INSTALLATION STATUS OF DEUTERON INJECTOR OF IFMIF PROTOTYPE ACCELERATOR IN JAPAN

H. Shidara, J. Knaster, IFMIF/EVEDA Project Team, Rokkasho, Japan
D. Bogard, N. Chauvin, P. Girardot, R. Gobin, F. Harrault, D. Loiseau, P.A.P. Nghiem, A. Roger, F. Senée, CEA, IRFU, Gif-sur-Yvette, France
L. Semeraro, F4E, Barcelona, Spain

Abstract

The International Fusion Materials Irradiation Facility (IFMIF) will generate a neutron irradiation field with the spectrum simulating the fusion D-T neutrons (14.1 MeV) to qualify suitable materials for fusion power plants. The IFMIF accelerator facility provides two CW / 40 MeV / 125 mA deuteron beams impacting in the IFMIF Lithium target facility. The project is presently in its Engineering Validation and Engineering Design Activities (EVEDA) phase. The concept of IFMIF accelerators is validated with the operation of a CW / 9 MeV / 125 mA deuteron accelerator prototype under installation in Rokkasho (JAEA). The Injector + LEBT has been designed, constructed and successfully tested by CEA Saclay. The ECR ion source produces a deuteron beam of 140 mA at 100 keV. In spring 2013, the injector will be delivered, and then re-installed on the Rokkasho site. This paper will focus on the detailed plan of the injector's re-assembly as well as on the re-commissioning. Further possible improvements are discussed in order to achieve reliable operation.

INTRODUCTION

A fusion relevant neutron source is an indispensable tool in the world nuclear fusion program. ITER will teach us how to confine plasma in suitable conditions to maintain stable deuterium-tritium nuclear fusion reactions. In DEMO, as in future fusion power plants, the fusion reactions will generate neutron fluxes in the order of 10^{18} $m^{-2}s^{-1}$ with an energy of 14.1 MeV that will be absorbed in the plasma facing components, a complex combination of layers of different materials that aims to maximizing the conversion of neutrons into thermal energy and breeding tritium. While in ITER the integrated neutronic damage in its operational life will not go beyond 3 dpa_{NRT} [1], in DEMO levels over 15 dpa_{NRT} per year of operation are expected [2]. The generation of He and H through transmutation will induce embrittlement with a potential dramatic increase of the ductile to brittle temperature transition (DBTT) of steels. The threshold energy for Fe and Cr transmutation being around 3 MeV, do not allow an efficient gas generation in experimental fission reactors (average neutron spectrum around 2 MeV). In turn, spallation sources, with tails in the order of hundreds MeV, generates significantly more damage including transmutation of light nuclides. The number of variables playing a significant role in the degradation of the impacted materials (neutron flux, spectrum, fluence, temperature, stress, microstructure, thermal-mechanical processing history, lattice kinetics…) makes the experiments with fusion relevant neutron sources unavoidable.

IFMIF, the International Fusion Materials Irradiation Facility, will generate a neutron flux with a broad peak at 14 MeV by Li (d,xn) reactions [3] thanks to two parallel deuteron accelerators colliding in a liquid Li screen with a footprint of 20 cm x 5 cm. The energy of the beam (40 MeV) and the current of the parallel accelerators (2 x 125 mA) have been tuned to maximize the neutrons flux and reach 10^{18} $m^{-2}s^{-1}$) to get irradiation conditions comparable to those in the first wall of a fusion reactor in a volume of 0.5 l that will house around 1000 small specimens being also developed in this EVEDA phase [4] (see Fig. 1).

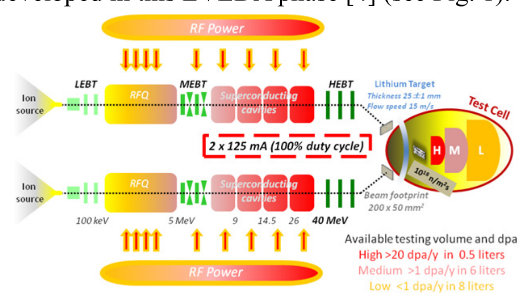

Figure 1: Schematic of IFMIF.

The validation of the accelerator concept will be attained by the construction and operation of the low energy part of one IFMIF accelerator at 125 mA CW current and 9 MeV energy, up to the first section of the SRF Linac [5]. The main components of LIPAc, the Linear IFMIF Prototype Accelerator, have been designed and constructed in European labs (see Fig. 2) and will be installed and operated in Rokkasho (Japan). Its objectives were defined already in 2003 [6].

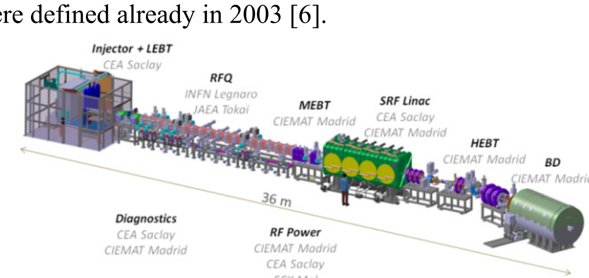

Figure 2: Layout of LIPAc and its construction sharing.

IFMIF DEUTERON INJECTOR

IFMIF ion source design follows the 2.45 GHz and the 875 Gauss Electro-cyclotron resonance (ECR) concept initiated in Chalk River [7] and successfully developed

ISBN 978-3-95450-122-9

and operated in CEA Saclay with SILHI [8]. The LEBT, with a dual solenoid focusing scheme, will match the extracted beam to the RFQ entrance with specified performance in the LEBT output current of 140 mA, beam energy of 100 keV with an RMS transverse emittance <0.3π mm·mrad and D^+ species fraction >95%. The design of IFMIF injector has been described elsewhere [9]. A beam emittance value of 0.3π mm·mrad will allow a transmission in the 9.8 m long RFQ of 90% [10]. The high current and low beam energy makes space charge aspects become a key factor in the control of the emittance growth [11]. Nevertheless, a safe operational margin on the emittance is to be attempted to enhance the transmission along the RFQ.

In November 2012, the acceptance tests of the Injector + LEBT were successfully accomplished in CEA Saclay [12], the injector + LEBT was disassembled, packed and shipped to Rokkasho (see in Fig. 3 the status of the equipment at the preparation of this paper).

Figure 3: View of the Injector + LEBT packed in Saclay.

INJECTOR INSTALLATION

All the installation and commissioning tasks related with IFMIF accelerator validation activities in Rokkasho will be coordinated by the LIPAC Installation and Commissioning (LIC) Unit of IFMIF/EVEDA Project Team (PT) under the structure described in Fig. 4.

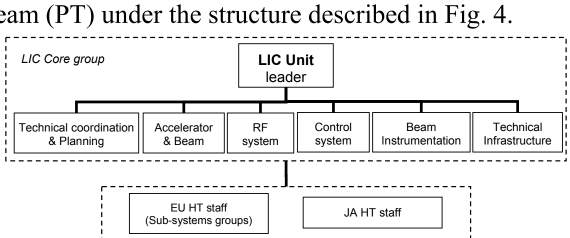

Figure 4: LIPAc Installation and Commissioning Unit.

The re-installation tasks being under Japanese Home Team (JA-HT) responsibility, the Individual System Tests (IST) in Rokkasho of the Injector + LEBT aiming at its final acceptance are under the PT responsibility; the responsibility of the conditioning will be under CEA staff temporarily seconded on site. The completion of the delivery of the 35 packages at Rokkasho site on May 2013 has become the beginning of the installation schedule. The building complex design, procured by JAEA, will allow carrying out the re-assembly procedure in three rooms in parallel (see Fig. 5). The ECR ion source and the accelerator column will be installed in the HV platform shielded by a grounded HV cage placed in the Accelerator Hall, as well as the LEBT equipped with its dedicated diagnostics and a chopper. In the Power Bay room, 8 cubicles will house the power supplies, vacuum controls and PLCs. The cooling skid will be housed in the HEX room and water conducted through stainless steel pipes. The specified resistivity in the primary circuit of $>10^6$ Ω·cm will be guaranteed with a demineralization column.

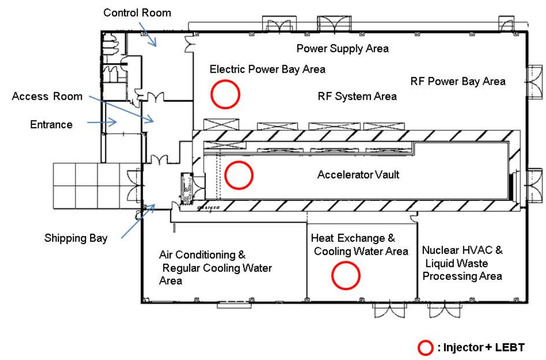

Figure 5: LIPAc complex building layout with indication of the position of Injector + LEBT related hardware.

The site preparation has focused to finish all potential dust raiser operations before the HV equipment is handled on site. A floor levelling (within <1 mm) to accommodate the grounded steel plates of the HV cage floor was identified as essential to ease the re-assembly tasks. Furthermore, recent survey simulations anticipated measurement uncertainties that would potentially jeopardize the achievement of the accelerator target alignment accuracies, which given the 1.125 MW average power of LIPAc, are essential to respect for investment protection aspects. Indeed, the nature of the accelerated particle (deuterons, which present high inelastic collision cross sections), combined with the high power, makes an optimal optical matching through interfacing hardware become essential. Negotiations with the Licensing body are under the responsibility of the host institute, JAEA. Though the output energy of the LEBT is relatively low, the beam power, which reaches 15 kW with high power densities and the presence of HV equipment build the relevance of a strict conventional health and safety rules. The Machine Protection System and Personnel Protection System, framed by EPICS, have been successfully tested in CEA Saclay and will be installed in Rokkasho with the help of the PT and the Japanese JA-HT. In turn, the Local Control System in Rokkasho will be driven by 1 PC running Linux, 1 PC specific for diagnostics and 1 laptop for the spectrometer.

ALIGNMENT ISSUES

An upgrade of the survey network in the Accelerator hall has been agreed. This decision has been taken because due to the masking of certain installed fiducials by auxiliary equipment the obtainable network uncertainty resulted too large to achieve the specified alignment accuracy; this situation could only worsen with the evolution of LIPAc installation tasks. Simulations carried out by F4E with the recent feature Unified Spatial Metrology Network (USMN) based on Monte Carlo algorithm (capable to provide the measurement uncertainty, as estimated variability of the result, together with the measurement) of SpatialAnalyzer® (SA) software by New River Kinematics (NRK), recommended the random positioning of 119 new fiducials to reach measurement uncertainities <30 µm (indispensable if precisions of 0.1 mm are targeted) (see Fig. 6). The accurate definition of the Global Reference System will allow the accurate positioning of the laser tracker Leica AT401 in any place of the accelerator hall during all future alignment tasks and it will be robust against potential seismic undesired movement of fiducials or survey pillar.

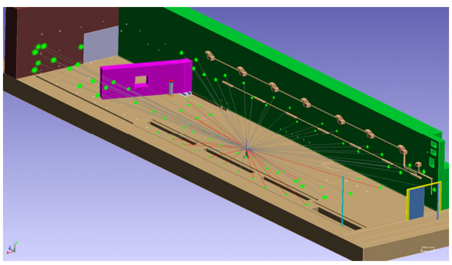

Figure 6: Simulation example of fiducial survey and uncertainty field analysis with USMN.

The Injector + LEBT will be pre-aligned following its beam axis with a Taylor-Hobson system. For this operation, a geodesic pillar needs to be installed around 2 or 3 meters downstream the RFQ entrance location (origin of coordinates) and precisely positioned; in addition, the position of the origin of coordinates for LIPAc shall be materialized. Once accomplished the pre-alignment, the equipment will be integrated in the Global Reference System and aligned to 0.1 mm accuracy by use of its 25 local fiducials.

COMMISSIONING IN ROKKASHO

The commissioning tasks carried out in CEA Saclay in November 2012 [12] will be repeated in Rokkasho once the installation phases are accomplished. The IST exercises in Rokkasho will be mainly performed with H^+ beams given that at half energy and half intensity present same speed and space charge than D^+ beams at nominal energy and intensity [11]. All the tests will be accompanied by support of beam dynamics simulations to deepen the understanding of the physics involved. It is essential to understand the emittance behaviour since its direct measurement cannot be carried out once the RFQ is in place. The IST of the Injector + LEBT will consist of three consecutive steps: 1) tests with H^+, up to full power, 2) tests with H^+, 1/2 energy, 1/2 current to learn of D^+ behaviour and 3) tests with D^+, up to full power. The IST will be considered accomplished once the predicted beam injection quality meets the RFQ beam requirements with adequate duty cycle and acceptable loss level in the LEBT.

In addition, the chopper was successfully tested in Saclay without beam, tests with beam, to demonstrate that the fall/rise time to 8 kV of 4 µs and 10 Hz repetition rate is feasible, will be performed.

CONCLUSIONS

Despite the success of the commissioning in CEA Saclay (reaching already unprecedented performance), and its acceptance by the PT, the full specified performance of the Injector + LEBT could not be demonstrated. The emittance values could not be measured at full current because the high beam density would damage the thermal screen. Solutions were envisioned but compliance with schedule led to the agreement of accomplishing these measurements in Rokkasho. In addition, the seeming observed correlation of the beam extraction voltage with emittance values [12], together with the potential space charge mitigation power if heavy gases with low partial pressures are present, allows anticipating further improvements in the already suitable beam characteristics before the RFQ installation starts. The accomplishment of the IST of the injector + LEBT is expected in 2013 [13].

REFERENCES

[1] M.I. Norgett et al, "A Proposed Method of Calculating Displacement Dose Rates", Nucl. Eng. Des. 33 (1975) 50.

[2] M.R.Gilbert, "An Integrated Model for Materials in a Fusion Power Plant: Transmutation, Gas Production, and Helium Embrittlement under Neutron Irradiation", Nucl. Fusion 52 (2012).

[3] M. Hagiwara et al., "Measurement of Neutron Emission Spectra in Li(d,xn) Reaction with thick and thin targets for 40 MeV deuterons", Fus. Sci. Techn. 48 (2005) 1320-1328.

[4] G.E. Lucas et al., "The Role of Small Specimen Test Technology in Fusion Materials Development", J. Nuc. Mat. 367–370 (2007) 1549–1556.

[5] A. Mosnier et al., "The Accelerator Prototype of the IFMIF/EVEDA Project", IPAC 2010, Kyoto.

[6] M. Sugimoto et al., "Issues to be verified by IFMIF Prototype Accelerator for Engineering Validation", J. Nuc. Mat. 307–311 (2002) 1691–1695.

[7] G.M. Arbique et al., "Multi-beamlet Injection to the RFQ1 Accelerator: a Comparison of ECR an Duopigatron Proton Sources", PAC 1991, San Francisco.

[8] R. Gobin et al., Saclay High Intensity Light Ion Source – Status, EPAC 2002, Paris.

[9] R. Gobin, "General Design of the International Fusion Materials Irradiation Facility Deuteron Injector: Source and Beam Line", Rev. Sci. Inst. 81, 02B301 (2010).

[10] M. Comunian et al., Beam Dynamics redesign of IFMIF-EVEDA RFQ for a Larger Input Beam Acceptance, IPAC 2011, San Sebastián.

[11] P.A.P. Nghiem et al., "The IFMIF-EVEDA Challenges in Beam Dynamics and their Treatment", Nucl. Inst. Meth. 654 (2011) 63–71

[12] N. Chauvin et al., "Beam commissioning of the Linear IFMIF Prototype Accelerator Injector: measurements and simulations", IPAC 2013, Shanghai.

[13] J. Knaster et al., "Installation and Commissioning of the 1.1 MW Prototype Deuteron Linac of IFMIF", IPAC 2013, Shanghai.