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Overview of the Validation Activities of IFMIF/EVEDA: LIPAc, the Linear IFMIF Prototype Accelerator and Lifus 6, the Lithium Corrosion Induced Facility

M. Sugimoto[1], P. Abbon[5], A. Aiello[8], T. Akagi[1], L. Antoniazzi[6], N. Bazin[5], P.-Y. Beauvais[3], L. Bellan[6], B. Bolzon[5], D. Bortolato[6], P. Cara[2], J. Castellanos[9], N. Chauvin[5], S. Chel[5], M. Comunian[6], C. de la Morena[9], H. Dzitko[3], E. Fagotti[6], P. Favuzza[8], D. Gavela[9], D. Gex[3], R. Gobin[5], F. Grespan[6], R. Heidinger[3], D. Jimenez-Rey[9], A. Jokinen[3], J. Knaster[4], A. Kasugai[1], I. Kirpitchev[9], K. Kondo[1], T. Ebisawa[1], Y. Hirata[1], R. Ichimiya[1], S. Maebara[1], A. Marqueta[3], J. Marroncle[5], P. Méndez[9], J. Molla[9], O. Nomen[10], K. Sakamoto[1], T. Shinya[1], M. Montis[6], I. Moya[3], C. Oliver[9], A. Palmieri[6], G. Phillips[3], A. Pisent[6], I. Podadera[9], G. Pruneri[7], B. Renard[5], F. Scantamburlo[6], F. Toral[9], R. Varela[9] and M. Weber[9]

[1]QST, Rokkasho, Japan, [2]IFMIF/EVEDA Project Leader, Rokkasho, Japan, [3]F4E, Garching, Germany, [4]F4E, Cadarache, [5]CEA/IRFU, Paris-Saclay, France, [6]INFL/LNL, Legnaro, Italy, [7]Consorzio RFX, Padova, Italy, [8]ENEA, Brasimone, Italy, [9]CIEMAT, Madrid, Spain, [10]Institu de Recerca en Energia de Catalunya, Spain

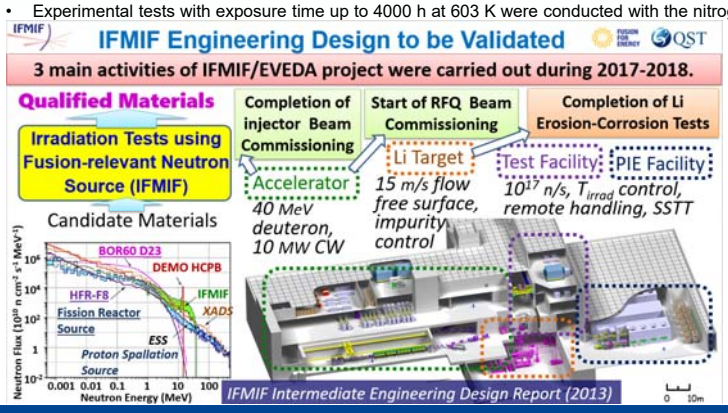
Abstract

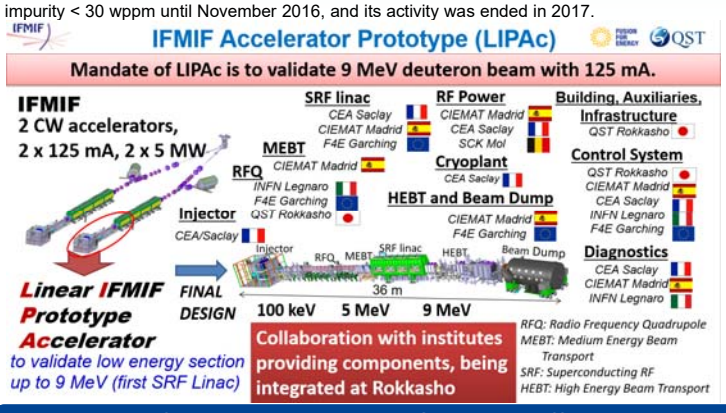
The results of the activities on the Engineering Validation and Engineering Design Activities for the International Fusion Materials Irradiation Facility (IFMIF/EVEDA) project under the framework of the Broader Approach agreement are overviewed. For the validation of the accelerator design to provide 40 MeV and 125 mA continuous wave deuteron beam on the liquid lithium target, the demonstration of the low energy section up to 9 MeV, called as Linear IFMIF Prototype Accelerator (LIPAc), is under the stepwise commissioning in Rokkasho. The first step to demonstrate the 100 keV deuteron and 50 keV proton beams from the LIPAc injector was completed by satisfying the target value of beam emittance, 0.25π mm mrad or less, at the beam current of 140 mA and 70 mA for deuteron and proton, respectively. The second goal for verifying the design of 175 MHz Radio-Frequency Quadrupole (RFQ) linear accelerator with the RF power system to accelerate deuteron to 5 MeV and the associated beam transport line to the beam from RFQ into the superconducting RF linear accelerator, has been started and a 2.5 MeV and 35 mA proton beam was obtained with the beam transmission, 90% or more. As for the validation of lithium target system, Lifus 6 plant was built in Brasimone to validate the design goal of erosion-corrosion rate for target material caused by 15 m/s lithium flow, and has been operated for one year with the continuous impurity monitoring and control, nitrogen < 30 wppm. The requirement of 1 mm/y or less was confirmed with a long-term test up to 4,000 h.

Introduction

The IFMIF/EVEDA project is conducted under the framework of the Broader Approach agreement between Japan and EURATOM since June 2007. The mission of the IFMIF/EVEDA project is to provide the detailed engineering design of the IFMIF plant and to validate the technological challenges on an accelerator-based neutron source to generate a DT fusion reactor relevant neutron flux higher than 10^{18} $m^{-2}\cdot s^{-1}$ and energy spectrum for fusion material development and testing. This report covers the following topics.

1) The demonstration of the low energy section up to 9 MeV of linear accelerator (Linac) of IFMIF to generate 40 MeV deuteron beam with current of 125 mA in Continuous Wave (CW) is the most challenging activity in the project, named as Linear IFMIF Prototype Accelerator (LIPAc), of which commissioning is ongoing in Rokkasho, Japan.
   - Experimental tests of the accelerator components for 5 MeV deuteron have been started in June 2018 using pulsed 50 keV proton beam with total current up to 40 mA.
   - Ion beam injector tests were completed in December 2017 for pulsed 100 keV deuteron beam with current up to 140 mA.
2) The IFMIF employed the flowing liquid lithium (15 m/s) as a neutron generating target bombarded by deuteron beam with a footprint of 200 by 50 mm^2. The erosion-corrosion of the target structure made of Reduced Activation Ferritic/Martensitic (RAFM) steel is a concern which may affect the stability of lithium flow and limit the service lifetime of the target assembly. A lithium loop, called as Lifus 6, for studying the erosion-corrosion phenomena was built in 2015 at ENEA Brasimone, Italy.
   - Experimental tests with exposure time up to 4000 h at 603 K were conducted with the nitrogen impurity < 30 wppm until November 2016, and its activity was ended in 2017.

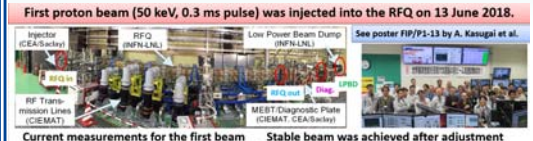




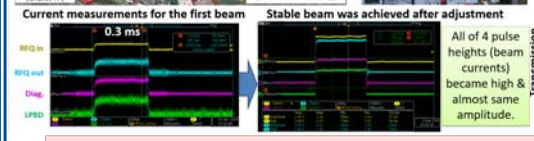
LIPAc: Beam Commissioning

First Beam Injection into RFQ: Ref. FEC2018 FIP/P1-13

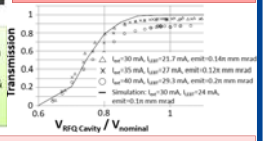
RF power form 8 independent RF power sources are successfully injected at the same time into a single RFQ cavity (length of 9.8 m and resonant frequency of 175 MHz).
This is a world first trial. Synchronization with White Rabbit technology is a new application.



Transmission (ratio of current at LPBD to RFQ input current) was measured by varying voltage applied to the RFQ cavity. Compared with beam dynamics simulation was made.



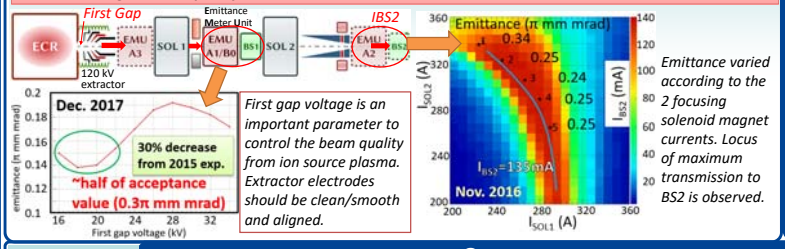
All of 4 pulse heights (beam currents) became high & almost same amplitude.



Beam energy was measured by using TOF among 3 Beam Position Monitors and agreed with design value, 2.5 MeV.

High Quality Deuteron Beam for RFQ Injection: Ref. FEC2018 FIP/P3-19

Deuteron beam with 100 keV/140 mA required for RFQ injection is ready for beam commissioning with a sufficient margin of the quality, i.e. beam emittance.



First gap voltage is an important parameter to control the beam quality from ion source plasma. Extractor electrodes should be clean/smooth and aligned.

Emittance varied according to the 2 focusing solenoid magnet currents. Locus of maximum transmission to BS2 is observed.

Lifus 6: Lithium Erosion-Corrosion Effects

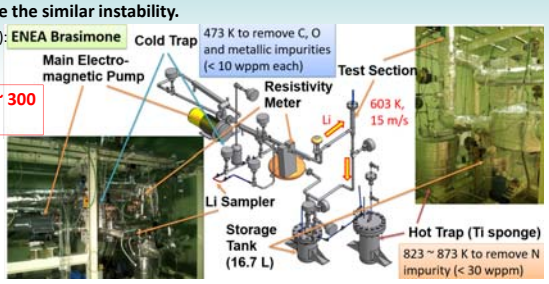
Stability of surface of Li flow is a major issue to cause the flow breakup in the extreme case. In long term operation, erosion-corrosion effects on the target structural material (RAFM steel) is a main concern to cause the similar instability.

Preliminary test in 2007 (Lifus3): corrosion rate **~3.2 μm/y** for Eurofer 97

ENEA Brasimone

Nitrogen concentration ~ 300 wppm is a main reason.

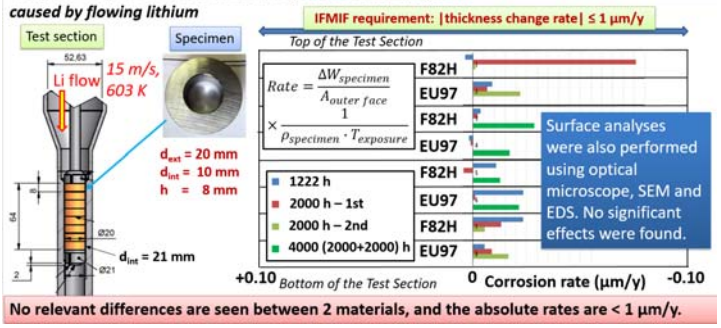
IFMIF Design Requirement: corrosion rate <1 μm/y (could be achieved by the purified Li with low nitrogen <30 wppm).



Corrosion Rate Measurements

Comparison of erosion-corrosion rates for F82H and Eurofer97 caused by flowing lithium

See ref. FED in press by P. Favuzza et al.



No relevant differences are seen between 2 materials, and the absolute rates are < 1 μm/y.

Summary

LIPAc:

- RFQ beam commissioning is started with 50 keV proton, and the initial measurements of RFQ transmission (96% at maximum) and beam energy (2.5±0.2 MeV) gave a good sign of RFQ design validity.
- Injector commissioning with 100 keV/140 mA deuteron beam was completed successfully with twice better than acceptable emittance.

IFMIF design on RFQ was validated for pulsed 50 keV proton and that on injector was verified for pulsed 100 keV deuteron.

Lifus 6:

- Corrosion rate requirement <1 μm/y for RAFM steels was achieved with controlled nitrogen impurity (about 30 wppm using Ti hot trap).

Lithium erosion-corrosion effects on RAFM steel can be managed if the impurity in Li is controlled properly (esp. N < 30 wppm) and the design requirement of corrosion rate (<1 μm/y) is achievable.

Reference papers and literatures

LIPAc, the Linear IFMIF Prototype Accelerator

- KASUGAI, A. et al., "RFQ Commissioning of Linear IFMIF Prototype Accelerator (LIPAc)", Proc. 27th IAEA Fusion Energy Conf., Gandhinagar, India, 2018. **FIP/P1-13 in this conf.**
- CHAUVIN, N. et al., "Deuteron Beam Commissioning of the Linear IFMIF Prototype Accelerator Source and LEBT", Proc. 27th IAEA Fusion Energy Conf., Gandhinagar, India, 2018. **FIP/P3-19 in this conf.**
- GRESPAN, F. et al., "IFMIF/EVEDA RFQ preliminary beam characterization", Proc. 29th Linear Acc. Conf., Beijing, China, 2018.

Lifus 6, the Lithium Corrosion Induced Facility

- FAVUZZA, P. et al., "Erosion-corrosion resistance of Reduced Activation Ferritic-Martensitic steels exposed to flowing liquid Lithium", Fus. Eng. Design in press.

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