EUROfusion

IFMIF-DONES – a fusion-line neutron source laboratory for the European fusion program

DNS-IV Workshop, Dubna | 6-7.12.2018

W. Królas, A. Ibarra, R. Heidinger et al.,

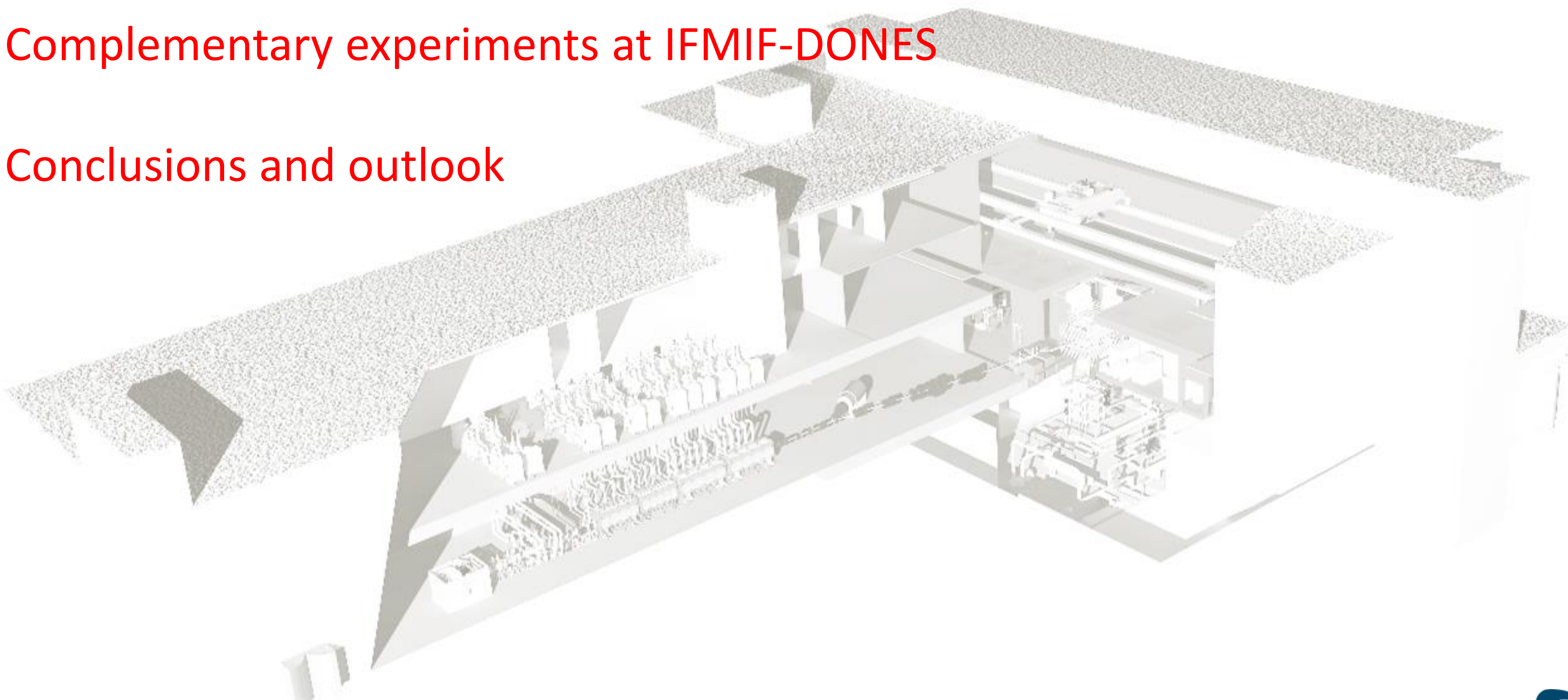
Institute of Nuclear Physics PAN, Kraków, Poland

Early Neutron Source work package

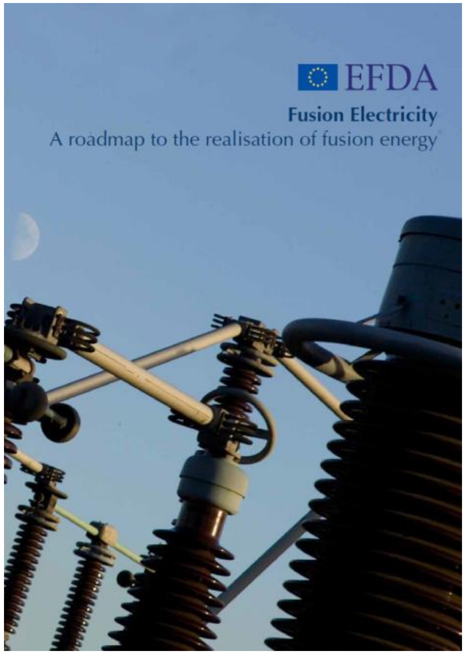
This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

IFMIF-DONES – a fusion-line neutron source

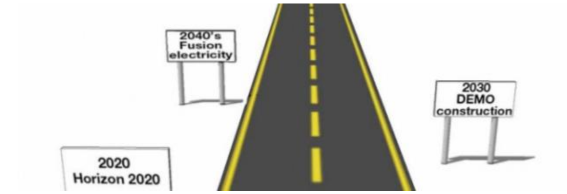
1. Materials irradiation facility within the European Fusion program
2. Basic concept and validation activities, Early Neutron Source work package
3. IFMIF-DONES laboratory – present status of the design
4. Complementary experiments at IFMIF-DONES
5. Conclusions and outlook



European roadmap to fusion energy



The goal of the program is to achieve production of electricity from a thermonuclear fusion reaction by 2050



ITER

International Thermonuclear Experimental Reactor

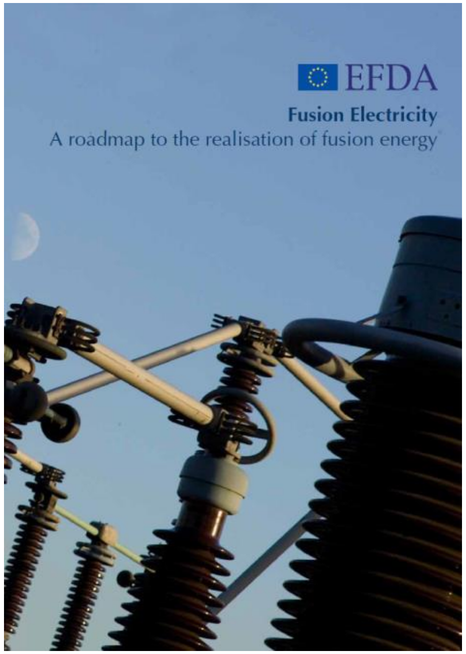
ted 2008

	ITER	DEMO1
Major radius R0 (m)	6.2	9.0
Magnetic field (T)	5.30	6.64
Fusion output (MW)	500	1793
Fusion gain (Q)	10	36
Neutron wall load (MW m^{-2})	0,5	1,15
Pulse length (h)	0,28	1,83

from F.P. Orsitto et al., Nuclear Fusion 56 (2016) 026009

DEMO *Demonstration Power Plant* 2030-2050

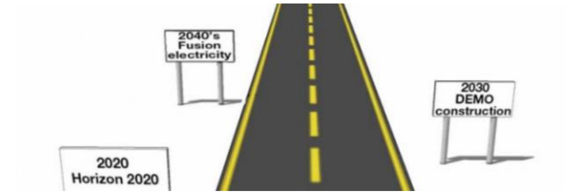
European roadmap to fusion energy



Executive Summary

- **ITER is the key facility in the roadmap.**
  ITER will break new ground in fusion science and the European laboratories should focus their effort on its exploitation. To ensure its success, the preparation of operation on JET and JT-60SA should be undertaken as main risk mitigation measures. Small and medium sized tokamaks, both in Europe and beyond, with proper capabilities, will play a role in specific work packages. No major gaps exist in the foreseen world programme concerning the possibilities to develop operation scenarios for ITER and DEMO. However, adequate enhancements of ITER and JT-60SA will have to be carried out in the period 2021-2030.
- **A solution for the heat exhaust in the fusion power plant is needed.**
  A reliable solution to the problem of heat exhaust is probably the main challenge towards the realisation of magnetic confinement fusion. The risk exists that the baseline strategy pursued in ITER cannot be extrapolated to a fusion power plant. Hence, in parallel to the programme in support of the baseline strategy, an aggressive programme on alternative solutions for the divertor is necessary. Some concepts are already being tested at proof-of-principle level and their technical feasibility in a fusion power plant is being assessed. Since the extrapolation from proof-of-principle devices to ITER/DEMO based on modelling alone is considered too large, a dedicated test on specifically upgraded existing facilities or on a dedicated Divertor Tokamak Test (DTT) facility will be necessary.
- **A dedicated neutron source is needed for material development.**
  Irradiation studies up to ~30 dpa with a fusion neutron spectrum are needed before the DEMO design can be finalised. While a full performance IFMIF would provide the ideal fusion neutron source, the schedule for demonstration of fusion electricity by 2050 requires the accelaration of material testing. By the end of FP7 the possibility of an early start to an IFMIF-like device with a reduced specification (e.g. an upgrade of the IFMIF EVEDA hardware) or a staged IFMIF programme should be assessed. A selection should be made early in Horizon 2020 of risk-mitigation materials for structural, plasma-facing and high-heat flux zones of the breeding blanket and divertor areas of DEMO, also seeking synergy with other advanced material programmes outside fusion.

The goal of the program is to achieve production of electicity from a thermonuclear fusion reaction by 2050



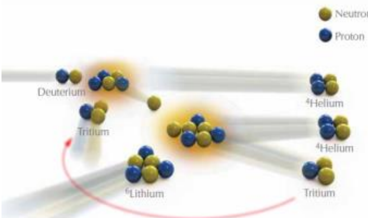
Executive Summary:

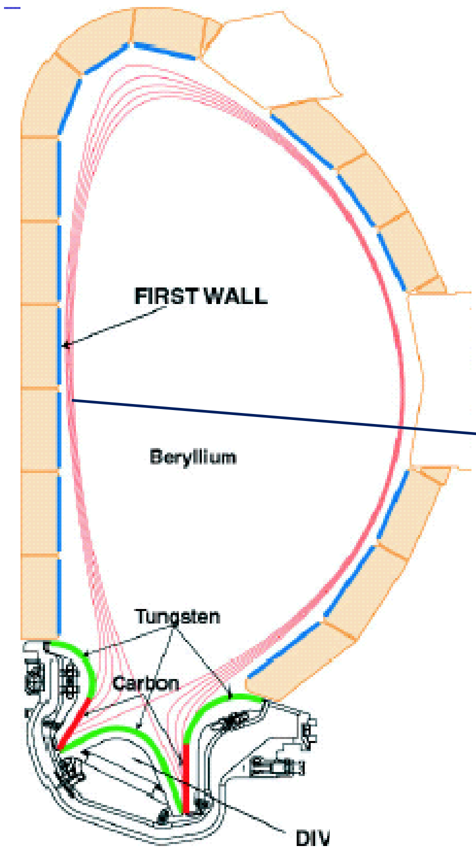
- **A high performance plasma is at the heart – ITER**
- **A solution to the heat exhaust in the fusion power plant is needed**
- **Robust materials are essential, needing a dedicated neutron source for validation and development**
  → **material studies and qualification**

Existing neutron sources do not reproduce the energy spectrum and other relevant conditions of D+T fusion environment

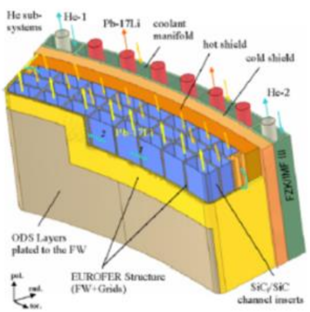
Qualifiction of FIRST WALL materials

First wall is to absorb neutron energy and bread tritium





Most of the neutron energy will be absorbed by the first wall material



First wall of ITER designed for

R < 2 [dpa]

DEMO reactor after 5 years of running

R ~ 30-100 [dpa]

Threshold (no existing data)

R > 30 [dpa]

At about 30 dpa, particular Helium effects are predicted to set in with respect to changes in the temperature of ductile to brittle transition

Materials to be studied and validated:

- Steel (EUROFER), structural material
- Tungsten W, divertor material
- Cu alloys

[dpa] displacement per atom in solid

Ductile vs. brittle materials behaviour

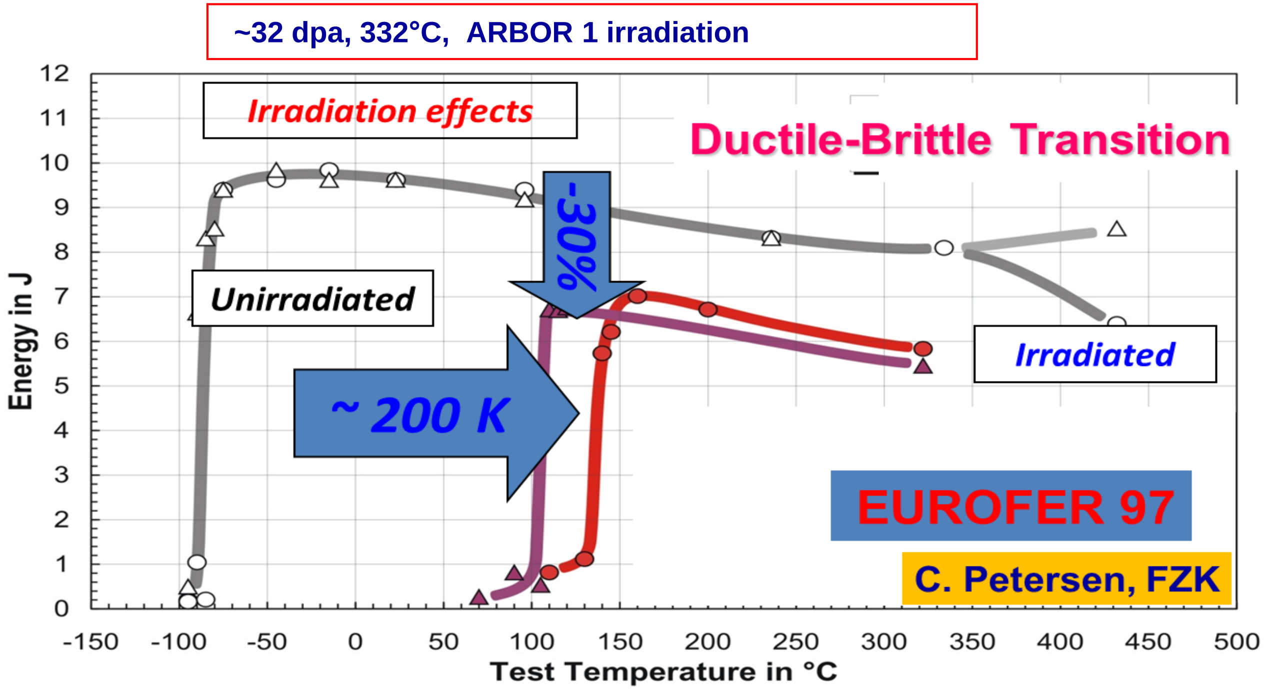
When loads (forces) exceed the limit given by the elastic regime

(a) Ductile Materials:
Materials deform irreversibly
→ "significant" plastic regime

Mask of Agamemnon

(b) Brittle Materials:
Materials crack instantaneously
→ "insignificant" plastic regime

Codex Hammurabi



Grey – non-irradiated material **Red Purple** –irradiated with 32 dpa

- ✓ Large shift in Ductile → Brittle transition temperature
- ✓ Potential effect of Helium generation

A neutron laboratory for the fusion program

1994 **IFMIF** – International Fusion Irradition Facility
concept developed by EU, Japan, US

2007 **IFMIF/EVEDA** – Engineering Validation and Design Activities (EU, Japan)

2013 **IFMIF** Intermediate Engineering Design report

2014 **IFMIF-DONES** DEMO-Oriented Neutron Source
– approach was recommended for further work (Aymar report)

2015 **Eurofusion ENS work package (WPENS)**
preparing the engineering design of DONES laboratory

2019 **DONES Preparatory Phase** program

2020 Targeted demonstration of full current D beam at 9 MeV
2021 by the IFMIF/EVEDA Project (LIPAc accelerator)

Targeted construction time of the **DONES** laboratory

2025

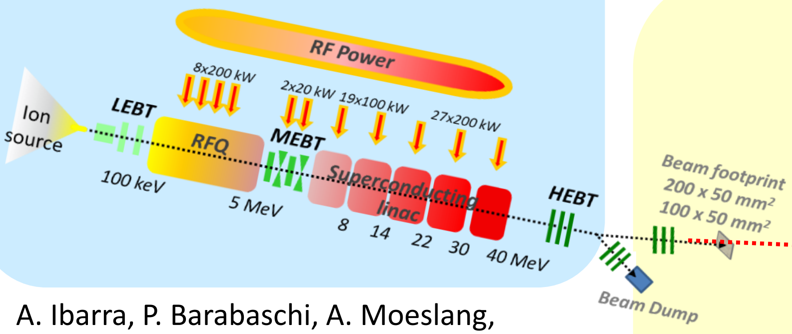
IFMIF-DONES principle of operation

Li(d,xn)

A fast neutron source based on the stripping reaction allows to reach the required flux and spectrum of neutrons relevant for fusion reactor environment

Linear accelerator

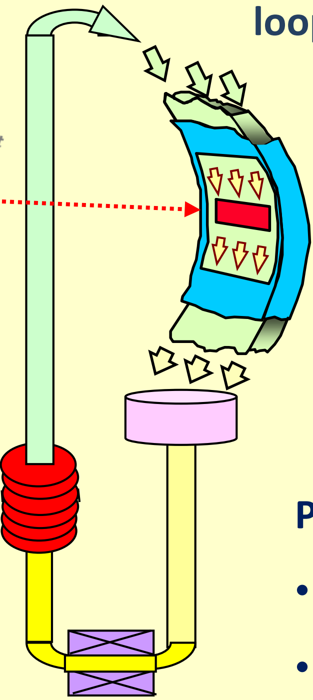
Deuteron beam 40 MeV 125 mA (5 MW)



A. Ibarra, P. Barabaschi, A. Moeslang, J. Knaster, R. Heidinger and the IFMIF Team

Lithium target

Liquid Li loop

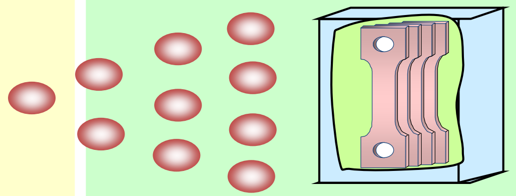


Lithium flowing at 15 m/s absorbs beam energy

Heat removal system

Test module

sample irradiation



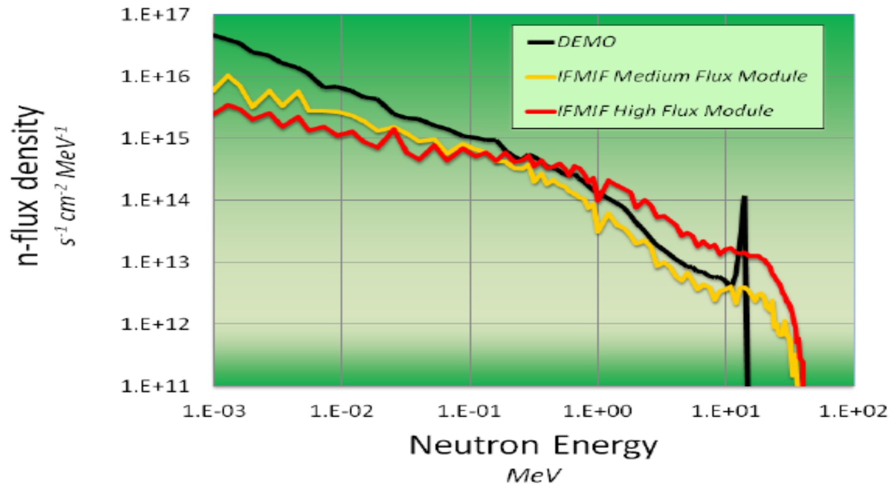
Neutron flux ~ 10^{18} n / m² s

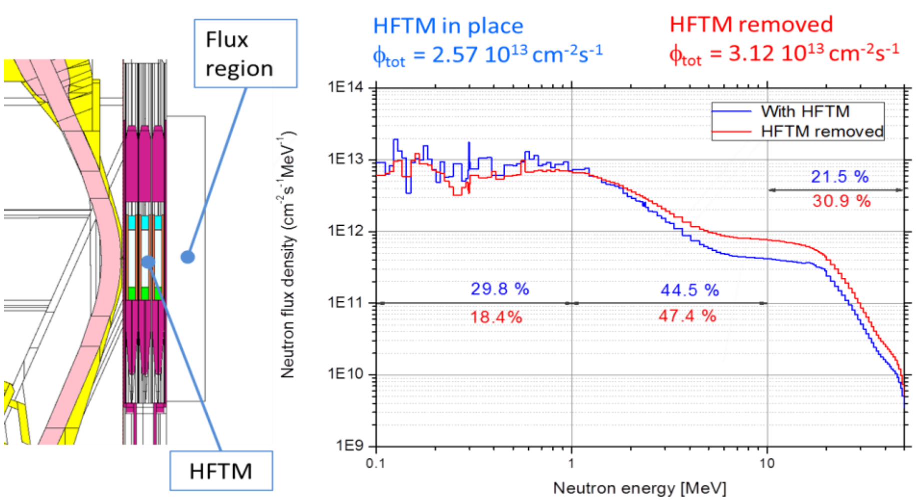
Parameters of the High Flux Test Module:

- Dose 20-35 dpa/y, volume 100 cm³
- Controlled irradiation temperature 250 < T < 1000 °C

Neutron energy spectrum, irradiation dose

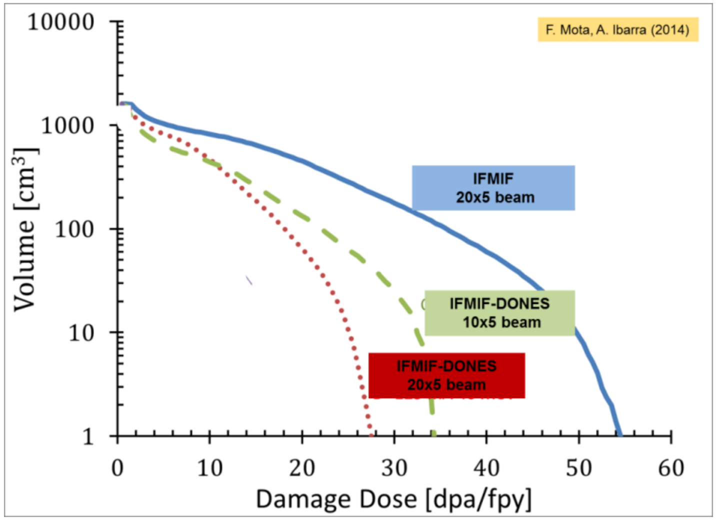
Neutron spectrum in DEMO vs. DONES irradiation





U. Fischer et al., DONES Neutron Flux Spectrum, IFMIF-ELAMAT Town Meeting, Rzeszów 2016

Available irradiation volume vs dpa



Range of interest is between 20 and 30 dpa after 1 year of irradiation

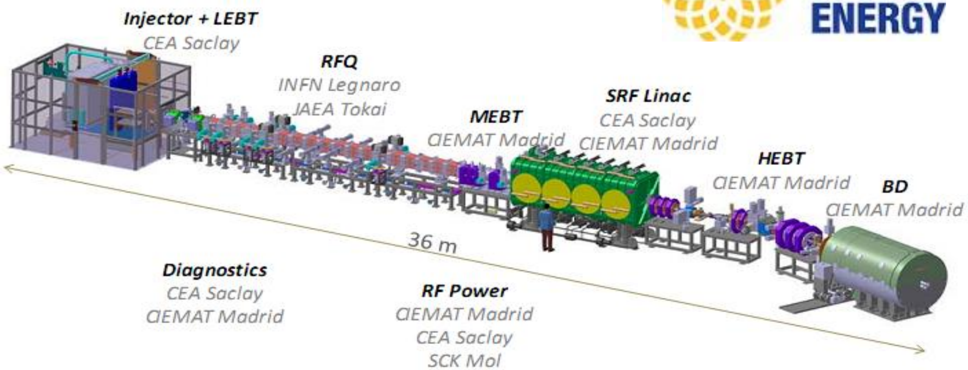
Obtained results will be used to validate DEMO design

Engineering Validation and Design Activities

LIPAc accelerator

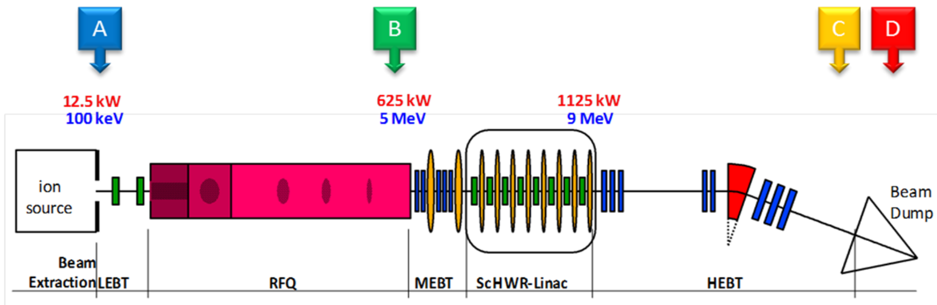
FUSION FOR ENERGY

part of Broader Approch agreement for fusion research between EU and Japan



Lithium target prototype

Going-on now – Beam commissioning with staged approach:



Phase A → **Phase B** → **Phase C/D**

Injector | CW | Diagnostic Box + Beamstop *(Apr.2015 - Aug.2017)*

Injector | RFQ + MEBT | 1 ms | Diag.-Plate + Low Power Beam Dump *(Jun.2018 -)*

Injector | RFQ + MEBT | SRFL + HEBT/D-Plate | 1 ms/CW | Final Beam Dump *Target date March 2020*

Courtesy of R. Heidinger (F4E) and IFMIF/EVEDA LIPAc team

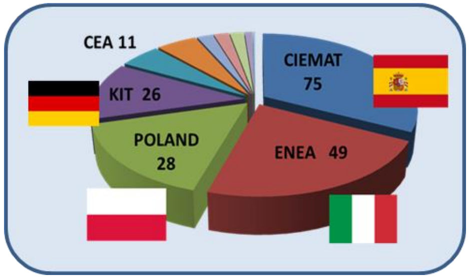
Early Neutron Source work package (WPENS)

From 2015 till 2020

Principal aim: preparation of the **Engineering Design of DONES**

Budget: ca. 36 M€ (21 M€ in 2015-18)

Participation: research units and industrial partners from 11 countries, ca. 70 full time persons (ppy)



From 2018 DONES part of the ESFRI roadmap

European Strategy Forum on Research Infrastructures

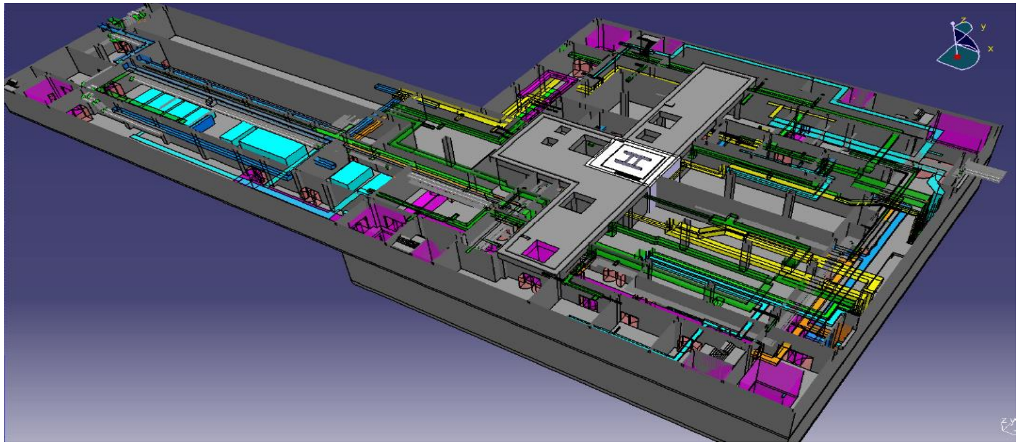
(…) IFMIF-DONES will play a strategic role in the Energy domain for the implementations of Nuclear fusion solutions to the massive production of energy (…)

DONES Preparatory Phase program will start in 2019

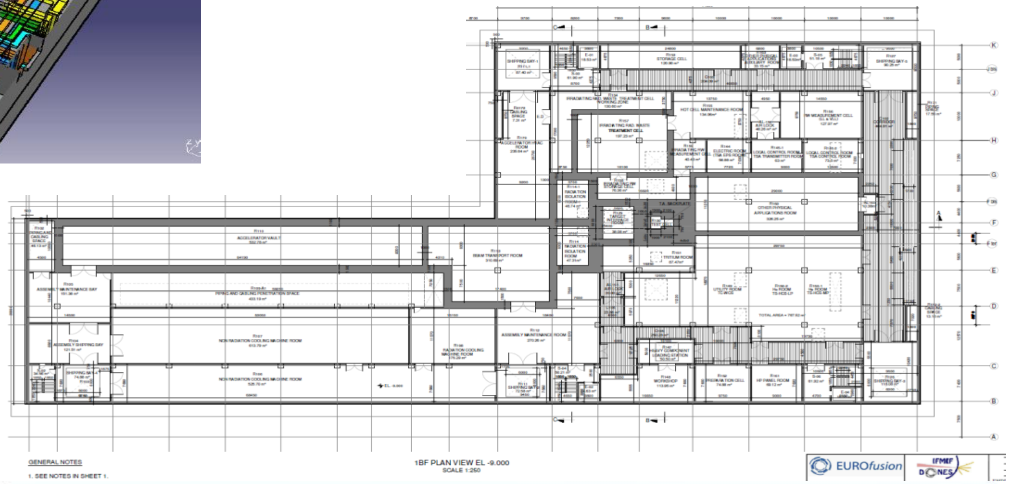
DONES Building and Plant systems

EMPRESARIOS AGRUPADOS

Building and Plant systems are being designed by **Empresarios Agrupados,** an industrial partner

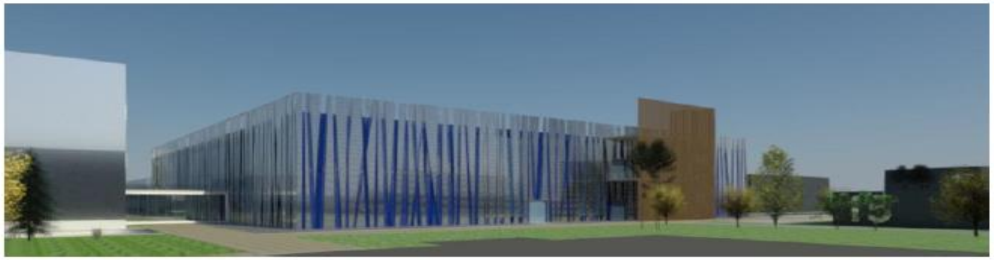


- External dimensions 159 x 75 m
- Two floors fully underground, starting at –18 m
- Floor space of about 9000 m^2



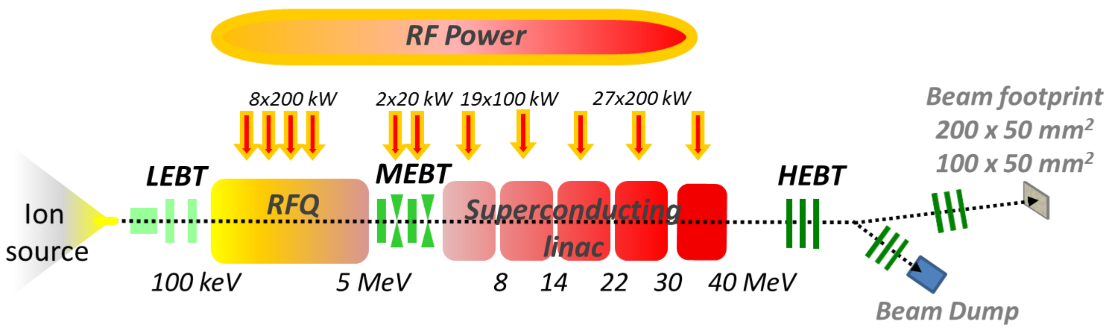
DONES Plant Systems:

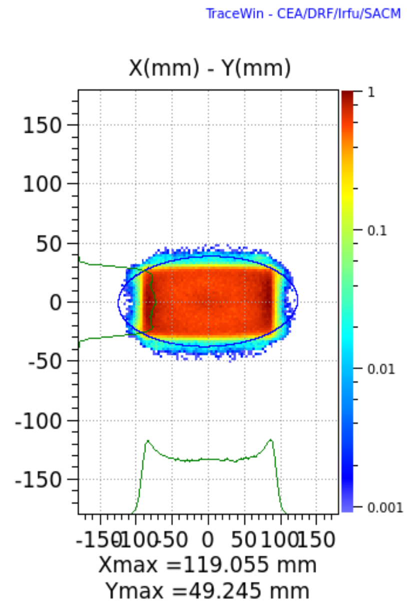
- Heating, Ventilation and AC (HVAC)
- Electrical Power System (EPS)
- Heat Rejection System (HRS)
- Service Water System (SWS)
- Service Gas System (SGS)
- Solid, Liquid and Gas Radioactive Waste Treatment Systems (S-, L-, G-RWTS)
- Fire Protection System (FPS)



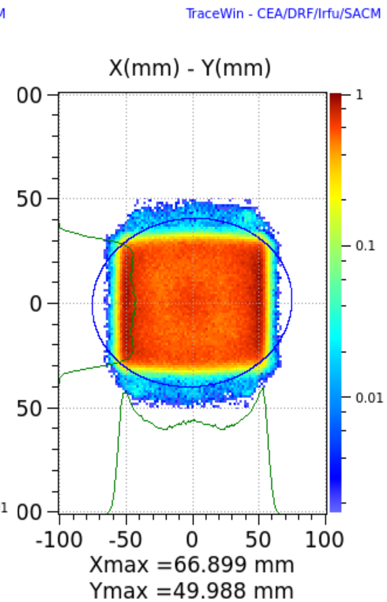
Accelerator Systems

175 MHz Solid State RF source





20x5 cm²



10x5 cm²

Beam D+

Final energy 40 MeV, current 125 mA (5 MW)

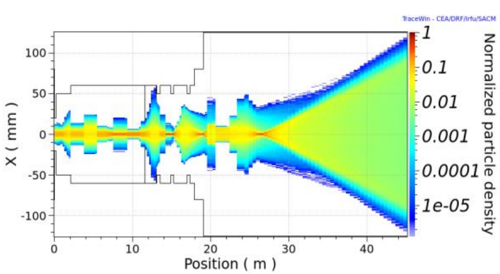
Continuous wave (CW) operation

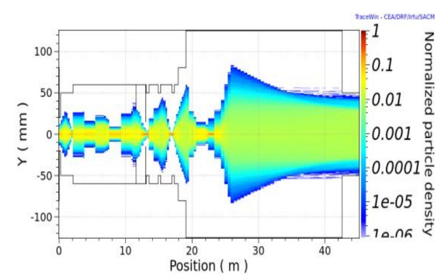
Required beam availability 87%

- Beam on target incident angle 9° (as in IFMIF), upgrade to two accelerators configuration possible
- RF power soure in Solid State technology
- Number of SRF cryomodules increased from 4 to 5 to reduce the required accelerating field strength
- Different beam on target footprint possible

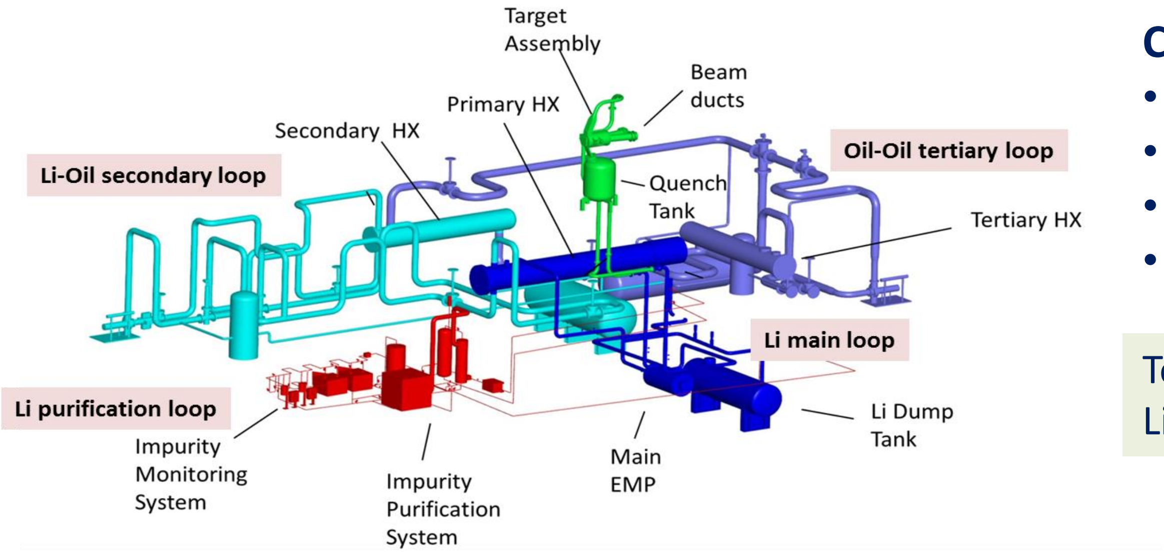
Ongoing work:

- Beam losses and energy dissipation on beamline elements





Lithium Systems and Lithium Target



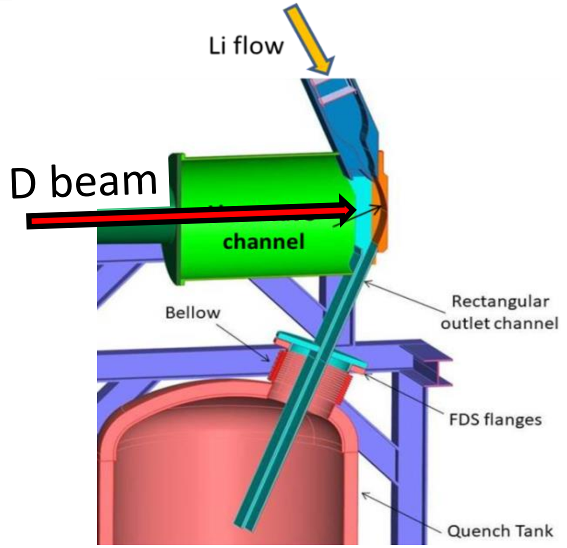
Components:

- Lithium Target assembly
- Quench Tank
- Heat removal system (two loops)
- Impurity control and purification

Total volume of Li in the loop ca. 8 m^3
Lithium flow rate ca. 100 l/s

Main parameters:

Li jet thickness:	25±1 mm
Flow velocity:	15 m/s
Li temperature (inlet):	250 °C
Vacuum pressure:	10^{-3} Pa

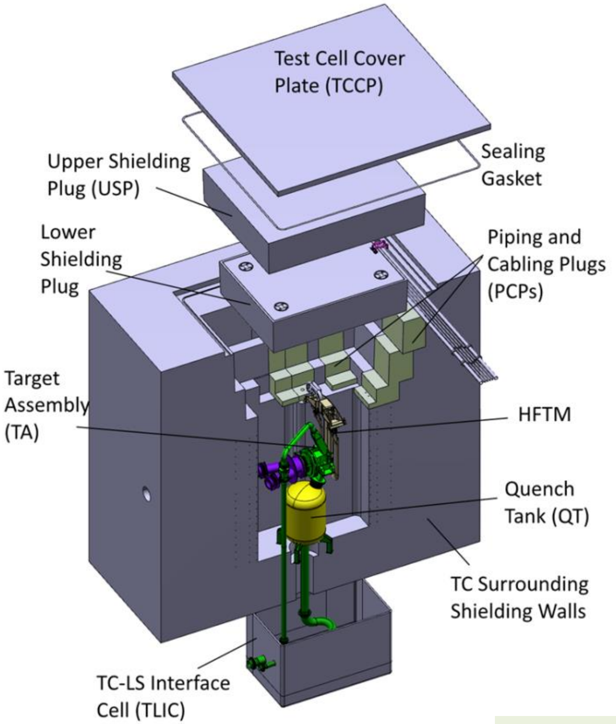


Lifetime of the **Target Assembly** is a critical parameter for the operation mode of the whole DONES facility:

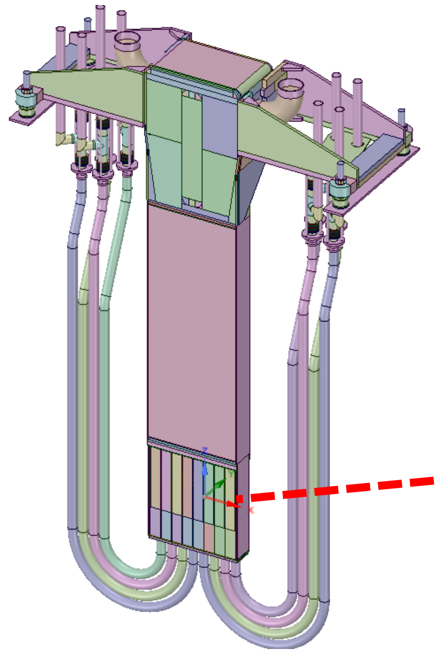
- TA will be exchanged after 10-12 months
- HFTM module will be exchanged at the same time
- Irradiated samples will be removed and investigated

Test Systems and High Flux Test Module

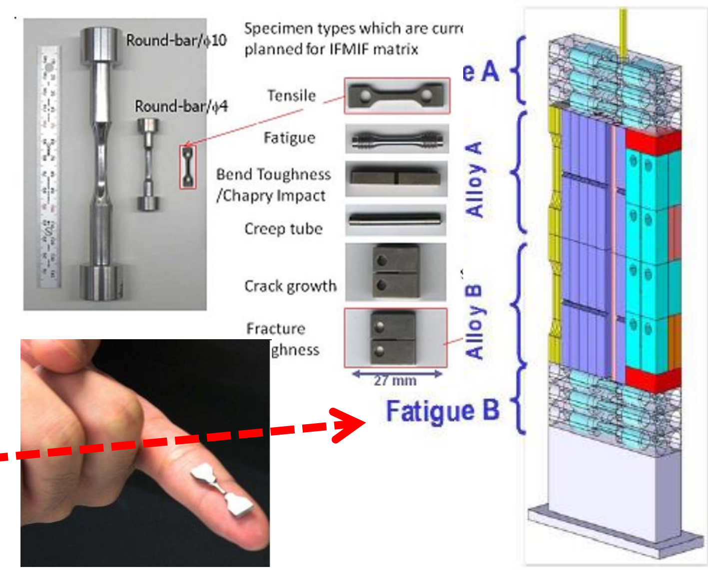
Test Cell
containing the Target and HFTM



High Flux Test Module



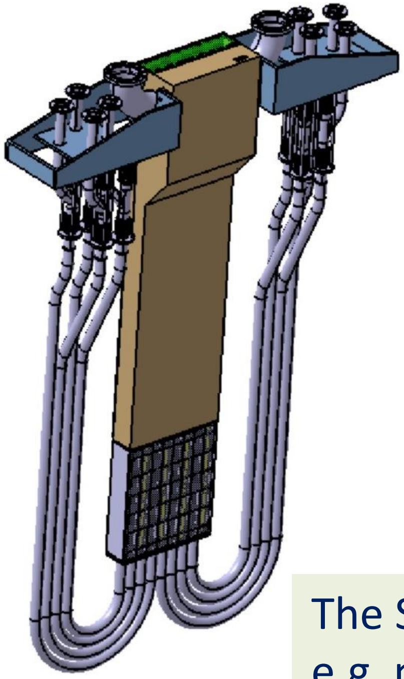
Small Sample Testing Technology (SSTT)



F. Arbeiter et al., Nuclear Materials and Energy (2016)

- The walls of the Test Cell will be cooled using water
- The HFTM will be cooled using Helium
- Individual HFTM capsules with cooling and heaters to allow stable and controlled temperature in the range of 250 – 550 °C

Start-up and Monitoring Module

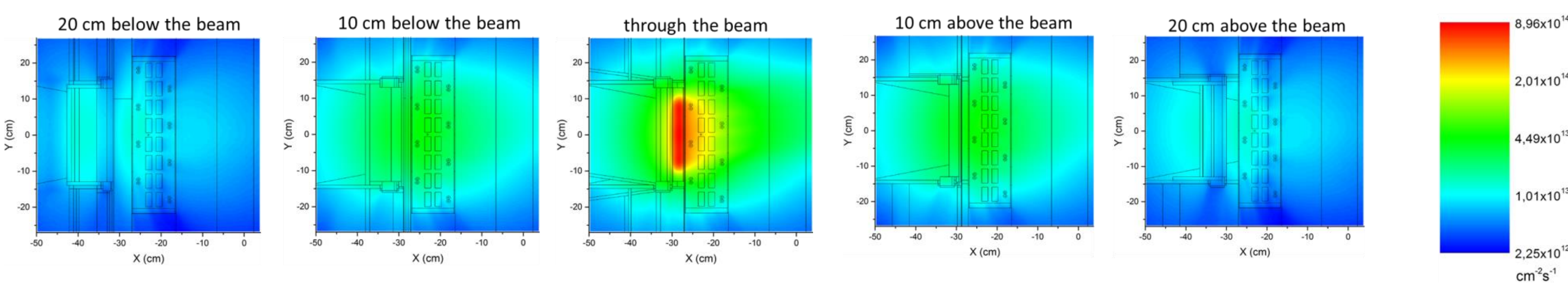


The STUMM module will be used to:

- Characterize the neutron flux at the irradiation position (measure its position, intensity, energy spectrum)
- Verify and validate neutronics modelling
- Measure the gamma radiation field
- Characterization of the gamma radiation field

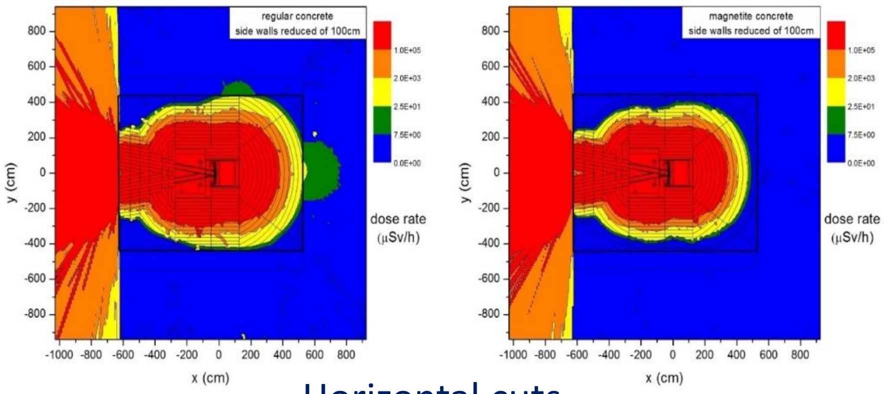
It will be used during beam commissioning and each time after a change in the configuration is made

The STUMM module will contain an array of neutron and gamma sensors, e.g. micro-fission chambers, a rabbit system, gamma thermometers, SPND detectors. **This module is designed in Poland by IFJ PAN and NCBJ**

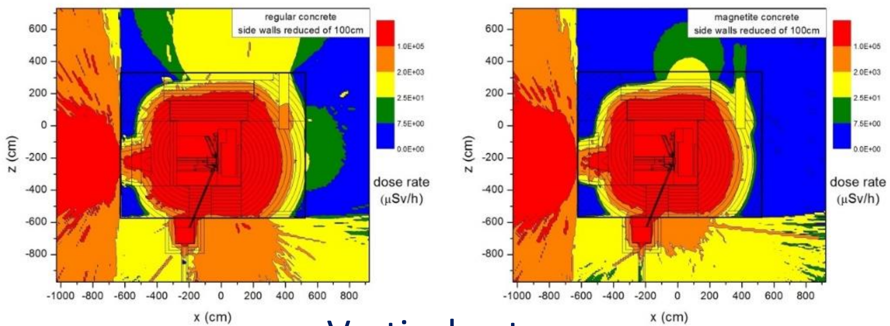


Neutronics modelling

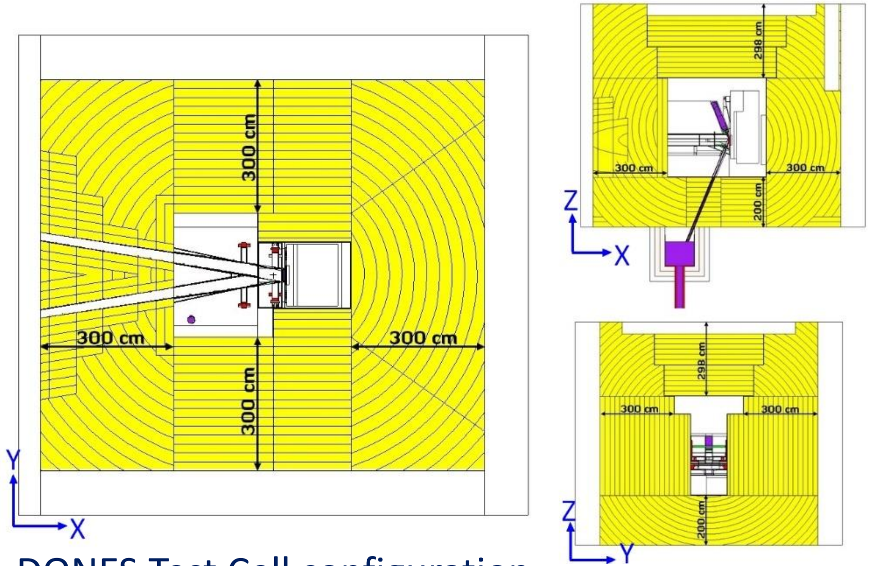
Modelling of the radiation field (neutron and gamma) in the **Test Cell** and in other rooms of the building for different configurations:
wall thickness / normal or high density concrete / during irradiation and beam-off periods



Horizontal cuts



Vertical cuts



DONES Test Cell configuration

MCNP radiation transport code running on large scale computing clusters

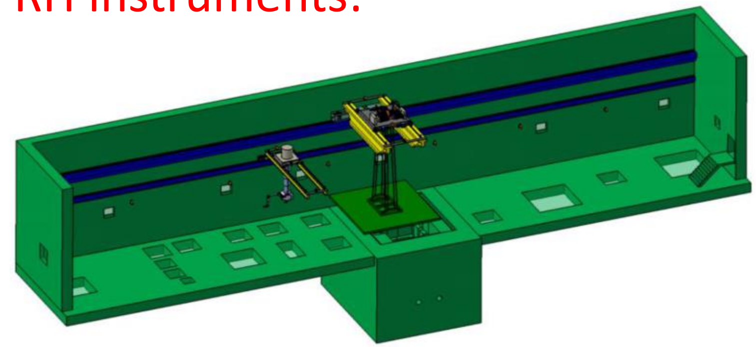
Remote Handling

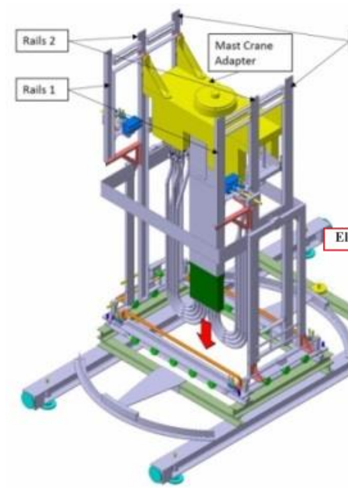
Most of the operations involving elements removed from the Test Cell will require **Remote Handling**

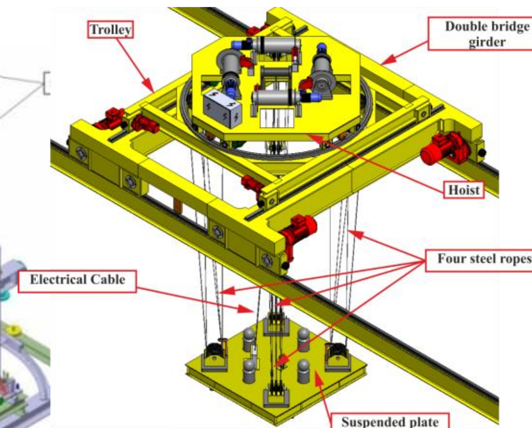
- Opening and closing of the Test Cell – removal and transport of the concrete blocks
- Exchanging of the Lithium Target Assembly
- Positioning and removal of the High Flux Test Module
- Installation and removal of the STUMM
- Retrieval of capsules containing irradiated samples from the HFTM
- Some maintenance activities

For all these operations procedures are being established and proper tools and equipment (cranes, manipulators) are being designed,

Access Cell and its RH instruments:







Jonathan Horne et al., CCFE
„Maintenance Logistics Simulation in VR for DONES Access Cell"

Complementary Experiments at DONES

An international advisory committee called by the Polish ELAMAT Consortium issued
„White Book on Complementary Scientific Program at IFMIF DONES"
IFJ PAN Report No. 2094/PL, 2016

Applications of medical interest
- Radiopharmaceuticals for therapy (e.g. ^{99}Tc)
- Accelerator-based boron-neutron-capture therapy (BNCT)
- ...

Basic physics studies
- Half-life measurements on long-lived isotopes
- Neutron and neutrino oscillations
- Solid state physics studies

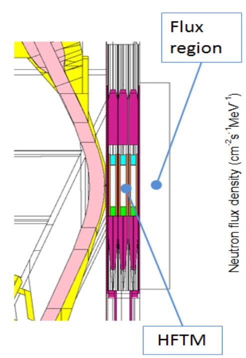
Their feasibility is to be evaluated

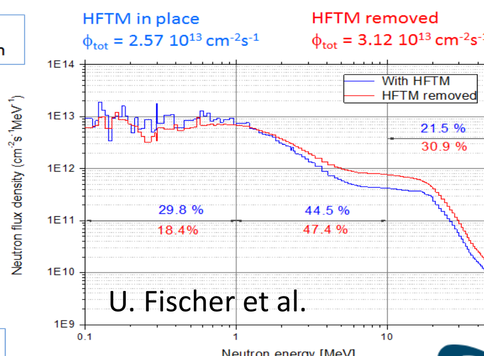
Nuclear physics and radioactive ion beam facility
- Nuclear Structure & Astrophysics
- Mechanism of nuclear fission
- Cross-section measurements for applied physics (n,γ), (n,xn), (n,lcp)
- ...

Industrial application of neutrons
- Mechanical properties of irradiated materials from small samples
- Computed tomography imaging using fast neutrons
- Transmutation doping of silicon and radiation-damage testing of electronics

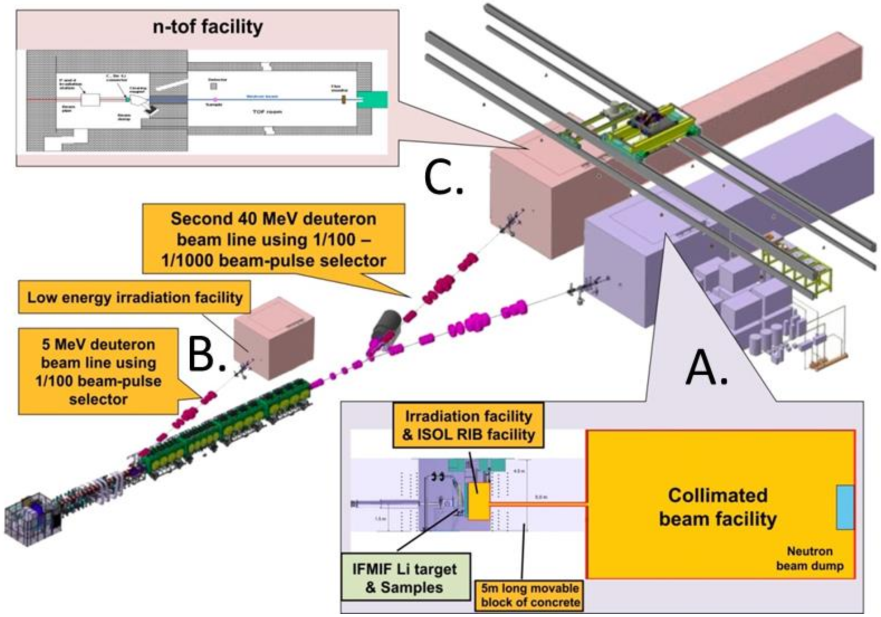
Main mission of **DONES:** fusion materials irradition
Complementary experiment taking advantage of:

- Existing **neutron flux** behind the HFTM module
- A small fraction of **deuteron** beam





Complementary Experiments at DONES



C. Experiments using a fraction of D beam at 40 MeV, **n-tof facility**

B. Experiments using a fraction of D beam at 5 MeV: **Low-energy irradiation facility**

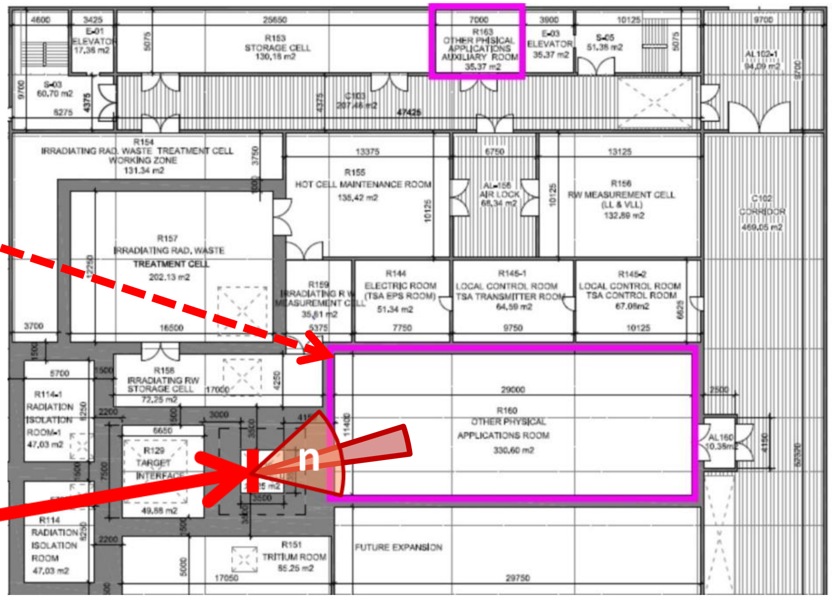
A. Complementary Experiments hall behind the HFTM module, or an ISOL RIB facility **Collimated neutron beam facility**

Complementary Experiments Hall

Room R160 29.00 m x 11.40 m, height 8.00 m, 330.60 m^2

Auxilliary Room R163

7.00 m x 5.07 m, 35.37 m^2



DONES site near Granada, Spain

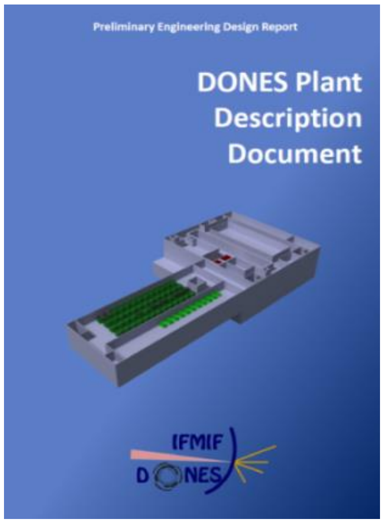
In 2017 an expert panel called by the Governing Board of **Fusion for Energy** has reviewed two site proposals submitted by Croatia and Spain

In the end of the proces a joint offer of Spain and Croatia was recommended for implementation with a primary site for DONES in Spain, near Granada

Escuzar site, ca. 10 ha

IFMIF-DONES summary and outlook

- Preliminary Engineering Design available, updated each year
- Design reviews of selected systems already started
- Preparation of specifications for tenders for items in the critical path staring from 2019



DONES Preparatory Phase (2019-2020)

- Licensing, site preparation
- Drafting of legal framework
- Complementary experiments

Construction of DONES in Spain, targeted to start in 2021

EUROfusion

FUSION FOR ENERGY

Early Neutron Source (2015-2020) work package team:

A. Ibarra, F. Arbeiter, D. Bernardi, M. Cappelli, U. Fischer, A. Garcia, R. Heidinger, W. Królas, F. Martin-Fuertes, G. Micciche, A. Muñoz, F.S. Nitti, M. Perez, T. Pinna, K. Tian (CIEMAT, ENEA, KIT, IFJ PAN)

Thank you for your attention!

Spare slides