Experimental Capabilities of the IFMIF-DONES facility

Moisés Weber (IFMIF-DONES España consortium)
with significant contributions from A. Ibarra (IFMIF-DONES España consortium), D. Cano (CIEMAT, Spain) A. Letourneau (CEA, France) A. Maj (IFJ-PAN, Poland) W. Krolas (IFJ-PAN, Poland)

RADNEXT 2nd Annual Meeting – 9-10 May 2023

https://indico.cern.ch/e/radnext-2023

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No **101008126**

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN

IFMIF-DONES ESPAÑA

Junta de Andalucía
Consejería de Universidad, Investigación e Innovación

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

10 May 2023

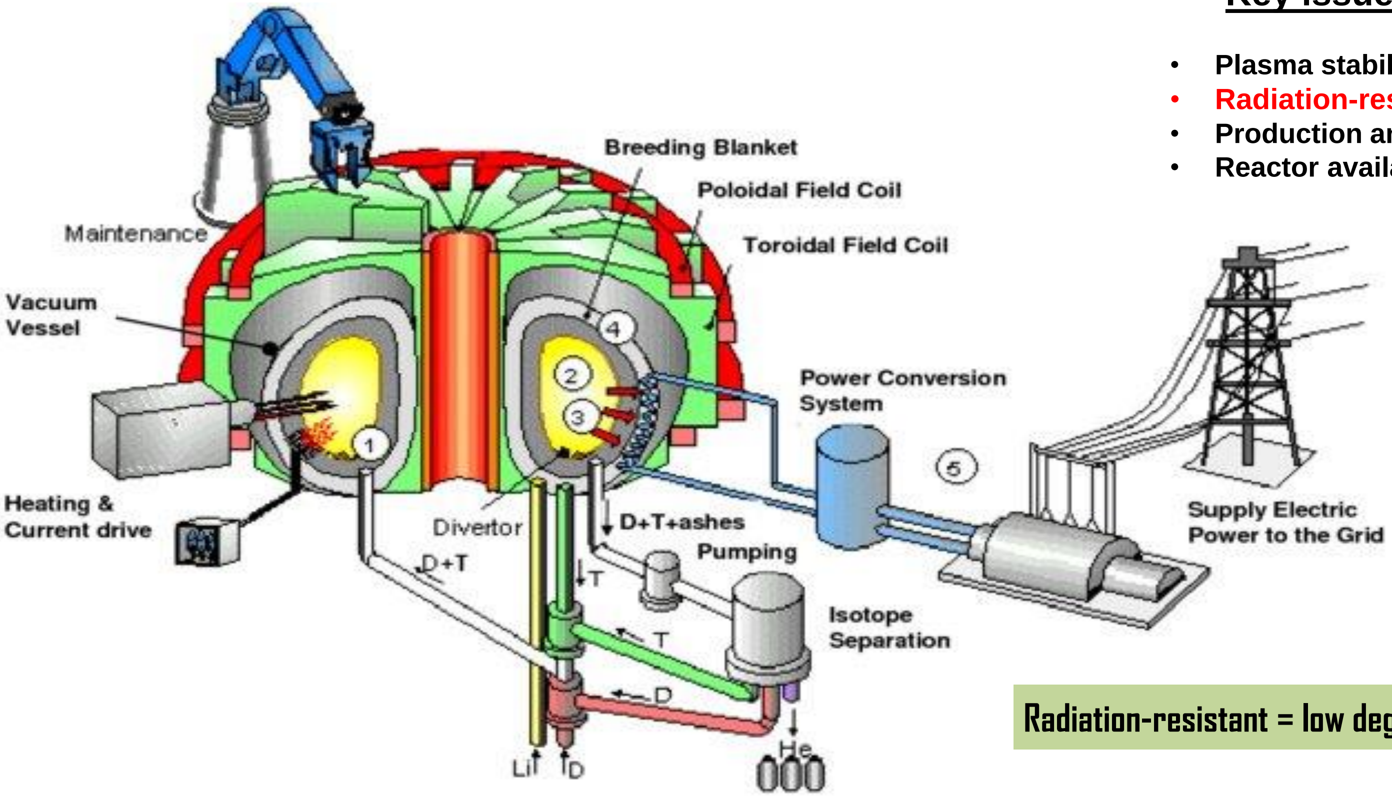
UNIVERSIDAD DE GRANADA

DONES

Outline

- **The “why and what” of IFMIF-DONES**
- **IFMIF-DONES experimental capabilities**

Towards a Fusion Power Plant

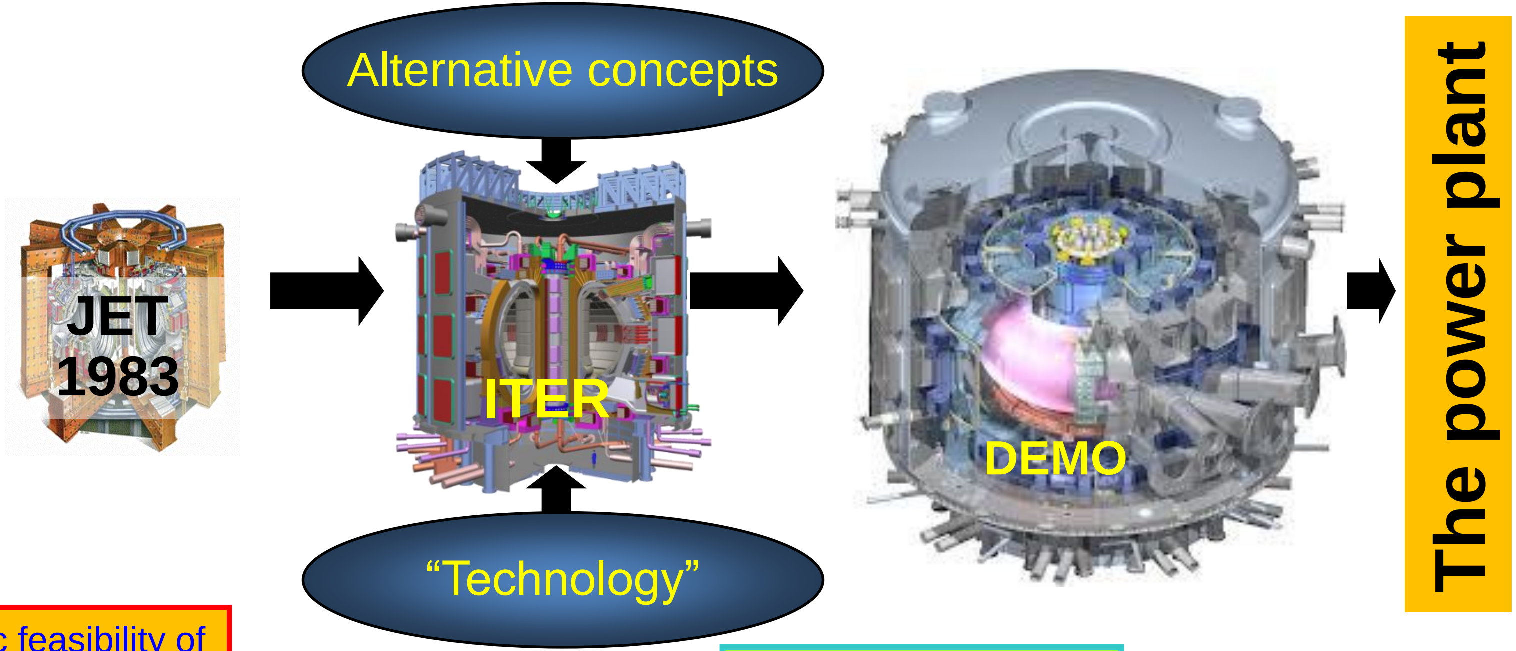


Key issues to be developed

- Plasma stability
- Radiation-resistant materials
- Production and processing of Tritium
- Reactor availability

Radiation-resistant = low degradation + low activation

EU strategy to fusion



JET: Scientific feasibility of the potential use of fusion reaction for energy production

ITER: scientific and technological feasibility of fusion energy

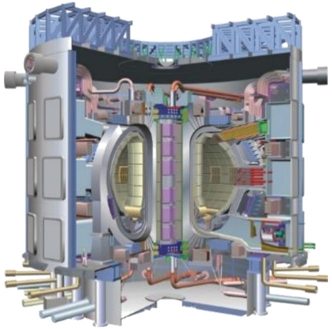
DEMO: Qualification of components and processes

Reactor: High availability, safe and environmental-friendly, economically acceptable

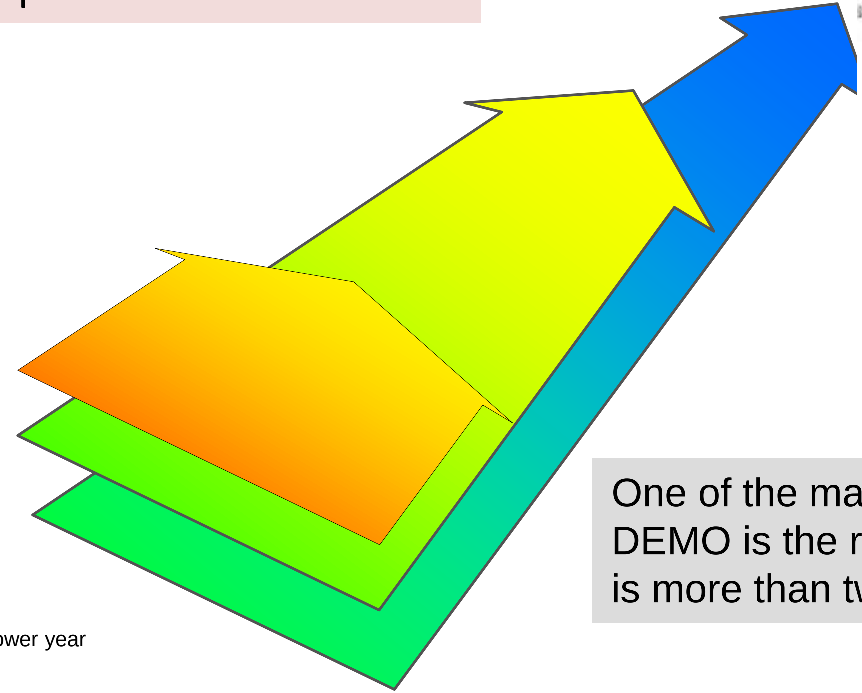
A question of neutrons

Currently affordable fusion reaction produces fast neutrons

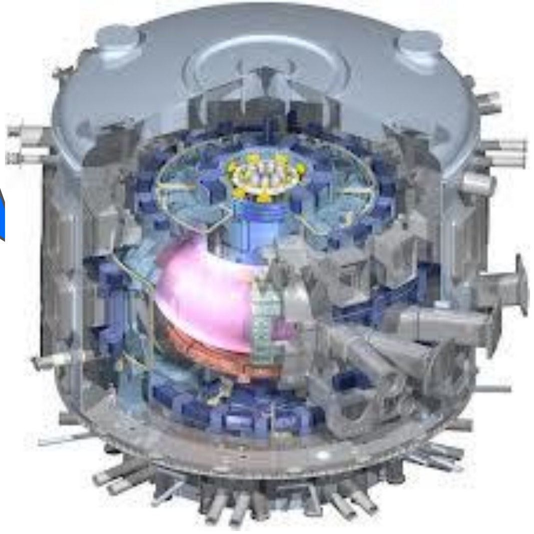
ITER



1-3 dpa/lifetime



DEMO

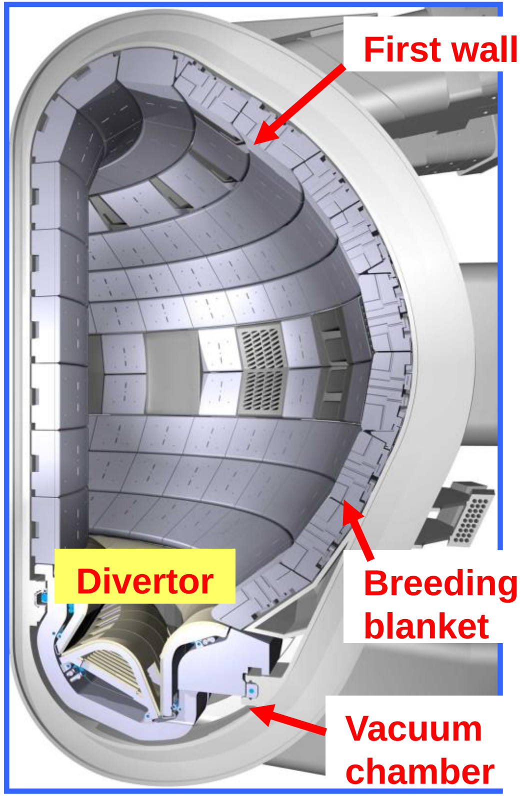


~15-20 dpa/fpy*

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

*dpa/fpy = displacement per atom/ full power year

So, why DONES?



Cost-effectiveness of fusion reactors can be modulated by (not only):

1. The size of the vacuum vessel (plasma volumen and shape)
2. The magnetic field (B, confinement)
3. Power (depending also on Size and B)

Neutron flux density becomes critical in reactors design.

For example

Higher B + Same size > Higher power > Higher neutron flux density > Shorter lifetime

Lifetime of irradiated key components is a main factor. These components will be activated and damaged. It depends on **neutron flux density**.

We need to **find the optimal cost-effectiveness design**, taking into account:

1. How long these components will last before they are replaced
2. How to qualify them according to regulators
3. How to find more durable materials to improve cost-effectiveness

Candidate Materials have to be tested!

Candidate irradiation sources:

- **Ionizing radiation sources** (X-ray, gamma, electron)
- **Displacement damage sources.**
  - **Ion accelerators** (ion irradiation: high dpa, short range)
  - **Nuclear reactors** (low energy neutrons)
  - **Accelerator-based neutron sources**
    - **Spallation** (high energy neutrons, pulsed)
    - **Stripping** e.g. Li(d , xn)
    - **Others** (DT sources)

Extrapolation of data when neutrons come from a different source, for different irradiation conditions is not obvious.

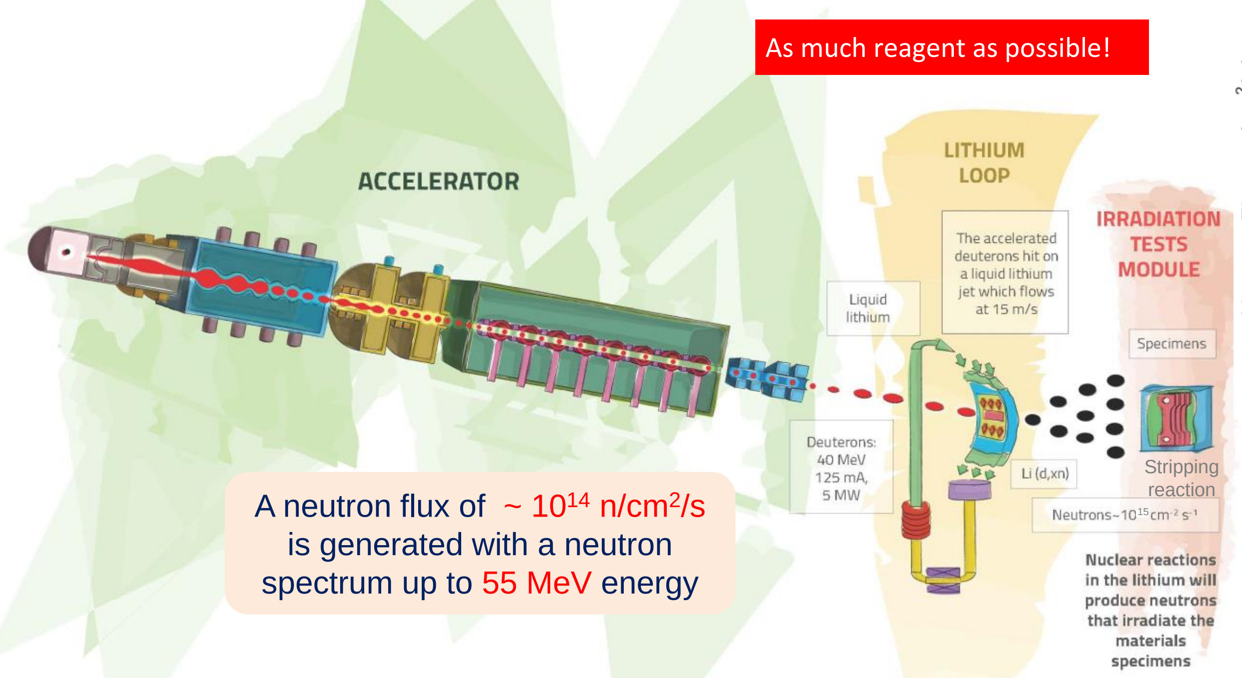
Fusion-like neutrons: neutron spectra causing damage and activation similar to that of a fusion reactor.

So, a fusion-like neutron source is urgently needed in order to understand/qualify the materials behaviour in a fusion reactor!!!

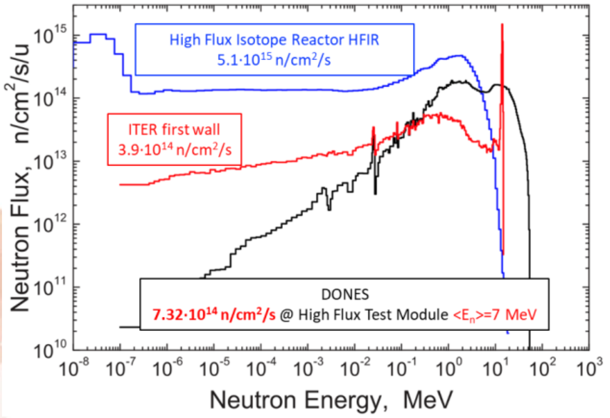
What is IFMIF-DONES?

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

As much reagent as possible!



A neutron flux of ~ 10^{14} n/cm^2/s is generated with a neutron spectrum up to 55 MeV energy



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

Controlled Temperature:
250 < T < 550 ºC

Identified as high priority in the EU Fusion Roadmap

Included in the ESFRI Roadmap as a EU strategic facility

The DONES Programme

DONES Programme Mission

The mission of the DONES Programme is to develop a database of fusion-like neutron irradiation effects in the materials required for the construction of fusion power reactors

DONES Programme Objectives

- **To provide a neutron source producing fusion-like neutrons at sufficient intensity and irradiation volume.**
- Generate materials irradiation test data for DEMO
- Generate data base for benchmarking with computational material science
- To develop a "Complementary Experiments" work programme

The IFMIF-DONES Facility

The fusion relevant neutron source and that will allow to fulfill the objectives of the Programme

The DONES Programme includes:

On-site

- The construction and operation (including running the irradiation experiments) of the IFMIF-DONES Facility

Off-site

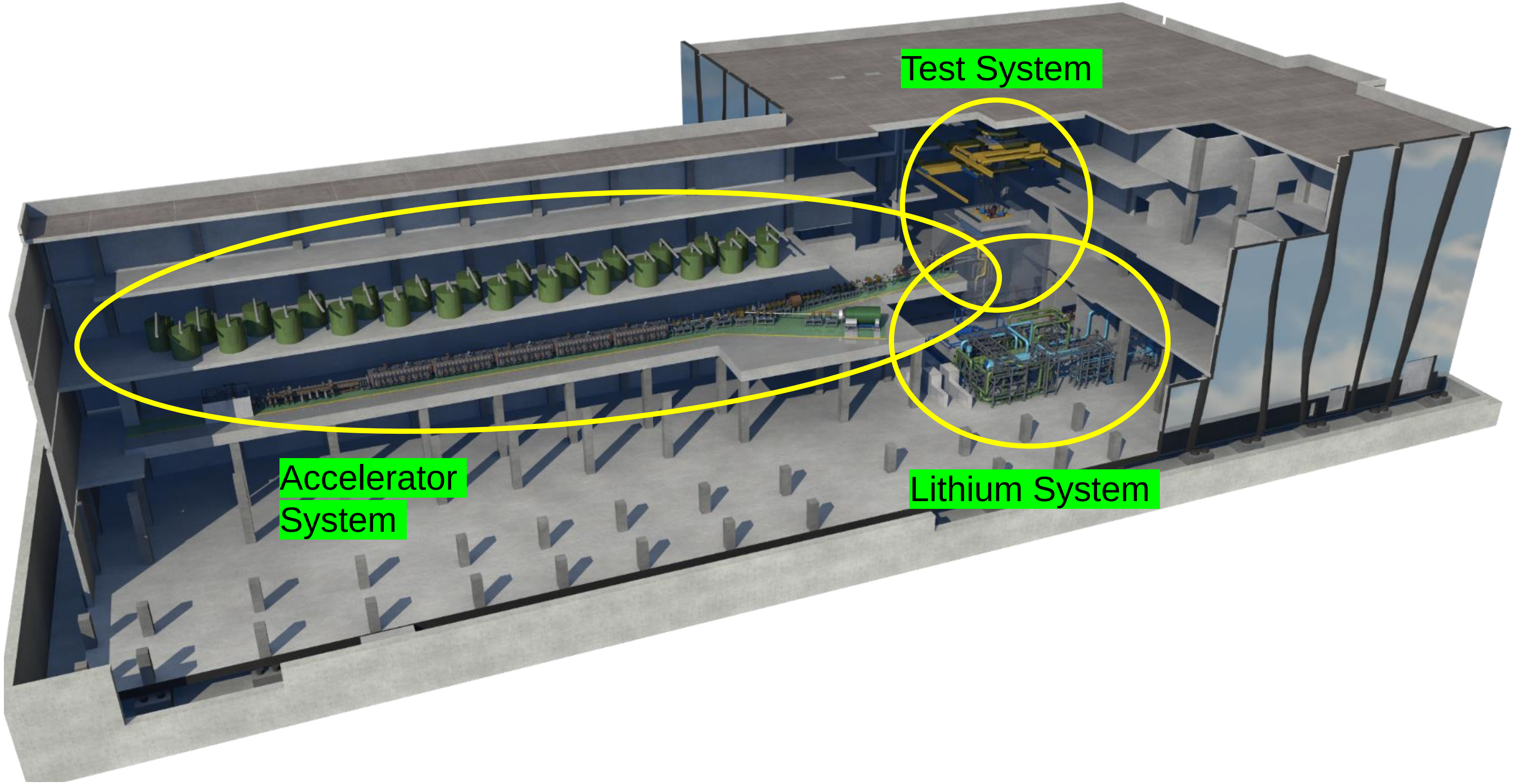
- The preparation of irradiation experiments (for fusion but also other applications)
- The analysis of the irradiation results
- The development of a qualified irradiation database, and of the required modelling and extrapolation capabilities

The launch of the construction phase of the IFMIF-DONES facility took place on 16 March 2023, in Granada, following the constitution of the DONES Steering Committee.

IFMIF-DONES Facility

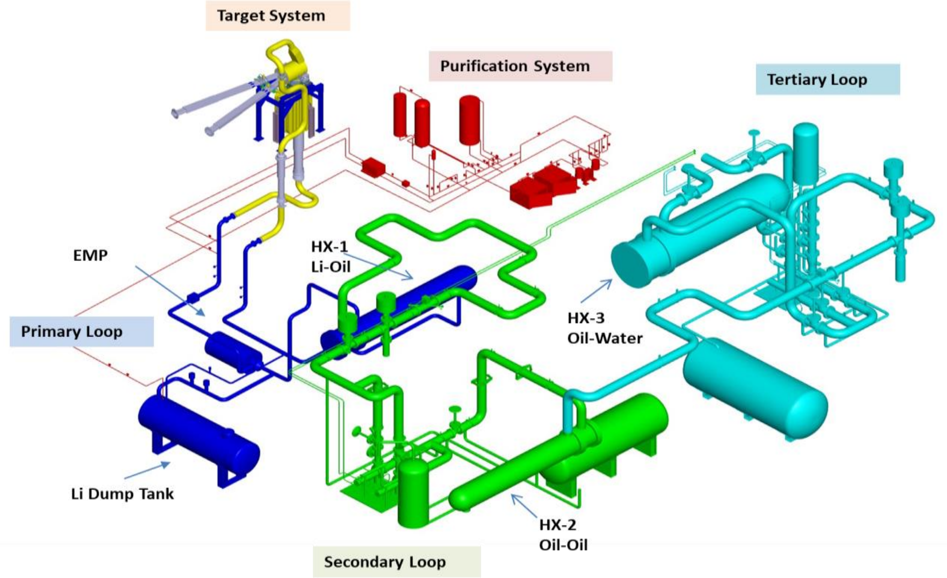
The site is located in Escúzar -18 km southwest from Granada city- Spain

IFMIF-DONES Plant



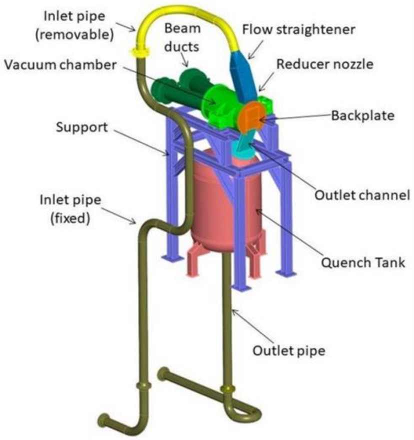
Lithium System

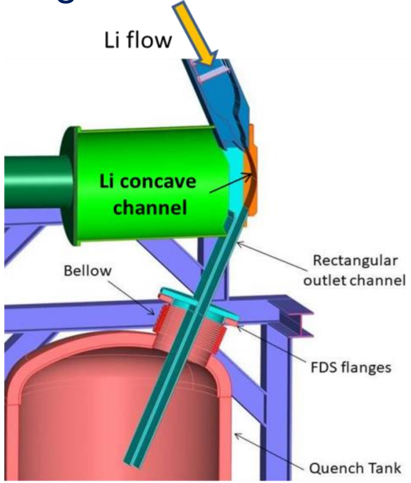
5 MW power handling, 15 m/s Li velocity, remote handling
Main requirements: Li flow stability and Li impurities control



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

Lithium target





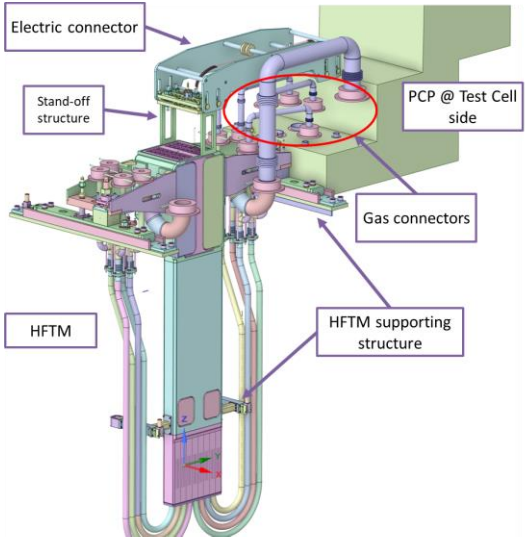
Jet thickness: 25±1 mm | Li flow velocity: 15 m/s
Chamber pressure: 10^{-3} Pa | Heat flux: 500 MW/m^2

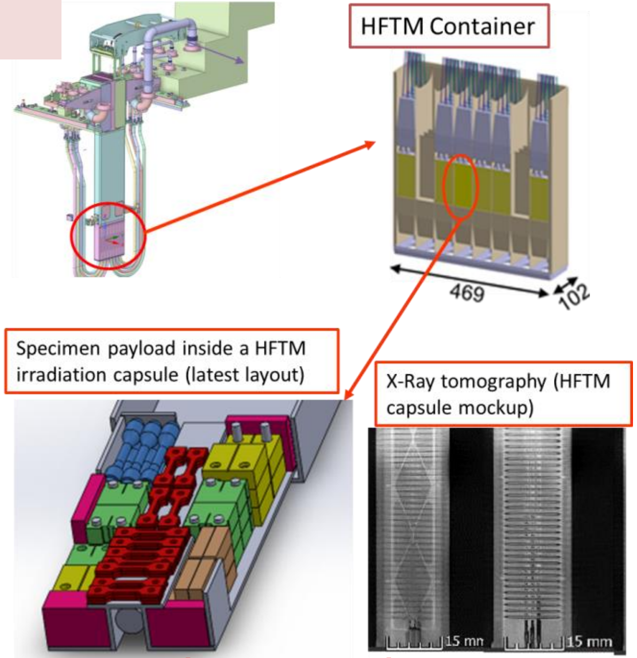
Test Systems

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 !!

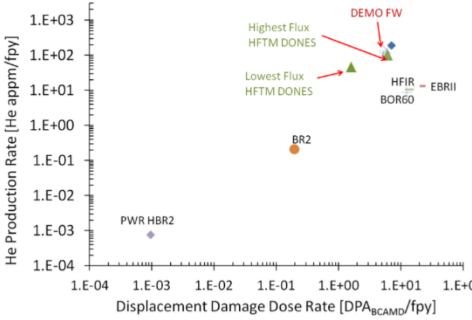
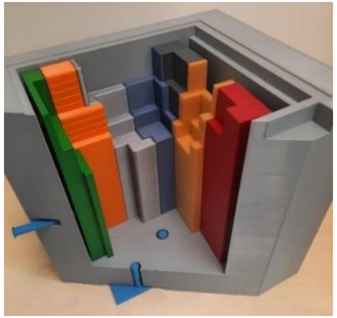


Fig. 44. He production rate [He appm/fpy] *versus* displacement damage rate [DPA_{BCAMD}/fpy].

https://doi.org/10.1140/epjp/i2019-12758-y

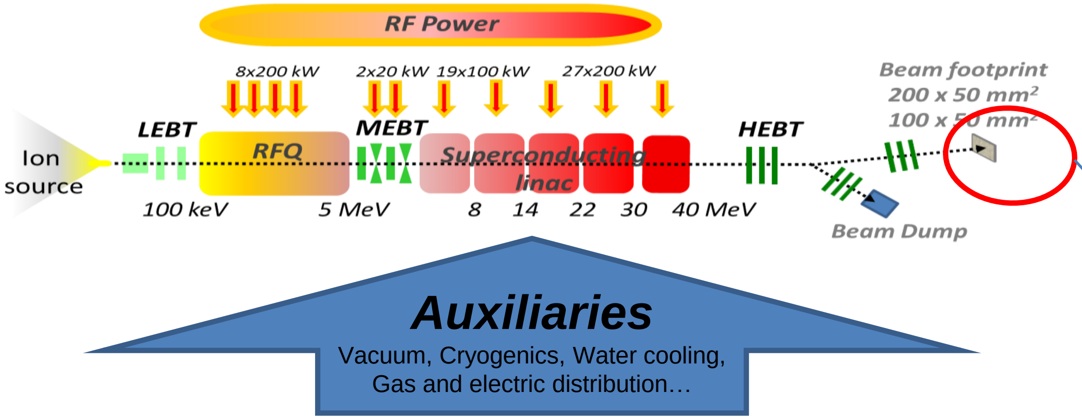


Test Cell Removable Shielding Blocks (Maintainability and minimizing neutron streaming)

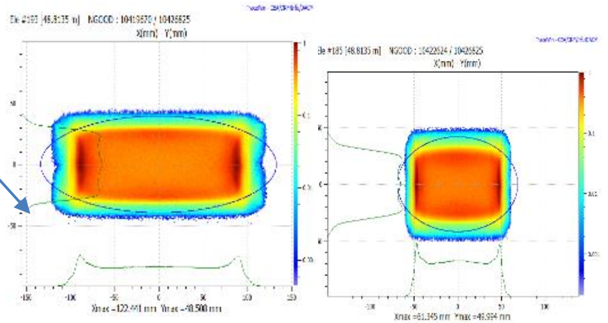
Additional Fusion aimed experiments are under development

IFMIF-DONES: Accelerator

175 MHz Solid State RF source



Beam footprint @ target



20x5 cm^2 footprint (reference)

10x5 cm^2 footprint (optional)

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%

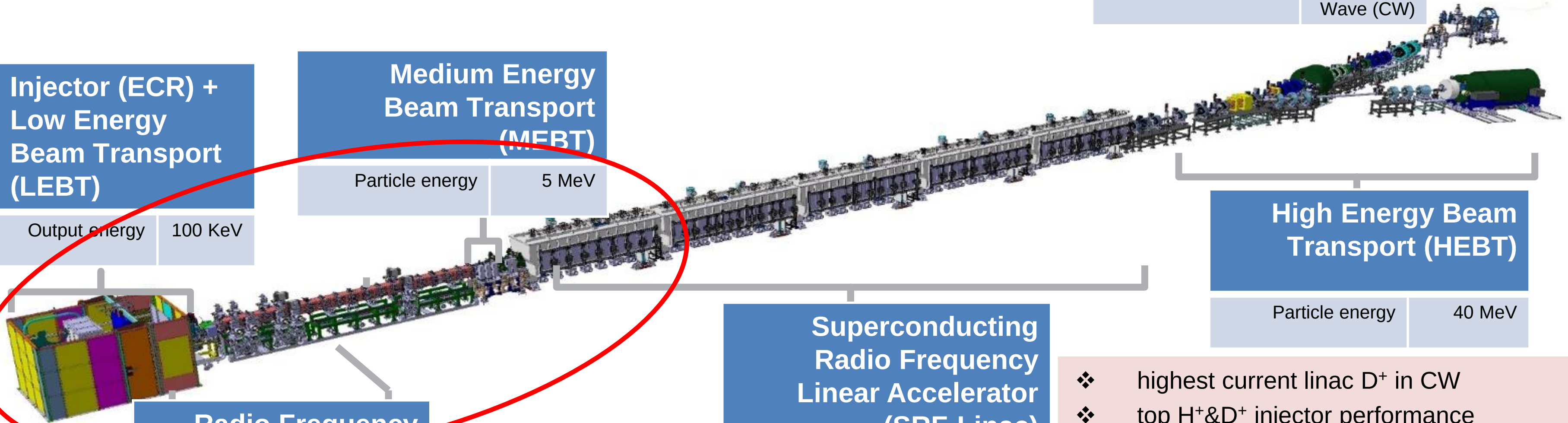
Accelerator systems summary

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)

Radio Frequency Power System (RFPS)

Output energy (RF@175 MHz)	> 10 MW Pulsed and Continious Wave (CW)



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 (125 mA) through SC cavities
- highest beam perveance

Complementary Applications

The **primary mission** of the facility is related to **fusion materials**, but it has unique features that **must be available for other scientific challenges**.

A systematic effort is being made to **evaluate different possible ideas** and integrate them into the engineering design of the facility.

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

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

The 1st IFMIF-DONES Users' Workshop was held on September 26-27, 2022

DONES Users Workshop

The main objectives of the workshop are:

- **to identify new ideas** that can be applied to the design of the facility
- **to review the priorities** of the irradiation programme
- **to create a community of IFMIF-DONES users** for fusion and non-fusion applications.

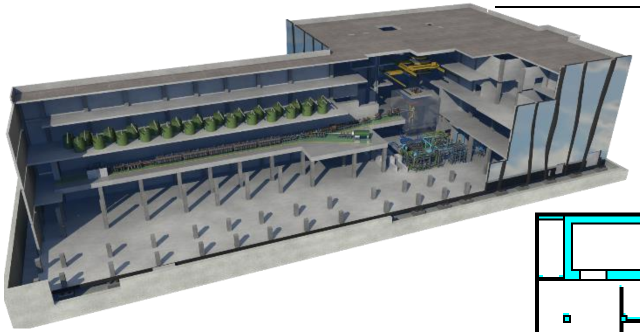
2nd DONES Users Workshop

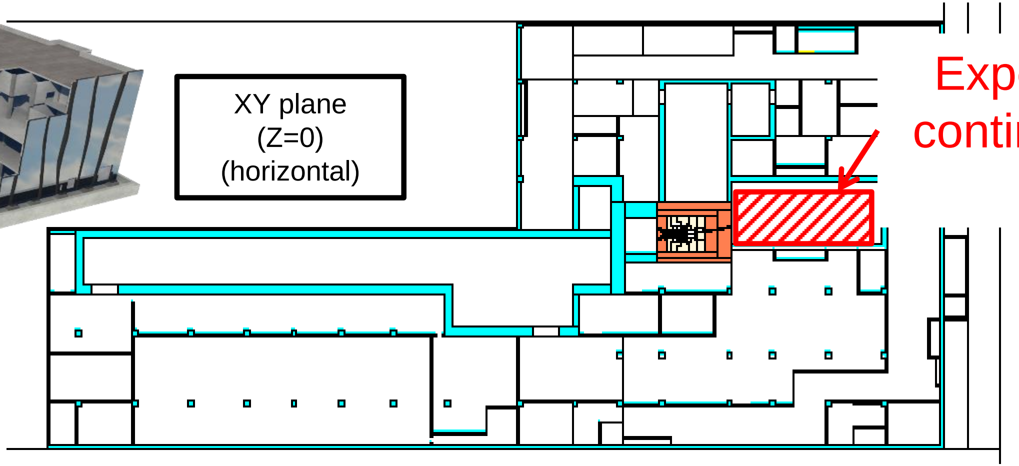
19–20 October 2023
Parque de las Ciencias, Granada

Do you want to take part?

https://indico.ifmif-dones.es/event/4/

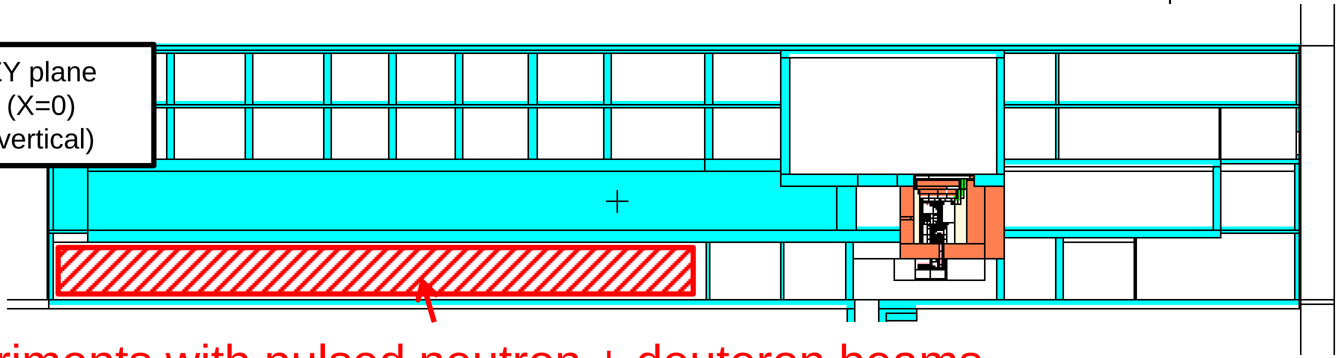
Additional experimental areas





XY plane
(Z=0)
(horizontal)

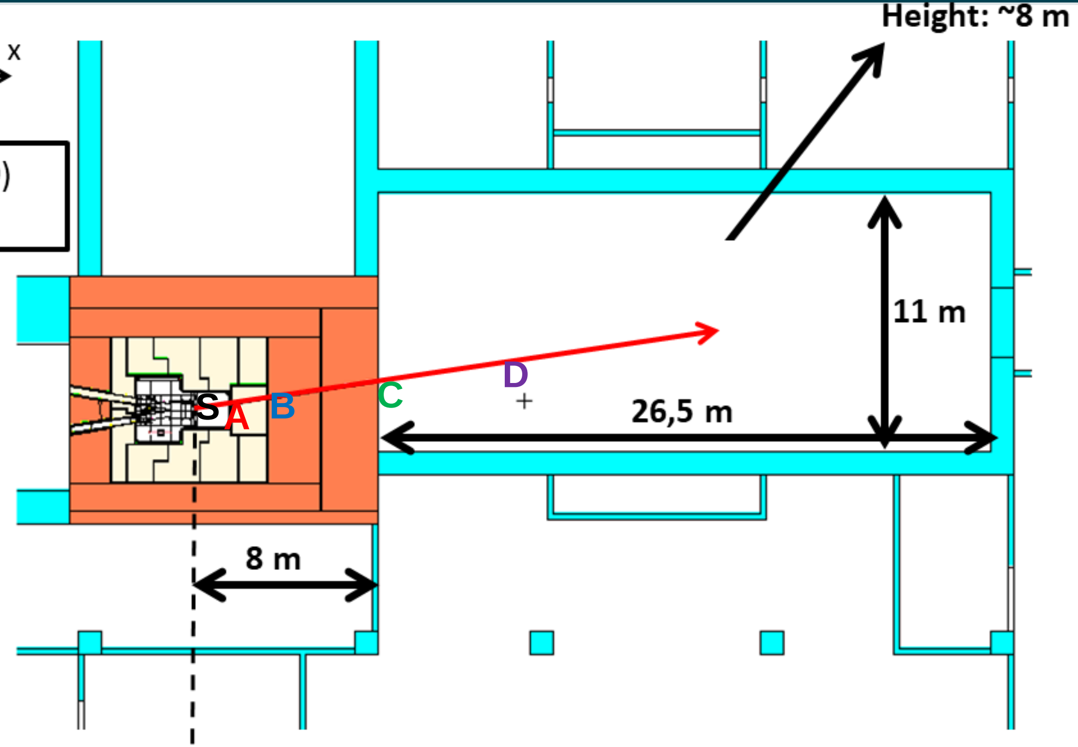
Experiments with continuous neutron beams



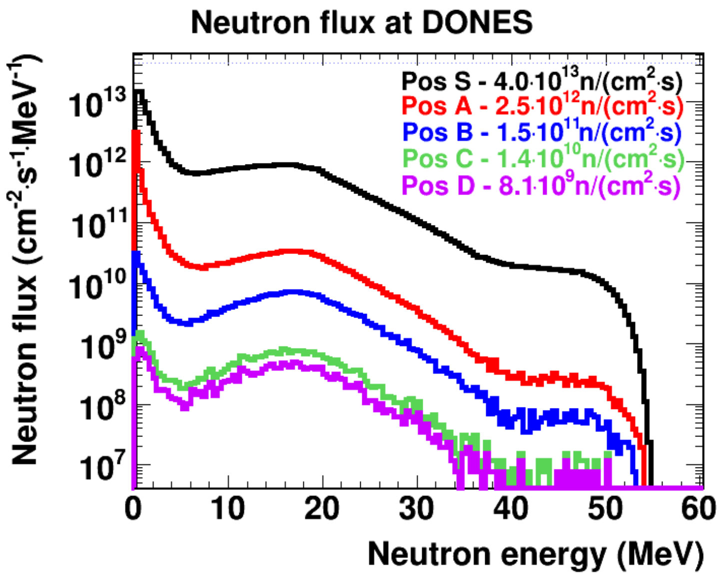
ZY plane
(X=0)
(vertical)

Experiments with pulsed neutron + deuteron beams

Continuous neutron beam experimental area



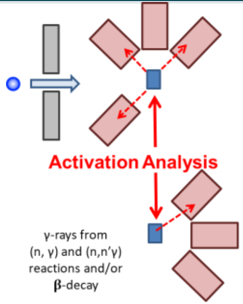
Very high neutron flux at very high energies!!!



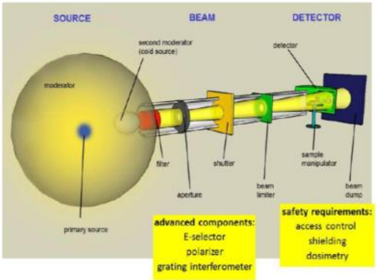
- High-flux (~2. 10^{10} n/cm^2/s at nominal operation 125 mA deuteron beam, covering a large energy range)
- Collimated neutron beam (~98% of the neutrons with $\theta < 1°$)

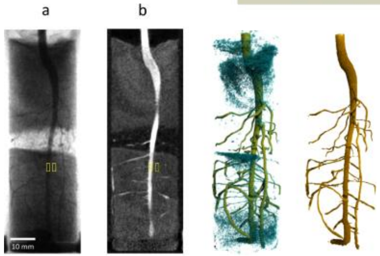
Potential experiments with neutrons

- **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-samples
  - Superconductive materials under fast neutron irradiation

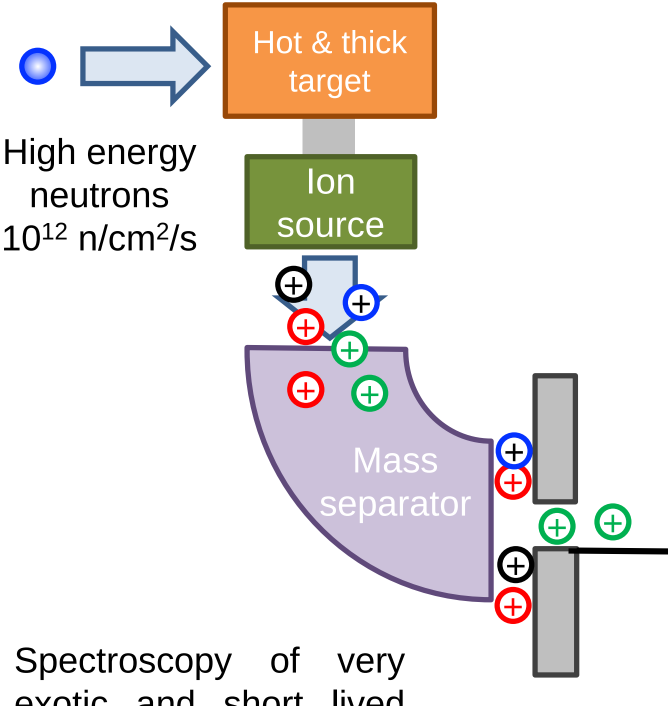


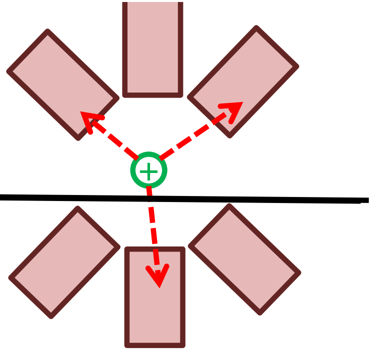


Potential experiments with neutrons

The **DOMISOL** consists of:
Similar to the OSIRIS separator in Studsvik.

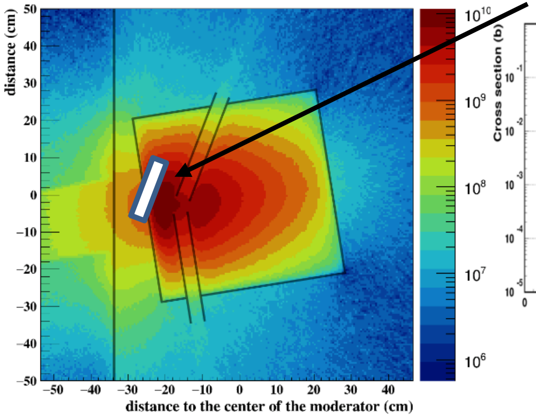
High energy neutrons 10^{12} n/cm^2/s

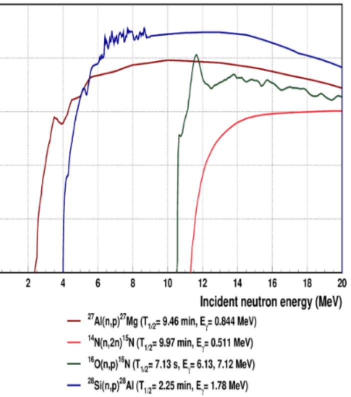


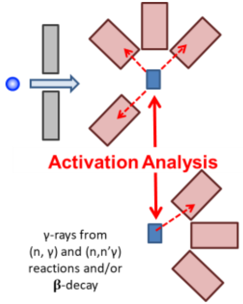


Spectroscopy of very exotic and short lived nuclei.

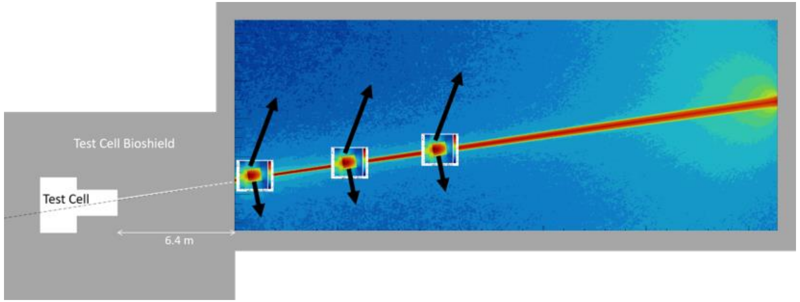
Fast Neutron Activation Analysis





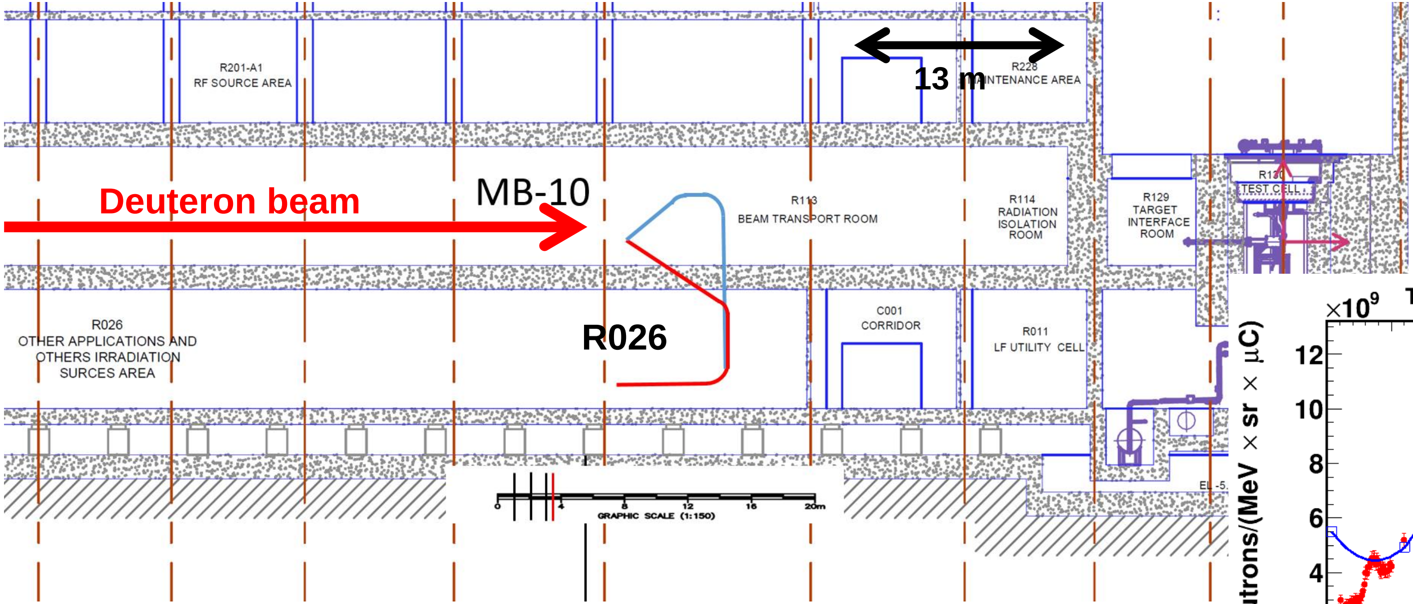


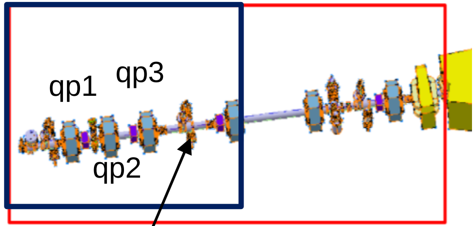
Moderated Neutrons

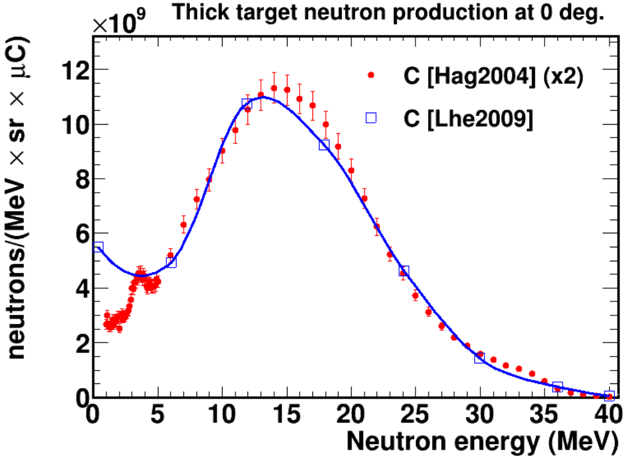


Pulsed beam experimental area

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 **septa** into a dedicated transfer line





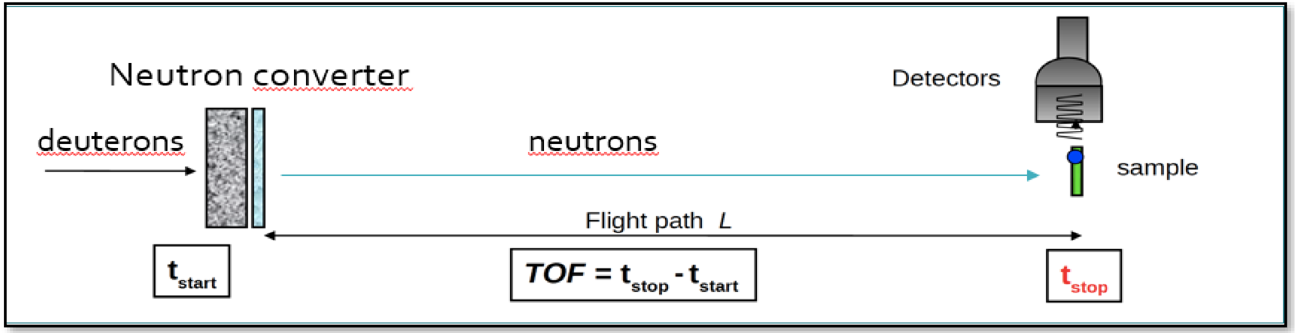


- Area: >2600 m^2 / Height: 7.5 - 8.5 m
- Extraction of the 40 MeV deuterons with kicker (1/1000 duty cycle or less, up to full beam power)

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

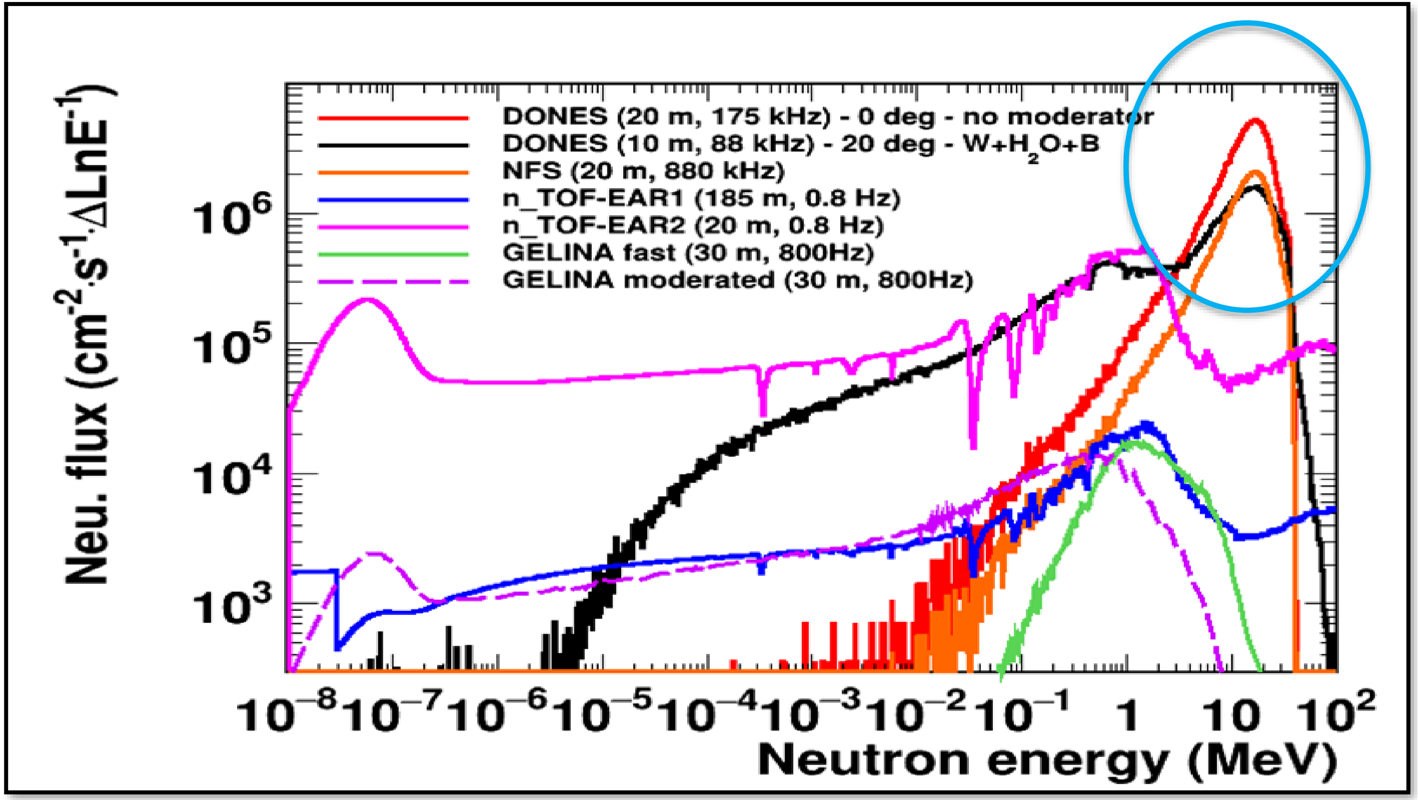
- **With pulsed neutron beam (ToF-DONES facility)→ with a** neutron production target
  - Neutron cross section measurements
  - Gamma-spectroscopy of nuclei produced in fast-neutron-induced fission reaction
  - Deuteron-induced proton transfer reactions (d,n)



Neutron time-of-flight facility (n_TOF)

TOF DONES

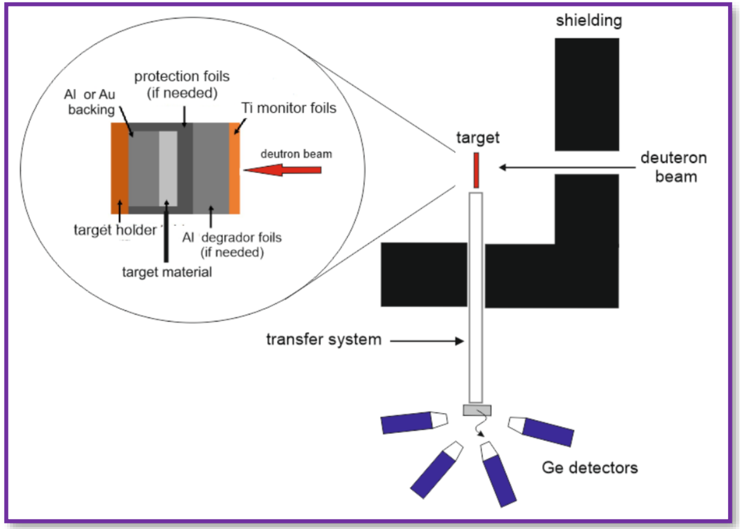
TOF DONES would be world's highest intensity TOF neutron source



M. Weber, RADNEXT 2nd Annual Meeting – 9-10 May 2023

Production of radionuclides with a high-intensity 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

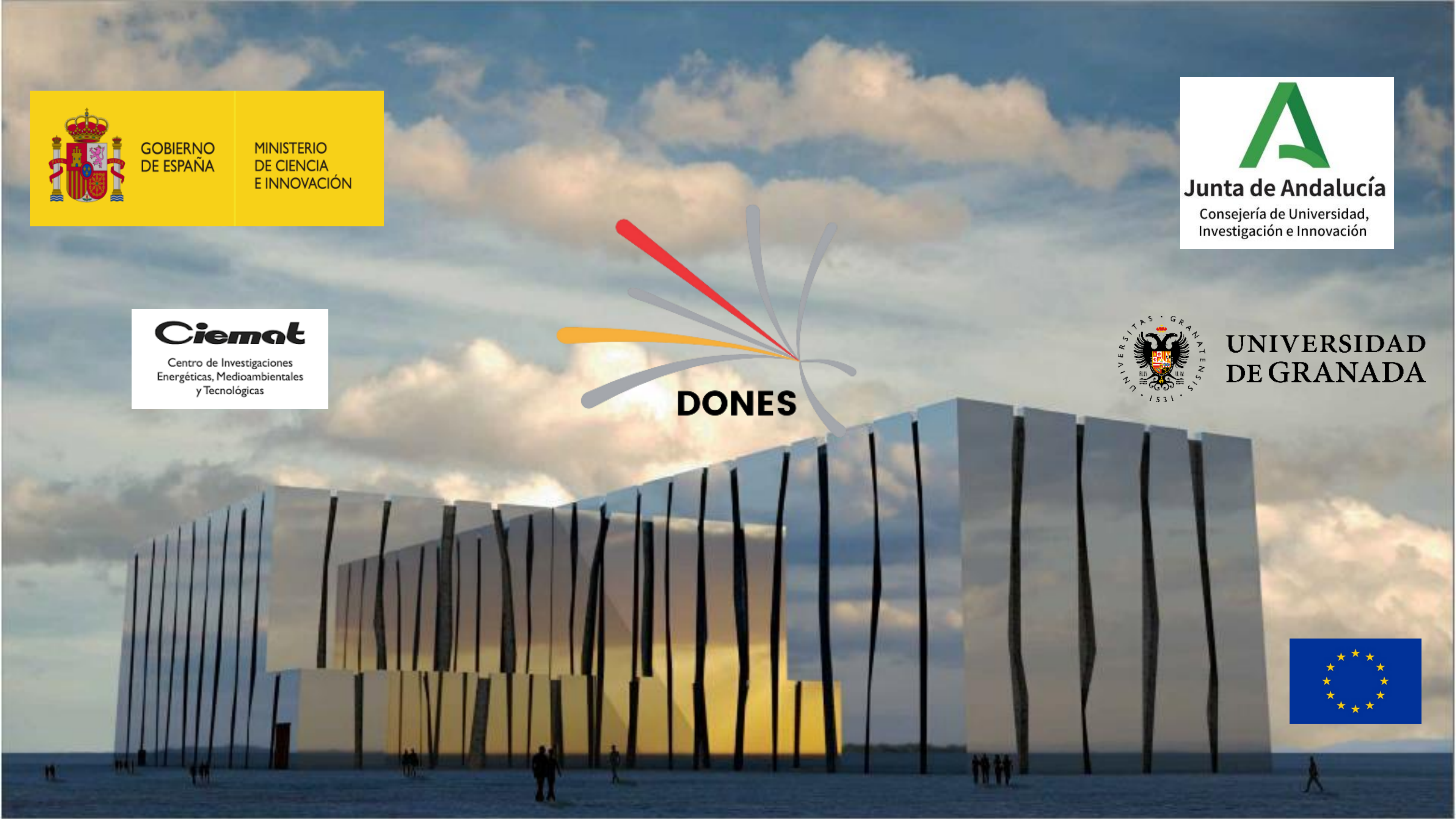


The very intense deuteron beam is ideal for the effective irradiation of samples and leads to the production of radionuclides with high activity.

Summary

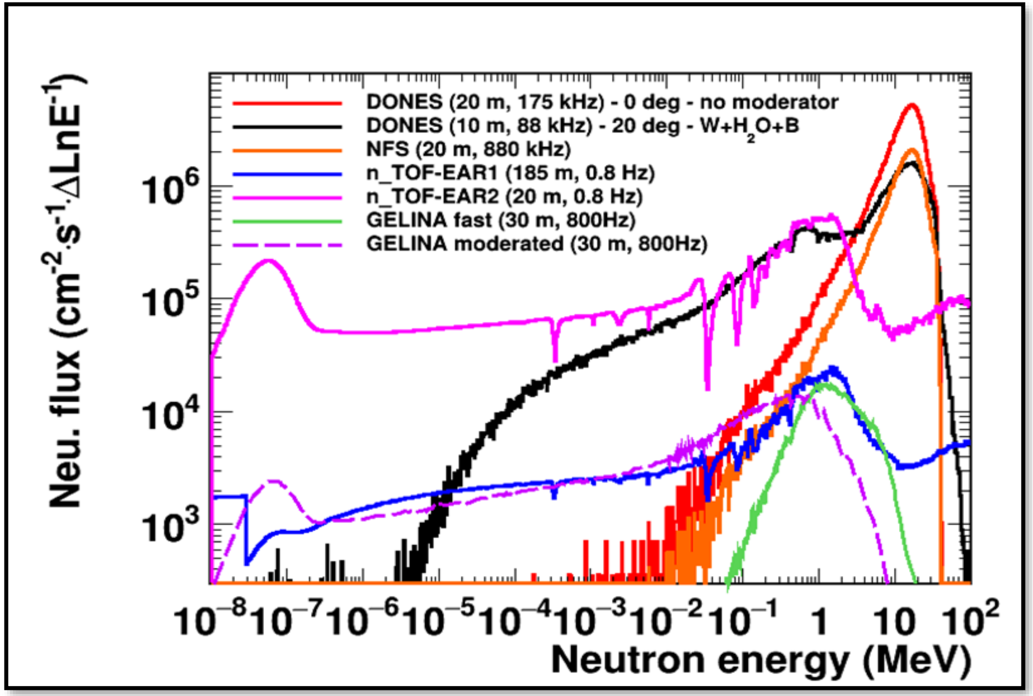
- **Materials, with emphasis in irradiation effects, is one of the key pending issues in the development of fusion as an energy source**
- **A fusion-like neutron source is needed as soon as possible for DEMO design**
- **IFMIF-DONES is the EU fusion-like neutron source to be implemented in Granada in the near future**
- **IFMIF-DONES is based on a high current D accelerator hitting on a liquid Li moving at high velocity. It will allow irradiation of around 1000 engineering-relevant samples at a dose rate around 10-20 dpa/fpy. The engineering design of the facility has been developed during the last 7 years**
- **The Project is progressing properly gaining momentum, international consensus and technical readiness. Formal start of the project took place in March 2023**
- **IFMIF-DONES will also allow relevant simultaneous experimental activities in other scientific areas:**
    - **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**
    - **The DONES Users Community is proposing potential alternative uses**

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


GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN
Junta de Andalucía
Consejería de Universidad, Investigación e Innovación
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
DONES
UNIVERSIDAD DE GRANADA

TOF DONES

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



NFS -Neutrons for Science (SPIRAL2)

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:

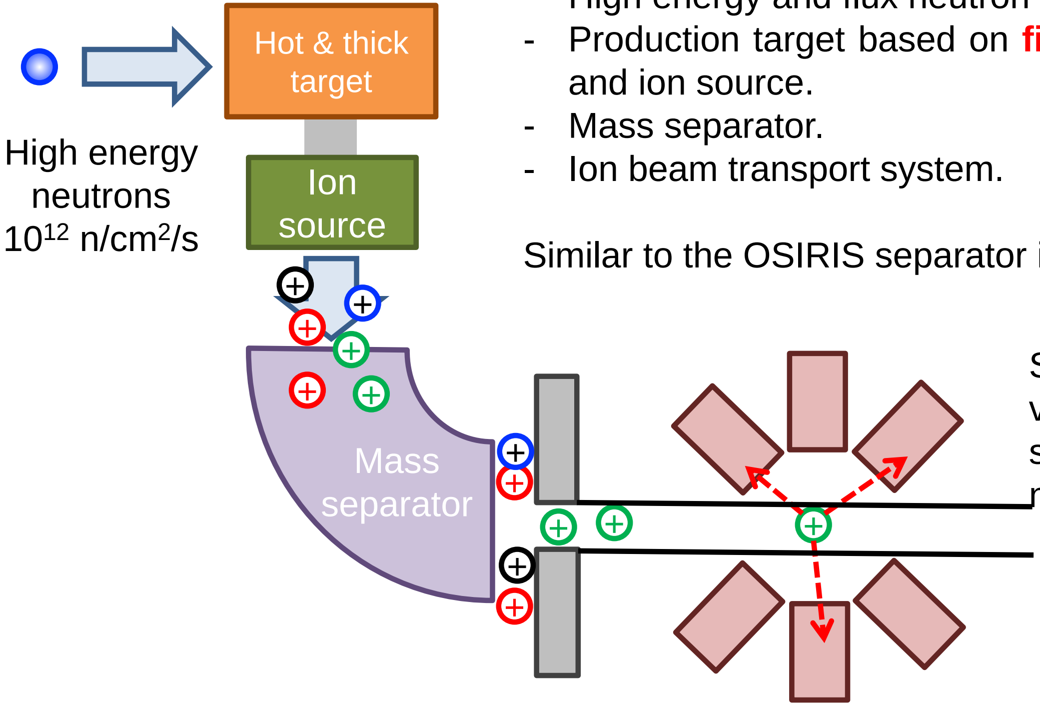
- 52 isotopes listed in the **High Priority Request List** for nuclear technologies.
- Over **35 (n,γ) prioritary cross section measurements** for astrophysics.

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.

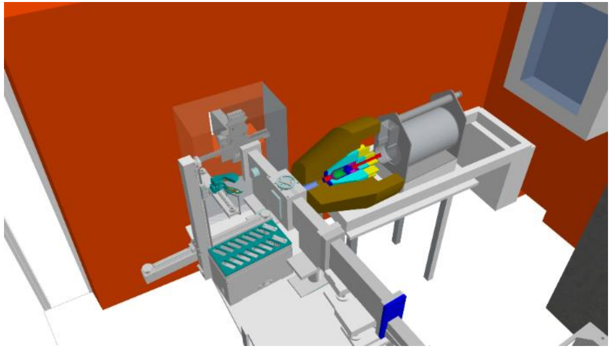
Similar to the OSIRIS separator in Studsvik.



Spectroscopy of very exotic and short lived nuclei.

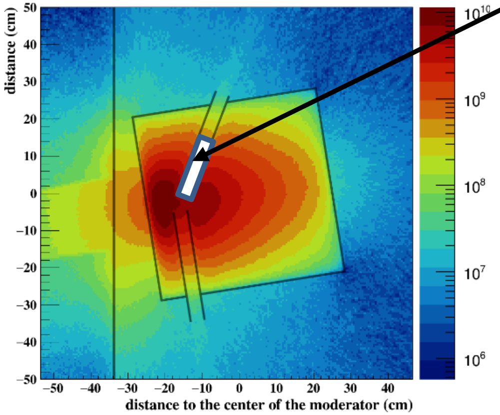
Neutron Activation Analysis

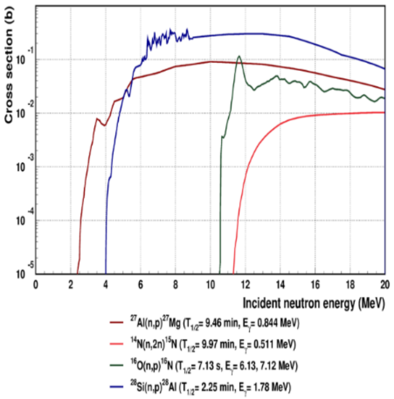
- Non-destructive method to determine the elemental composition of materials
  - with thermal Neutrons (NAA and Prompt Gamma AA)
  - with Fast Neutrons (FNAA and FPGAA).
- Neutron flux is a key ingredient:
  - ~$10^{12\text{-}14}$ n/cm^2/s for NAA ; ~10^8 n/cm^2/s for PGAA,
  - ~10^8 n/cm^2/s for FNAA



PGAA station @Budapest Neutron Center

Irradiated sample to be analyzed

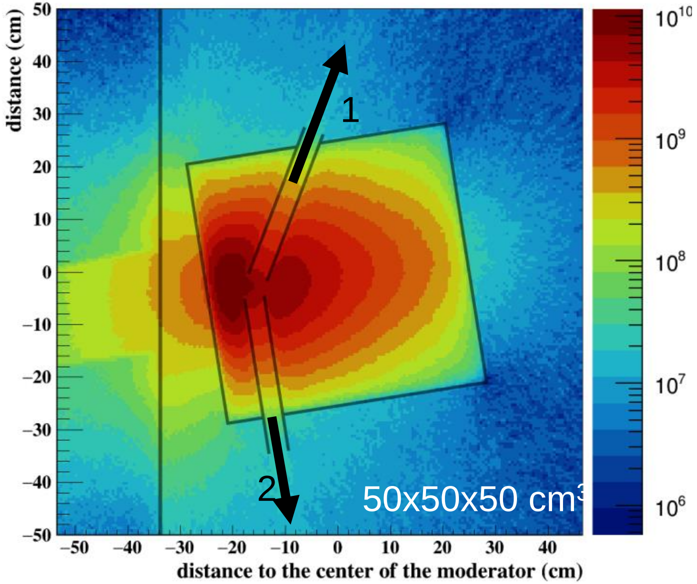


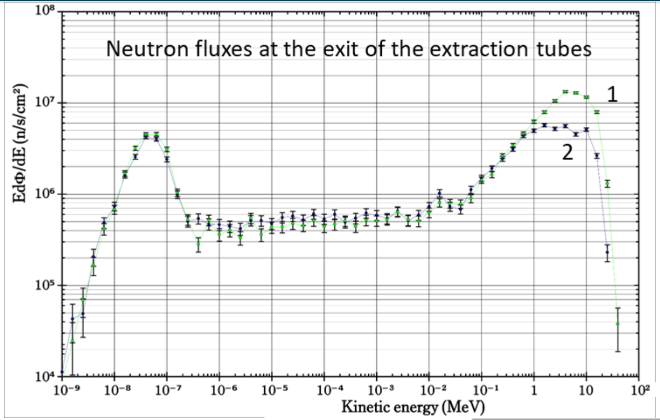


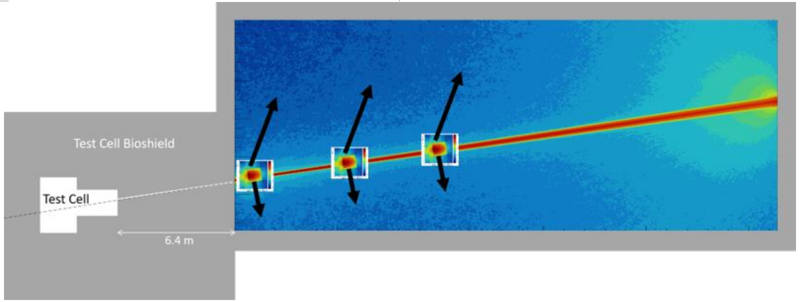
Fast Neutron Activation Analysis

➢ 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)