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**See Annex of J. Pamela et al., "Overview of Recent JET Results and Future Perspectives",*
*Fusion Energy 2000 (Proc. 18th Int. Conf. Sorrento, 2000), IAEA, Vienna (2001).*

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## 1. INTRODUCTION.

Handling heat flux deposition from Edge Localized Modes (ELMs) is an essential issue for a next step fusion device. In JET, a high time resolution infrared system is used to measure temperature distribution and evolution on the divertor target plates. The quantitative and time resolved estimate of the heat flux is computed with the 2D code THEODOR [1] constrained by the IR temperature measurements. This procedure can be complicated by the presence of a thin surface layer of low thermal conductivity and low adherence, resulting in a higher surface temperature for a given heat flux [2]. This paper presents an experimental technique, based on a power step L-Mode discharge and a flexible 1D model calculation, to assess the surface layer properties onto the JET divertor tiles.

## 2. THE POWER STEP METHOD.

Basically, the presence of the surface layer on the bulk material introduce an abnormal high surface temperature for a given deposited heat flux. During a power step (constant deposited heat flux), a normal evolution of the surface temperature is a square root function of time. With an extra surface layer this typical behaviour might change according the surface layer properties. For instance, depending on whether the thermalcontact between the film and the bulk material is good or not the surface temperature could be more like as a step function than a square root function. In the JET divertor one can clearly see this effect on the inner tile during DOC-L operation (Diagnostic Optimized Configuration where both strike points, inner and outer, are positioned on the vertical tiles for optimized infrared measurements). A possible way to model the observed surface layer effect is to assume that a variation of the deposited heat flux (ΔQ) will produce a direct increase of the surface temperature $\Delta T_s = \Delta Q/h_{layer}$, where hlayer represents the heat exchange coefficient between the surface layer and the bulk material. To experimentally assess this value, which characterizes the surface layer properties, the idea is simply to perform a power step in the DOC-L configuration (fig.5), measure ΔTs and then deduce hlayer as far as we know ΔQ. To achieve the surface layer assessment a reference power step discharge consisting of five 2s-steps of 1.4MW each (from neutral beam supply) has been performed during the experimental campaign. Fig. 1 shows the total input power ($P_{NBI}$) and the total radiated power (PRAD) for two similar reference pulses well separated in time by about two thousand pulses. Since the experimental time window (~15s) is smaller than the characteristic time for the heat to diffuse into the tile (~30s for typical surface temperature conditions), one can use the Infinite Wall Approximation (IWA) combined with the previously described surface layer model to compute the surface temperature during a power step:

$$T_s(t) = T_0 + \frac{2 \cdot \Delta Q}{\kappa_{bulk}(T_s)} \sqrt{\frac{D_{bulk}(T_s) \cdot t}{\pi}} + \frac{\Delta Q}{h_{layer}}$$

where $\kappa_{bulk}$ and $D_{bulk}$ are respectively the temperature-dependent heat conductivity and diffusion of the bulk material (CFC-Dunlop). In the following analysis the deposited heat flux ΔQ is adjusted to match the Langmuir probes measurements and hlayer is adjusted to fit the surface temperature as well as possible with the experimental data.

## 3. OUTER TILE CASE.

On the outer tile, the surface temperature varies always as a square root of time (fig.2, blue curve), thus no significant effect of any film is observed on that tile (hlayer is too high to be observed). The temperature on the outer tile is therefore used to test the validity of the IWA model. Without any surface layer, the input deposited heat flux is simply adjusts (cf. equation above) to match the experimental temperature data. Figure 2 shows the simulated and the experimental surface temperatures for the most recent of the two reference pulses (Pulse No: 58850). To check the validity of this model, the previously adjusted Q profile has been used in a 3-D heat conduction simulation (CASTEM-2000 code [4]). A deposited heat flux profile similar to that expected on the outer wall is used and a variation with the assumed profile width is investigated. Flat and a peaked deposited heat flux profiles have been studied and the corresponding simulations are plotted and compared with the IWA simulation on fig.2. The flat case is close to the IWA simulation while the peaked case gives a similar trend about a 25% lower value. The experimental deposited heat flux profile lies between the flat and peaked Q profiles, so the IWA model is estimated to be valid in the present conditions up to 25%. Aside from quantitative accuracy, this model can be use in any case to estimate the sensitivity of the heat flux to other quantities, such as the relative change with the assumed conductivity due to films.

## 4. INNER TILE CASE.

On the inner tile, the surface temperature varies more as a step function (fig.3(a)), pointing out a clear signature of a poorly adhered film. As a first approximation the input deposited heat flux has been varied to fit the Langmuir probe measurement (fig.3(b)). The thermal contact parameter $h_{layer}$ is afterwards adjusted to fit the experimental surface temperature. With hlayer sets to 20 $kW{\bullet}m^{-2}{\bullet}K^{-1}$, the simulated temperature (fig.3(a), green curve) matches the experimental data during the power step phase, but this model is slightly too high during the cooling down phase. Note that without any surface layer model the simulated surface temperature (purple curve) is far lower from the experimental data (blue curve). A second trial is made with a lower heat flux (red curve on fig. 3(b)) and by varying the heat exchange coefficient $h_{layer}$ during each step (for instance supposing that the thermal contact varies with the surface temperature), the cooling down is better matched. The second simulated surface temperature is plotted on fig.3(a) (red curve) with the corresponding used $h_{layer}$ coefficients. Since the IWA simulation is based on two unknown parameters (Q and $h_{layer}$) neither of the proposed solutions is definitive, but both are limited by the possible range of Q which is consistent with the Langmuir probe data. Considering the two possible sets of solutions (red and blue curves) the range of possible values to model the thermal contact of the surface layer is found for the presented pulse (Pulse No: 58850) to lie between about 10 and 20 $KW{\bullet}m^{-2}{\bullet}K^{-1}$ . When the same method is used to analyse a pulse (Pulse No: 56803) performed a few thousands pulses before then the thermal contact is found to lie between about 5 and 10 $KW \cdot m^{-2} \cdot K^{-1}$ (the total measured $\Delta Ts$ due to the surface layer is indeed much higher during this pulse). The estimated thermal contact $h_{layer}$ increases from about a factor of two after a few thousand pulses indicating a possible surface cleaning effect consistent with the higher frequency of DOC-L operations in between the considered pulses.

## 5. SPATIAL DEPENDENCE OF THE SURFACE LAYER.

A dedicated pulse has been performed to investigate the spatial dependence of the surface layer properties for two strike point positions distant by 2cm in the vertical direction. Similar power steps have been applied (fig.4) for both strike point positions (fig.5). Using the IWA power step method to assess the surface layer, one can see from figures 6(a) (outer tile) and 6(b) (inner tile) that no significant modification of the surface layer outcomes on both sides during the shifted down phase (the value $h_{layer} = 20KW \cdot m^{-2} \cdot K^{-1}$ once again fits the surface temperature data on the inner tile), indicating that the surface layer properties are possibly rather uniform onto the tiles.

## CONCLUSIONS.

We have developed a flexible and reliable indirect tool to assess the surface layer properties in JET. By comparing two similar pulses separated by a few thousand discharges, we have established that the thermal contact slowly increases consistently with a possible surface cleaning. The vertical dependence of the surface layer along the tile has been also analyzed for two different strike point positions distant by ±2cm and no significant modification of the surface layer has been observed. The resulting heat exchange coefficient has been used in the 2D inverse heat conduction code Theodor to compute the heat flux during ELM transient events [5].

## REFERENCES:


[1]. A. Herrmann et al., Plasma Phys. Control. Fusion **37** (1995) 17

[2]. P. Andrew et al,. 15 th PSI Conference, Gifu, Japan 27-31 May 2002

[3]. T. Eich et al., 28 th EPS Conference, Funchal, 18-22 June 2001, ECA Vol. 25A (2001) 1809-1812

[4]. R. Mitteau, et al., J Nucl Mater 290-293 (2001) 1036.

[5]. P. Monier-Garbet et al., this conference.

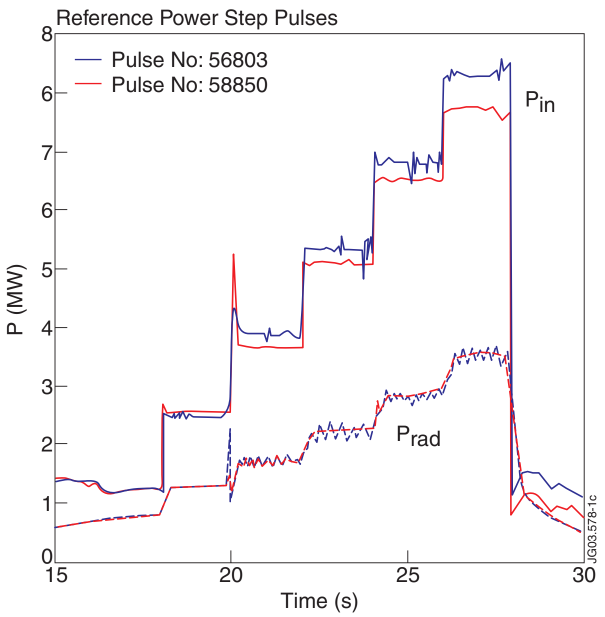


*Figure 1: Input and radiated power for Pulse No's: 56803 (blue) and 58850 (red)*

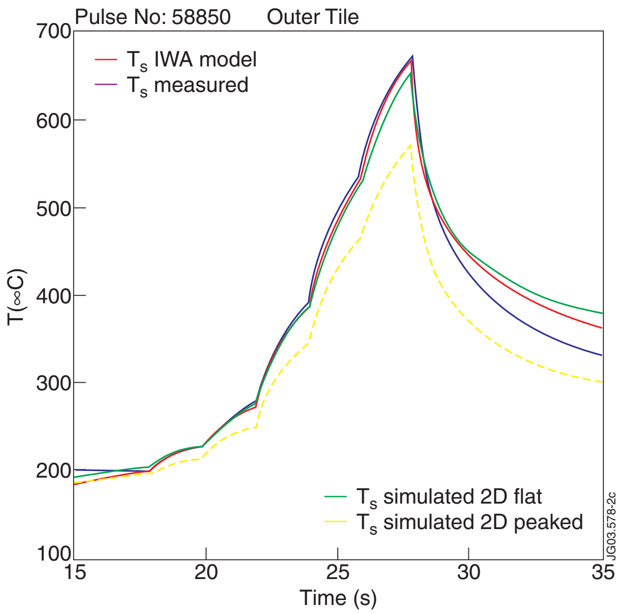


*Figure 2: Surface temperature on the outer tile, measured (blue), simulated with the IWA model (red), and with Castem with a flat (green) and peaked (yellow) Q profile.*

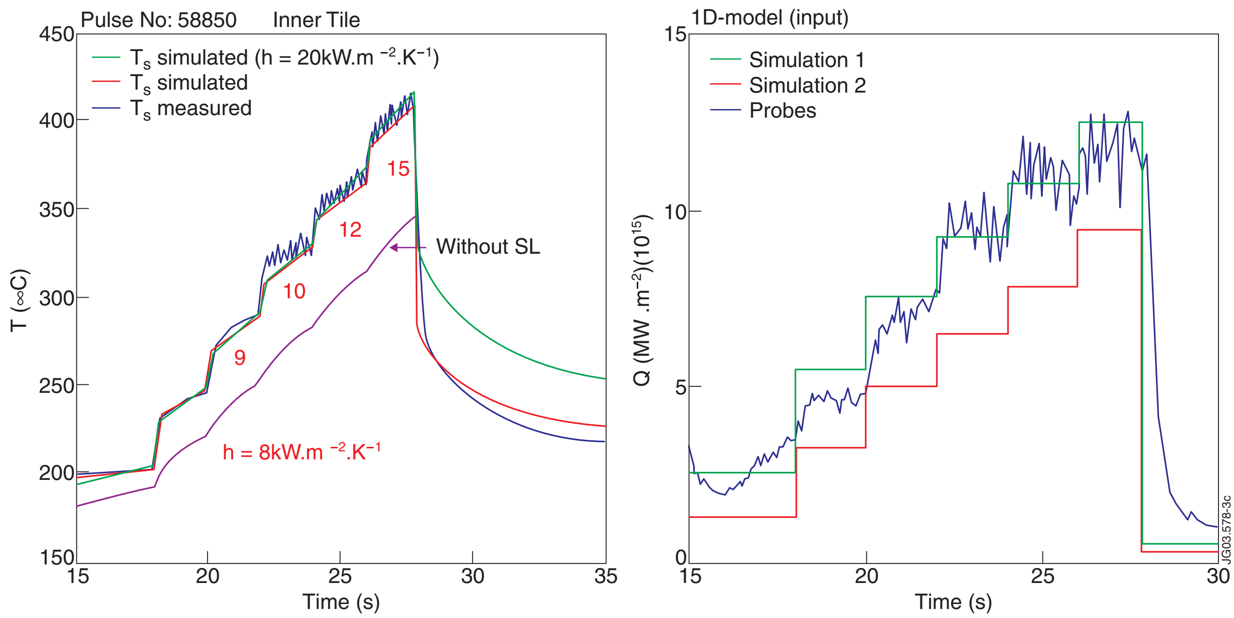


*Figure 3: (a) Experimental and simulated surface temperature on the inner strike point with hlayer constant (green curve) and hlayer variable (red curve). (b) Deposited heat flux measured (blue curve) and used for the 1D simulation with hlayer constant and variable.*

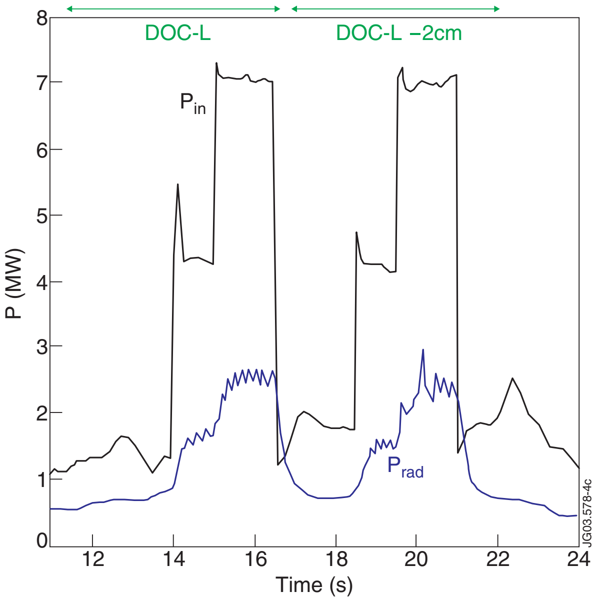


*Figure 4: Input and radiated power during Pulse No: 58833*

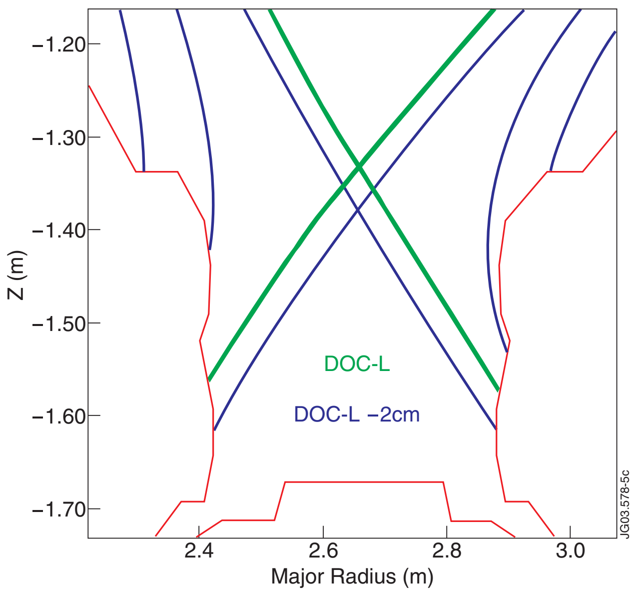


*Figure 5: Magnetic configurations during Pulse No: 58833 outer tile*

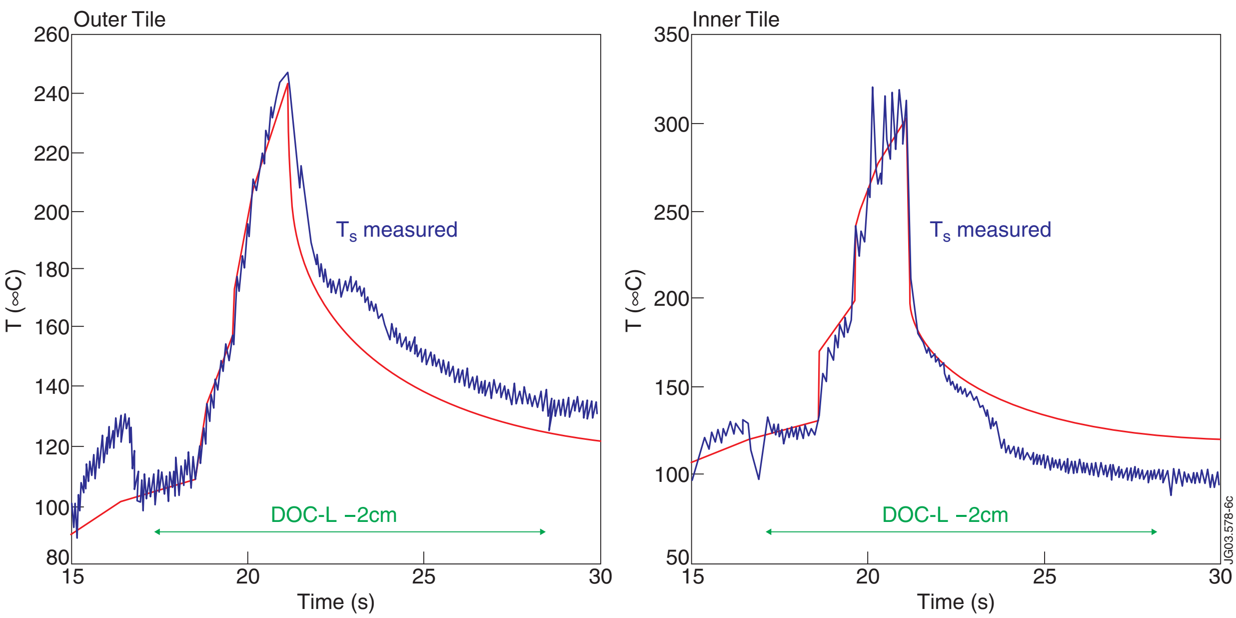


*Figure 6: Simulated (red) and measured (blue) surface temperature on the outer (a) and the inner strike point (b) during the shifted down phase (DOC-L –2cm).*