Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2023

DPA Calculation for Helium and Iron Beams on ARAA using SRIM code in KAHIF Accelerator

Kihyun Lee [*], Seunghyun Lee, Sangbeen Lee, Dongwon Lee and Dae-Sik Chang
Korea Atomic Energy Research Institute, Daejeon, Republic of Korea

[*]*Corresponding author: khlee08@kaeri.re.kr*

***Keywords :** SRIM, DPA, heavy ion beam, accelerator, KAHIF

1. Introduction

Nuclear fusion power plants hold potential as a sustainable energy source for the future. However, to realize this potential, the core components of these power plants, such as plasma facing components, and a structural material, must demonstrate stable performance even in extreme environments. These components are exposed to high temperatures and neutron radiation, making material selection to minimize damage a critical research topic.

Facilities like IFMIF generate high-power neutrons to evaluate the durability of these materials. [1] However, beam service time for neutron irradiation test on various material candidates is not sufficient, necessitating alternative methods. While direct neutron irradiation has complex effects on materials, such as causing displacements per atom (DPA) and generating helium bubbles [2], it's difficult to replace. Yet, when focusing on DPA, utilizing heavy-ion beams is effective. These beams are easier to produce compared to neutrons and can induce DPA effectively due to their high mass. Additionally, the use of He ion beams allows for simultaneous measurement of effects caused by helium.

The Korea Atomic Energy Research Institute (KAERI), as part of an international collaboration, imported a heavy-ion linear accelerator from Japan in 2015, naming it Korea Heavy-ion Irradiation Facility (KAHIF) and has been operating the facility for beam service since 2022. At this facility, helium and argon beam can be irradiated, and preparations are underway for iron ion beam production. In this paper, we estimate the expected DPA on the Advanced Reduced-Activation Alloy (ARAA) [3] target material from heavy-ion beam (He, Fe) irradiation using SRIM simulation code [4] to establish test conditions for fusion reactor material

2. DPA calculation using SRIM code

2.1 SRIM simulation setup

The SRIM simulation setup consists of ion beam conditions and target conditions. Specific conditions for the KAHIF ion beam used in the simulation are presented in Table 1.

Table 1 Specification of KAHIF ion beam (RFQ only)

Parameters	He	Fe (Under preparing)
Mass	4	55.8
Charge	2	14 (expected)
Energy	0.688 MeV	9.632 MeV
Current	20 uA	1 uA (expected)

The KAHIF heavy-ion irradiation facility mainly operates using He and Ar ions. Ions with a charge to mass ratio of 4 are accelerated to an energy of 0.172 MeV per nucleon through the RFQ (Radio Frequency Quadrupole).

The ongoing upgrade for iron ion beam production will utilize 14+ charged iron ions to satisfy the current charge to mass ratio of 4. In KAHIF, ions accelerated up to the RFQ stage reach an energy of 0.172 MeV per nucleon. Thus, iron ions, with an atomic mass of approximately 56, will have an energy of 9.632 MeV. Producing metal ions like iron is more challenging than generating ions from gases like He or Ar that exist in a gaseous state at room temperature. Due to the requirement of a high charge state, the extracted current is expected to be lower.

ARAA is a material developed in Korea to reduce radioactivity for use in nuclear fusion reactors. To set up a target made of this material in the SRIM simulation, a compound must be created using the elements that compose the material. Table 2 displays the configuration values of the used ARAA target.

Table 2 SRIM setup for ARAA target

Components	Wt.%	Fe (Under preparing)
Cr	9	40
W	1.2	90
Mn	0.45	40
V	0.2	25
C	0.1	28
Si	0.1	15
Ta	0.07	90
N	0.01	28
Ti	0.01	25
Zr	0.01	40
Fe	Balanced	40

2.2 Calculation results

The SRIM simulation was conducted for the ARAA target by injecting He and Fe ions for 1 hour, using a condition of 10,000 ions for each case. Figure 1 display the calculated results for DPA and concentration for He ions and Fe ions, respectively.

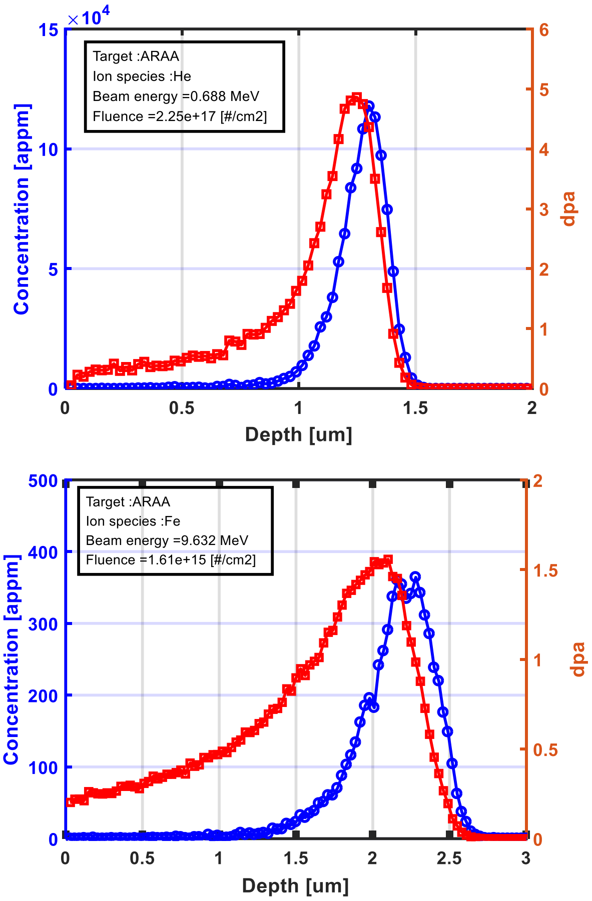

Fig. 1 Results of DPA and ion concentration calculations: He ion beam case (Top), and Fe ion beam case (Bottom)

According to the calculations, the depths at which ion concentration is highest are 1.24um for helium and 2.12um for iron. These results can be a vital reference for material tests after irradiation. For helium ions, the DPA distribution is primarily concentrated around the peak, whereas for Fe ions, the distribution of DPA occurrence is relatively broader. The DPA value for helium was approximately 5, which is higher than that for iron. This discrepancy arises from differences in beam current and charge state, resulting in helium's fluence being over 100 times higher. Specifically, the DPA per fluence was 9.4E-16 for iron ions and 2.2E-17 for helium, with the value for iron ions being over 40 times higher.

The magnitude of DPA changes with fluence, maintaining a consistent distribution, and this fluence value is proportional to the beam current and irradiation duration. Therefore, the DPA based on beam operating conditions can be estimated as depicted in Figure 2. In IFMIF, the goal is to reach a DPA target of 50 through neutron irradiation. [1] To meet this target at the KAHIF facility, it implies that the Fe ion beam would need to be irradiated for about 30uAhr. If future advancements allow the Fe ion beam current to reach up to 5uA, it's anticipated that a mere 6 hours of irradiation would be sufficient to achieve the DPA levels targeted in IFMIF.

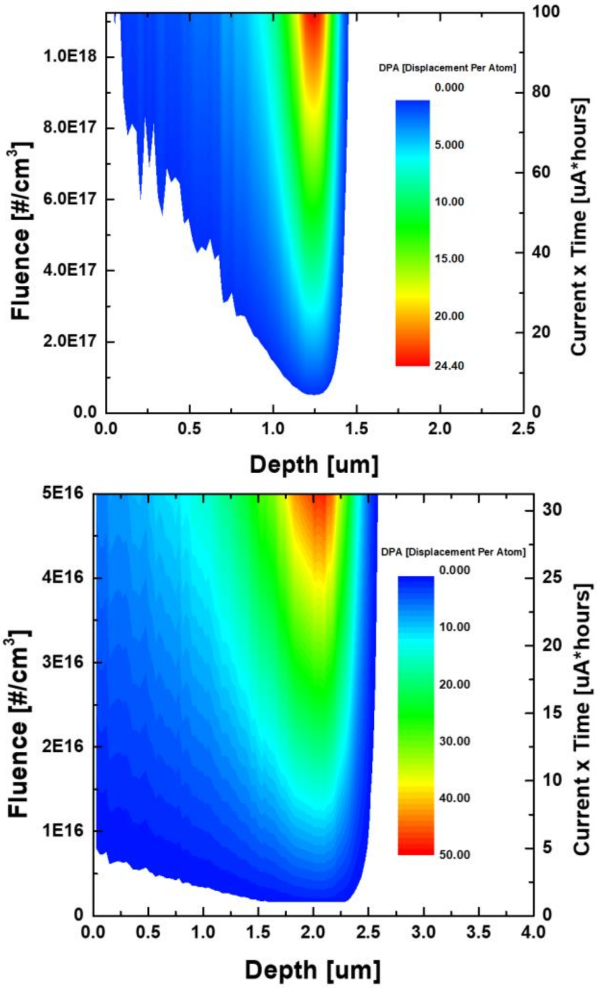

Fig. 2. DPA distribution based on fluence: He ion (Top), and Fe ion (Bottom)

3. Conclusions

The DPA arising from the ion beam irradiation test of ARAA target in the KAHIF facility was successfully calculated using the SRIM simulation code. As anticipated, by utilizing the injection of heavy ions like Fe, it has been confirmed that the KAHIF facility can achieve the high DPA values of over 50, as required by IFMIF. Additionally, based on our research results, the operational conditions necessary to meet the DPA requirements for material irradiation tests have been established. Upon the completion of the ongoing upgrade for Fe ion beam production, actual irradiation tests will be conducted.

Acknowledgement

This work was supported by National R&D Program through the National Research Foundation of Korea(NRF) funded by the Korea government (Ministry of Science and ICT) (RS-2023-00156272)

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