Neutron-induced Defect in First Wall of Nuclear Fusion Reactor

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Nuclear fusion reactors produce high energy neutrons of 14 MeV in their core plasma when the reactors cause deuterium-tritium fusion reaction. When plasma-facing wall, or first wall, are exposed to the neutrons, vacancies and displacement occur in the wall. We will explain mechanism of these phenomena in this presentation.

In Nov. 2006, the ITER agreement was officially signed at the Elysée Palace in Paris by Ministers from the seven ITER members; China, European Union, India, Japan, Korea, Russia, and United States. ITER is an experimental nuclear fusion reactor, that is under construction at Cadarache in France.

ITER is an experimental fusion reactor to test all of the components for next prototype reactors, including the first wall. Design parameters of ITER are described in Table 1. ITER will hold experiments for long pulse of 400 seconds with D-T reaction. D and T mean deuterium and tritium respectively, which are isotopes of hydrogen. The reaction is described with the following equation.

$$D + T \rightarrow He\ (3.5\ MeV) + n\ (14\ MeV)$$

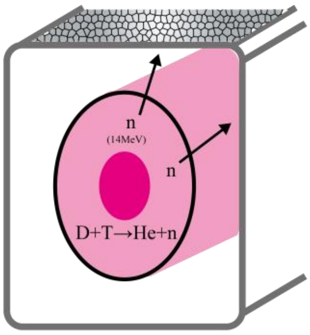

Figure 1. Exposure of neutrons from the core plasma into the first wall of fusion reactor

The temperature at the center of fusion plasma reaches 10 keV. It corresponds to 100×10^6 K. High energy helium particles are ionized and hold electrically positive charges in fusion plasma at the temperature. Therefore, they do not collide with the first wall of fusion reactors. Otherwise, high energy neutrons do not hold charges and flow into the first wall directly. The neutron cause vacancies and displacement of atoms in the first wall. To evaluate the effect of neutron flux, we use the unit of dpa (displacement per atom). It means that how many times a single atom moved in the material due to collision with neutrons. When the displacement happens, the configuration and specifics of materials changes. It leads to embrittlement and swelling, which mean a loss of ductility and the increase in volume respectively[1].

TABLE 1. DESIGN PARAMETERS AND RADIATION FLUX OF ITER

Parameter	Value	Remark
Major Radius	6.2 m	The distance from the poloidal center to the toroidal axis of the plasma
Minor Radius	2.0 m	The radius of the plasma on the poloidal cross section
Burn time	400 s	The duration which D-T reaction continues for in a single experiment.
Plasma Current	15.0 MA	The toloidal current which flows in the plasma.
Fast Neutron Flux	3×10^{18} $(m^2s)^{-1}$	The number of fast neutrons which pass through the first wall.
Neutron Flux	2×10^{25} $(m^2s)^{-1}$	The number of all neutrons which pass through the first wall.

The phenomena due to collisions of neutrons into materials are studied in the nuclear fission engineering. The mean energy of neutrons are up to 2 MeV and the effect reaches dozens of dpa. On the other hand, the mean energy is 14 MeV and the effect reaches 100 dpa in fusion reactors[2]. We can say that the requirement of materials about neutron resistance for fusion reactors is more severe than fission reactors.

For a long time, studies have been conducted on materials on the first wall to realize ITER. Finally, tungsten and copper are applied to the material of the first wall. It is because they are heavy atoms and it leads to the resistance against neutron-induced displacement. Furthermore, tungsten has the high melting point, which is important to bear high heat flux from fusion plasma. Copper has high heat conductivity and it is used at the water cooling pipes in the first wall. However, resistance for neutron flux is not enough for the next prototype fusion reactor because it must realize steady D-T reaction for around 1 year at least without any maintenance on the first wall.

In the presentation, we will explain the detail of the requirement for the first wall and the present approaches for the next prototype reactor such as a liquid-metal wall.

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