Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2012

Monte-Carlo Simulation of Particle Beam Irradiation for Fusion First-Wall

Yong-Kyo Lee(1) and Myung-Hyun Kim(1)&(2)
(1) Department of Nuclear Engineering, Kyung Hee University, 446-701, Rep. of Korea
(2) Reactor Engineering Division, Argonne National Laboratory, IL 60439, USA
mhkim@khu.ac.kr

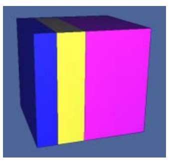
1. Introduction

One of the urgent tasks in fusion tokamak development is the appropriate choice or development of plasma facing materials. The sustainable operation of fusion reactors would be difficult due to plasma facing component(PFC) from being damaged by high-temperature and high-energy particles irradiation. Research about PFC located in the most demanding environment of the fusion reactor should be carried out continuously to make room for the appropriate choice and development. In this study, the characteristics of the damage of PFC have been analyzed by computer simulation using MCNP code. There are realistic limitations in experiments; impossible now in continuation of irradiation time and in providing enough high-energy particle fluxes. Even in the reactor experiment of neutrons only, high DPA cannot be tested; in case of HANARO, total irradiation time should be one year for 1 DPA [1].

2. Methods of Analysis and Results

Characteristics of candidates for PFC should have low neutron activation and excellent heat resistance. Choice of such materials is very limited. Tungsten(W), SiC, C composites, V alloys, etc. are examples. Detail design for the first wall is not known clearly and may not be fixed yet, so analysis was done for the simple geometry.

A model structure is a plane of three material layers as shown in Fig.1. The quantity of 14.06 MeV neutrons is assumed ~3% of the quantity of 2.45MeV neutrons by KSTAR conditions [2]. Center temperature of plasma is hundreds of millions Celsius. But temperature of plasma boundary contact with the PFC is approximately 1,000℃. Thus first region temperature of first wall is assumed to be 1,000℃. He coolant used in the HCSB blanket has an inlet temperature of 300℃ and an outlet temperature up to 500℃ [3]. The second region temperature is assumed to be 500℃ and the third region 300℃ because the second region is a heat sink that has a good thermal conductivity.



region	*First*	*Second*	*Third*
Material	*Any materials*	*Cu*	*SS316L*
Depth(cm)	*1.5*	*2*	*4.9*
Temperature(℃)	*1000*	*500*	*300*

Fig.1. Structure Model of Evaluation Target

2.1 DPA(Displacement Per Atom) Analysis

DPA means how many displaced target atom from the original position due to collisions between particles and target atom. Theoretically, this is the best way to describe the degree of damage. But it is difficult to experimentally determine the value of DPA.

$$DPA = \int \sigma_{dis}(E)\varphi(E)dE \qquad (1)$$

Where σ_{dis} is the displacement cross-section, φ is the neutron flux. Displacement cross-section σ_{dis} is calculated as follows

$$\sigma_{dis} = \frac{0.8}{2E_d}\sigma_d T_d \qquad (2)$$

where σ_d is the damage cross-section, T_d is the value that can be called "average damage energy", E_d is the displacement threshold energy [4]. σ_d and T_d can be got by MCNP code. MT number of damage cross-section is 444. This number is used in FM card in MCNPX. And heating number(MeV/collision) is used to get T_d.

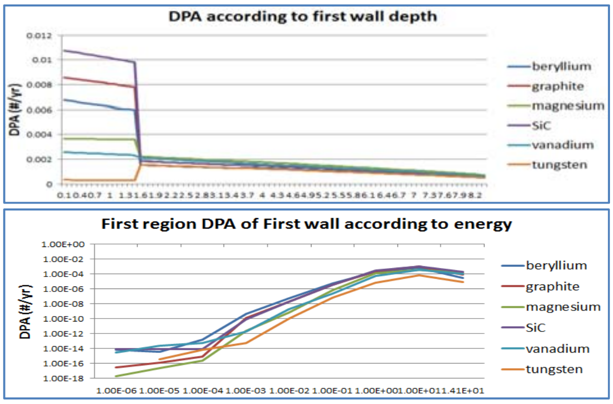


Fig.2. Calculated DPA at different materials

The DPA values are very low due to low neutron flux in KSTAR. Tungsten has the lowest value in these materials. After first region, the values of all cases are almost same because second region and third region are fixed materials. The value is affected by high-energy neutrons upper than ~100KeV.

2.2 Neutron flux analysis

High-Level-Waste in blanket is burned out more easily at high energy neutron(> ~1MeV). The blanket is located next to the first wall. So I have found which material transmits the larger fraction of high-energy neutron.

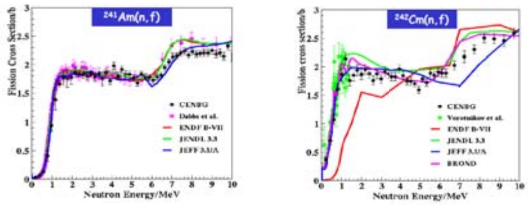


Fig.3. Fission XS of minor actinides

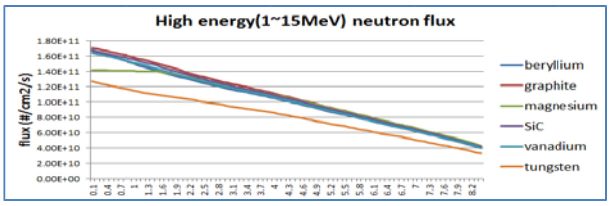


Fig.4. Variation of fast neutron flux to first wall depth

High-energy neutron flux is lowest when the first region material is tungsten. But the end of first wall, every material has almost same flux. In other words, there is no significant effect by neutron flux.

2.3 Proton flux and energy deposition

If energy deposition is high, material will be damaged quickly. And proton influence on material damage is needed to analyze because high-energy protons are generated due to D-D reaction in KSTAR. Proton is a charged-particle and does not penetrate deeply into the materials. So, proton can damage the material surface more severely.

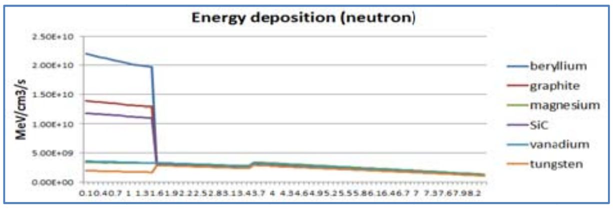


Fig.5. Change of energy deposition by neutron to first wall depth

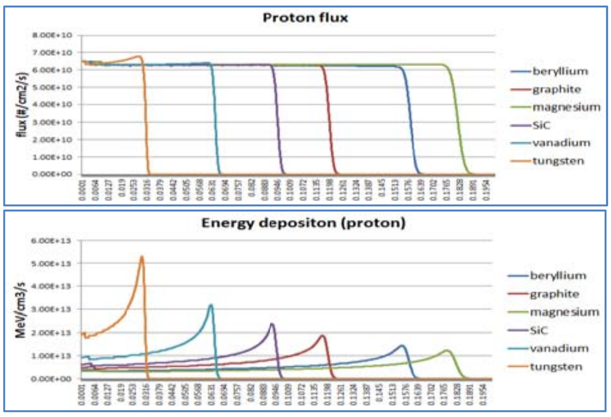


Fig.6. Change of Proton flux and energy deposition to first wall depth

In terms of energy deposition by neutron, tungsten is more good than the other materials. But, In case of proton, it has most bad effect on first wall surface because proton does not penetrate deeply in tungsten compare with the others.

2.4 Secondary particle production rate

Secondary particles that are produced by high-energy neutrons passing through the PFC can cause significant damage.

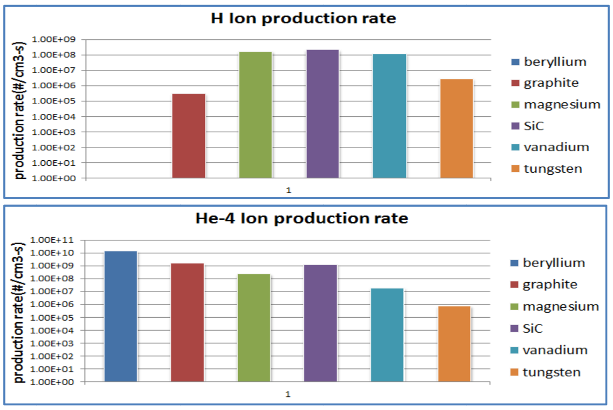


Fig.7. Hydrogen and helium production rate

Beryllium, graphite and tungsten are good materials in terms of hydrogen production rate. But the quantity of helium production in beryllium and graphite is very high by comparison with tungsten. So tungsten is good enough material of PFC.

3. Conclusion

Tungsten has a good effect in terms of neutron calculation; DPA, energy deposition on neutron, and secondary particle production rate. But energy deposition on proton has a very bad effect on first wall surface. DPA calculation in proton transport is very important for accurate first wall damage quantification. But current MCNPX does not facilitate the DPA calculation for proton due to not including proton information in MCNPX. In future, some potential materials will be studied with more detailed geometrical model of target. And efforts will be put for accurate material damage calculations.

REFERENCES

[1] K.M.Kim and M.H.Kim, "Analysis on Radiation Damage Effects at the Plasma Facing Materials," M.S. Thesis, Kyung Hee University(in Korean), 2011.
[2] Hyunduk Kim, et al., "Radioactivity Evaluation for the KSTAR Tokamak", Radiation Protection Dosimetry, v.116, 2005.
[3] Myeun Kwon, et al., "Current Status of Nuclear Fusion energy Research in KOREA", Nuclear Engineering and Technology, Vol. 41 NO.4, May, 2009.
[4] A.Yu.Konobeyev, et al., "Neutron displacement cross-sections for structural materials below 800MeV", Journal of Nuclear Materials, Vol.186, pp. 117-130, 1992.