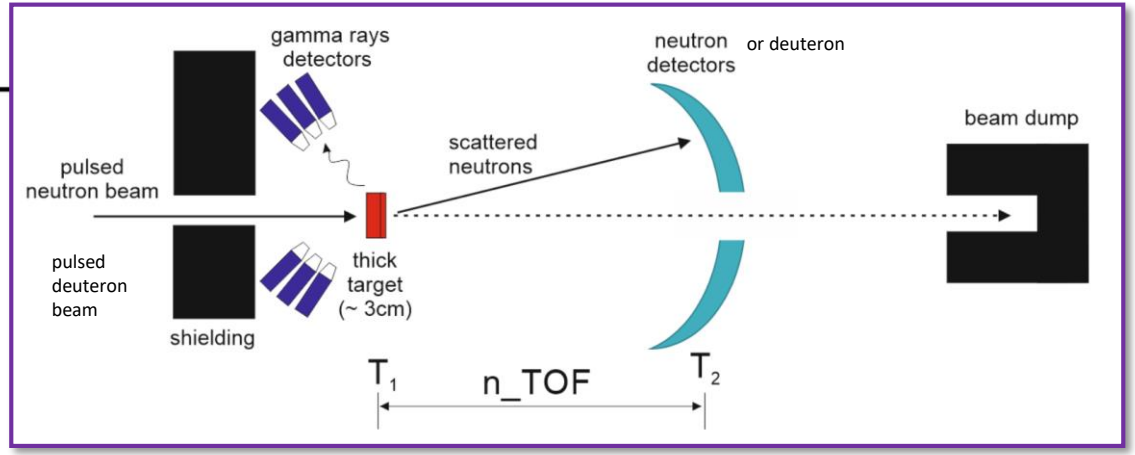
Measurements over several decades:

- 52 isotopes listed in the **High Priority Request List** for nuclear technologies.
- Over **35 (n,γ) prioritary cross section measurements** for astrophysics.

Study of the pygmy dipole resonance with (n,n'γ) or (d,d'γ) reactions



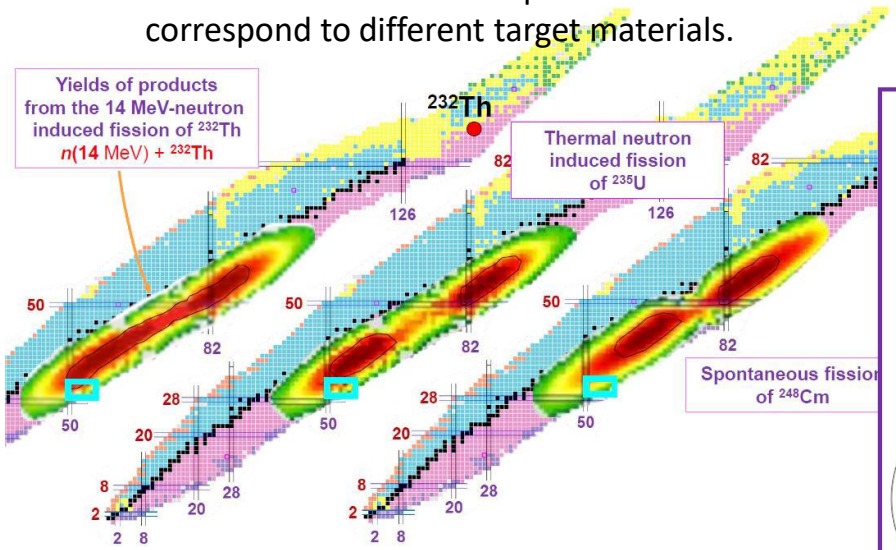
(Such experiments are already performed at NFS@GANIL/SPIRAL2)

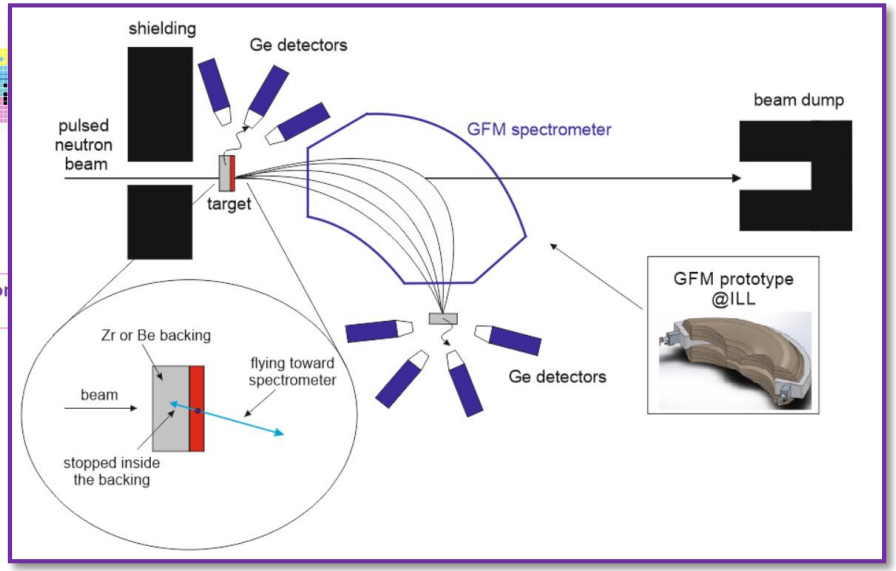


The DONES facility is an excellent place to systematically study PDR excitations in nuclei from different regions of the nuclear chart using neutrons or deuterons as a probe.
The high intensity of the neutron/deuteron beam and the possible long duration of the experiments will ensure high statistics data which is crucial for obtaining detailed information on the nature of pygmy dipole resonances.

Gamma spectroscopy of the nuclei produced in fast-neutron-induced fission reaction

Distribution of the fission products which correspond to different target materials.

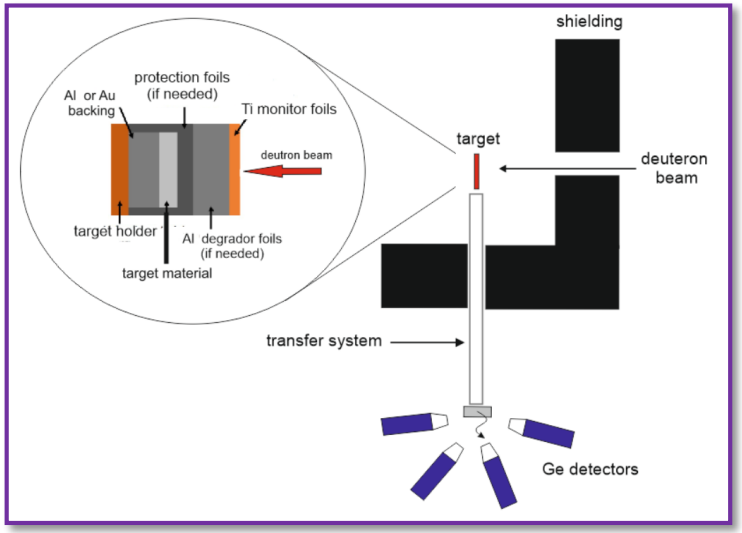




The secondary beam line at DONES offers unprecedented opportunity for gamma spectroscopy studies of neutron-rich nuclei, as it should allow accessing excited states and observing their gamma decay in nuclei which could not be reached for nuclear structure investigations so far.

Production of radionuclides (^{44}Sc, ^{64}Cu, ^{186}Re) with a high intense deuteron beam

	Reaction threshold (MeV)	Half-life	Time of max prod.	Isotopic fraction (%)
^{44}Ca(d,2n)^{44g}Sc	6.9	3h 58m 12s	2d 2h 43m	51.4
^{44}Ca(d,2n)^{44m}Sc	7.2	2d 10h 36m 0s	21d 18h 10m	19.8
^{64}Ni(d,2n)^{64}Cu	4.8	12h 42m 3s	5d 17h 23m	46.4
^{186}W(d,2n)^{186g}Re	3.6	3d 18h 0m 0s	29d 2h 24m	2.8



The very intense deuteron beam is ideal for the effective irradiation of samples and leads to the production of radionuclides with high activity.

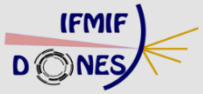
Summary

The IFMIF-DONES facility, to be built in Granada aimed to the qualification of fusion reactor materials will also allow relevant simultaneous experimental activities in other scientific areas.

In the case of nuclear physics:

- **The collimated neutron beam allows IFMIF-DONES to be a first class facility for techniques using fast neutrons and a medium flux facility for techniques using thermal neutrons.**
- **The deuteron pulsed beam allows IFMIF-DONES to be a first class TOF facility**

Your help in order to further progress with these ideas is welcome and we are open to collaborations!!!



FUSION FOR ENERGY

GOBIERNO DE ESPAÑA

MINISTERIO DE CIENCIA E INNOVACIÓN

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Junta de Andalucía

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