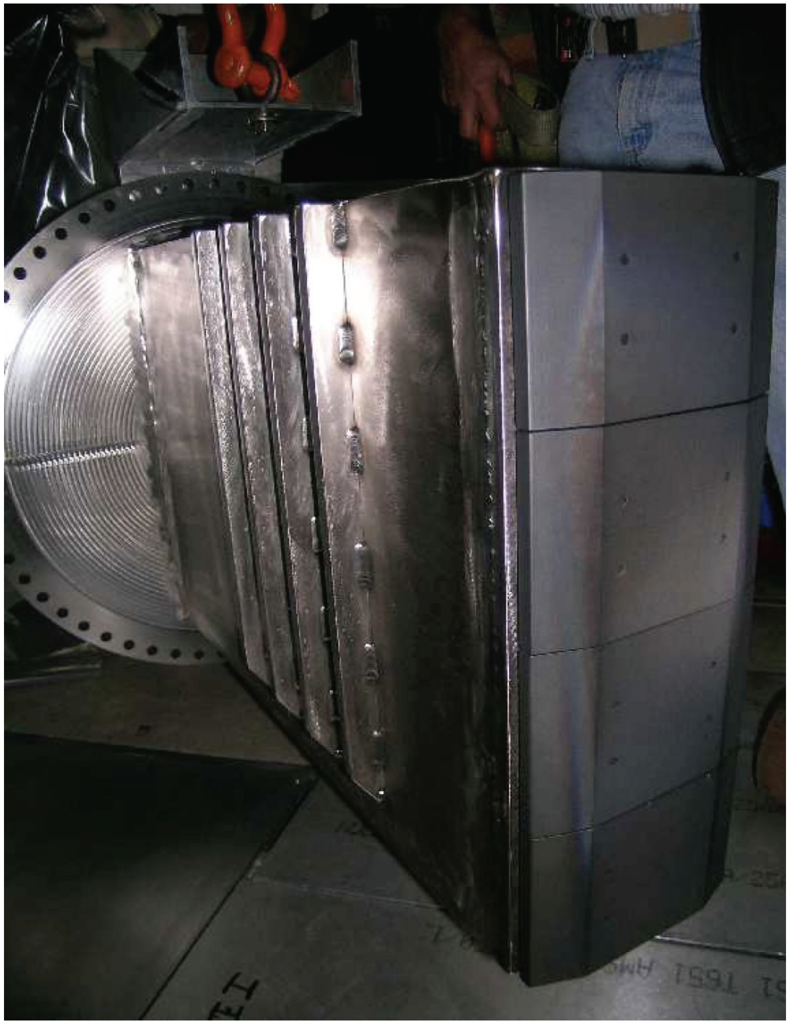
Fast Ion Effects During Test Blanket Module Simulation Experiments in DIII-D

by
G.J. Kramer
with
R.V. Budny, M. Gorelenkova,
W.W. Heidbrink, T. Koskela,
R. Nazikian, A. Salmi, M.J. Schaffer,
K. Shinohara, J.A. Snipes,
D.A. Spong, and M.A. Van Zeeland



Presented at the
52nd Annual Meeting of
the APS Division of Plasma Physics
Chicago, Illinois

November 8-12, 2010

DIII-D NATIONAL FUSION FACILITY

PPPL PRINCETON PLASMA PHYSICS LABORATORY

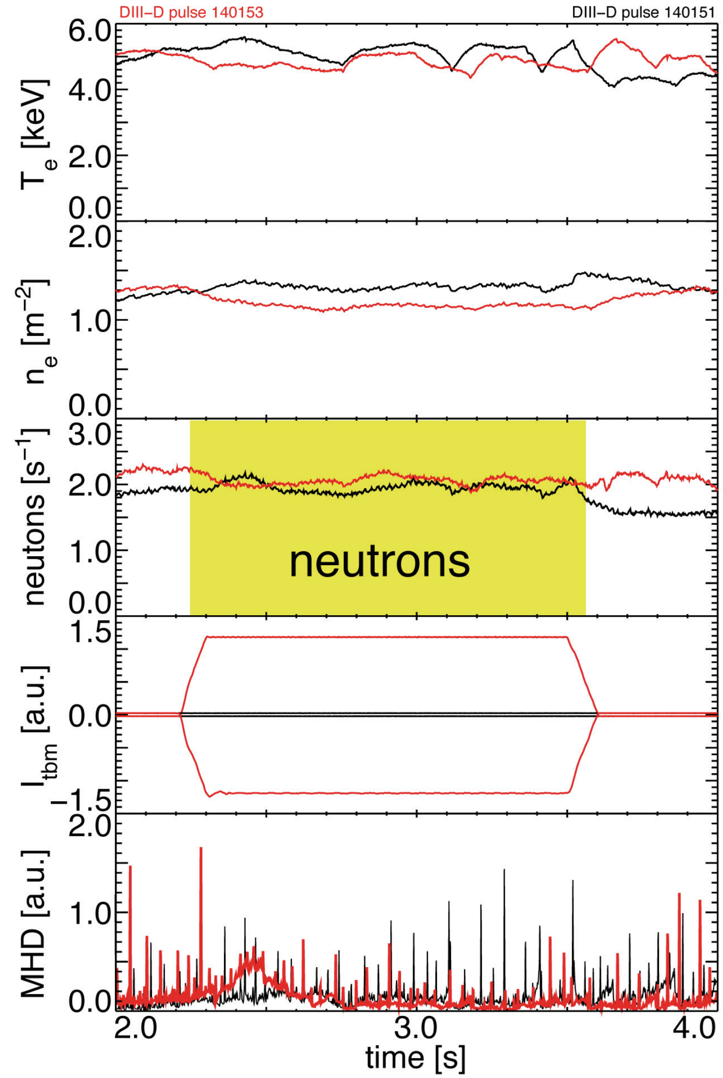
309-10/FT/jy

Introduction and Summary

- During the TBM experiments in DIII-D strong heating was observed of the plasma facing protective carbon tiles
- Different orbit-following codes agree on the lost power due to the TBM fields
- A thermal analysis showed that the simulated heat loads can account for the observed TBM tile temperature excursions
- This heating is caused by the loss of fast beam-ions that were deposited near the plasma edge
- The validated codes can now be used to calculate heat loads on the TBM modules in ITER

The Fast-ion Core Confinement is Unaffected by the TBM Fields

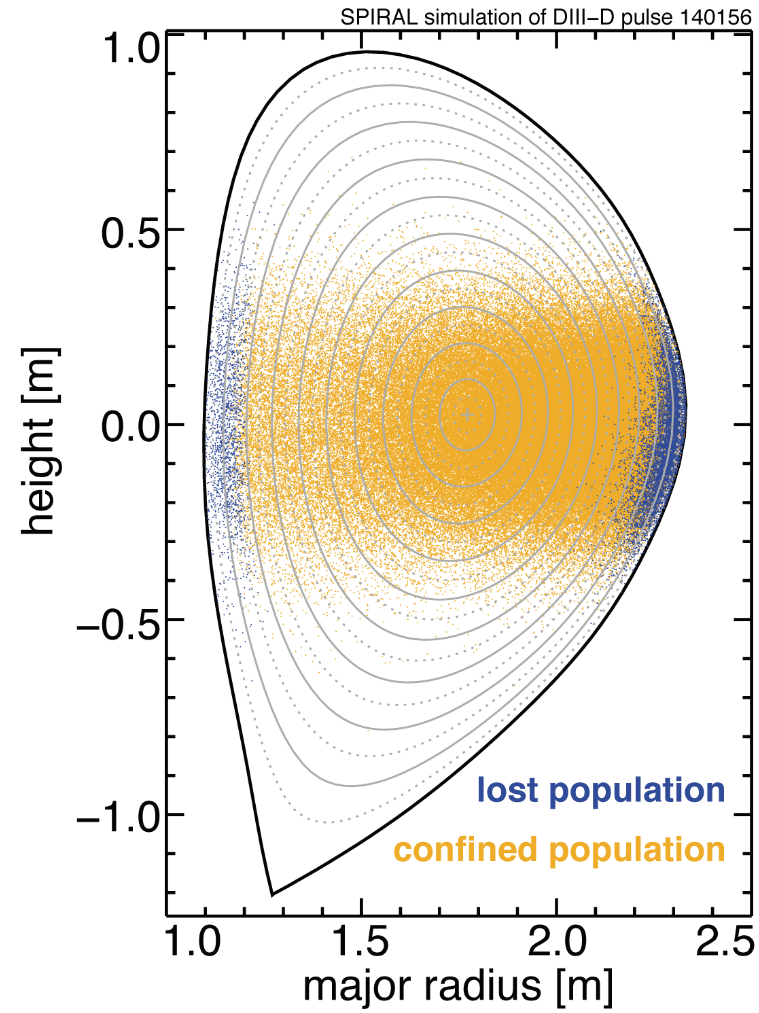
- **The effects of the TBM fields on the fast ions was studied by comparing identical discharges with and without the TBM fields present**
- **Core fast-ion signals such as fast ion D_α and neutrons did not change within their experimental uncertainty with the TBMs energized**
- **Plasma conditions: ELMing H-modes**
  plasma current: 1.4 MA
  toroidal field: 1.7 T
  NBI heating: 5.8 MW



DIII-D NATIONAL FUSION FACILITY SAN DIEGO

Simulations Indicate Good Core Confinement — this is in Agreement with the Experiments

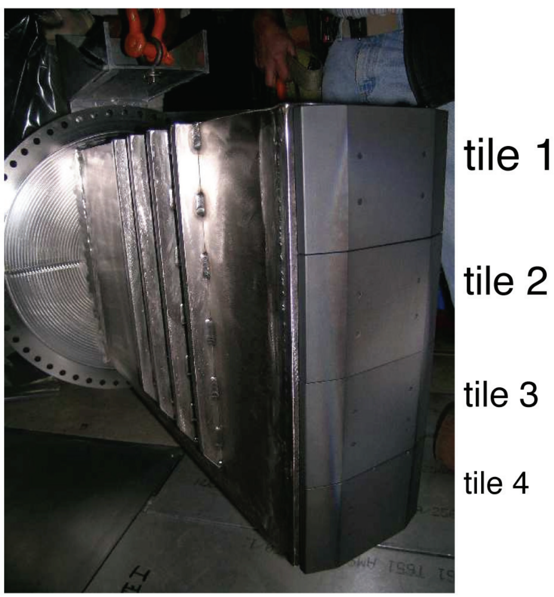
- **In the simulations losses are found to arise from the plasma edge (r/a > 0.7)**
- **This is in good agreement with the observations:**
  Core fast-ion signals such as fast ion D_α and neutrons did not change within their experimental uncertainty with the TBMs energized
  (no losses from within r/a=0.5 in the simulations)
- **Fast beam-ions lost from the plasma edge created a hot spot on the TBM tiles as will be discussed in the remainder of this presentation**

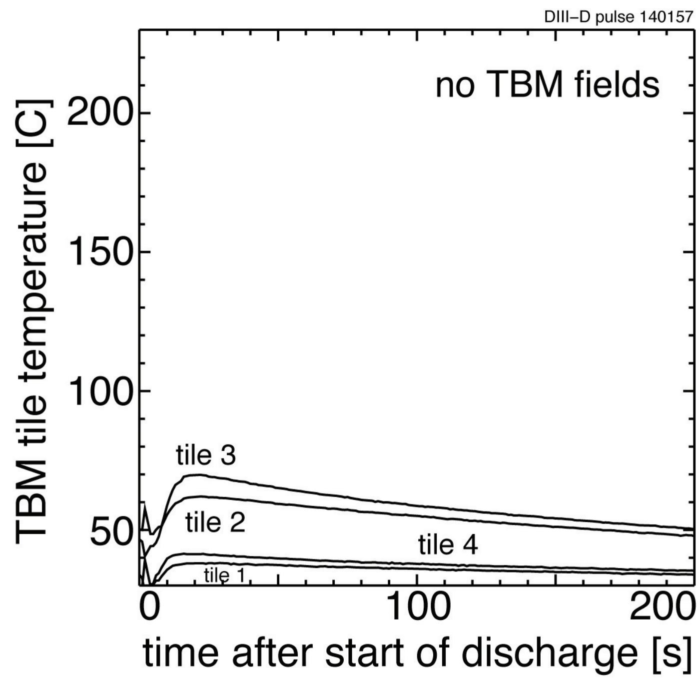


DIII–D
NATIONAL FUSION FACILITY
SAN DIEGO

No Significant Heating of the TBM Tiles was Observed when the TBM Fields were Off

- **The TBM mock-up is protected by four 2.5 cm thick carbon tiles**
- **Tile temperatures are measured with a thermocouple mounted on the back of the tiles**
- **Without the TBM fields, tile temperature increases of less than 20°C were found 10 to 20 s after the discharge was finished**

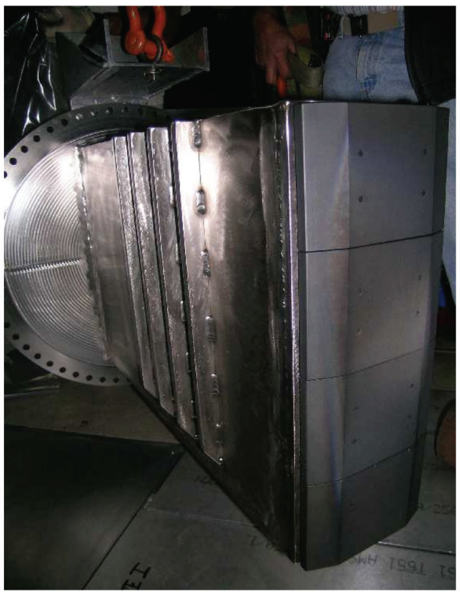


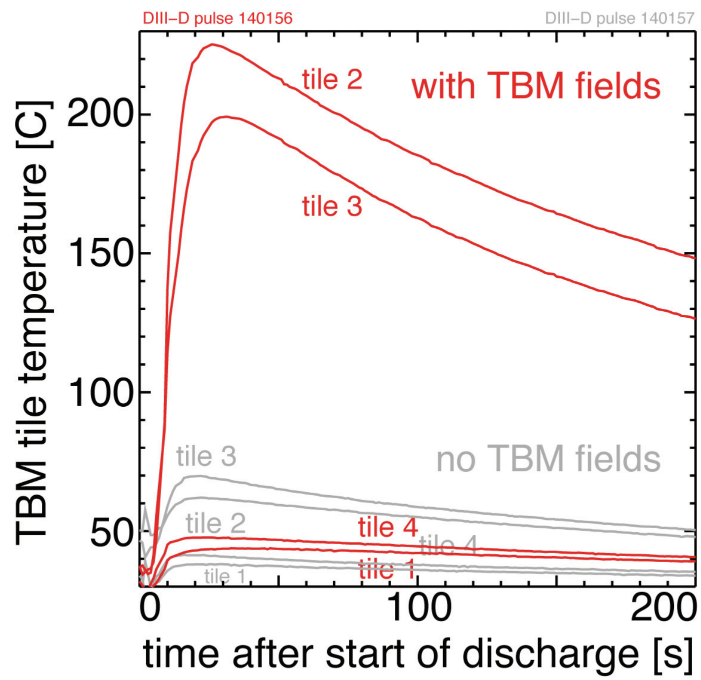


DIII–D
NATIONAL FUSION FACILITY
SAN DIEGO

Heating on the Middle Two Tiles was Observed when the TBM Fields were Present

- **With the TBM fields tile temperature, increases of up to 190°C were found for the middle two tiles 10 to 25 s after the discharge was finished**
- **The top and bottom tiles remained cool (less than 15°C increase)**



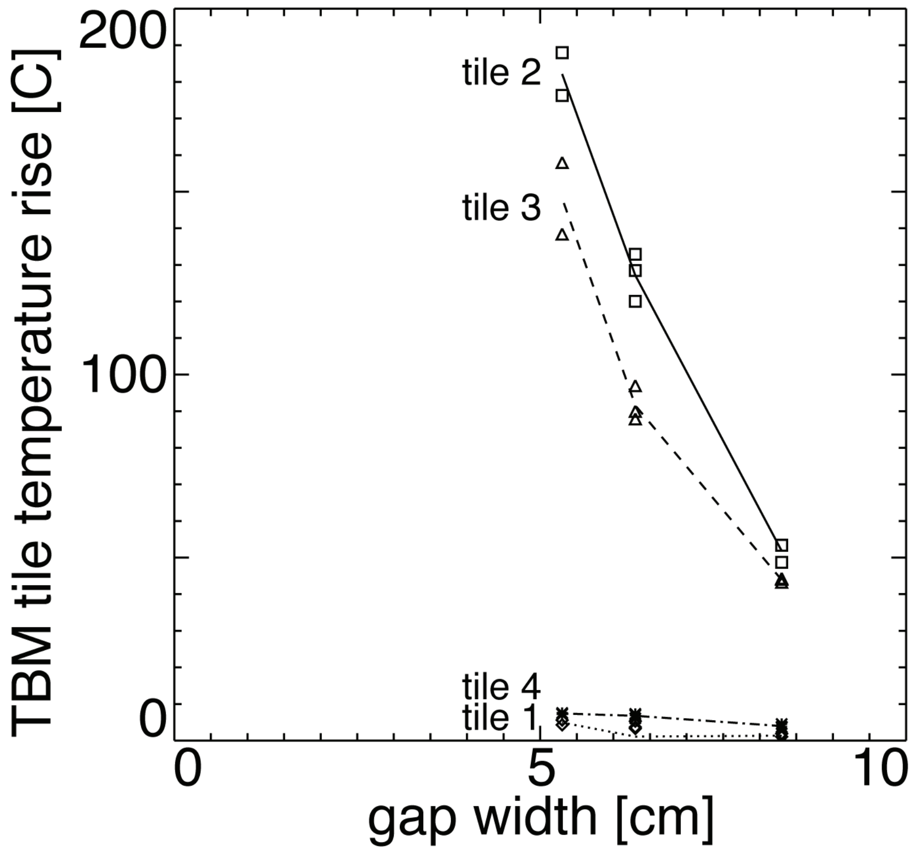


Tile Temperature Increases are Correlated with Gap Between the Separatrix and TBM Surface

- **In a number of similar discharges the gap between the separatrix and the TBM surface was varied**

- **A strong increase in the tile temperature was found with decreasing gap width**

- **The heating is not due to the thermal plasma because the scrape-off temperature length was much smaller than 5 cm**

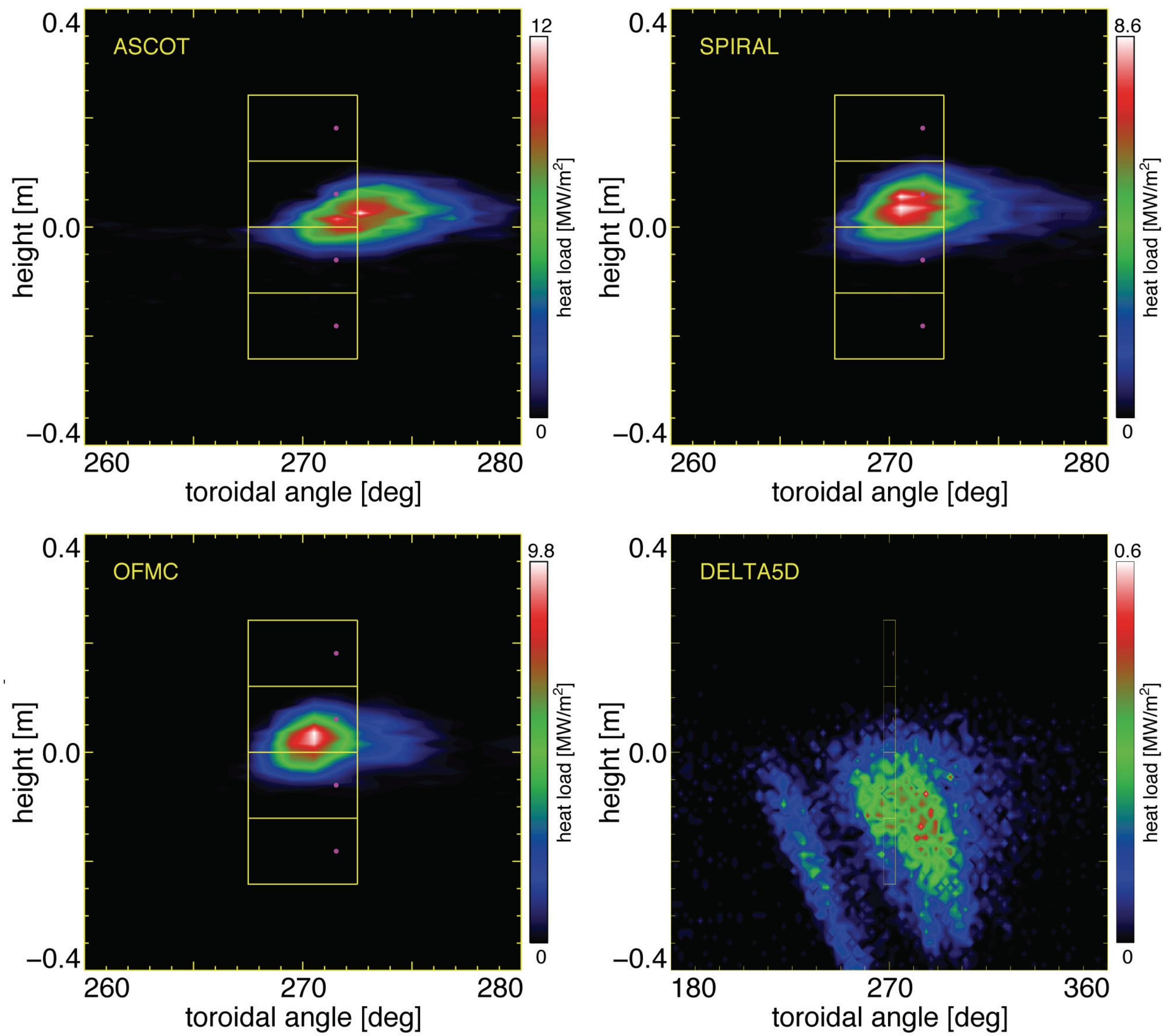


- **In the following deuterium beam loss simulations are presented which can explain the observed temperatures**

DIII-D
NATIONAL FUSION FACILITY
SAN DIEGO

Four Different Orbit Following Codes found the Hot Spot on the Middle Two TBM Tiles

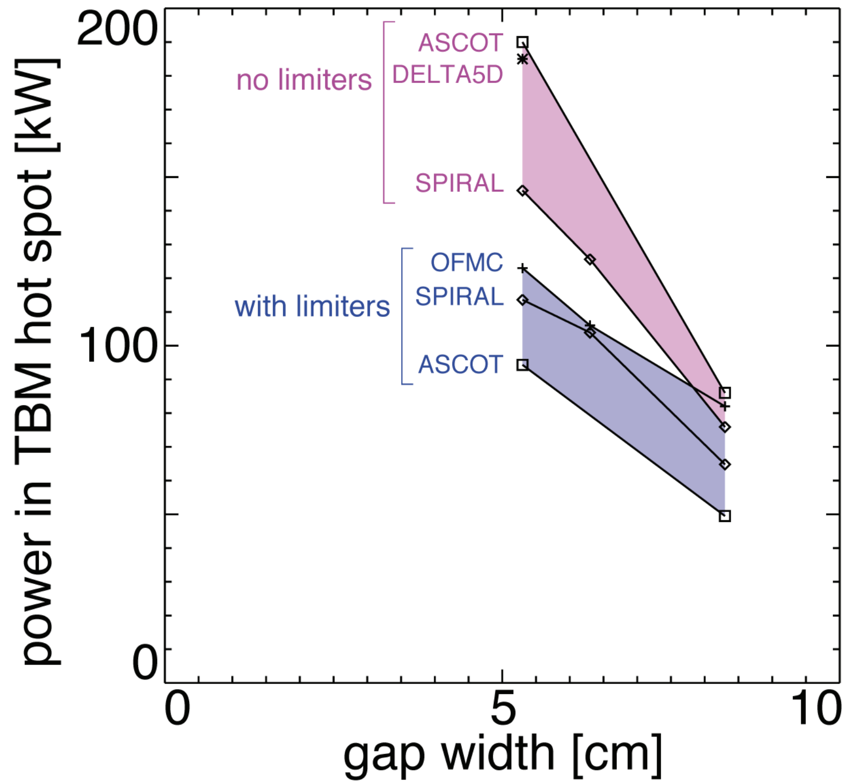
- **ASCOT and OFMC are guiding-center following codes**
- **SPIRAL is a full-orbit following code**
- **These codes predict a hot spot on or near the middle two tiles**
- **DELTA5D is a guiding-center following code using a 3–D VMEC equilibrium**
- **Its hot spot is more extended**



DIII-D NATIONAL FUSION FACILITY SAN DIEGO

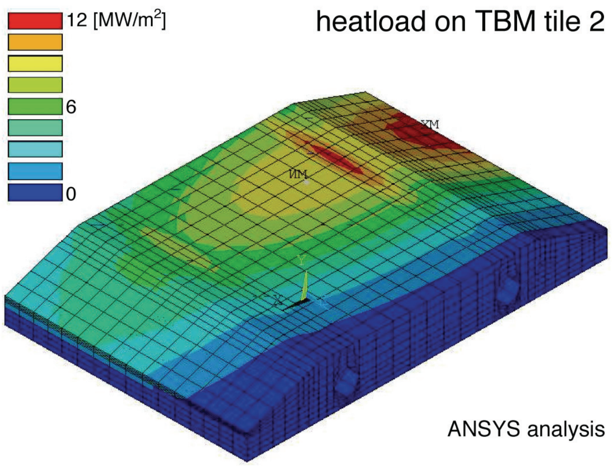
The Codes Show that Heat Load on the TBM Tiles Depends Strongly on the Gap Width

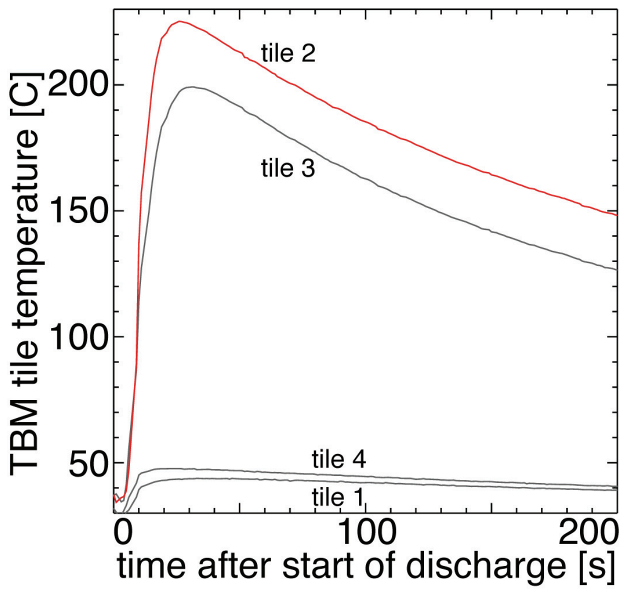
- **ASCOT, OFMC, and SPIRAL reproduce the trend observed in the gap scan**
- **The inclusion of the DIII-D limiters reduce the heat load on the TBM tiles**
- **The increased losses due to the TBM fields in DELTA5D at a 5 cm gap agree with the other codes**
- **Thermal modeling is needed to obtain the temperature behavior which can be compared with the thermocouple measurements**

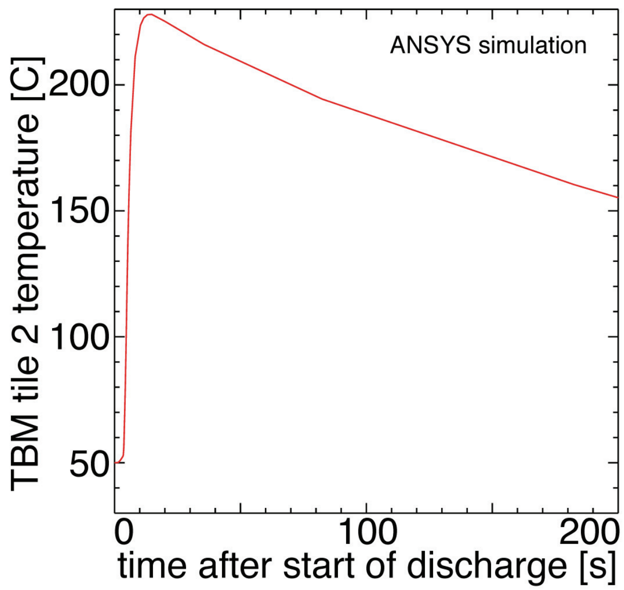


Thermal Modeling can Reproduce the Measured Tile Temperatures

- Power is deposited on the tile surface
- The thermocouples are located on the back of the 2.5 cm thick carbon tiles
- A FEM calculation can reproduce the observed temperature behavior







DIII-D NATIONAL FUSION FACILITY SAN DIEGO

Heat Loads Needed in the Thermal Modeling are Comparable to the Simulated Ones

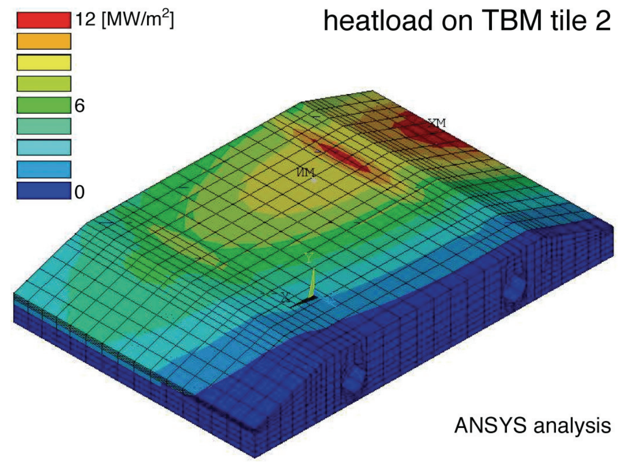
- **Power is deposited on the tile surface**
- **The thermocouples are located on the back of the 2.5 cm thick carbon tiles**
- **Power depositions needed in the FEM calculations to reach the observed tile temperature are comparable with the simulated deposited powers:**

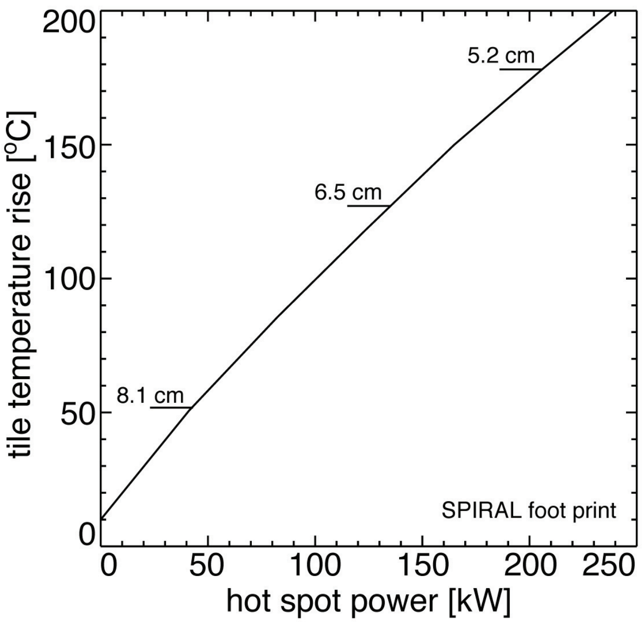
  5.2 cm gap: 100–200 kW

  6.5 cm gap: 60–120 kW

  8.1 cm gap: 50–90 kW

- **TBD: measure the hot spot foot print to reduce the uncertainty in the thermal modeling**





DIII-D NATIONAL FUSION FACILITY SAN DIEGO

Summary

- During the TBM experiments in DIII-D strong heating was observed of the plasma facing protective carbon tiles
- This heating was caused by fast beam-ion losses that were deposited near the plasma edge
- Different orbit-following codes agree on the lost power due to the TBM fields
- A thermal analysis showed that the simulated heat loads can account for the observed TBM tile temperature excursions
- The validated codes can now be used to calculate heat loads on the TBM modules in ITER