IFMIF-DONES – a fusion-line neutron source laboratory for the European fusion program

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Early Neutron Source work package
1. Materials irradiation facility within the European Fusion program

2. Basic concept and validation activities, Early Neutron Source work package

3. IFMIF-DONES laboratory – present status of the design

4. Complementary experiments at IFMIF-DONES

5. Conclusions and outlook
The goal of the program is to achieve production of electricity from a thermonuclear fusion reaction by 2050.

**ITER**

*International Thermonuclear Experimental Reactor*

<table>
<thead>
<tr>
<th>Parameters</th>
<th>ITER</th>
<th>DEMO1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major radius R0 (m)</td>
<td>6.2</td>
<td>9.0</td>
</tr>
<tr>
<td>Magnetic field (T)</td>
<td>5.30</td>
<td>6.64</td>
</tr>
<tr>
<td>Fusion output (MW)</td>
<td>500</td>
<td>1793</td>
</tr>
<tr>
<td>Fusion gain (Q)</td>
<td>10</td>
<td>36</td>
</tr>
<tr>
<td>Neutron wall load (MW m^-2)</td>
<td>0.5</td>
<td>1.15</td>
</tr>
<tr>
<td>Pulse length (h)</td>
<td>0.28</td>
<td>1.83</td>
</tr>
</tbody>
</table>

from F.P. Orsitto et al., Nuclear Fusion 56 (2016) 026009

**DEMO** *Demonstration Power Plant* 2030-2050
European roadmap to fusion energy

The goal of the program is to achieve production of electricity from a thermonuclear fusion reaction by 2050

Executive Summary:

- A high performance plasma is at the heart – ITER
- A solution to the heat exhaust in the fusion power plant is needed
- Robust materials are essential, needing a dedicated neutron source for validation and development
  → material studies and qualification

Existing neutron sources do not reproduce the energy spectrum and other relevant conditions of D+T fusion environment
Qualification of FIRST WALL materials

First wall is to **absorb neutron energy and bread tritium**

Most of the neutron energy will be absorbed by the first wall material

First wall of ITER designed for

\[ R < 2 \text{ [dpa]} \]

DEMO reactor after 5 years of running

\[ R \sim 30-100 \text{ [dpa]} \]

Threshold (no existing data)

\[ R > 30 \text{ [dpa]} \]

At about 30 dpa, particular Helium effects are predicted to set in with respect to changes in the temperature of ductile to brittle transition

**Materials to be studied and validated:**

- Steel (EUROFER), structural material
- Tungsten W, divertor material
- Cu alloys

[dpa]

*displacement per atom in solid*
Ductile vs. brittle materials behaviour

When loads (forces) exceed the limit given by the elastic regime

(a) Ductile Materials:
Materials deform irreversibly → “significant” plastic regime

(b) Brittle Materials:
Materials crack instantaneously → “insignificant” plastic regime

Grey – non-irradiated material
Red Purple – irradiated with 32 dpa

✓ Large shift in Ductile → Brittle transition temperature

✓ Potential effect of Helium generation
A neutron laboratory for the fusion program

1994
IFMIF – International Fusion Irradition Facility
concept developed by EU, Japan, US

2007
IFMIF/EVEDA – Engineering Validation and Design Activities (EU, Japan)

2013
IFMIF Intermediate Engineering Design report

2014
IFMIF-DONES DEMO-Oriented Neutron Source
– approach was recommended for further work (Aymar report)

2015
Eurofusion ENS work package (WPENS)
preparing the engineering design of DONES laboratory

2019
DONES Preparatory Phase program

2020
Targeted demonstration of full current D beam at 9 MeV
by the IFMIF/EVEDA Project (LIPAc accelerator)

2021
Targeted construction time of the DONES laboratory

2025
A fast neutron source based on the stripping reaction allows to reach the required flux and spectrum of neutrons relevant for fusion reactor environment.

$\text{Li(d,xn)}$

**Linear accelerator**

Deuteron beam 40 MeV 125 mA (5 MW)

- LEBT
- RFQ
- MEBT
- RF Power
- Ion source
- 200 keV
- 5 MeV
- 8 MeV
- 14 MeV
- 22 MeV
- 30 MeV
- 40 MeV

**Lithium target**

- Liquid Li loop
- Beam footprint 200 x 50 mm$^2$
- $100 \times 50$ mm$^2$
- 4 W
- Beam Dump

**Test module**

- Sample irradiation
- Neutron flux $\sim 10^{18}$ n / m$^2$ s

**Parameters of the High Flux Test Module:**

- Dose 20-35 dpa/y, volume 100 cm$^3$
- Controlled irradiation temperature $250 < T < 1000$ °C

A. Ibarra, P. Barabaschi, A. Moeslang, J. Knaster, R. Heidinger and the IFMIF Team

Lithium flowing at 15 m/s absorbs beam energy

Heat removal system
Neutron energy spectrum, irradiation dose

Neutron spectrum in DEMO vs. DONES irradiation

Available irradiation volume vs dpa

Range of interest is between 20 and 30 dpa after 1 year of irradiation

Obtained results will be used to validate DEMO design

U. Fischer et al., DONES Neutron Flux Spectrum, IFMIF-ELAMAT Town Meeting, Rzeszów 2016
LIPAc accelerator

part of Broader Approach agreement for fusion research between EU and Japan

Lithium target prototype

Going-on now – Beam commissioning with staged approach:

Phase A  Phase B  Phase C/D

Injector  CW  Diagnostic Box + Beamstop  (Apr.2015 - Aug.2017)

Injector  RFQ + MEBT  1 ms  Diag.-Plate + Low Power Beam Dump  (Jun.2018 - )

Injector  RFQ + MEBT  SRFL + HEBT/D-Plate  1 ms/CW  Final Beam Dump  Target date March 2020

Courtesy of R. Heidinger (F4E) and IFMIF/EVEDA LIPAc team
Early Neutron Source work package (WPENS)

From 2015 till 2020

Principal aim: preparation of the Engineering Design of DONES

Budget: ca. 36 M€ (21 M€ in 2015-18)

Participation: research units and industrial partners from 11 countries, ca. 70 full time persons (ppy)

From 2018 DONES part of the ESFRI roadmap

European Strategy Forum on Research Infrastructures

(...) IFMIF-DONES will play a strategic role in the Energy domain for the implementations of Nuclear fusion solutions to the massive production of energy (…)

DONES Preparatory Phase program will start in 2019
Building and Plant systems are being designed by Empresarios Agrupados, an industrial partner.

- External dimensions 159 x 75 m
- Two floors fully underground, starting at –18 m
- Floor space of about 9000 m²

**DONES Plant Systems:**

- Heating, Ventilation and AC (HVAC)
- Electrical Power System (EPS)
- Heat Rejection System (HRS)
- Service Water System (SWS)
- Service Gas System (SGS)
- Solid, Liquid and Gas Radiactive Waste Treatment Systems (S-, L-, G-RWTS)
- Fire Protection System (FPS)
Accelerator Systems

175 MHz Solid State RF source

Beam D+
Final energy 40 MeV, current 125 mA (5 MW)
Continuous wave (CW) operation
Required beam availability 87%

- Beam on target incident angle 9° (as in IFMIF), upgrade to two accelerators configuration possible
- RF power source in Solid State technology
- Number of SRF cryomodules increased from 4 to 5 to reduce the required accelerating field strength
- Different beam on target footprint possible

Ongoing work:
- Beam losses and energy dissipation on beamline elements
Lifetime of the **Target Assembly** is a critical parameter for the operation mode of the whole DONES facility:

- TA will be exchanged after 10-12 months
- HFTM module will be exchanged at the same time
- Irradiated samples will be removed and investigated

**Components:**
- Lithium Target assembly
- Quench Tank
- Heat removal system (two loops)
- Impurity control and purification

**Total volume of Li in the loop ca. 8 m³**

**Lithium flow rate ca. 100 l/s**

**Main parameters:**
- Li jet thickness: 25±1 mm
- Flow velocity: 15 m/s
- Li temperature (inlet): 250 °C
- Vacuum pressure: $10^{-3}$ Pa
Test Systems and High Flux Test Module

Test Cell containing the Target and HFTM
- The walls of the Test Cell will be cooled using water
- The HFTM will be cooled using Helium
- Individual HFTM capsules with cooling and heaters to allow stable and controlled temperature in the range of 250 – 550 °C

High Flux Test Module

Small Sample Testing Technology (SSTT)

F. Arbeiter et al., Nuclear Materials and Energy (2016)
The STUMM module will be used to:
- Characterize the neutron flux at the irradiation position (measure its position, intensity, energy spectrum)
- Verify and validate neutronics modelling
- Measure the gamma radiation field
- Characterization of the gamma radiation field

It will be used during beam commissioning and each time after a change in the configuration is made.

The STUMM module will contain an array of neutron and gamma sensors, e.g. micro-fission chambers, a rabbit system, gamma thermometers, SPND detectors. **This module is designed in Poland by IFJ PAN and NCBJ**
Neutronics modelling

Modelling of the radiation field (neutron and gamma) in the **Test Cell** and in other rooms of the building for different configurations: wall thickness / normal or high density concrete / during irradiation and beam-off periods.

Horizontal cuts

Vertical cuts

**DONES Test Cell configuration**

**MCNP radiation transport code running on large scale computing clusters**
Remote Handling

Most of the operations involving elements removed from the Test Cell will require **Remote Handling**

- Opening and closing of the Test Cell – removal and transport of the concrete blocks
- Exchanging of the Lithium Target Assembly
- Positioning and removal of the High Flux Test Module
- Installation and removal of the STUMM
- Retrieval of capsules containing irradiated samples from the HFTM
- Some maintenance activities

For all these operations procedures are being established and proper tools and equipment (cranes, manipulators) are being designed,

**Access Cell and its RH instruments:**

Jonathan Horne et al., CCFE „Maintenance Logistics Simulation in VR for DONES Access Cell”
Complementary Experiments at DONES

An international advisory committee called by the Polish ELAMAT Consortium issued „White Book on Complementary Scientific Program at IFMIF DONES”
IFJ PAN Report No. 2094/PL, 2016

**Main mission of DONES:** fusion materials irradiation

**Complementary experiment**
- Existing **neutron flux** behind the HFTM module
- A small fraction of **deuteron beam**

**Applications of medical interest**
- Radiopharmaceuticals for therapy (e.g. $^{99m}$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
  - $(n,γ)$, $(n,xn)$, $(n,lcn)$
- ...

**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 at DONES

A. Complementary Experiments hall behind the HFTM module, or an ISOL RIB facility

B. Experiments using a fraction of D beam at 5 MeV: Low-energy irradiation facility

C. Experiments using a fraction of D beam at 40 MeV, n-tof facility

Complementary Experiments Hall
Room R160 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

Collimated neutron beam facility
In 2017 an expert panel called by the Governing Board of **Fusion for Energy** has reviewed two site proposals submitted by **Croatia and Spain**.

In the end of the process a joint offer of Spain and Croatia was recommended for implementation with a primary site for DONES in Spain, near Granada.
IFMIF-DONES summary and outlook

- Preliminary Engineering Design available, updated each year
- Design reviews of selected systems already started
- Preparation of specifications for tenders for items in the critical path starting from 2019

DONES Preparatory Phase (2019-2020)
- Licensing, site preparation
- Drafting of legal framework
- Complementary experiments

Construction of DONES in Spain, targeted to start in 2021

Early Neutron Source (2015-2020) work package team:

Thank you for your attention!