A neutron source for fusion: The DONES Project

A. Ibarra (CIEMAT, Spain)

CERN
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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**
- **Summary**

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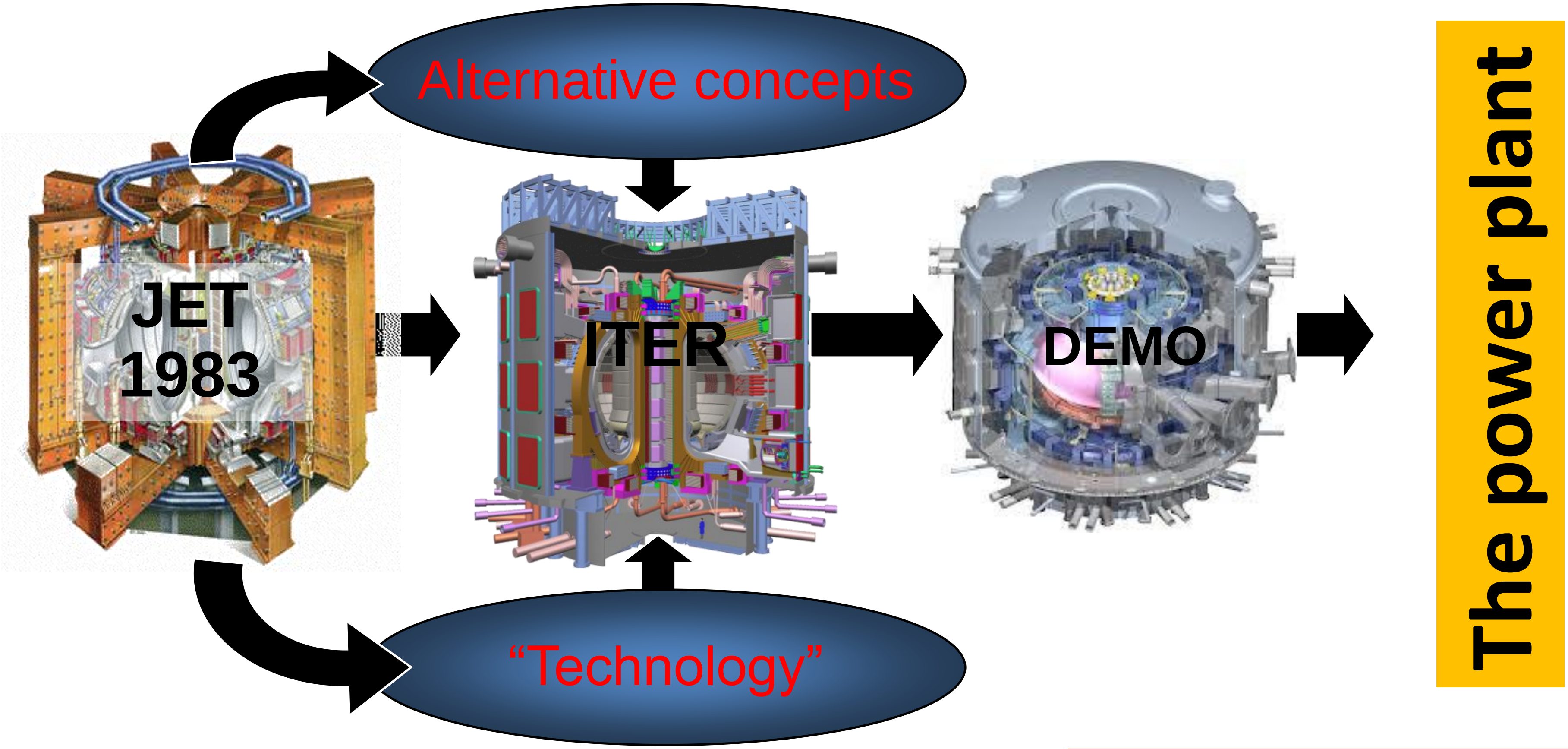
The EU strategy towards fusion energy



ITER: scientific and technological feasibility of fusion energy

DEMO: Qualification of components and processes

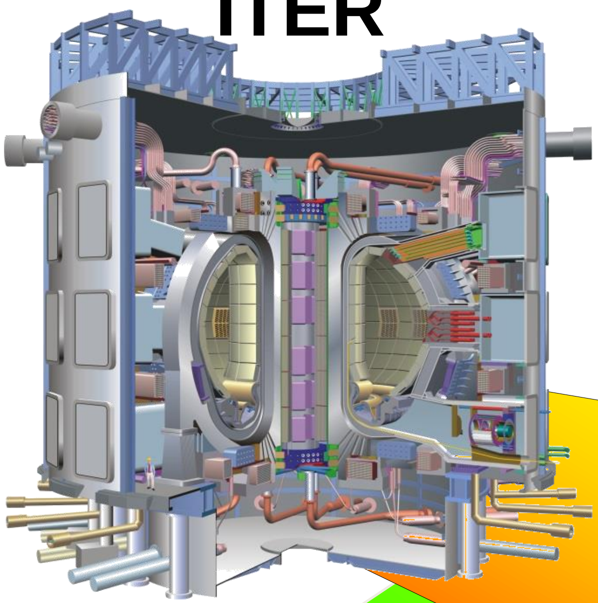
Reactor: High availability, safe and environmental-friendly, economically acceptable

After ITER

DEMO

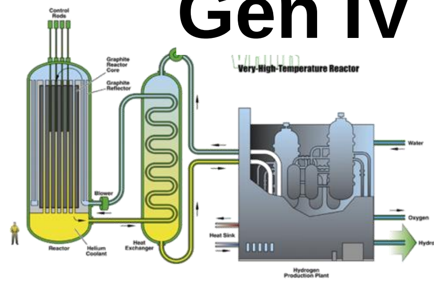
30 dpa/year

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



ITER

3 dpa/lifetime



Gen IV

~25 dpa/year

Radiation damage: Primary effects

Transmutation

- Due to nuclear reactions, new ions appear inside the materials, giving rise to new impurities (main ones are H and He, but others can be also relevant)
- It can induce also the activation of the material (some of these new impurities can be radioactive isotopes). This is the main reason for the development of low-activation materials.
- The amount and specific new ions is a function of the type of incident particle, its energy and the target ion. If enough information of the target material (impurities can be very relevant) is available, usually it is feasible to make a rough stimation

Point defects (holes and interstitials)

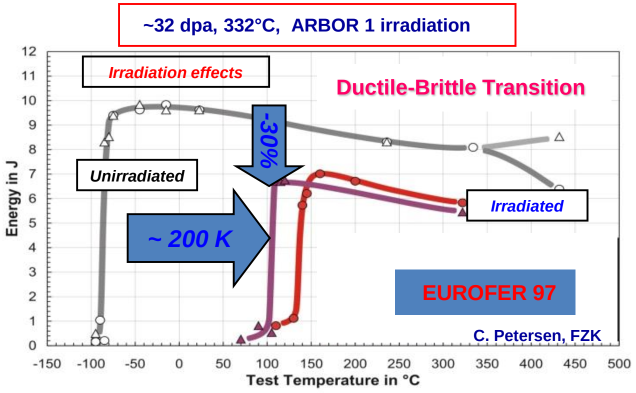
- It is a complex function of the incident particle, its energy, the materials characteristics and temperature
- After their creation, they can move around being trapped in previous defects or on new ones giving rise to extended defects (dislocations, bubbles, loops, precipitates,…)
- If dose/dose rate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

Radiation damage: Macroscopic effects

Both the 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:

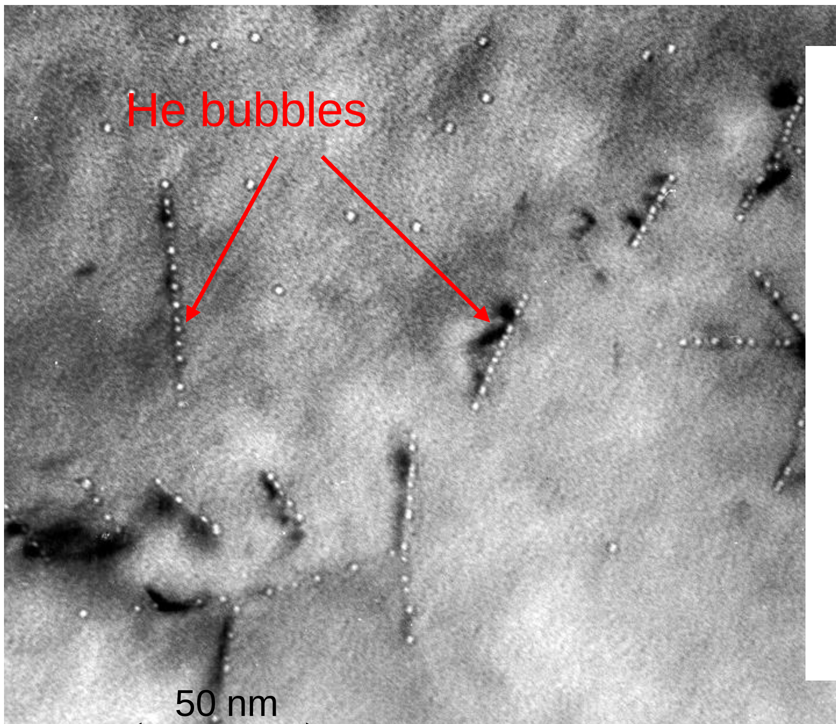
- Increased hardening
- Decreased ductility
- Decreased heat conduction
- Swelling
- Embrittlement
- Blistering
- …

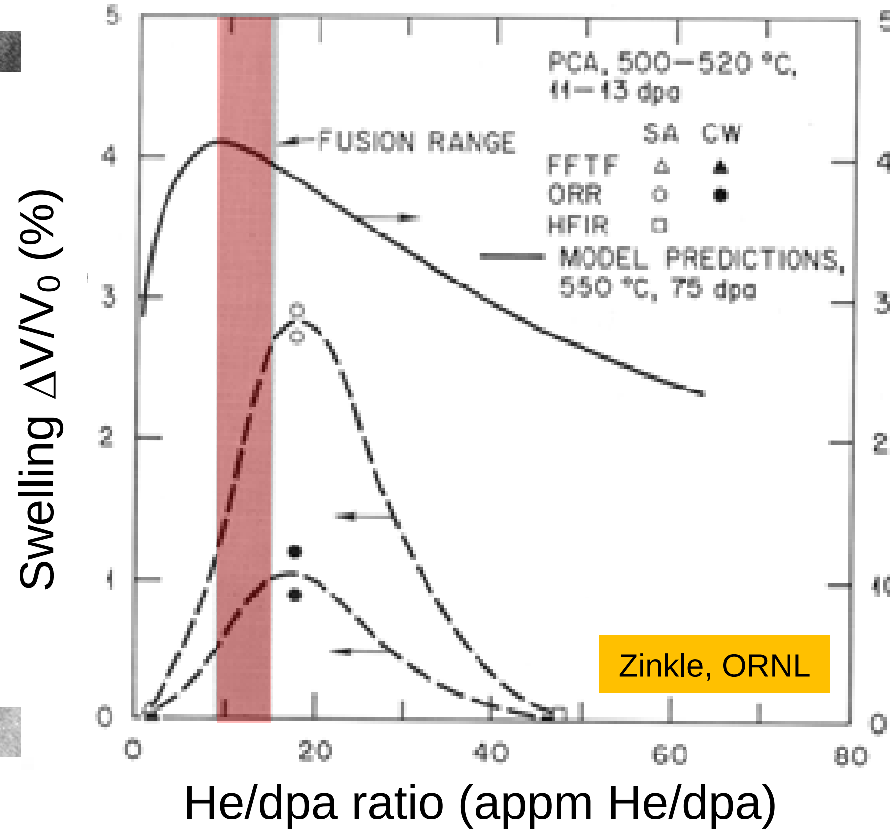


Consequences to be taken into account in the design of irradiated components:

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

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



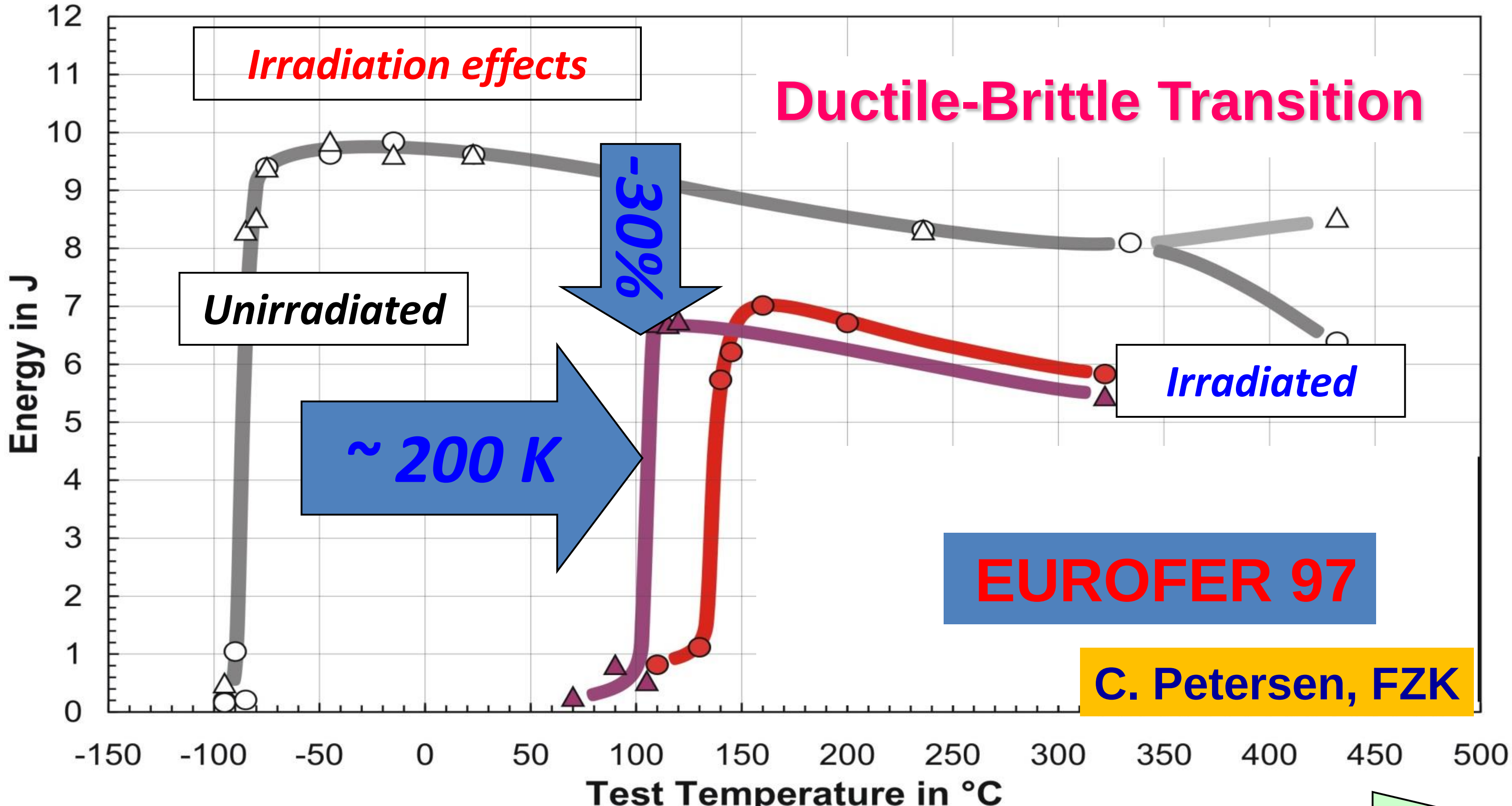


He bubbles

- 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

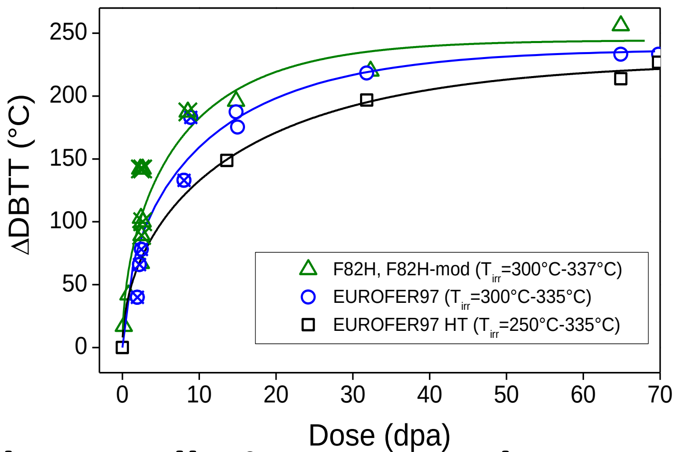
~32 dpa, 332°C, ARBOR 1 irradiation

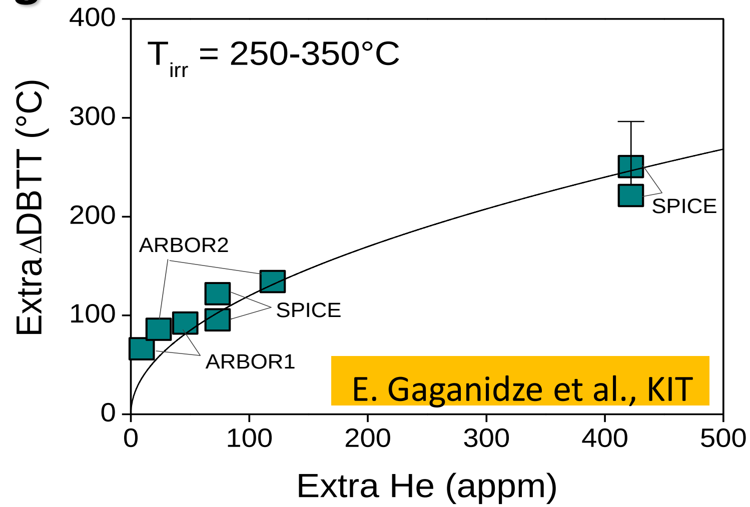


Concerns: i) ΔDBTT > 200 K
ii) Effect of Helium?

"Helium" effect on DBTT

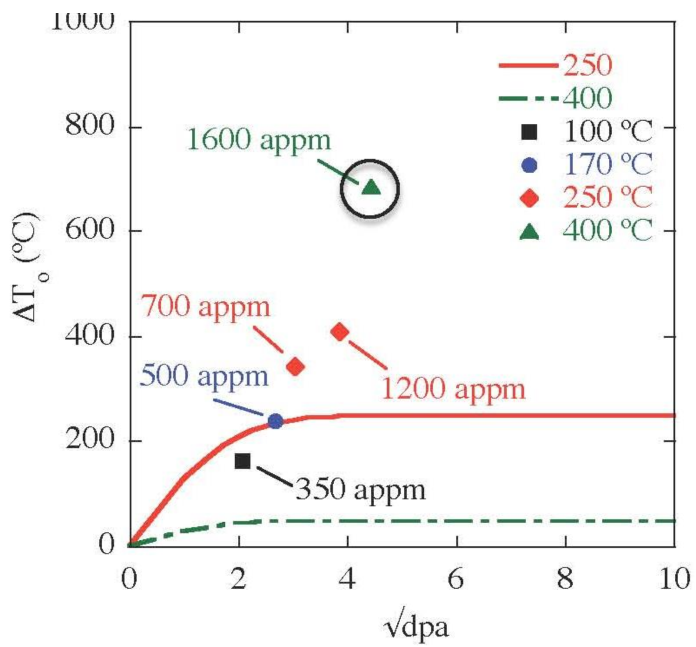
based on fission irradiation after B-doping

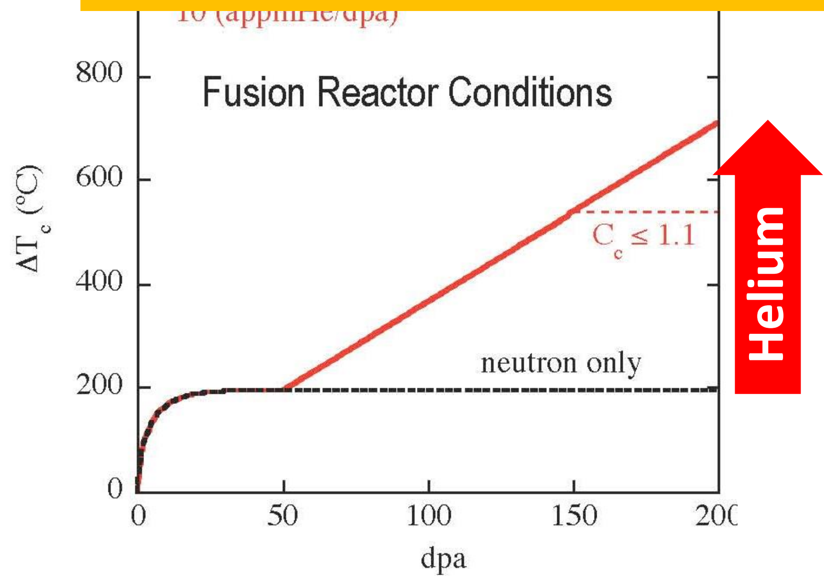




E. Gaganidze et al., KIT

based on spallation source data

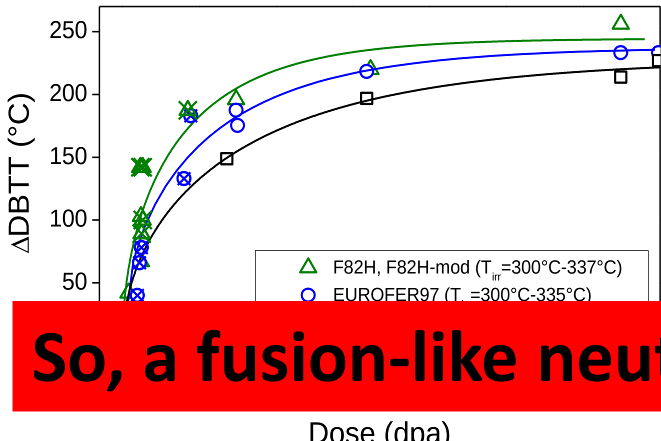


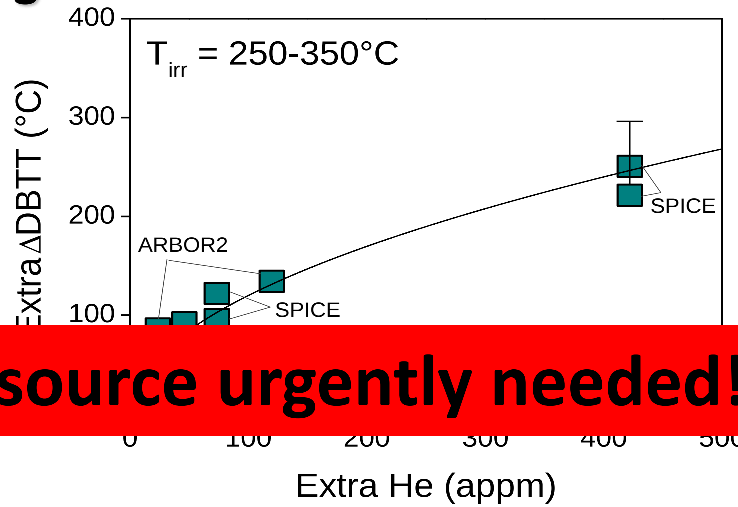


Kurtz, Odette, Yamamoto, Dai; SOFT-26, Porto 2010

"Helium" effect on DBTT

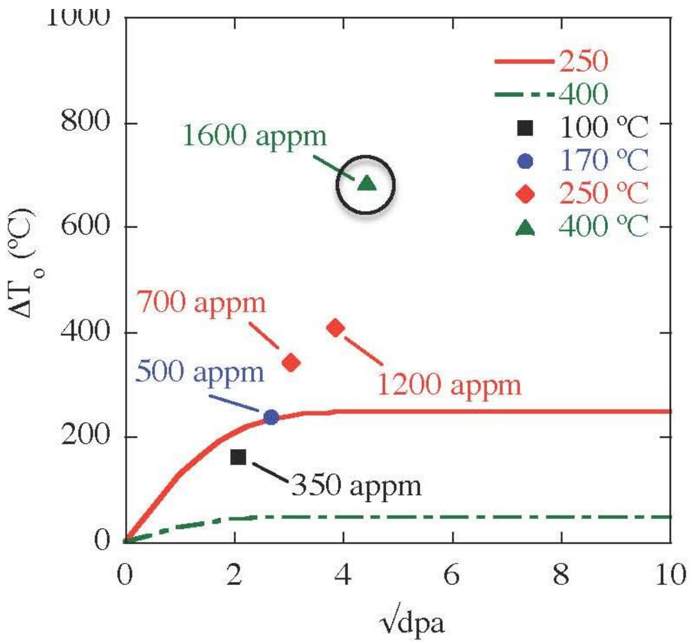
based on fission irradiation after B-doping



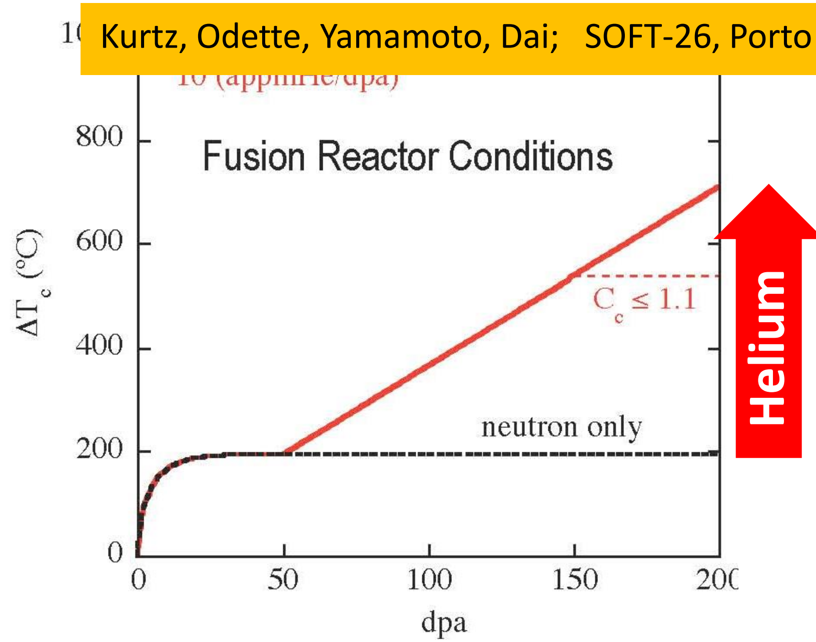


So, a fusion-like neutron source urgently needed!!!

based on spallation source data



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



Comparison criteria-I

High-dose radiation effects in materials can only be properly understood if many different irradiation sources are used and a proper “common” model is developed.

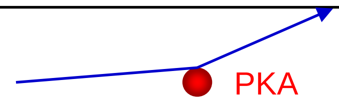
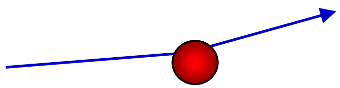
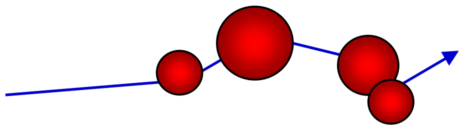
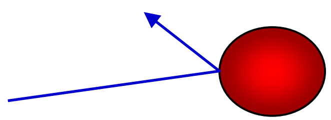
How they can be compared? (the neutron/particle spectra is not so important: the important thing is the effects on the materials –*NOTE: the effects can be different for different materials*-)

Radiation effects in materials are very complex processes that can strongly depend on many parameters (total dose, dose rate, irradiation temperature, time from irradiation, material characteristics,…).

The comparison is based in the initial phases of interaction of radiation particles with the material:

- i) scattering of particles. This is measured with **the parameter “dpa”-total dose and dose rate-** and with **W(T) –damage function-** (a parameter that describes in a qualitative way the “type” of damage in the material)

Comparison criteria-II

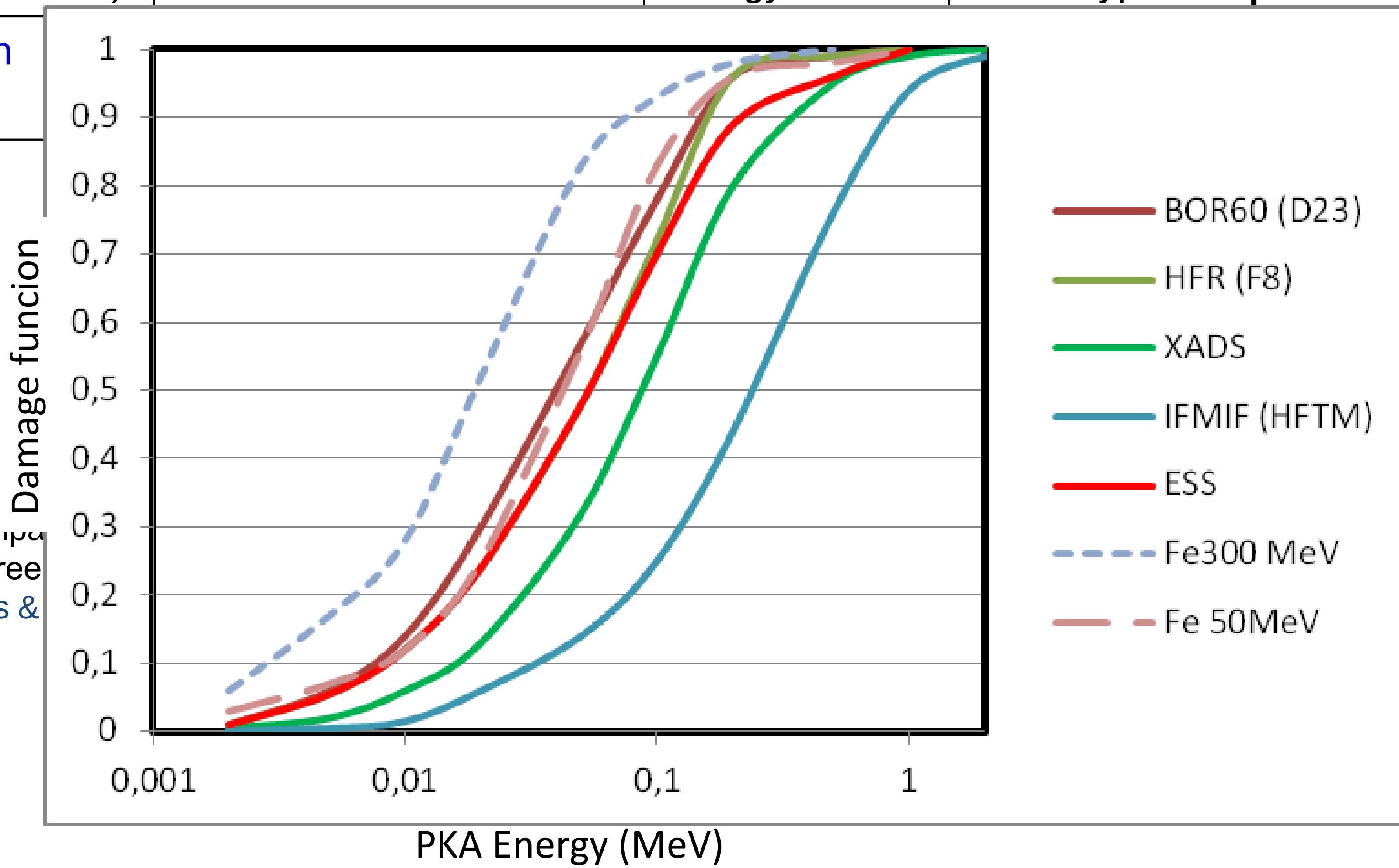
Particle type (E_{kin} = 1 MeV)	Typical recoil (or PKA) feature	Typical recoil energy T	Dominant defect type
Electron		25 eV	Frenkelpairs (FP: Vacancy-Insterstitial pair)
Proton		500 eV	
Fe-ion		24 000 eV	
Neutron		45 000 eV	Cascades & sub-cascades

Typical impact on materials properties:
FPs as "freely migrating defects": Alloy dissolution, segregation, irradiation creep
Cascades & sub-cascades: Irradiation hardening, ductility reduction

Comparison criteria-II

Particle type (E_{kin} = 1 MeV)	Typical recoil (or PKA) feature	Typical recoil energy T	Dominant defect type
Electron			
Proton			
Fe-ion			
Neutro			

Typical ir
FPs as "free
Cascades &



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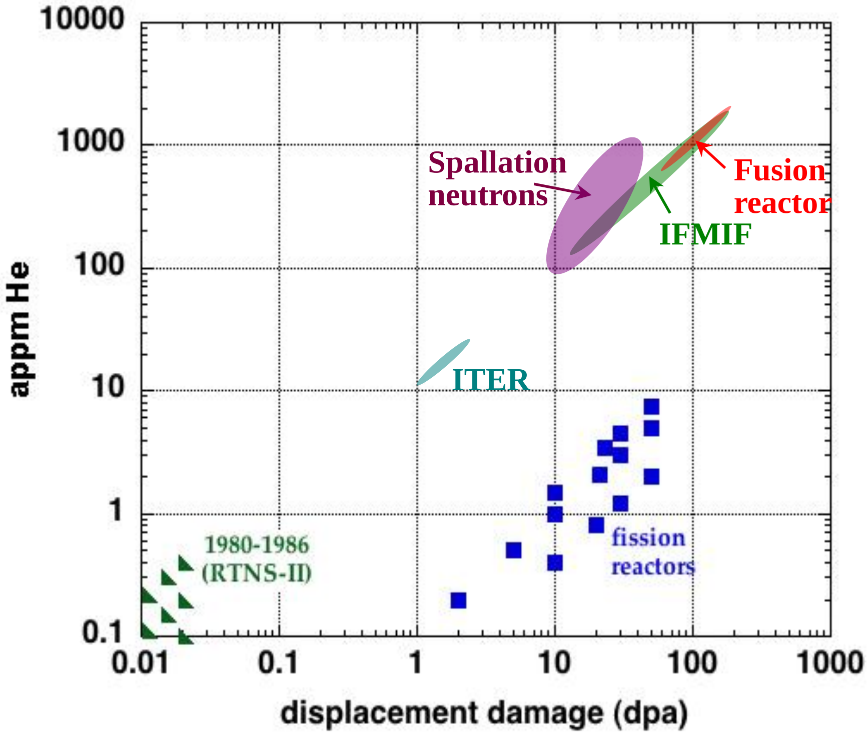
The comparison is based in the initial phases of interaction of radiation particles with the material:

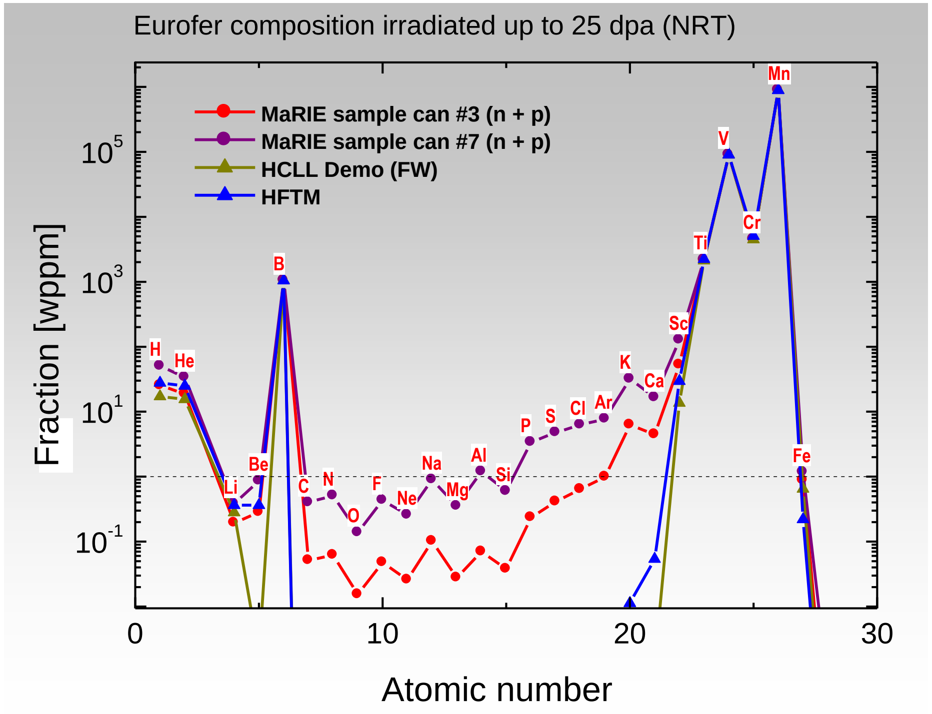
- i) scattering of particles. This is measured with **the parameter "dpa"-total dose and dose rate-** and with **W(T) –damage function-** (a parameter that describes in a qualitative way the "type" of damage in the material)

- ii) Nuclear reactions, giving rise to "new" ions not previously in the matrix. In the case of fusion-like neutrons the main impurities induced are He and H. This is measured with the **He/dpa**, **H/dpa** **ratios** and other impurities production.

+ other obvious comparison criteria like **irradiation volume**, **feasible temperature range**,…

Comparison criteria-III





Based on A. Möslang (2014)

Irradiation sources

Very different irradiation sources can be used, as a function of the issues to be investigated

(note that the use of a irradiation source different to the "original" one assumes the capability to extrapolate between different irradiation conditions –something that is not obvious at all-): role of modelling and the use of normalized samples and materials

Types of 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 sources** (high energy neutrons, pulsed)
        - **Stripping**
        - **Others (DT sources)**

Neutron source requirements

Along the time, it has been widely recognize that 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

IFMIF/EVEDA activities

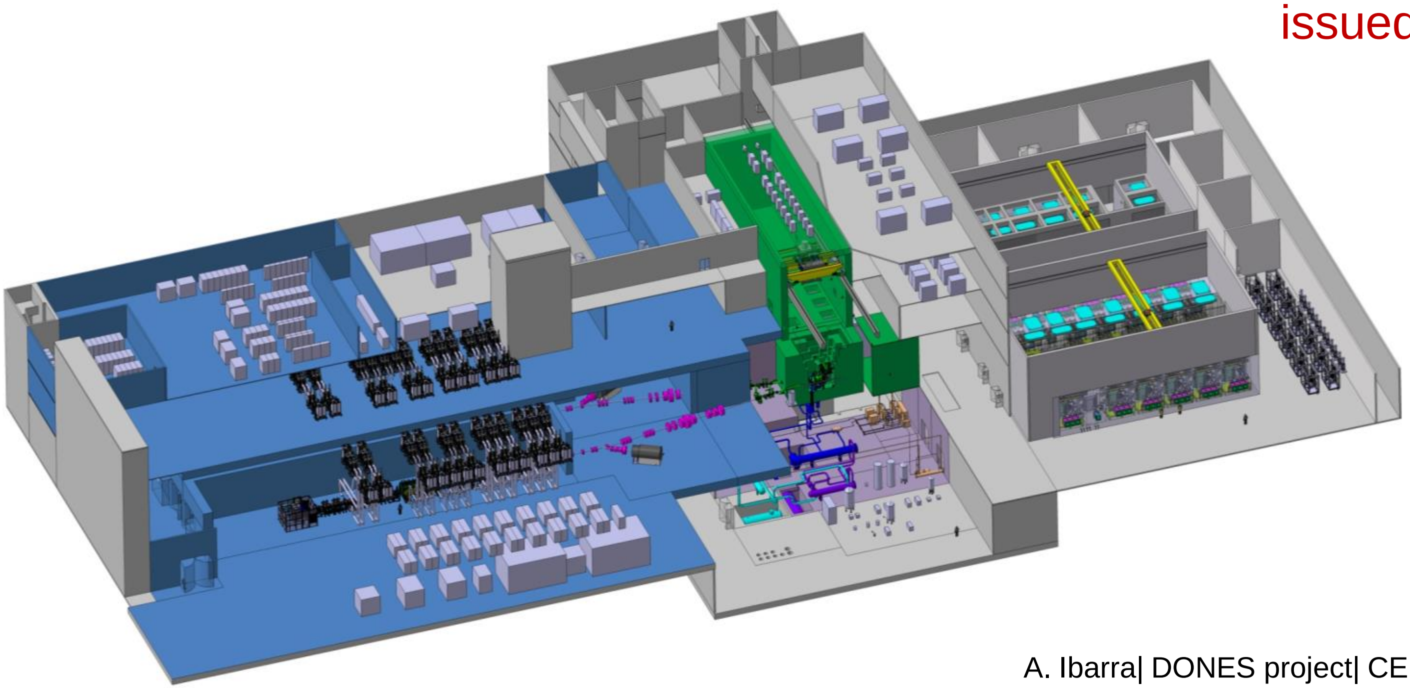
- Long history towards a Li(d,xn) facility: FMIT, ESNIT, IFMIF
- Since 2007, **IFMIF/EVEDA project included in the EU-JA Broader Approach Agreement**

The Engineering Validation Activities (EVA)

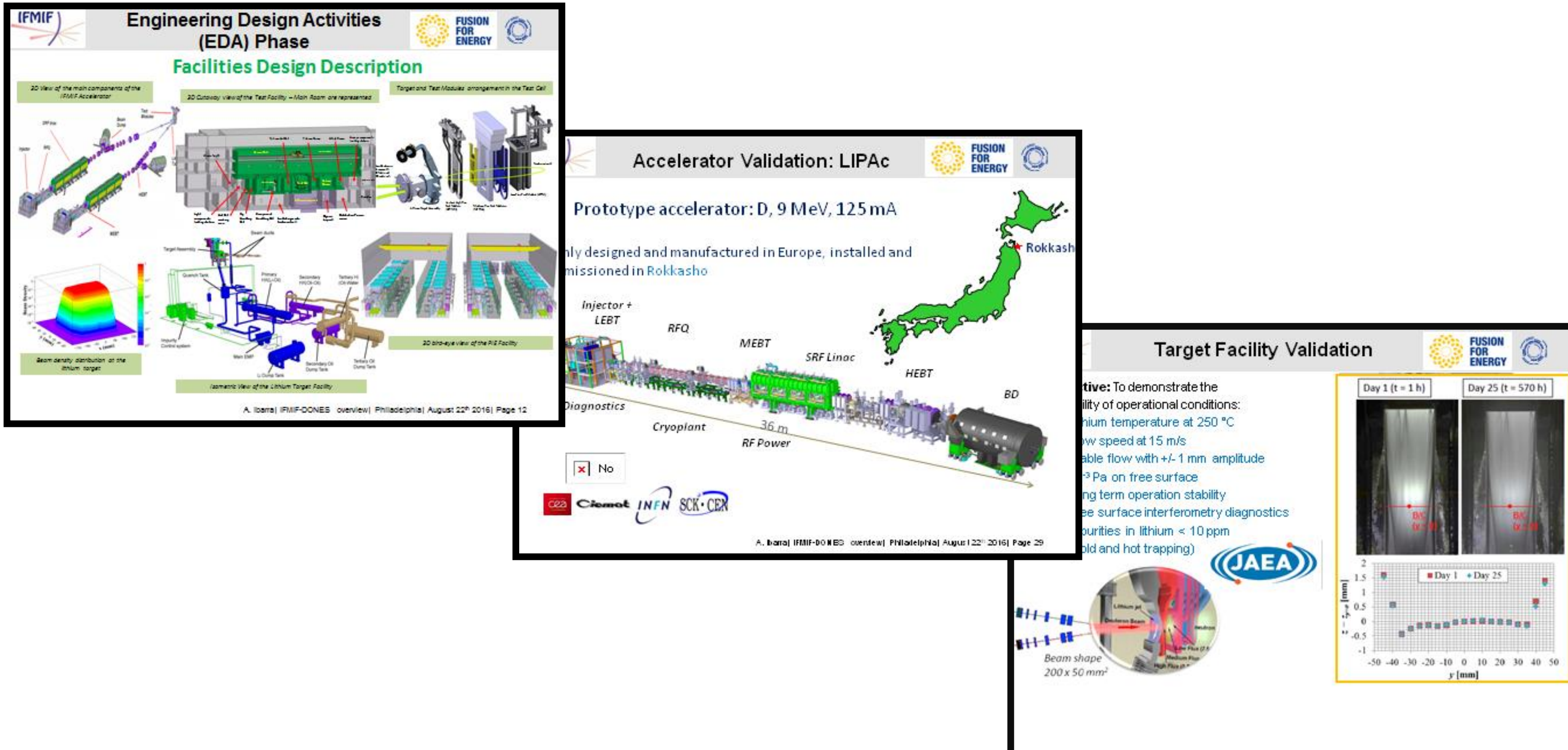
=> Experimental support to the IIEDR mostly finished 2015 (prototype accelerator installation and commissioning till 2019)

The Engineering Design Activities (EDA)

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



IFMIF-EVEDA Activities



+ many other additional validation activities in many different aspects

In general: actual design seems feasible

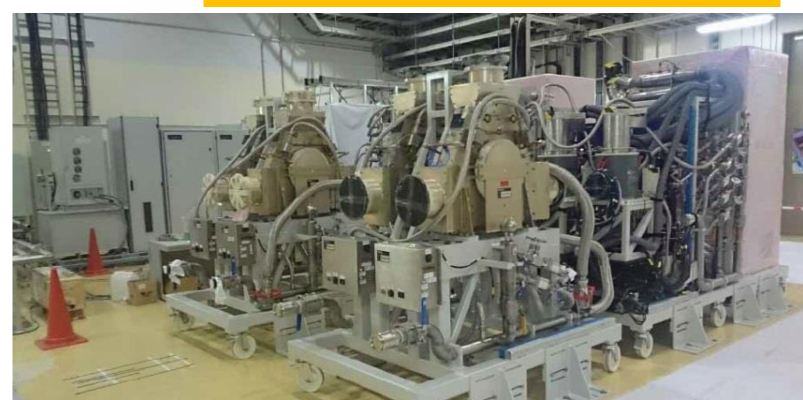
Construction status of LIPAc

Injector under operation in Rokkasho

MEBT at Rokkasho site

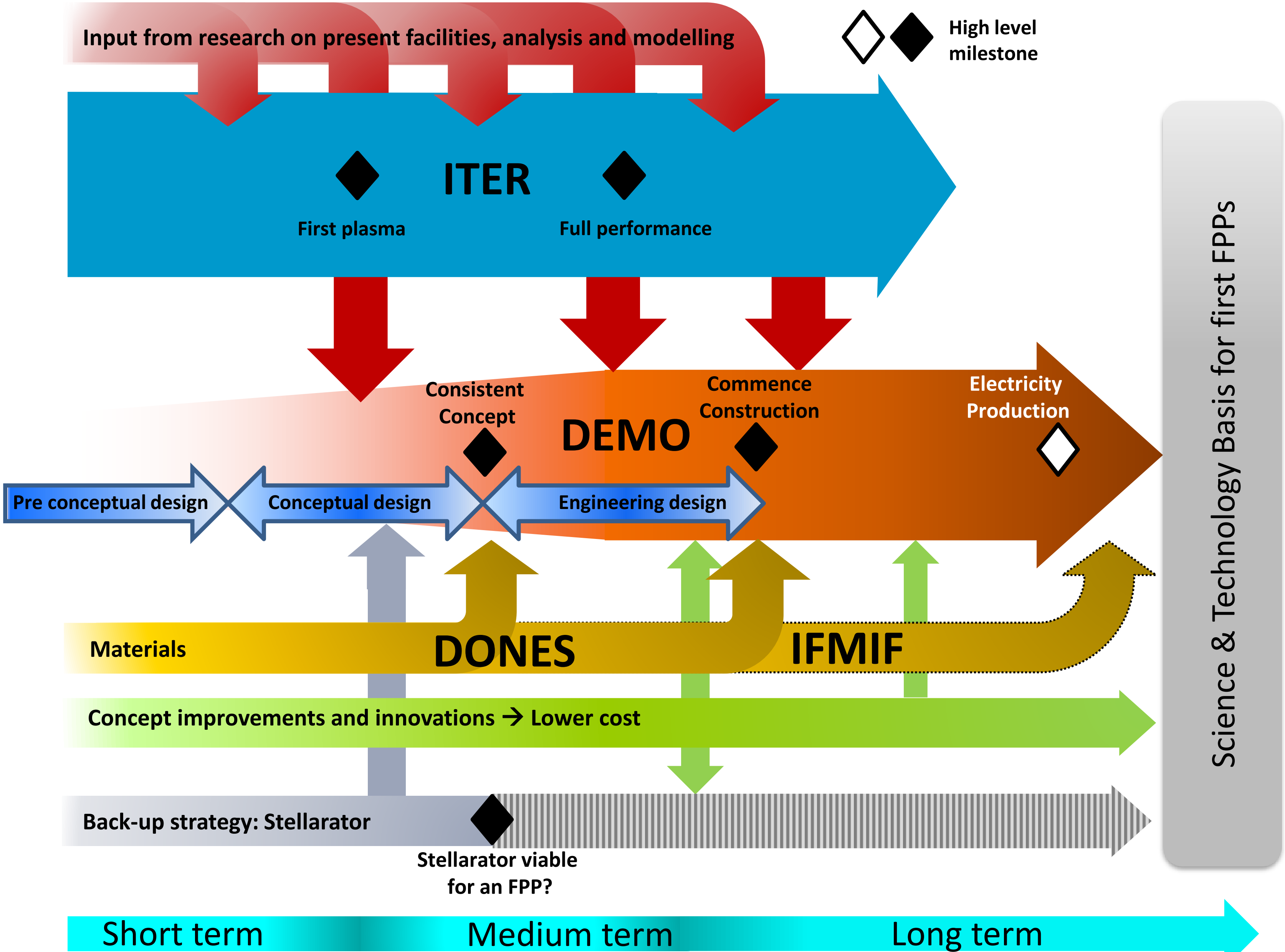
Diagnostics Plate at Rokkasho site

RFQ presently under commissioning at Rokkasho



Part of the RF sytem under operation at Rokkasho

Fusion Roadmap



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- **Complementary experiments area**
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Neutron source requirements

Along the time, it has been widely recognized that a fusion-like neutron source is needed for fusion materials qualification both for DEMO and the power plant development

Requirements based on EU DEMO needs

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)

> 10 dpa(Fe)/fpy

20 dpa(Fe) in 1.5 y

50 dpa(Fe) in 3.5 y

300 cm3

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

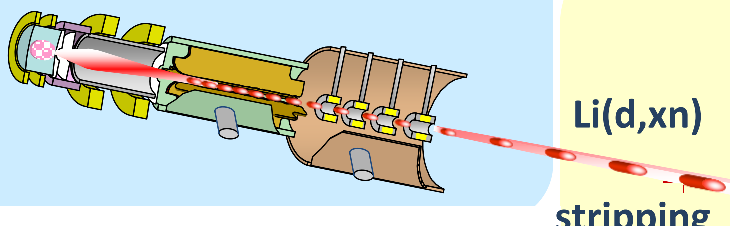
The IFMIF project since 90´s

The DONES project!!!

DONES Main Systems

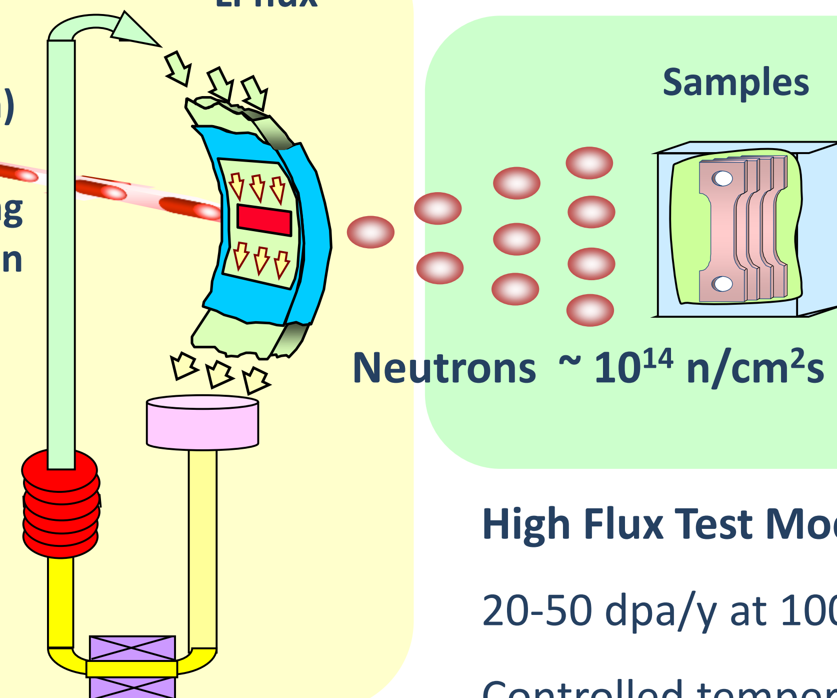
Accelerator

Deuterons: 40 MeV 125 mA (5 MW)



Lithium Loop (Target)

Test (Irradiation) Module



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

Heat removal by high velocity Li flux

High Flux Test Module:

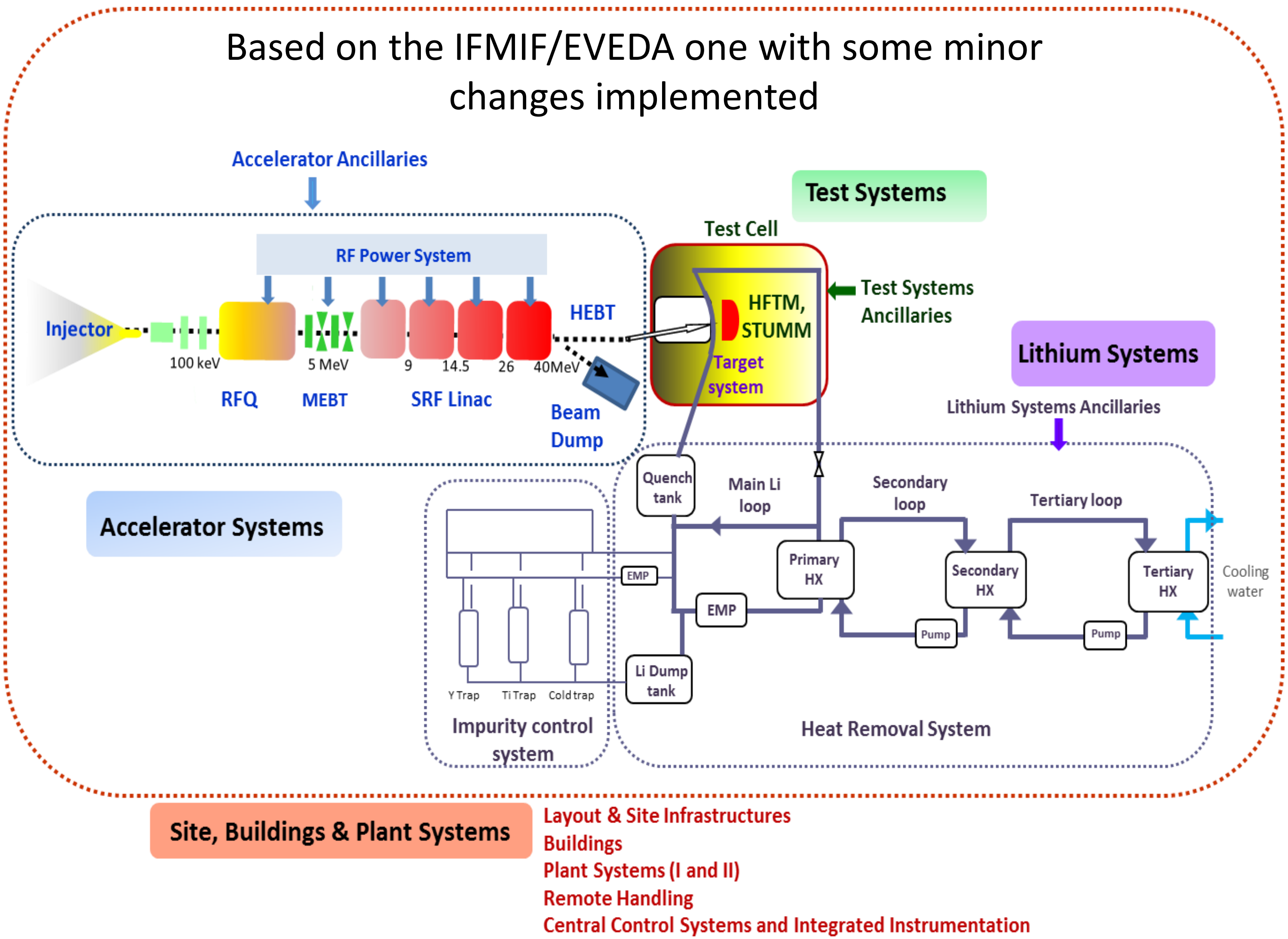
20-50 dpa/y at 100 cm^3

Controlled temperature:
250 < T < 1000 °C

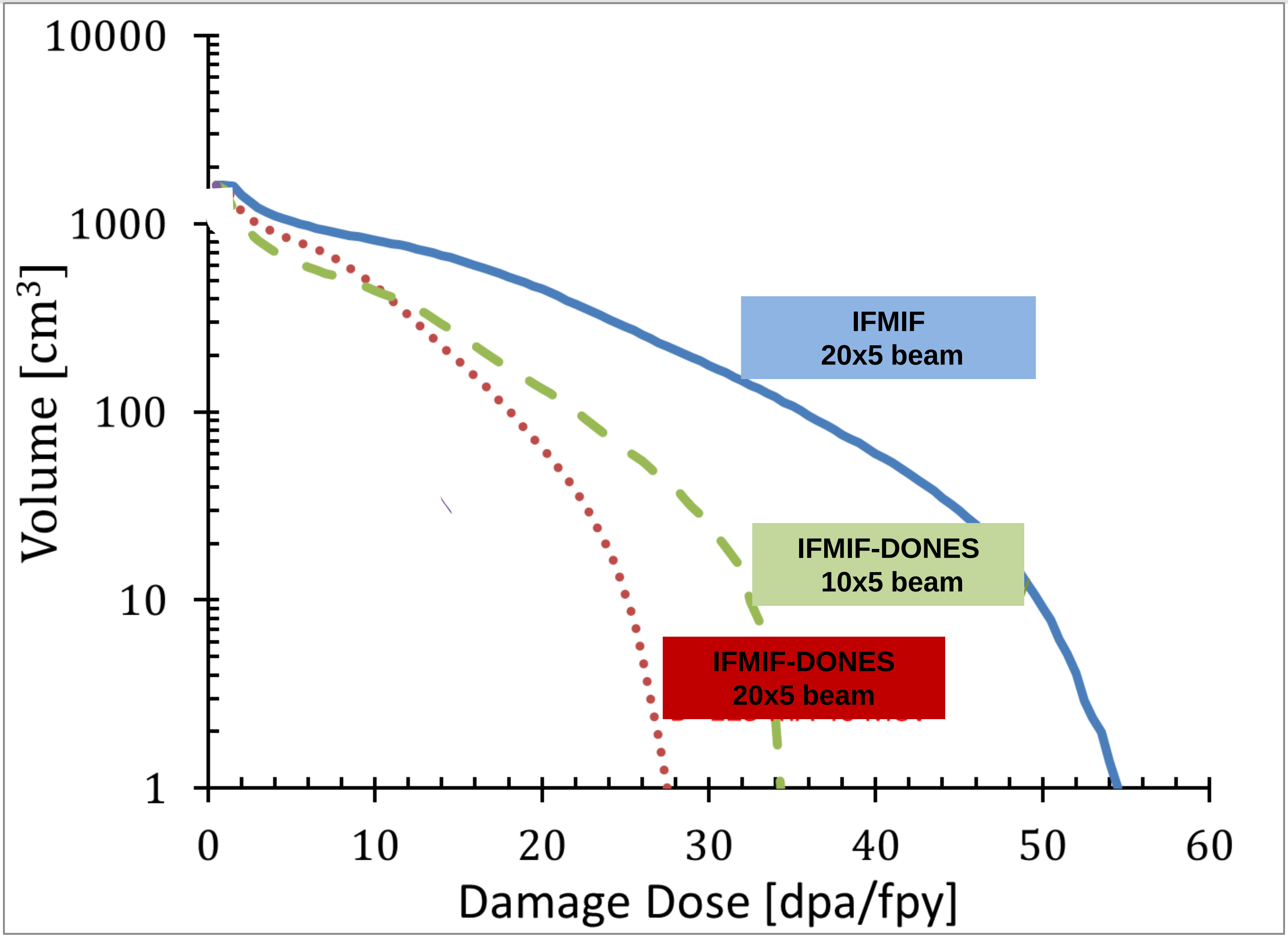
A neutron flux of ~ 10^{14} $cm^{-2}s^{-1}$ is generated with neutron spectrum up to 50 MeV energy

DONES plant configuration

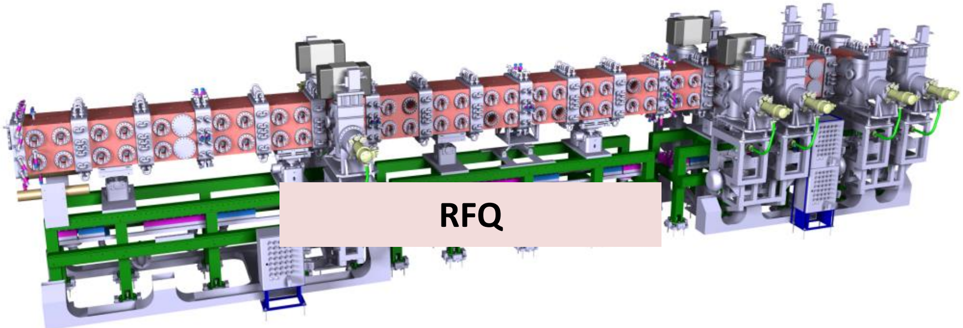
Based on the IFMIF/EVEDA one with some minor changes implemented



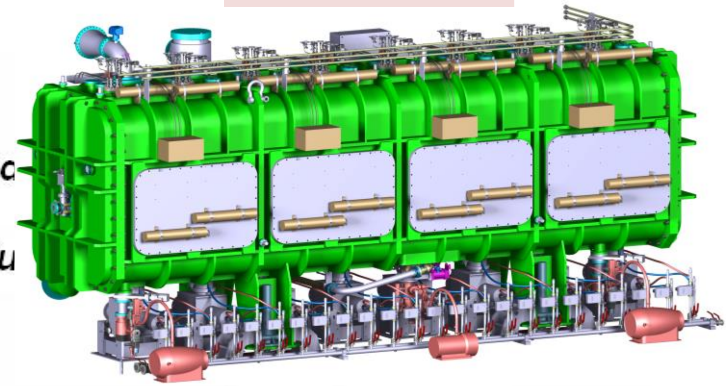
Available Irradiation Volume vs DPA

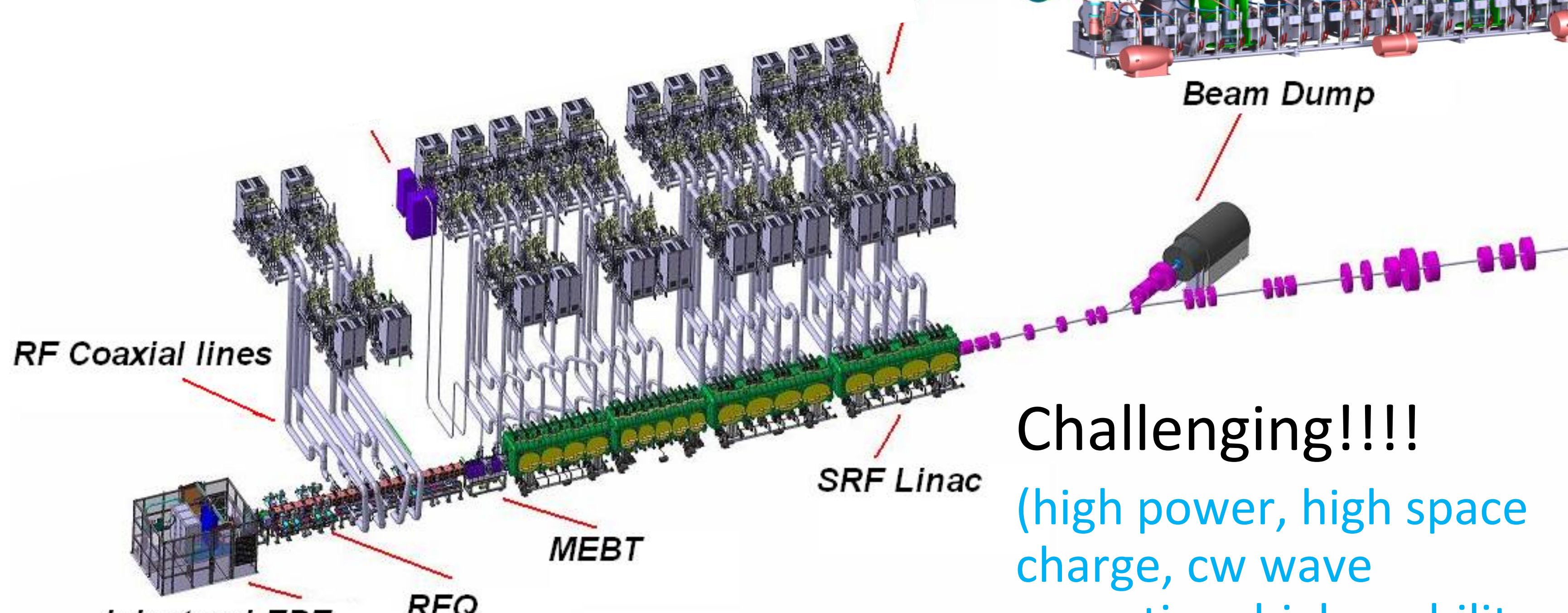


Accelerator systems summary



SRF cryomodule





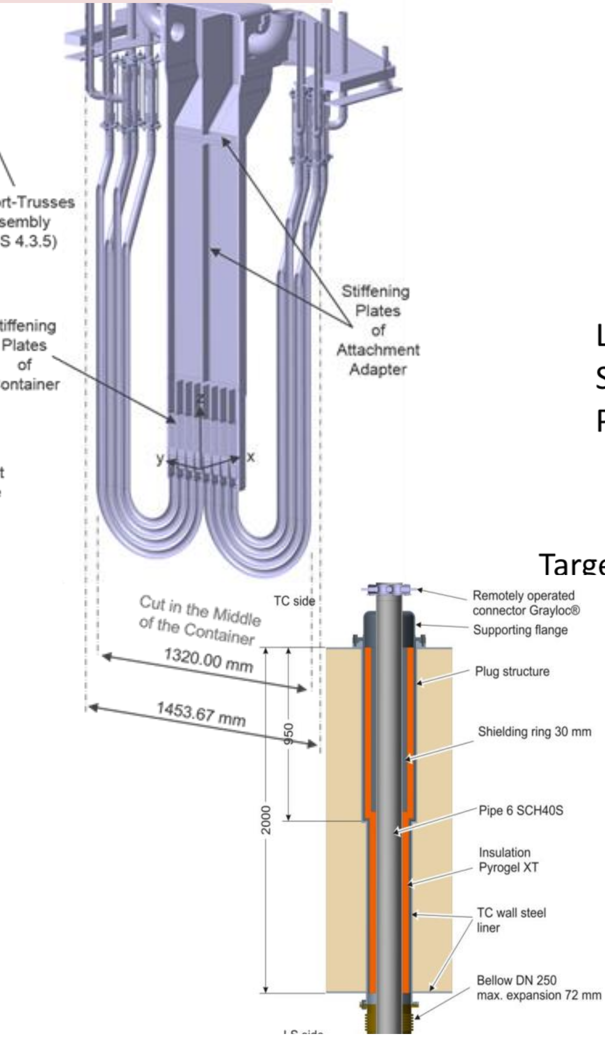
Challenging!!!!

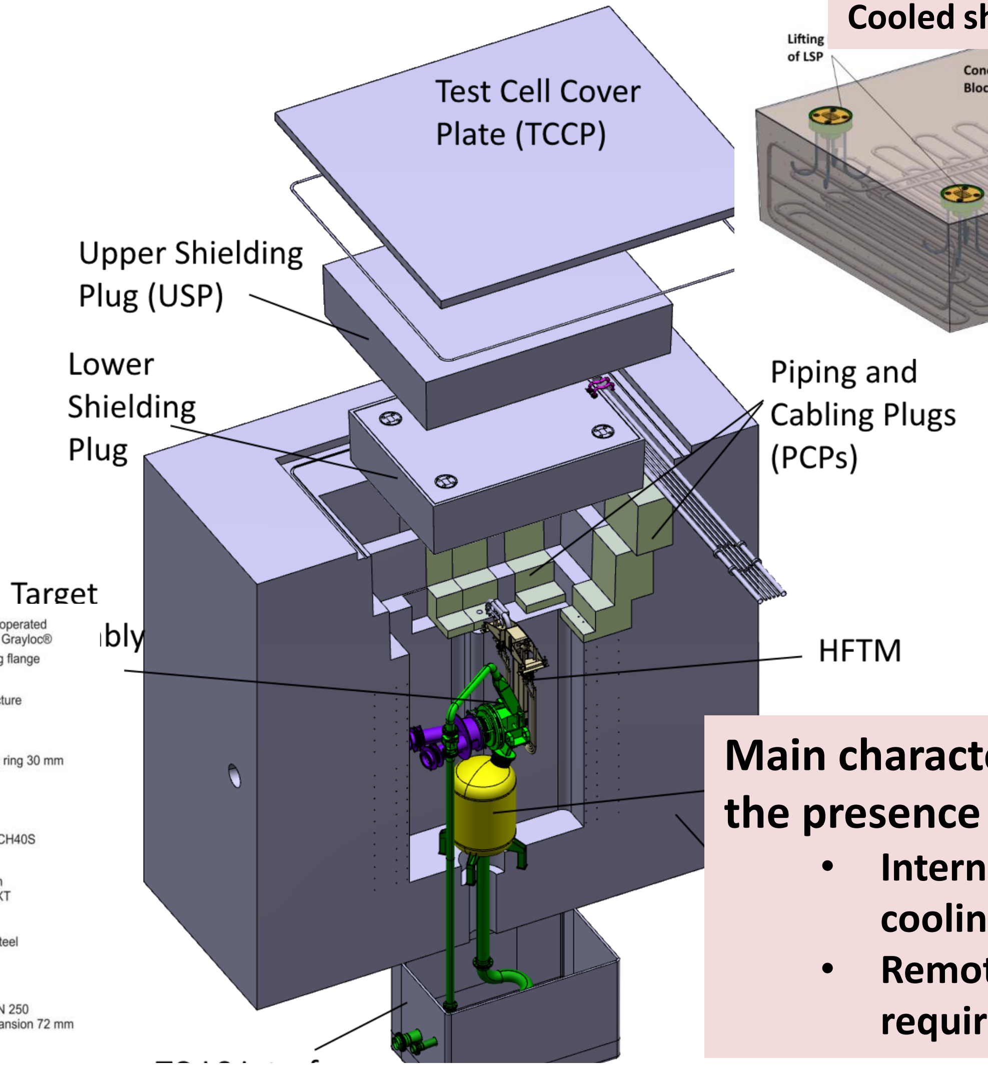
(high power, high space charge, cw wave operation, high reability, longest RFQ,…)

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

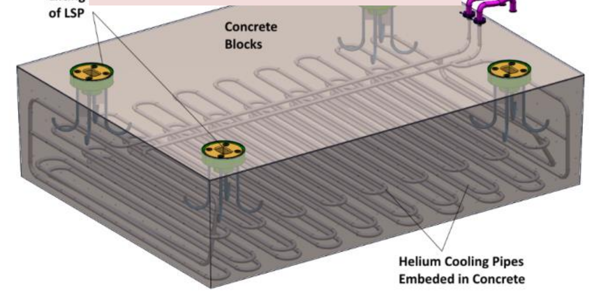
Test Systems summary

Irradiation module





Cooled shielding plug



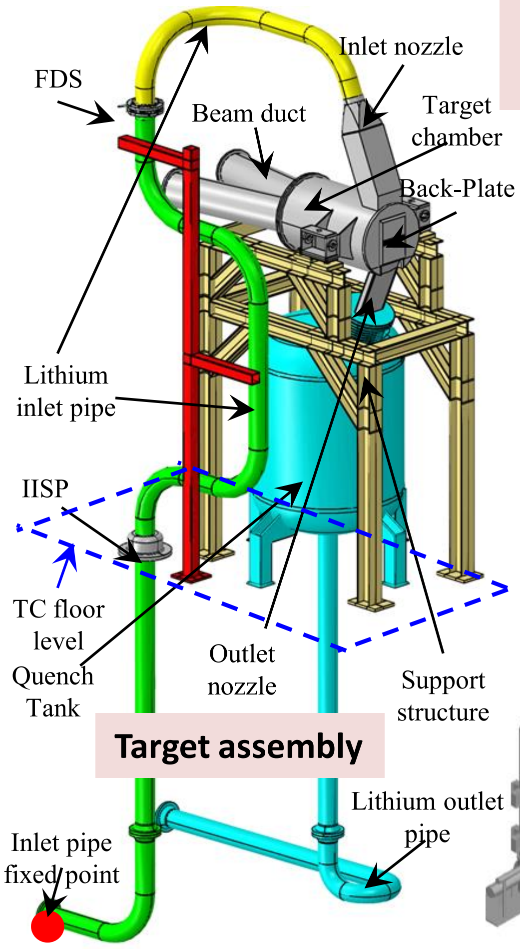
Main characteristics driven by the presence of neutrons and Li

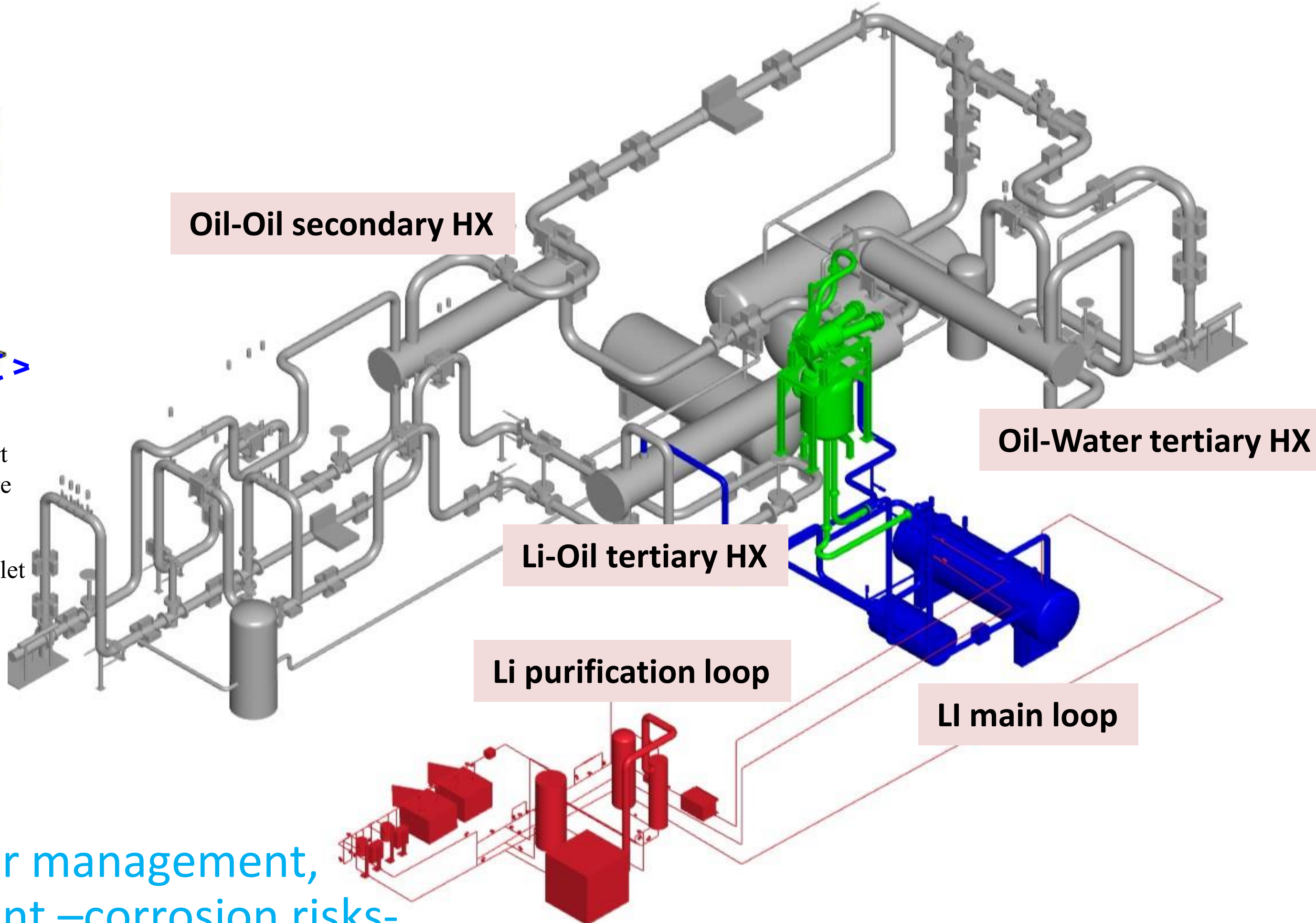
- **Internal components cooling by He**
- **Remote Maintenance required**

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

Li systems summary

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

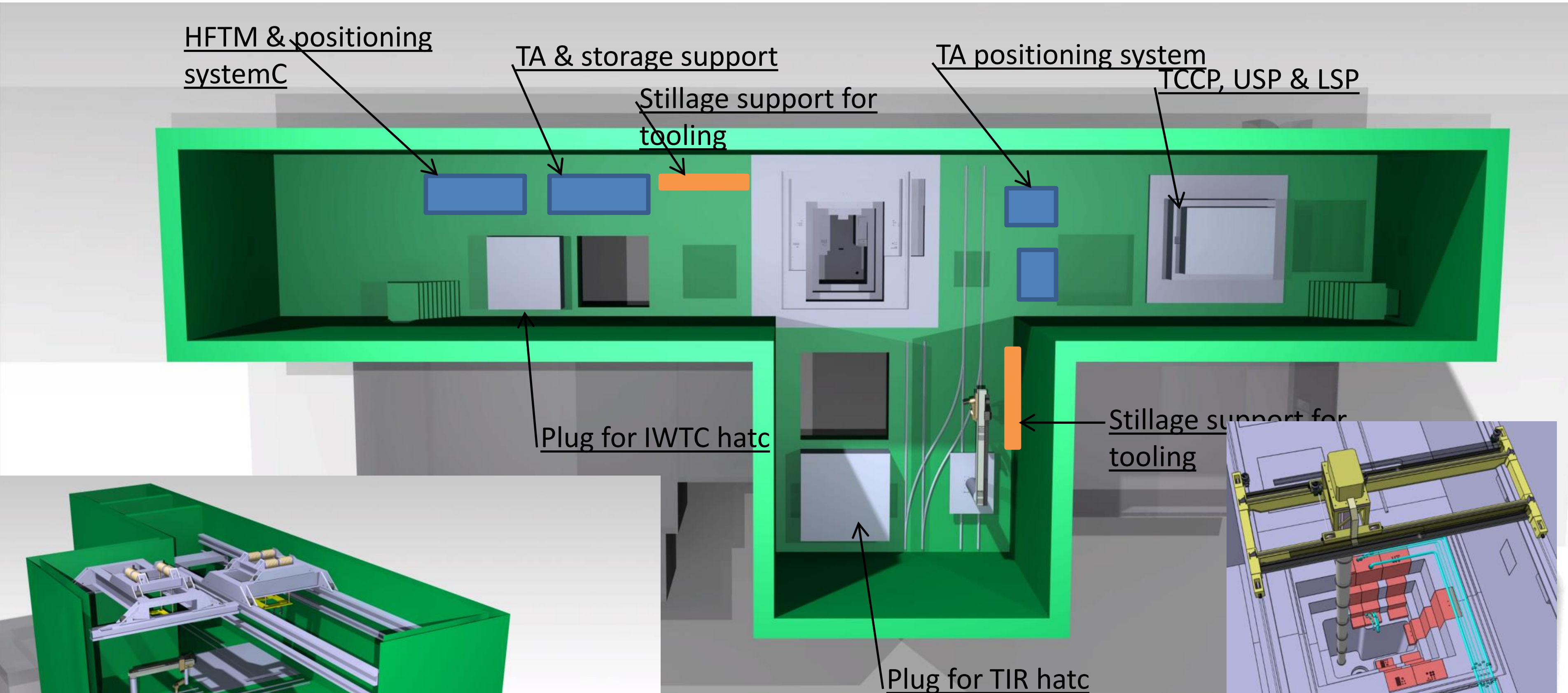


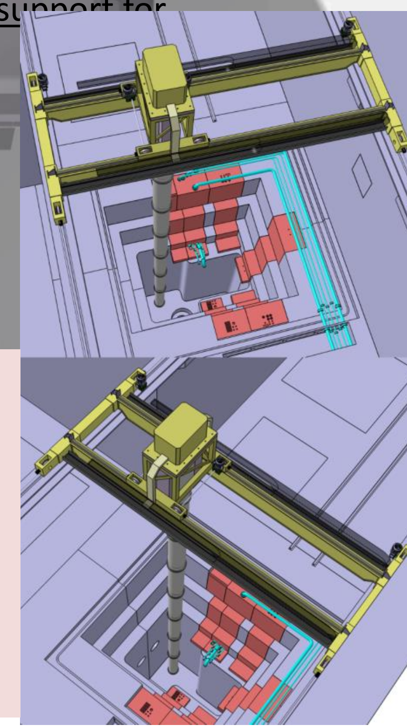


Challenging!!!!

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

Remote Handling System



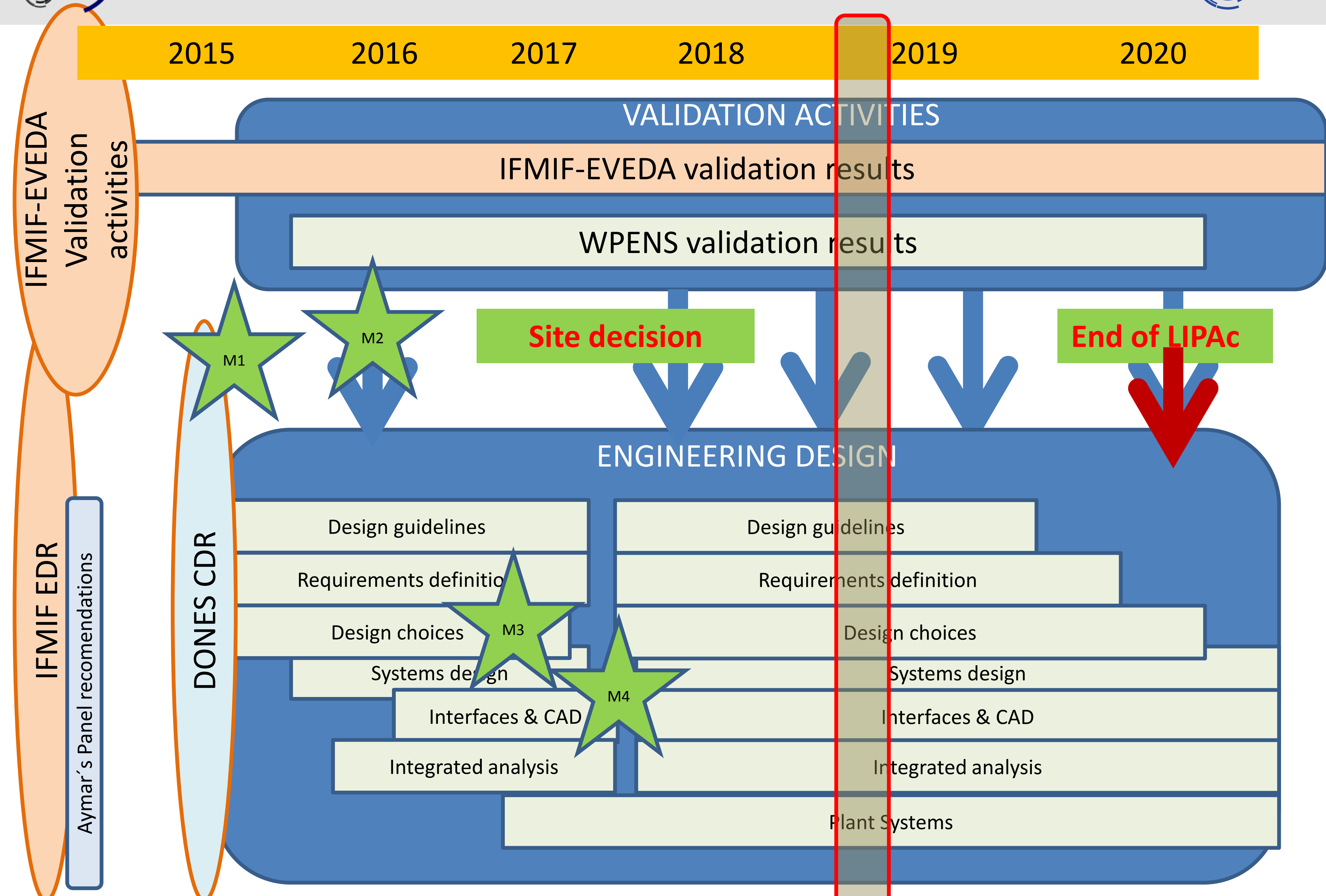


Main RH operations are made in the Access Cell

Other relevant ones (no regular ones):

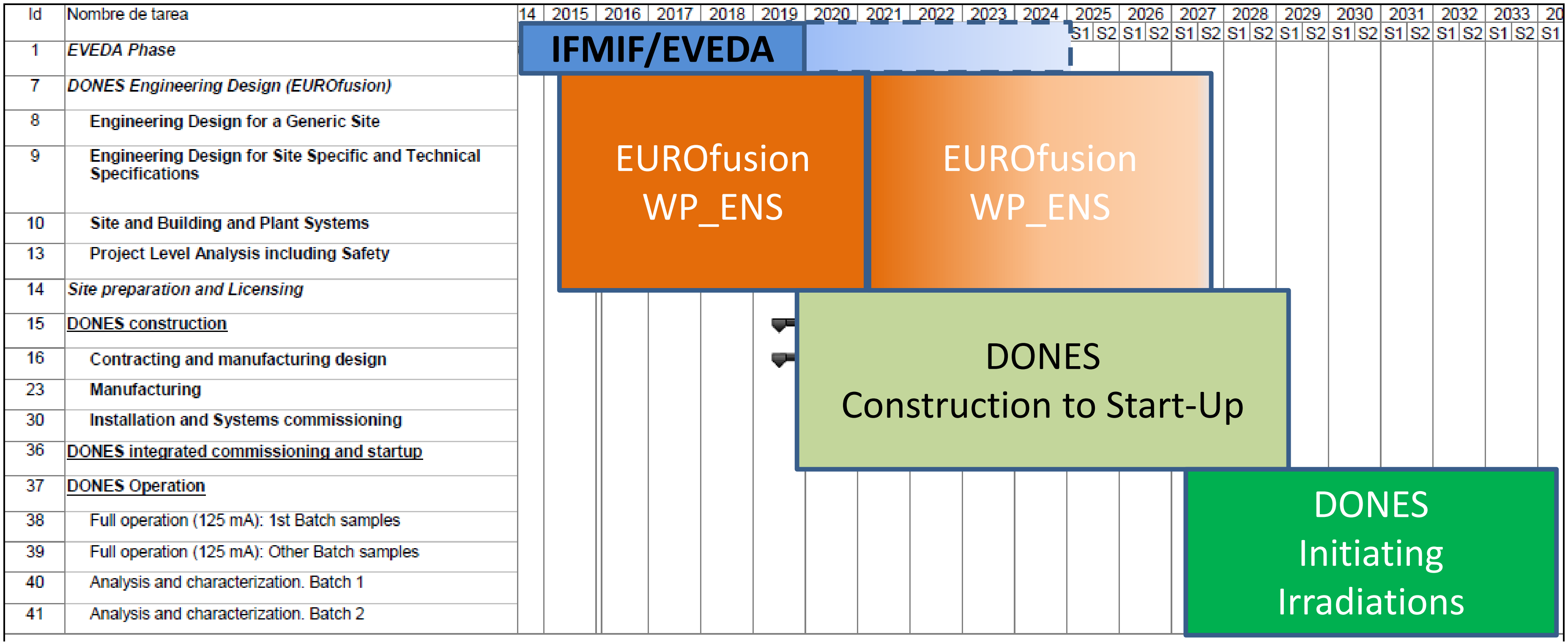
- for the accelerator Beam Dump (managed by a Cask Transporter)
- Li loop area

Where we are?



2015
2016
2017
2018
2019
2020
IFMIF-EVEDA Validation activities
VALIDATION ACTIVITIES
IFMIF-EVEDA validation results
WPENS validation results
M1
M2
Site decision
End of LIPAc
ENGINEERING DESIGN
IFMIF EDR
Aymar´s Panel recomendations
DONES CDR
Design guidelines
Requirements definition
Design choices
M3
Systems design
M4
Interfaces & CAD
Integrated analysis
Design guidelines
Requirements definition
Design choices
Systems design
Interfaces & CAD
Integrated analysis
Plant Systems

Reference Time Schedule

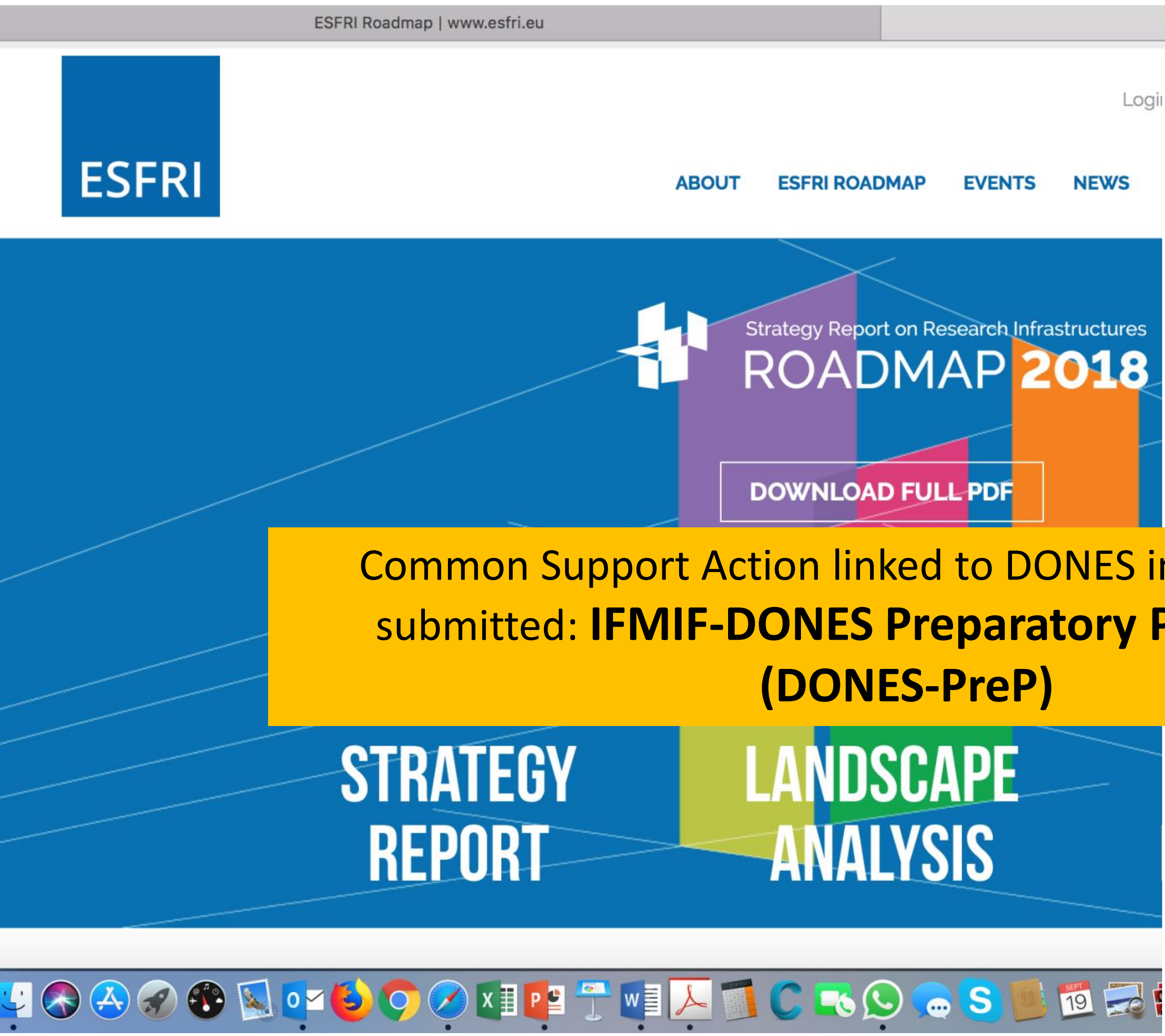


Time schedule based on the assumption that engineering design activities are steadily ongoing (WP_ENS), manufacturing activities will be linked to results obtained by the IFMIF/EVEDA project_ and on budget availability after 2020

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
[…]

operation: […]

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 […]ent […]

[…]ion […]hibit 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 submitted: **IFMIF-DONES Preparatory Phase Project (DONES-PreP)**

Outline

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

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

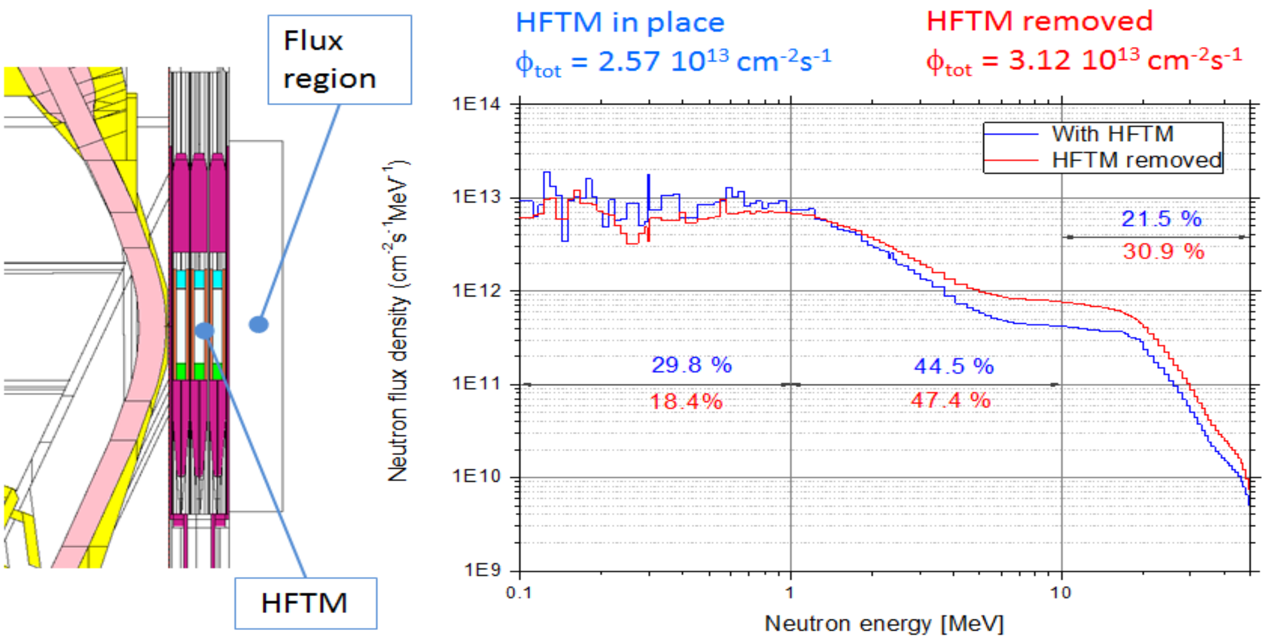
- Mechanical properties of irradiated materials from small samples
- Computed tomography imaging using fast neutrons
- Transmutation doping of silicon and radiation-damage testing of electronics

Complementary Experiments: Boundary conditions

Main DONES mission: irradiation of fusion materials

Complementary experiments could use:

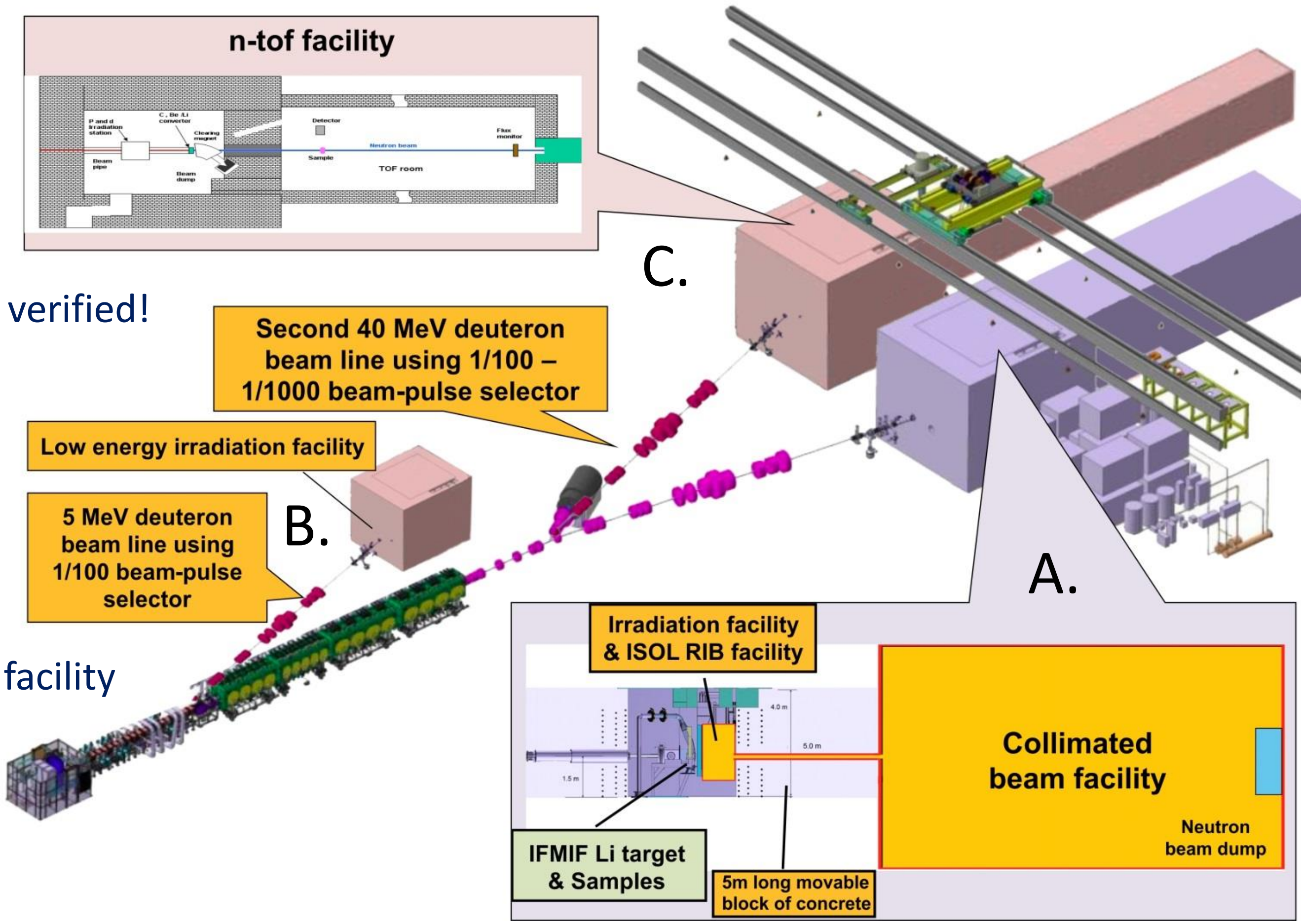
- **Deuterons** extracted from the accelerator beam but only a small fraction (a few percent)
- **Neutrons** available behind the Irradiation Module either inside the Test Cell or in a dedicated additional experimental hall



Flux region behind High Flux Test Module with HFTM in place and removed

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

Complementary Experiments Area (option A) incorporated into the DONES building design

Complementary Exp Area

Room R160

Dimensions

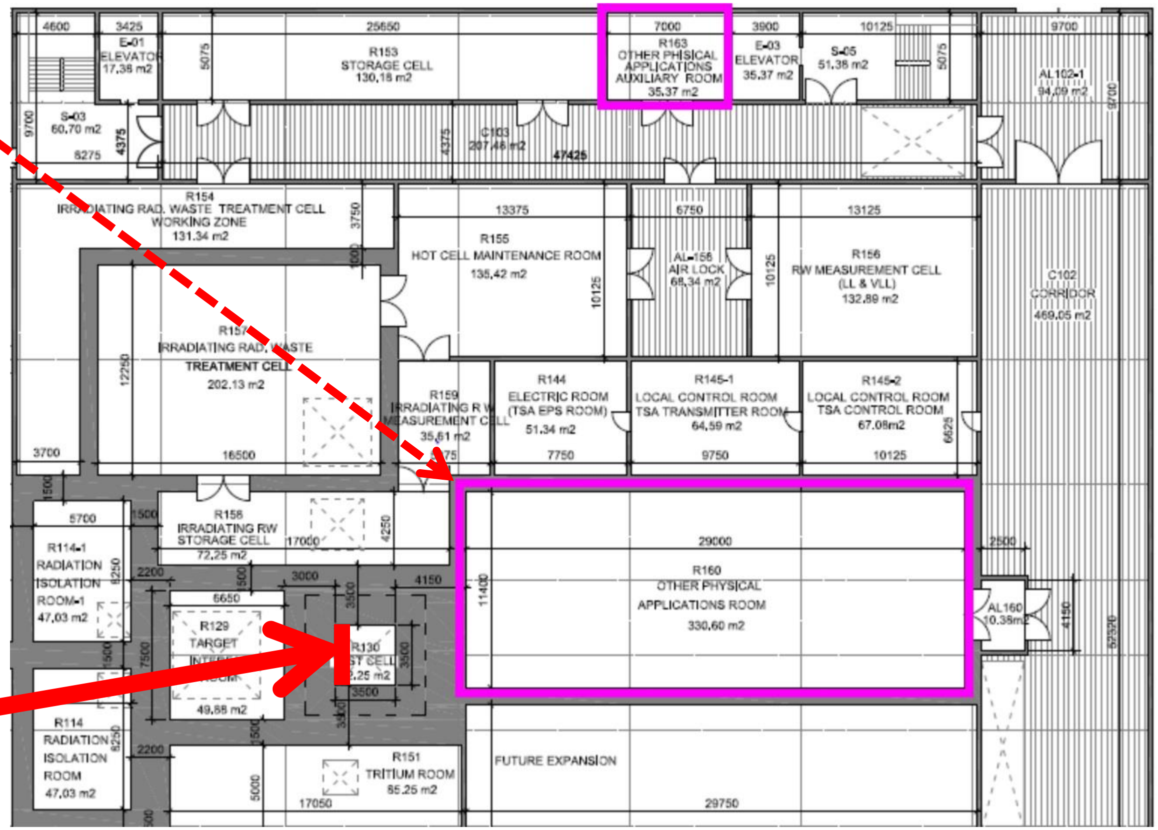
29.00 m x 11.40 m,

height 8.00 m, 330.60 m^2

Auxiliary Room R163

7.00 m x 5.07 m, 35.37 m^2

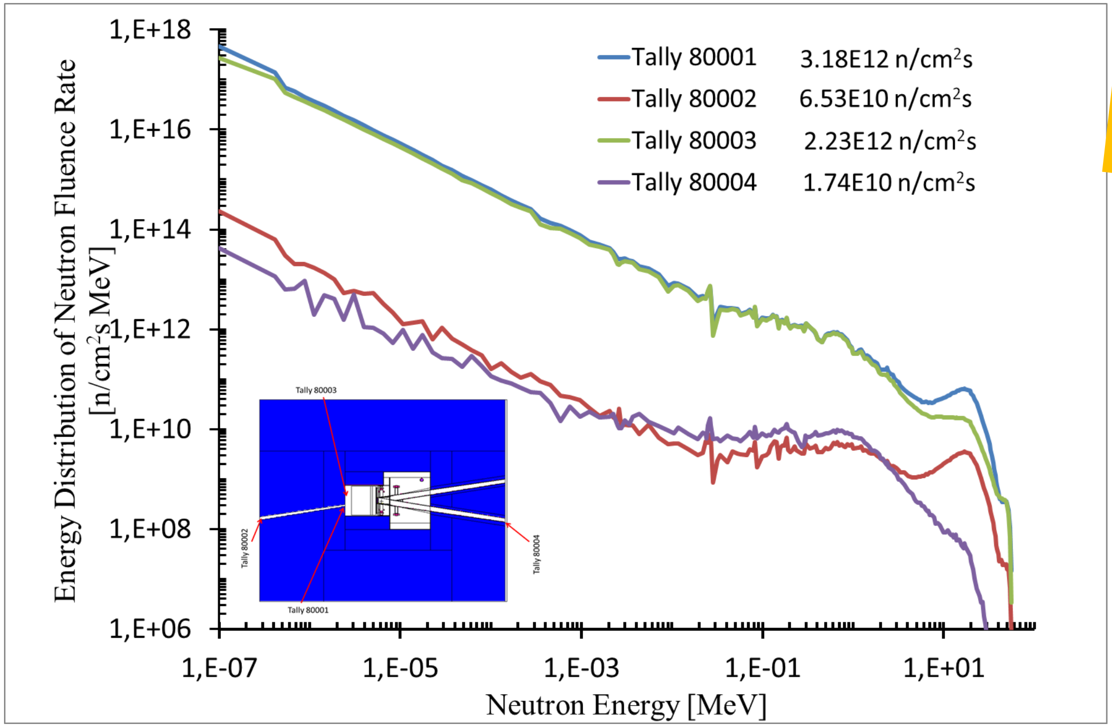
40 MeV deuteron beam arrives from this direction



Part of the DONES first floor plan (as in the PEDR)

- ❖ **Ongoing discussion on shielding, arrangement of experimental setups in R160**
- ❖ **Other remaining proposals** (deuteron beam kicker at 5 or 40 MeV) **are on-hold** pending feasibility confirmation and external user interest

Complementary Experiments Area (option A)



Relevant neutron source could be available!

- Conceptual design activities are presently being carried out to define a possible electronics irradiation area, an isotopes production area and a nuclear physics area

- Additional ideas/designs are welcome!!!!

Outline

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Summary

- A fusion-like neutron source is needed as soon as possible for DEMO design
- IFMIF-DONES is the EU proposed alternative to be implemented 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 20 dpa/fpy
- There is a Spanish proposal to host it in Granada and there is agreement at the EU level that if DONES is built in EU it will be built in Granada
- The facility can be used simultaneuosly for Other Complementary Experiments. Ideas and colaborations are welcome

End