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MODELING CARBON REDEPOSITION IN THE TORE SUPRA ACTIVELY COOLED LIMITER CIEL

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1. Introduction

The creation of an extrapolable model for carbon erosion and re-deposition processes is needed to evaluate possible tritium retention and diagnostic coating rates in ITER. Tore Supra experiments relevant to this topic have been made, with a high level of heat extraction (>0.6 GJ), for long pulses (t> 4 mins), using the CIEL (Composants Internes et Limiters) actively cooled heat and particle exhaust system [1]. To contribute to the analysis of these experiments, a detailed simulation model for these processes in CIEL has been created, combining the BBQ 3-D Monte Carlo scrape-off layer impurity transport code with core radial impurity transport codes (SANCO / MIST). A BBQ-only model for erosion processes from the CIEL superstructure was compared with spectroscopic measurements from the Limiter Demarrage de CIEL [2, 3]. Here we describe the combined CIEL model (superstructure, leading edge and neutralizer region) required to simulate the re-deposition and total build-up of carbon from a series of long pulse discharges.

2. Model

The model starts from a detailed description of the CIEL geometry using a modification of the CASTEM-2000 thermal analysis code [4]. Using available data for background plasma parameters in the edge/SOL, the 3D incident D^+ deposition profile is determined. Using, in addition, available information about surface temperature distributions on the CIEL structure and a model for sheath acceleration, the spatial and velocity-space distribution of emitted C fluxes due to the physical, chemical, and radiation enhanced sublimation (RES) processes which are driven by the D^+ source is calculated. Using these D-related emission distributions, the BBQ Monte Carlo calculation follows the resulting C evolution in 3-D (τ_{equil} ~ 10 ms) until final disposition (striking plasma-facing components, or entrance to the core plasma), thus calculating re-deposition and the rate of penetration of carbon into the core plasma region. The resulting charge-distributed C influx to the core plasma then provides the boundary condition for the core radial impurity transport code. The radial code follows the core impurity evolution using this source until equilibration (τ_{equil} ~0.1s). Subsequently, the calculated C efflux from the radial code constitutes an additional self-sputtered impurity source in BBQ.

While the C influx to the core is drawn from the various CIEL regions, C efflux from the core falls mainly on the super-structure surface. C^0 from the superstructure region is quickly ionized, so that the core influx lies mostly in low ionization stages, while fluxes from the leading edge and neutralizer region dwell for a longer time in the SOL and can attain a higher charge before penetrating the plasma core (defined as ρ=0.71m). After residence in the core for τ_p^+, however, the core efflux stream has a broad distribution of charges. Each of these species has a different sheath-accelerated energy, and hence self-sputtering yield.

Thus, additional CASTEM maps are created for each impurity ion. Using this information, and the effluxes from the radial transport code, an iteration to account for self-sputtering is made, with the self-sputtered impurities followed by BBQ and the products of self-sputtering re-introduced into the core calculation. The iterative solution allows description of the possible development of slow secular growth in Z_{eff}, which would signal the absence of a true steady state solution. Figure 1 conveys the general outline of the overall scheme with a schematic diagram of the process. Figure 2 shows the convergence of a sample BBQ/MIST iteration.

3. Examples

Calculations using this model are underway for the conditions of a series of Tore Supra shots (29930 – 30093) in which pulse lengths of several of the discharges exceeded 1 minute. Starting with boronization prior to the first discharge, at the end of the sequence a deposited layer of 140 μm was observed at the entrance of the neutralizer [see 5]. In place of direct measurements of SOL properties, for these sample calculations we assume electron density at the last closed magnetic surface n_e(LCMS) =7.10^{18} m^{-3}, T_e(LCMS) =50 eV, and the scrape-off layer decay lengths for density (λ_N) and temperature (λ_T) are 4 cm and 5 cm, respectively. Z_{eff}~ 2 for long discharges in this shot sequence. Figure 3 shows typical BBQ particle orbits for sources from the super-structure, leading edge and neutralizer regions, along with the (θ,ϕ) distribution of emergent D^+-sputtered fluxes from these areas. The tendency toward higher charge states for core penetrators originating from the leading edge/neutralizer is demonstrated in Fig. 4, which shows the charge state distribution for C ions entering the core from the various regions. Figure 5 shows the resulting radial distributions of C ion density for the leading edge and neutralizer region sources. High charge state distributions are found deep in the SOL for sources from the leading edge/neutralizer. The use of high power LH in long pulse discharges has resulted in the observation of zones of local high heat deposition on the leading edge and neutralizer regions [1]. The examples discussed here suggest that such a deep SOL source can produce a higher density of more highly ionized C in the SOL than that from the strongly attenuated convective flux to the superstructure, and thus could generate C through self-sputtering at rates consistent with the strong observed build-up. This is a qualitative conjecture, which could be improved with the availability of SOL plasma parameter data from discharges similar to those considered.

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References

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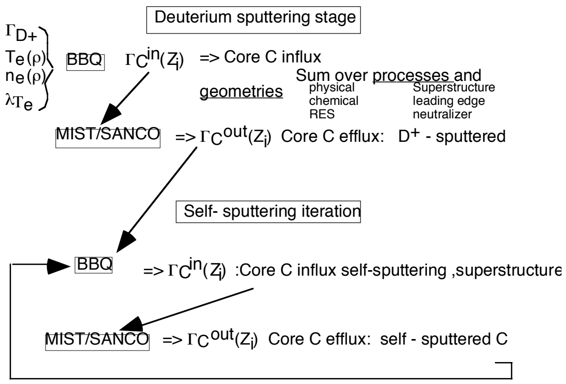

Figure 1. General outline of BBQ core /transport iteration

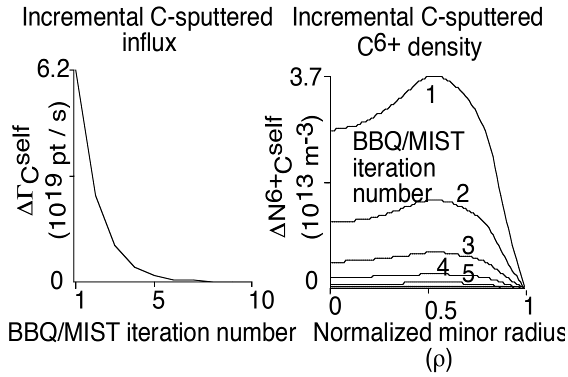

Figure 2 . Example of BBQ/MIST iteration. (left) incremental C influx , (right) incremental N_C^{6+}

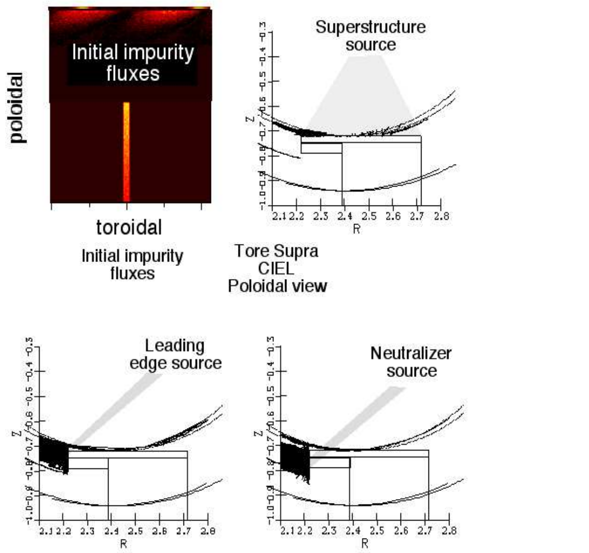

Figure 3. BBQ particles orbits: emitted flux distributions (top left) and particle orbits for superstructure, leading edge and neutralizer sources

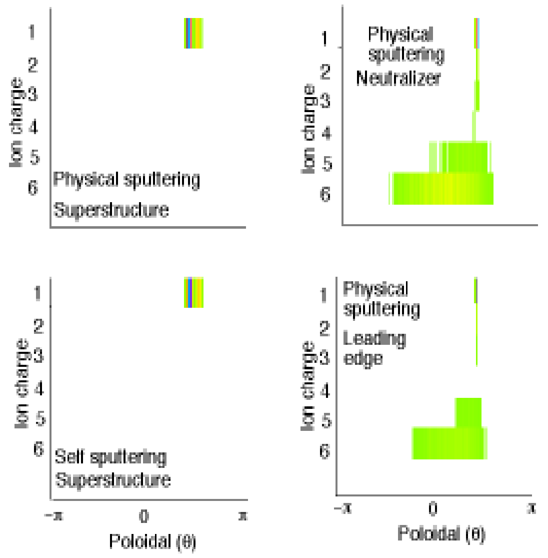

Figure 4. Charges state distributions of C entering core plasma influx (= color scale (rel.)

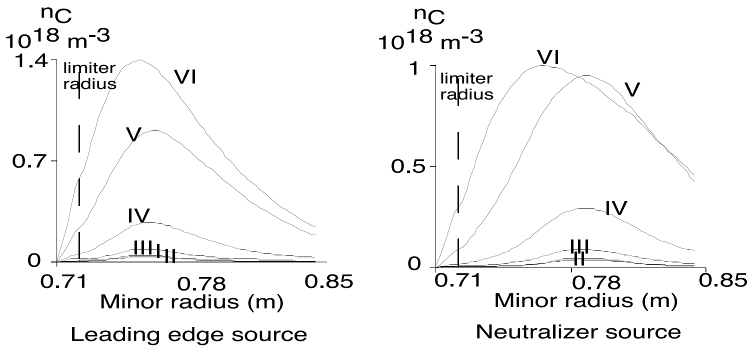

Figure 5. Radial distribution of C ion density for leading edge and neutralizer sources.