The IFMIF-DONES project: a neutron source for fusion-like materials testing

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Outline

- Introduction and some history
- The IFMIF-DONES Project
- Summary
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• Introduction and some history
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  • Summary
The EU strategy towards fusion energy

JET 1983

ITER

DEMO

Alternative concepts

"Technology"

ITER: scientific and technological feasibility of fusion energy

DEMO: Qualification of components and processes

Reactor: High availability, safe and environmentally friendly, economically acceptable
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
- **DEMO**: 30 dpa/year
- **Gen IV**: ~25 dpa/year
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
• …
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

Irradiation effects

Ductile-Brittle Transition

Unirradiated

~ 30%

~ 200 K

Irradiated

Energy in J

Test Temperature in °C

Concerns: i) $\Delta$DBTT $> 200$ K

ii) Effect of Helium?
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 (FMIT, ESNIT, IFMIF)
IFMIF Main Systems

Accelerator

Deuterons: 40 MeV 2*125 mA (10 MW)

Lithium Loop (Target)

Li(d,xn) stripping reaction

Heat removal by high velocity Li flux

Test (Irradiation) Module

Samples

Neutrons \( \sim 10^{14} \text{ n/cm}^2\text{s} \)
IFMIF/EVEDA activities

• 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

Spain has a very relevant role in this project (around 20%)
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 system under operation at Rokkasho
Fusion Roadmap

Science & Technology Basis for first FPPs

Input from research on present facilities, analysis and modelling

High level milestone

ITER

First plasma
Full performance

Consistent Concept
Comence Construction
Electricity Production

DEMO

Pre conceptual design
Conceptual design
Engineering design

DONES

Materials
Concept improvements and innovations → Lower cost

IFMIF

Back-up strategy: Stellarator
Stellarator viable for an FPP?

Short term
Medium term
Long term

F. Martín-Fuertes | IFMIF-DONES project | FinnFusion | June 4, 2018 | Page 14
• Introduction and some history

• The IFMIF-DONES Project (WPENS)
  ▪ Plant Specifications
  ▪ Main Systems
  ▪ Transversal design activities
  ▪ Complementary experimental areas

• Summary
Neutron Source Requirements

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The IFMIF project since 90’s

**The IFMIF-DONES project!!!**

Requirements based on EU DEMO needs

- > 10 dpa(Fe)/fpy
- 20 dpa(Fe) in 1.5 y
- 50 dpa(Fe) in 3.5 y
- 300 cm³
Based on the IFMIF/EVEDA one with some minor changes implemented.
Neutron flux $\sim 10^{14} \text{ cm}^{-2}\text{s}^{-1}$ with neutron spectrum up to 50 MeV energy

High Flux Test Module: 20 dpa/y in 0.1 L; 10 dpa/y in 0.3 L

Controlled temperature: $250 < T < 500 \degree \text{C}$
Accelerator Systems

- **SRF cryomodule**
- **RFQ**
- **Anode module**
- **Beam Dump**

**RF Coaxial lines**
- **MEBT**
- **SRF Linac**

**Challenging!!!!**
(high power, high space charge, cw wave operation, high reliability, 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)
Li Systems

- 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,...)
Test Systems (i)

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,...)
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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
### Site, Buildings and Plant Systems

1. Remote Handling System
   - RH for the Plant Systems
   - RH for the Lithium Systems
   - RH for the Test Systems
   - RH for the Accelerator Systems
   - Local control of RH system
2. Heating, Ventilation and Air Conditioning (HVAC) System
   - HVAC Water Subsystem
   - Differential Pressure Measuring Subsystem
   - HVAC for Main Building
3. Electric Power System (EPS)
   - Power System Substation
   - SIC Emergency Power Subsystem
   - Electric Distribution Subsystem
4. Heat Rejection System (HRS)
   - Potentially Contaminated Water Cooling Subsystem
   - Non-Contaminated Water Cooling Subsystem
5. Service Water System (SWS)
   - Potable Water Subsystem
   - Demineralized Water Service Subsystem
   - Industrial Service Water Subsystem
6. Service Gas System (SGS)
   - Argon Supply Subsystem
   - Helium Supply Subsystem
   - Compressed Air Supply Subsystem
   - Nitrogen Supply Subsystem
7. Solid Radioactive Waste Treatment System (S-RWTS)
   - Transferring and Storage Devices
   - Transfer, Tools and Treatments Devices
   - Measurement Devices
8. Liquid Radioactive Waste Treatment System (L-RWTS)
   - Collecting Subsystem
   - Storage Subsystem
   - Measurement Subsystem
   - Transfer Subsystem
9. Gas Radioactive Waste Treatment System (G-RWTS)
   - Vent Gas Detritiation Subsystem (VDS)
   - Glove Box Detritiation Subsystem for VDS (GDS-V)
   - Emergency Detritiation Subsystem (EDS)
   - Glove Box Detritiation Subsystem for EDS (GDS-E)
10. Fire Protection System (FPS)
    - Fire Detection Subsystems
    - Fire Extinguishing Subsystems
    - Passive Fire Protection
Safety: Dynamic confinement
VALIDATION ACTIVITIES

IFMIF-EVEDA validation results

WPENS validation results

ENGINEERING DESIGN

Design guidelines
Requirements definition
Design choices
Systems design
Interfaces & CAD
Integrated analysis
Plant Systems

Site decision

M1
M2
M3
M4
PEDR

WHERE WE ARE?


DONES CDR

M1

M2

M3

M4

End of LIPAc

IFMIF-EDR

Aymar’s Panel recommendations

IFMIF-EVEDA Validation activities

F. Martín-Fuertes | IFMIF-DONES project | FinnFusion | June, 4 2018 | Page 27
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.
It has been recently 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,...)

F. Martín-Fuertes | IFMIF-DONES project | FinnFusion | June, 4 2018 | Page 29
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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. ⁹⁹Tc)
- 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,lp)
- ...

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

Their feasibility is to be evaluated
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
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 m²

Auxiliary Room R163
7.00 m x 5.07 m, 35.37 m²

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
• 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!!!!**
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- 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 simultaneously for Other Complementary Experiments. Ideas and collaborations are welcome