Task Title: INTERNAL PFC COMPONENTS BEHAVIOUR AND MODELLING

INTRODUCTION

Power flux deposition on the divertor during Edge Localised Modes (ELMs) is a crucial issue for the divertor in ITER. Power flux and energy distribution in space and time are key parameters that determine the ablation rate of the material. In present tokamak such as JET, during experimental campaign, the temperature is measured with thermocouples inserted in the tiles and with infrared camera measuring the surface temperature. Then, the power flux is calculated from the surface temperature evolution as function of time.

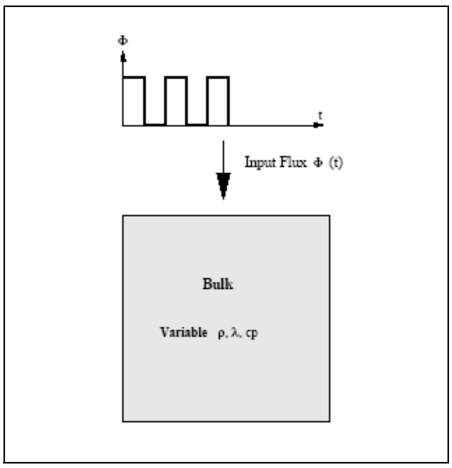
During transient high heat loads the power calculated using standard material properties for PFC is over-estimated [1] due to carbon layer deposition on the tile occurring during plasma operation: surface temperatures are higher than expected on initial PCF material. Moreover, for transient events such as ELMs with a duration in the range of 100-400 µs in JET, energy can not be measured from thermocouples due to the long time constant $\tau = l^2/D$ (where l is the distance between the thermocouple location and the tile's surface and D the thermal diffusivity of the material). To compensate this effect, the surface layer has been modelled by introduction of a heat transmission factor [1]. Since the thermo mechanical parameters (ρ, λ, Cp) of the surface layer are unknown, the uncertainty on the heat transmission coefficient induces large error bar on the calculated heat load. Moreover, parametric study of the heat transmission coefficient has demonstrated that its value, at a given location of the layer, is not unique but can change with time or temperature during a plasma discharge [2]. In fact, characterization of the redeposited layer cannot be achieved *in situ* in a tokamak since both the power flux and the thermal properties of the layer are unknown.

In order to improve power estimation and provide tools for better power/energy measurements in tokamaks, model validation and experiments on divertor tiles are on going. This work is carried out within the Fusion Technology (FT) Task force (TF) at JET and in the European national laboratories in collaboration with the JET Operator (UKAEA) and is part of the "Internal plasma facing components behaviour and modelling" research topic.

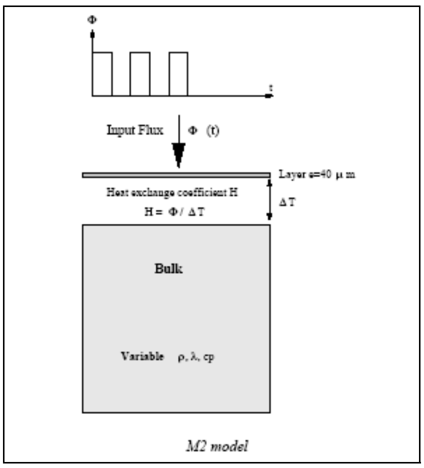
2004 ACTIVITIES

Experiments on divertor tiles have been carried out in 2003 within the Fusion Technology (FT) Task force (TF) at JET and in the European national laboratories in collaboration with the JET Operator (UKAEA). Two MkII divertor tiles, installed in JET during the 1995-1996 campaign, one from the inner side showing thick coating layer and one from the outer side showing erosion dominated and thin coating areas, have been selected to be exposed to power flux in the range from 5 to 100MW/m². Both tiles were equipped with 12 thermocouples inserted at different depth from the surface allowing measuring the thermal diffusivity in the bulk and the total energy impinging on the tile. The surface temperature was to be recorded by using a fast infrared camera and a standard IR camera.

In 2004, post-tests thermal calculations of JET divertor tiles have been performed to calculate the surface and in-depth temperature distribution on the actual JET divertor tiles during high frequency energy deposition. These calculations have been reported in [12]. Different tiles configurations have been considered in the numerical simulations taking into account the possible modification of the surface of the tiles (erosion, re-deposition):



M1 model : Fresh tile

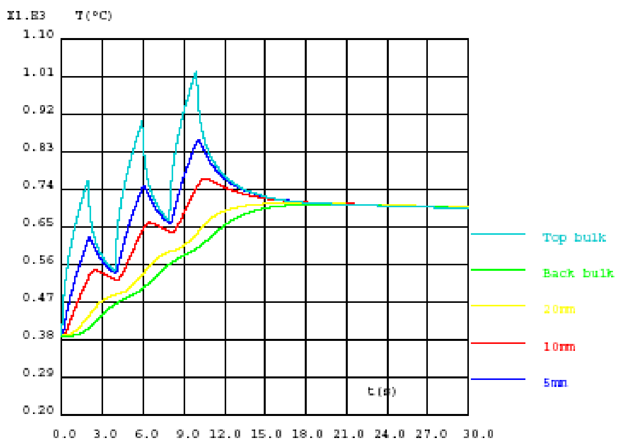


M2 model ; Bulk + deposited layer

The heat exchange between the layer and the bulk material is an adjustable parameter together with the thermal conductivity of the layer.

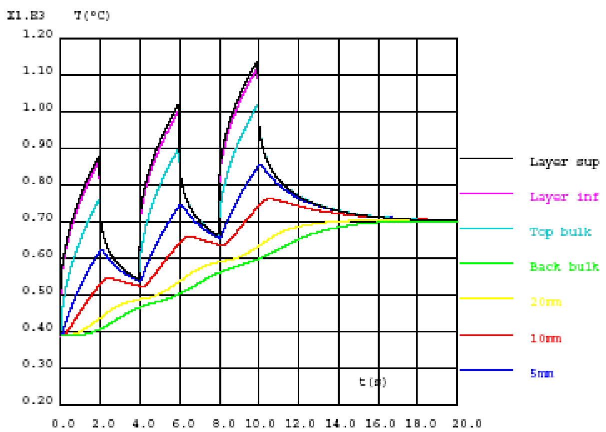
In a first step, a simple 1-D model (with CAST3M finite element code developed at CEA, see [6]) was considered to validate the models and to study the influence of the layer and of the heat exchange between the layer and the bulk on bulk surface and in-depth thermocouples temperatures.

Main conclusion about the influence of re-deposited layer on surface temperatures was that it was necessary to consider a model with a heat exchange coefficient between the bulk and the surface layer (M2 model) and the value of heat exchange coefficient is about 50 kW/m^2 with a heat flux of 5 MW/m^2.



Zoom on temperature evolution at different locations

1-D Model M1 : bulk without additional layer

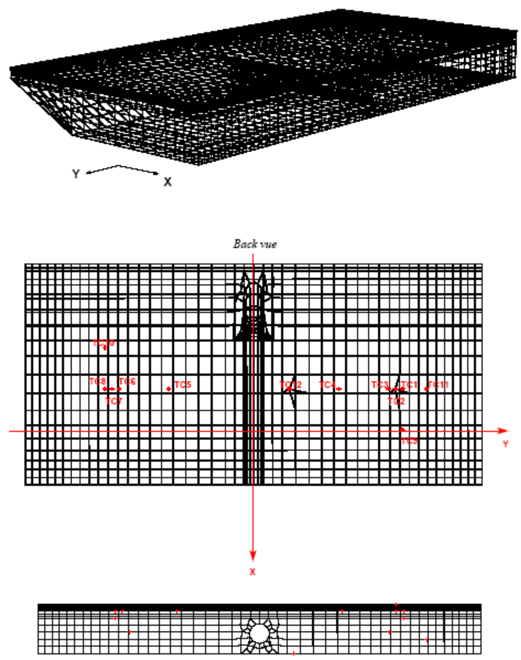


Zoom on temperature evolution at different locations

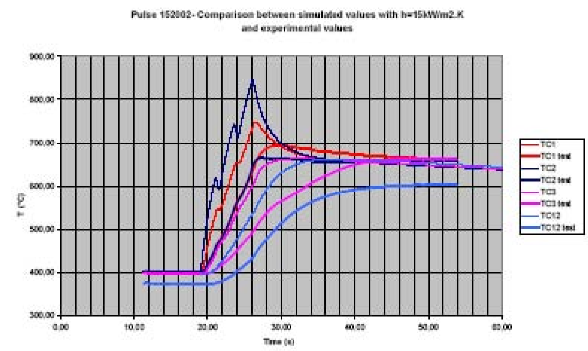
1-D Model M2 : bulk + additional layer and heat exchange coefficient of 50 kW/m^2.K

Pulse n°152448 5 MW/m^2 2s/2s for 3 cycles

In a second step, the real geometry of tiles has been taken into account in a complete 3-D model using the CAST3M code (see also pre tests calculations reported in [10] and [11]) to calculate the surface and in-depth temperature distribution on the actual JET divertor tiles during high frequency energy deposition:



3-D Finite element mesh of the tile type 4 LH with thermocouples positions



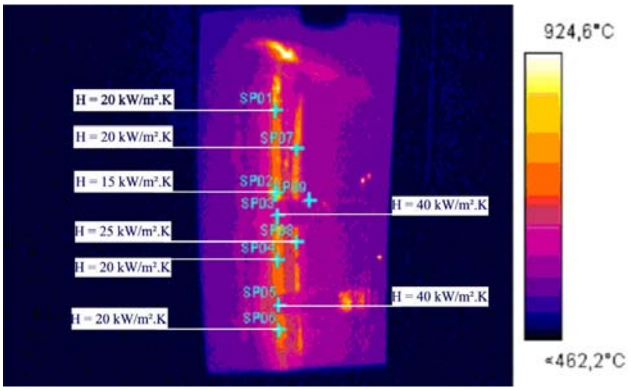
Comparison of experimental and calculated temperature evolution at different thermocouples for Model M2 3-D and heat exchange coefficient of 15kW/m^2.K

Pulse n°152448 5MW/m^2 2s/2s for 3 cycles: calculated temperatures for 100 % input flux

All calculations with 90 % of the experimental flux (possible over-estimation of the experimental flux) give a better agreement with equilibrium temperature but there were some discrepancies between experimental and calculated bulk temperatures (possible bad CFC thermal properties).

Modelling of the surface temperature has been successfully achieved using a 2D array variable, the heat exchange coefficient being governed by the co-deposited pattern.

Additionally, it has been shown that the thermal properties of the co-deposited layer changed from shot to shot , due to annealing of the layer inducing structural modification (graphitisation).



Heat exchange coefficient H on different location on the tile for pulse 152306 at 5 MW/m²

CONCLUSIONS

Post-tests 3-D thermal calculations of JET divertor tiles have been performed in 2004. A detailed 3-D model was developed using the CAST3M code to calculate the surface and in-depth temperature distribution on the actual JET divertor tiles during high frequency energy deposition. Different tiles configuration have been envisaged in the numerical simulations taking into account the possible modification of the surface of the tiles (erosion, re-deposition). All calculations with 90% of the experimental flux (possible over-estimation of the experimental flux) give a better agreement with equilibrium temperature but there are still some discrepancies between experimental and calculated bulk temperatures (mainly due to bad thermal contacts between the thermocouples and the tile). Concerning surface temperatures, results obtained with modelling a modification of the surface of the tiles (erosion, re-deposition) with a heat exchange coefficient in the range of 15 to 50 kW/m^2.K, give good agreement with experimental values.

Results have been presented at the PSI conference in May 2004 and published in Journal of Nuclear Material. Draft report has been sent in June 2004 and after amendments, Final report on FT3.1 task has been accepted in December 2004. The task is now completed.

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TASK LEADER

Eric GAUTHIER

DSM/DRFC/SIPP
CEA-Cadarache
F-13108 Saint-Paul-Lez-Durance Cedex

Tél. : 33 4 42 25 42 04
Fax : 33 4 42 25 49 90

E-mail : eric.gauthier@cea.fr

In collaboration with :

Laetitia NICOLAS

DEN/DM2S/SEMT
CEA-Saclay
F-91191 Gif-sur-Yvette Cedex

Tél. : 33 1 69 08 55 40
Fax : 33 1 69 08 86 84

E-mail : laetitia.nicolas@cea.fr