IFMIF-DONES

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

~32 dpa, 332°C, ARBOR 1 irradiation

Irradiation effects

Unirradiated

Irradiated

~ 200 K

Ductile-Brittle Transition

Concerns: i) $\Delta$DBTT $>$ 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)**
  - Li(d,xn) stripping reaction
  - Heat exchanger
  - Heat removal by high velocity Li flux

- **Test (Irradiation) Module**
  - Neutrons ~ $10^{14}$ n/cm²s
  - Samples
  - High Flux Test Module:
    - 20-50 dpa/y at 100 cm³
    - Controlled temperature: $250 < T < 550$ °C

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

Lithium Loop (Target)
Li(d,xn) Li flux

Test (Irradiation) Module

One of the more powerful accelerators in the world

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

Challenges: Biggest Li loop in the world

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

Challenges: RH, reability and long term control,...

A neutron flux of $\sim 10^{18} \text{ m}^{-2}\text{s}^{-1}$ is generated with a 14 MeV neutron spectrum (up to 50 MeV energy)
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), ....
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
• Engineering design
  – Developed for IFMIF (and some complementary) up to 2013 in the framework of IEA and EBA (IFMIF/EVEDA)
  – Developed for IFMIF-DONES from 2015 in the framework of the ENS Wp of EUROfusion

Advanced enough to start construction phase
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  ![Advanced enough to start construction phase]

• 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
IFMIF-EVEDA Validation Activities

Accelerator Validation: LIPac

Prototype accelerator: D, 9 MeV, 125 mA
Mainly designed and manufactured in Europe, installed and commissioned in Rokkasho

Target Facility Validation

Objective: To demonstrate the feasibility of operational conditions:
- Lithium temperature at 250 °C
- Flow speed at 15 m/s
- Stable flow with +/- 1 mm amplitude
- 10^-2 Pa on free surface
- Long term operation stability
- Free surface interferometry diagnostics
- Impurities in lithium < 10 ppm (cold and hot trapping)

+ many other additional validation activities in many different aspects
Recent important milestone: 125 mA of D+ in pulsed mode transmitted by the RFQ with very high efficiency.
 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 prototype 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 connection system.
- **Multipurpose VaCuum accidental scenarios (MuVaCas).** To analyze different possible accidental scenarios.
- **Electromagnetic Pump prototype.** To characterize pump performance.
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  **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

Main conclusion up to now: Design seems feasible (more results to come but no showstoppers identified)
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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• The site
  – Available and fully characterized

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• The site
  – Available and fully characterized

• 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)
IFMIF-DONES in EU: Schedule milestones

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

Technical manageable & Schedule achievable !!!

First materials PIE data around 2035-37
Likely three campaigns until end of DEMO EDA
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  – Some decisions are expected in the short term
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In July 2021 it has been signed the agreement between Spanish Government and regional Government (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

- **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

**Fraction of D beam deflected at 40 MeV**

- Complementary Exp Area-I
  - Dimensions: 29.00 m x 11.40 m,
  - Height 8.00 m, 330.60 m²

- Complementary Exp Area-II
  - Additional floor below the accelerator
• 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
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)
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.

Complementary Experiments at IFMIF-DONES

- 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 $(n,\gamma)$, $(n,xn)$, $(n,\alpha)$
- ...

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

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

175 MHz Solid State RF source

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
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)

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

NO DECISION ON IMPLEMENTATION YET!
<table>
<thead>
<tr>
<th>Proposal</th>
<th>Neutron converter</th>
<th>Beam requirements</th>
<th>Target characteristics</th>
<th>Detection system</th>
<th>Uniqueness @ DONES</th>
<th>Foreseen outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma spectroscopy of the nuclei produced in fast-neutron-induced fission reaction</td>
<td>Yes</td>
<td>pulsed deuterons;</td>
<td>radioactive fissile actinide targets; few hundreds ns; milligram samples; Zr or Be backing</td>
<td>HPGe detectors; GFM spectrometer; TOF measurement</td>
<td>pulsed intense beam; long duration of measurement; combining with GFM spectrometer;</td>
<td>gamma-ray spectroscopic studies of hitherto inaccessible exotic nuclei near the doubly magic $^{79}$Ni</td>
</tr>
<tr>
<td>Production of radionuclides with high intense deuteron beam</td>
<td>No</td>
<td>continuous or pulsed deuterons; powder targets; backing</td>
<td>HPGe detectors; pneumatic transfer system</td>
<td>high beam intensity;</td>
<td>production of Cu-64, Re-186g, and in vivo Sc-44m/Sc-44g generator</td>
<td></td>
</tr>
<tr>
<td>Investigation of pygmy dipole resonance (PDR) in stable nuclei via $(n, n')$ and $(d, d')$ reactions</td>
<td>Yes/No</td>
<td>pulsed deuterons;</td>
<td>stable targets; about 3 cm thick</td>
<td>PARIS detectors; neutron detectors; TOF measurement</td>
<td>pulsed intense beam; two probes (n and d);</td>
<td>studies of the fine structures of pygmy dipole resonances in various nuclei e.g. $^{89}$Zr, $^{113}$Sn, $^{208}$Pb ... with neutron and deuteron probes</td>
</tr>
<tr>
<td>Half-life measurements of long-lived isotopes</td>
<td>Yes</td>
<td>continuous</td>
<td>stable targets; &gt; 1 gram samples</td>
<td>HPGe detectors; pneumatic transfer system</td>
<td>high beam intensity;</td>
<td>precise half-lives measurement of long-lived $^{73}$Se, $^{99}$Zr, $^{207}$Pb, $^{129}$I, $^{132}$Xe, $^{139}$Cs ... isotopes</td>
</tr>
<tr>
<td>Deuteron-induced reactions</td>
<td>No</td>
<td>pulsed deuterons;</td>
<td>stable targets</td>
<td>neutron detectors; HPGe detectors; TOF measurement;</td>
<td>pulsed intense beam;</td>
<td>spectroscopic factor and excitation energy determination for the low-spin states in nuclei in close proximity of the path of stability</td>
</tr>
<tr>
<td>Neutron Time Of Flight (n-TOF) facility</td>
<td>Yes</td>
<td>pulsed deuterons;</td>
<td>stable and fissile targets</td>
<td>neutron detectors; GFM spectrometer</td>
<td>pulsed intense beam;</td>
<td>cross sections studies of various neutron-induced reactions</td>
</tr>
</tbody>
</table>
175 MHz, 5MW, 125 mA, CW, high availability: One of the more powerful accelerators in the world

Challenging!!!!
(high power, high space charge, cw wave operation, high reability, longest RFQ,...)
Li volume $\sim 8 \text{ m}^3$  
Li flow rate $\sim 100 \text{ l/s}$  
Temperature (cold side) $\sim 300 \, ^\circ\text{C}$

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

Lithium target

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

Challenging!!!!

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

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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,...)