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Feasibility Study on the Radiation Damage of Nuclear Materials Induced by High-Energy Proton Beam

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1. Introduction

High dose irradiation induced damages make some troubles in structural materials used in the fusion reactor, ADS, fast reactor, etc. These materials experience high dose irradiation during operation. [1] So, to develop nuclear reactors and fusion reactors, we should investigate degradation of mechanical properties of the structural materials by the damages induced by radiation of neutron. [2]

Heavy ion and proton beam irradiation has been used for radiation damage test of nuclear materials because they can induce higher DPA value compared to neutron during same irradiation time.

The KOMAC (KOrea Multi-purpose Accelerator Complex) has started proton beam irradiation service from last July. Among the 10 target rooms, two target rooms were assigned to nuclear material test. To specify the design concept of the target room, this feasibility study on high-energy proton beam induced radiation damage was conducted. In this paper, the procedure and key parameters that we have to consider are reported.

2. Methods and Results

2.1 SRIM Code Simulation

The DPA value was calculated by using SRIM code [3] and the results were compared to the result of another group. Dr. Yosuke Iwamoto calculated radiation damage using PHITS [4] and compared to the other SRIM code simulation results [5]. As shown in Fig. 1, our calculated result is well matched to their SRIM code simulation result.

Table I: SRIM code simulation results

Material	20-MeV Proton Beam		10-MeV Proton Beam	
	Ion Range [mm]	Fluence for 1DPA [p/cm^2]	Ion Range [mm]	Fluence for 1DPA [p/cm^2]
Graphite	2.09	9.49E+20	0.6	4.17E+20
Al	2.11	3.25E+20	0.62	1.72E+20
Cu	0.79	1.65E+20	0.24	6.06E+19
STS	0.85	2.41E+20	0.26	4.99E+20
W	0.52	5.71E+19	0.17	3.54E+19
Ti	1.44	1.72E+20	0.43	1.10E+20
Zr	1.21	1.81E+20	0.38	6.90E+19

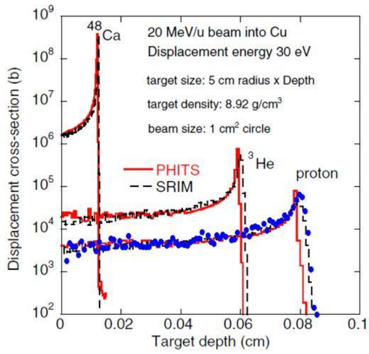


Fig. 1. SRIM code calculation results (filled dot) compared to others; depth dependence of the displacement cross section is shown for a 5 cm radius and 0.1 cm thick copper and tungsten target irradiated by 20 MeV/u proton, ^{3}He and ^{48}Ca beams.

From the calculation results summarized in Table I, we recognize that proton beam irradiation dose for 1 dpa has to be more than 5E+19/cm^2 at least.

2.2 Irradiation Chamber

For high-dose irradiation, specific irradiation chamber was developed. The design concept is shown in Fig. 2. The system is composed of sample holder, beam window, vacuum pump, sample temperature controller and Faraday cup. The sample temperature can be controlled by cooling and heating system installed in the backside of the sample. Beam window is designed to maintain the vacuum pressure of the chamber with minimized proton beam energy loss.

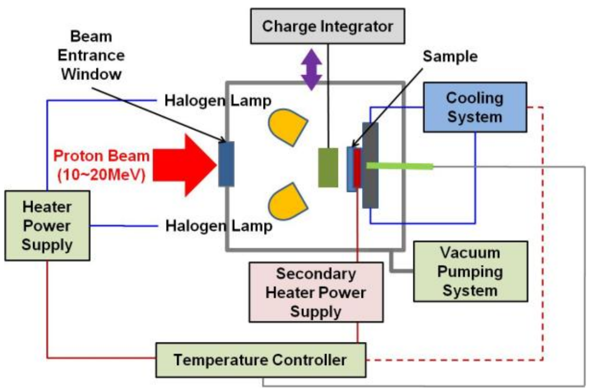


Fig. 2. Design concept of proton beam irradiation chamber system.

Manufactured irradiation chamber was shown in Fig. 3. The beam window and sample holder are designed to be replaceable because they can be highly activated by the proton beam bombardment. And to minimize the radio-activity, the components which can meet proton beam were made of Al.

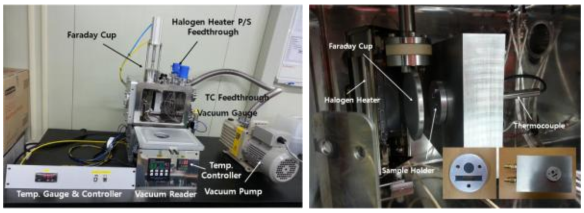


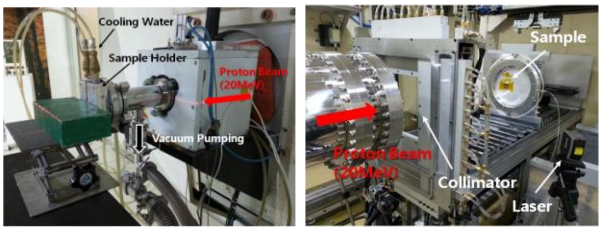
Fig. 3. Proton beam irradiation system.

The beam window is made of 500-μm thick Al, the front wall of the chamber also made of 5-mm thick Al plate, and can be replaceable. The Faraday cup has 5-cm diameter and 4mm thickness, the 20-MeV proton beam can be fully stopped inside. The sample temperature can be reached to 400℃ heated by halogen lamps in a few minutes.

2.3 Proton Beam Irradiation Experiments

The different materials have different threshold dpa value. For graphite, change of mechanical property is started from 0.02 dpa. To obtain 0.02 of graphite, 20-MeV proton beam have to be irradiated to 1.9E+19/cm^2. The irradiation time is 84.4 hours with 10-μA/cm^2 proton beam.

The proton beam irradiation experiments for graphite and STS304 samples were conducted at KIRAMS and KOMAC as shown in Fig. 4.



(a) at KIRAMS (b) at KOMAC

Fig. 4. Proton beam irradiation experiments at KIRAMS and KOMAC.

2.4 Suggestion of Specific Irradiation Facilities

The total irradiation doses were limited by beam time and beam current. To satisfy the required beam time and beam current, specific nuclear material test facility has to be installed at KOMAC. The TR25 and TR101 can be the candidates for these applications. To handle highly-activated samples, some apparatuses, such as hot-cell, sample transport system, etc., have to be installed in the accelerator & beam utilization building of KOMAC.

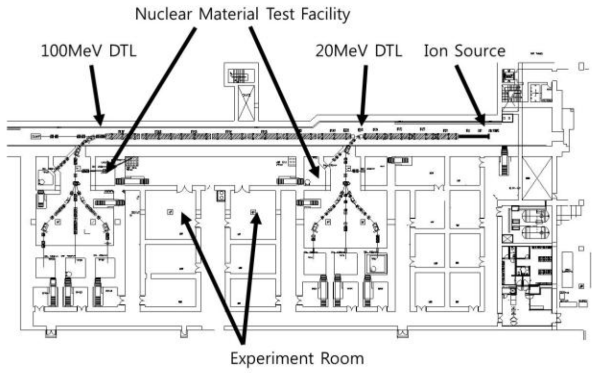


Fig. 5. Accelerator building of KOMAC.

3. Conclusions

The possibility of high-energy proton beam utilization for the study of radiation damage effects on nuclear materials was performed. As a result, we can find out that high-dose irradiation of nuclear materials is not possible using existing facilities. For the radiation damage test of nuclear materials, specific facilities in which high-current and long-time proton beam irradiations are possible. And radiation-shielded facilities, such as shielding case and hot-cell, are necessary. The TR25 and TR101 of KOMAC can be candidates for these applications. In these facilities, more than 10-μA/cm^2 proton beam can be irradiated during more than several tens of hours.

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