Overview of IFMIF/EVEDA project and DONES Programme

A. Ibarra & K. Hasegawa and
IFMIF/EVEDA and DONES Teams

Fusion Energy Conference, Chengdu (China)
October 18th 2025

Outline

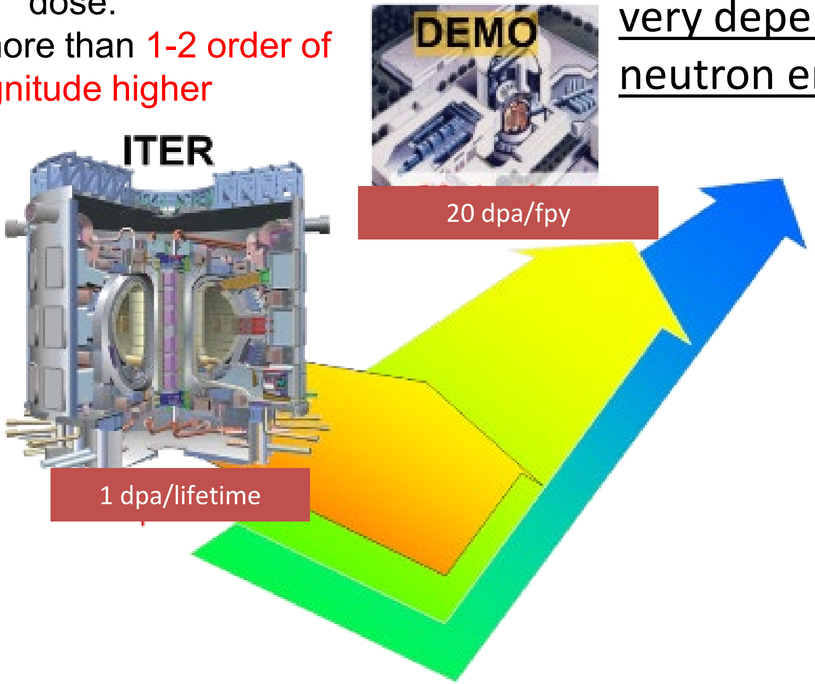
- The fusion-like neutrons facility Project
- Validation and prototyping activities
- Experimental capabilities
- DONES Programme Status
- Summary

Outline

- **The fusion-like neutrons facility Project**
- Validation and prototyping activities
- Experimental capabilities
- DONES Programme Status
- Summary

Why DONES?

One of the main differences between **ITER** and **DEMO** (or any fusion power plant) is the radiation dose:
at DEMO more than 1-2 order of magnitude higher



Radiation damage processes and effects <u>are very dependent on the neutron energy spectrum</u>

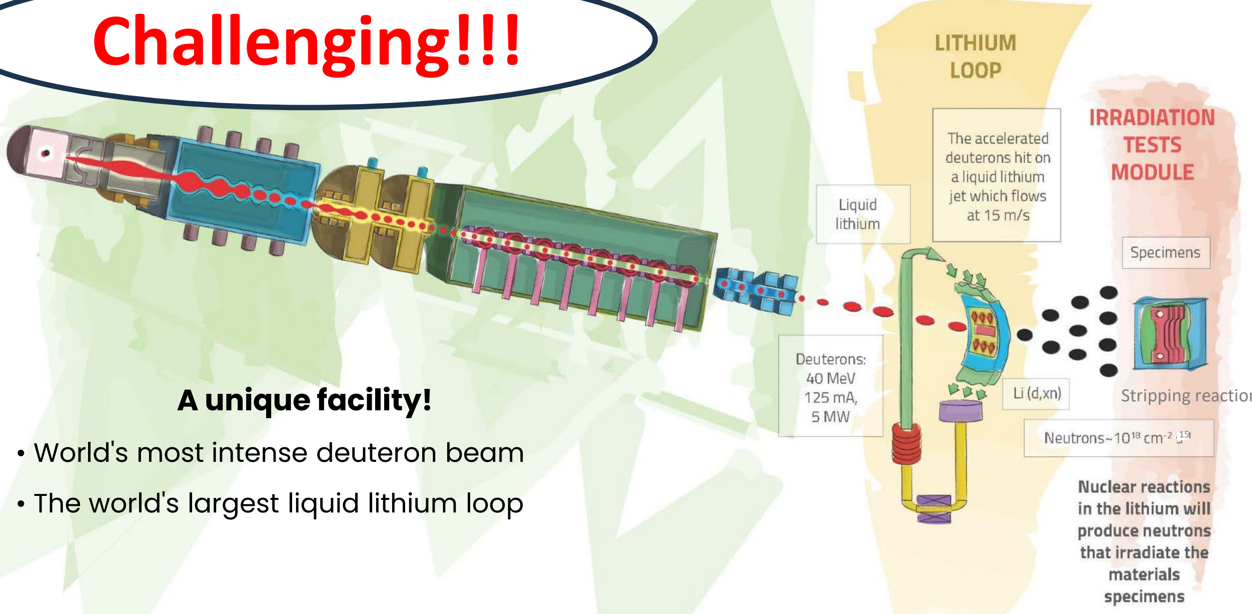
Fusion neutrons spectrum <u>differ significantly</u> from the ones of Fission Reactors

An intense fusion-like neutron source is needed to validate fusion materials and components!!!

What is IFMIF-DONES?

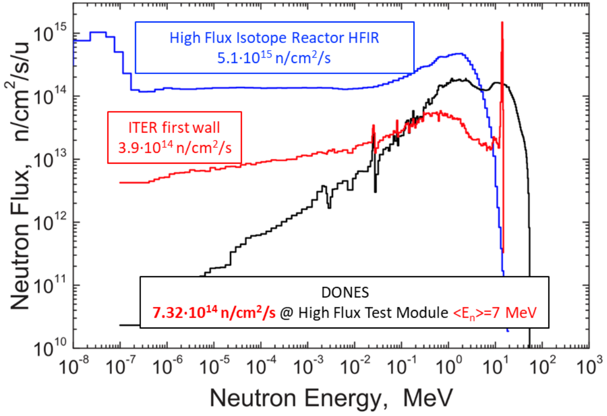
An accelerator based fusion-like neutron source required for the qualification of the materials to be used in fusion reactors

Challenging!!!



A unique facility!

- World's most intense deuteron beam
- The world's largest liquid lithium loop



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

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

What is IFMIF-DONES?

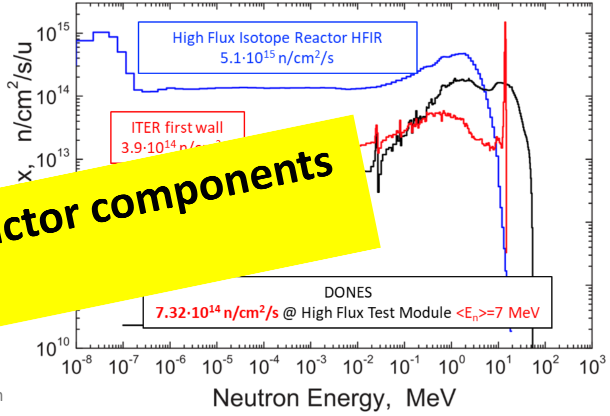
An accelerator based fusion-like neutron source required for the qualification of the materials to be used in fusion reactors

Challenging!!!

A uni...

- W...
- The ... lithium loop

It will be the only facility able to reach EoL of DEMO-like reactor components in the near (20 years?) future



A neutron flux of ~ 10^{15} n/cm²/s is generated with a neutron spectrum up to 55 MeV energy

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

Based on widely spread efforts!!!

The need for a facility of this type was identified long time ago and work has been carried out by using different frameworks. **In the last 15 years, key projects** are:

FUSION FOR ENERGY QST

IFMIF/EVEDA

(included in the BA)

IFMIF ⇨ Design and Validation Activities ⇨ **design is feasible**

EUROfusion

WPENS

(EUROfusion WP)

IFMIF DONES ⇨ Design and Validation Activities ⇨ **Defining the design: ready for construction!!!**

Ciemat IFMIF-DONES ESPAÑA

DONES-PreP + DONES ConP1

(EURATOM CSA)

DONES Preparatory Phase ⇨ Elaborate and draft the international consortium agreement ⇨ **international implementing scheme defined**

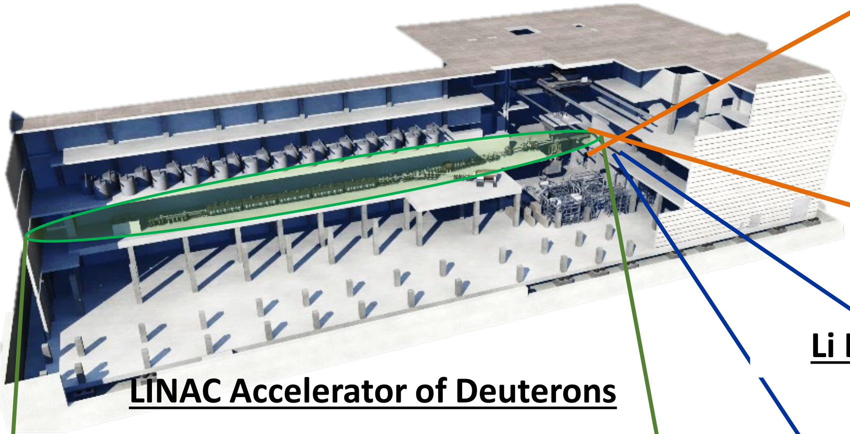
Ciemat

DONES-PRIME/UGR

(Spanish projects)

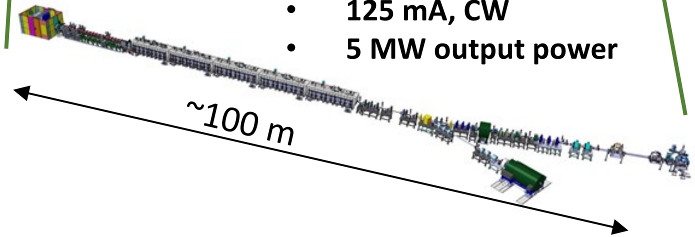
DONES-PRIME DONES-UGR ⇨ Engineering and Construction Activities ⇨ **Starting the work on site (first auxiliary buildings)**

The IFMIF-DONES Facility

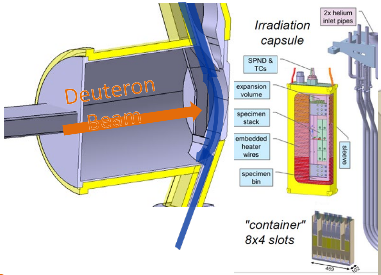


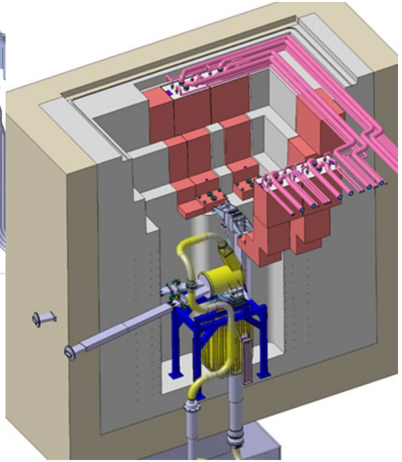
LINAC Accelerator of Deuterons

- 40 MeV
- 125 mA, CW
- 5 MW output power

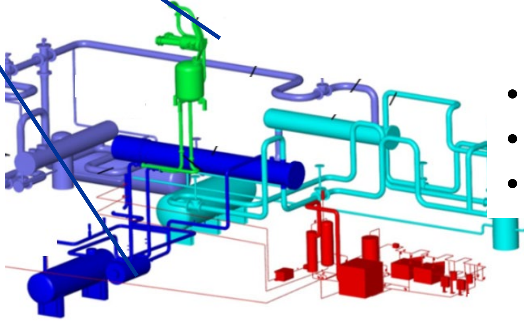


Li Target, Irradiation Modules and Test Cell





Li Loop and Oil Cooling Loops



- 100 l/s Li
- Strict Li Purity Control
- ~15 m3 of Li

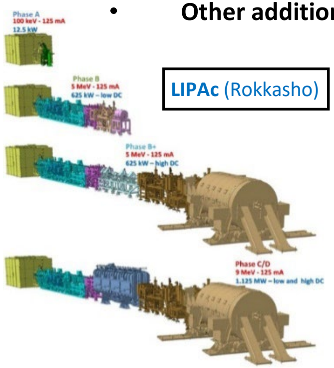
Outline

- **The fusion-like neutrons facility Project**
- **Validation and prototyping activities**
- Experimental capabilities
- DONES Programme Status
- Summary

DONES Status

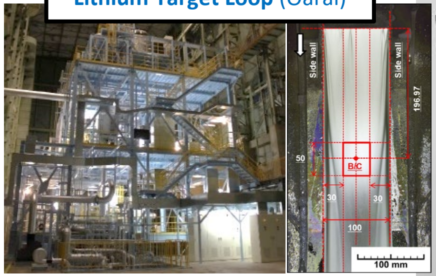
Prototyping and validation

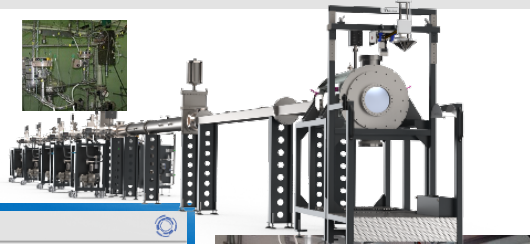
- Being developed for IFMIF (and a generic site) in the framework of BA (IFMIF/EVEDA)
- **Developed for IFMIF-DONES from 2015 in the framework of the ENS WP of EUROfusion**
- **Other additional national projects**

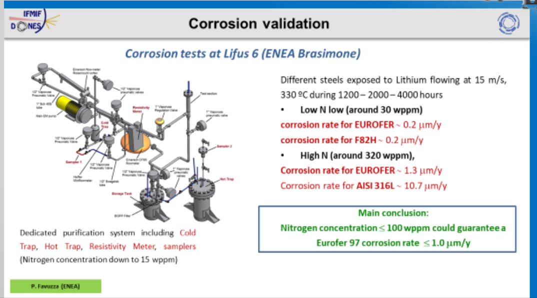


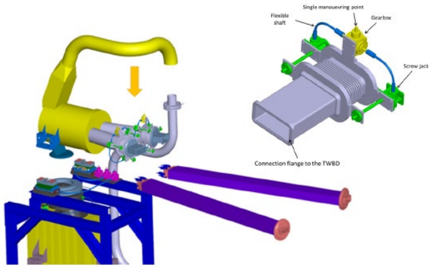
LIPAc (Rokkasho)

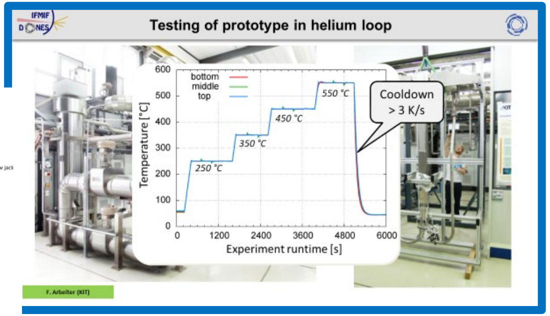
Lithium Target Loop (Oarai)









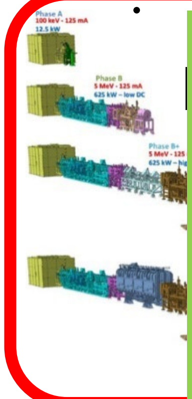


- ❑ **Start-Up Monitoring Module** (STUMM). Irradiation module to used during the commissioning phase in order to fully characterize radiation map
- ❑ **Quick Disconnecting System** (QDS). To validate RH conection system
- ❑ **Multipurpose VaCuum accidental scenarios** (MuVaCas). To analyze different posible accidental scenarios
- ❑ **Electromagnetic Pump prototype**. To characterize pump performance
- ❑ Li purification prototipe loop (**LITEC**) to test impurities control technology
- ❑ **LIFIRE** facility to study Lithium fire risks
- ❑ **High Beta cavity & RF coupler**
- ❑ **Meander-type beam extraction** system
- ❑ **SSPA** @175 MHz 200 kW CW
- ❑ Shielding benchmarking using a 35 MeV (p, Be) neutron source
- ❑ **VALERIA** for virtual reality RH simulation
- ❑ Digital Mockup development

DONES Status

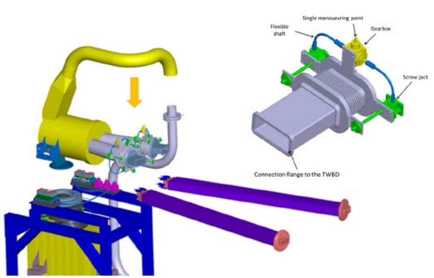
Prototyping and validation

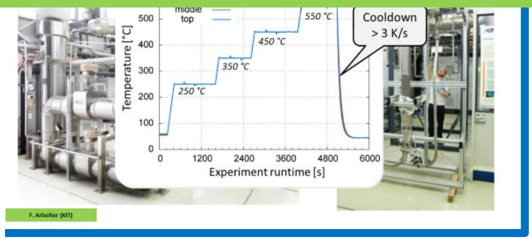
- Being developed for IFMIF (and a generic site) in the framework of BA (IFMIF/EVEDA)
- Developed for IFMIF-DONES from 2015 in the framework of the ENS WP of EUROfusion
- Other additional national projects



In this talk, we will report on recent validation results on:

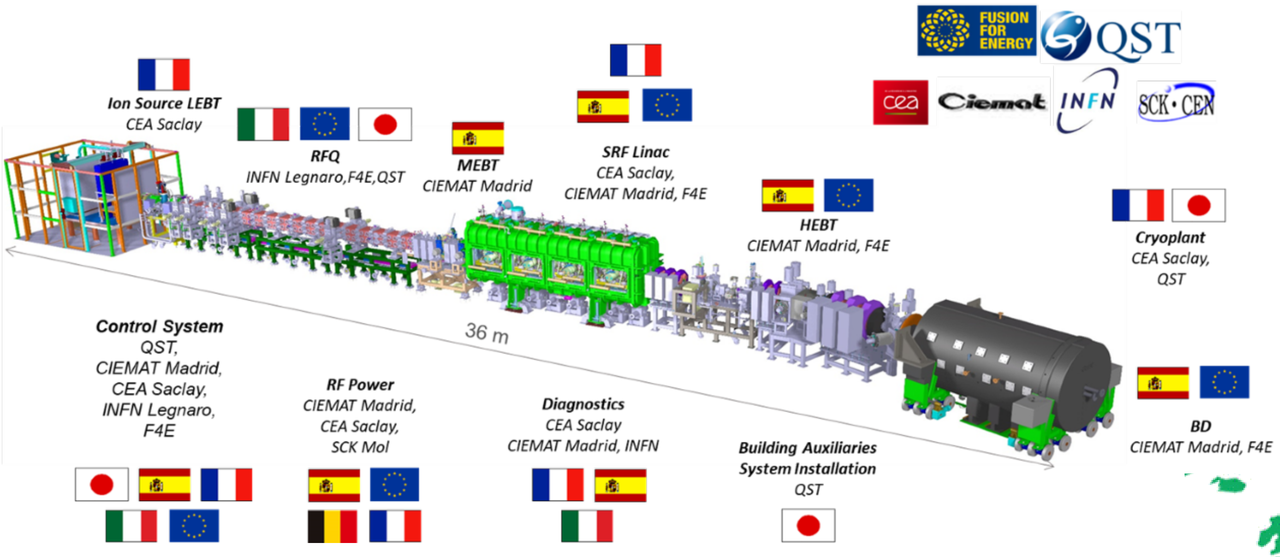
- **Accelerator Technologies: LIPAc**
- **Lithium Technologies: LITEC & JA Li loop**
- **Safety Technologies: MuVaCas & Lithium fires**





- ❑ **Electromagnetic Pump prototype**: To characterize pump performance
- ❑ Li purification prototipe loop (**LITEC**) to test impurities control technology
- ❑ **LIFIRE facility** to study Lithium fire risks
- ❑ **High Beta cavity & RF coupler**
- ❑ **Meander-type beam extraction** system
- ❑ **SSPA** @175 MHz 200 kW CW
- ❑ Shielding benchmarking using a 35 MeV (p, Be) neutron source
- ❑ **VALERIA** for virtual reality RH simulation
- ❑ Digital Mockup development

Linear IFMIF Prototype Accelerator (LIPAc) : EU/JA Collaboration



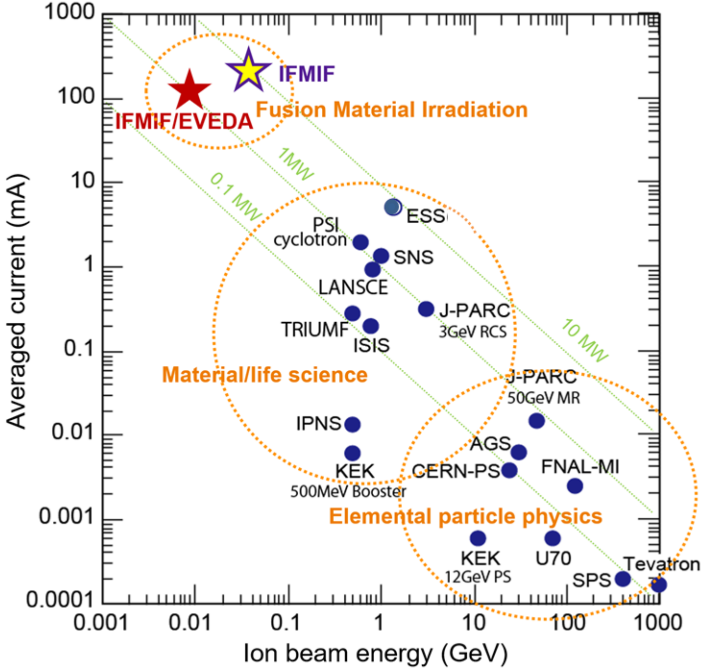
Equipment designed and constructed in Europe,

installed and commissioned in Rokkasho, Japan.

Central Control Room in Rokkasho
Remote participation to LIPAc operation from Europe

Challenges of LIPAc

IFMIF-DONES: the world's highest beam current (125 mA), highest power (5 MW)



Average beam Current vs. Energy

Challenges of LIPAc (IFMIF/EVEDA)

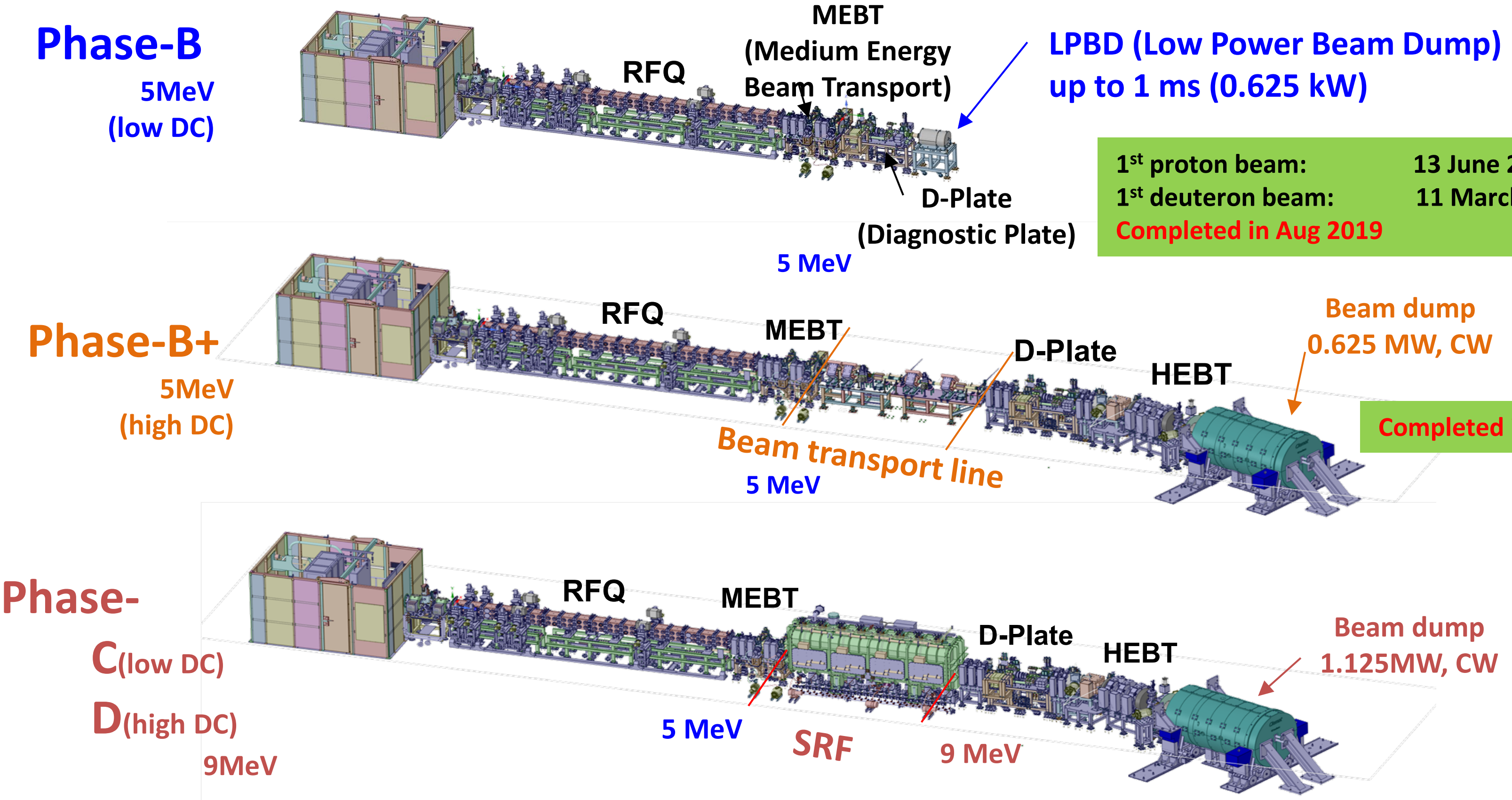
- **High Current: 125 mA, Deuteron, high space charge**
- **High Duty Cycle: 100 % (CW)**

Challenges

- **Injector: high current, low emittance, CW**
- **RFQ: the world's most powerful, longest, CW**
- **RF source: 200 kW x8, CW, synchronized injection**
- **SRF: the highest current for hadrons**
- **Beam diagnostics: pulse to CW, no interceptive**
- **Low beam loss, space charge mitigation**
- **Heat removal, temperature control**

etc.

Staged Approach Toward 9MeV/CW



1st proton beam:	13 June 2018
1st deuteron beam:	11 March 2019
Completed in Aug 2019	

Completed in June 2024

Phase B+: High-duty deuteron beam test

Phase B+ commissioning consists of three stages

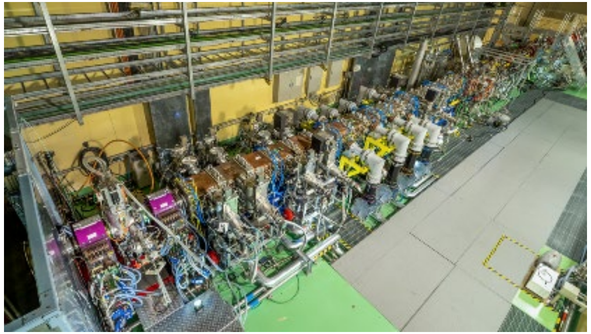
- **Stage 1: Low current, low duty H+/D+ beam (probe beam) → Completed December 2021** Checking electromagnets, beam dumps, and diagnostics
  → Overheating and vacuum leak happen on RFQ RF couplers. Some measures were taken.

- **Stage 2: Rated current (125 mA), low-duty D+ beam → Started in August 2023 and ended in December**
  Testing and beam characterization of various beam transport modes (different buncher settings), BPM optimization, longitudinal emittance measurement, non-destructive profiler testing, etc.

- **Stage 3: Rated current (125 mA), high duty D+ beam → Started in December 2023 and finished in June 2024**
  Start with 1~5% Duty and increase Duty to CW if possible
  Duty limit range and maximum value are determined by looking at RFQ conditioning and coupler thermal behavior

Over 8 months beam study

2023/8～12
2024/3～6



LIPAc in Phase-B+

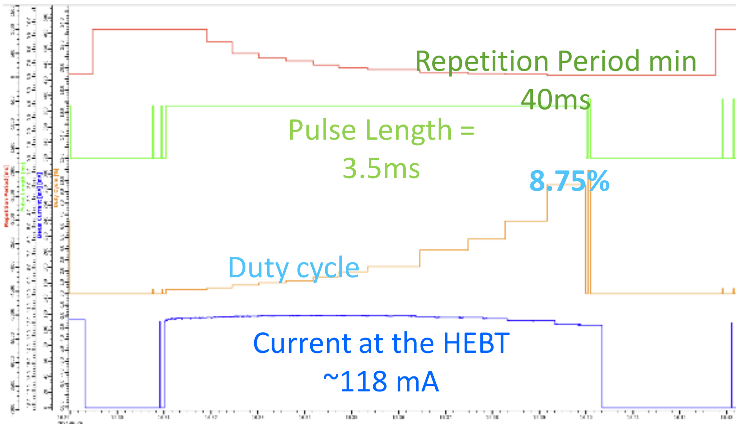
CCR during operation

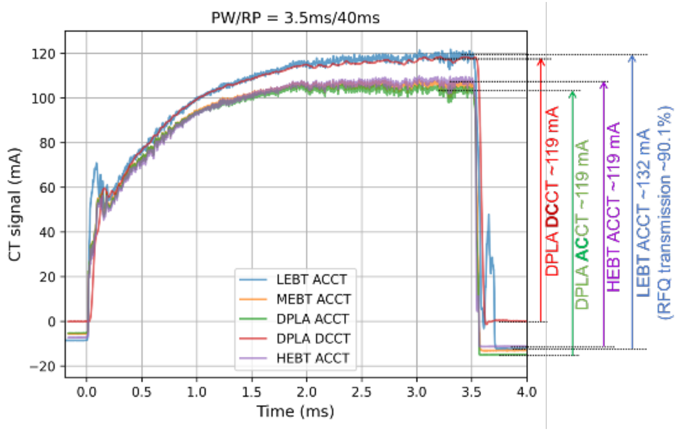
High duty operation: duty 10% operation

Completed high duty deuteron beam test at the end of June 2024

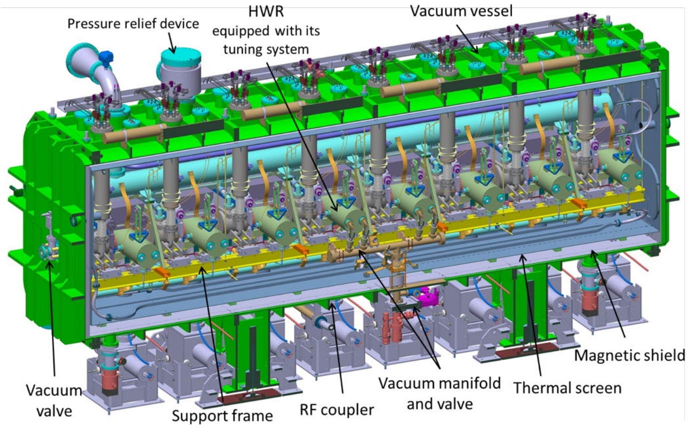
Stage 3 : Rated Current (125 mA), High Duty (<10%)

- The maximum duty of beam acceleration is 8.75 % (pulse width 3.5 ms, pulse repetition period 40 ms, duration approx. 1 minute) The vacuum and temperature of the RFQ are almost constant. The beam current is approximately 119 mA, and the RFQ beam transmittance is 90.1%.
- RFQ average beam power: 40~45kW
- The RFQ cavity conditioning reached CW at about 80% of the deuteron acceleration voltage and the duty of 27% at the deuteron acceleration voltage, but the overheating of the couplers happened.
- It became clear that the current RF coupler is the bottle neck to increasing duty further

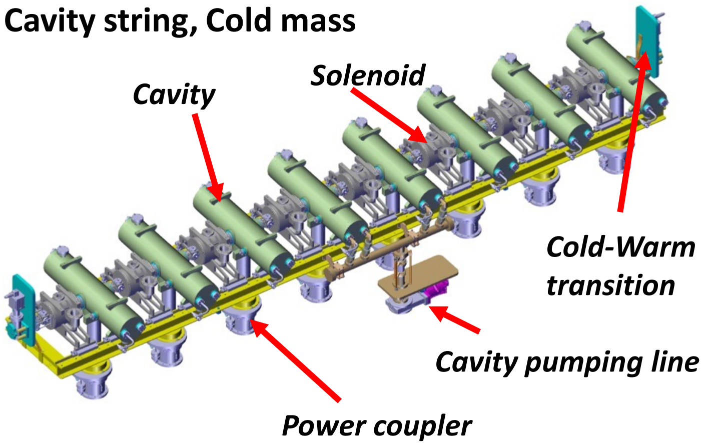




Preparation for Phase-C/D LIPAc Cryomodule



Cavity string, Cold mass



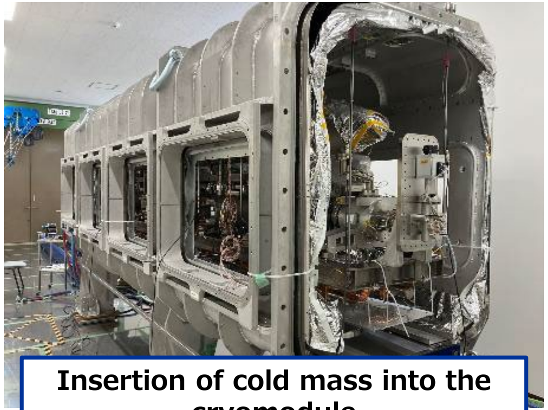
- Overall design and components procurement by CEA/Saclay
- **Eight half-wave resonators**
  - **175 MHz, b=0.094**
  - **$E_{acc\text{-}nom}$ = 4.5 MV/m, $Q_0 \geq 5 \times 10^8$**
  - **Operating temperature: 4.4 K**
- **Power Couplers**
  - **Designed to handle 200 kW CW**
  - **70 kW CW maximum on LIPAc**
- **Eight superconducting solenoid** packages designed and procured by CIEMAT
  - **Two-nested solenoids to focus the beam (6T) with reduced fringe field (20 mT on cavity flange)**
  - **Two steerers for horizontal and vertical orbits**
  - **Beam position monitors (BPM) and micro loss monitors**

SRF Assembly at Rokkasho

Connecting a cavity in the clean room

Assembled string

In the accelerator vault



Insertion of cold mass into the cryomodule

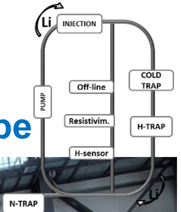
Unloading to the LIPAc Building

Ready for beam operation in 2027

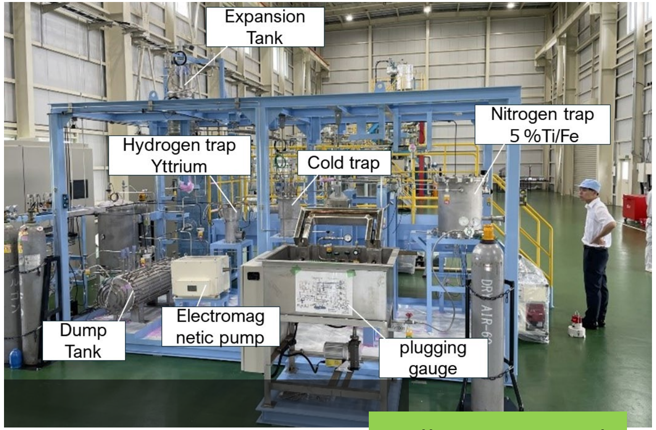
Li technologies validation activities

Fluiddynamics stability already shown around 10y ago (ELTL loop in Oarai –biggest Li loop in the world- in the framework of IFMIF/EVEDA project)

Key pending topic: impurity control

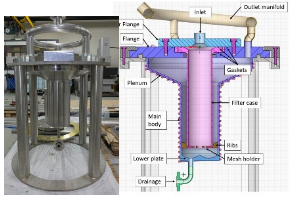


1/10-scale test Li loop in Japan

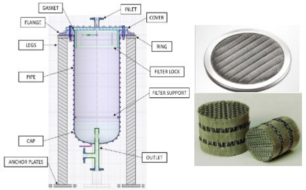


Fully operational

Hydrogen trap



Cold trap



Nitrogen trap

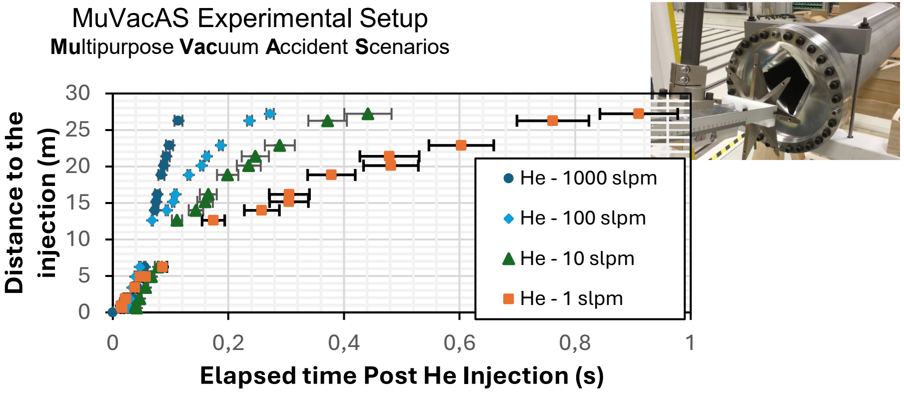
1/1-scale test Li loop in Europe

Operational during 2026

Safety technologies validation activities

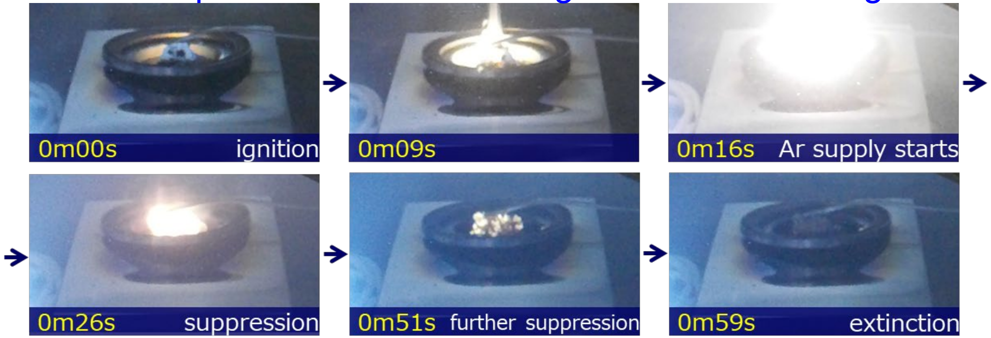
MuVacAS Experimental Setup

Multipurpose **Vac**uum **A**ccident **S**cenarios

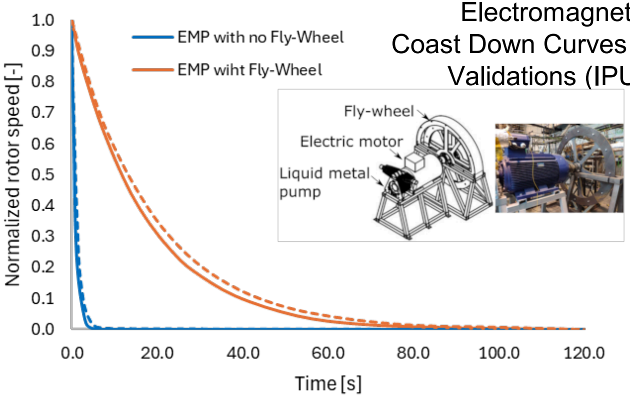


Wavefront detection for various He flow rates

Li fire experiment demonstrating extinction with Ar gas



Electromagnetic Pump
Coast Down Curves and Transient
Validations (IPUL-Latvia)

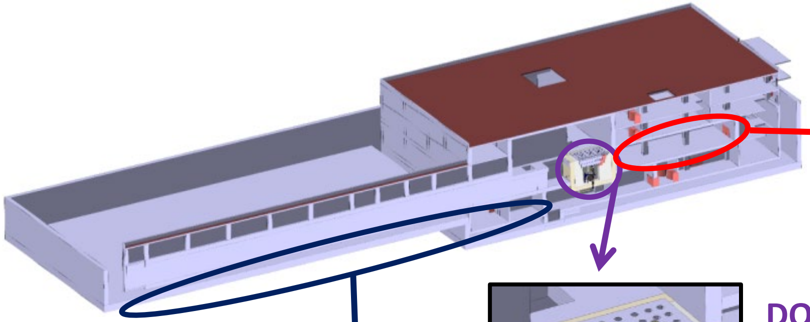


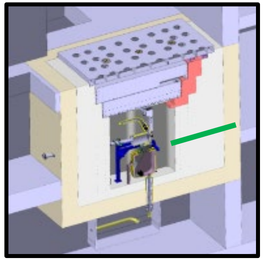
LiFire Facility (CIEMAT)

Outline

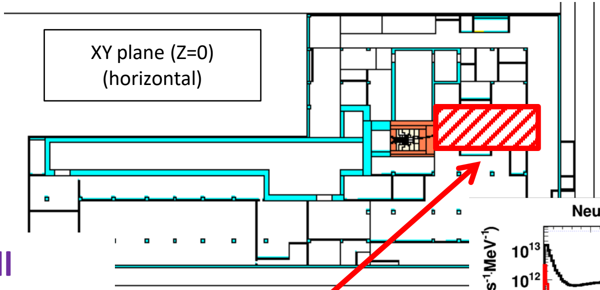
- **The fusion-like neutrons facility Project**
- **Validation and prototyping activities**
- **Experimental capabilities**
- **DONES Programme Status**
- **Summary**

IFMIF-DONES Experimental capabilities



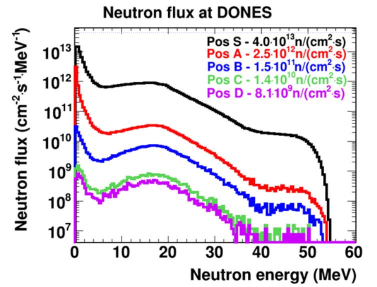


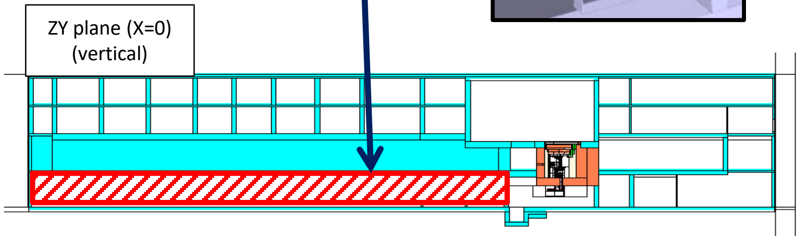
Collimated neutron beam facility – behind the Test Cell

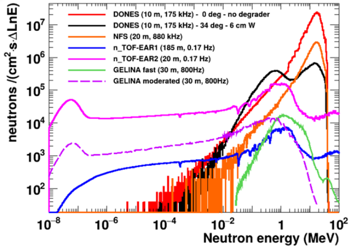


DONES Test Cell
(highest neutron flux)

Experiments with continuous neutron beam







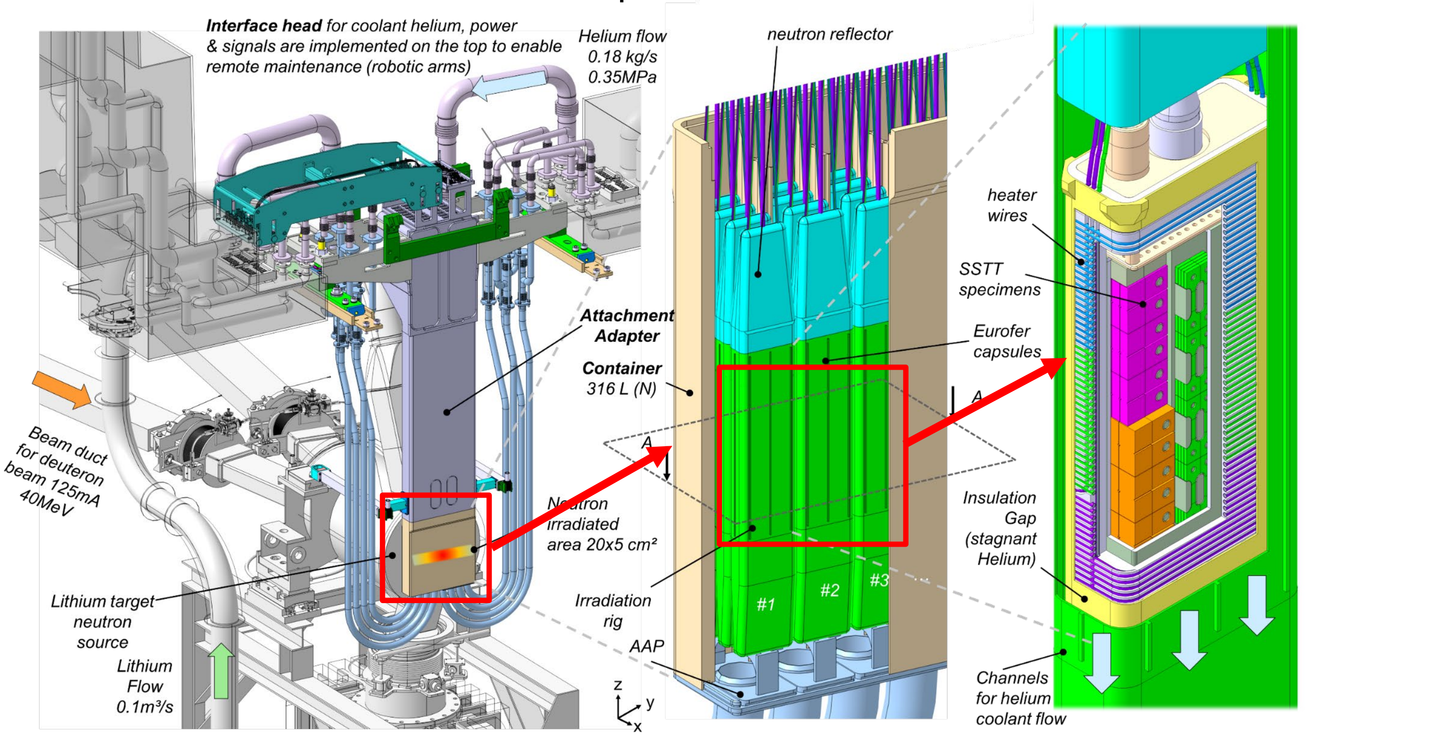
Experiments with pulsed deuteron & neutron beams
(one level below the accelerator vault) E.g. nTOF

HFTM for fusion materials qualification

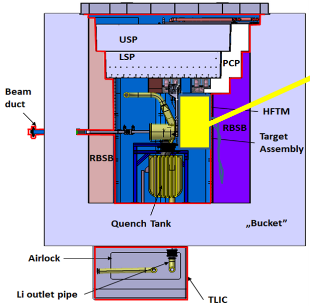
DONES baseline focuses on the High Flux Test Module (HFTM) for high-priority structural materials irradiation.

Objective: to irradiate a large volume of **SSTT samples** in the high flux region of DONES. First-to-be-installed irradiation experiment

- Heating: Nuclear **2.3 W/g peak**, 17 kW tot., 1.5 kWe per capsule
- Cooled by **low pressure helium** gas (0.3MPa, 50°C), **Sodium** heat transfer filler
- Lifetime: 1year / 2.5 years (**53 dpa**). Body made from **316LN** (acc. RCC-MRx)
- **Applicable, with small changes, to steel, ODS-steels, Copper alloys and W materials irradiation**



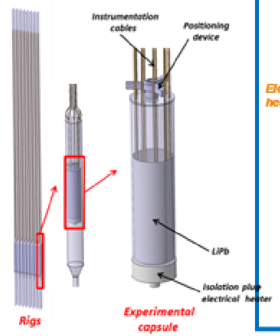
Materials and breeding blankets qualification

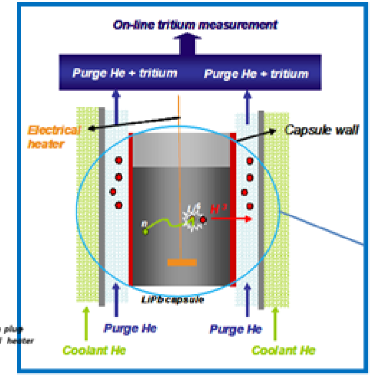


- For other materials properties **(in-situ creep-fatigue, in-situ diagnostics, in-situ superconducting materials, in-situ corrosion testing,…)**

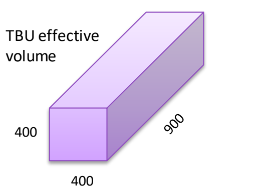
- For tritium technologies validation (**in-situ ceramic breeder, in-situ liquid breeder,…**)

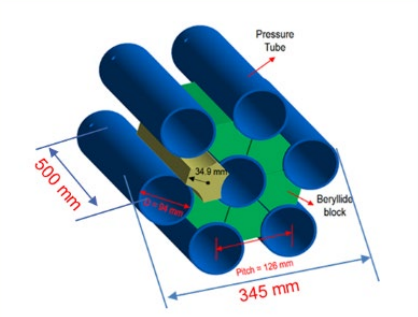
- For divertor technologies validation



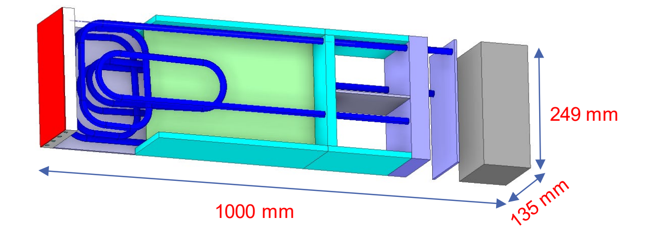


TBU for the WCLL and HCPB → basic elements





Dimensions of HCPB blanket breeder zone



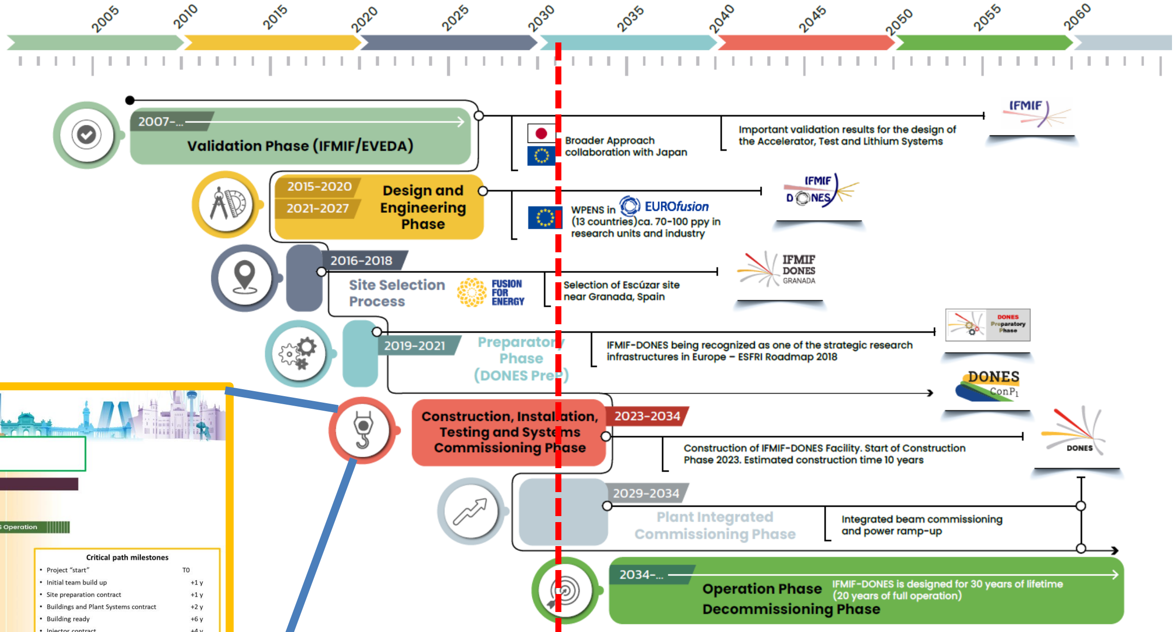
Dimensions of WCLL blanket BZ + manifold

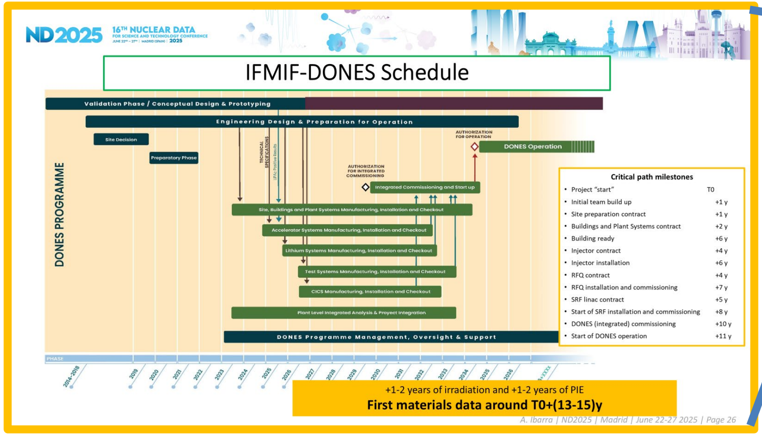
Outline

- The fusion-like neutrons facility Project
- Validation and prototyping activities
- Experimental capabilities
- DONES Programme Status
- Summary

DONES Programme Phases

The objective of the DONES Programme is not only for building the IFMIF Facility...
but also to operate and to exploit it!!





Site Status

Outline

- The fusion-like neutrons facility Project
- Validation and prototyping activities
- Experimental capabilities
- DONES Programme Status
- Summary

Summary

- A fusion-like neutron source for qualifying fusion materials is urgently needed for fusion development as a viable energy source. The more feasible one is based on D-Li reactions

- IFMIF/EVEDA project (included in the EU-JA Broader Approach Agreement) has played and plays a key role for the validation of key technologies required for the development of this type of facilities

- The **DONES Programme**, including the IFMIF-DONES facility under construction in Granada, has entered into its **Construction Phase…**

- DONES will be able to provide materials data as well as other fusion technologies validation required by the fusion technology development

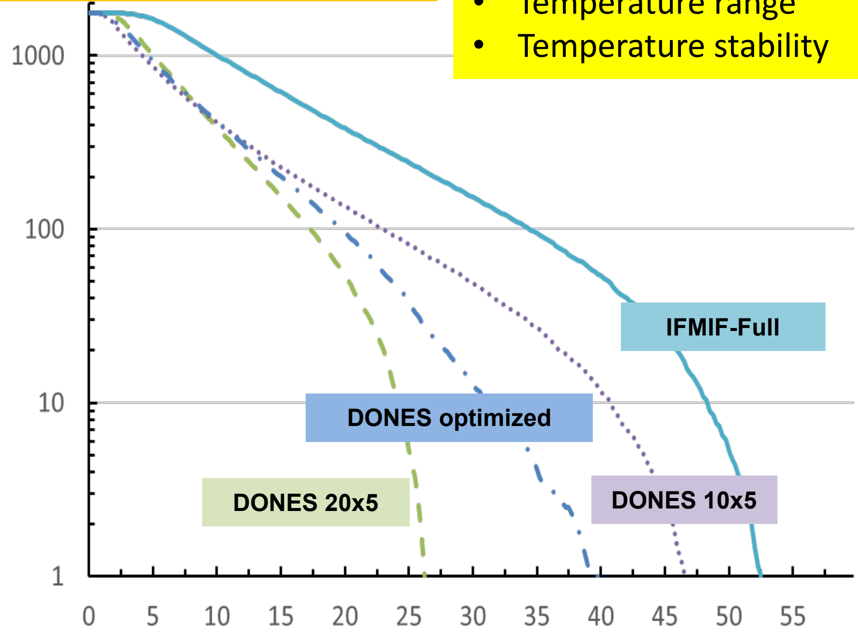

IFMIF-DONES
E S P A Ñ A
FUSION
FOR
ENERGY
QST
IFMIF
DONES

Irradiation capabilities

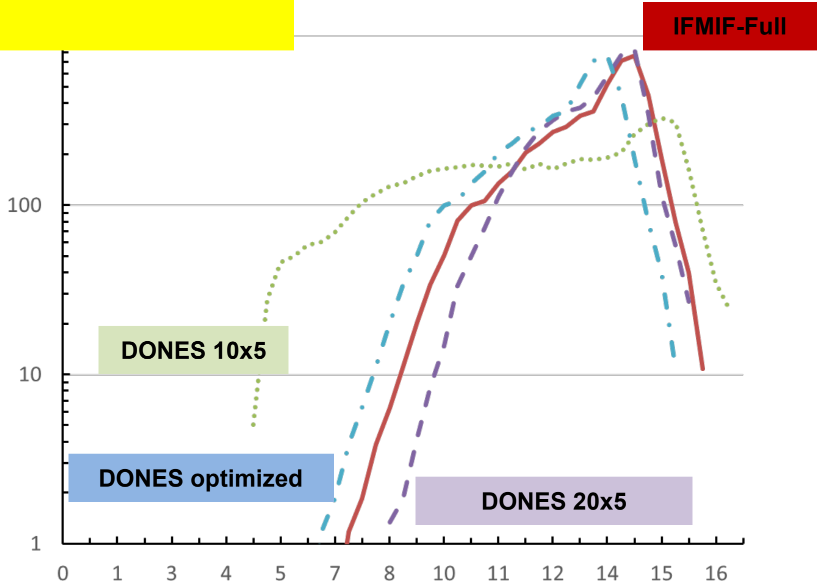
Key parameters for the different irradiations:

- Total neutron dose (EoL of the material under study)
- Dose rate
- He and H transmutation rate (He/dpa and H/dpa ratios)
- Temperature range
- Temperature stability

Available Irradiation Volume (cm^3) vs DPA (dpa/fpy)

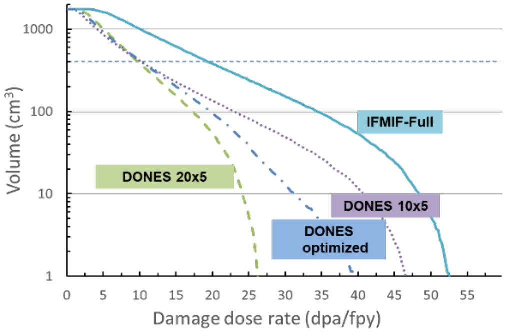


Available Irradiation Volume (cm^3) vs He/dpa ratio (HE appm/dpa)

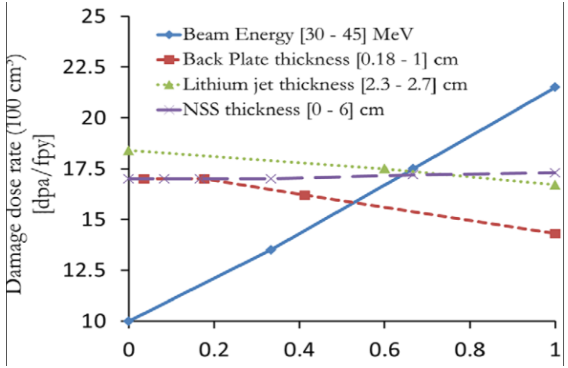


Irradiation capabilities: flexibility

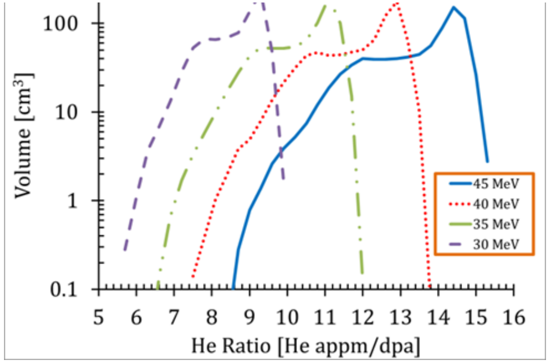
IFMIF-DONES design is **flexible**, in order to accommodate for different irradiation conditions



Variation of the damage dose rate of the central part of the HFTM for different IFMIF-DONES parameters



Available irradiation volume of the central part of the HFTM vs He appm/dpa for different IFMIF-DONES D energy

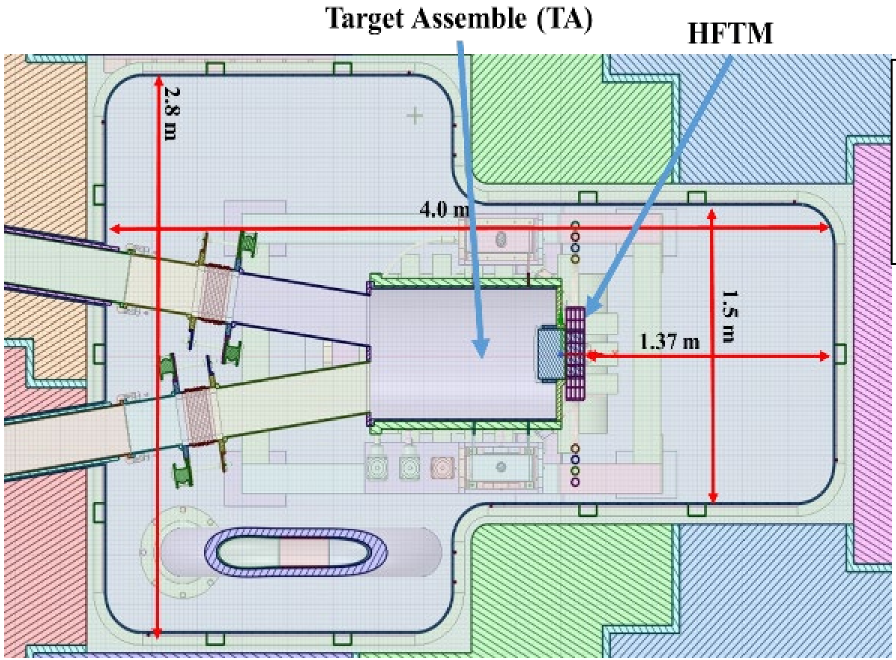


Flexibility on:

- Continuous or pulsed irradiation
- Dose rate (beam current and shape)
- Neutron spectra (i.e. He/dpa and H/dpa ratios)
- Temperature range
- Irradiation modules

IFMIF-DONES test area

- Available irradiation volume in DONES is huge and represents an important benefit → large margin to propose new experiments.



x-axis: 1.37 m in the direction of the beam (excluding the HFTM)
y-axis: 4 m in the vertical direction
z-axis: 1.5 m in the horizontal direction