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Ionbeam-Induced DPA Value Calculation Using SRIM code for the High-DPA Irradiation System Development

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1. Introduction

Charged particle irradiation studies have been utilized for understanding irradiation effects on the micro-structure and microchemistry in materials for many decades [1–3]. Proton irradiations with damage rates of 10^{-5} dpa/s have demonstrated much success in determining the mechanistic behavior of materials under light water reactor relevant conditions [4]. Heavy ion irradiation experiments with damage rates of 10^{-3} to 10^{-4} dpa/s have replicated the microstructure observed in reactor irradiated materials also with good success [5,6]. These experiments have provided optimism for using ion irradiations as a surrogate for reactor irradiation [7].

Ion irradiations offer indispensible scientific value for understanding specific aspects of the typically very complex radiation effects phenomena in materials. Indeed, in many aspects ion beams are better suited for these fundamental scientific studies than neutron irradiations due to generally superior experimental control and accessibility during irradiation as well as the ability to individually vary key experimental parameters such as ion energy, flux and ion species in order to systematically explore single-effects parameters such as PKA spectrum, dose rate and temperature. Ion beams generally offer advantages for in-situ irradiation microstructural and chemical studies compared to neutron irradiations [1]. The development of HighFor these kinds of studies on the nuclear material damage, a high-temperature and high-DPA ion beam irradiation facility is induced by the development of the irradiation of In this paper, the DPA values induced by ion beam irradiations, such as Fe, He, proton, etc. were calculated using SRIM code simulation. These kinds of ion beams can be provided by the 1.7 MV tandem accelerator being operated by the KOMAC (Korea Multi-purpose Accelerator Complex).

2. Methods and Results

2.1 Ions from 1.7 MV Tandem Accelerator of KOMAC

The energy of ion beams produced by the tandem accelerator is decided by the terminal voltage and the charge status after passing the charge exchange cell. The minimum and maximum energy ranges for the ion beams are summarized in Table 1. For the iron beam, we can use Fe^{3++} ion beam in the range of 1.0 ~ 6.8 MeV. The beam currents are varied by the ion species, charge status, energy, and accelerator operation conditions such as stripping gas pressure, etc.

Table I: Energy Range of Ions

	Minimum Energy [MeV]	Maximum Energy [MeV]
Proton & Ions (+1q)	0.5	3.4
Ions (+2q)	0.75	5.1
Ions (+3q)	1.0	6.8
Ions (+nq)	0.25+(n*0.25)	1.7+(n*0.25)

2.2 Nuclear Materials

In the review article about Structural materials for fission and fusion energy, written by Steven J. Zinkle and Jeremy T. Busby, they compares the proposed operating temperatures and lifetime displacement damage levels for structural materials in the six Generation IV concepts and three fusion energy systems with the existing knowledge base as shown in Fig. 1. A ODS steel, F/M steel, V alloy, SiC, etc. are the representative structural materials for the fission and fusion energy. The operating temperature is 200~1100 °C and the maximum DPA value is 200 dpa.

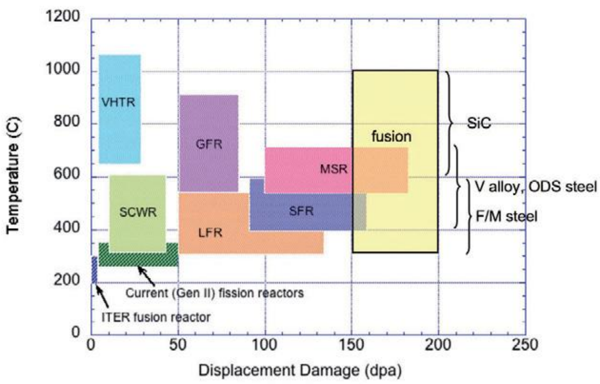

Fig. 1. Overview of operating temperatures and displacement damage dose regimes for structural materials in current (generation II) and proposed future (Generation IV) fission and fusion energy systems. The six Gen IV fission systems are Very High Temperature Reactor (VHTR), Super Critical Water Reactor (SCWR), Lead Fast Reactor (LFR), Gas Fast Reactor (GFR), Sodium Fast Reactor (SFR), and Molten Salt Reactor (MSR) [7].

2.3 SRIM Code Simulation

SRIM code [8] has been used for the ion stopping power and ion range calculations for various ion species. The ion beam induced displacements also can be calculated by using SRIM code. Even though many kinds of simulations codes, PHITS[9], MARS15 [10], FLUKA[11], and MCNPX[12] can be used for the calculations of DPA, SRIM code is widely used for the same purpose because of the simplicity of usage.

We calculated the DPA value induced by ion beam irradiations on Zr-alloy. For the 3-MeV, 10-μA proton beam irradiation, the DPA value is ~0.01 dpa/hr on surface, ~0.063 dpa/hr in depth, nearby ion range, 570 μm. The result means that 100-hours irradiation is required for 1-DPA radiation damage of Zr-alloy using 3-MeV proton beam.

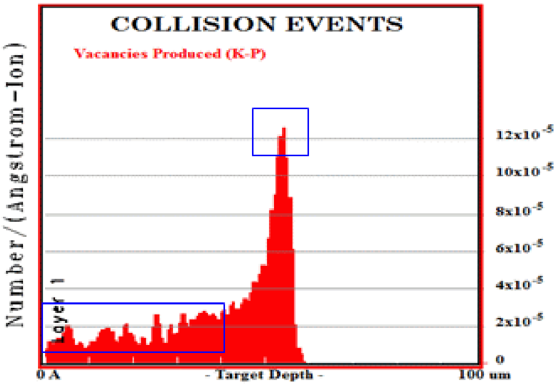

Fig. 2. Calculated depth-profile of DPA value induced by 3-MeV proton beam irradiation on Zr-alloy.

For the 5-MeV, 5-μA iron beam irradiation, the induced DPA value is 21~236 dpa/hr, and ion range is 4 μm as shown in Fig. 3. The result means that only 15~180 seconds are required for the 1 DPA radiation damage.

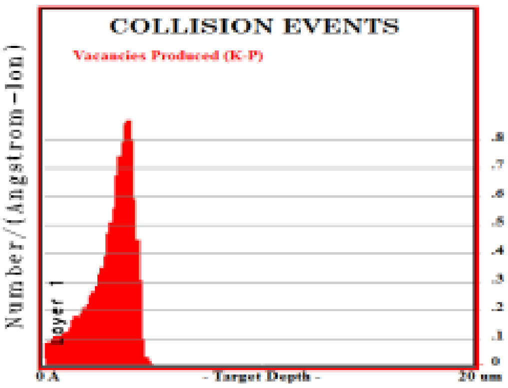

Fig. 3. Calculated depth-profile of DPA value induced by 5-MeV iron beam irradiation on Zr-alloy.

3. Conclusions

SRIM code calculations for the DPA value calculation induced by ion beam irradiations were performed for the several ion beams and promised structural materials for fission and fusion energies. We can estimate the irradiation time and optimized the experiment conditions. The calculation results show that heavy ion beam can be high-DPA radiation damage with very limited penetration depth. On the other hand, light ion, such as proton, can make voids relatively deep site of materials but the induced DPA value is very low compared to the heavy ions'. The calculation results can be the basis of the design of the high-DPA irradiation facility and optimization of the irradiation conditions.

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