EUROfusion

Challenges of Target and Irradiation Diagnostics of the IFMIF-DONES Facility

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On behalf of the IFMIF-DONES Team

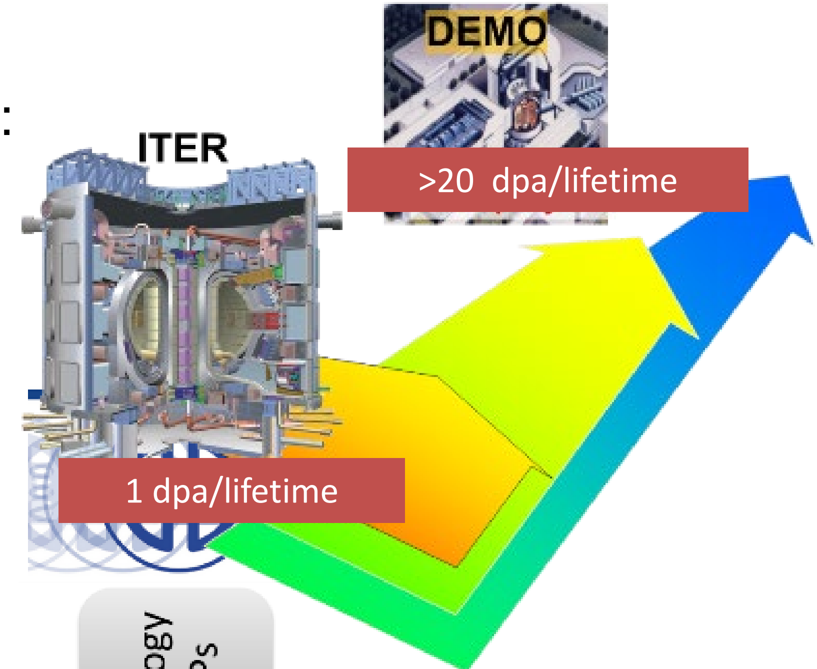
Hadron Beams 2023. CERN, Geneva, 11/10/2023

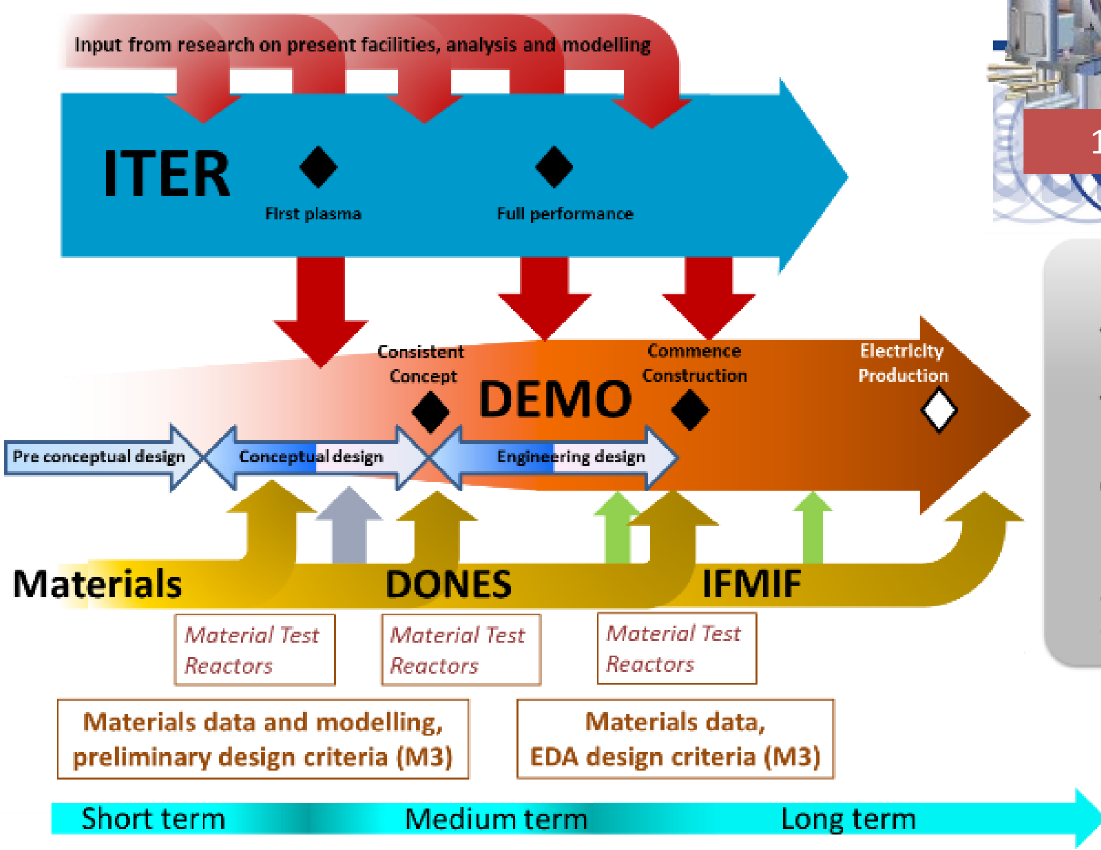
This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Outline

Fusion RoadMap

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





Science & Technology
Basis for first FPPs

Material qualification in a field that **best mimics 14 MeV neutrons** is necessary to validate in-vessel materials

A fusion-like neutron source

We need to produce **fusion-like neutrons** with:

- **Intensity** large enough for accelerated testing (as compared to DEMO)
- **Damage level** above the expected operational lifetime
- **Irradiation volume** large enough for the characterization of the macroscopic properties of the materials of interest required for the engineering design of DEMO (and the Power Plant)

The most feasible approach based on **Li(d,xn) sources**

The **IFMIF project** since 90´s

Broader Approach **IFMIF/EVEDA** since 2007
(LIPAc & IFMIF IIEDR)

EUROfusion **WPENS** since 2015

Requirements based on EU DEMO needs

> 10 dpa(Fe)/fpy

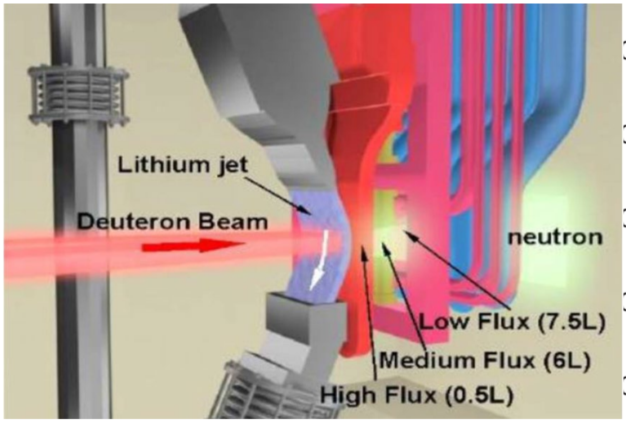
20 dpa(Fe) in 1.5 y
50 dpa(Fe) in 3.5 y

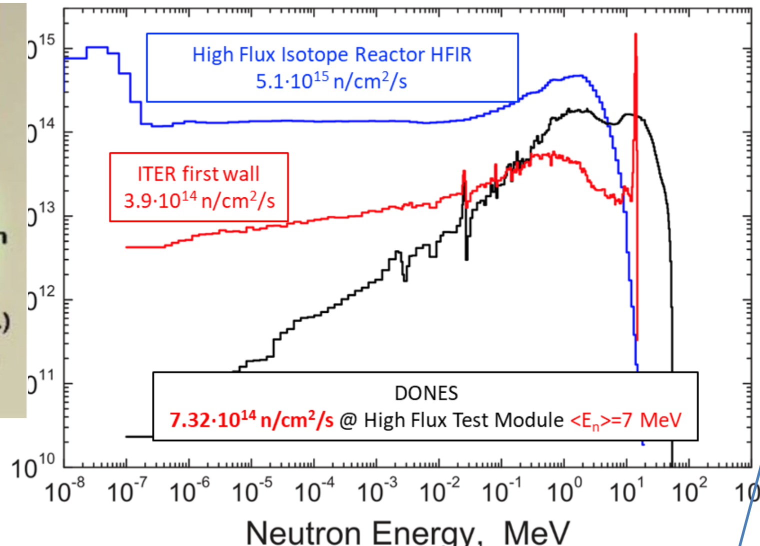
300 cm^3

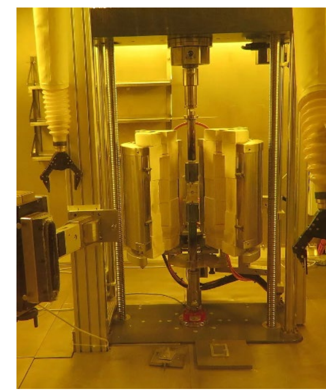
The IFMIF-DONES Project

What is IFMIF-DONES?

IFMIF-DONES is an **accelerator-based fusion-like neutron source**







IFMIF-DONES is a combination of:

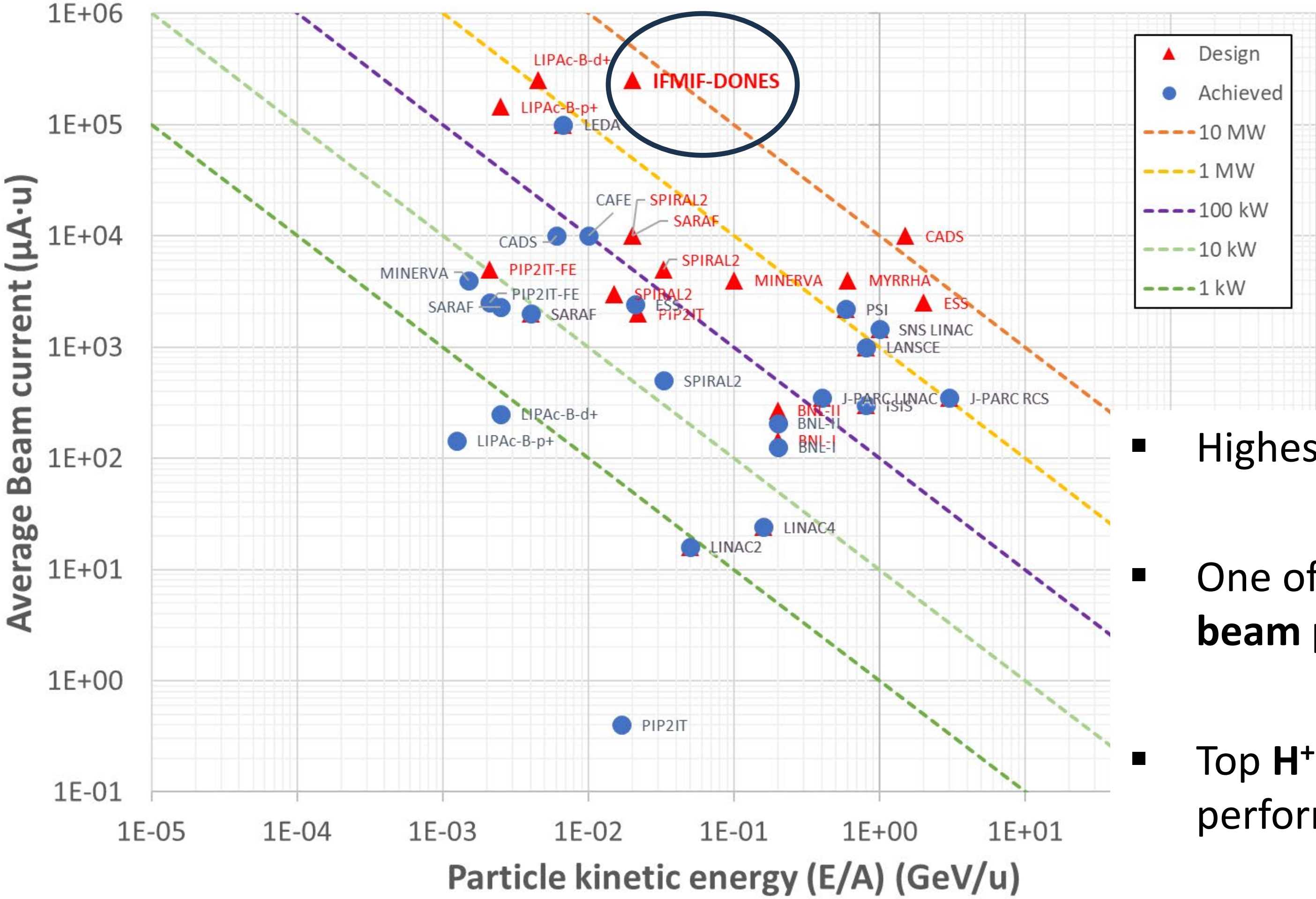
1) High Intensity **Deuteron Accelerator**
2) **Liquid Lithium Loop Facility**
3) **Irradiation Modules** to house material specimens in a controlled environment

IFMIF-DONES Site

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

IFMIF-DONES 5 MW Accelerator Design

40 MeV / 125 mA CW / 5 MW Super-Conducting LINAC

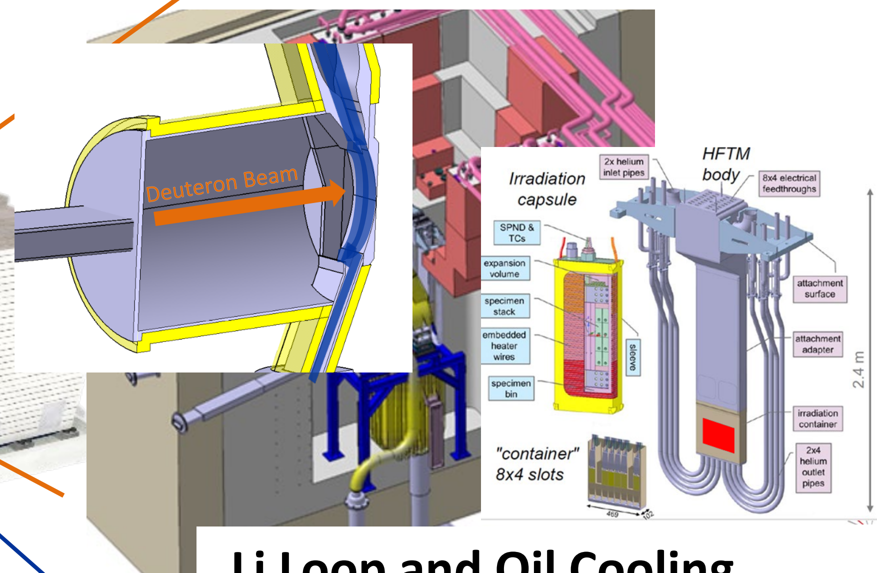


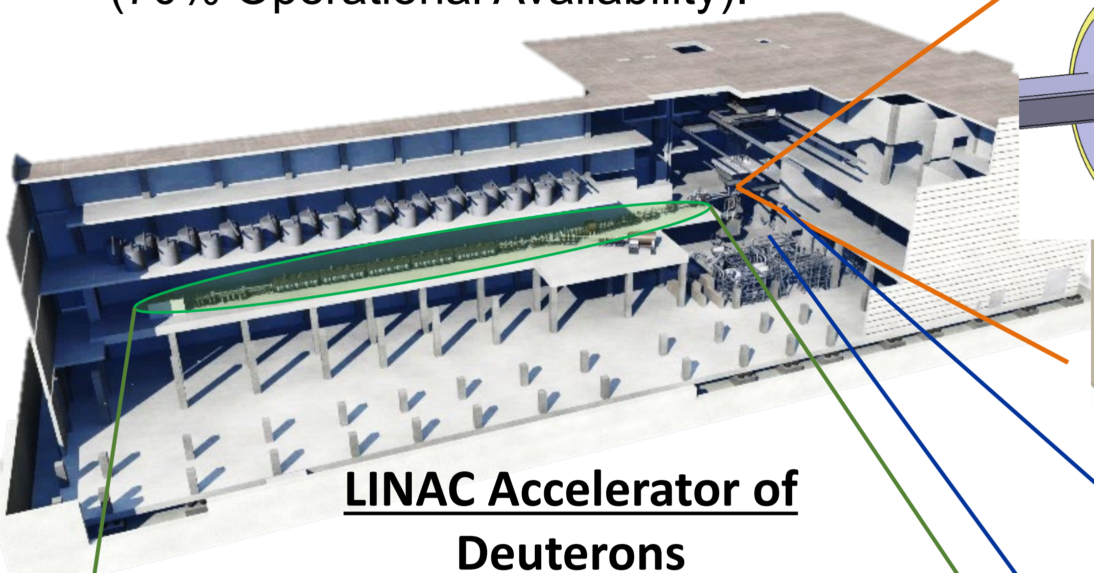
- Highest **D⁺ current** LINAC
- One of the highest **average beam power**
- Top **H⁺ & D⁺ Injector** performance
- Longest **RFQ**

The IFMIF-DONES Facility

- Irradiation Facility delivering up to **10^{15} n/cm²s** (**10^{17} n/s**) with a broad peak at 14 MeV.
- Operational at least 255 days/year (70% Operational Availability).

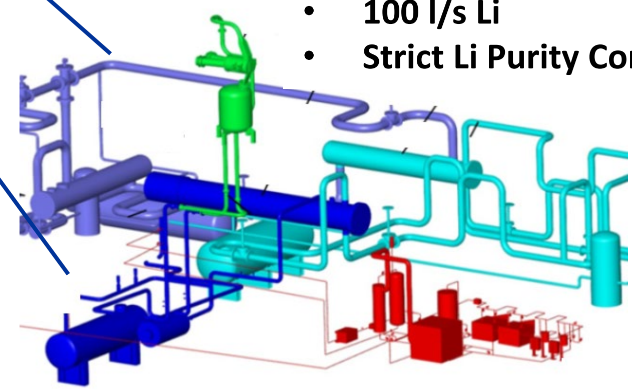
Li Target, Irradiation Modules and Test Cell





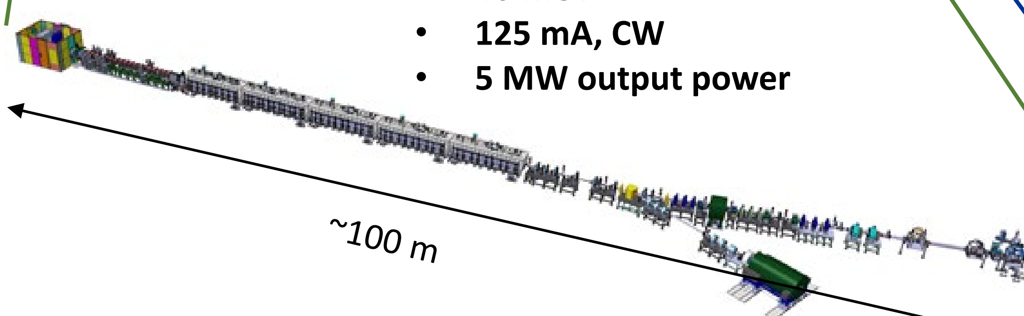
Li Loop and Oil Cooling Loops

- 100 l/s Li
- Strict Li Purity Control



LINAC Accelerator of Deuterons

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



Outline

1 Introduction to the IFMIF-DONES Facility

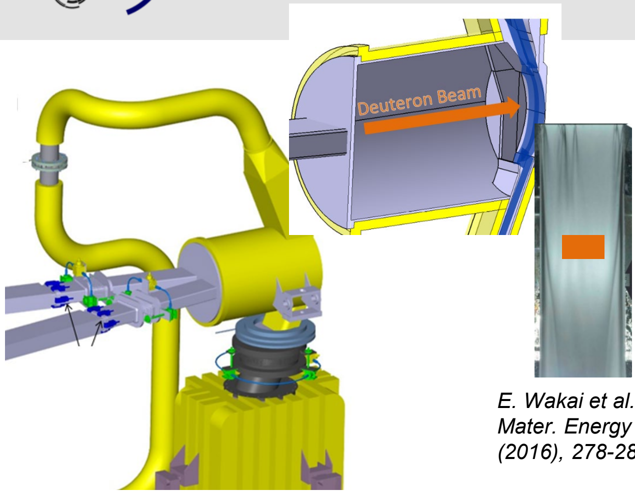
2 **The IFMIF-DONES Target and Irradiation Modules**

3 Li Target Diagnostics

4 Irradiation Module Diagnostics

5 Conclusions

Target and Li Systems



E. Wakai et al., Nucl. Mater. Energy 9 (2016), 278-285

<u>Li Target:</u> Jet flowing at 15 m/s, thickness = 25+/- 1 mm.

Jet stability & Target position is **critical** to avoid Back-Plate rupture.

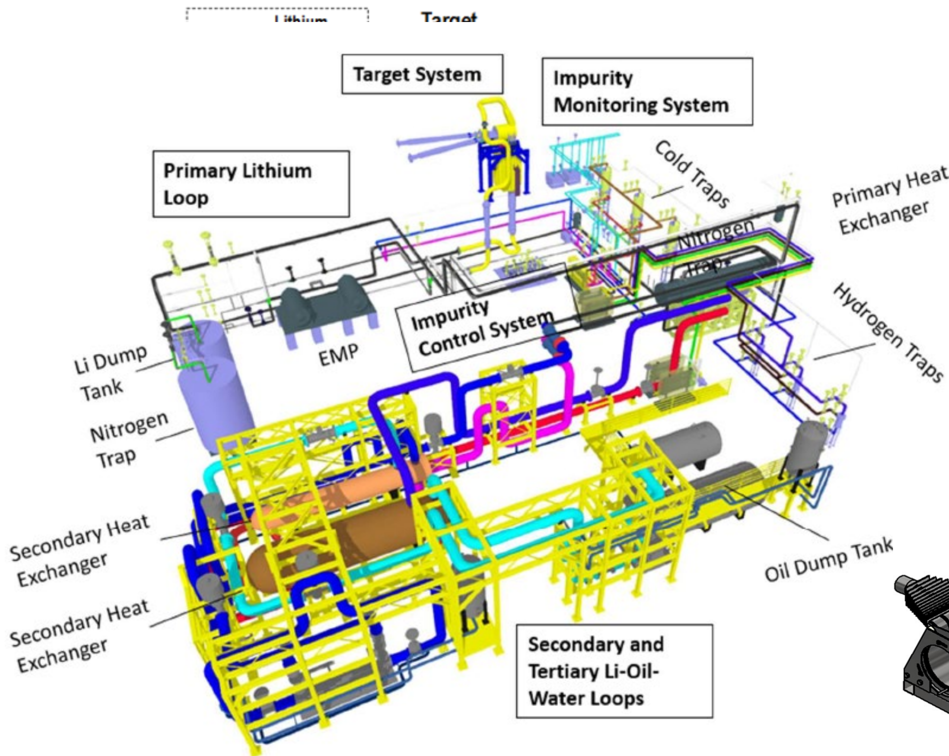
Target Vacuum Chamber shall be within 10^{-4} -10^{-5} mbar.

Full RH replacement/maintenance.

<u>Primary (Li), Secondary (oil) and Tertiary (oil) Loops:</u>

100 l/s of Li at 300 °C.

EMP Pump, heaters, Heat-Exchangers and Dump tank. **Li Loop room in Inert atmosphere**.

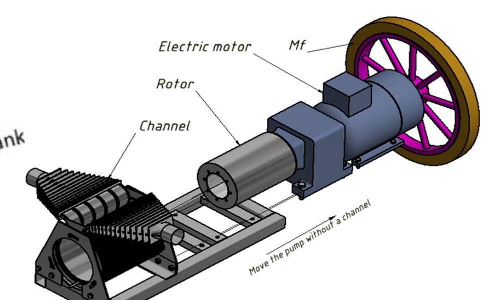


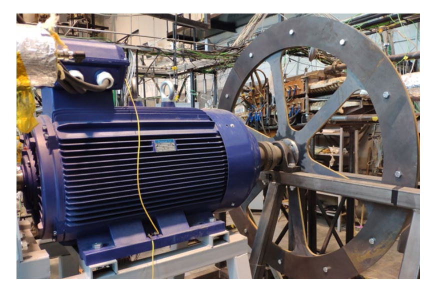
<u>Li Impurity Control Purification Loop:</u>

2 l/s, monitoring impurities (offline methods) and purification traps:

- H traps, Cold Traps, N Traps. (placed in hot cells)

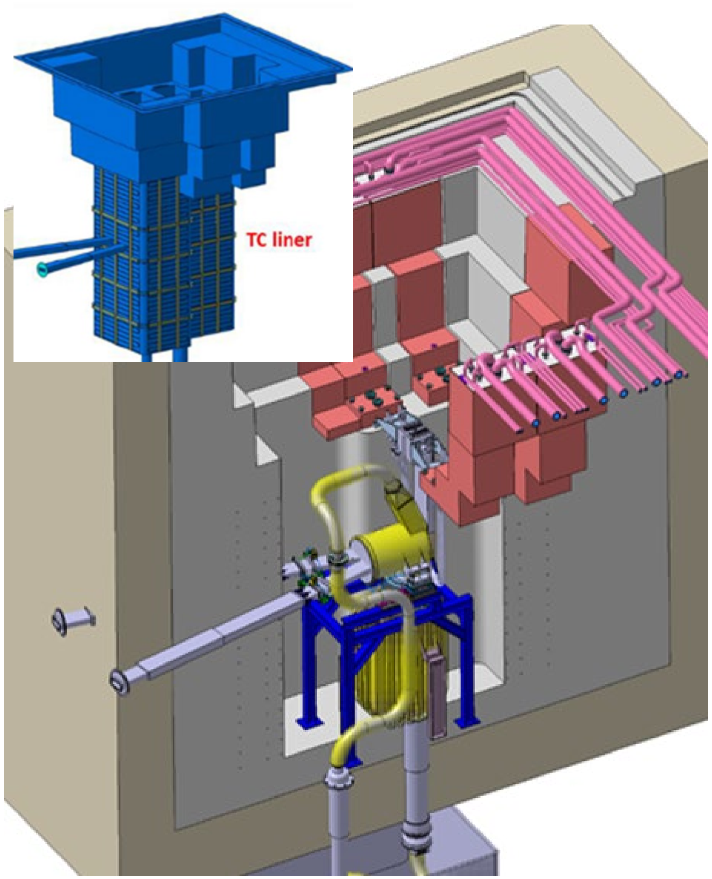
Permanent Magnets EMP





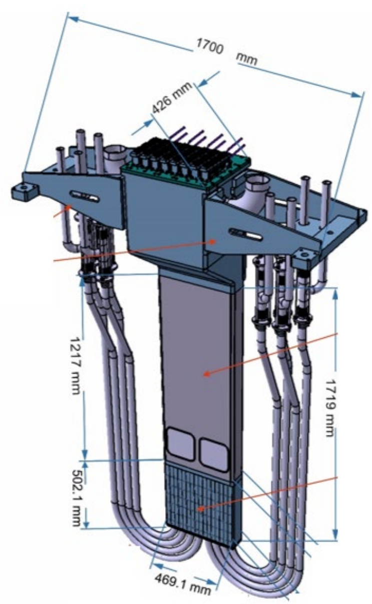
Irradiation Modules

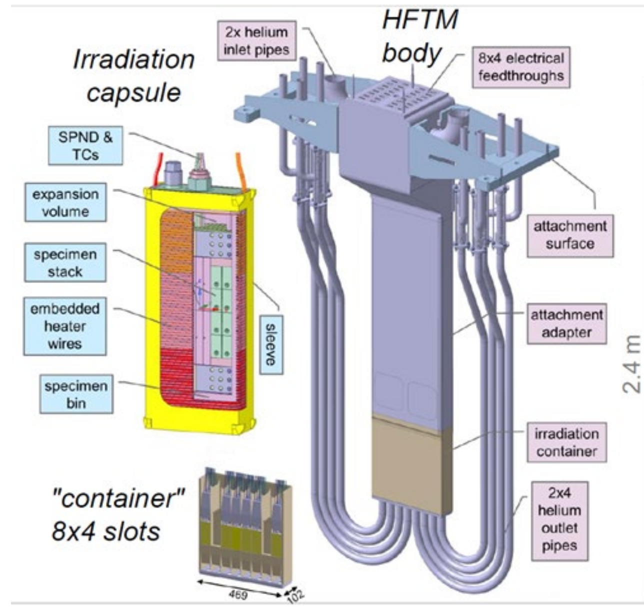
Test Cell: Inert atmosphere (He/Ar) at 20-90 mbar and confinement barrier (Liner + Plug and Gaskets), biological shielding, cooling…



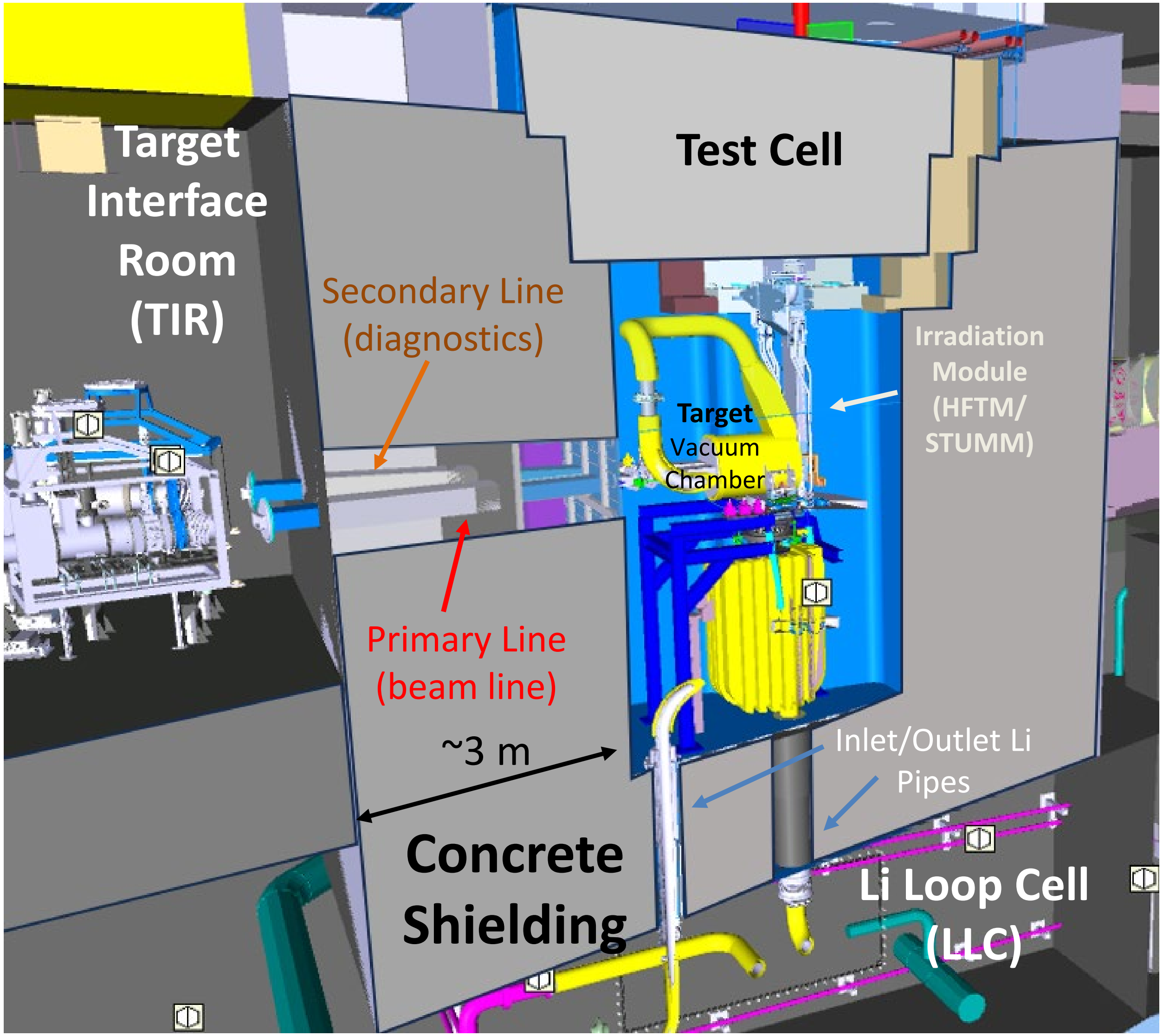
HFTM: High Flux Test Module

STUMM: Start-Up Monitoring Module





Target and Irradiation Modules Configuration



<u>Radiation in the exposed zone of Irradiation Modules:</u>

10^4 MGy/fpy

30 MGy/fpy (at the connectors bridge)

<u>Radiation in around the Target Vacuum Chamber:</u>

100 MGy/fpy

<u>Radiation in the Target Interface Room (TIR):</u>

1-2 MGy/fpy

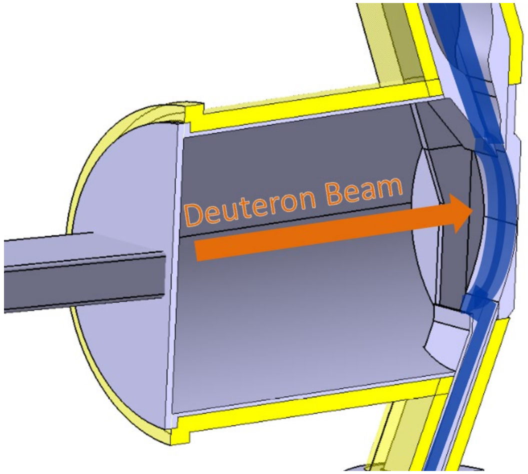
<u>Radiation in Li Loop Cell (LLC):</u>

~ kGy

Outline

Req. and Challenges of the Li Target Diagnostic (1)

1) Monitoring the Li Target curtain thickness

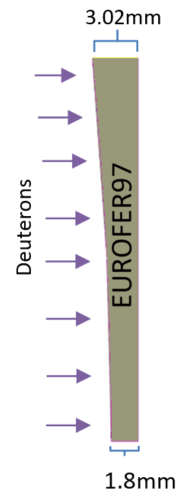


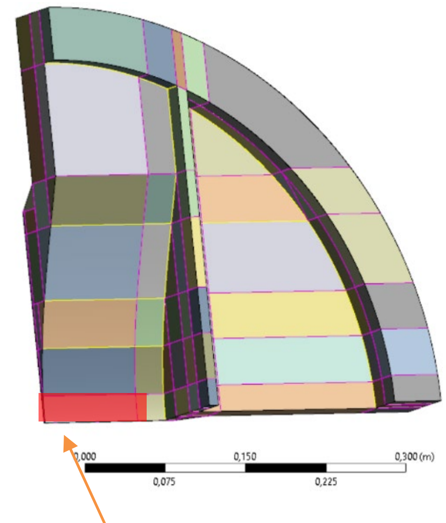
<u>Nominal Li curtain Thickness:</u>

25 mm

<u>Back-Plate Thickness:</u>

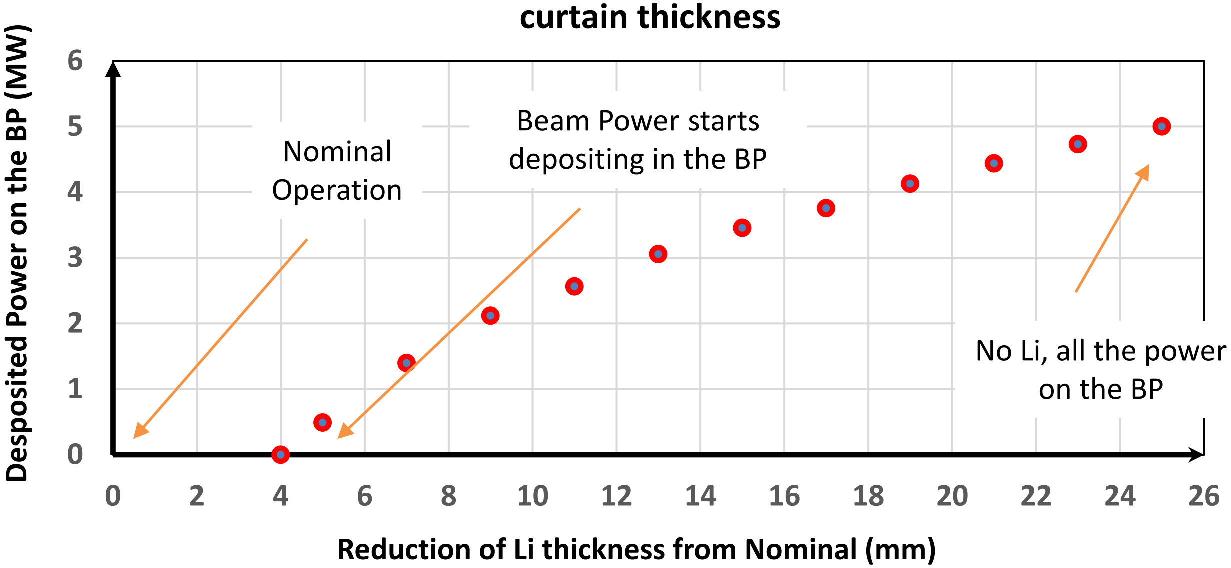
1.8-3 mm





Beam Foot-print Area (20 x 5 cm)

Power deposited in the BP as function **of the Reduction in Li curtain thickness**

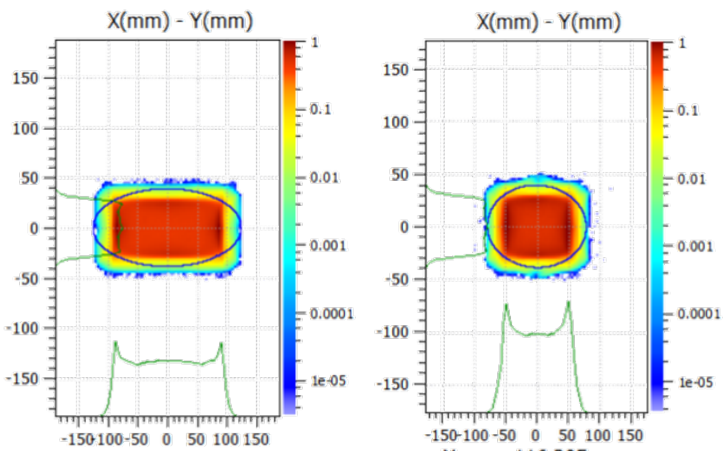


A Li thickness **reduction > 3 mm would** lead to **power deposition in the Back-Plate**

Failure/melting could take place **in tens of milliseconds**

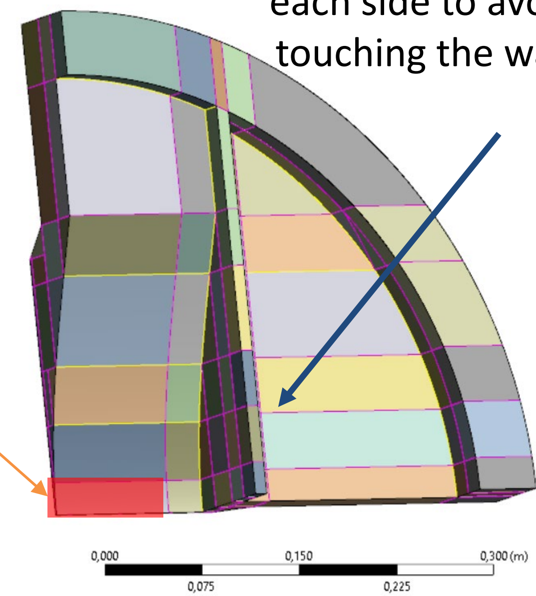
Req. and Challenges of the Li Target Diagnostic (2)

2) Monitoring the Beam Footprint on Target

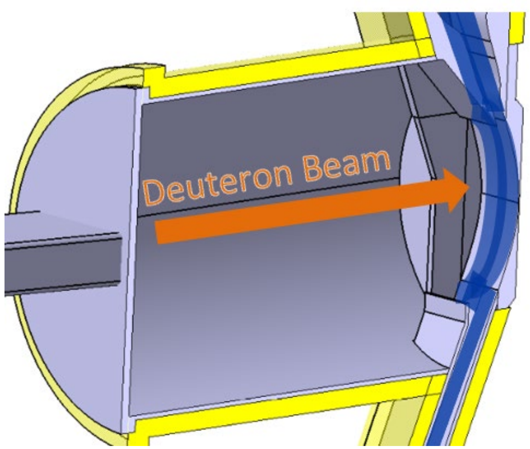


Beam foot-print Area (20 x 5 cm) (Up to **25 cm wide** counting with the tales)

Only **5 mm margin** in each side to avoid touching the wall



3) Monitoring the vacuum pressure in the TVC

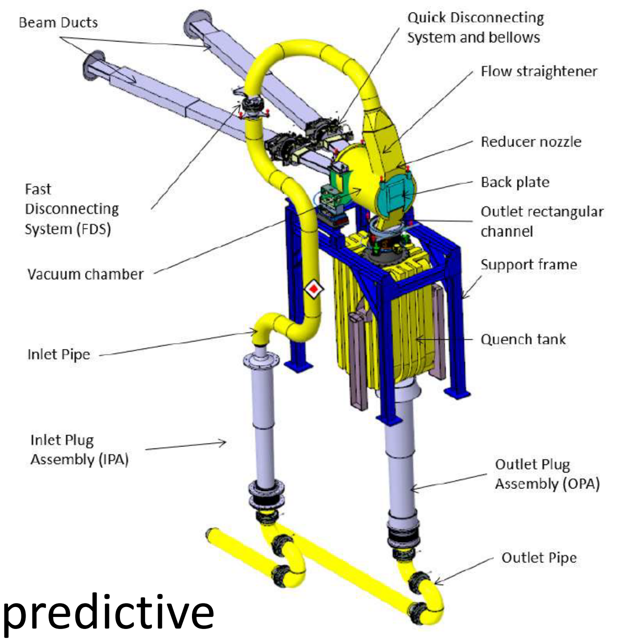


- Pressure at the TVC shall be kept **within 10^{-4} – 10^{-5} mbar** (avoid Li boiling..)
- Managed by **Ar injection** system to achieve a differential vacuum pressure

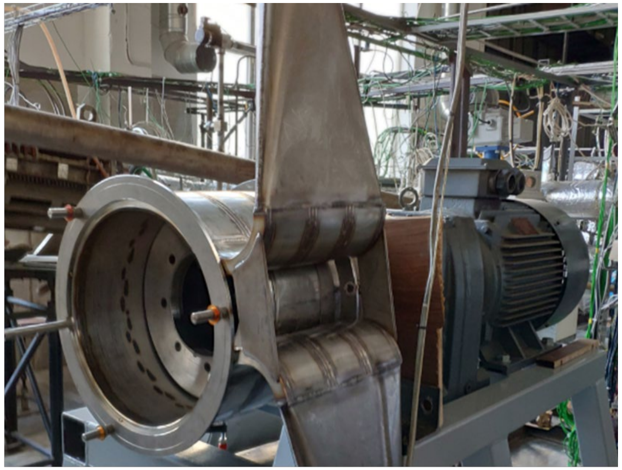
- **Very high radiation** (100 MGy/fpy) disables the installation of vacuum gauges in the TVC..

4) Monitoring the Li mass flow to the Target

- **High frequency acquisition flowmeters** are necessary to detect eventual Li instabilities and shutdown the beam before BP damage.
- Aiming at **Safety-credited** instruments



5) EMP and Li Leaks Diagnostics



- Detect flow instabilities/cavitation/predictive failure..
- Detect Li leaks..

6) Monitoring Li Impurities

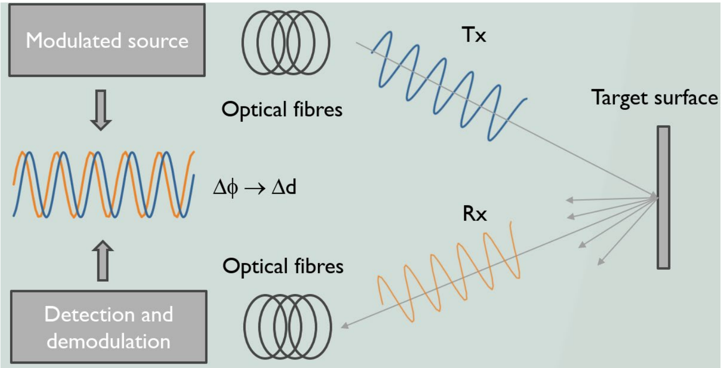
Requirements:

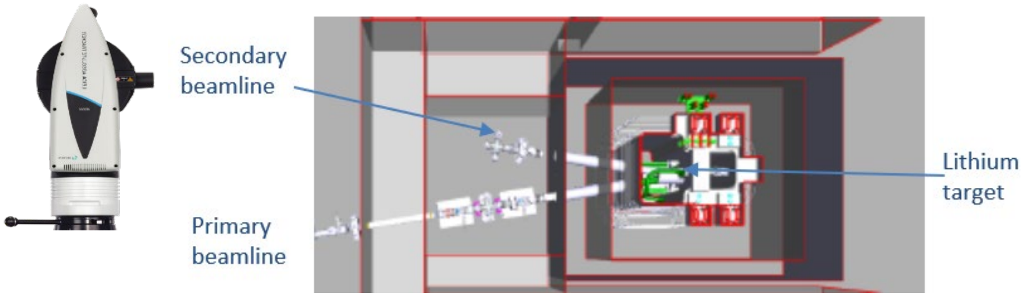
- H and O < 10 wppm
- N < 30 wppm

Li Diagnostics: Proposed Solutions (1)

1) Li curtain Thickness Diagnostics

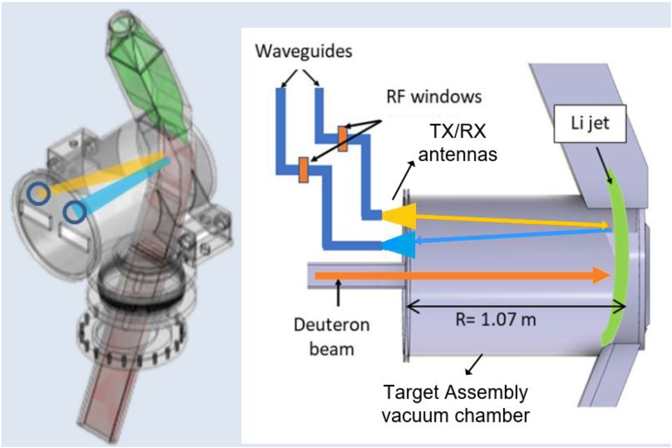
Optical metrology measurement: Amplitude-modulated Continuous-wave Light Detection and Ranging (**AMCW LiDAR**)



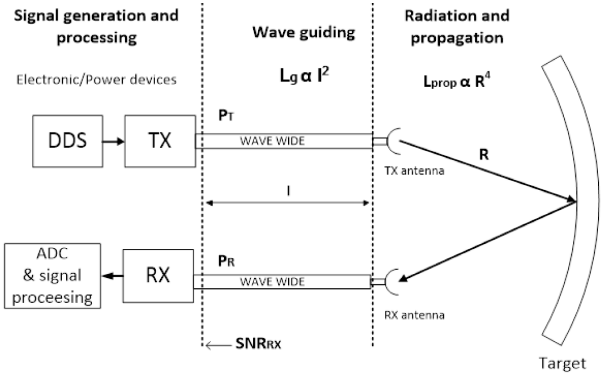


- High-frequency modulation at 550 MHz
- 100 microns accuracy
- Acquisition times within 1 ms per point and <100 ms per line.
- Compatible with the 1-2 MGy/fpy in the TIR

Radiofrequency (mmWave radar techniques)



Linear Frequency Modulated Continuous Wave (LFM-CW) Radar



Li Diagnostics: Proposed Solutions (2)

2) Monitoring Beam Footprint

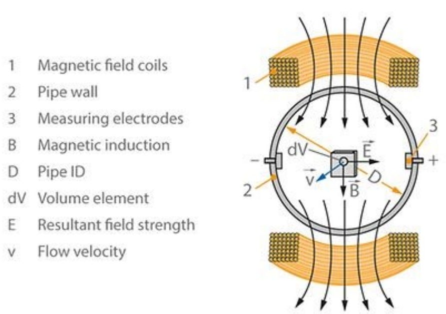
- Camera pointing to the jet through an optical path from the TIR diagnostic port.
- Recording interaction between the beam and the **lithium surface** (OTR) and **residual gas fluoresce**

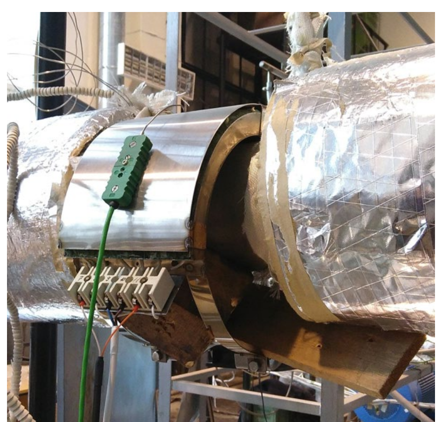
Y. Momozaki et al. Journal of Radioanalytical and Nuclear Chemistry volume 305, pages 843–849 (2015)


Still image of the film with beam taken at 368 sec.

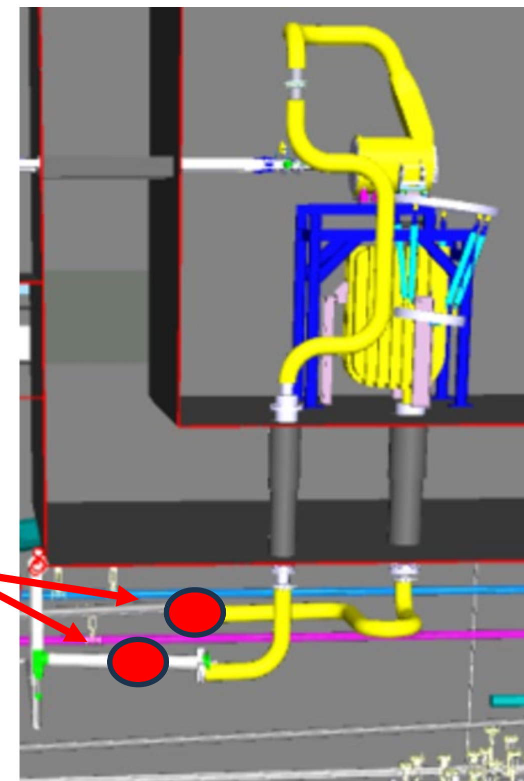
3) Monitoring the Li mass flow to the Target

- Use electromagnetic flowmeters with high acquisitions response times (1 ms)



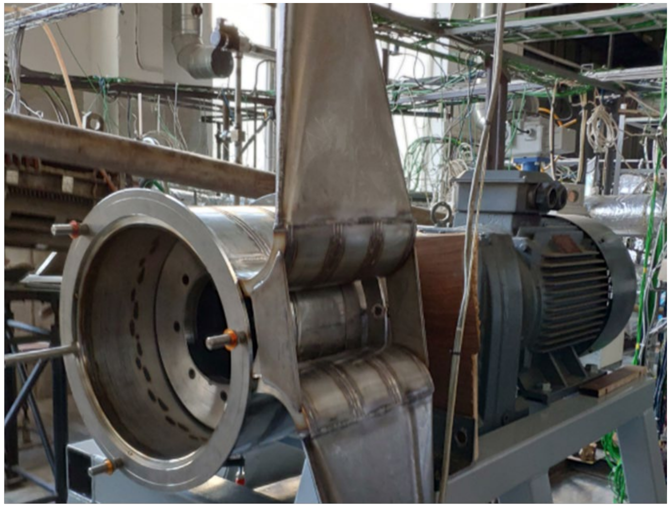


Shielded in the LLC.
Inlet/outlet Li pipes

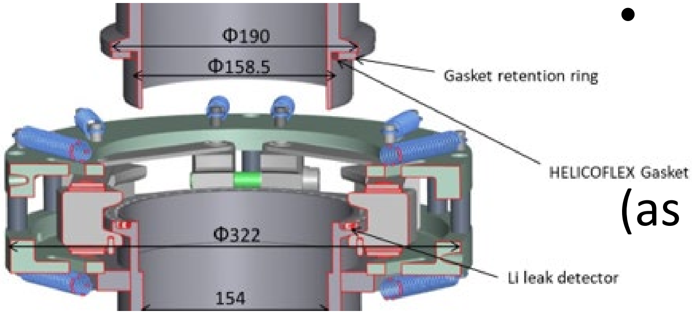


Li Diagnostics: Proposed Solutions (3)

4) EMP and Li Leaks Diagnostics



- Power control, optical encoders, accelerometers



- Lithium Leak detectors based on electric contact (as in SNS)

5) Li Impurity Diagnostics

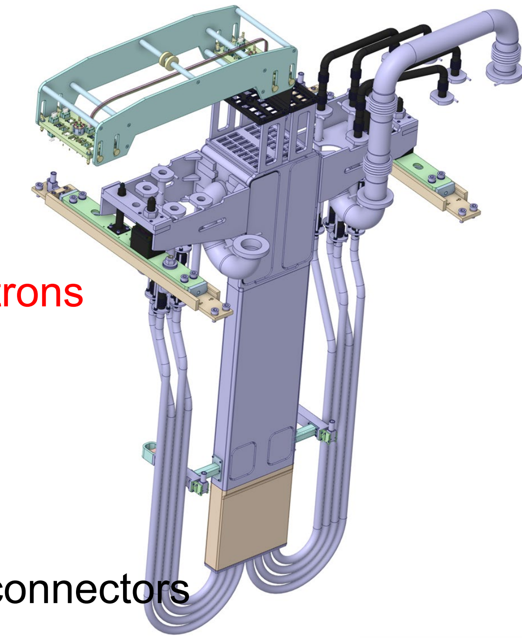
- Mostly relying on **offline analysis** by periodical extraction of Li samples from the Impurity control loop (due to low concentrations involved).
- Other proposed online methods under consideration include a Resistivity Meter for online N monitoring and Electro-chemically based H sensor

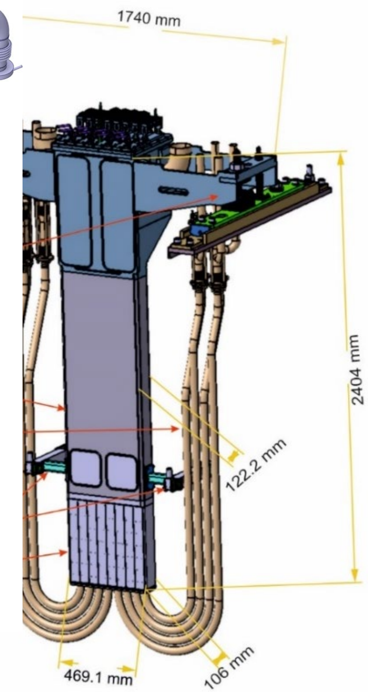
Outline

Req. and Challenges of Irradiation Diagnostics

<u>**1) Monitoring and characterizing the radiation field** with high spatial and time resolution</u>

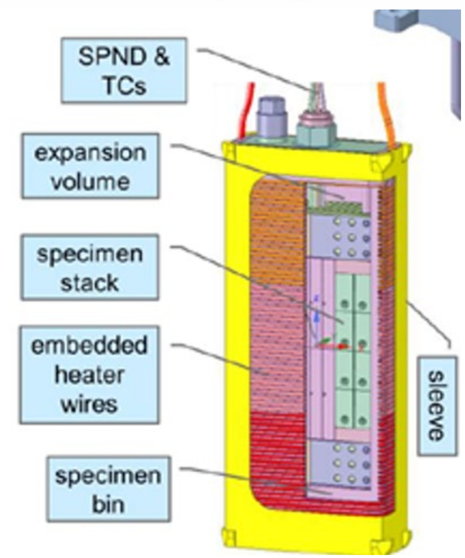
- $5 \cdot 10^{14}/10^{15}$ n/cm²s
- <u>Up to 14 MeV (80% above 1 MeV).</u> Fast neutrons dominating
- Spatial resolution: 10 mm
- Time resolution: 10 µs.
- Maintain n-field calibration during 1 year
- **10^4 MGy/fpy** exposed zone, **30 MGy/fpy** at connectors plate
- Surface of **50x40 cm** for integrating remote handling connectors for **more than 330 different signals**.
- Very low current signals, long cables, EMC sensibility..





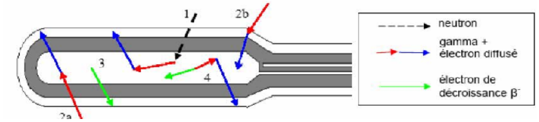
<u>2) Monitoring the irradiation capsule conditions</u>

- Irradiation **temperatures** shall be controlled within 250 – 550 C.
- Necessary to know **the integral radiation** to which the specimens have been exposed



Irradiation Diagnostic: Proposed Solutions

Online Radiation Monitors

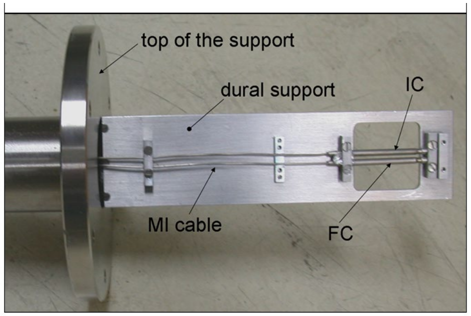


- **SPNDs** (Self-powered Neutron Detectors).
  (compatible with high temperatures)

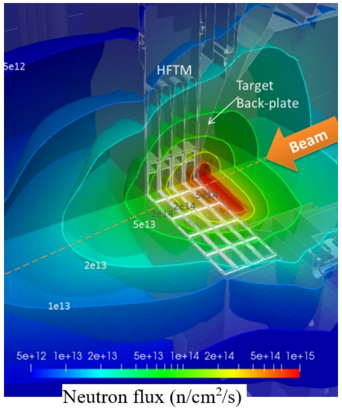
  Irradiation at NEAR station at CERN's nTOF ongoing!

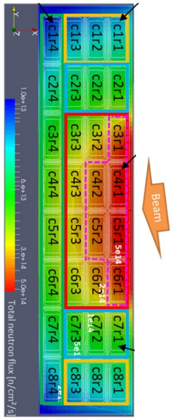
- **µFission** (U238/U235) & **Ionization chambers**

  Irradiation campaigns performed in the BR2 reactor, Belgium

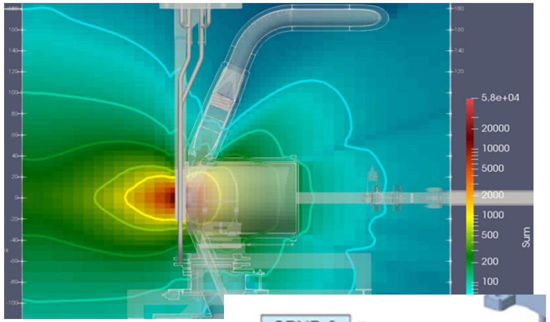


- **ϒ-thermometers**





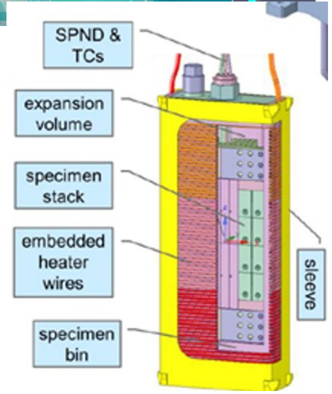
Offline Methods



- **Activation foils** inside the irradiation capsules.

(iron, cobalt, nickel, yttrium, and gold under investigation)

Irradiations were performed at the cyclotron of NPI Řež (Czech Republic)



- Pneumatic Rabbit transporting **activation balls** (for the STUMM)

Outline

Conclusions

1) IFMIF-DONES is **1st kind and 1st Class** Facility**.**

2) Its **technological challenges** are **pushing the state-of-the-art** on Diagnostics Techniques (among others).

3) Abundant **Diagnostics synergies** with Accelerator technologies, Fusion Reactors, and Fission reactors.

4) R&D programs are **ongoing** to develop the technical solutions required (and many more will follow..)

5) Execution of **validation campaigns** in close collaboration with other **institutions and facilities** will be **essential**.


Thanks very much!!
Questions?