Service Status of a KAERI Heavy-ion Irradiation Facility (KAHIF) in 2025 and Future Plans for nuclear fusion/fission material irradiation experiments

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1. Introduction

For the commercialization of next-generation nuclear systems, such as Small-Modular Reactors (SMR), Molten-Salt Reactors (MSR), and nuclear fusion reactors, it is essential to develop and validate structural materials capable of withstanding harsh neutron environments [1-3]. In particular, the structural materials of fusion reactors are subjected to extreme neutron irradiation damage reaching hundreds of displacements per atom (dpa). While large-scale research reactors are utilized to evaluate this damage, they present significant constraints, including lengthy testing periods, prohibitive costs, and the high residual radioactivity in samples. As an effective alternative, accelerator-based ion beam irradiation testing, which simulates neutron irradiation damage over a much shorter time frame, is being actively adopted worldwide.

To address this national research demand, the Korea Atomic Energy Research Institute (KAERI) has established and operates the KAERI Heavy Ion Irradiation Facility (KAHIF). Based on a linear radio-frequency (RF) linear accelerator, KAHIF has provided various gas ion beams such as Helium (He), Argon (Ar), and Xenon (Xe). Notably, starting in 2025, KAHIF has successfully extracted an Iron (Fe) solid metal ion beam, enabling the facility to support the most advanced dpa simulation testing in Korea [4-6].

This paper outlines the operational performance of KAHIF in 2025, a year in which the facility transitioned from a general-purpose irradiation service to a specialized infrastructure for high-dose irradiation. Furthermore, it presents mid-to-long-term strategic plans for 2026 and beyond.

2. Utilization Status and Service Statistics in 2025

2.1. Establishment of a High-flux Fe^{13+} Ion Beam system

The most precise method to simulate neutron irradiation damage in nuclear and fusion structural materials, as same steel alloys, without chemical interference is self-ion irradiation using Fe ions, which are identical to the base element. In 2025, KAHIF successfully optimized the MIVOC (Metal Ions from Volatile Compounds) system to vaporize solid iron compounds (Ferrocene) at room temperature, stably extracting a Fe^{13+} ion beam.

The extracted beam was accelerated to 9.68 MeV through a Split Coaxial Radio-Frequency Quadrupole (SC-RFQ) accelerator, maintaining a high beam current of approximately 1.0 ㎂ at the target surface. Through this, a groundbreaking achievement was reached by completing a high-dose irradiation of 20 dpa (~2.1×10^{16} ions/㎠) on an Advanced Reduced Activation Alloy (ARAA) sample for fusion applications in just 7 days.

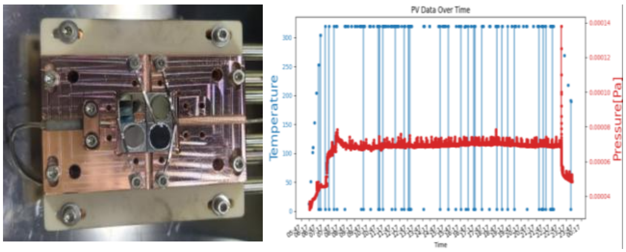

Figure 1. KAHIF Fe^{13+} 20 dpa ARAA samples (left), and beam irradiation operation data summary (right)

2.2. Beam Service Statistics and Revenue Growth

The technical upgrade directly led to an increase in demand for KAHIF. In 2025, KAHIF recorded an all-time high of 239 hours of total beam irradiation time, with an equipment operation rate reaching 80%. A total of 230 samples were processed successfully across 45 independent irradiation tests. The user service revenue surged to approximately 66.27 million KRW, an increase of about 3.8 times compared to 2024 (17.27 million KRW).

An analysis of the user statistics in 2025 by research field revealed that the nuclear fission field accounted for approximately 65% of the total beam time, while the nuclear fusion especially Reduced Activation Ferritic-Martensitic (RAFM) steels accounted for 35%. Most of the experiments focused on nuclear fuel research, particularly on the development of next-generation nuclear fuels for high-flux neutron environments.

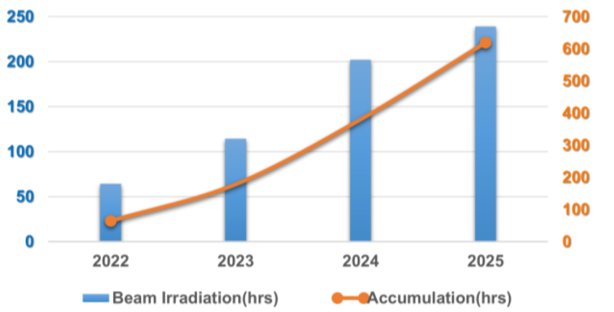

Figure 2. KAHIF Beam Time Usage Statistics by Year (2022–2025)

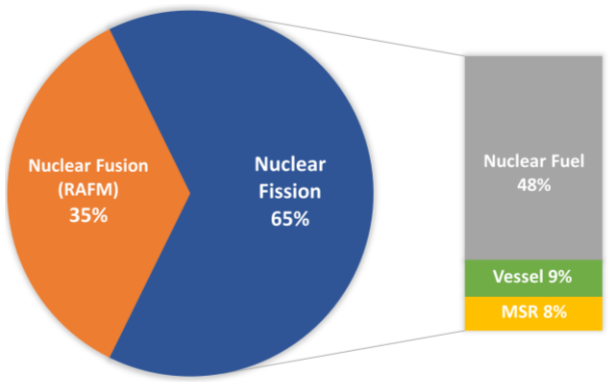

Figure 3. Distribution of Research Fields at KAHIF

3. Future Plans in 2026

Building upon the operational successes of 2025 and aligning with strategic national initiatives such as the GlobalTOP Strategic Research Group program, KAHIF is poised to implement the following infrastructure advancements in 2026:

1) Ultra-High-Temperature Target Chamber: To simulate the severe thermal-mechanical conditions of Generation IV and fusion systems, a new target chamber will be integrated, expanding the thermal testing envelope from 450°C to 900°C.
2) New MEBT Beamline and Advanced Beam Diagnostics: A new Medium Energy Beam Transport (MEBT) line will be commissioned to facilitate sophisticated beam-shaping and real-time beam diagnostics, ensuring unprecedented precision in irradiation control.
3) Flux Optimization and Dual-Beam Architecture Design: Through improvements to the MIVOC system, the Fe ion beam current will be enhanced to over 2.0 μA to significantly reduce irradiation durations. Furthermore, physical design of an He/Fe dual-beam system is being started to investigate the synergistic effects of gas production and displacement damage.

4. Conclusion

In 2025, KAHIF successfully completed a 20 dpa irradiation using a high-flux Fe^{13+} ion beam for the first time in Korea. This achievement signifies the facility's successful transition from a conventional irradiation facility into a national infrastructure dedicated to the rigorous validation of nuclear and fusion materials under extreme environmental conditions.

The record-breaking 239 hours of operation and explosive revenue growth demonstrate the expanding demand for ion beam irradiation in Korea. With the forthcoming integration of the 900°C ultra-high-temperature chamber and the simultaneous dual-beam irradiation system architecture, KAHIF will serve world-class experimental capabilities to the domestic research community.

Acknowledgement

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