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Current Status and Plans of KAHIF for nuclear fusion/fission material research

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1. Introduction

Research on the effects of high-dose neutron irradiation on materials is essential for the advancement of nuclear fusion and fission reactors. When neutrons with high flux pass through materials in the reactor, they cause damage and corrosion, leading to stress cracking, creep, fatigue, and reduced fracture toughness. Hence, material research is necessary to analyze the impact of neutron irradiation on the core materials within the reactor [1].

The neutron irradiation dose of commercial light water reactors (LWRs) is estimated to be approximately 1 dpa (Displacement per atom) throughout their usage cycle. However, the amount of neutron irradiation is expected to be about 150 dpa for the next-generation fission reactors and fusion power reactors [2]. Furthermore, when dealing with nuclear fusion reactions, it is essential to consider the impact of the helium particles. It can make a helium bubble, which can lead to swelling and fractional damage to the material itself.

To conduct basic and application/development research on materials that can respond to neutron irradiation, a dedicated irradiation facility that can directly irradiate high-dose neutrons is essential, and for this purpose, facilities such as IFMIF that can irradiate very high neutron fluxes are essential [3]. Although efforts are being made to build test research facilities, it is very difficult to respond to all diverse basic/applied research demands due to extremely high construction costs and radiation issues.

The neutron irradiation simulation test method through heavy ion beam irradiation is emerging as an alternative, and research is being actively conducted around the world [4]. At the same time, efforts are being made around the world to conduct active research and utilization research, such as establishing international standards using this method.

In this paper, we describe a summary of the user services offered by KAHIF (KAERI Heavy-ion Irradiation Facility) for research on nuclear fission/fusion materials. We also introduce our plans to improve the MEBT beam-line for Fe ion irradiation to better support high dpa research. Additionally, we present KAHIF's operational direction and suggest potential research projects that can be pursued using our facility.

2. Current Status of KAHIF

A heavy ion beam irradiation facility has been constructed at Korea Atomic Energy Research Institute (KAERI), Daejeon, Korea, for nuclear/fusion materials research and development. This facility, first called Daejeon Ion Accelerator Complex (DIAC) and later renamed Korea Atomic Energy Research Institute Heavy Ion Irradiation Facility (KAHIF), produces heavy ion beams with energies up to about 1 MeV/nucleon [5][6]. Our facility offers a beam user service that can irradiate accelerated heavy-ion beams such as He, Ar, and Fe. The target chamber with sample supporter, which can reach temperatures of around 450°C, allows us to evaluate material damage in various environments. This system has proven to be advantageous assessment of the effects of high temperatures on different materials.

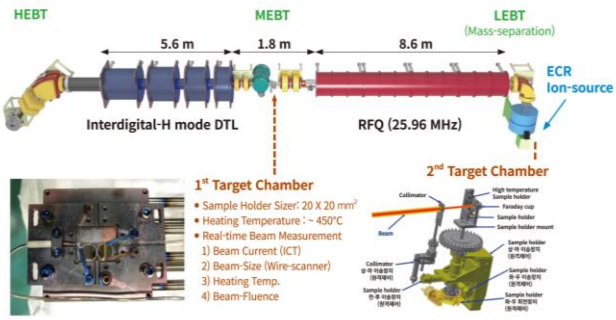

Figure 1. Summary of the KAHIF

Table 1. Performance parameters of the KAHIF

	SC-RFQ	IH
Frequency	25.96 MHz	51.92 MHz
Mass-to-charge ratio (A/q)	≤ 28	≤ 9
Input energy	2.07 keV/u	178.4 keV/u
Output energy (MAX)	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

KAHIF commenced its operations in 2022 and is currently supporting 7 institutions, and 20 users in conducting and facilitating research on 8 different topics. The facility's operating hours have been increasing by 100% every year, and it is currently being utilized very actively, operating at 70% of its available hours.

Table 2. The KAHIF Beam Irradiation Conditions

	Value
Ion Species	He^{2+}, Ar^{10+}, $Fe^{11\sim13+}$
Beam energy (±5%)	0.688 MeV @He
	6.871 MeV @Ar
	9.605 MeV @Fe
Beam current (MAX, ±5%)	20 μA @He
Beam Spot Area	< 2.8 cm^2
Beam Flux ($\#/cm^2 \cdot s$)	1.68 x 10^{13} @He
	4.02 x 10^{12} @Ar
Heating System	< 450℃

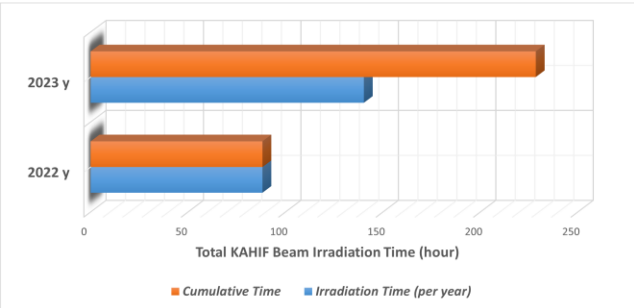

Figure 2. Survey of beam service time of the KAHIF

3. Fe ion beam irradiation in MEBT beam-line

The most effective way to evaluate the degree of neutron irradiation damage through ion beam irradiation is to use the ionic species that account for the highest proportion of the material as a projectile. It accelerates the analysis time and dynamics of neutron irradiation damage compared to other methods. Therefore, it is recommended to use an accelerated iron (Fe) ion beam for neutron damage assessment [7]. Currently, we are working on improving the 18 GHz ECR ion source with MIVOC (Metal Ions from VOlatile Compounds) vacuum chamber to generate iron ions [8]. We have already confirmed that the ion source can generate an iron ion plasma, and we are developing the capability to irradiate up to 20 dpa/hr through iron ion beam irradiation up to 9.6 MeV (0.172 MeV/n) by accelerating to RFQ.

To make the iron ion beam more usable and reliable, we are planning to upgrade the MEBT (Medium-Energy Beam Transport) beam-line. The beam line consists of two quadrupole magnets and a steering magnet that are used to control the ion beam in stable. Additionally, a beam measurement system with a wire scanner and a Faraday cup will also be included. The beam chamber can heat up to 900℃ and provides a quick sample replacement solution. It also offers a test report that summarizes the data from the beam irradiation experiment.

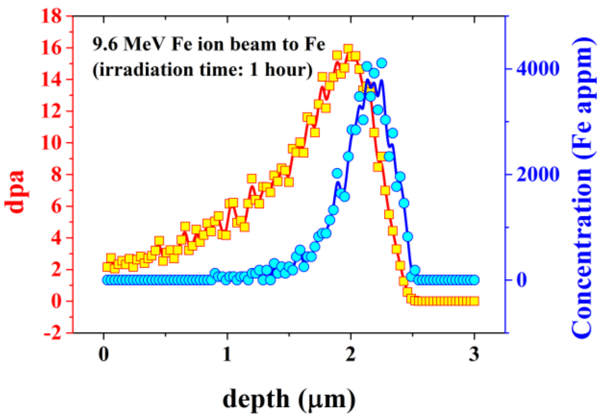

Figure 3. Simulation result of Fe ion beam irradiation

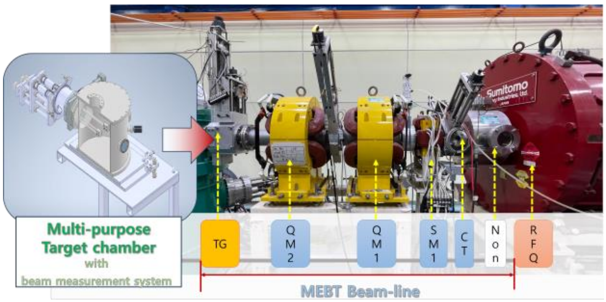

Figure 4. Upgrade of a MEBT beam-line in KAHIF

4. Research Plans for nuclear material research

The KAHIF facility is dedicated to advancing the field of research by expanding its scope beyond neutron irradiation damage research. It is now researching corrosion and neutron absorption. To diversify the irradiation damage research, the facility has improved its facilities for dual ion beam irradiation. It has also established plans to conduct various studies such as nuclear fuel evaluation research for SMR and corrosion impact assessment for Ni beam-based MSR. The facilities required for these studies have been ongoing, and will soon be established. This will enable quick acceptance of the demand of researchers who previously relied on foreign facilities, thus contributing to the development of domestic material technology.

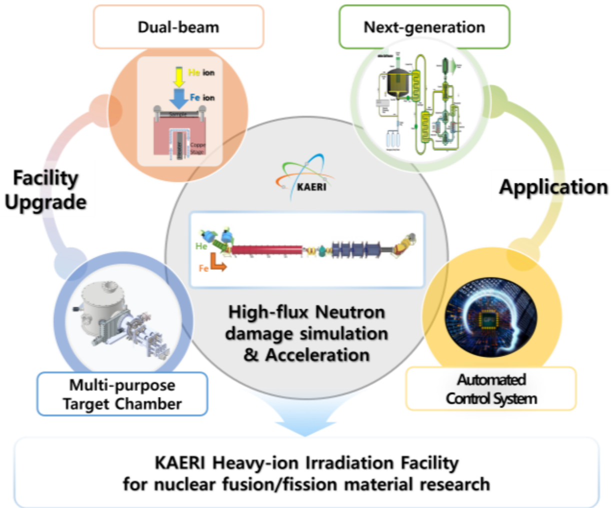

Figure 5. Plans of the KAHIF for nuclear material research

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