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OBSERVATION OF LOCALIZED FAST-ION INDUCED HEAT LOADS IN TEST BLANKET MODULE SIMULATION EXPERIMENTS ON DIII-D

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GENERAL ATOMICS

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Observation of Localized Fast-Ion Induced Heat Loads in Test Blanket Module Simulation Experiments on DIII-D

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Infrared imaging of hot spots induced by localized magnetic perturbations using the Test Blanket Module (TBM) mock-up on DIII-D [1,2] is in good agreement with beam-ion loss simulations as shown in fig. 1. The hot spots were seen on the carbon protective tiles surrounding the TBM as they reached temperatures over 1000°C. Both the localization and peak intensity of the hot spots are in good agreement with simulations using a range of codes: ASCOT [3], SPIRAL [4], and OFMC [5]. The orbit calculations take into account the birth profile of the beam ions as well as the scattering and slowing down of the ions as they interact with the localized TBM field. The close agreement between orbit calculations and measurements validate the analysis of beam ion loss calculations for ITER where ferritic material inside the tritium breeding TMBs is expected to produce localized hot spots on the first wall.

Six TBMs, two in each of three equatorial ports, are envisioned for ITER to fulfill a major goal on ITER: the study of tritium breeding in blanket modules. The TBMs contain a significant amount of ferritic steel, and thus, the TBMs will create three highly localized distortions of the magnetic field which can reduce the confinement of fast ions, especially the fusion-born alpha particles. The lost fast-ions can create intense hot spots on the surface of the TBMs which can potentially threaten the integrity of the first wall near the TBMs. It is therefore important to simulate with confidence localized heat loads caused by lost fast-ions to design the first wall in such a way to mitigate the effects of those hot spots. A careful benchmark of those codes against current fast-ion loss experiments is of paramount importance to reliably predict fast-ion losses in ITER.

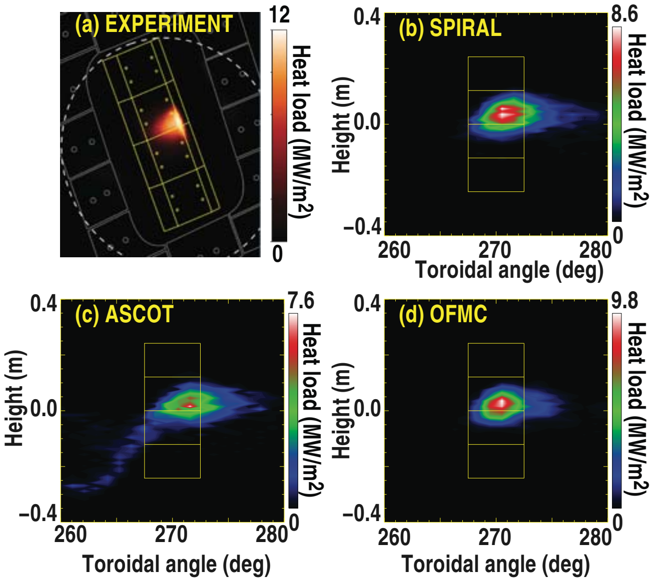

FIG. 1. (a) Measured heat loads compared with simulated heat loads for a similar discharge calculated with the (b) SPIRAL, (c) ASCOT, and (d) OFMC codes. The protective TBM tiles are indicated with the yellow lines. In the modeling flat tiles were used while in in the experiments they have beveled edges.

From the four orbit-following codes used in the current benchmark study, two codes, OFMC and DELTA5D [6], use the guiding center approximation while the other two, SPIRAL and ASCOT, calculate the full orbit. The DELTA5D code uses a 3-D equilibrium as calculated with the VMEC code that include the plasma response to the TBM fields while the other three codes add the vacuum TBM fields as a perturbation to plasma equilibrium fields.

In a series of recent DIII-D experiments the hot spots on the protective tiles of the scaled mock-up of two TBMs for ITER were directly imaged with an infrared (IR) camera. Heat loads were obtained from neutral beam injection (NBI) at a range of pitch angles by using the co-, counter, and off-axis beam lines of DIII-D. Numerical analysis indicated that the dominant beam ion loss comes from beam ions deposited near the plasma edge.

The IR imaging allows for a better validation of orbit following codes than from previous experiments where heat loads were deduced from thermocouple measurements at the back of the 2.5 cm thick protective carbon tiles using a thermal transport code [2]. The orbit-following ASCOT, OFMC, and SPIRAL codes which add the vacuum TBM fields as a perturbation to plasma equilibrium fields, all broadly agreed on the total power deposited in the hot spot but they differ on the details of the shape, location, and peak heat load. Those differences can now be compared directly with the measured IR images and help to improve the fast ion loss modeling further to obtain the most accurate predictions for TBM-induced heat loads on the ITER first wall.

The DELTA5D code which used the 3-D VMEC equilibrium that include the plasma response to the TBM fields, did not agree well with the thermocouple data. The IR images in the recent experiments confirmed this finding and validated the effectiveness of vacuum field calculations in predicting the losses to the TBM tiles, suggesting that the plasma response to the TBM fields is not a significant contributor to the loss measurements.

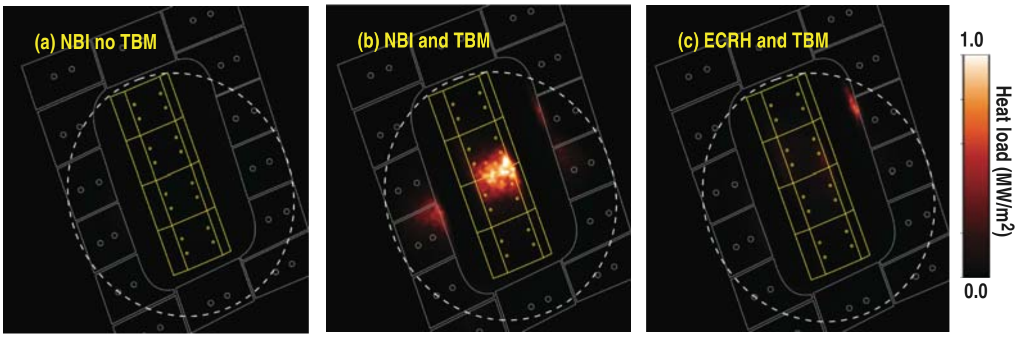

FIG. 2. Heat loads in similar discharges: (a) 3.3 MW ECRH with TBM fields, (b) 3 MW of NBI with TBM fields, and (c) 2 MW NBI without TBM fields.

The recent experiments also differentiated between plasma thermal heat loads and heat loads from lost beam ions on the TBM by using Electron Cyclotron Resonance Heating (ECRH) with comparable power to neutral beam injection. It was found that in ECRH only discharges with the TBM fields present [fig. 2(a)] no hot spots were observed while in similar NBI heated discharges a hot spot appeared [fig. 2(b)]. In NBI heated discharges without TBM fields [fig. 2(c)] no hot spots were observed, validating the role of the TBM fields in producing the hot spots. These experiments demonstrate that beam-ions in combination with the TBM fields produce the observed hot spots on the TBM protective tiles in DIII-D and validate models used to predict similar localized beam ion heat loads in ITER.

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