A neutron source for fusion: The DONES Project

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The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Outline

- Introduction and some history
- The IFMIF-DONES Project
- Complementary experiments area
- IFMIF-DONES and HiRadMat
- Summary

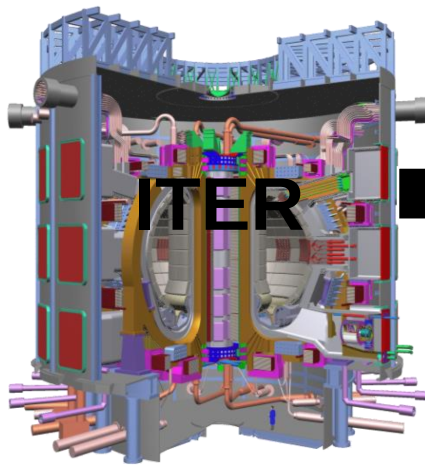
Fusion: *A Tale of Two Cities*

<u>Two Challenges</u>:

1. **Plasma** Control & Improvement: Stability, density , temperature…
2. **Radiation** and thermal load on Structural and Functional **materials**: metals embrittlement, insulator failure, first wall damage…

<u>Mainly Plasma studies</u>

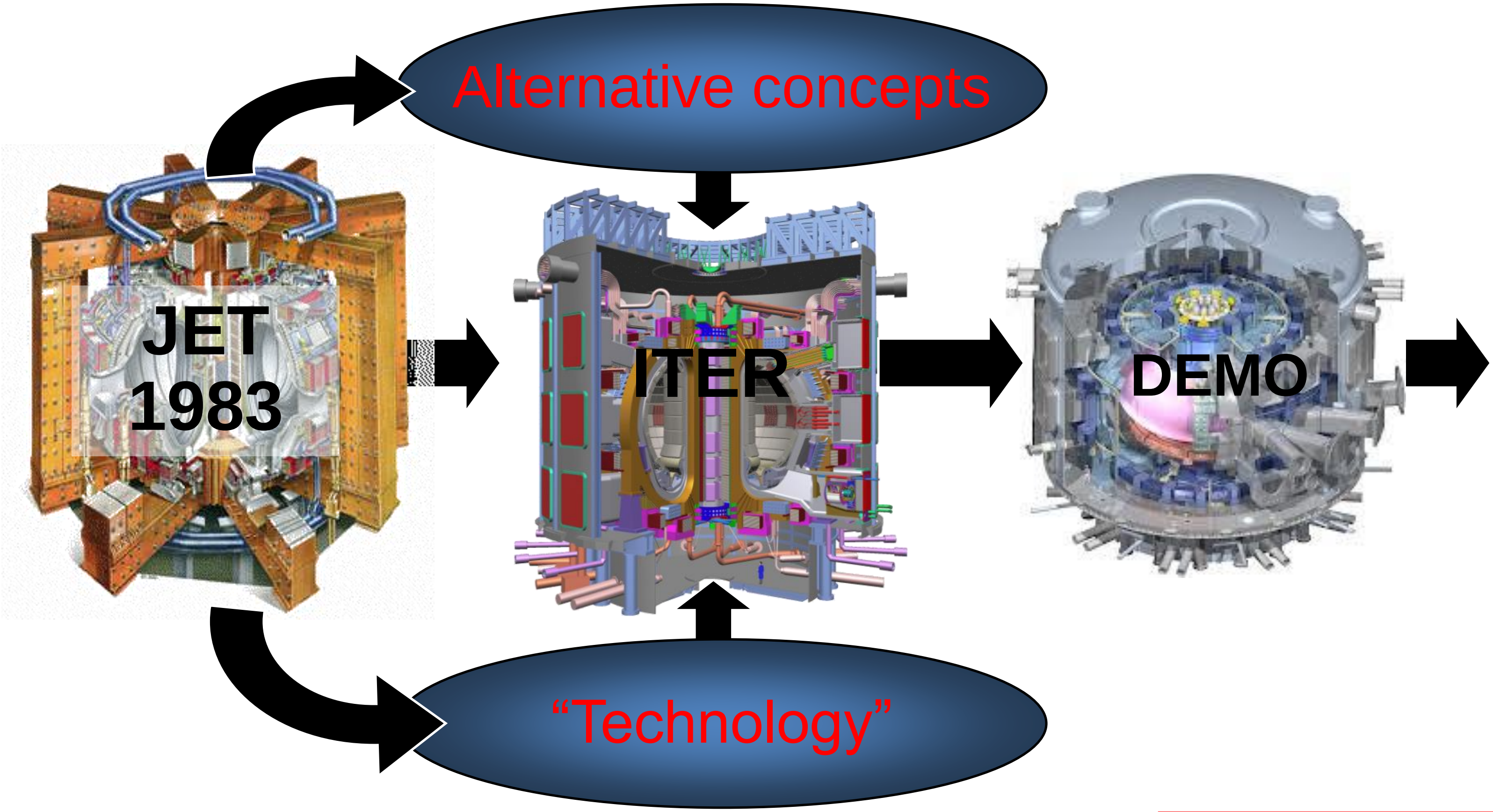
<u>Increasing role of Radiation Damage</u>



The power plant

<u>Increasing neutron production</u>

The EU strategy towards fusion energy



The power plant

<u>ITER</u>: scientific and technological feasibility of fusion energy

<u>DEMO</u>: Qualification of components and processes

<u>Reactor:</u> High availability, safe and environmental-friendly, economically acceptable

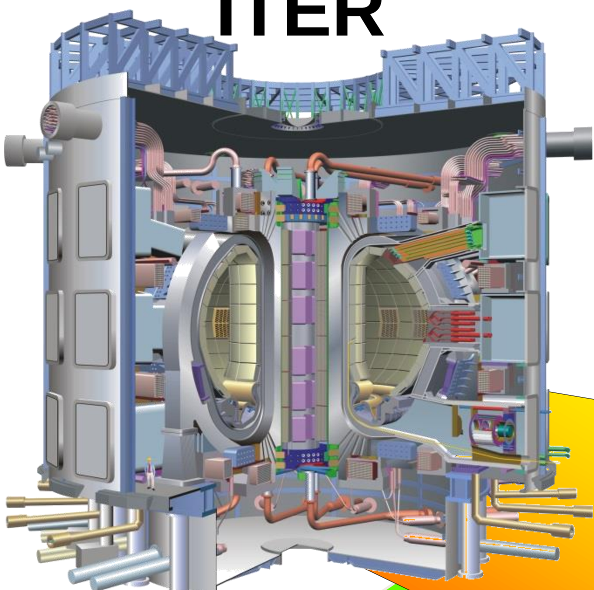
After ITER

DEMO

20- 30 dpa

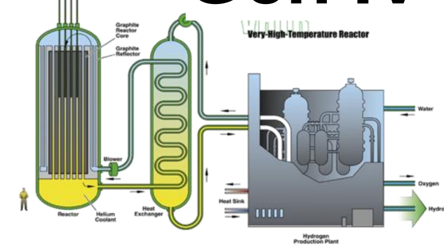
One of the main differences between ITER and DEMO is the radiation dose: at DEMO more that one order of magnitude higher

ITER



3 dpa/lifetime

Gen IV



~25 dpa/year

Radiation damage: Primary effects

Transmutation

- Nuclear reactions, → Giving rise to new impurities (main ones are H and **He**, but others can also be relevant)
- Activation of the materials →This is the main reason for the development of low-activation materials.
- A function of the neutron energy, fluence and the target ion.

- **Point defects (holes and interstitials)**

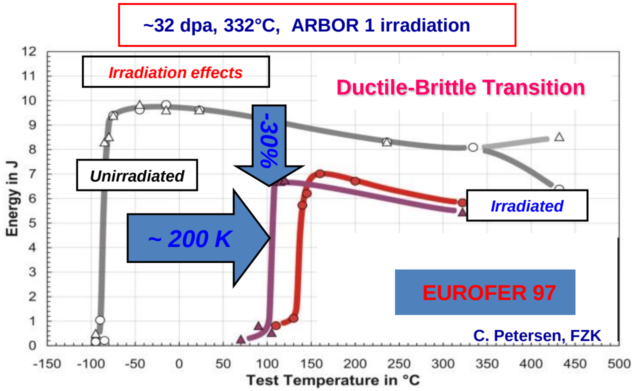
- It is a complex function of the incident particle, its energy, the materials characteristics and temperature
- After their creation, they can move giving rise to **extended defects** (dislocations, bubbles, loops, precipitates,…)
- If dose/dose rate is high enough, it can be produced **severe functional and structural changes** in the material (amorphization, new cristalline phases, new compounds,…)

Radiation damage: Macroscopic effects

Dose, dose rate and the shape of the energy spectra of the incident particle, have important consequences in the materials properties.

Main changes in mechanical properties of interest for irradiated components design:

- Increased hardening
- Decreased ductility
- Decreased heat conduction
- Swelling
- Embrittlement
- Blistering
- …

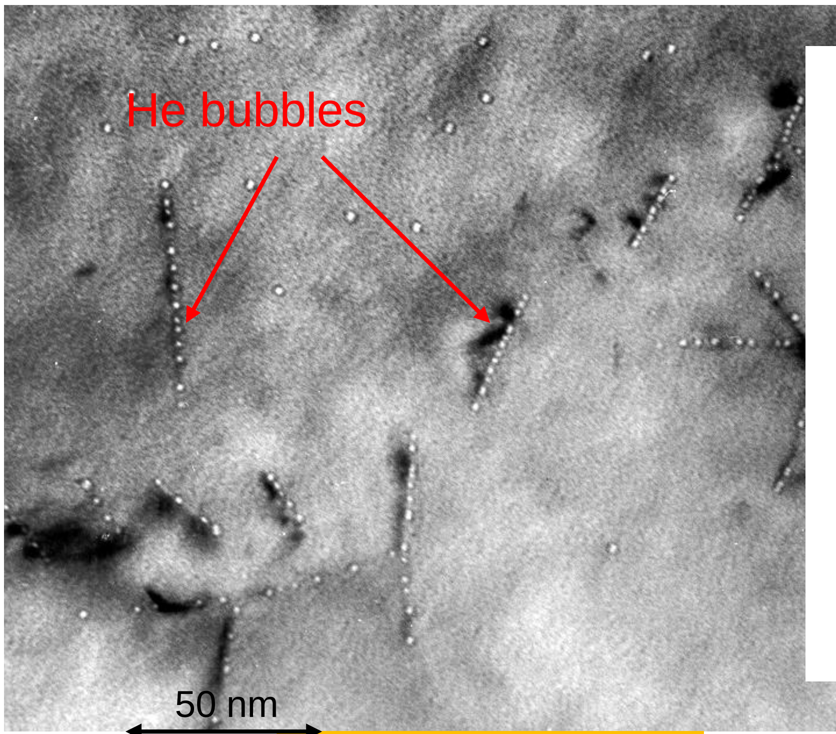


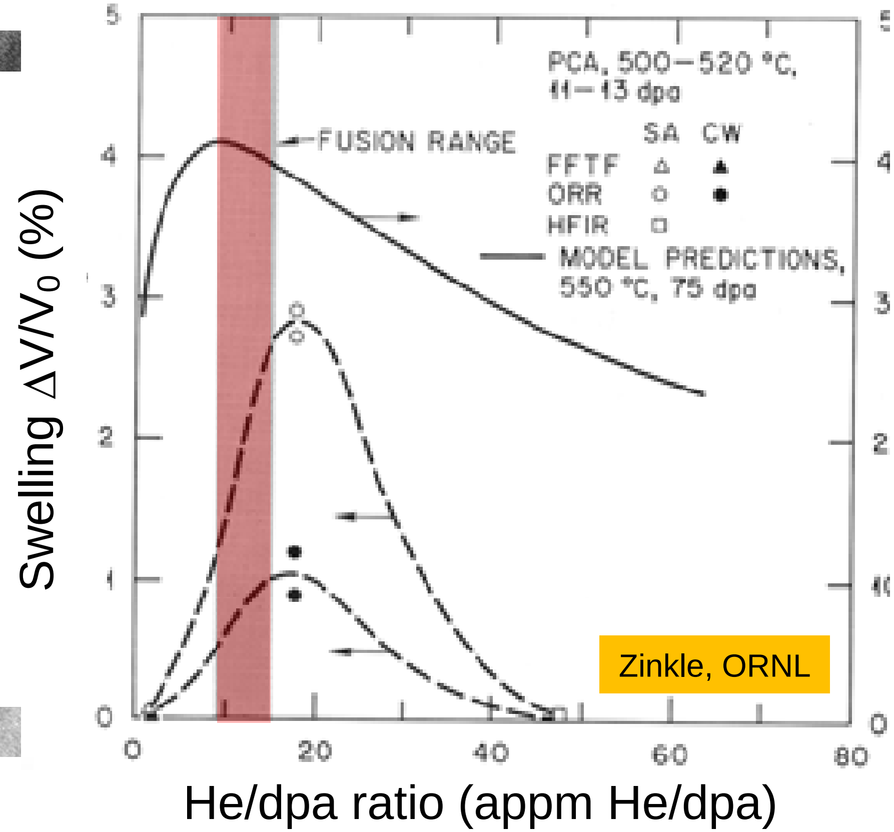
Consequences to be taken into account in the **design** of irradiated components:

- Changes in the mechanical properties of structural materials
- Changes in physical properties (corrosion, diffusion, conductivity, optical transmission,…)
- Welding, joints,… must be evaluated
- Systems behaviour under radiation (radiation enhanced phenomena)
- Remote Handling
- …

- So, what's the Helium problem in Fusion?

Why is the He/dpa ratio important for fusion materials?

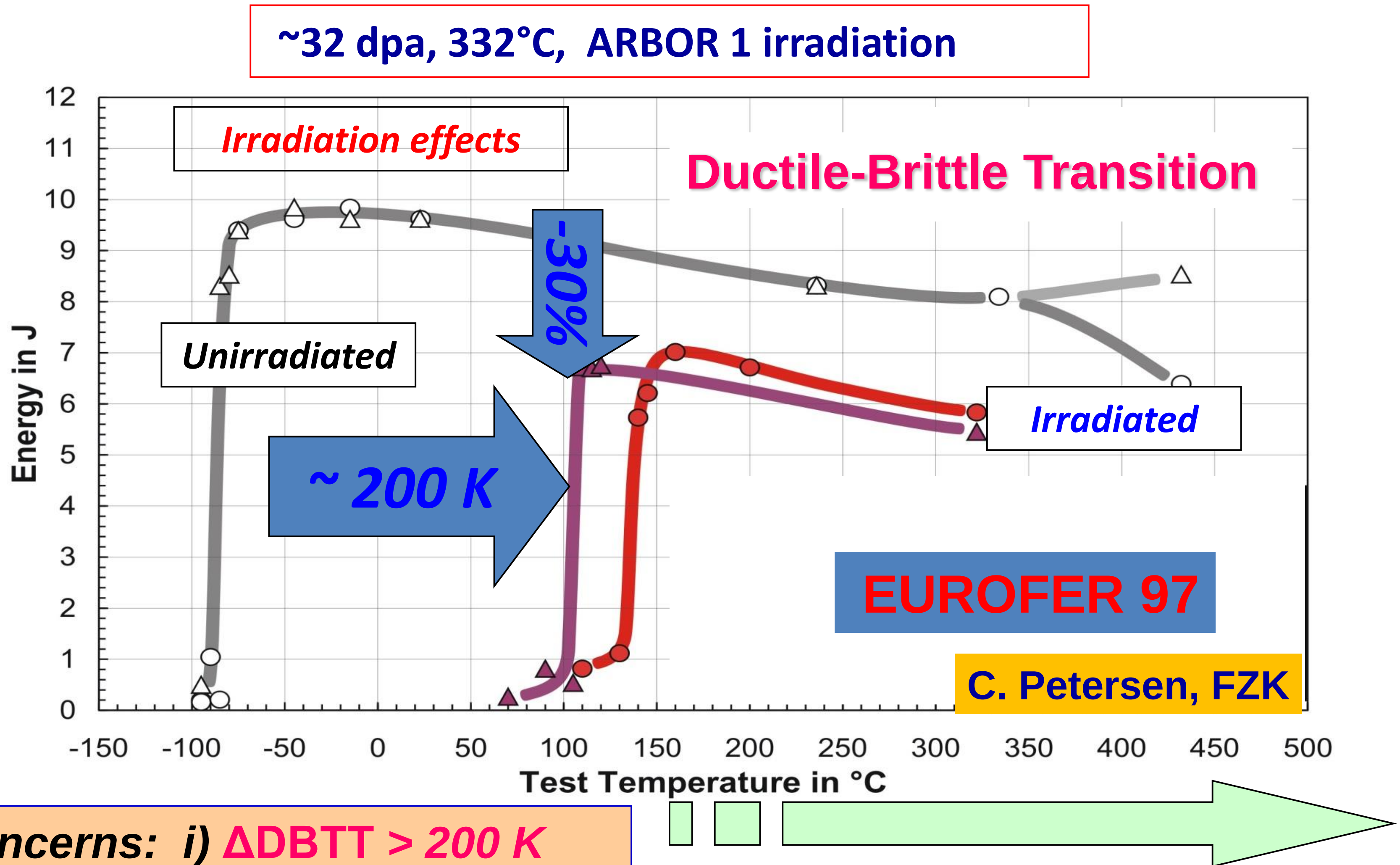




He bubbles

- can cause severe grain boundary embrittlement at high temp. (fcc alloys)
- can severely enhance fracture toughness degradation at low temp. (bcc alloys)

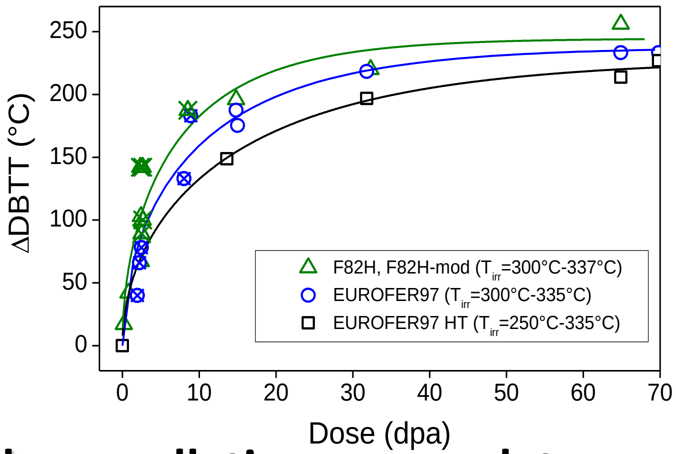
Impact properties degradation

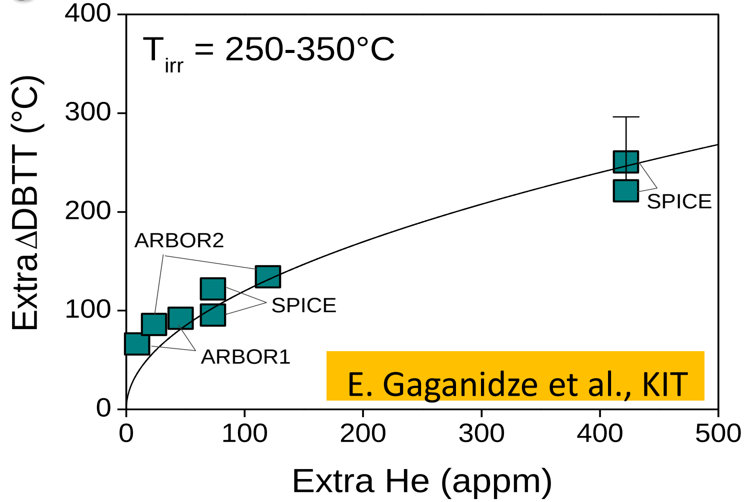


Concerns: i) ΔDBTT > 200 K
ii) Effect of Helium?

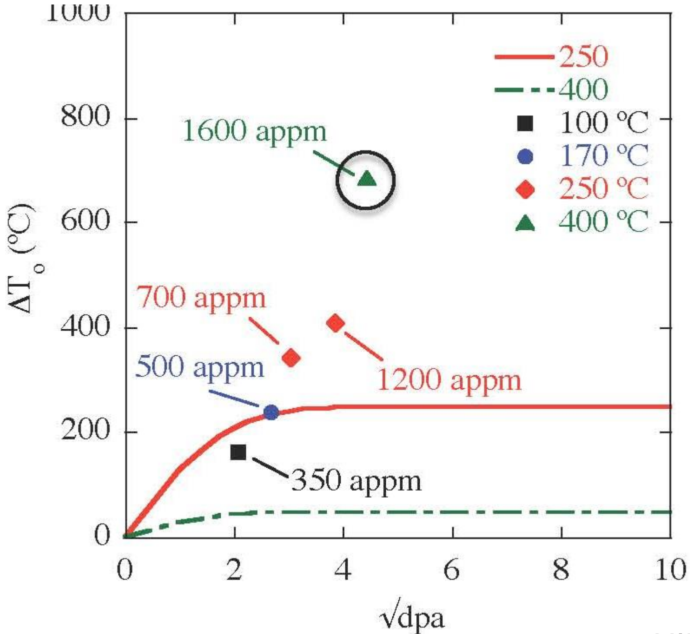
"Helium" effect on DBTT

based on fission irradiation after B-doping

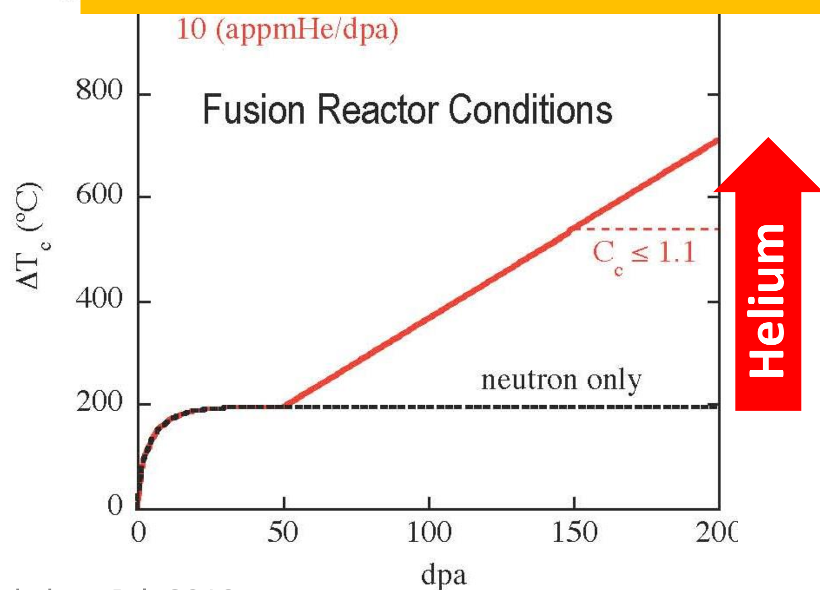




based on spallation source data



Kurtz, Odette, Yamamoto, Dai; SOFT-26, Porto 2010



"Helium" effect on DBTT

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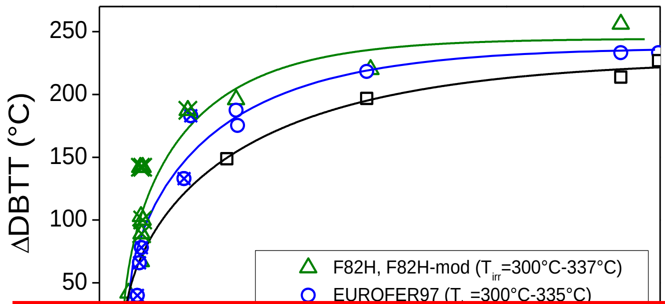
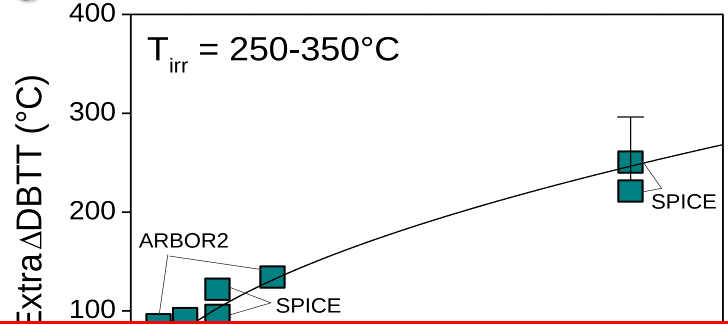
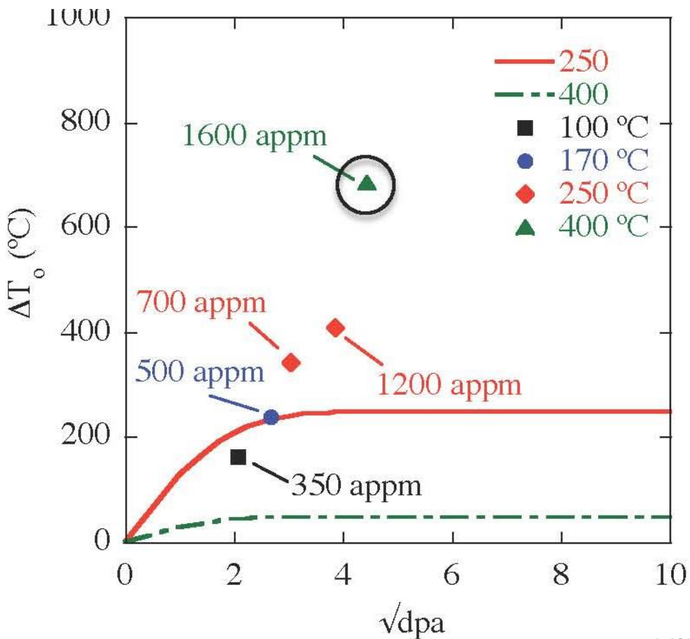


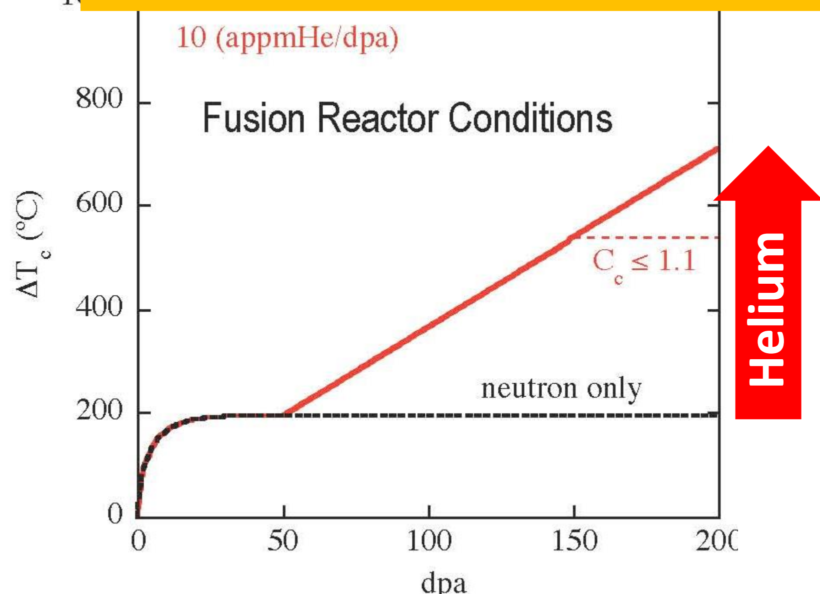


Amount of He and He/dpa ratio are crucial
So, a fusion-like neutron source is urgently needed!!!

based

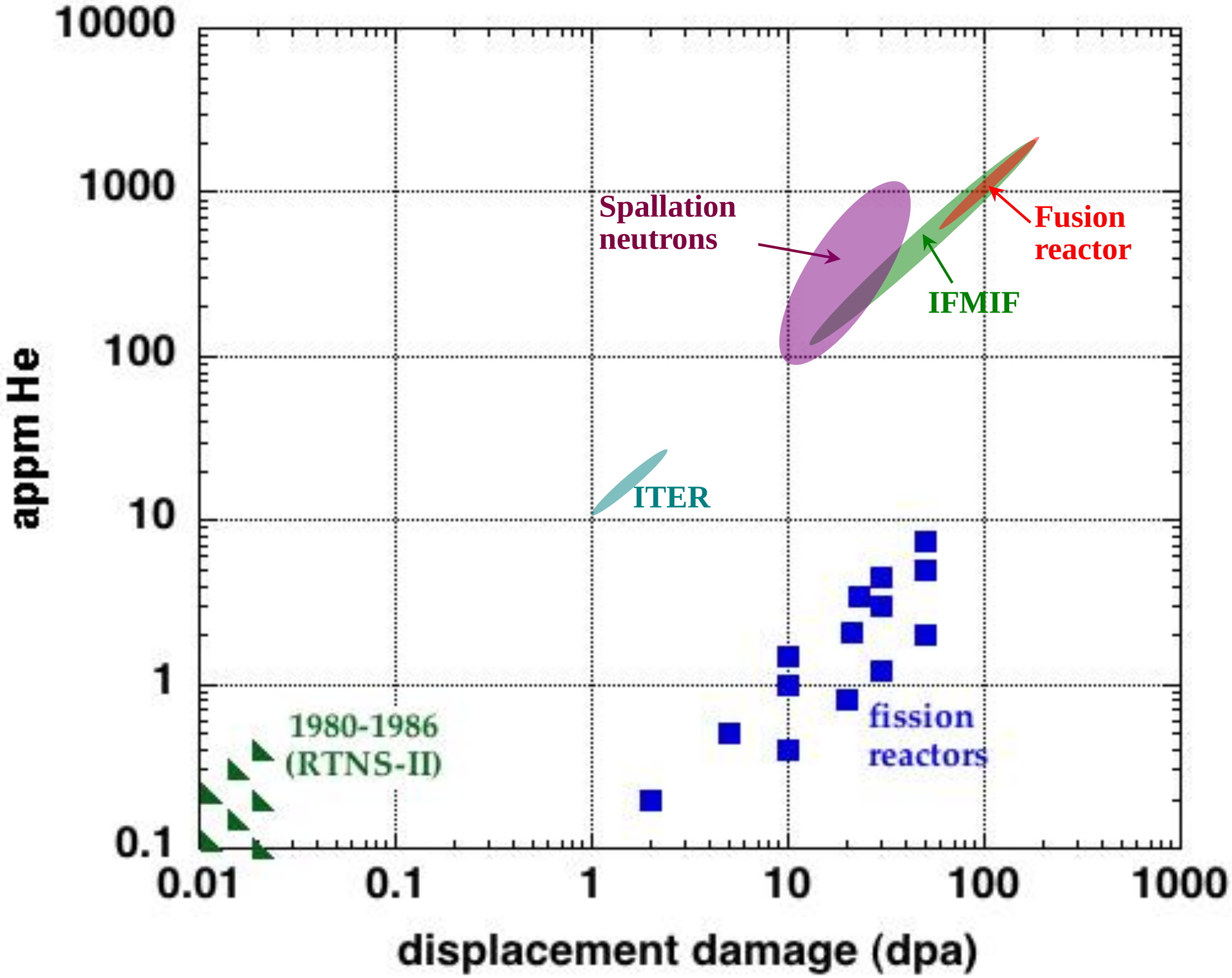
Kurtz, Odette, Yamamoto, Dai; SOFT-26, Porto 2010





Comparison criteria: He/dpa

Different sources



Neutron source requirements

A fusion-like neutron source is needed for fusion materials qualification both for DEMO and the power plant development.

The requirements are to produce **fusion-like neutrons**

- Intensity large enough to allow accelerated (as compared to DEMO) testing,
- Damage level above the expected operational lifetime,
- irradiation volume large enough to allow 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

Outline

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IFMIF/EVEDA activities

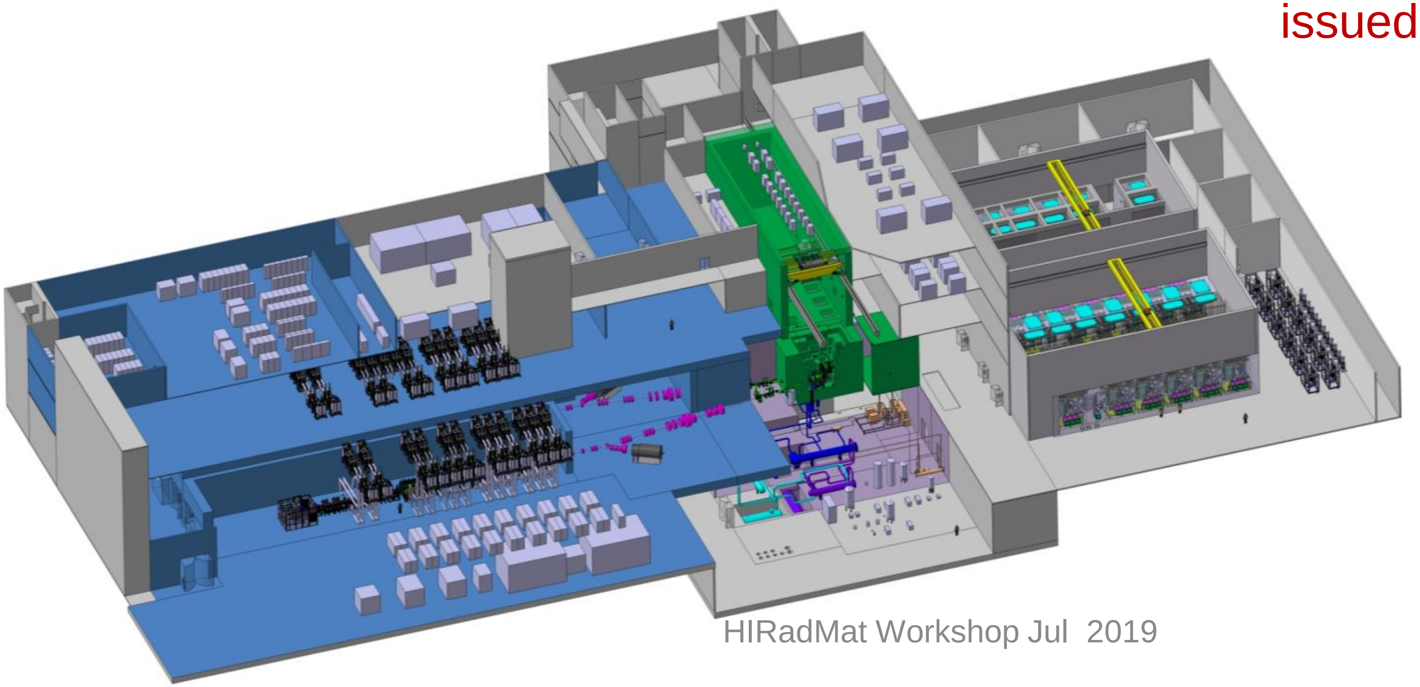
- Long history towards a Li(d,xn) facility: FMIT, ESNIT, IFMIF
- Since 2007, **IFMIF/EVEDA project included in the EU-JA Broader Approach Agreement**

The Engineering Validation Activities (EVA)

=> Experimental support to the IIEDR mostly finished 2015 (prototype accelerator installation and commissioning till 2019)

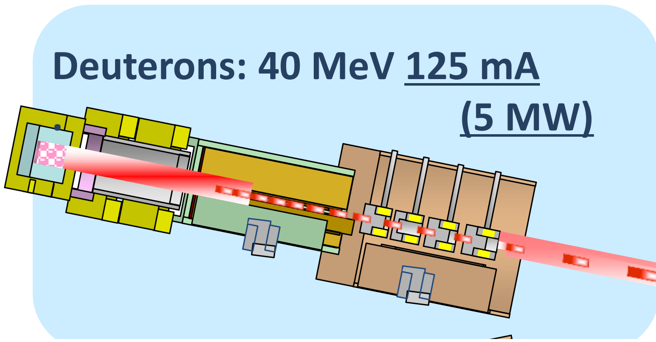
The Engineering Design Activities (EDA)

=> Intermediate IFMIF Engineering Design Report (IIEDR) issued in June 2013

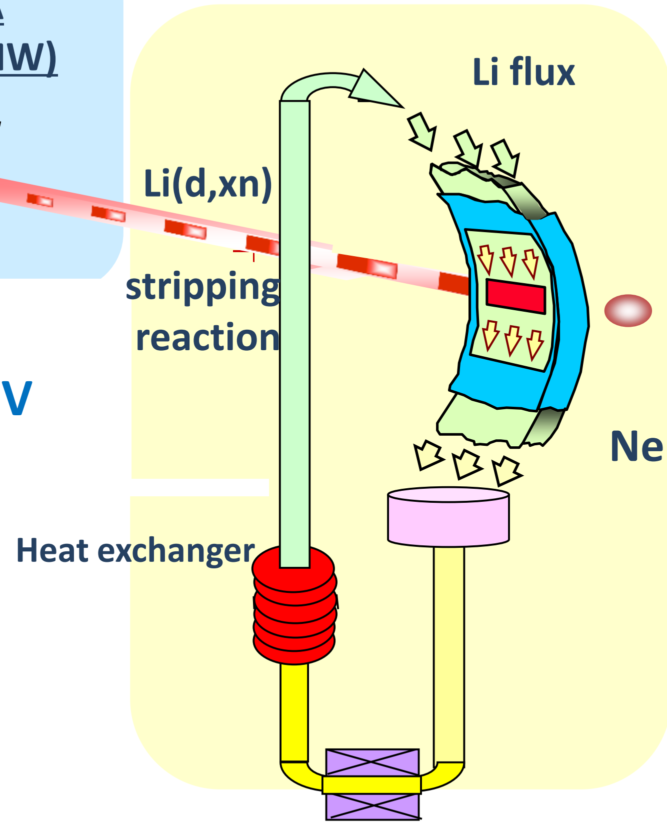


DONES Main Systems

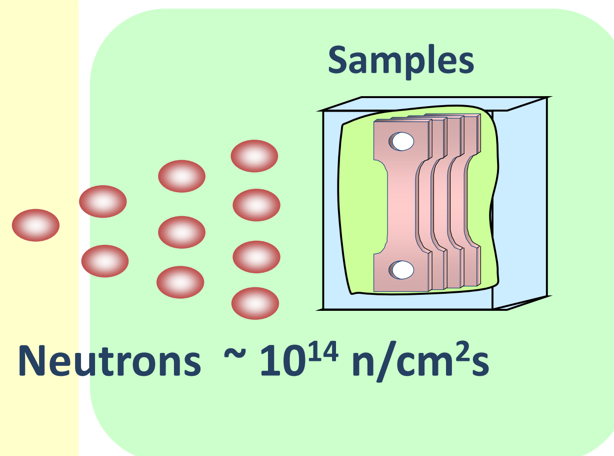
Accelerator



Lithium Loop (Target)



Test (Irradiation) Module



Deuterons at 40 MeV collide on a liquid Li screen flowing at 15 m/s

High Flux Test Module:

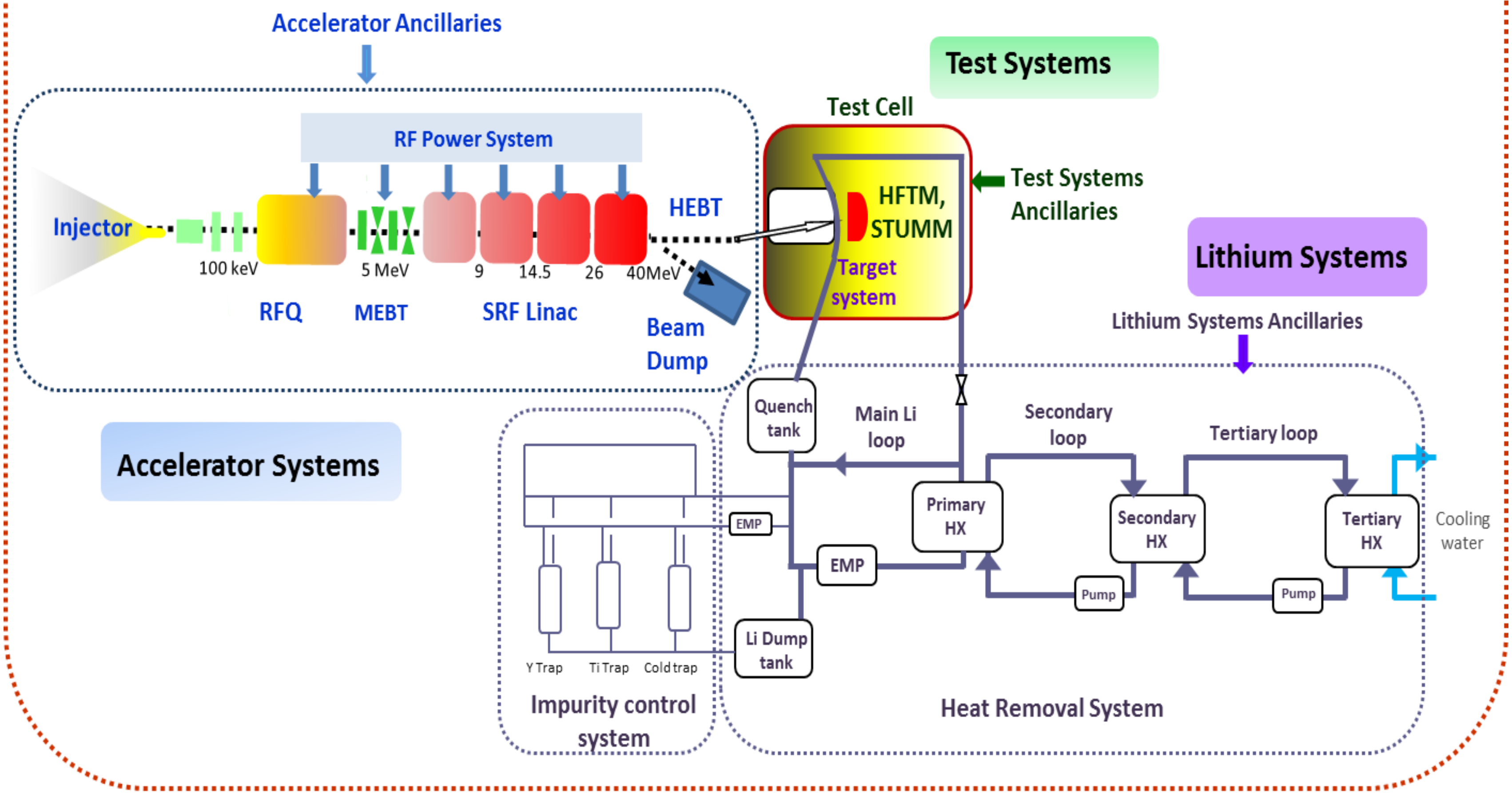
20-50 dpa/y at 100 cm^3

Controlled temperature:
250 < T < 1000 °C

A neutron flux of ~ 10^{14} cm^{-2}s^{-1} is generated with neutron spectrum up to 50 MeV energy

DONES plant configuration

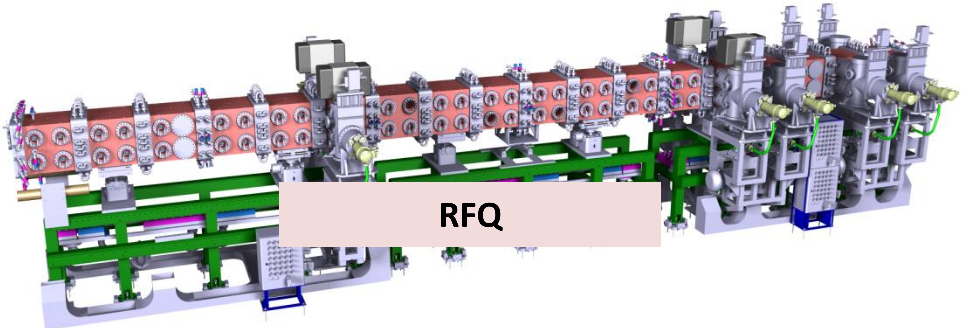
Based on the IFMIF/EVEDA one with some minor changes implemented

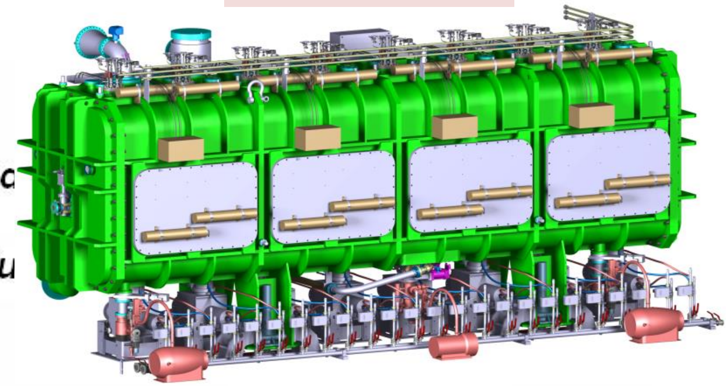


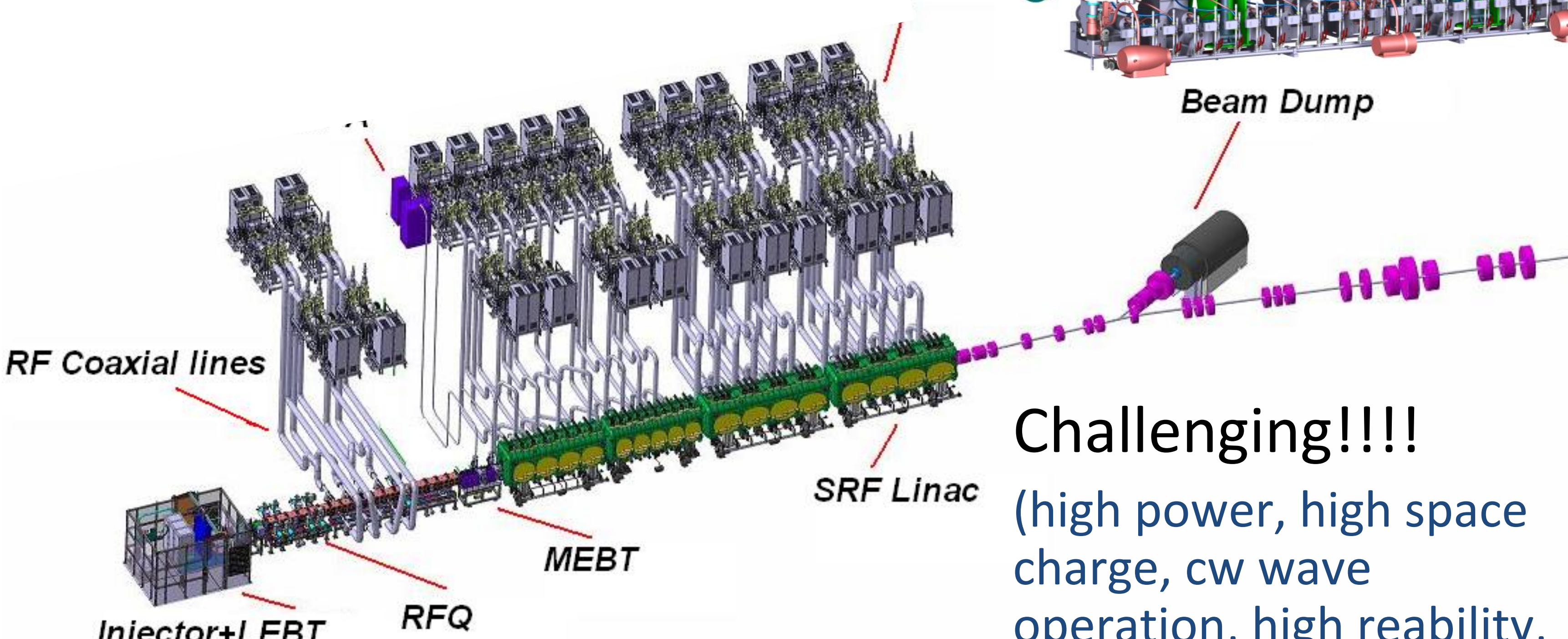
Site, Buildings & Plant Systems

- Layout & Site Infrastructures
- Buildings
- Plant Systems (I and II)
- Remote Handling
- Central Control Systems and Integrated Instrumentation

Accelerator systems summary







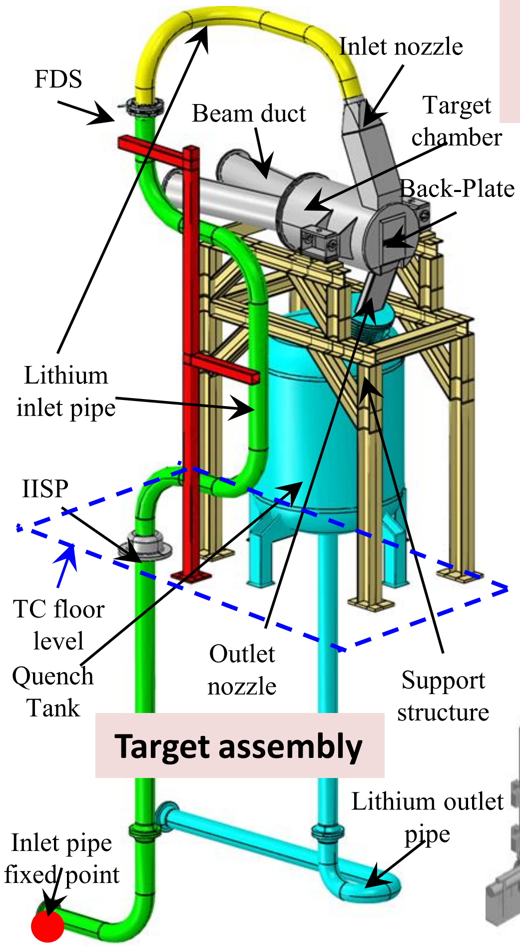
- **175 MHz, 5MW, 125 mA, CW, high availability: One of the more powerful accelerators in the world. Waiting for validation results from LIPAc (Rokkasho)**

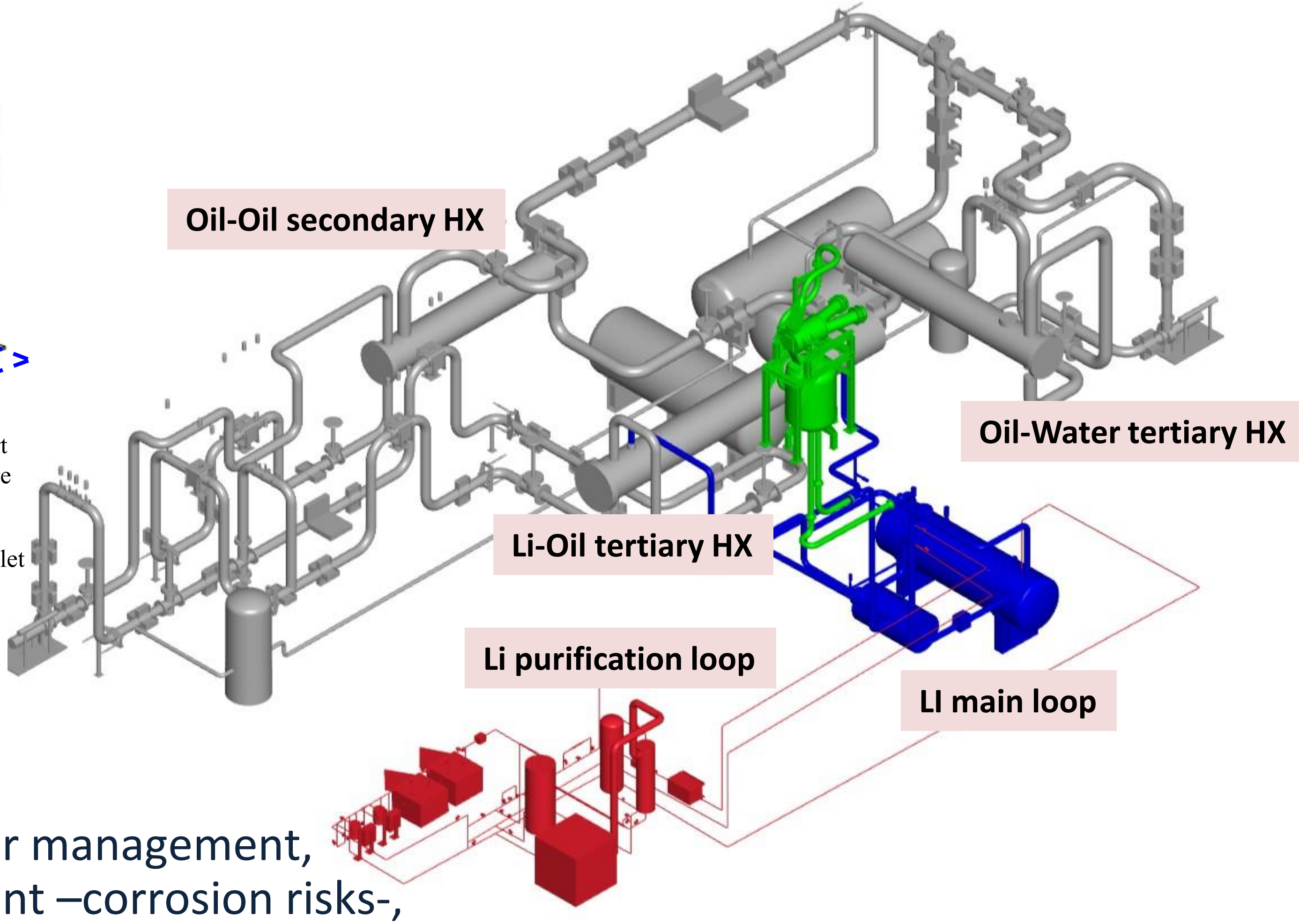
Challenging!!!!

(high power, high space charge, cw wave operation, high reability, longest RFQ,…)

Li systems summary

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



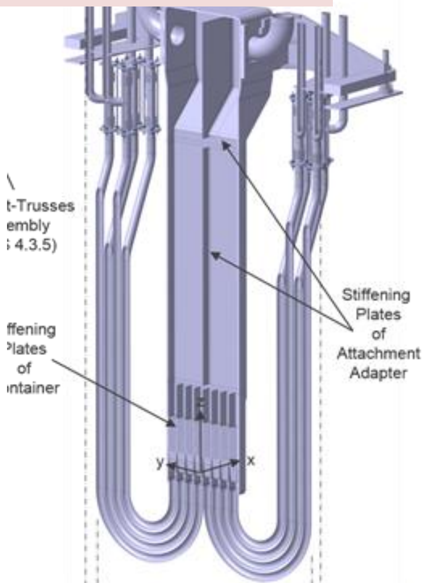


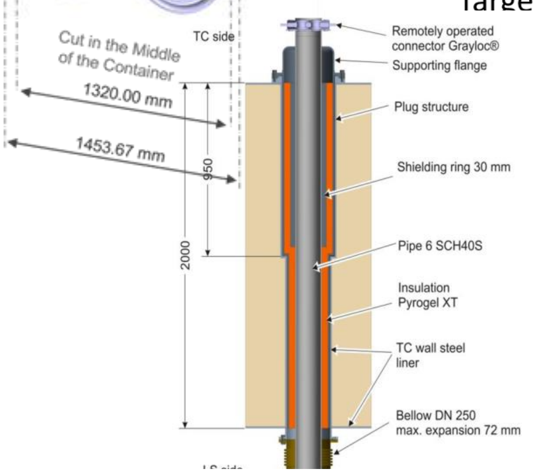
Challenging!!!!

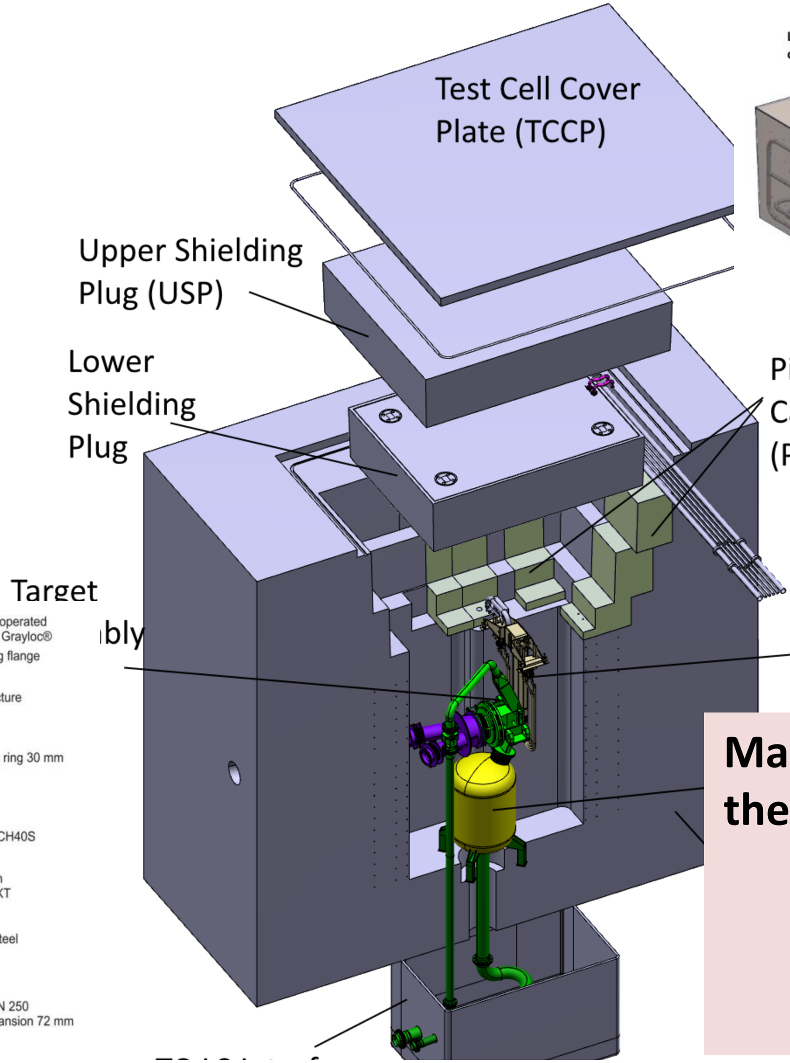
(Biggest Li loop, power management, impurities management –corrosion risks-, reliability, lifetime,...)

Test Systems summary

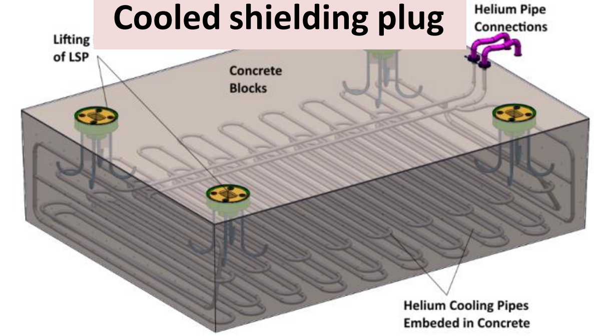
Irradiation module







Cooled shielding plug

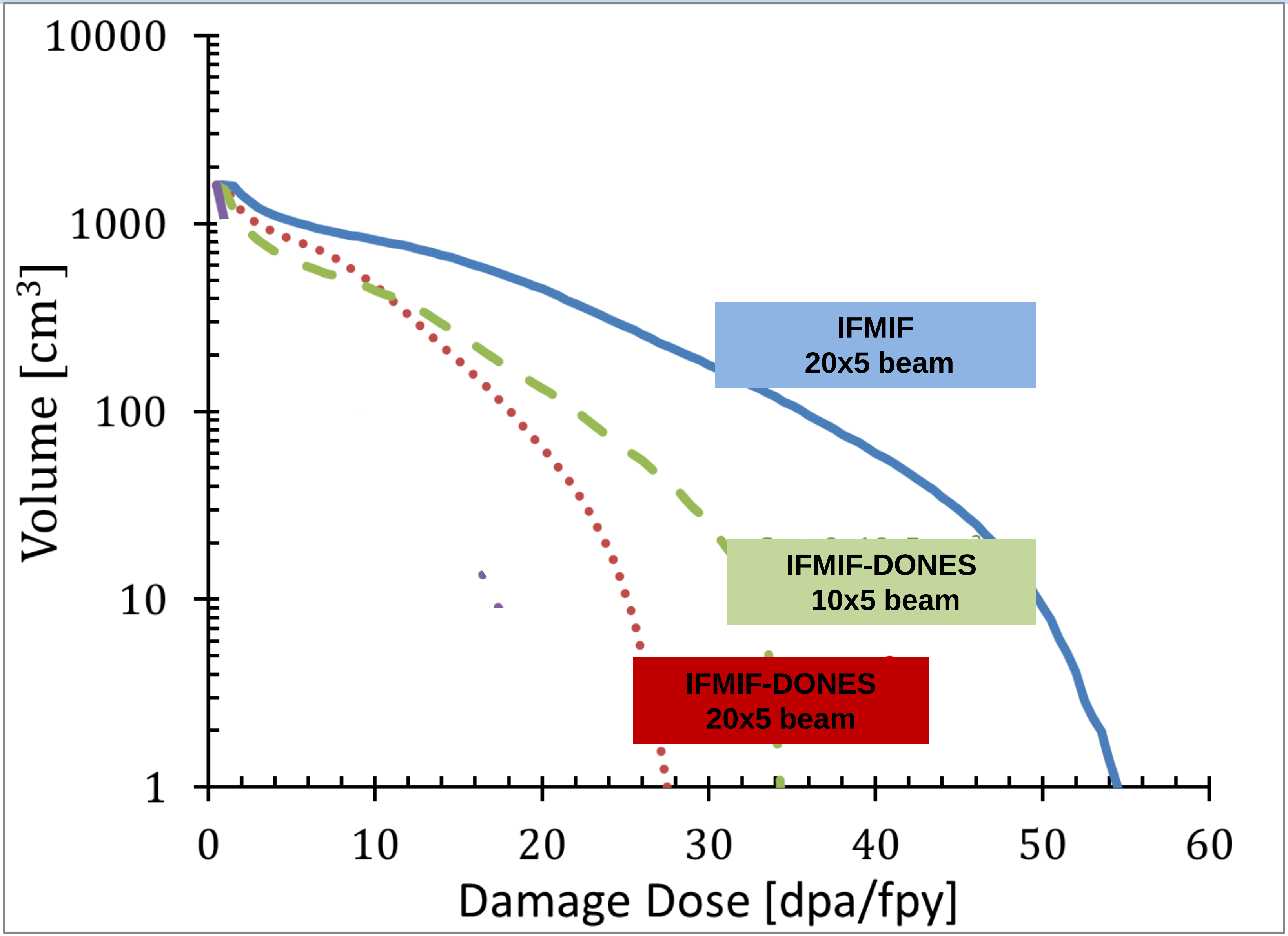


Main characteristics driven by the presence of neutrons and Li

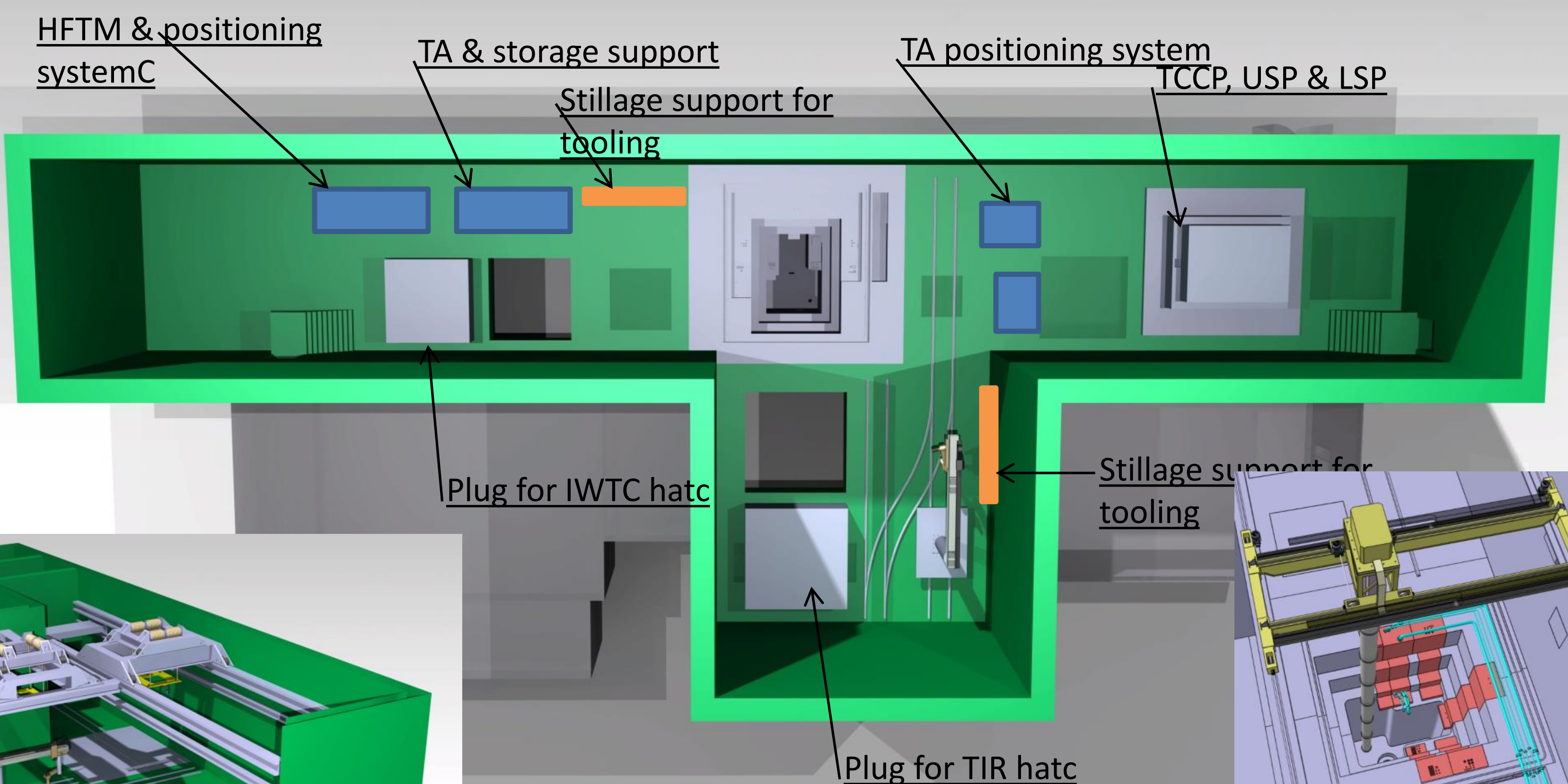
- **Internal components cooling by He**
- **Remote Maintenance required**

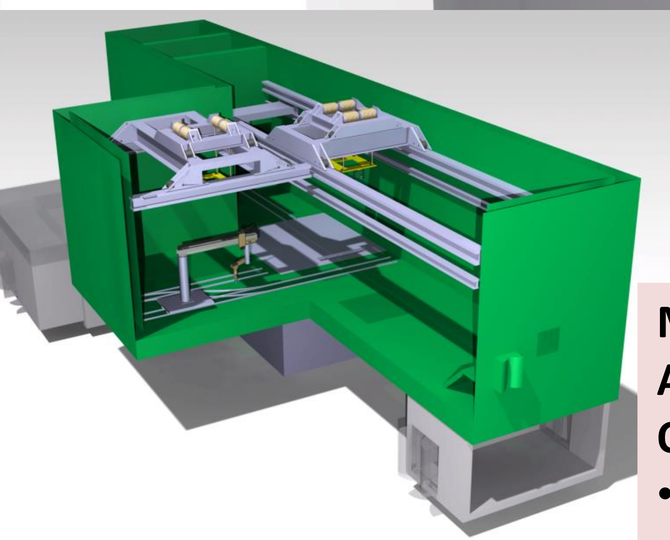
Challenging!!!!:(RH, reliability and long term control,…)

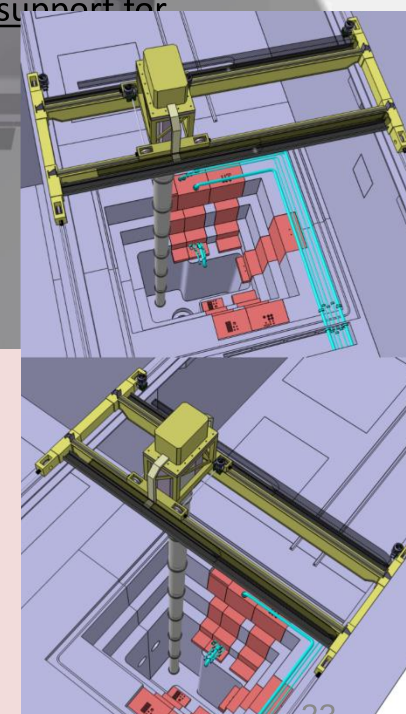
Available Irradiation Volume vs DPA



Remote Handling System







Main RH operations are made in the Access Cell

Other relevant ones (no regular ones):

- for the accelerator Beam Dump (managed by a Cask Transporter)
- Li loop area

Construction status of LIPAc

Injector under operation in Rokkasho

MEBT at Rokkasho site

Very important to validate the beam

Diagnostics Plate at Rokkasho site

RFQ presently under commissioning at Rokkasho

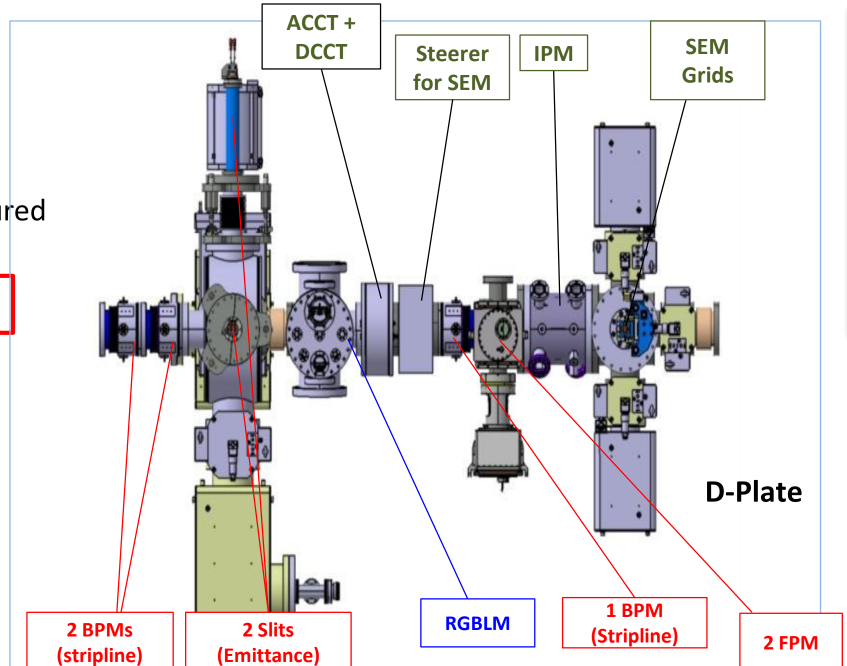
Part of the RF sytem under operation at Rokkasho

Beam instrumentation overview

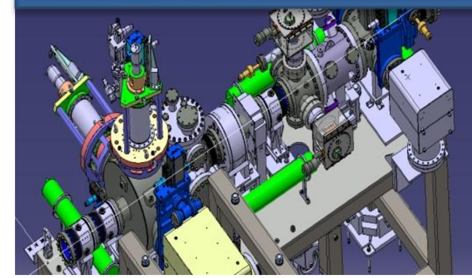
DIAGNOSTICS GLOSSARY

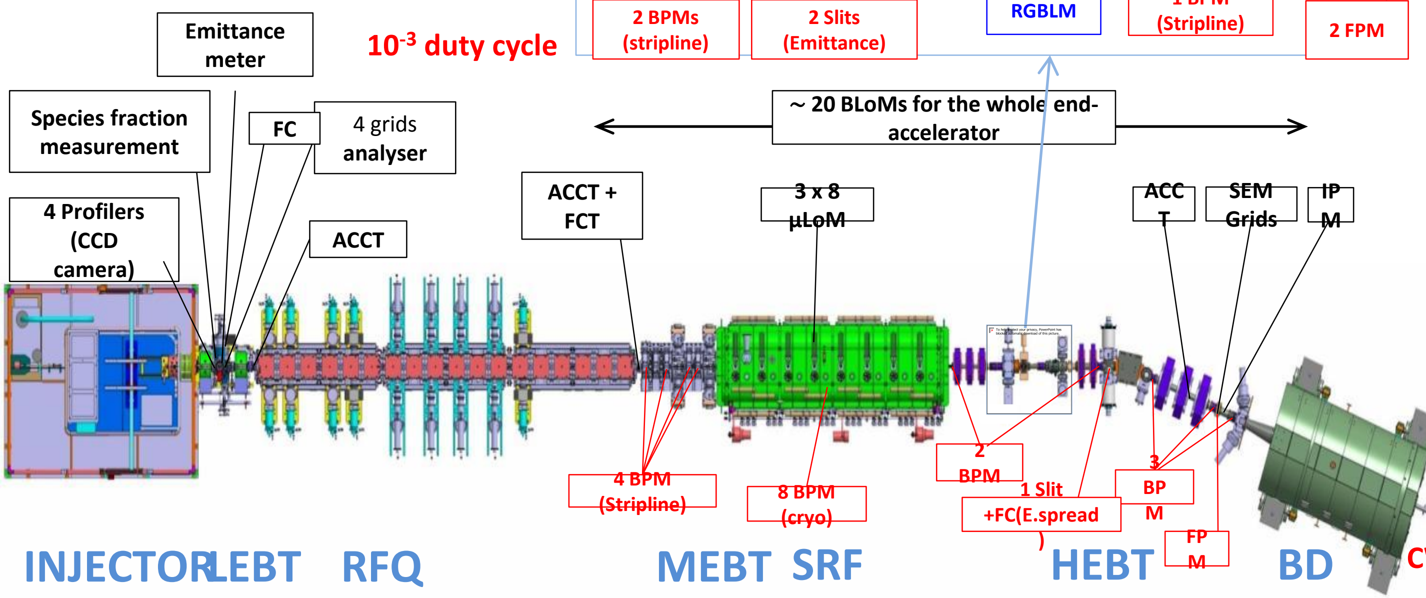
CT: Current Transformer (ACCT, DCCT, FCT)
BLoM: Beam Loss Monitor
RGBLM: Residual Gas Bunch Length Monitor
BPM: Beam Position Monitor
IPM: Ionization Profile Monitor
FPM: Fluorescence Profile Monitor
Interceptive: Slits and Faraday Cup
SEM: Secondary Emission Monitor

Manufactured by:
- CIEMAT
- INFN
- CEA

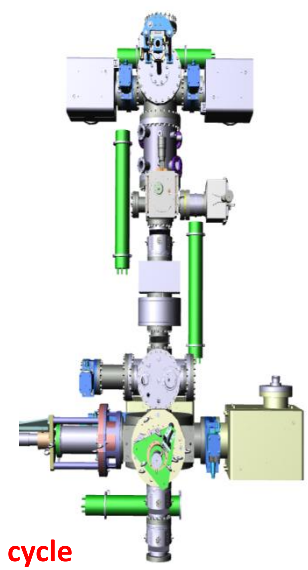


Challenges for beam instrumentation
High intensity in CW **(125 mA @ CW)**
Low beam energy **(5-9 MeV)**
High beam power **(up to 1.12 MW)**
Low Beta **(with D+ and H+)**

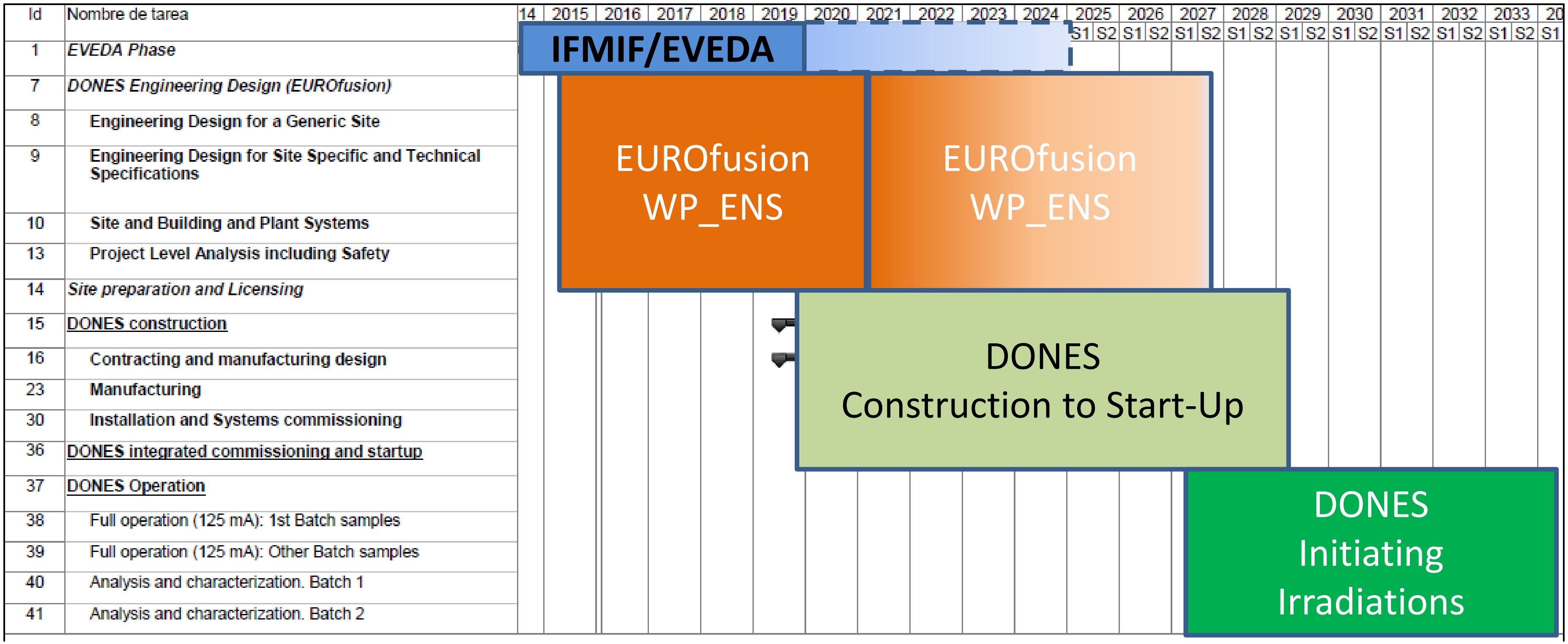




CW duty cycle



Reference Time Schedule



Time schedule based on the assumption that engineering design activities are steadily ongoing (WP_ENS), manufacturing activities will be linked to results obtained by the IFMIF/EVEDA project_ and on budget availability after 2020

Proposal to host DONES in Granada

It has been agreed at F4E level that if DONES is built in Europe, it will be in Granada (a lot of uncertainties still present: budget availability, japanese role and involvement, project organization,…)

DONES in ESFRI Roadmap

ENERGY | ESFRI PROJECTS

A UNIQUE RESEARCH INFRASTRUCTURE FOR TESTING FUSION MATERIALS IN REALISTIC CONDITIONS

TYPE
single-sited

LEGAL STATUS
pending

POLITICAL SUPPORT
lead country: ES
prospective member country: HR, (EUROfusion)
The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY
2018

TIMELINE

HEADQUARTERS
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas – CIEMAT
Madrid, Spain

WEBSITE
www.ciemat.es

SPAIN

IFMIF-DONES

International Fusion Materials Irradiation facility - DEMO Oriented NEutron Source

DESCRIPTION

The International Fusion Materials Irradiation Facility - Demo Oriented NEutron Source (IFMIF-DONES) is a single-sited novel Research Infrastructure for testing, validation and qualification of the materials to be used in a fusion reactor. It is based on a unique neutron source with energy spectrum and flux tuned to those expected for the first wall containing future fusion reactors. Materials irradiation data under such conditions are of fundamental interest for the fusion community as those will feed and validate the modelling tools for materials radiation damage phenomena. The IFMIF-DONES will be a major step towards IFMIF as it will develop a unique high-current high-duty cycle accelerator technology, liquid metal target technology and advanced control systems.

IFMIF was first proposed to the ESFRI …

… higher cross-sections for nuclear reactions that will generate significant amounts of H and He, as well as atomic displacements, leading to a presently undetermined degradation of structural materials after a few years of operation. Although fission and fusion materials share common issues, the study of radiation-induced damage for fusion materials necessarily has to go far beyond the damage level which is relevant for fission materials due to the the harder neutron spectrum. Therefore, specific sources, like the IFMIF and DONES, must be built to enable the development of fusion technology.

The original IFMIF project started in 1994 as an international scientific research program, carried out by Japan, the European Union, the United States, and Russia, and managed by the International Energy Agency (IEA). Since 2007, it has been pursued by Japan and the European Union under the Broader Approach Agreement in the field of fusion energy research, through the IFMIF/EVEDA (IFMIF Engineering Validation and Engineering Design Activities) project, which conducts engineering validation and engineering design activities for IFMIF, including IFMIF engineering design, Validation Activities of the Lithium Loop System, Validation Activities of the Irradiation Area System, Validation Activities of the Accelerator System that is still on-going with the design of the LIPAc prototype for the low energy section (9 MeV) of the IFMIF deuteron accelerator.

IFMIF-DONES is based on a 40 MeV, 125 mA in continuous wave mode (CW) deuteron accelerator (5 MW beam average power) hitting with a rectangular beam size (approx. 20 cm x 5 cm) a liquid Li screen target flowing at 15 m/s – to dissipate the beam power – and generating a flux of neutrons of 10^{18} m^{-2} s^{-1} with a broad peak at 14 MeV through stripping nuclear reactions, reproducing the expected conditions of fusion power plants. Materials are irradiated by the neutron beam as close as possible to the Li target to obtain damage rates up to 15 atomic displacements per year (dpa/year) under temperature controlled conditions. After a long irradiation period (up to two years), irradiated modules will be partially dismantled and the irradiated samples will be characterized.

STEPS FOR IMPLEMENTATION

EUROfusion and Fusion for Energy (F4E) started in 2015 a process to develop the engineering design of DONES and to identify possible EU sites to host the facility. In December 2017, F4E positively evaluated the joint Spain-Croatia proposal to site DONES in Granada. As the IFMIF-DONES enters the Roadmap 2018, it will be eligible for the Preparatory Phase grant by the EC and, simultaneously, will begin the Implementation Phase with the initial steps for the construction of the civil engineering infrastructure. Intense international activity is sought in order to benefit from the final results of the Broader Approach Agreement and to establish the broadest international collaboration in the design and construction of the DONES. ESFRI will assist and monitor since the beginning the developments of IFMIF-DONES.

ESFRI ROADMAP 2018 – STRATEGY REPORT ON RESEARCH INFRASTRUCTURES

Common Support Action linked to DONES in ESFRI recently approved: **IFMIF-DONES Preparatory Phase Project (DONES-PreP)**

DONES Complementary Science Program

A White Book report on ***„IFMIF-DONES for isotope production, nuclear physics applications, materials science and other research topics"*** **IFJ PAN Report No. 2094/PL, November 2016;** Eds. A. Maj, M.N. Harakeh, M. Lewitowicz, A. Ibarra, W. Królas

was prepared by an international science committee based on the conclusions of a Workshop held in Poland during 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)
- ...

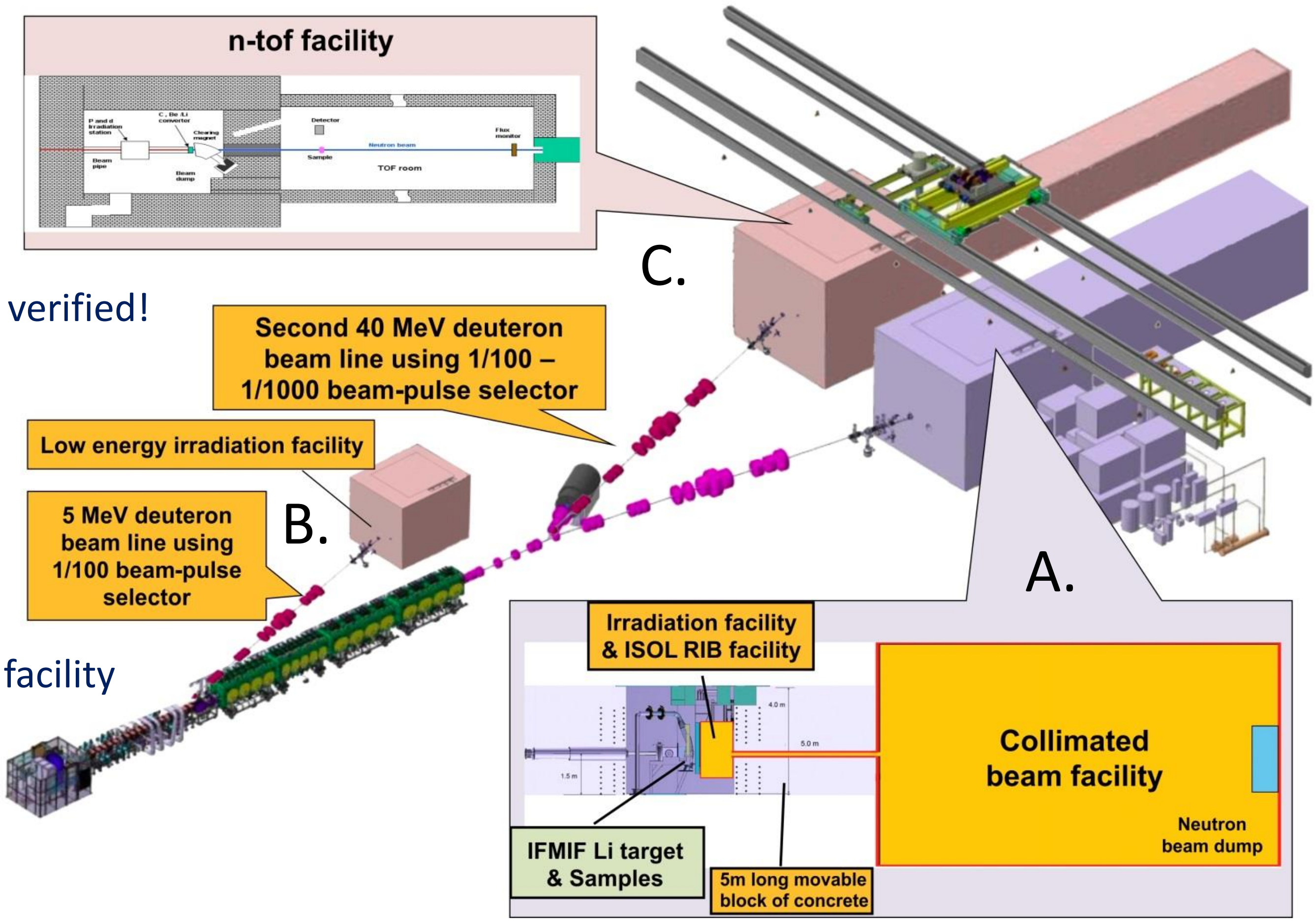
Industrial application of neutrons

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

Complementary Experiments Areas: White Book proposal

C. A **second 40 MeV deuteron beam** line using 1/100 to 1/1000 beam-pulse selector to a neutron Time-of-Flight facility – feasibility must be verified!

B. A **5 MeV deuteron beam line** using 1/100 beam-pulse selector to a low-energy irradiation facility



A. Irradiation facility and ISOL RIB facility behind the HFTM;
Collimated beam facility with an 8 m long neutron line

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- **IFMIF-DONES and HiRadMat**
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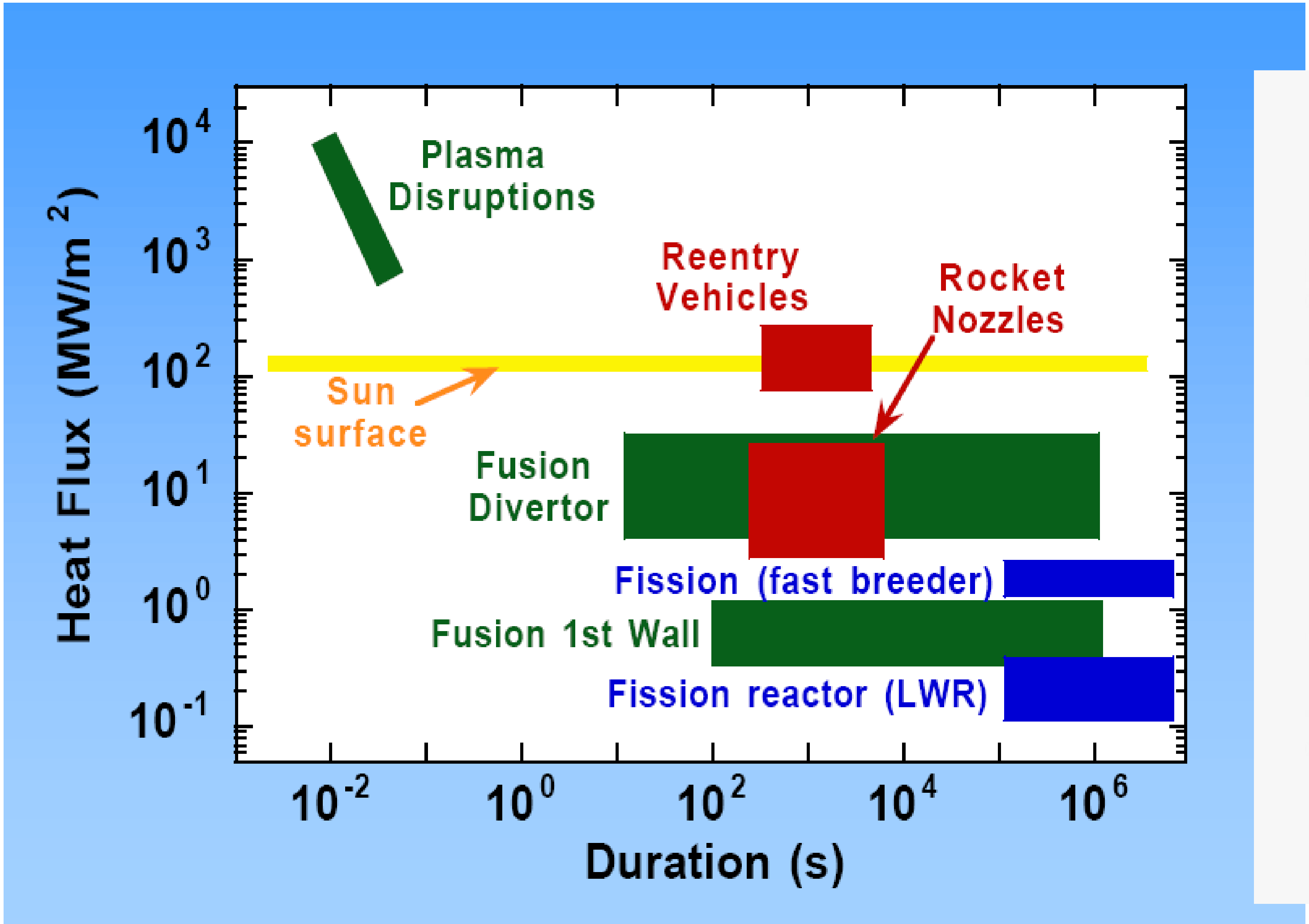
Structural Fusion Materials studies	HiRadMat
Damage occurs in a period of **years** (low dose rate)	Damage occurs in **8 µs**
Neutron energy < 14 MeV (down to thermal)	Protons of 440 GeV Deposited power of ~ 3.4 MJ for ions 21 kJ
He effects too different	
Fluences 1-30 x 10^{25} n/m^2	100 high-intensity pulses: 5.10^9 to 3. 10^{13} /pulse protons
Very low fluence → only for pre-neutron damaged materials.	
Moderate temperature increases	Near Melting temperature
Can be interesting for pre-irradiated materials and/or specific model validation ad-hoc experiments	

First Wall Fusion Materials studies (Be & W alloys)	HiRadMat
High thermal loads → High temperature increases. Especially in divertor area. Can reach melting temperature * good agreement	
Plasma –wall interactions occurs in short to long time scale *some agreement	Damage occurs in **8 μs**
Neutron energy 14 MeV and mainly **low energy D , T & He** (eV's) * large difference: effects on load/damage depth profile	Protons of 440 GeV Deposited power of ~ 3.4 MJ for ions 21 kJ
Large areas affected	Very **concentrated** area: Larger thermal lateral gradients?

Thermal loads in Fusion



DONES accelerator vs HiRadMat

Deuteron energy up to 40 MeV	Protons of 440 GeV
125 mA → Power 5 MW	Deposited power of ~ 3.4 MJ
CW	Pulse **7 μs**
Need of a Beam dump	
Possible damage on collimators / beam line / Diagnostics → Several common issues. Most promising collaborations	

Preliminary ideas on collaborations

- Possible beam damage on **components** : experience on beam resistant materials can be used for DONES
- Diagnostics qualification.
- Other components qualification?
- Operational expertise (safety, RAMI,…)?
- Design reviews participation
- Other proposals?

Summary

- A fusion-like neutron source is needed ASAP for DEMO design and beyond.
- IFMIF-DONES is the EU proposed alternative to be implemented in the near future
- It will allow irradiation of around 1000 engineering-relevant samples at a dose rate around 20 dpa/fpy
- The knowledge gained in *HiRadMat* facility can be useful for DONES accelerator components but difficult to apply to fusion materials. Best chance: first wall materials
- For other *Complementary Experiments*, ideas and collaborations are welcome.

Thank you for your attention

Fusion Roadmap