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Evolution and thermal analysis of carbon deposits on Tore Supra neutraliser carbon tiles

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Introduction:

The first divertor of ITER is foreseen to have carbon target plates. The principal diagnostic proposed to protect them from excessive powerfluxes uses infrared (IR) thermography surface temperature measurements. The calculation of powerfluxes from the IR thermography are complicated by the formation of carbon deposits. Knowledge of the thermal properties of the deposit/substrate composites would help to refine the power flux analysis. Components in Tore Supra comparable to the deposition zones in ITER are the actively cooled neutraliser plates which intercept the first few cm of the plasma scrape-off layer below the toroïdal limiter. Thick layers of deposited carbon accumulate there. An in-situ fibre optic enables the non constant surface temperature measurement of the components. In May 2005, one of the 12 neutralisers was dismantled and replaced by a new one. We present an investigation of the thermal behaviour of the new neutraliser and his evolution during a long period of operation in Tore Supra. We use a 2D heat flux calculation which is able to take into account the presence of a thin layer. We study the evolution of the most significantly parameter of the deposit that evolves.

Temperature measurements:

The diagnostic PRISME [1] allows the surface temperature measurements in three locations (top, bottom and middle) of the neutraliser for three wavelength: 1.6, 2 and 4.2µm using fibre optics. In this paper, we use the temperature measurement of the top of the neutraliser because this is the location where the flux is maximum, and the measurement at 1.6µm since the signal is the highest. The fibre optic observes a zone of *10mm* diameter. The study of these temperature measurements shows a relatively fast evolution of the deposits. We can see on the same fig.1a, the time evolution of the neutraliser surface temperature for three similar shots but obtained at different dates. The black curve is the surface temperature for the shot *n°34314* corresponding to *783s* of plasma after the replacement of the neutraliser. The blue curve is the *n°34453* after *1057s* of plasma and the red curve the shot *n°34641* after 3309s of plasma. These temperatures should have the same order of magnitude but the growth of the deposit perturbs the surface measurement. The measured temperature is the temperature of the deposit and not that of the component.

Flux estimation:

First, we try to compute the powerfluxes with only surface temperature measurements, without taking deposits into account. This approach is supposed to be valid, at the beginning of the campaign. To do that, we use a flux computation method that we have developed [2] which consists in the deconvolution of the temperature data with the 2D step function response of the component. The step response function is computed with the thermal quadrupoles method [3]. The method was tested and validated with numerical data coming from a finite element method calculation (CAST3M).

On fig.1b are presented the application of this computation on the experimental surface temperature. For the shot *n°34314* (783s of plasma after the beginning of the campaign) in black, the flux level is about 1.5MW/m². For the similar shot *n°34641*, the flux level is about 10MW/m², and big negative flux appears after the power cut-off at the time *t=16s*. A little negative flux is also present in the first case. This is explained by the deposits which grow at a rate of about *30nm/s* [4]. For the shots *n°34314* and *n°34641*, it corresponds to a deposit of about *25µm* and *100µ*m respectively. So the safety of the component cannot be realised with this type of diagnostic without an information about the deposits.

Deposit modelling:

The flexibility of our flux computation method allows to complete the modelling with a deposit modelling. A layer can be modelled with three parameters which are the thickness (in *m*), the thermal conductivity (in *W/m.K*) and the thermal diffusivity (in *m²/s*). In our case, these three parameters are not well known. So, we will choose the thickness from the relation of the deposit growth rate. The other parameters will be determined for every shot with the assumption that it is not possible to have a negative flux after the power cut-off. Including the approximation of our flux computation particularly in terms of geometry, the negative flux level has to be lower than 5% of the maximum flux computed in the shot.

So, if one parameter is given, we have to choose the others. A sensibility study shows that one parameter which is a combination of the thickness and the thermal conductivity is very sensitive. This parameter is defined as the equivalent thermal resistance of the layer, so we will name it $R_{eq} = e / k$ *(in m².K/W)*.

The powerflux computation with the deposit modelling yields the same order of flux level for the three comparable shots that we have studied and the negative fluxes are not significant (fig.2). This method applied on a large number of shots has allowed to study the evolution of the deposit parameter R_{eq} during the Tore Supra operation. This evolution is presented on fig.3, where R_{eq} is plotted with the plasma duration in seconds. The R_{eq} parameter is growing with different slopes. Between the shot 34343 and 34450, the growth is changing and becomes faster. Then, after the shot 34500 (disruption), the rise becomes faster again and stays linear until the end of our investigation. In another context, namely when cleaning the neutralisers, we observed that thin layers are very adherent while thick layers are easily detached from the substrate.

Discussion:

The analysis of the new neutraliser surface temperature with a flux calculation and a deposit modelling has allowed to study the evolution of the most sensitive parameter of the layers which is its equivalent thermal resistance (R_{eq}). We observe the growth of this parameter during the Tore Supra operation and in particular an acceleration of the evolution after 1500s of plasma. We can propose three hypothesis: the deposit is growing faster than 30nm/s, the thermal conductivity of the deposit decreases or it appears a thermal contact resistance between the deposit and the substrate, that traduces the bad mechanical attachment of the layer to the substrate. This analysis had allowed to obtain orders of magnitude of the parameters of the layers that we shall confront to results we will obtain in laboratory with a thermal parameters characterization experiment with a flash method.

References:

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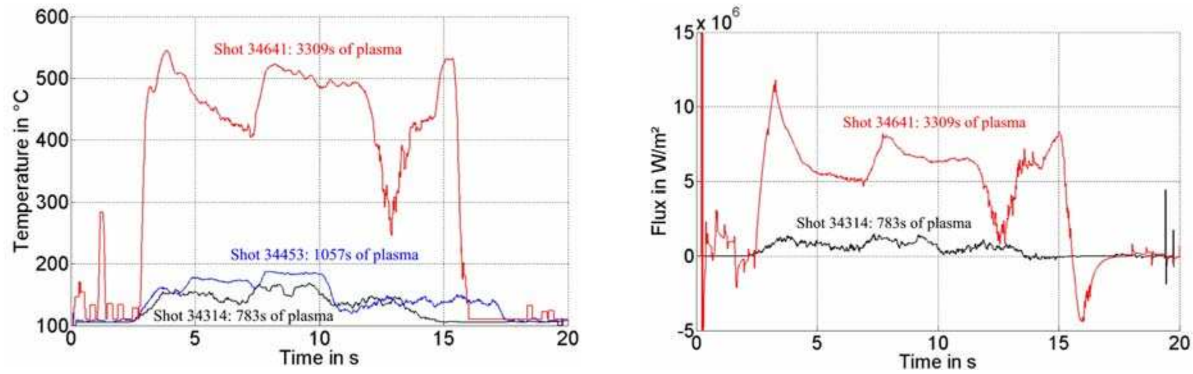

a) b)

Figure 1a: Temperature evolution of three similar shots at three dates

Figure 1b: Flux computed without deposit modelling evolution of two shots

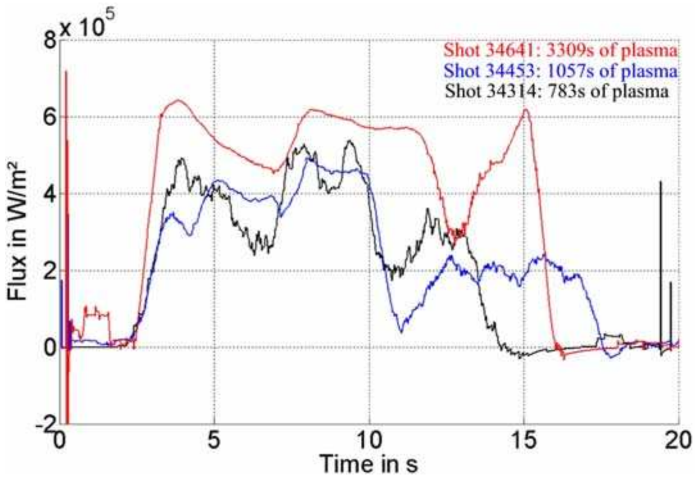

Figure 2: Flux corrected with the deposit modelling

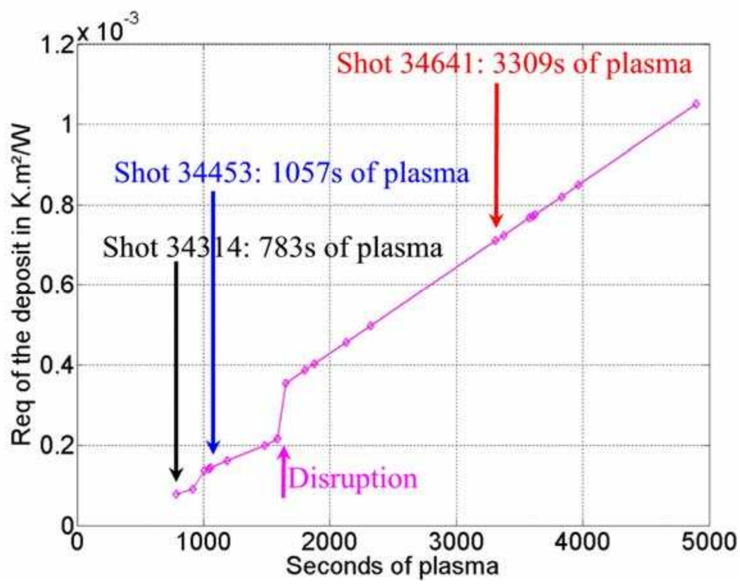

Figure 3: Evolution of the R_{eq} parameter