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A KAHIF-upgrade project for fusion/fission material irradiation evaluation

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1. Introduction

The development of a next-generation nuclear fission power plant, including a small modular reactor (SMR) [1], and a fusion reactor, led by the ITER (International Thermonuclear Experimental Reactor) project [2], are both ongoing. Research on next-generation nuclear fission and fusion projects is particularly dependent on experimental data of the material damage caused by high-energy neutron irradiation.

High-energy neutrons cause changes the elemental arrangement inside the structural materials, resulting in radiation hardening, ductility reduction, and volumetric swelling [3]. As a result, facilities like IFMIF that can generate high-flux fast neutrons are being constructed [4]. Nevertheless, it has the constraints as a high construction fund and human resource, maintenance human cost, and so on.

To compensate, heavy ion beam irradiation research has been steadily progressing. In order to conduct material damage research quickly and validate the results, the heavy ion beam irradiation experiment for the material of surface level about μm can closely resemble the high-energy neutron irradiation experiment [3]. Despite these numerous advantages, conducting heavy-ion beam irradiation research in Korea was difficult due to a lack of utilization facilities.

The Korea Atomic Energy Research Institute (KAERI) has established a heavy ion beam irradiation facility capable of producing heavy ion beams with varying energies at the highest rate of dpa (displacement per atom) in Korea.

This paper introduces the KAHIF (KAERI Heavy-ion Irradiation Facility) upgrade project for nuclear/fusion material damage assessment, and provides a summary of the required equipment and system contents.

2. Overview of a KAHIF

As part of an international cooperation project, Korea Atomic Energy Research Institute brought a heavy ion beam linear accelerator from Japan's KEK TRIAC (Tokai radioactive ion accelerator complex) in 2015, installed it, and completed beam commissioning the entire accelerator facility by 2020 [5].

Only stable non-radioactive beams can be produced by the KAHIF. The low-energy beam transportation (LEBT) beamline receives ions heavier than protons from the 18 GHz electron cyclotron resonance (ECR) ion source. The split-coaxial radiofrequency quadrupole (SC-RFQ) linac at 25.96 MHz accelerates heavy ions to 178 keV/nucleon. The accelerated heavy-ions are then transported to the 51.92 MHz interdigital H-type (IH) linacs via a transport system consisting of an RB and two sets of quadrupole doublets. Finally, the IH linacs can reaccelerate the ions up to 1.09 MeV/nucleon. The HEBT transports the ions to the target chamber that can control target position and heating temperature. Figure 1 and table 1 contain the major features of the KAHIF accelerator. The switching powers of linacs can be used to select available beam energies.

The facility can accelerate various heavy ion beams for example He, Ar, Fe, and Xe. Due to the use of a high-temperature heating system that exceeds 600 degrees, it has the advantage of being able to evaluate material damage in a variety of environments. By maximizing the benefits of this facility, the new basic science project for evaluation of fusion structural material damage has been going in 2022.

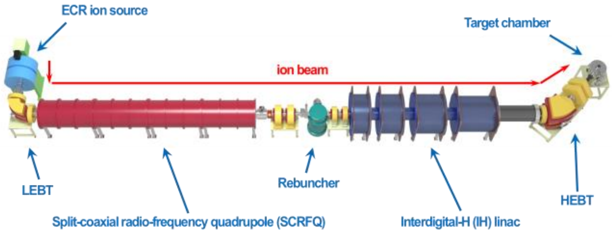

Figure 1. Overview of KAHIF accelerator

Table 1. Summary of KAHIF operation parameters

Parameters	SC-RFQ	IH
Frequency	25.96 MHz	51.92 MHz
Synchronous phase	- 30 deg.	- 25 deg.
Charge-to-mass ratio	≥1/28	≥1/9
Input energy	2.07 keV/u	178.4 keV/u
Output energy	178.4 keV/u	178.4 – 1090 keV/u
Normalized emittance	0.6π mm·mrad	0.6π mm·mrad
Energy spread	1.03%	≤2.8%
Duty factor	30 – 100%	100%
Repetition rate	20 – 1,000 Hz	20 – 1,000 Hz
Total length	8.6 m	5.6 m

3. Upgrade Plan

We are planning on doing research in four major parts in order to carry out the KAHIF upgrade project.

(1) Install a new compound chamber that uses the Metal Ions from VOlatile Compounds (MIVOC) method [6] to provide the metal beams (Fe, iron) most frequently requested by users in the currently built ECR ion source.
(2) Replace the existing chamber system with a load-lock chamber so that samples can be exchanged easily while the target system is kept at high vacuum, and mount a new twin-exhaust vacuum system.
(3) Develop an ion beam diagnostic system that can check the beam characteristics and quantitative results of the irradiated ion beam in real time, such as beam current, beam size, and beam energy.
(4) Upgrade a main control system and a data storage server, as well as an assistant solution for determining the KAHIF accelerator operating state parameters.

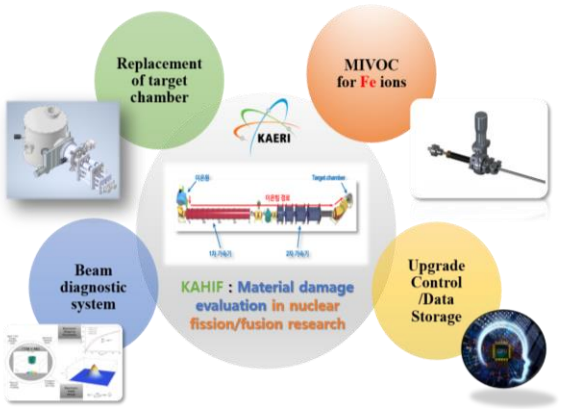

Figure 2. Upgrade plan summary in KAHIF

This upgrade project research is being conducted from 2023 to 2026, and it is expected to result in Korea's best and only facility capable of irradiating iron ion beams of 50 dpa/hour or more with optimized performance for material damage evaluation.

4. Conclusion

As Korea's only ion beam irradiation facility for material damage evaluation, if KAHIF is upgraded, it will be capable of considerably contribute to research on nuclear fusion and fission materials. It will be possible to contribute to the development of domestic material technology by quickly accepting the demand of researchers who previously relied on foreign facilities.

Acknowledgement

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