TO: M. JAWORSKI, S. GERHARDT
FROM: M.L. REINKE
SUBJECT: MODIFICATION OF HEAT FLUX REQUIREMENTS FOR OBD R3 & R4 TILES

Recommendation

A. Adjust the OBD R4/5 heat flux requirement for CASE #1, #2 and #3 in Table 4.4-3 of [1] to add an Extent of 11 cm. This will have the effect of reducing the net energy input into the tile rows, bringing it more in line with the estimate from power balance.
B. Remove the OBD R4/5 CASE #4 requirement in Table 4.4-3 of [1]. Scrutiny of scenarios shows driving scenarios will not place the strike point on R4.
C. Adjust the OBD R3 heat flux requirement for CASE #1 in Table 4.4-2 of [1] to add an Extent of 11 cm. This will have the effect of reducing the net energy input into the tile row, bringing it more in line with the estimate from power balance.

Reasoning

Demonstrating that new OBD-R3 and R4 tiles can meet the requirements laid out in present version of the system requirements document is proving to be challenge from the perspective of T-bar slot and shear pin stresses. Results from B. Linn presented at recent Weekly Meetings indicate that T-bar stresses flexural loads which are impacted by different T-bar designs, which also modify the E&M load at the shear pin. If T-bar slot stresses are driven by thermal stresses (e.g. 'bowing' of the tile), then having an accurate estimate of the total energy input into the tile is important, as might be possible with more accurate heat flux profiles.

Presently, the requirements state that the given heat flux should be applied uniformly over the full PFC surface for both OBD-R3 and OBD-R4/5 in [1].

Specific Case of OBD-R4

Examining PFCR-MEMO-008 [2] in more detail reveals the origin of the SRD requirement for OBD-R4 (CASE#1 through CASE#3). These are lower single null L-mode cases which create high heat flux due to weak flux expansion, despite limited input power. The most challenging requirement is CASE#1 which requests OBD-R4 sustain 4.3 MW/m^2 for 2 seconds. This is from the TT_2-05b case in Table 4.2.4 in [2], which is an L-mode plasma with 3 MW of input power.

Assuming 30% radiation and 70% going to the outer divertor, this is a total of 1.47 MW of power. The area of the OBD-R4 region is computed from a conical surface from (R,Z)=(96.65,149 cm) to (107.96,144.75), leading to a surface area of 0.773 m^2. Note that adding up the x96 over and x96 under tile front surface

areas from the prior NSTX/NSTX-U beveled design estimate gives 0.666 m^2. Neither of these accounts for tile gaps. If 4.3 MW/m^2 is assumed to be uniformly deposited on the swept conical R4 surface, then the total power deposited is 3.32 MW, over estimating the power input by roughly a factor of two. This is consistent with inspection of Figure 1, as the heat flux of 4.3 MW/m^2 describes the 'peak' which is not evenly distributed over the 11-12 cm length of the R4 surface. Adding an 'Extent' of 11 cm to Table 4.4-3 in [1] for CASE#1, CASE#2 and CASE#3 would improve agreement (Recommendation A).

The CASE#4 requirement for OBD-R4/5 is based on a long pulse, lower power request from the material and PFC topical science group. The science need is to maximize the fluence of particles at/near the MAPP diagnostic and can deliver this result using repeated, shorter plasmas rather than longer pulses. Examining [2] in further detail and discussing with the MPFC TSG leader reveals that these scenarios do not have the strike point on R4, thus this CASE#4 makes an excessive demand of the PFCs. While the common flux decay of the heat flux is expected to load R4, the MPFC TSG group will design experiments to meet the delivered tiles specified by CASE#1-CASE#3. Thus CASE#4 in Table 4.4-3 in [1] should be removed (Recommendation B).

Specific Case of OBD-R3

Examining [2] for what drives the SRD requirement for OBD-R4, CASE#1, the use is much different than R4. As outlined in Section 7, the R3 tile is meant to support low-triangularity H-mode research and as such has much higher input power than for OBD-R4. In fact, many DivSOL and PED requests have heat flux

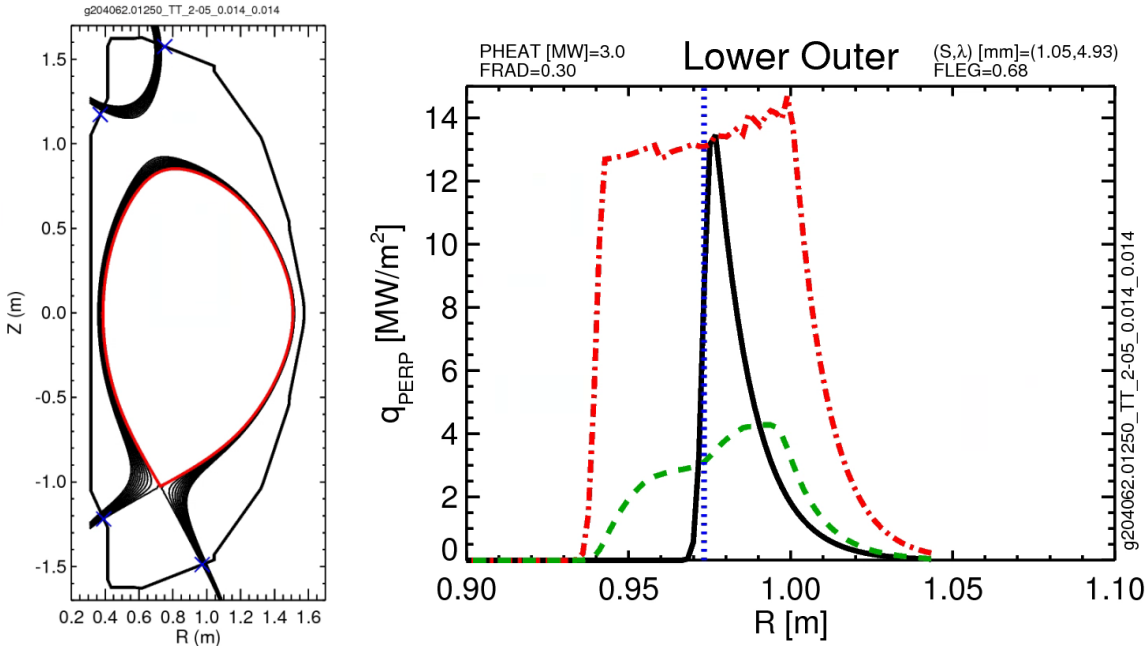

Figure 1: Equilibrium which drives OBD-R4 requirement for CASE#1 and the heat flux profile modeling (right). The green-dashed line is the time-averaged heat flux, assuming fast sweeping.

that exceed CASE#1, but are declared to be to challenging without additional radiative exhaust or further confirmation of the heat flux width scaling. This means the physics program would benefit from an OBD-R3 which can exceed the given requirements.

Following the same analysis as above, the swept surface area of the R3 tiles is computed from (R,Z)=(84.9,153.7) to (96.4, 149.1) cm results in an area of 0.705 m^2. The CASE#1 has 7 MW of input power, resulting in 3.43 MW of power going to the outer divertor. The requirement for 10.5 MW/m^2 applied uniformly over the tile would lead to 7.4 MW of power going into the PFC. Once again this is approximately twice the power that is being delivered and adding an 'Extent' to the heat flux requirement of 11 cm would bring the power delivered closer in line to the underlying scenario and bring the heat flux profile closer to matching what is shown in Figure 2 (Recommendation C).

The CASE#2 requirement should remain as-is. While the 3.0 MW/m^2 of power over the tile surface also implies an excess power to the tile region as compared to the scenario (MPFC 3-02 would have 0.98 MW of power to the OBD), the low-power, long pulse scenarios for the OBD-R3 were not thoroughly investigated in [2]. Maintaining a 3.0 MW/m^2 for 5 sec requirement will ensure operational flexibility and presently is not expected to be a challenge for t-bar based PFCs.

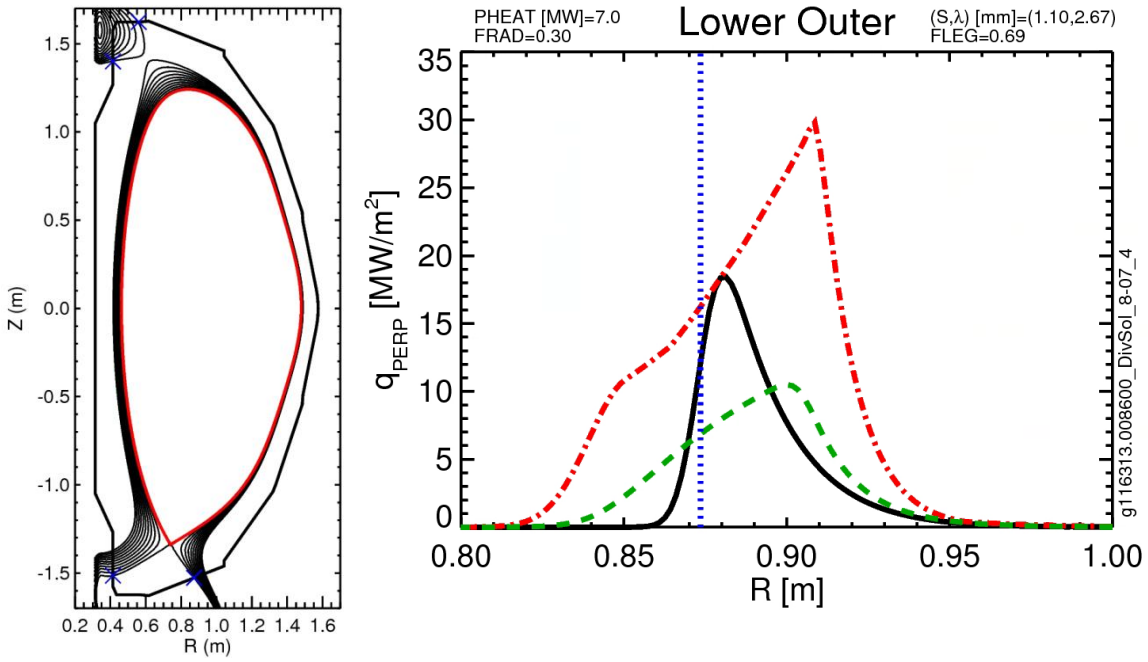

Figure 2: Equilibrium which drives OBD-R3 requirement for CASE#1 and the heat flux profile modeling (right). The green-dashed line is the time-averaged heat flux, assuming fast sweeping.

Outlook

More accurate heat flux profiles could be derived from Figure 1, Figure 2 and/or similar TSG input, but it is recommend to avoid confusion and to move on with investigating the impact of reducing the net energy input, that the 'Extent' specification is added to Table 4.4-3 and 4.4-2. Further analysis of more accurate heat loading of this region can be done in the future, after designs have been delivered while scoping commissioning of NSTX-U, post-Recovery.

References

[1] NSTX-U-RQMT-SRD-003
[2] PCFR-MEMO-008

Record of Changes

Rev.	Date	Description of Changes
0	1/22/18	Initial draft release to M. Jaworski and S. Gerhard for comment
1	2/7/2018	Updated with R3 information and completed R4 Recommendations, Released to the PFCR-WG and sent to Recovery Project