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IFMIF/EVEDA Project: Achievements and Outlooks beyond 2020

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IFMIF, the International Fusion Materials Irradiation Facility is conceived to generate fusion relevant neutrons with a broad peak at 14 MeV through Li(d,xn) nuclear reactions. IFMIF will enable accelerated neutron irradiation of structural materials at above 20 dpa/fpy (full power year) in 500 cm3 for the high flux test module. IFMIF is presently in its Engineering Validation and Engineering Design Activities (EVEDA) phase under the Broader Approach (BA) Agreement signed between EURATOM and Japanese Government in 2007. This agreement mandates validating the design of the different systems of IFMIF and producing an integrated engineering design of IFMIF, together with the data necessary for future decisions on the construction, operation, exploitation and decommissioning of the plant (1). While the Engineering Design Activity was completed with the Engineering Validation Activity (EVA) of the Lithium Target Facility and the Test Facility by constructing prototypes, the EVA phase of the Accelerator Prototype Facility is still on-going. The first phase of the project will end up by 31 March 2020, and a new phase is planned to enhance the entire system and to finalise the complete design of the future Fusion Neutron Source.

IFMIF Engineering Design Activity

The Engineering Design Activity phase of IFMIF was accomplished within the allocated time successfully fulfilling its mandate (2). It is composed by an IFMIF Plant Design Description (PDD) document including interfaces based on a 3D-model of the full plant, licensing scenarios and nuclear safety aspects. A careful cost and schedule report, based on the experience gained in recent years with the construction of prototypes was also prepared. The PDD is supported by 35 different Design Description Documents (DDDs) of all plant subsystems. The design is also supported by profound Reliability, Availability, Maintainability and Inspectability (RAMI) analysis performed for each facility that is an integral part of the Annexes of the PDD.

Lithium Target Facility

The EVEDA Lithium Test Loop has successfully demonstrated the long-term stability of a lithium flow under IFMIF nominal operational conditions with 25 days continuous operation in Oarai (JAEA, Japan) (3). In turn, the feasibility of a lithium target was demonstrated in Brasimone (ENEA, Italy) implementing a concept that allows its removal every year without welding operations. The ENEA studies included also erosion/corrosion tests at the LIFUS6 facility where structural RAFM material candidates, namely F82H and EUROFER97 steels, were exposed to flowing lithium under IFMIF relevant conditions.

Test Facility

A full-scale prototype of the high flux test module was built and successfully tested in the HELOKA loop in Karlsruhe (KIT, Germany) (4) demonstrating the technical feasibility of the uniformity in the temperature selected for the specimen set to be irradiated in each capsule. In turn, three capsules fitted with small specimens, heaters and thermocouples were irradiated at the fission reactor BR2 in Mol (SCK-CEN, Belgium) to detect the design, fabrication, samples cooling & retrieval and decommissioning difficulties of the capsules.

Accelerator Facility

The Accelerator Facility validation activities will run until March 2020 within the originally assigned credits by the BA Agreement. Starting from FMIT conceptual design (2) and outcomes of high intensity beam experiments carried out at Los Alamos in the 80's , the LIPAc aim at demonstrating the acceleration of 125 mA D+ beam up to 9 MeV while keeping the beam losses under 1 W/m. It is now the goal of the Linear IFMIF Prototype Accelerator (LIPAc), presently under installation and commissioning in Rokkasho (Fig. 1), to validate the concept of the IFMIF Accelerators with a D+ beam of 125 mA and 9 MeV.

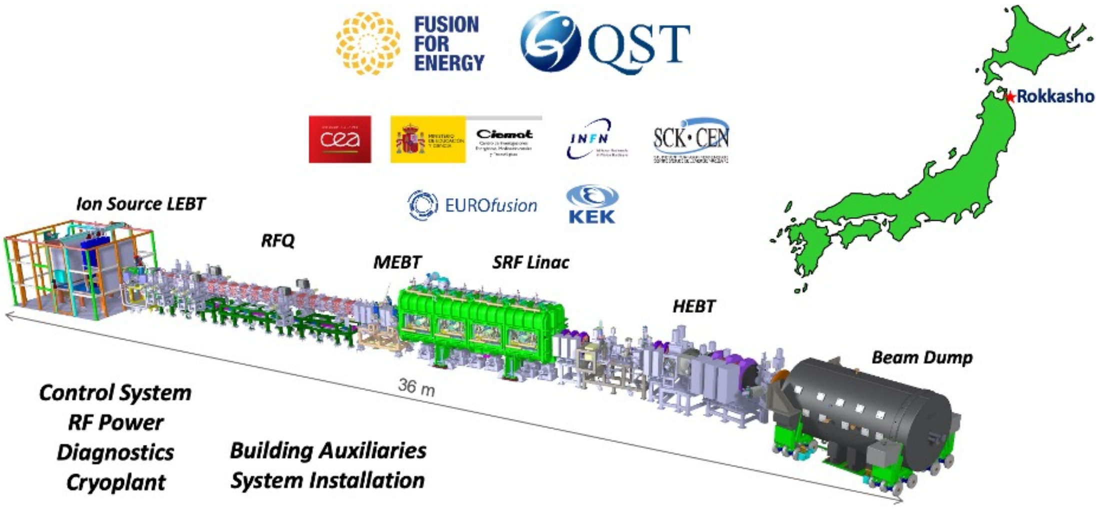

Figure 1: Japan-Europe scientific collaboration

A 140 mA and 100 keV D+ beam with beam emittance <0.3π.mm.mrad will be generated in an Electron Cyclotron Resonance (ECR) ion source to be injected in a Radio-Frequency Quadrupole (RFQ) through Low Energy Beam Transport (LEBT) line and accelerated to 5 MeV with <10% losses. The 125 mA beam at 5 MeV will be injected in a Superconducting Radio-Frequency (SRF) linac after transfer through the Medium Energy Beam Transport (MEBT) line. The beam is accelerated in the SRF linac to the LIPAc design value of 9 MeV. It is then transported through the High Energy Beam Transport (HEBT) line, which includes a Diagnostics Plate (DP) for beam characterization and a bending magnet in order to reduce the irradiation from the 1.125 MW Beam Dump, where the beam is finally stopped.
The LIPAc commissioning is currently on-going in Rokkasho Fusion Institute. After having completed the commissioning of the Injector (ion source and LEBT) at 100 keV, with 1st deuteron beam in July 2015 (5), an important milestone was reached in June 2018 with 1st proton beam accelerated in the RFQ at 2.5 MeV (6), and in July 2019 (Fig. 2) a significant project milestone was reached with a 125 mA deuteron beam accelerated at 5 MeV with 0.1% duty cycle (1 ms pulse) and transported to the Low Power Beam Dump (LPBD) (7).

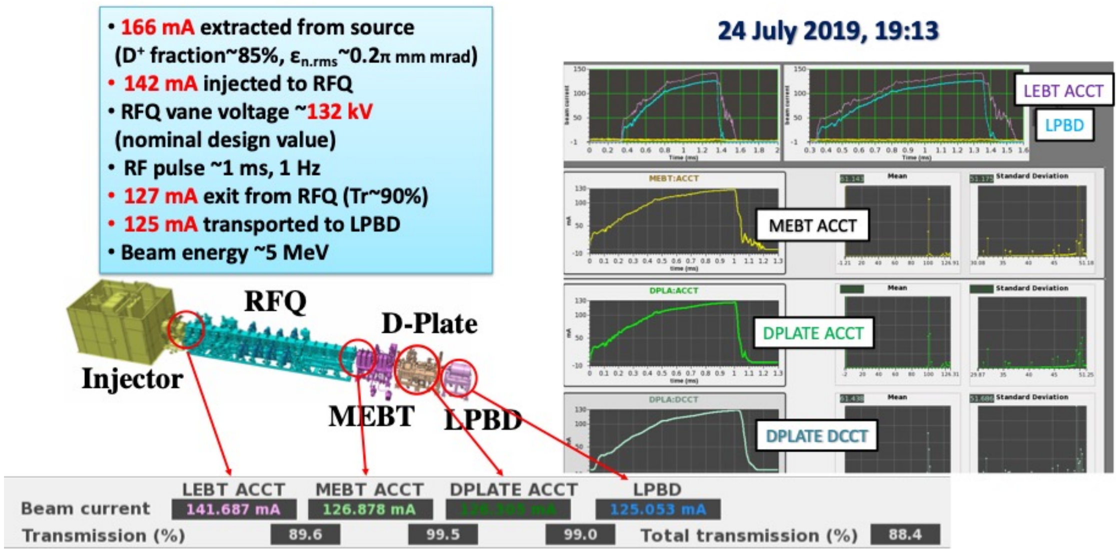

Figure 2: Completion commissioning 125 mA, D+, 5MeV, 0.1 d.c.

To reach this important milestone, a fine adjustment of the system composed by the RFQ and its RF chains was mandatory. Indeed, to enable the transmission of the nominal deuteron beam, the conditioning of the RFQ up to the required electrical field at low duty cycle was reached by tuning and controlling the eight RF chains, to minimize the reflecting power, and by optimizing the beam loading compensation control.
During the beam experimentation, after having commissioned the different beam instrumentations distributed along the line, the beam distribution was characterised validating the modelling developed during this engi-

neering validation phase. For instance, the use of the Beam Loss Monitor for the neutron measurements has allowed to demonstrate the absence of any significant beam losses trace at high energy, being in line with the simulation.

Hence, we have been able to demonstrate that all the components needed to run the LIPAc accelerator in this phase configuration are working as expected, validating the beam transmission awaiting the thermo mechanical design validation in CW operation.

IFMIF/EVEDA Outlook

The commissioning of the LIPAc at high duty cycle is expected to resume on second quarter of 2020, after having completed the installation of the high energy beam transport parts, and it is expected to complete the commissioning at 9 MeV in CW during the BA Phase II (April 2020 up to March 2025). In the meantime, enhancement activities will be carried out in order to be ready to complete the full engineering design of the future fusion neutron source.

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