§8. Evaluation of Neutron Irradiation Damages for the Novel Divertor Concept Proposed in the FFHR-d1 Design

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Neutron damages on the divertor components are one of the most important factors to be investigated in a fusion reactor design, because the magnitudes of the damages dominate selection of the divertor materials and a schedule of the replacement. In the helical reactors, divertor components can be placed behind a radiation shield. Therefore, it is expected that the neutron irradiation damages on the divertor system can be suppressed efficiently and a copper material with a high thermal conductivity can be used for the cooling tubes instead of a low activation ferritic steel with a low thermal conductivity. Previously, neutron environment around the helical divertor system in the FFHR-d1 design has been evaluated by a 3-D neutron transport calculation. [1] The maximum damages on copper was 1.6 dpa/year (dpa: displacement per atom) at the inboard divertors. If the copper materials can be used up to ~1 dpa,[2] the inboard divertor components with copper cooling tubes are required to be replaced almost every year.

For the further suppression of the neutron damages on the divertor components, the novel divertor concept has been proposed in the FFHR-d1 design activity (Fig. 1).[3] In this concept, the radiation shield protecting the side surface of the superconducting helical coils are shortened from the original design. Since the magnetic field is generated along the circular lines around the helical coils without hitting the radiation shield, the divertor components can be placed just behind the helical coils.

A 3-D neutron transport calculation was performed with the MCNP-5 code and JENDL-3.3 nuclear data library. The cross section of the 3-D FFHR-d1 model simulating the novel divertor concept is shown in Fig. 2 with distribution of fast neutron fluxes. The present evaluation to investigate the shielding performance of the concept was performed at the toroidal angle θ=9°. To simulate the geometrical features, one of the side shield of the helical coil is removed to make opening for the magnetic field lines. Another side shield is closed. Magnitudes of the irradiation damages on copper were evaluated by using the MT=444 card of the MCNP code and assuming the displacement energy of 40 eV.

The damage at the original divertor position was ~1.2 dpa/year in the result shown in Fig. 2. The fast neutron flux at the back side of the helical coil (Position #1) was suppressed to ~1/5 compared with that at the original helical divertor position. At the deeper position (Position #2), the flux was suppressed to ~1/10. Irradiation damages were also suppressed significantly at those positions and the suppression ratios were <~1/5 and <~1/20, respectively. Difference in the suppression ratios of the fast neutron flux and the magnitude of irradiation damage at Position #2 is considered due to the drastic change in the neutron energy spectrum.

Assuming that the limit for blanket materials is 100 dpa, inboard blanket modules have to be replaced every ~6 years with full power operation. Although erosion of the W block surfaces bombarded by high particle fluxes would be the factor to determine the lifetime of the divertor component, the present result indicates that the novel divertor concept would extend the lifetime significantly from the view point of irradiation damages on the copper cooling tubes. If the lifetime of the divertor components can be comparable to that of the blanket modules, decrease in the reactor availability due to the divertor replacement process could be avoided.

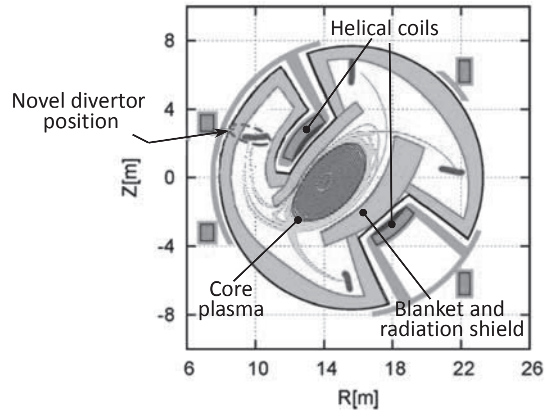

Fig. 1. The cross section of FFHR-d1 with the novel diverter concept.[3]

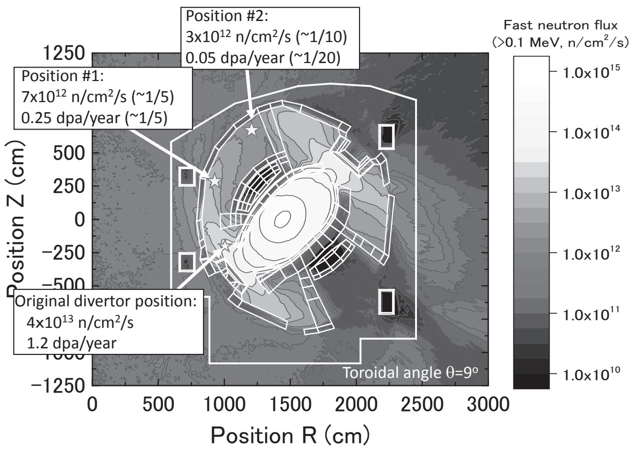

Fig. 2. Fast neutron flux distribution calculated for the novel divertor concept and suppression of irradiation damages on copper at the back side of the helical coil.

1) Tanaka, T. et al.: Fusion Eng. Des. **89** (2014) 1939.
2) Tokitani, M. et al.: Plasma Fusion Res. **10** (2015) 3405035.
3) Tamura, H. et al.: Fusion Eng. Des. **98-99** (2015) 1629.