IFMIF: STATUS AND DEVELOPMENTS*

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Abstract

On the way to the fusion demonstrator (DEMO), ITER is designed to tackle the physics properties of thermonuclear plasmas in relevant conditions, as well as the key technologies. But because of its experimental character, the amount of neutrons produced by ITER all along its life will be about two orders of magnitude below what is expected in a fusion Power Plant. A dedicated facility, called IFMIF (International Fusion Materials Irradiation Facility), is thus mandatory to study and analyse the behaviour of materials under a high flux of energetic neutrons (14 MeV). The Engineering Validation and Engineering Design Activities (EVEDA), launched in the framework of a bilateral agreement between Euratom and the Government of Japan in February 2007, with a duration of 6 years, aims at producing the detailed design file enabling the further construction of IFMIF. The key systems will be also tested during this phase: the low energy part of the accelerator, the lithium target and the high flux test module main elements.

INTRODUCTION

On the way to the fusion reactor, the knowledge and characterization of materials submitted to the intense flux of neutrons becomes more and more stringent. Fusion neutrons have an energy of 14 MeV, much higher than those of fission and their effects on plasma facing components, as well as structural materials must be understood, to prepare the design of the demonstrator, which should follow ITER. The International Fusion Materials Irradiation Facility (IFMIF) aims at offering a dedicated facility producing a large amount of neutrons (10^{18} n/m^2/s) with the appropriate energy spectrum. Its principle, summarised in the Figure 1 is the following:

Two parallel deuteron accelerators bring their beams, carrying each of them 125 mA in continuous wave, to an energy of 40 MeV. These two beams interact with a 25 mm thick liquid lithium "curtain" flowing at about 15 m/s in front of them. The high flux of neutrons generated, whose energy spectrum is rather representative of the one calculated for a fusion demonstration reactor, irradiate the test modules, located just behind the lithium target, and where samples of materials are placed. Post Irradiation Experiment cells where the irradiated samples will be characterised complete the facility.

This facility is described in the Comprehensive Design Report [1], summarising the conceptual studies performed earlier in another context.

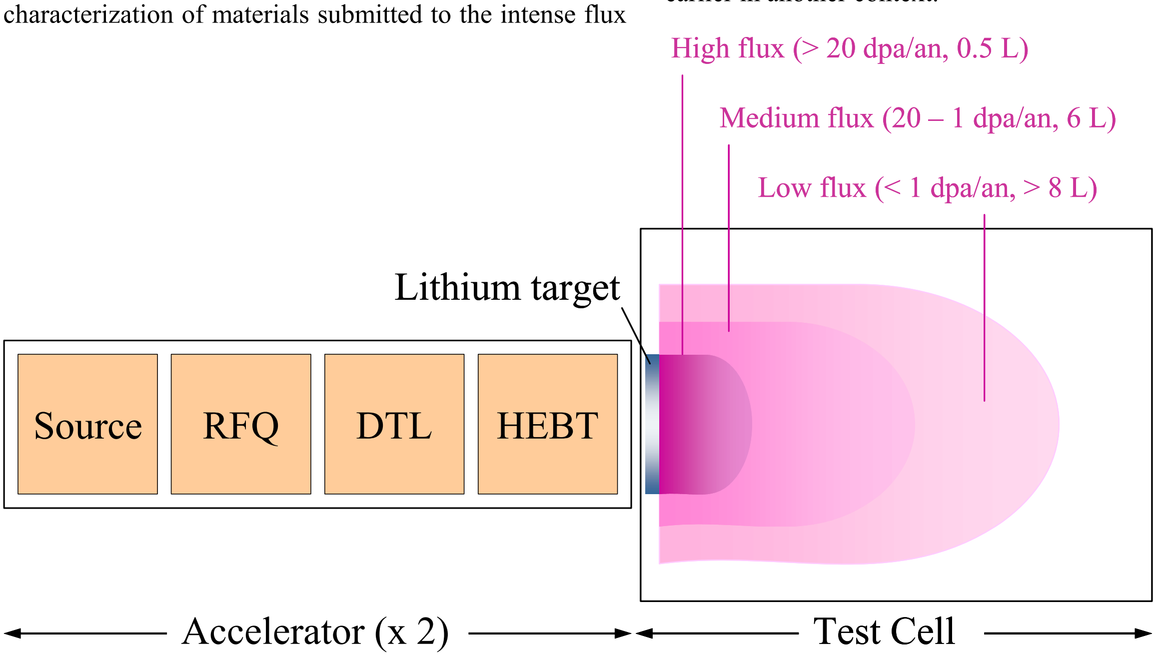

Figure 1: Principle of IFMIF: the two accelerators bring the deuteron beams (125 mA each) to an energy of 40 MeV. The neutrons produced by their interaction with a liquid lithium flow irradiate three sets of volumes called High Flux Test Module, Medium Flux Test Module and a low flux region.

DESCRIPTION OF THE FACILITY

The Accelerator

The two linear accelerators, which are subdivided in the classical injector, low energy beam transport line, radiofrequency quadrupole, matching section, half wave resonator linac and finally high energy beam transport line, have the particularity to carry a very intense deuteron beam of 125 mA in continuous wave (CW).

The ion source development and construction will be based on a prototype built by CEA and called SILHI.

Based on an electron cyclotron resonance at a frequency of 2.45 GHz at 875 Gauss, the source will deliver a deuteron beam of 140 mA at 100 keV in CW. Because of these characteristics, a calculation code has been especially developed to simulate the growth of space charge potential and then its neutralization by electrons coming from the residual gas.

After the Low Energy Beam Transport line, equipped with relevant diagnostics, the RadioFrequency Quadrupole is a four vane structure developed by INFN, with the inclusion of RF couplers, developed by JAEA.

With a Gaussian distribution, an input emittance of 0.22 results in an exit emittance better than 0.26 π.mm.mrad, with a transmission of 95.5 %. Some further optimization is still possible, and error simulations remain to be studied. Losses should be limited mainly in the low energy part of he RFQ, as shown in Figure 2:

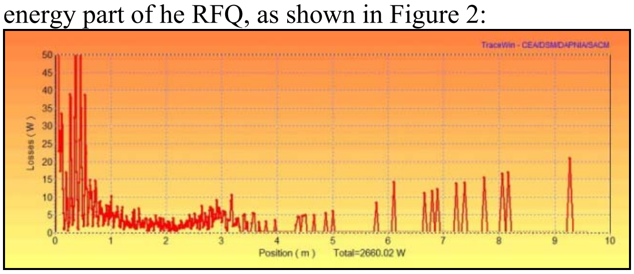

Figure 2: Beam losses (in Power) along the RFQ Case of an unmatched beam coming from the LEBT

The Beam Dynamics activities related to the DTL sections were oriented to the Half Wave Resonator (HWR) superconducting solution. Several versions of superconducting HWR DTL have been studied to accelerate D^+ particles from the RFQ exit (5 MeV) to the final energy (40 MeV). From these studies, a 22 m long LINAC consisting of 4 cryomodules is proposed. The cryomodules contains 21 solenoids of the same type, and 42 resonators from two different families.

The main parameters of the different cryomodules are listed in the following table:

Table 1: Parameters of the 4 Cryomodules of the DTL

Cryomodules number	1	2	3 & 4
Output energy (MeV)	9	14.5	26 & 40
Cryostat length (m)	4.6	4.3	6.0
Number of periods per cryostat	8	5	4
Number of solenoids per period	1	1	1
Number of cavities per period	1	2	3
Cavity β	0.094	0.094	0.166
Cavity length (mm)	180	180	280
Beam aperture (mm)	40	40	48

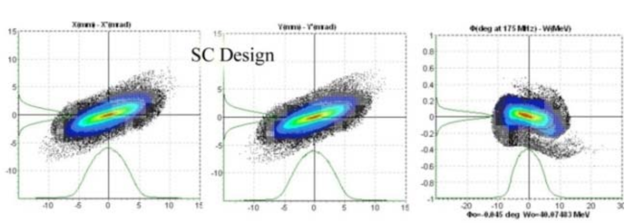

Figure 3: Phase space diagram of the DTL.

At present, no much work has been made on the High Energy Beam Transport line, which includes a delicate optics to convert the circular beam cross section of about 20 mm in diameter to a rectangle of 200 x 50 mm^2.

The RF system is based on standardised units of 60, 110 and 220 kW each at 175 MHz.

The lithium target

The lithium target is also a very innovative concept, represented schematically in the following Figure 4:

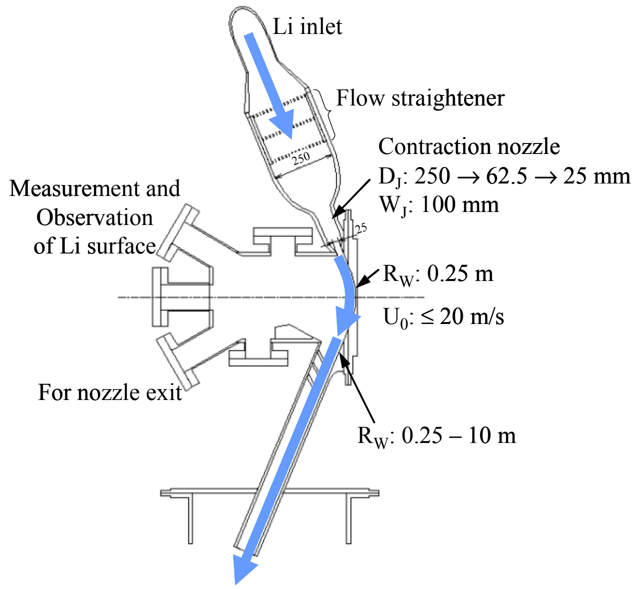

Figure 4: Schematic view of the liquid lithium target. After purification, the lithium is injected on the backplate thanks to a nozzle, which contracts the flow thickness from 250 down to 25 mm. The width of the lithium flow, perpendicular to the Figure, is 260 mm.

The first measurements of lithium erosion and corrosion speed performed in the framework of the project confirm preliminary previous experiments and show the necessity to keep the impurity level at the level of a few 10 wppm, in particular for O, N and C. Because of the tritium generated in the interaction between neutrons and ^{6}Li, hydrogen must also be kept at a very low level.

The Tokyo and Kyushu Universities are studying respectively a nitrogen purification hot trap using a Fe-Ti alloy and a H purification hot trap based on Y bed. Preliminary experiments, performed at reduced scale have shown very promising results in 2007.

One of the most challenging aspects of the target assembly is the ability to regularly exchange (probably once per year) the backplate, which will suffer the highest flux of neutrons (up to 60 dpa/year). Two concurrent concepts are being studied: a European bayonet principle (sliding plate on a frame, the tightness being ensured by a gasket, see Fig. 5 below) and a Japanese lip welded concept. Because of its promising characteristics, these highly irradiated elements will be manufactured in ferritic martensitic steel as Eurofer or its Japanese equivalent F82H.

Figure 5: photograph of the bayonet backplate, designed by ENEA.

The Test Facilities

The last major technological elements in IFMIF are the Test Facilities. Integrated in the test cell (also containing the lithium target assembly), the Test facilities are subdivided into 3 main areas:

The High Flux Test Module is, in the reference design, a set of 4 x 3 capsules, containing a total of about 1000 samples of reduced size. These capsules, filled with NaK to ensure a good thermal contact with the samples, are heated by means of an external heater, while a flux of helium enables a good regulation of the temperature (typically 350 °C).

Three complementary Medium Flux Modules are foreseen today:

- A Creep Fatigue Test Module: this module will enable the study of the behaviour of samples under cycling effort under irradiation;
- A Tritium Release Module, to better simulate under relevant irradiation the materials foreseen in the blanket of the fusion reactors;
- A Liquid Breeder Validation Module, to carry out experiments on a particular technology foreseen for the breeding blankets of the fusion reactors.

The low flux region of the Test Cell is hosting so-called Vertical Irradiation Tubes, which could accept many candidates like windows, isolators necessary for the characterization or monitoring of plasmas, located in low flux regions compared to plasma facing components.

These modules and the Test Cell are shown in the Figure 6 below. The lithium target is also represented, as well as the apertures for the deuteron beams.

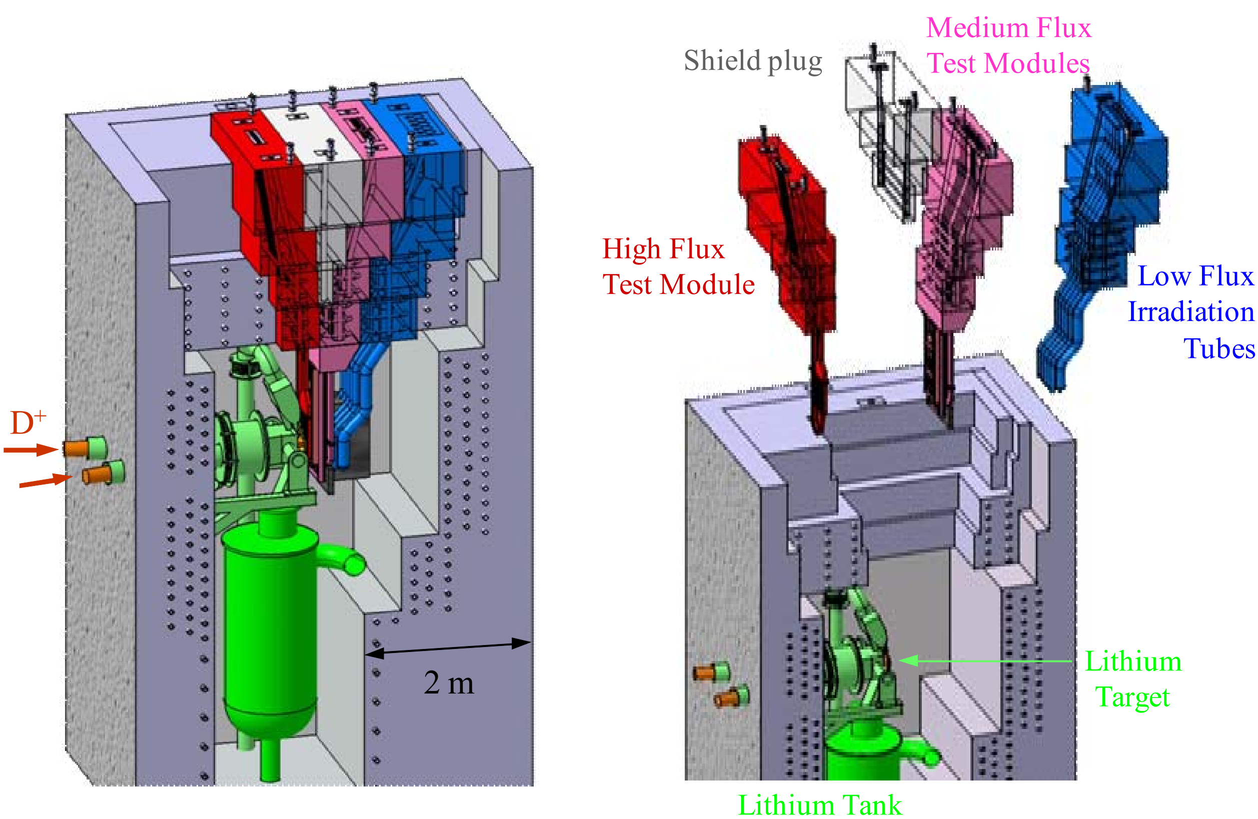

Figure 6: Cut of the Test Cell with the Modules in position (left part of the figure) or out of it (at the right).

SCOPE OF EVEDA

The Engineering Validation and Engineering Design Activities of IFMIF are one of the 3 projects of the Broader Approach agreement between Europe and Japan, aiming at a faster demonstration of fusion as a viable source of energy by preparing DEMO, the next step after ITER.

The main goal of the project is to deliver in a 6 year framework (i.e. June 2013) the Engineering Design File of IFMIF, enabling its rapid construction.

This design file will be validated thanks to the design, he manufacturing and the tests of 3 main prototypes:

- The **low energy part of the Accelerator**, including the injector (at full current), the Low Energy Beam Transport line, the RFQ, the Matching Section and the first cryomodule of the DTL, bringing the energy of the beam of 125 mA at 9 MeV in CW. The manufacturing is basically a European contribution, with a Japanese contribution. Japan will also provide the building, whose construction has just started at Rokkasho, Aomori prefecture. Tests also aim at verifying a hands-on maintenance and a specific 1.2 MW beam dump will be built.
- The whole **Lithium Loop**, with a reduced scale of 1/3 in width for the target assembly. All other characteristics of the target (height, speed and thickness of lithium) are similar to those of IFMIF. This experimental loop (basically a Japanese work with a European contribution) will be installed at Oarai, Ibaraki prefecture. It will enable the characterization of the hydraulic properties of the lithium flow on the target, the actual purification possibilities of the hot and cold traps and prepare some diagnostics in a less aggressive environment than IFMIF's one.
- The **High Flux Test Module** of the Test Facilities (European task) also belongs to the validation activities by the manufacturing of a 1:1 scale rig with samples and its irradiation (at a lower level than IFMIF). These experiments, combined to helium hydraulic measurements in dedicated facilities, should validate the principles (heating of the capsules, *in situ* measurements, etc.

CONCLUSION, PERSPECTIVES

One year after the start of the project, no showstoppers have been identified:

- Beam dynamics calculations, even if not yet completed, confirm the capacity to accelerate with reasonable characteristics the full beam;
- All thermal and mechanical objectives of the accelerator sub-systems seem achievable;
- Hydrodynamics experiments, conducted in Osaka University in particular, are rather promising, with the clear constrain that the lithium purity must be kept at the highest level, in order to avoid a rapid erosion of the nozzle, degrading the flow stability;
- Lithium purification techniques are progressing well: basic principles have been identified and will now be studied at a larger scale;
- The design of the High Flux Test Module rigs is now available and preliminary tests in a first helium loop have led to some optimization of the design; a full capsule is prepared and will be ready soon for irradiation.

REFERENCES

[1] IFMIF Comprehensive Design Report, by the IFMIF International Team, an activity of the International Energy Agency, Implementing Agreement for a Program of Research and Development on Fusion Materials, January 2004

[2] The IFMIF-EVEDA Accelerator Activities, A. Mosnier, A. Ibarra, A. Facco, this conference