Analysis on Radiation Effects of Fusion Material proposed for ITER First-wall through Particle-beam Irradiation

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1. Introduction

As a main concern of generating energy from fusion of atomic nuclei, all memebers involved in improvement of ITER are working on the physical and technical feasibility check for fusion source in which first wall will also take main role to be investigated. In this paper, the radiation damage of fusion materials through particle-beam irradiation is parametrically checked through Monte Carlo simulation. Consequently, it is targeted to propose a database of basic physical properties for the sake of selecting proper plasma-faced component (PFC) which will be used in a fusion reactor. Simulation of fusion materials under the assumption of the particle-beam irradiation was carried out so as to investigate damages related with neutron beam as well as electron and ion, and thermal load.

The PFCs of fusion reactors are operated under very critical environments. Thus, it is crucial that a reliable and proper database should be constructed for fusion material which can convey physical properties in accordance with desired performance tests. Calculated simulations will be used as a valuable database of basic physical properties for the plasma-faced component (PFC) development in a fusion reactor. In this research, the configuration of proper material position is optimized and analyzed under parametric study such as a deposition energy, Displacement per Atom (DPA), and power density. It was found that Case-3; the material arrangement in which tungsten, copper and stainless steel-316 are assembled in order, provided lowest DPA value whereas other two cases gave higher ones. The deposition energy in Case-1 is the highest which can lead to losing of thermo-mechanical integrity while Case-3 achieves lowest deposition energy which are proportional to power density.

2. Methods and Results

2.2 Calculation Tool

As a calculation tool, the MCNPX code [1] which is a recent three-dimensional Monte Carlo code, has been used for whole parametric analysis. As a continuous energy library without any averaging of cross sections, the required cross section data starting from the Fusion Evaluated Nuclear Data Library FENDL-2.1[2] for specific condition, are generated as precisely as possible for further MCNP processing. The neutron induced damage in the 'low-energy' region was calculated by means of MCNPX tallies using damage production cross-sections (MT = 444) generated from FENDL-2.1.

2.2 Methodology

The MCNP runs are processed to check a deposition energy, power density and DPA for each case under consideration with the aim of investigation into control of interaction between plasma and PFC. For deposition energy evaluation, small track lengths within same material are considered to be specified in order to achieve best estimated energy deposition along the track lengths of all materials. In turn, this calculation can be simply performed through use of energy deposition tally card namely F6.

Once the deposition energy calculation is accomplished by using type 6 tally, estimation of power density is proceeded firstly by multiplying neutron numbers (neutron/sec) and divided by each cell volume. After reaction. The DPA calculations can be achieved with the following equation:

$$\mathrm{DPA} = \left(\int \sigma_{DX}(E) \cdot \varphi(E) \cdot dE\right) \cdot t$$

Where, σ_{DX} is the displacement cross-section for an incident particle at energy, and $\phi(E)$; the incident particle flux for protons or neutrons and t; the irradiation time.

2.3 Simulation Model

Based on the basic design parameter used for limiter first wall previously proposed by ITER members (ITER Garching Joint Work Site, Germany) as shown in Fig 1[3], selection of appropriate materials and configuration has been considered for modeling.

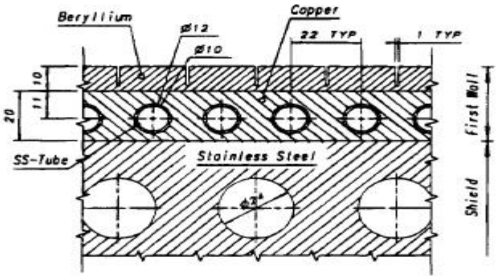

Fig1. Primary first wall cross-section

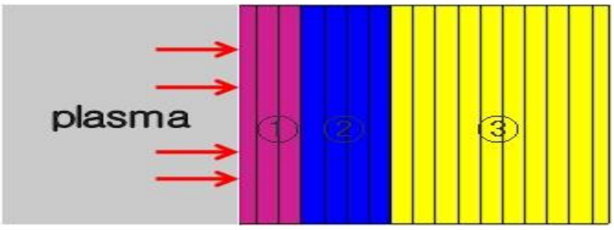

Fig2. MCNP model

For the sake of choice of materials, three cases for primary materials in contact with plasma such as Be, Graphite and Tungsten, are studied with the help of MCNP simulation as shown in Fig 2. In case-1, the plasma vertically incident on first-wall is placed touching with the materials in the order of Be, Cu and SS316. For other two cases, primary touching materials are changed although second and third layers are kept same:

Case-1 (①Be-②Cu-③SS316),
Case-2 (①Graphite-②Cu-③SS316),
Case-3(①W-②Cu-③SS316)

When taking into account of geometry of each layer, the lengths of each layer are respectively decided; 1.5 cm for layer ①, 2 cm for layer ②, 4.9 cm for layer ③. In Monte Carlo simulation, energy group in DPA calculation was divided into 5 groups in order to achieve best estimate results following:

Group1→ 0~0.1eV, Group2→ 0.1eV~1KeV, Group3→ 1eV~1MeV, Group4→1MeV~10MeV, Group5→ 10MeV~14MeV.

2.4 Calculation and Results

From the viewpoint of material integrity, largest deposition energy found in Case-1 is unfavorable while the calculation result of Case-3 is lower than two other cases as described in Fig 3. To be able to withstand larger deposition energy, the materials and geometry configuration used in Case-3 will be desirable. The average deposition Energy of Case-1 is 1.17E-3MeV and Case-2 is 7.81E-4MeV, Case-3 is 2.43E-4MeV. The variation of power densities according to cell arrangements are found proportional to that of deposition energy as presented in Fig 4. The average power density of Case-1 is 7.57E-2MW/m3 and Case-2, 4.71E-2MW/m3, and Case-3, 8.04E-3MW/m3.

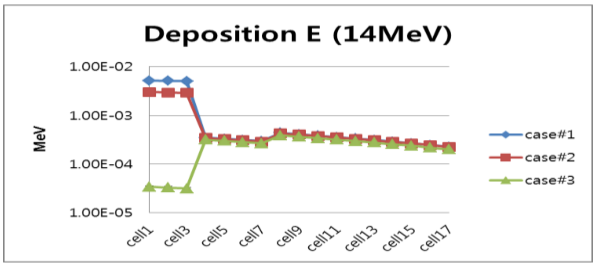

Fig3. Deposion Energy

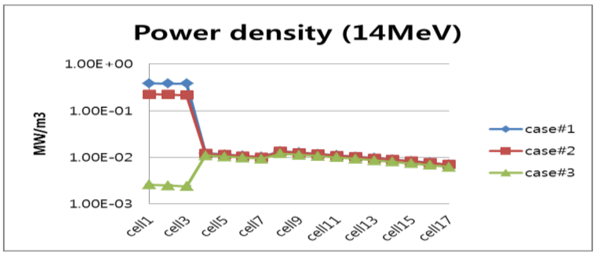

Fig4.Power density

	cell1	cell2	cell3	Avg.
case#1(Be)	2.80E-03	6.98E-03	4.48E-03	4.75E-03
case#2(C)	3.63E-03	6.84E-03	4.45E-03	4.97E-03
case#3(W)	5.20E-03	7.03E-03	4.44E-03	5.56E-03

Table1. DPA Calculation

And the DPAs for each case are compared in Table 1. Expecting better results of DPA in each layer, those are evaluated by dividing 0.5 cm within three layers of interest. The average DPA of Be is 4.75E-3#/cm3, that of C, 4.97E-3#/cm3, and that of W, 5.56E-3#/cm3 which is found lowest among three cases.

3. Conclusions

When high energy neutrons at 14.1 MeV are irradiated to first wall for a long time, what changes the properties of materials are studied with three parameters such as deposition energy, DPA, and power density. These are required to be confirmed with experimental results. As more proper materials optimization, the deuteron, and helium for first wall will be investigated for future study.

REFERENCES

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