SIMULATION OF ASDEX DIVERTOR ACTION USING A REALISTIC NEUTRAL GAS MODEL

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Simulations of the plasma flow and the energy transport in the scrape-off layer of the ASDEX tokamak have been previously carried out using the one-dimensional, 2-fluid code SOLID /1/ to describe the parameter variation along the magnetic field lines. These calculations showed the existence of strong gradients in density and temperature between the midplane and the target plate vicinity, and three different regimes of divertor recycling also identifyable in experiments. The quantitative validity of these calculations was limited, however, by the use of a strongly simplified neutral gas model. For the present calculations the elaborate Monte-Carlo model DEGAS /2/ for two-dimensional dynamics of neutral molecules and atoms in the divertor chamber has been combined with the above fluid description of the plasma, where DEGAS now provides for all significant atomic reactions as well as for a realistic 2-dimensional divertor geometry (Fig.1).

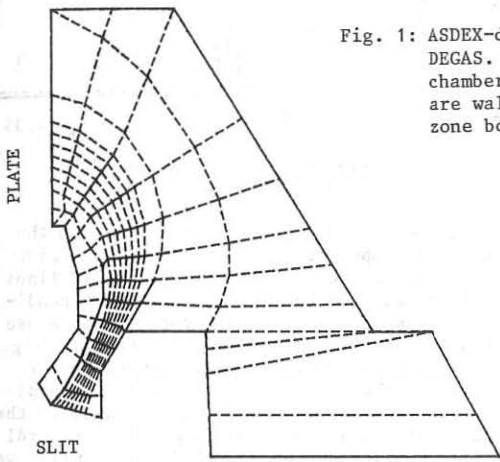

Fig. 1: ASDEX-divertor geometry used in DEGAS. Only the outer divertor chamber is modelled. Solid lines are walls, dashed lines are plasma zone boundaries.

The scrape-off plasma and the neutrals in the divertor chamber are strongly interdependent. A coherent description therefore requires the simultaneous treatment of the plasma flow and heat-conduction along the magnetic field lines onto the divertor plates and the atomic processes arising from the neutral molecules and atoms in contact with the plasma and the walls. In a preliminary version the fluid code and the Monte-Carlo code are not yet directly coupled, but are run one after the other. First the plasma profiles, i.e. the plasma density and temperatures, together with the reaction and energy transfer rates along the field lines are computed by SOLID with a simplified neutral gas model prescribing the spatial neutral particle distribution.

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Then the plasma parameters are transferred to DEGAS to calculate improved neutral particle profiles and atomic reaction data. By iterating this procedure, we get already qualitatively consistent solutions. A particular example is discussed below in detail:

For a given particle- and energy flux of $.1 \times 10^{22}$ 1/s and .75 MW into one divertor chamber the results of the fluid calculation are shown in Fig. 2 (n_e and T_e, T_i along the field lines within the divertor chamber, corresponding to the distance s from midplane of 10 to 15 m). The thickness of the scrape-off region was assumed to be 2 cm; for the confinement time of the neutrals in the divertor chamber 20 msec was taken. The electron density in the vicinity of the target plates is about a factor of two higher than at the divertor entrance and outside the divertor. The temperatures decrease from T_e = 45 eV, T_i = 70 eV at midplane to T_e = 40 eV, T_i = 45 eV at the divertor throat and finally to T_e = 25 eV, T_i = 10 eV near the target plates.

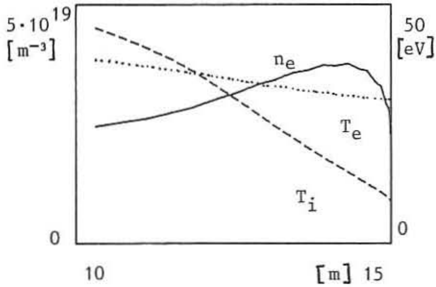

Fig. 2: Plasma profiles ∥ B

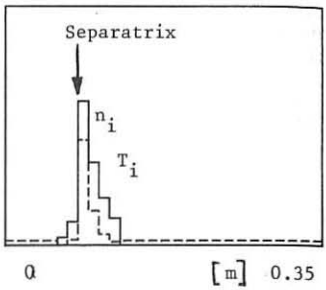

Fig. 3: Plasma profiles ⊥ B (same units as Fig. 2)

The 2-D Monte-Carlo neutral particle code DEGAS requires as input from the fluid model the plasma density and the temperatures in the divertor region and the recycling flux onto the divertor plate. Parallel to the field lines the plasma profiles can be directly taken from the SOLID results. Perpendicular to the field lines, where SOLID assumes a constant profile, we choose an asymmetric exponentially decreasing density and temperature profile (Fig.3) in accordance with experimental findings /3/ (outward decay length of the density in front of the plate: 3 cm, of the temperature: 1.5 cm). Perpendicular to the magnetic field the distance x is measured from the inner to the outer divertor wall; the profiles are taken at s $\approx$ 13 m. Equal line integral densities were assumed for normalization. Gettering at the divertor walls was adjusted in order to obtain a neutral gas confinement time of 20 ms.

The neutral hydrogen densities parallel to the field lines calculated by DEGAS agree reasonably well in absolute size and shape with the profiles used in SOLID (Fig.4 ; DEGAS: solid curve, SOLID: dotted curve). The DEGAS results especially show three distinguishable regions of behaviour: in a region immediately in front of the divertor plate a part of the neutral flux originating from the plate is quickly ionized and the density decreases rapidly. Then in a plateau region the density is fairly constant. The neutrals in this region primarily arise from the dissociation of molecular hydrogen, which has a nearly constant density outside the plasma channel. Inside the divertor slits the density decreases further because the slit walls shield the plasma from the influx of molecular hydrogen. The profiles perpendicular to the field lines confirm these conclusions. In the plateau region (Fig.5) the maximum of the neutral atom density (solid line) occurs at the outward side of the scrape-off plasma where the neutral molecules are dissociated. The molecular density (dashed line) is nearly constant in regions without plasma and about an order of magnitude larger than the atomic density. Its absolute number of $5 \cdot 10^{18}$ m^{-3} is comparable to ASDEX measurements with similar plasma conditions /3/. The neutral hydrogen temperature along s calculated by DEGAS is nearly constant (Fig. 6), thus being in reasonable agreement with the constant value of 10 eV used in SOLID.

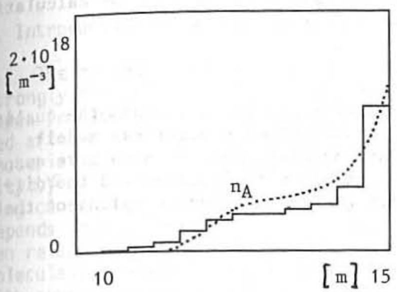

Fig. 4: Neutral atom density // B

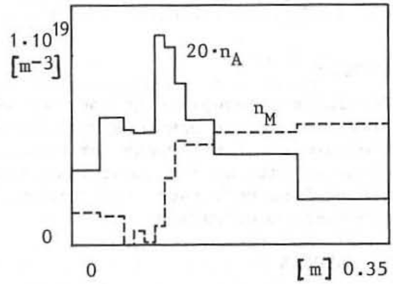

Fig. 5: Neutral densities ⊥ B

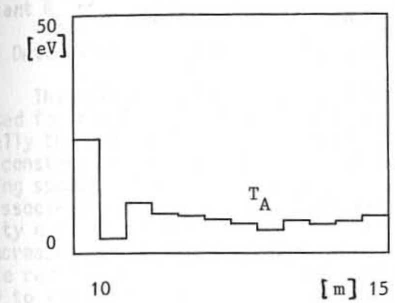

Fig. 6: Neutral atom temperature // B

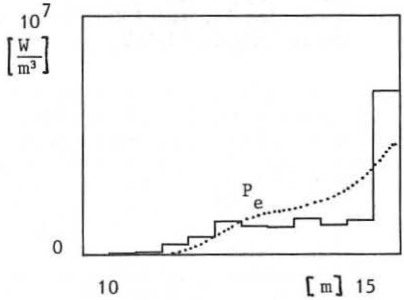

Fig. 7: Electron power loss // B

Besides the primary quantities like particle density and temperature, the dissociation-, ionization- and CX-rates together with the associated power loss densities from the electrons and ions are calculated. The agreement between the profiles along s calculated by DEGAS and the corresponding quantities used in SOLID is rather good. The total power loss density from the electrons is plotted in Fig. 7 for the two calculations (DEGAS: solid line, SOLID: dotted line). The total power loss from the electrons is .120 MW (radiative: .04 MW, ionization: .06 MW, dissociation: .03 MW). The total power loss from the ion channel (CX losses) is comparatively small: .01 MW. The comparison of this quantity was not quite as satisfactory as for the electrons. This is partly due to the fact that near the target plates the difference between the temperatures of the ions and the neutral atoms can be small and may even change sign forming a local energy sink or source, respectively.

Starting from this example, a variation of the input particle flux, which should be a monotonic function of the averaged electron density in the bulk plasma, verified the same general features as reported in /1/.

An important quantity with respect to experimental measurements is the neutral gas divertor time constant which is defined as the ratio of the total neutral particle content in the divertor and the neutral particle outflux through the divertor slit. Considering the outer divertor chamber only, we obtain τ_{vac} = 25 msec in the absence of plasma; with plasma, the calculation yields τ_{div} = 150 msec, i.e. the plasma nearly plugs the slits.

SUMMARY

The indirect coupling of the two codes SOLID and DEGAS has shown the qualitative validity of previous results using a simplified neutral gas model. The results of the Monte-Carlo code DEGAS, however, provide much more quantitative information about the neutral particle distributions and the different loss processes. For further investigations a direct coupling of the two codes is necessary.

REFERENCES

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