§15. Comprehensive Investigation on the Role of Numerical Simulations for Heat and Particle Control in Fusion Reactor

Takizuka, T. (Osaka Univ.), Sagara, A., Fukada, S. (Kyushu Univ.), Furukawa, H. (Inst. Laser Tech.), Hatayama, A. (Keio Univ.), Hoshino, K. (JAEA), Ibano, K. (Osaka Univ.), Kaburaki, H. (JAEA), Kawamura, G., Konno, C. (JAEA), Masuzaki, S., Kunigi, T. (Kyoto Univ.), Morishita, K. (Kyoto Univ.), Murata, I. (Osaka Univ.), Norimatsu, T. (Osaka Univ.), Satake, S. (Tokyo Univ. Sci.), Tanaka, T.

Heat and particle control is the most critical issue to realize the fusion reactor without serious erosion of the plasma facing components. Besides experimental studies, numerical simulations play an important role for the development of the control methods. Several years ago, we delivered a serial lecture "The fusion reactor wall is getting hot! –Challenge towards the future for numerical modeling", where a wide range of issues in heat and particle control around the reactor wall were reviewed; What is happening between plasma edge and wall, on the wall surface, and in the wall? How is the wall heated and damaged? How is the fuel made up in the wall? and so on.[1)]

The divertor heat load q_{div} in toroidal magnetic confinement devices becomes very large because of the narrow heat channel in the scrape-off layer due to the fast heat transport parallel to the magnetic field line. Without the sufficient radiation cooling by impurity seeding, the q_{div} is estimated as large as several 10 MW/m^2 in a fusion reactor with alpha heating power of several 100 MW. To enhance the radiation cooling with a low impurity level, a long-leg divertor configuration was designed for a tokamak DEMO reactor. Numerical simulations using SONIC code, however, showed that the q_{div} was not satisfactorily reduced because of the narrowed magnetic flux tube in the simple long-leg divertor.[2)] Advanced divertor concepts, e.g., a snowflake divertor, an X divertor and a super-X divertor, were proposed to expand the flux tube in the divertor region. Simulation studies using SONIC have been also carried out on these advanced divertors for tokamak reactors.[3)]

Taking account of the engineering applicability to fusion reactors, we newly proposed a "flux-tube-expansion divertor (FTE)" concept.[4)] A divertor coil and separatrix configuration coils (sep. c.), which have co-currents to the plasma current, are placed outside the toroidal-field (TF) coils. The sep. c. coil is important to form a long-leg separatrix line nearly straight in the divertor region. A set of cusp coils of co-current and counter-current is put inside the TF coils like an X divertor. These cusp coils are called FTE coils, and expand the flux tube near the divertor plate while maintain the separatrix shape. We consider that such a straight long-leg divertor configuration is highly applicable to tokamak DEMO reactors. Figure 1 shows a preliminary example of a FTE divertor for a DEMO (plasma current I_p = 15 MA, toroidal field B_t = 6.3 T, major radius R = 8.2 m, minor radius a = 2.6 m and elongation K = 1.8). The divertor coil current outside TF coils is about 34 MA. The FTE coil currents are Ic = +4 MA and –4 MA. This FTE current is much smaller compared with the divertor current as planned. The shape of the separatrix is quite general and simple. The FTE aspect is compared between Fig. 1 (b) for I_c = 0 MA and (c) for I_c = 4 MA. The rate of the FTE at the strike point, G_{FTE}, is about 2.7. It is found that the separatrix shape is well maintained, while the flux tube is sufficiently expanded. The divertor heat load in this FTE divertor can be reduced to the desirable value q_{div} ~ 5MW/m^2 by the expanded wet area, the lengthened magnetic-field line and the enlarged radiation volume from the value of q_{div} ~ 20 MW/m^2 in a long-leg divertor. This expectation will be examined by the comprehensive divertor simulations.

The development and improvement of the comprehensive divertor simulation codes are proceeding. SONIC code for tokamak divertor simulation has been improved especially in the Monte-Carlo impurity transport part IMPMC to reduce the computation cost and to increase the accuracy.[5)] EMC3-EIRENE code for helical divertor simulation has been extended to treat the divertor leg region in LHD.[6)]

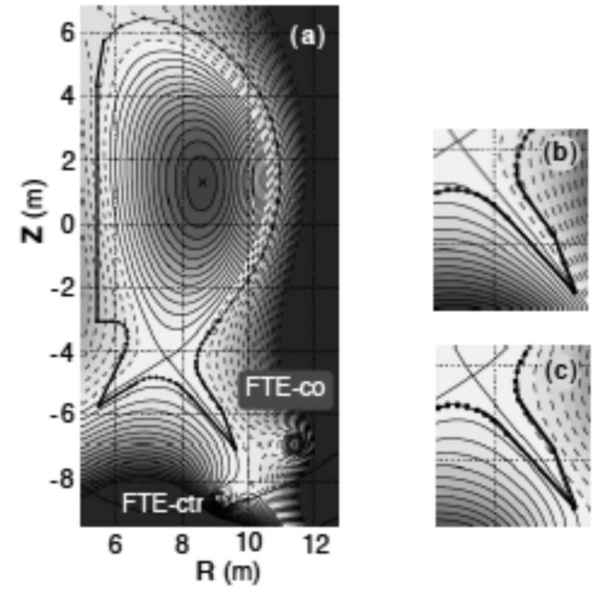

Fig. 1. Example of the FTE divertor for a DEMO reactor with I_p = 15 MA. FTE currents are I_c = +4 MA and –4 MA. Rate of the FTE, G_{FTE} = 2.7, is evaluated by comparing (b) I_c = 0 MA and (c) I_c = 4 MA.

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4) Takizuka, T. et al.: J. Nucl. Mater. (2015) in press, doi.org/10.1016/j.jnucmat.2014.12.065.
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6) Kawamura, G. et al.: Contrib. Plasma Phys. **54** (2014) 437.