IFMIF-DONES

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Jornada FUSIONa2
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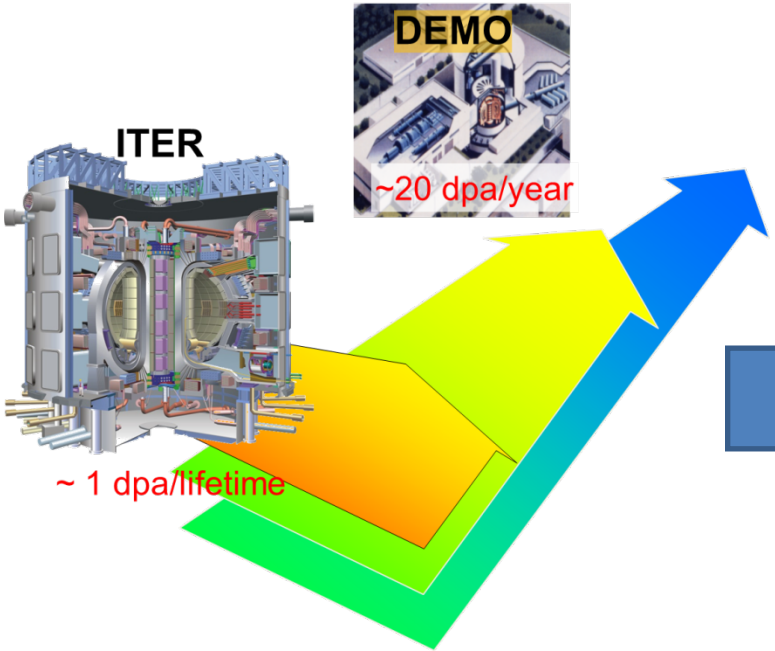
IFMIF DONES GRANADA

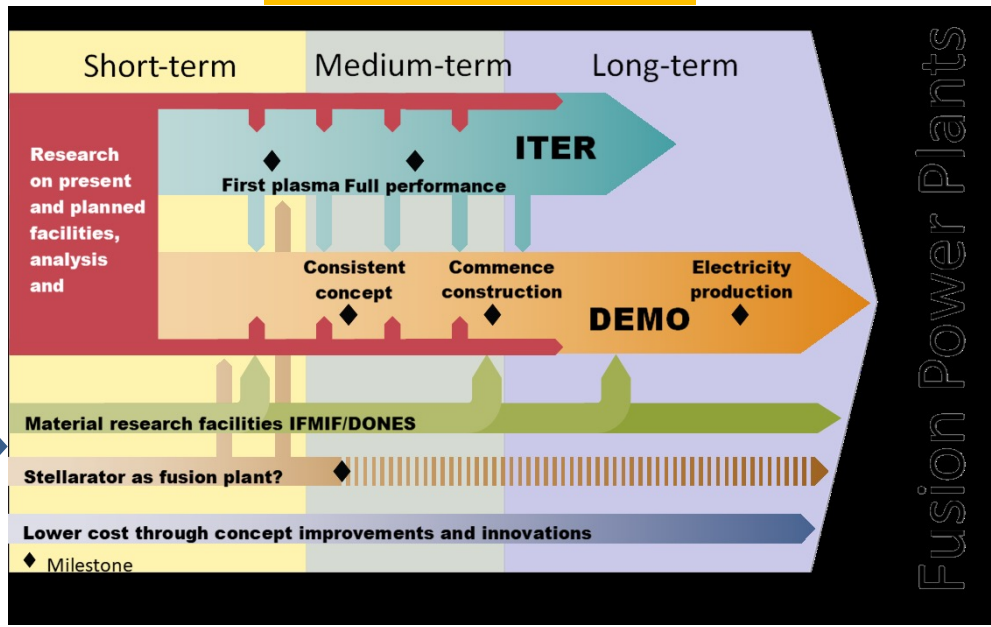
DONES Preparatory Phase

Why DONES?

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

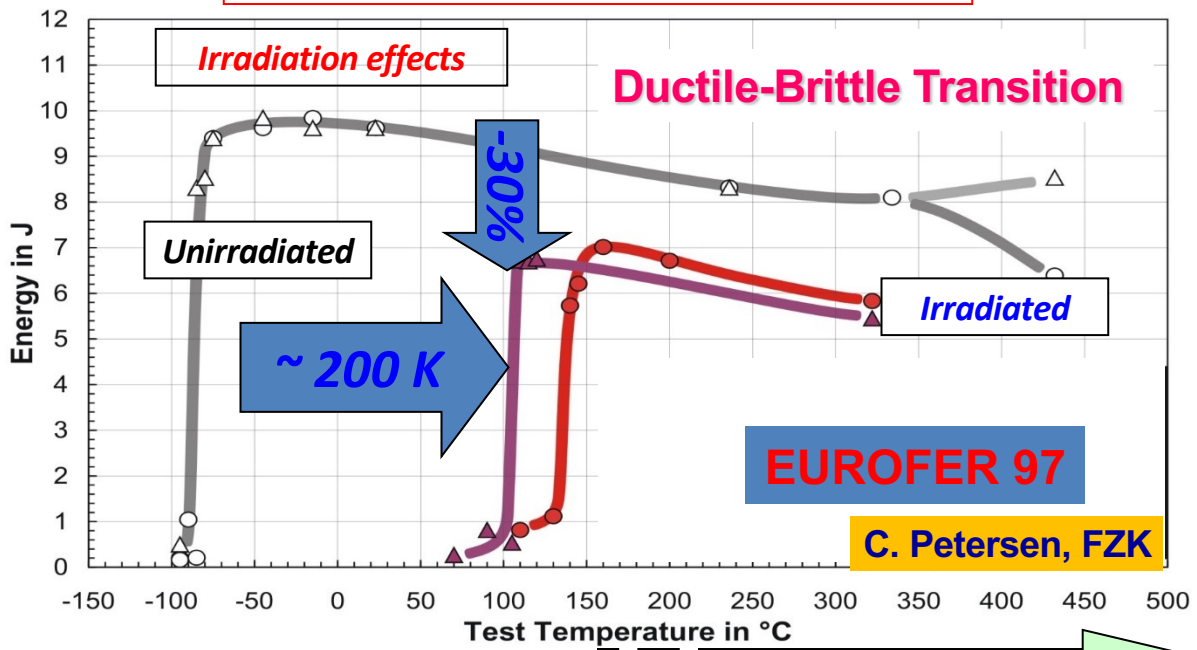


EU Fusion Roadmap



Impact properties degradation

~32 dpa, 332°C, ARBOR 1 irradiation



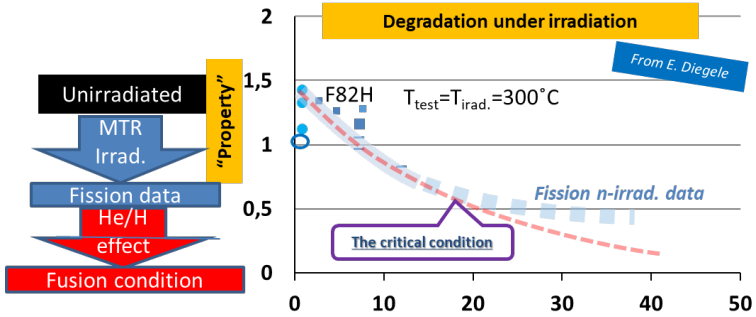
Concerns: i) ΔDBTT > 200 K
ii) Effect of Helium?

EU Strategy for Material n-Irradiation

Fission irradiations

- **Intensive and broad use of MTR (Material Test Reactors) fission irradiation:** EU plans for 50M€ in the next decade
- **Complementary irradiation modelling and verification (multi-ion beams)**

To establish 1st step "best estimate" to perform engineering design



Fusion-like irradiations

- Mandatory: a dedicated facility for material qualification that best mimics 14Mev neutrons with reasonable irradiation volume, fluence, and optimized homogeneity in T with the objective to (finally) validate in-vessel materials

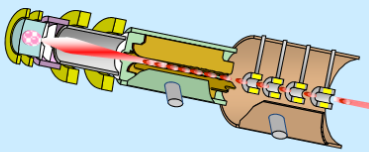
Based on the assumption that fusion-related effects will appear only at high dose (>10-20 dpa)

What is the IFMIF-DONES project?

The fusion-like neutron source required for the qualification of the materials to be used in the EU DEMO

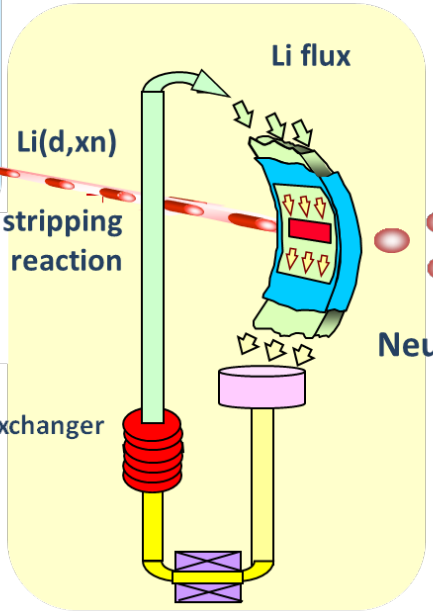
Accelerator

Deuterons: 40 MeV 125 mA (5 MW)



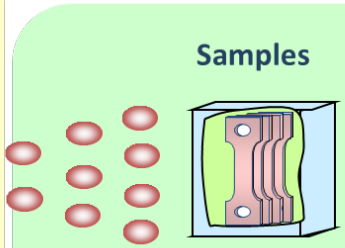
Deuterons at 40 MeV collide on a liquid Li screen flowing at 15 m/s

Lithium Loop (Target)



Heat removal by high velocity Li flux

Test (Irradiation) Module



Neutrons ~ 10^{14} n/cm^{2}s

High Flux Test Module:

20-50 dpa/y at 100 cm^3

Controlled temperature:

250 < T < 550 ºC

A neutron flux of ~ 10^{18} m^{-2}s^{-1} is generated with a 14 MeV neutron spectrum (up to 50 MeV energy)

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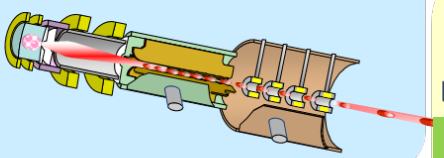


One of the more powerful accelerators in the world

Challenges:high power, high space charge, cw wave operation, high reability, longest RFQ,…

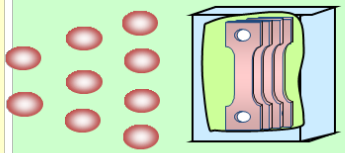
Lithium Loop (Target)

Biggest Li loop in the world

Challenges: Biggest Li loop in the world, power management, impurities management –corrosion risks-, reability, lifetime,…

Heat removal by high velocity Li flux

Test (Irradiation) Module



utrons ~ 10^{14} n/cm^{2}s

Challenges: RH, reability and long term control,…

A neutron flux of ~ 10^{18} m^{-2}s^{-1} is generated with a 14 MeV neutron spectrum (up to 50 MeV energy)

DONES overall framework

The need for a facility of this type was identified long time ago and work has been carried out by using different frameworks

In the last 15 years, key projects are: IFMIF/EVEDA (included in the BA), WPENS –including specific Industry contract- (EUROfusion WP), DONES-PreP (EURATOM CSA), DONES-PRIME and DONES-UGR (Spanish funded projects), ….

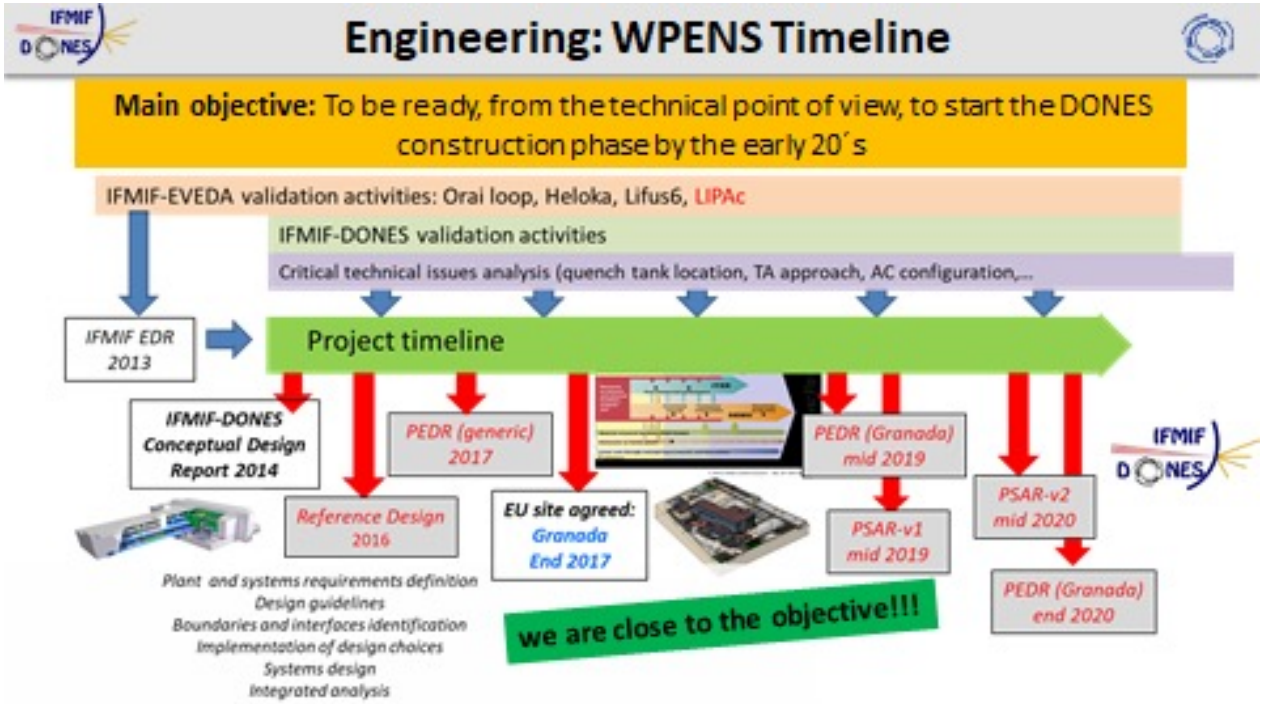
IFMIF

IFMIF DONES

DONES-PRIME
DONES-UGR

Project status

- **Engineering design**
  - Developed for IFMIF (and a generic site) up to 2013 in the framework IEA and BA (IFMIF/EVEDA)
  - Developed for IFMIF-DONES from 2015 in the framework of the ENS WP of EUROfusion



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- **Engineering design**
  - Developed fo BA (IFMIF/EVEDA)
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Advanced enough to start construction phase

Project status

- **Engineering design**
  - Developed fo[illegible]BA (IFMIF/EVEDA)
  - Developed fo[illegible]EUROfusion
- **Prototyping and validation**
  - Being developed for IFMIF (and a generic site) in the framework of BA (IFMIF/EVEDA)
  - Developed for IFMIF-DONES from 2015 in the framework of the ENS WP of EUROfusion
  - Other additional national projects

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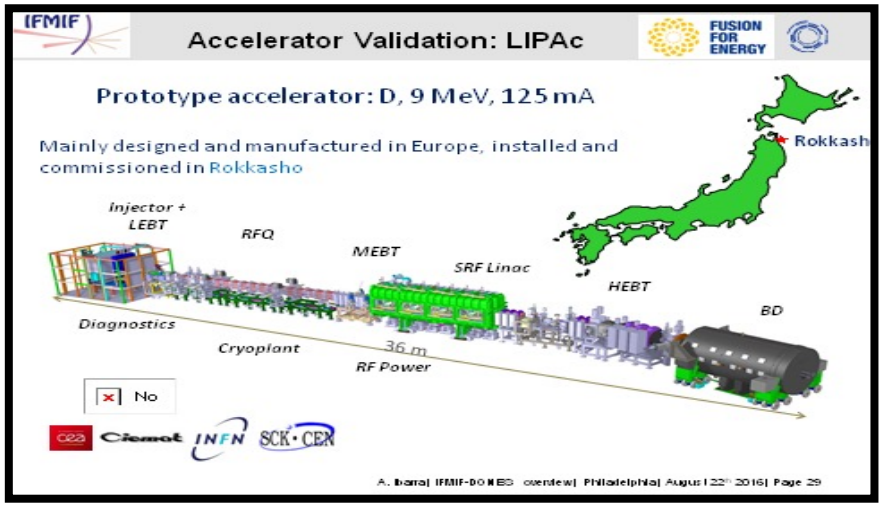
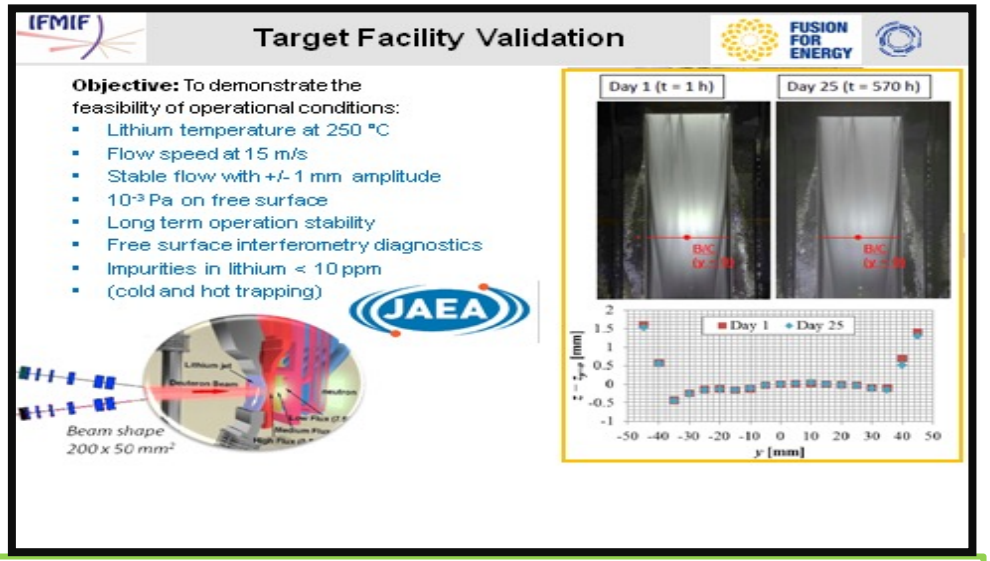
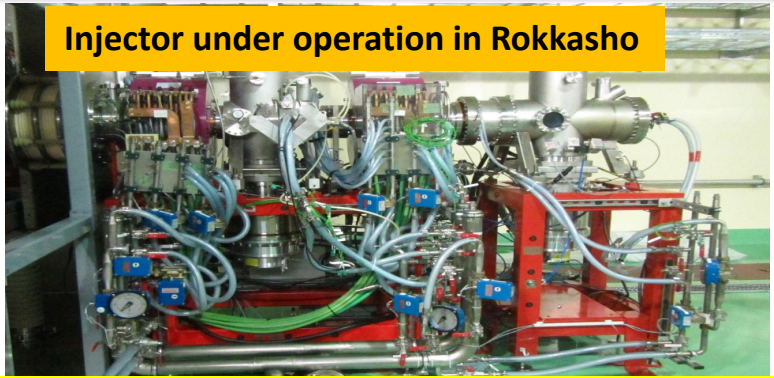
IFMIF-EVEDA Validation Activities





+ many other additional validation activities in many different aspects

Construction status of LIPAc



Injector under operation in Rokkasho

MEBT at Rokkasho site

Diagnostics Plate at Rokkasho site

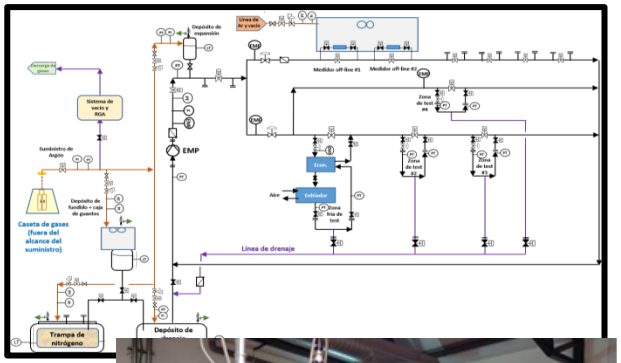
Recent important milestone: 125 mA of D+ in pulsed mode transmitted by the RFQ with very high efficiency

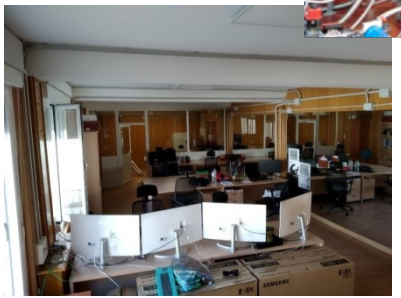
RFQ presently under commissioning at Rokkasho

Part of the RF sytem under operation at Rokkasho

Specific Facilities under development

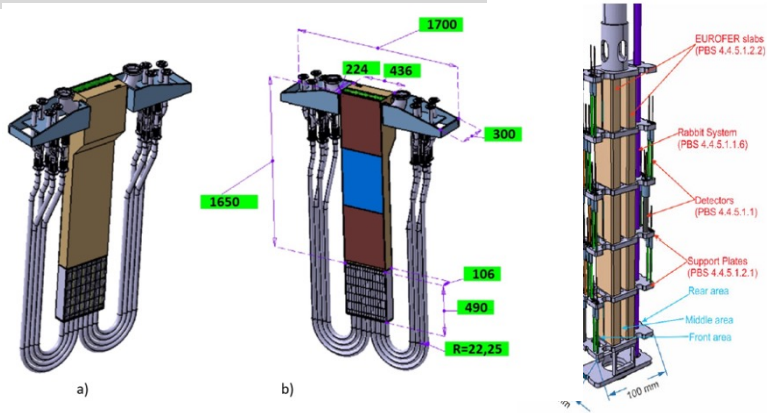
- **Virtual Reality lab** for Remote Handling simulation
- **Control Systems Lab** with the target to develop a digital mockup of the facility
- **High-power RF Lab** to test SSPA technology and components
- Li purification prototipe loop (**LITEC**) to test impurities control technology
- **LIFIRE** facility to study Lithium fire risks

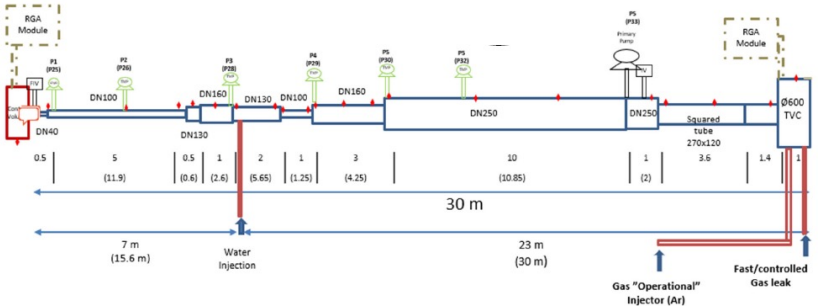


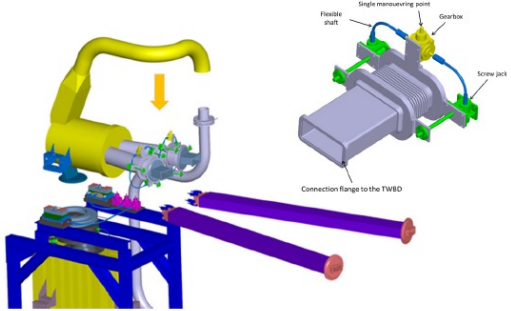


Specific prototypes under construction

- **Start-Up Monitoring Module** (STUMM). Irradiation module to used during the commissioning phase in order to fully characterize radiation map
- **Quick Disconnecting System** (QDS). To validate RH conection system
- **Multipurpose VaCuum accidental scenarios** (MuVaCas). To analyze different posible accidental scenarios
- **Electromagnetic Pump prototype**. To characterize pump performance







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- **Prototyping and validation**
  - Bei[illegible]
  - Dev[illegible]
  - Other additional national projects

Advanced enough to start construction phase

Main conclusion up to now: Design seems feasible (more results to come but no showstoppers identified)

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  - Other additional national projects
- **The site**

Advanced enough to start construction phase

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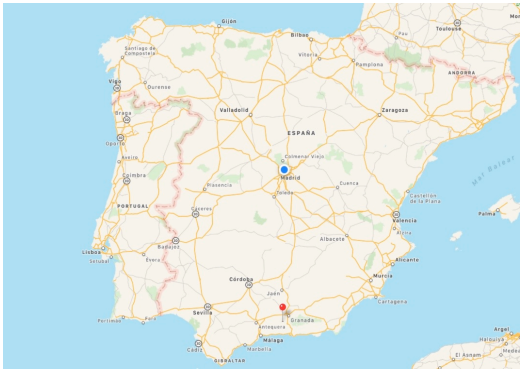
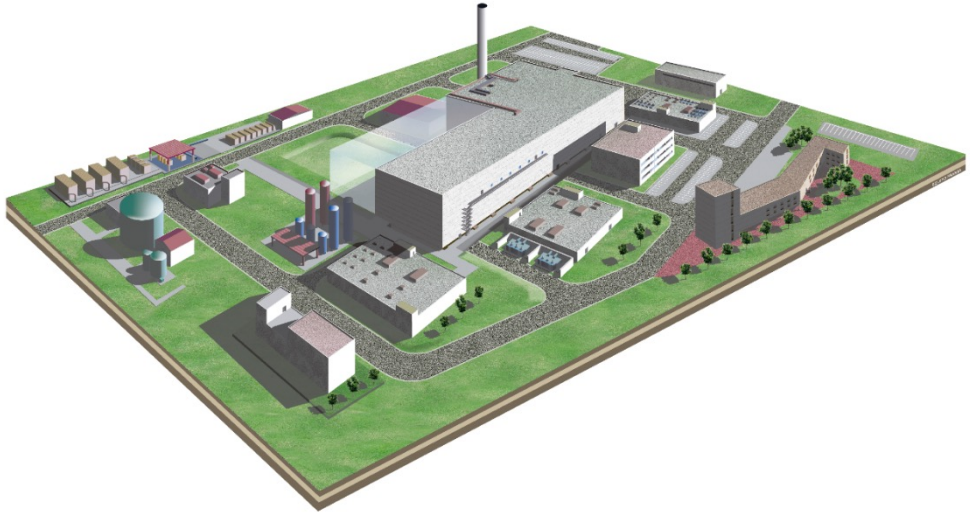
The Site

It has been agreed that if it is built in EU, it will be located in the Granada province (Andalusia region – southern Spain), 18 km southwest from Granada city in the Granada Metropolitan park (Escúzar).





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Available and fully characterized

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- **The site**
- **Implementation**
  - In order to prepare for the project implementation, a complete planning of the project has been prepared (Project Plan, Time Schedule, Cost Estimate, Risk Analysis, Quality, Project Lifecycle,…)
  - At this moment, high level discussions are going on in order to define the international implementation of the project (up to 15 countries and international organizations involved)

Advanced enough to start construction phase

Main conclusion up to now: Design seems feasible (more results to come but no showstoppers identified)

Available and fully characterized

IFMIF-DONES in EU: Schedule milestones

10-11 years up to full operation

Technical manageable & Schedule achievable !!!

Critical path milestones

• Project “start”	2022
• Initial team build up	2022
• Site preparation contract	2024
• Buildings and Plant Systems contract	2024
• Building ready	2028
• Injector contract	2025
• Injector installation	2028
• RFQ contract	2025
• RFQ installation and commissioning	2029
• SRF linac contract	2025
• Start of SRF commissioning	2030
• DONES commissioning	2031
• Start of DONES operation	2032

Hold point linked to LIPAc results

First materials PIE data around 2035-37
Likely three campaigns until end of DEMO EDA

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Advanced enough to start construction phase

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Available and fully characterized

Some decisions are expected in the short term

IFMIF-DONES Spain Consortium

In July 2021 it has been signed the agreement between Spanish Goverment and regional Goverment (Junta de Andalucia) to create a new institution that will be in charge of the project development

Expected role of the Spanish Consortium

- In charge of the Spanish contribution (50% of the construction costs)
- A significant fraction of the international Program Team
- Legal representative of the facility
- In charge of the operation of the facility

Complementary Experiments

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

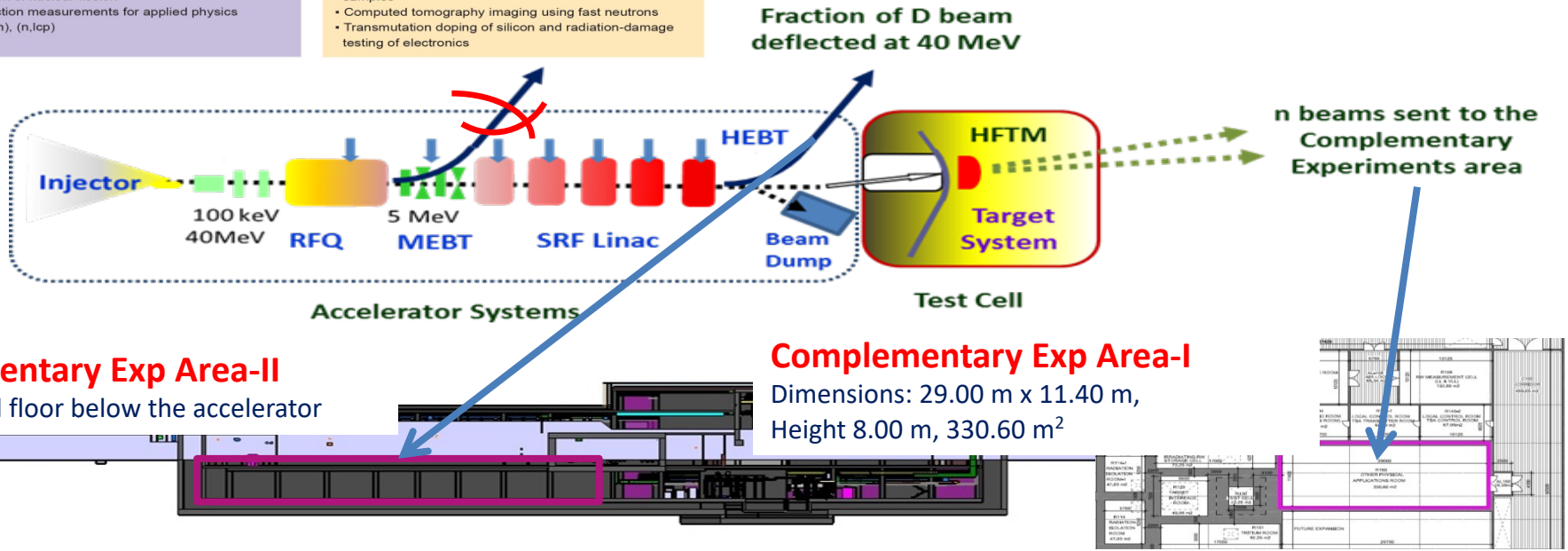
Basic physics studies
- Half-life measurements on long-lived isotopes
- Neutron and neutrino oscillations
- Solid state physics studies

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

❖**Deuterons** extracted from the accelerator beam but only a small fraction (a few percent)

❖**Neutrons** available behind the Irradiation Module either inside or outside the Test Cell



Summary

- IFMIF-DONES is the EU proposed fusion-like neutron source to be implemented in the near future at Granada
- 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 higher than 10 dpa/fpy. The engineering design of the facility has been developed during the last 5 years
- Facility design is flexible enough to accommodate different irradiation needs that will evolve along the time
- Facility design is flexible enough to accommodate simultaneously other type of experiments of interest in other scientific areas
- The Project is progressing properly gaining momentum, international consensus and technical readiness. Significant decisions are expected in the short term

FUSION FOR ENERGY

EUROfusion

IFMIF DONES GRANADA

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN

Junta de Andalucía
Consejería de Transformación Económica, Industria, Conocimiento y Universidades

Laboratorio Nacional de Fusión Ciemat
CCFE UK Atomic Energy Authority
cea
ENEA
EMPRESARIOS AGRUPADOS
IFPiLM
TÉCNICO LISBOA
INFN Istituto Nazionale di Fisica Nucleare
KIT
mta EK
on granada TECH CITY
RB
SCK·CEN
UNIVERSIDAD DE GRANADA
Warsaw University of Technology

Impacto socioeconómico

Impacto muy relevante, pero además es importante resaltar el tipo de impacto: esencialmente tecnológico

(que normalmente tiene un gran poder multiplicador en otras áreas de la sociedad)

Complementary Experiments at IFMIF-DONES

- There is interest in science communities outside of the fusion research program to take advantage of the unique features of IFMIF-DONES
- Complementary experimental program must be implemented in parasitic mode, thus not affecting the main mission of IFMIF-DONES

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

Nuclear physics and radioactive ion beam facility

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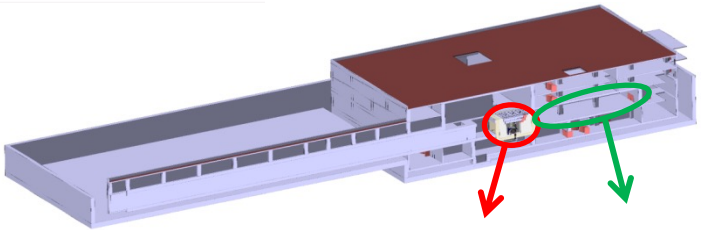
- ...

Industrial application of neutrons

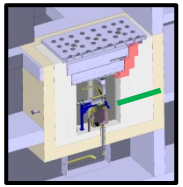
- Mechanical properties of irradiated materials from small samples
- Computed tomography imaging using fast neutrons
- Transmutation doping of silicon and radiation-damage testing of electronics

... this list is not final

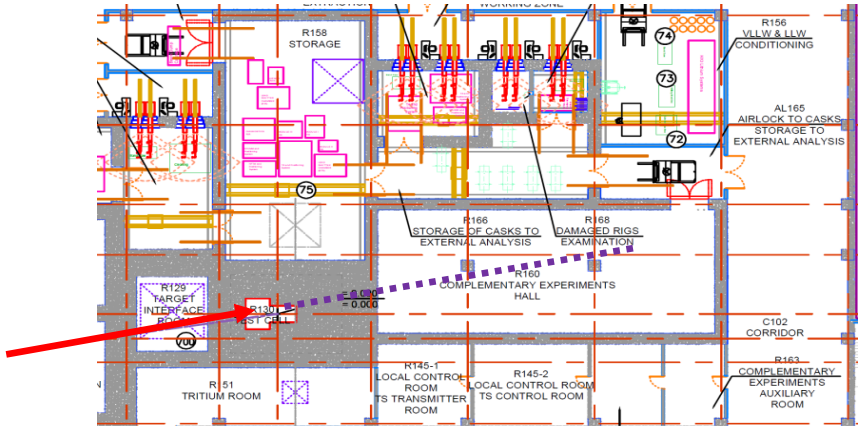
Complementary experiments with neutrons



DONES Test Cell

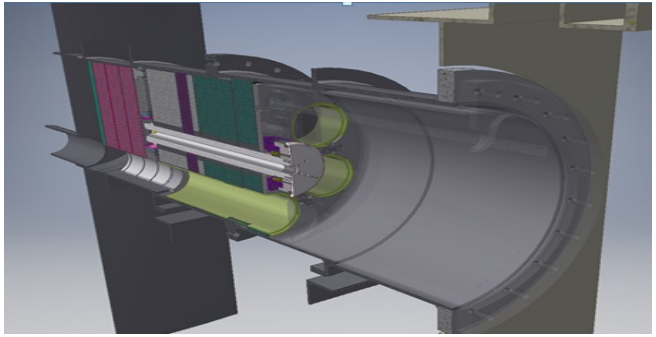


Collimated neutron beam facility – behind the HFTM!

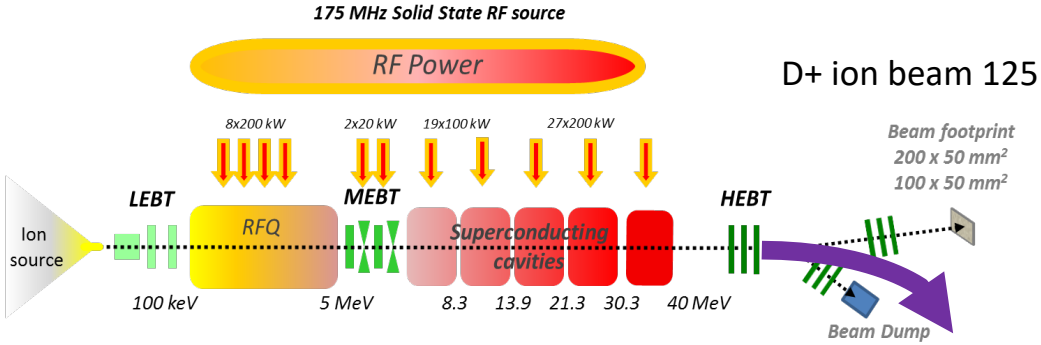


- ✓ A neutron transport line is placed from the Test Cell to a collimated neutron beam facility
- ✓ A neutron shutter is being designed to operate the complementary experiments facility independently of the Test Cell irradiation
- ✓ Possible moderation of the neutron flux is considered

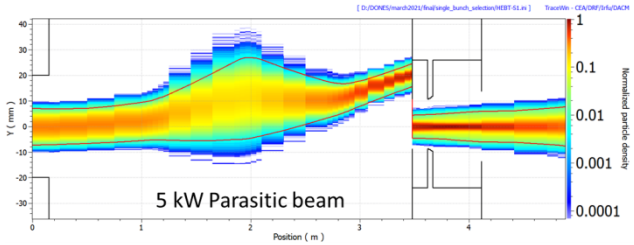
THIS IS IMPLEMENTED in IFMIF-DONES design!

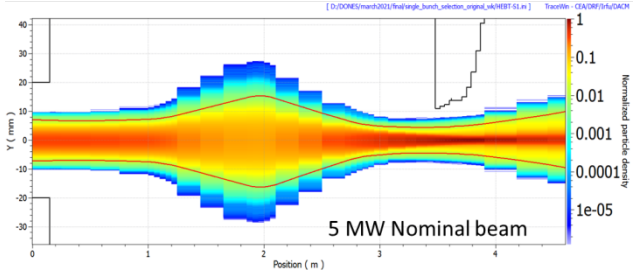


Complementary experiments with deuterons



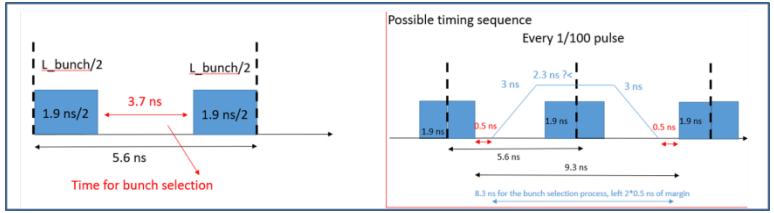
D+ ion beam 125 mA / 40 MeV (5 MW)





Possible extraction of a fraction (1-0.1%) of the beam at 40 MeV:

- ✓ Extraction in the high-energy beam transport line
- ✓ A configuration of a meander line of 3.5 m + electrostatic septum + septum magnet is proposed
- ✓ Timing conditions: a beam bunch length of 1.9 ns, separation between bunches of 3.7 ns
- ✓ Other option a slow extraction, more flexible

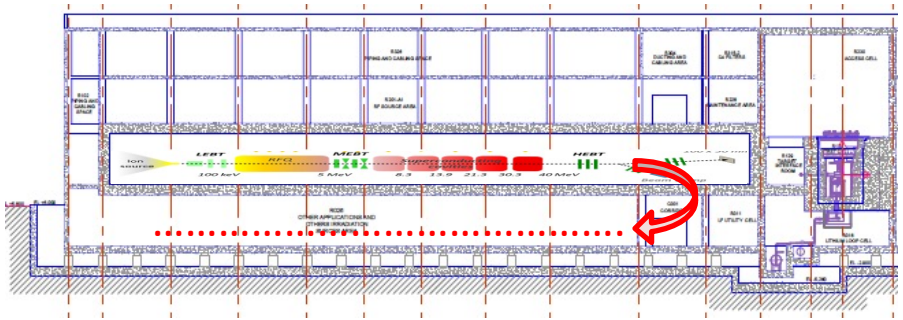


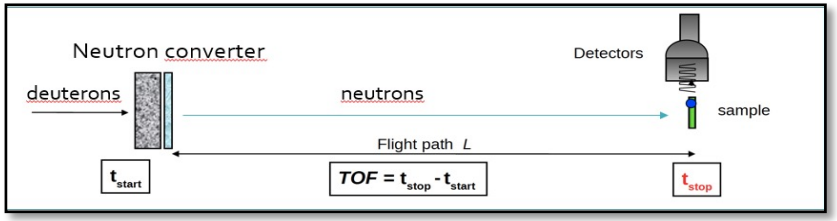
Potential use of 40 MeV deuterons: TOF facility

- ✓ A pulsed beam of 40 MeV deuterons could be used directly for (nuclear) physics experiments
- ✓ It could also be used on another production target (e.g. Li, Be, graphite) **to produce neutrons**,
  → in that way a **pulsed source** of neutrons would be obtained

(similar to NFS facility at GANIL, n_TOF at CERN)

DONES building, section view
Accelerator at level 1, FCE at ground level





Neutron time-of-flight facility (n_TOF)

NO DECISION ON IMPLEMENTATION YET!

This option under study:
- Possible characteristics of parasitic D beam
- Integration with the optics of the nominal beam
- Feasibility of n_TOF facility (or experiments with D)
- Catalogue of possible experiments

DONES Preparatory Phase

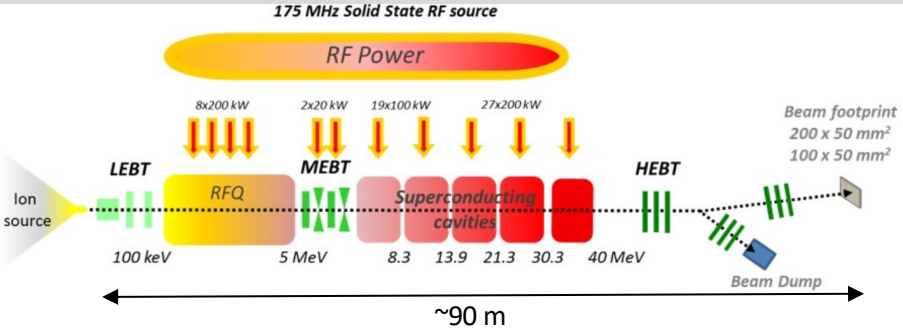
Possible experiments with pulsed deuteron or secondary neutron beams

IFMIF DONES GRANADA

Proposal	Neutron converter	Beam requirements	Target characteristics	Detection system	Uniqueness @ DONES	Foreseen outcome
Gamma spectroscopy of the nuclei produced in fast-neutron-induced fission reaction	Yes	pulsed deuterons; repetition time: few hundreds ns; pulse width: 1-2 ns	radioactive fissile actinide targets; milligram samples; Zr or Be backing	HPGe detectors; GFM spectrometer; TOF measurement	pulsed intense beam; long duration of measurement; combining with GFM spectrometer;	gamma-ray spectroscopic studies of hitherto inaccessible exotic nuclei near the doubly-magic ^{78}Ni
Production of radionuclides with high intense deuteron beam	No	continuous or pulsed deuterons;	powder targets; backing	HPGe detectors; pneumatic transfer system	high beam intensity; long irradiation time	production of Cu-64, Re-186g, and *in vivo* Sc-44m/Sc-44g generator
Investigation of pygmy dipole resonance (PDR) in stable nuclei via (n, n') and (d, d') reactions	Yes/No	pulsed deuterons; repetition time: few hundreds ns; pulse width: 1-2 ns	stable targets; about 3 cm thick	PARIS detectors; neutron detectors; TOF measurement	pulsed intense beam; two probes (n and d); complementary to the studies in other labs	studies of the fine structures of pygmy dipole resonances in various nuclei e.g. ^{90}Zr, ^{124}Sn, ^{208}Pb ... with neutron and deuteron probes
Half-life measurements of long-lived isotopes	Yes	continuous	stable targets; > 1 gram samples	HPGe detectors; pneumatic transfer system	high beam intensity; long irradiation time	precise half-lives measurement of long-lived ^{79}Se, ^{93}Zr, ^{107}Pd, ^{129}I, ^{129}Xe, ^{135}Cs, ... isotopes
Deuteron-induced reactions	No	pulsed deuterons; repetition time: few hundreds ns; pulse width: 1-2 ns	stable	neutron detectors; HPGe detectors; TOF measurement; GFM spectrometer	pulsed intense beam	spectroscopic factor and excitation energy determination for the low-spin states in nuclei in close proximity of the path of stability
Neutron Time Of Flight (n-TOF) facility	Yes	pulsed deuterons; repetition time: few hundreds ns; pulse width: 1-2 ns	stable and fissile targets	neutron detectors; HPGe detectors; fission chamber	pulsed intense beam; long duration of measurement; long base for n-TOF	cross sections studies of various neutron-induced reactions

Accelerator systems summary

175 MHz, 5MW, 125 mA, CW, high availability: One of the more powerful accelerators in the world

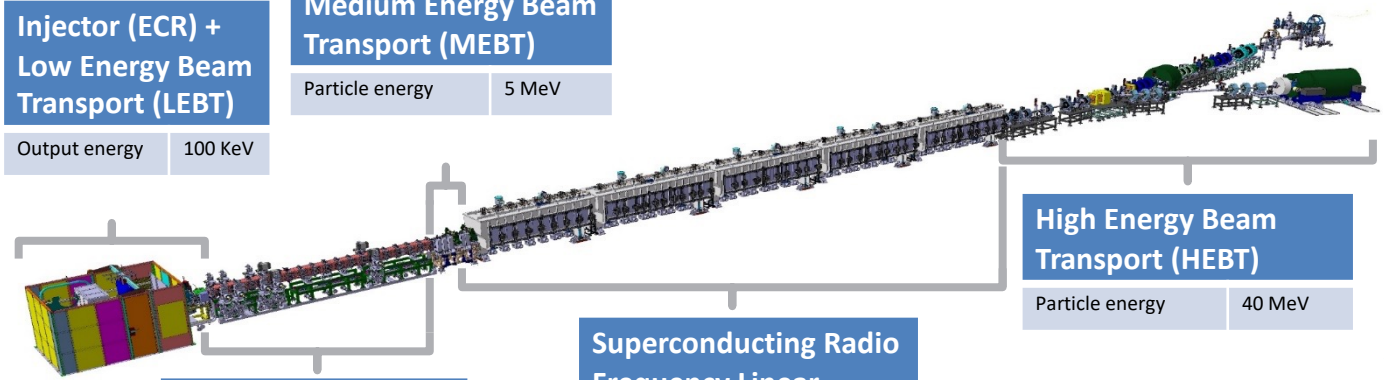


Injector (ECR) + Low Energy Beam Transport (LEBT)

Output energy	100 KeV

Medium Energy Beam Transport (MEBT)

Particle energy	5 MeV



Radio Frequency Quadrupole (RFQ)

Output energy	5 MeV

Superconducting Radio Frequency Linear Accelerator (SRF-Linac)

Output energy	40 MeV

High Energy Beam Transport (HEBT)

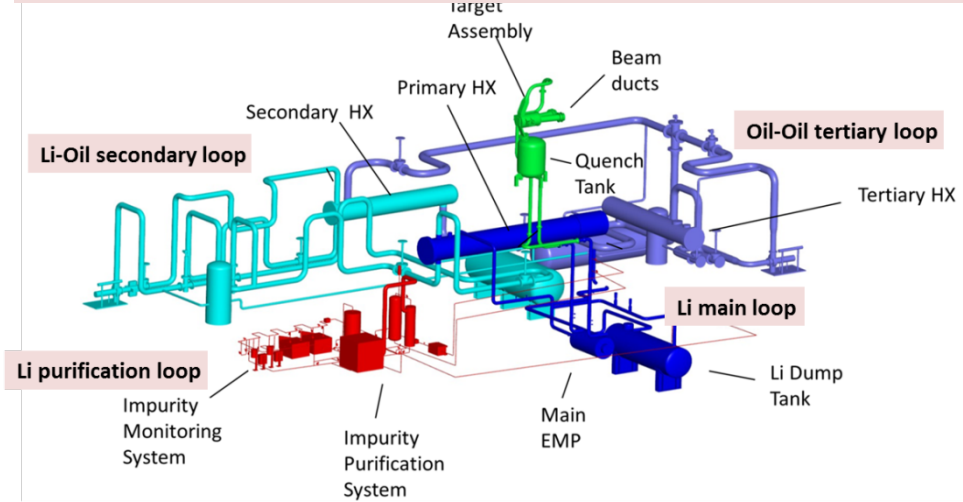
Particle energy	40 MeV

Challenging!!!!

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

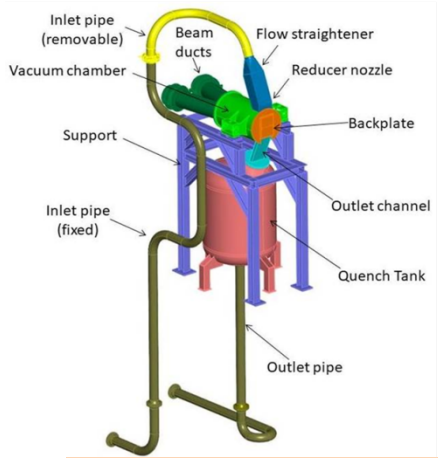
Li systems summary

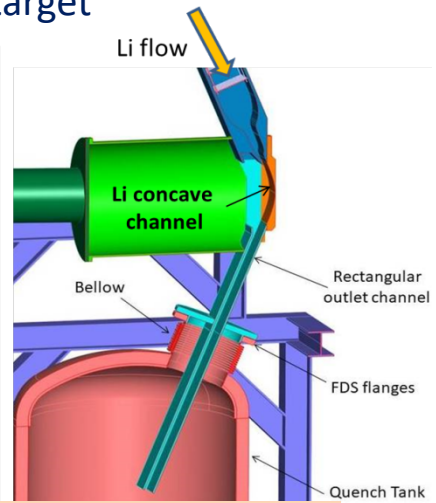
5 MW power handling, 15 m/s Li velocity, remote handling
Main requirements: Li flow stability and Li impurities control



Li volume ~8 m^3 Li flow rate ~100 l/s
Temperature (cold side) ~300 °C

Lithium target





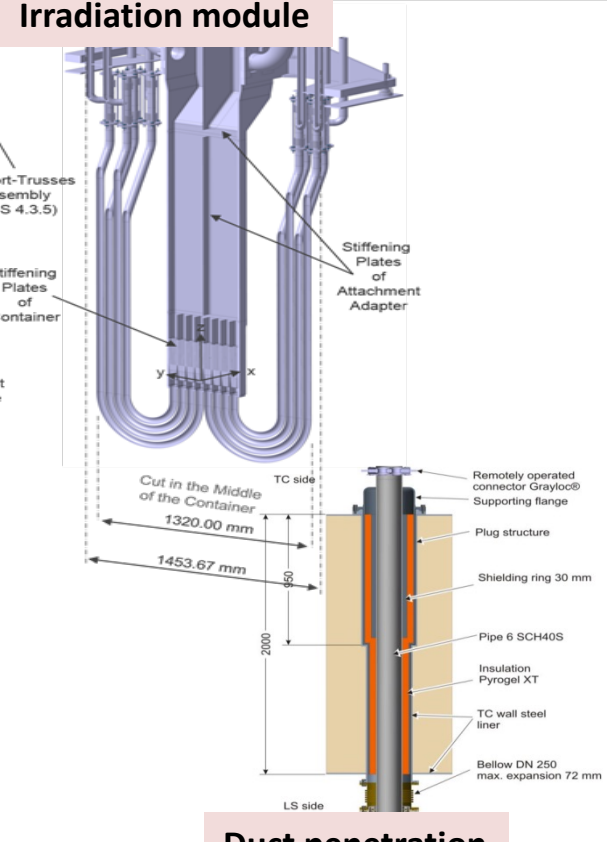
Jet thickness: 25±1 mm Li flow velocity: 15 m/s
Chamber pressure: 10^{-3} Pa Heat flux: 500 MW/m^2

Challenging!!!!

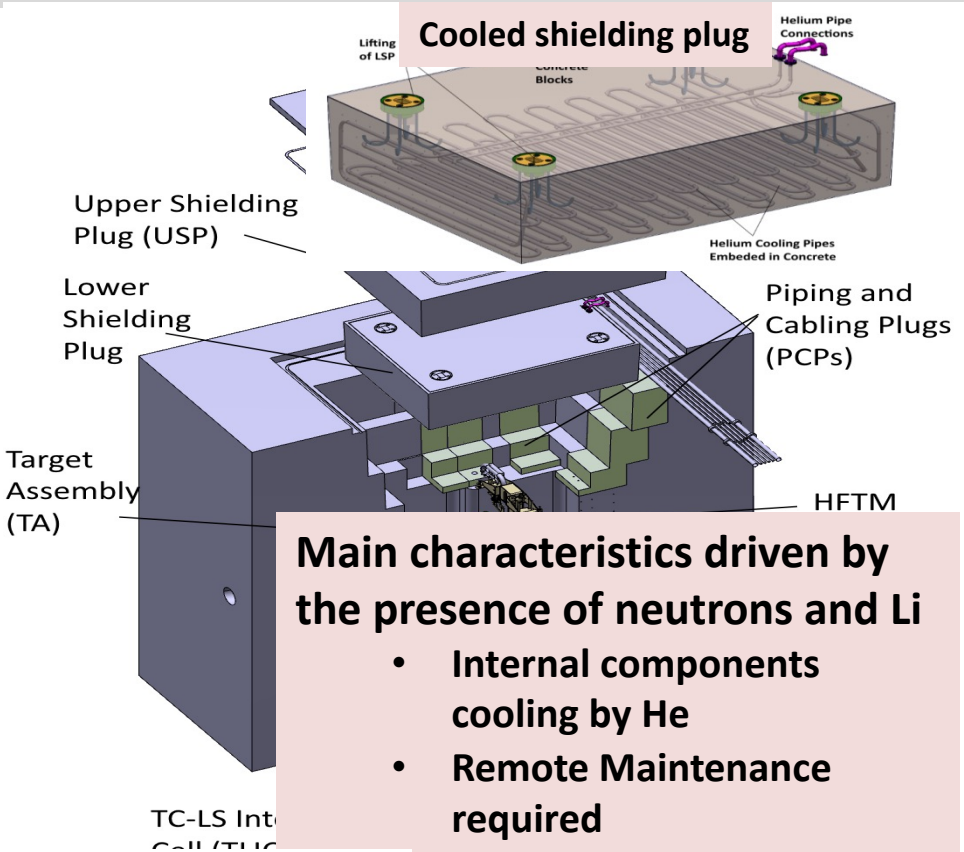
(Biggest Li loop in the world, power management, impurities management –corrosion risks-, reability, lifetime,...)

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, reability and long term control,…)