Contribution ID: **1174** Type: **Regular Poster**

SOLPS analysis of necessary conditions for detachment cliff in HL-2M advanced snowflake minus and DIII-D conventional divertors

Wednesday, May 12, 2021 6:25 PM (20 minutes)

Hailong Du1*, Guoyao Zheng1, Xuru Duan1, Houyang Guo2, Jiaxian Li1, Lei Xue1 and Yue Zhou1
1Southwestern Institute of Physics, Chengdu, 610041, China
2General Atomics, PO Box 85608, San Diego, CA 92186-5608, United States of America
Email: duhl@swip.ac.cn

A new mid-size device, HL-2M [1], is being installed at SWIP to address critical physics and technology issues towards advanced divertor development for CFETR and future fusion reactors. The divertor structure of HL-2M has been designed to be compatible with various advanced divertor magnetic configurations, including snowflake (SF-, SF+ and Trip), as well as advanced divertor structure with a V-shaped target in the lower outer divertor, similar to the new small angle slot divertor (SAS) in DIII-D [2]. Furthermore, other advanced divertor configurations will be explored with the upper divertor in the near future. A major purpose of the optimization of divertor configuration is to facilitate access to highly radiative divertors, which are the operational regimes required for power load control in ITER and nuclear fusion reactors, In particular, the control of detachment has been identified recently as a serious challenge due to the rapid decrement of divertor target electron temperature (called detachment cliff). This work systematically examines the formation of necessary conditions of such a detachment cliff in HL-2M SF-divertor, and comparisons are made with the DIII-D conventional open divertor. Both HL-2M and DIII-D tokamas have almost the same size, as shown in figure 1. The modeling with SOLPS including drifts have uncovered that the root cause for the formation of detachment cliff is the strong interplay between the E×B drift and the carbon radiation loss under the condition of high confinement (H-mode) plasmas.

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SOLPS modeling results showed that the E×B drift exhibits a strong influence on power dissipation and detachment in both HL-2M SF- and DIII-D open divertors. For the favorable Bt direction, i.e., with the ion grad-B drift toward the X-point, a large number of particles are driven by the Er×B drift from the outer divertor into the inner divertor through the private flux region. This reduces the plasma density and hence the power radiation loss in the outer divertor, thus driving the outer divertor plasma away from detachment. The detachment cliff occurs in both HL-2M SF- and DIII-D outer divertors, as marked by a pronounced drop in the electron temperature, Te, at the divertor target, when ne,sep, is ramped up to a sufficiently high level, as shown in Fig. 2 and Fig. 3, respectively. The SOLPS analysis reveals a strong coupling between the E×B drift-driven flows and carbon radiation in HL-2M SF- and DIII-D. The high confinement H-mode facilitates the formation of the detachment cliff due to the narrow SOL width and hence steep radial gradients near the separatrix, which enhances the polodial E×B drift,(Fig.2 (a), Fig. 3(a)). Furthermore, the SOLPS modeling indicates that carbon radiation also plays a key role in the formation of the detachment cliff in HL-2M SF- and DIII-D without additional impurity seeding [3, 4], thus uncovering the common physics mechanisms for this critical issue in both devices.

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Acknowledgments
This work was supported by National Natural Science Foundation of China under Grant Nos. 11805057, 11775071; National Key R&D Program of China No. 2018YFE0301101.

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Country or International Organization

China

Affiliation

Southwestern Institute of Physics

Primary authors: DU, Hailong (Southwestern Institute of Physics); Prof. ZHENG, Guoyao (Southwestern Institute of Physics); DUAN, Xuru (Southwestern Institute of Physics); GUO, Houyang (General Atomics); Dr LI, Jiaxian (Southwestern Institute of Physics, Chengdu, Sichuan, China); XUE, Lei (Southwestern Institute of Physics); Ms ZHOU, Yue (Southwestern Institute of Physics)

Presenter: DU, Hailong (Southwestern Institute of Physics)

Session Classification: P4 Posters 4

Track Classification: Magnetic Fusion Theory and Modelling