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OVERVIEW OF ACHIEVEMENTS AND OUTLOOK OF THE IFMIF/EVEDA PROJECT

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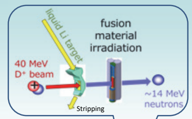
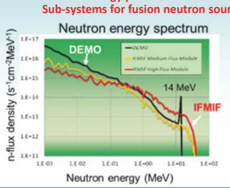
Abstract

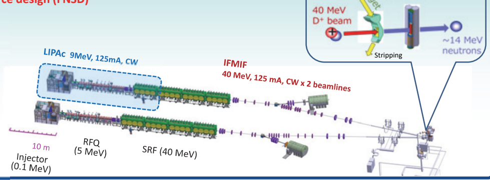
The Engineering Validation and Engineering Design Activities for the International Fusion Materials Irradiation Facility (IFMIF/EVEDA) project is underway as one of the three projects (IFMIF/EVEDA, IFERC and JT60SA) of the Broader Approach (BA) agreement between EURATOM and the Japanese government since 2007. The IFMIF is to provide accelerator-based D-Li neutrons at appropriate energy and sufficient intensity to test samples for candidate materials in fusion energy reactors such as DEMO. The mission of the IFMIF/EVEDA project is to produce detailed engineering design of the IFMIF and to validate on major components: Accelerator Facility, Lithium Target Facility and Test Facility. In the first phase of the BA which ended by March 2020, the Engineering Validation Activity (EVA) of the Lithium Target Facility and Test Facility was completed by constructing prototypes. The EVA of Accelerator Facility with the Linear IFMIF Prototype Accelerator (LIPAc) is still on-going. In the new phase (II), the activities are focused on continuing the commissioning of the LIPAc and enhancement of some sub-systems for fusion neutron source design (FNSD).

Introduction

EVEDA (Engineering Validation and Engineering Design Activities)
- Providing the Engineering Design of IFMIF (International Fusion Materials Irradiation Facility)
- Validating the key technologies
  - The low energy part of accelerator: LIPAc (Linear IFMIF Prototype Accelerator)
  - Sub-systems for fusion neutron source design (FNSD)



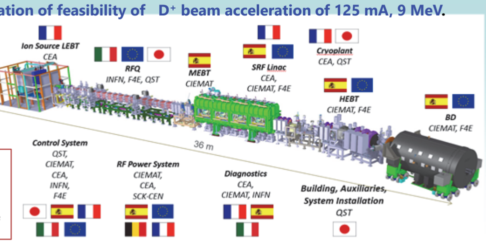




LIPAc Configuration

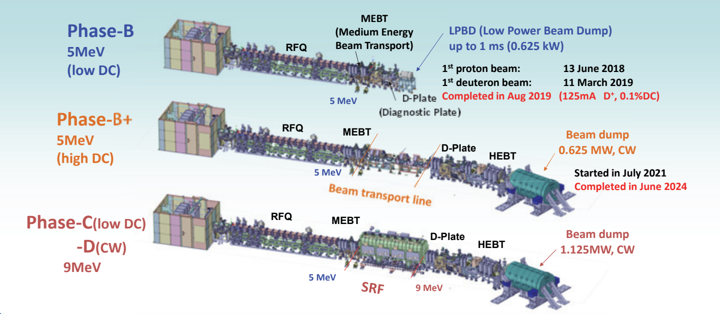
- **Mission of LIPAc:** demonstration of feasibility of D+ beam acceleration of 125 mA, 9 MeV.

LIPAc Challenges
- World highest beam current (125mA)
- CW (100% duty cycle)



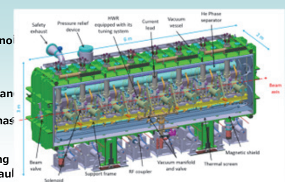
- All accelerator equipment is procured through in-kind contribution
- Installation is carried out by QST with EU support
- Commissioning is carried out by the Japan-Europe joint team

Staged Approach toward 9 MeV / CW



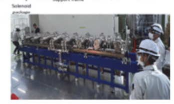
Preparation of Phase C/D

- The module assembly was carried out in a clean room at Rokkasho Institute.
- In 2019, work began but suspended due to solenoid defects and COVID outbreak.
- Aug. 2022, resumed assembly work
- Sept. 2024, completed the String Assembly (connection work of cavities and solenoid coils) and extracted from the clean room.
- Jan. 2025, completed the insertion of the cold mass into the cryomodule.
- March 2025, transported from the Assembly Building to the IFMIF/EVEDA Accelerator Building
- Assembly work is underway in the accelerator vault for the phase C/D.



HWR	175 MHz
β	0.094
E_a	4.5 MV/m
Q_0	1.4E9
Solenoid	**6 T**
∫B.dl on axis	1 T.m
Field at Cavity flange	< 20 mT

Assembly work in the clean room



Extraction of the SRF beam line components from the clean room

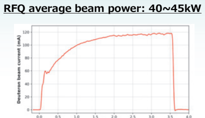
The SRF cryomodule work in the vault

Results of Phase B+

Objectives of Phase B+
- Demonstration of deuteron long pulse beam acceleration by RFQ (5 MeV, 125 mA, high duty cycle)
- Validation of the no interceptive Diagnostics at high DC
- Validation of the beam dump at high power (0.6 MW) and associated diagnostics
- Characterization of the beam injected into the SRF Linac (to be installed after Phase-B+ completion)

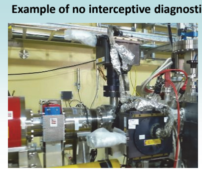
Completed high duty deuteron beam test at the end of June 2024

- The maximum duty of beam acceleration is 8.75 % (3.5msec x 25Hz)
- The beam current is approximately 119 mA, and the RFQ beam transmittance is 90.1%.
- RFQ average beam power: 40~45kW



Beam current waveform at the HEBT at 8.75% duty cycle

Example of no interceptive diagnostics

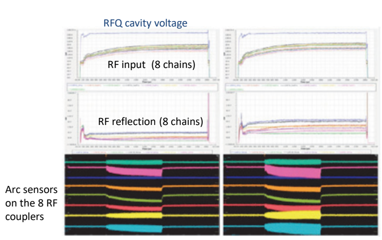


Fluorescence Profile Monitor (CIEMAT)
Collect light from ionization of beam particles + residual gas

What is a limitation of the duty cycle？

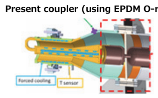
- Duty cycle increase up to 10% is difficult with present RF couplers.
- At long-pulse, high-duty, multipacting varies at different ways between couplers, resulting in an imbalance in each RF chain. As a result, the interlock from RF signals stops before the cavity temperature and vacuum level reach a steady state level.

→ Preparation of couplers for high-duty (brazed) is carried out with high power test.

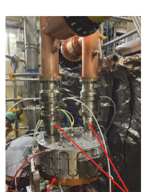


Cavity voltages, input/reflection powers of the RFQ, and detected light in the couplers

Present coupler (using EPDM O-ring)



High-duty coupler (brazed)



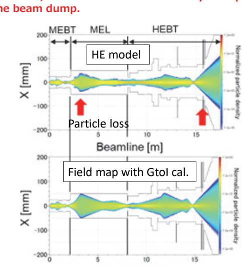
High-power test of brazed coupler

During commissioning, unexpected particle losses were observed

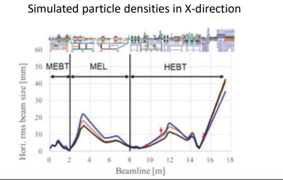
- Discrepancies appeared between simulated and measured rms beam seizes
- Initial simulations used a Hard-Edge model for Q-mags
- Incorporated realistic field maps (incl. Fring Fields)
- Calibrated GtoI conversion coefficients using 5 MeV D+ beam

→ After calibration and re-optimization, particle losses were reduced. And simulated beam sizes aligned better with measurements.

A 120 mA/5 MeV beam was successfully transported to the beam dump.



Simulated particle densities in X-direction



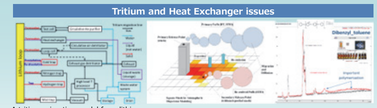
Simulated and measured rms beam sizes

FNSD Activities

Engineering design activity

EU-JA activities related to Engineering Design have primarily implemented the following:
- Evaluation of tritium generated at neutron source facilities and the environmental impact of radioactive materials in accidents
- New proposals for heat transfer fluids in heat exchangers and effects of radiation on heat transfer fluids
- The following items through LIPAc beam operations (LIPAc as test facility):
  - Testing of radiation-based beam diagnostics
  - Neutron field verification and activation・LIPAc nuclear analysis
  - LIPAc RAMI

Tritium and Heat Exchanger issues



A tritium migration model from lithium loop under steady operation of FNS (JA). Physical Model Schematic of Developed Tritium Environmental Diffusion Code ROPUCO (JA). Overlay chromatograms of irradiated and non-irradiated HX oil samples (EU).

LIPAc as test facility (Diagnostics and Neutronics)

CAD model of LIPAc Phase B+ and detector positions.

Calculated dose rate map in Phase B+ operation (EU).

Lithium Target Facility activity

EU-JA activities related to LiTF Activities implemented the following:
- Development of purification validation using a full-scale and compact Li purification system Equipment (LITEC-EU and LIPSE-JA) and Verification of Removal Performance
- Development of Remote Diagnostic Methods for Lithium Target Surfaces Using Laser Diagnostics and Diagnostic Equipment Layout Design
- Other tasks include surface analysis of ELTL materials, erosion and corrosion evaluation of target assemblies, and verification of lithium fire ignition characteristics and the suppression technologies.

Lithium purification validation

LIthium TEchnologies CIEMAT loop(Spain-LITEC) (Full-scale purification examination apparatus)

Lithium Purification System Equipment (JA-LIPSE) and Hydrogen-Nitrogen Concentration Analyzer Overview

Lithium surface diagnostics

Remote Diagnosis Using Laser Methods with GaInSn and results of measurements (EU).

Remote Diagnosis Using Laser Methods with Lithium flow (Osaka-Univ.) and Dose Analysis for Laser Diagnostic Equipment Placement (JA)

Conclusion

- The research and development of IFMIF is currently in the stage of engineering demonstration and engineering design activities (EVEDA).
- Stepwise installation and beam commissioning of LIPAc have been and are being conducted.
  - (Phase B) in Jul. 2019, successful acceleration to 5 MeV 125 mA D^+ short pulsed beams,
    - ✓ First time in the world in accelerating >100 mA D^+ beams by RFQ
  - (Phase B+) in June. 2024, long pulse demonstration at 5 MeV.
    - ✓ RFQ successfully operated at a rated current of approximately 10% duty cycle.
    - RF couplers are identified as a bottleneck to achieve CW operation, and mitigations (brazed couplers) are being conducted
  - (Phase C/D) Preparation of SRF for 9 MeV, 125 mA D^+ CW
- LIPAc is on the right track to demonstrate the IFMIF accelerator concept.
- On FNSD, we have many valuable outcomes on the Engineering design activities and Lithium Target Facility Activities.
- The IFMIF/EVEDA achievements are successful Japan-EU partnership in Broader Approach activities.
- Ultimate objectives: support the design, construction and operation of the accelerator for the neutron source facility, such as DONES and A-FNS, to provide material data for Fusion DEMO.

Related presentations

- Oral: TEC/4-5 Oct.17 15:20 T. Akagi, "Accomplishment Of High Duty Cycle Beam Commissioning Of Linear IFMIF Prototype Accelerator (LIPAc) At 5 MeV, 125 mA D+"
- Poster: 2688 Oct.16 K. Kumagai, "Quantitative Evaluation Of Beam Loss Based On Radiation Detection In High-Duty Beam Commissioning Of LIPAc RFQ"
- Poster: 2973 Oct.16 T. Itagaki, "Analysis Of Background Plasma Behavior Under External Fields In The Low Energy Beam Transport Section Of LIPAc"
- Poster: 3021 Oct.16, S. Kenjo, "Radiological Safety Assessments For Fusion Neutron Source In Engineering Design Activities Under IFMIF/EVEDA Project"

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