CX-RECOMBINATION SPECTROSCOPY DURING NBI HEATING OF ECRH TARGET PLASMAS IN W VII-A STELLARATOR AND COMPARISON WITH A TRANSPORT MODEL

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Radiation in most of the Wendelstein VII-A plasmas has been dominated by oxygen impurities. In discharges that have been sustained by NB heating, starting from OH-target plasmas, beam injected oxygen along with some oxygen influx from the walls of the vacuum vessel has been shown to account for the observed radiation losses. In some particular cases also high Z radiation (Fe) was observed to yield some contribution to the radiation losses at late times during the discharge, when the electron temperature drops. These experimental results were summarized in /1/ and compared with transport calculations.

The knowledge of time history and radial distribution of the relevant ionization stages are thus of large interest, in particular in connection with numerical transport studies. In this paper we will report on measurements of time history and to some extent also on spatial information of O^{8+} and O^{7+} intensities.

The plasma under consideration starts out from an ECR (70 GHz) produced target plasma, which is further heated and sustained by NB injection ($\simeq$ 750 kW) after the ECH power has been switched off.

Central densities up to 8×10^{13} cm^{-3} and electron temperatures between 300 and 600 eV, with ion temperature slightly above the electrons, have been achieved. (For a more detailed description of NB heating from ECR target plasmas see paper /2/ at this conference.) Figure 1 shows some parameters of such discharges, but with a second ECRH pulse applied in the late NB-injection phase. During the time interval shown, spectroscopic measurements of O^{7+} and O^{8+} will be compared with code simulations.

By injection of energetic neutral hydrogen atoms from a separate diagnostic injector (E_o = 26 kV, I_o = 6.5 A, species mix $E_o:E_o/2:E_o/3$ $\simeq$ 20:30:50, half width $\simeq$ 4 cm and Δt = 15 ms) highly excited O^{7+*} ions originate from CX-recombination ($H_o + O^{8+} \rightarrow H^+ + O^{7+*}$) /3/. Radiation from the $8^2H_{9/2} \rightarrow 7^2G_{7/2}$ transition at λ = 2976 Å was observed spectroscopically from the intersection volume between the line of sight of the spectrometer and the diagnostic beam. The intensity of this radiation is given by

$$B_\lambda^{CX} = \frac{1}{4\pi} \sum_{j=1}^{3} \langle\sigma v\rangle_j^\lambda \int n^{O^{8+}} n_j^H \, dl \quad [\text{Photons/cm}^2 \text{ s sterad}]$$

where $\langle\sigma v\rangle_j^\lambda$ is the rate coefficient for excitation, j denotes the 3 beam components with density n_j^H and the integration is across the diameter of the diagnostic beam.

There is no temperature dependence in $\langle\sigma v\rangle$ and from n_e-profiles and line density measurements also n_j^H is calculated to show little variation throughout the beam cross-section. Therefore from the observed signal we can derive $\int n^{O^{8+}} dl$ as a function of time. Moreover since the n_e and T_e

profiles are flat within the beam cross-section with steep gradients outside, this line integral is also a measure of the behavior of the central density of $n^{O^{8+}}$ and can be compared with a transport model.

On the other hand, the same transition is also observed with the diagnostic beam off. In this case it must be due to electron collisional excitation and thus this signal is proportional to the O^{7+} density

$$B_\lambda^{e-} = \frac{1}{4\pi} \int_0^L n_e(r)\, n^{O^{7+}}(r)\, q_{1s\to np}(r)\, B\, dl \quad [\text{Photons/cm}^2\ \text{s sterad}]$$

where $q_{1s\to np}$ is the rate coefficient for electron collisional excitation, B the branching ratio and L the plasma diameter.

It is interesting to note that Doppler temperature measurements from the passive (electron excited) and active (beam excited) signal lead to the same ion temperature and support the interpretation of the signal as being due to electron excitation.

COMPARISON OF MEASUREMENTS WITH SIMULATIONS

The total soft X-radiation from the intrinsic impurities for this discharge type is shown in Fig. 2a. The increase of the central raditaion is described reasonably well by the O VII + O VIII radiation calculated with our neoclassical transport code SITAR /1/ with a 1 % oxygen beam contamination and a wall influx of O raising from 1.9×10^{18} to $4.7 \times 10^{18}\ s^{-1}$ during the discharge (Fig. 2b). At the late stage of the discharge, however, the soft X-radiation is not correctly reproduced by the oxygen simulation. In order to reduce the discrepancy, high Z material has been included in the simulations for this discharge type (Fig. 2c). In fact, oxygen radiation cannot account for the drop of the soft X-radiation observed late in the discharge, as T_e decreases. In addition high Z material in low density neutral beam sustained discharges seems very likely, since local Fe-fluxes of about $2 \times 10^{17}\ s^{-1}$ originating from sputtering by fast ions on lost orbits at the vacuum vessel wall have been measured earlier /5/. The code results of Fig. 2c were obtained with a Fe influx increasing from 1.9×10^{17} to $4.7 \times 10^{17}\ s^{-1}$ during the discharge. The steep increase of the calculated O VII + O VIII radiation at $\simeq$ 105 ms is essentially a consequence of the T_e drop observed after switching off the ECH pulse. The related decrease of the O^{8+} density is clearly confirmed by CX-recombination measurements (active signal) mentioned above. The measured and calculated O^{8+} densities are shown in Fig. 3.

The time evolution of the electron excited passive signal for the same discharge type is shown in Fig. 4. The simulated signal has been obtained by using the equation for B_λ^{e-} given above with the electron density and temperature taken from Thomson scattering measurements, the rate coefficient from calculations by P.R. Summers /4/ and the O^{7+} densities from the transport simulations.

The time evolution of the signal is very well reproduced by the model up to 90 ms. The small discrepancy shown at later times is believed to be caused by the uncertainties in the electron temperature due to temperature interpolations between the measured temperature profiles.

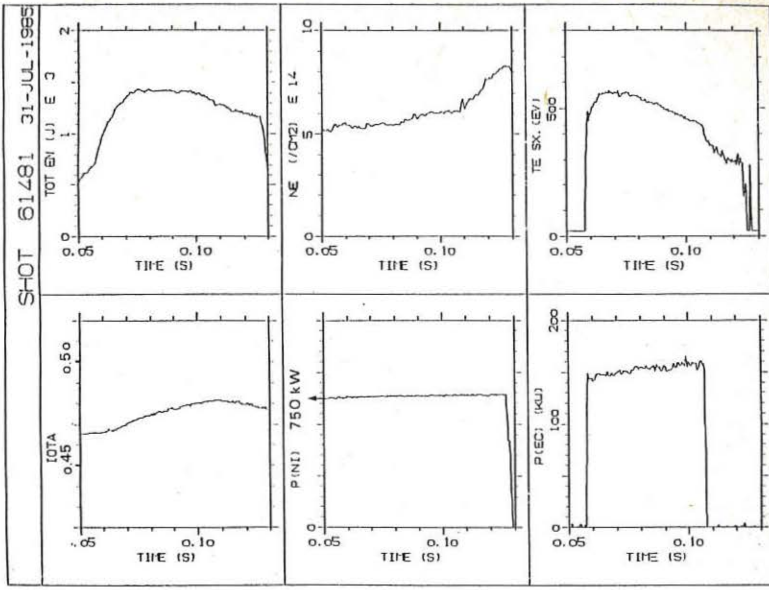

Fig. 1: Plasma energy, line integrated density, electron temperature, edge value of iota, neutral injection power and ECH power during the second ECH pulse (t $\simeq$ 58 - 108 ms).

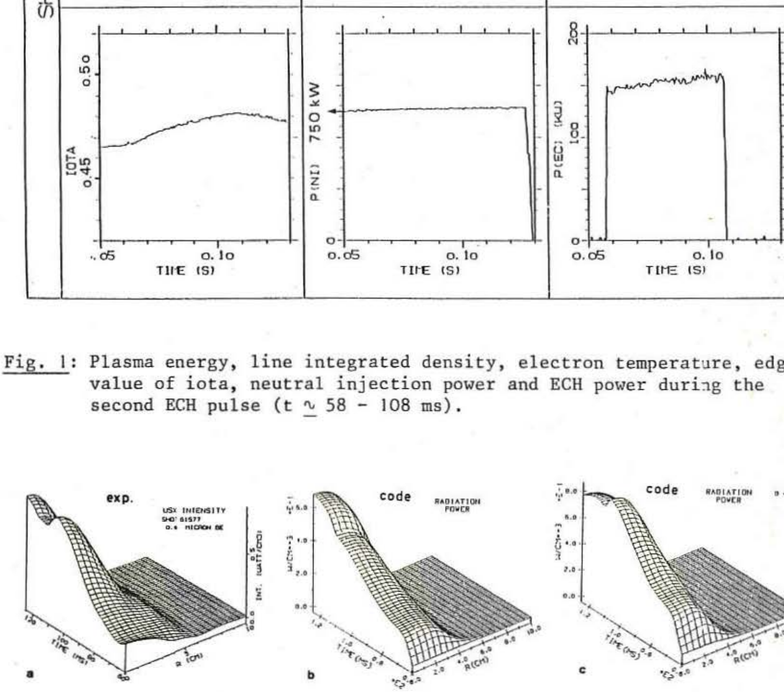

Fig. 2: a) Evolution of soft X-radiation for the NI+EC heated discharge shown in Fig. 1.
b) Code simulation with oxygen impurities and neoclassical transport fluxes
c) Same as b) but with additional iron impurities.

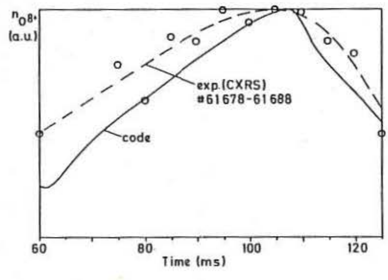

Fig. 3 Central O^{8+} density (a.u.) vs. time from active CXRS measurements in comparison with code calculations.

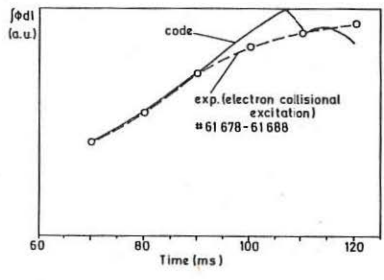

Fig. 4 Flux of O VIII (2976 Å) line intensity (a.u.) (electron excitation) vs. time in comparison with code calculations.

REFERENCES

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*, **, *** see H. Renner et al., this conference.