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IMPURITY STUDIES IN THE ADVANCED TOROIDAL FACILITY

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Abstract

Impurities have played an important role in the initial stages of operation of the Advanced Toroidal Facility (ATF).[1] Cleanup practices have been adequate enough that plasmas heated by ECH only can be operated in a quasi-steady state; however, neutral-beam injected plasmas always collapse to a low temperature. It is not clear whether impurity radiation is actually responsible for initiating the collapse, but at the time the stored energy reaches a maximum, there are indications of poloidal asymmetries in radiation from low ionization stages, such as observed in marfes, which could play a dominant role in the plasma evolution.

ECH plasmas and cleanup

The earliest ATF plasmas were heated with only 200 kW of 53 GHz, second harmonic gyrotron power. Discharge cleaning in this period was accomplished using a 2.45 GHz, 4 kW, ECR source. The discharges exhibited uncontrollable rises in electron density and spectral line radiation because of impurity influxes, and they always collapsed to low temperature plasmas before the end of the ECH pulse. This behavior is illustrated by the O V emission from shot 679 (100 ms ECH pulse) shown in Fig. 1 where arrows indicate the time of collapse. Following a rapid increase in radiation from intermediate stages of ionization, such as O V and O VI, a precipitous temperature drop occurs at 50 ms leaving O II and O III as the dominant oxygen ions. The electron density falls along with the temperature because of recombination. The addition of glow discharge cleaning together with baking the vacuum vessel reduced the impurity content significantly. Within 10 days of this type of cleaning, discharges could be operated up to 280 ms (shot 1080), and within two weeks, collapses could be avoided completely as illustrated by the O V signal from shot 1156 which decays only when the ECH is turned off at 450 ms. Discharges up to 1s long have been operated with no observable buildup of contaminants.

NBI plasmas

Quasisteady operation has not been achieved with neutral beam injection. Following the onset of injection, the electron density and stored energy both rise briefly, but in typical non-gettered operation they start to decrease at 50-70 ms after injection starts. Figure 2 shows the behavior of the central electron and ion temperatures during 100 ms of 750 kW NBI. The 200 kW ECH heating is operated from 0-400 ms. The electron temperatures are measured continuously from electron cyclotron emission and the ion

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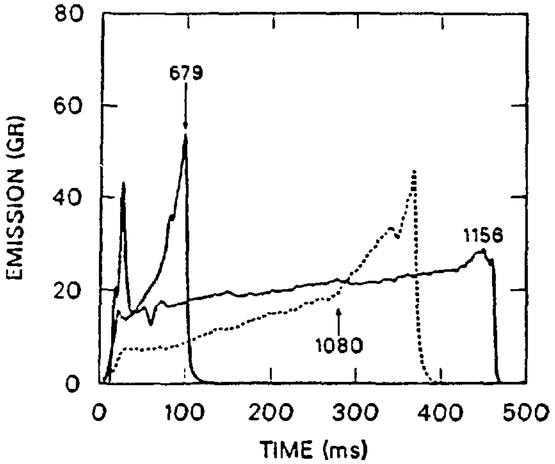

Fig. 1. O V emission for specified shot numbers

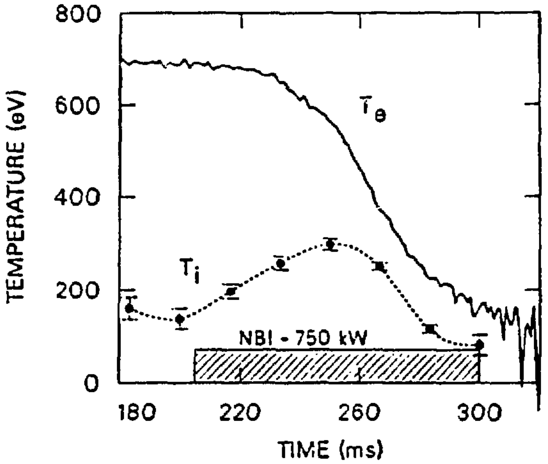

Fig. 2. Time history of $T_e(0)$ and $T_i(0)$ during 750 kW NBI injection.

temperatures are obtained from the Doppler widths of the O VII line at 1623 Å averaged over 16 ms intervals. The neutral beam pulse clearly heats the ions initially, but similar heating is not observed in the electrons. Both temperatures fall after 260 ms. It is still an open question whether impurity radiation alone is responsible for the inability to maintain the electron temperature at a high level during NBI.

Detailed interpretation of impurity behavior is complicated by the rapidly changing temperature and density, but certain general aspects are readily deduced. Characteristic carbon signals are shown in Figs 3 and 4 for a discharge in which injection lasts from 100-200 ms. It is noteworthy that the C III radiation, one of the most intense transitions, is relatively weak in the target plasma, 7 GR, and that after injection it increases by a factor of 10 up to the peak of the stored energy at 150 ms. Even so, it radiates only 13 kW out of 400 kW of absorbed power. Typically, the radiated power at the time of the peak in the stored energy is only 30-40% of the absorbed power. The intense peak in the C III emission that develops after 170 ms is the result, not the cause, of the severe drop in T_e; it appears only when the temperature is low enough for C III to be a dominant ion.

Radiation from C V and C VI are used to determine the carbon density during injection. The C VI signal comes overwhelmingly from charge-exchange excitation (CXE)^2, and is proportional to the C^{6+} density in the interior of the plasmas. Emission from the 2271Å line of C V (Fig. 4) indicates a substantial fraction of C^{5+} is also present in the center. This conclusion is drawn from the difference between the radiation when injection from the two beams is alternated from shot to shot. The grazing incidence spectrometer on ATF has a field of view that encompasses only beam #1. The trace in Fig. 4a is taken with beam #1 operating and is the sum of electron excited and charge-exchange excited emission, whereas Fig. 4b is recorded with only beam #2 operating and, hence represents only electron excitation, i.e., the signal is related only to the density of C^{4+} and not to C^{5+}. The difference of the two signals, which depends only on the C^{5+} density, is shown in Fig. 4c. The fact that the carbon is not burned out in the center implies that the diffusion coefficients are rather high, 1-2 X 10^4 cm^2/s. The rapid rise of the CXE signals when the beam is turned on provides a measure of the carbon content before its concentration changes substantially from that of the ECH target plasma. Subsequent evolution is representative of the change in the impurity

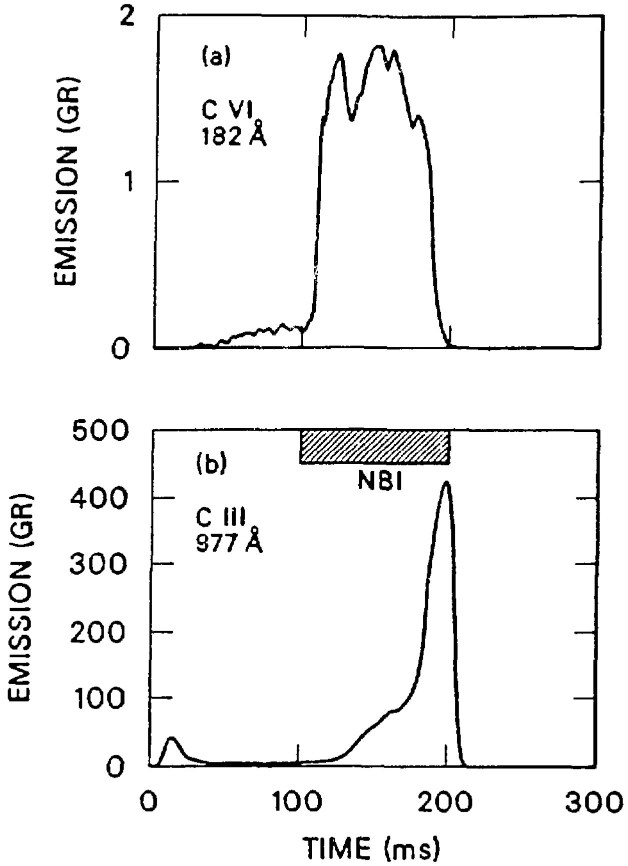

Fig. 3. Emission from a CXE line and a strong $\Delta n=0$ line in NBI discharges.

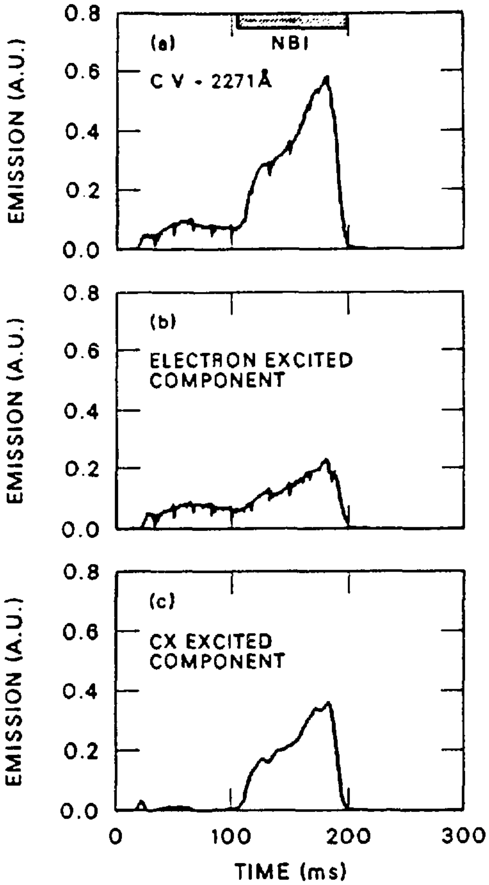

Fig. 4. C V emission (2271 Å), (a) CXE and electron excited, (b) electron excited only, and (c) CXE only.

level as the discharge progresses. For a wide variety of conditions, analysis shows that the central densities of oxygen, carbon, and nitrogen all increase by factors of 1.5-3. The increase appears to result from a greater influx during injection; there is no strong evidence that injection engenders accumulation.[3] Because the electron density also rises, Z_{eff} does not increase very much; it remains in the range 1.5-2.0. Gettering approximately 30% of the vacuum vessel with chromium reduces the edge radiation by factors of 3-4 in ECH plasmas, although the central densities change by only about 30%. Higher electron densities can be achieved by gettering, but the discharges still terminate similarly to ones where gettering is not employed.

The relatively low impurity content and low fraction of radiated power at the time of the peak in the stored energy would make it seem unlikely that impurities alone are responsible for the collapse, but modelling studies using the PROCTR code indicate that this may indeed be the case for the plasmas described here which have substantially reduced volumes because of the presence of large magnetic islands. Also, there are some indications that marfe-like structures, which could drive the collapse, may develop just prior to the time the stored energy peaks. Fig. 5 shows the chordal signals from C IV and their Abel inversions as a function of vertical position for several times. Up to

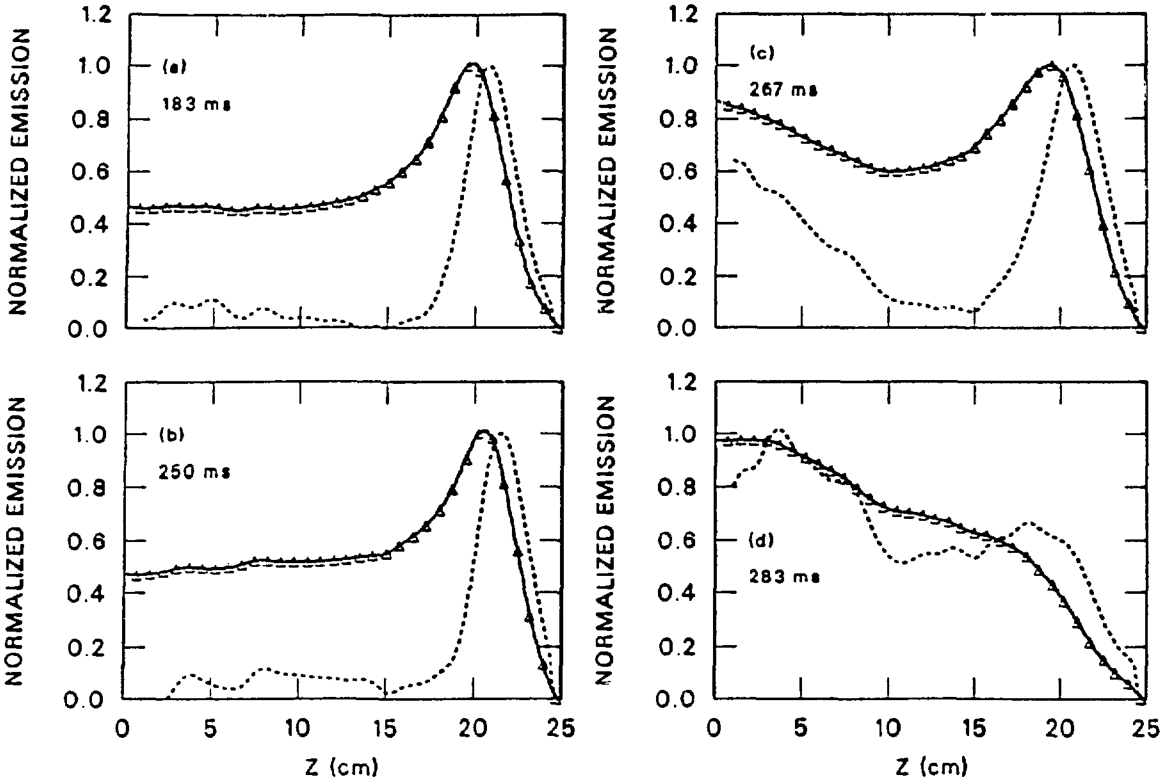

Fig. 5. Chordal signals (solid lines) and Abel inversions (dashed lines) for the 2271 Å line of C V. Neutral beam injection lasts from 200-300 ms.

50 ms after injection the signal is peaked in the periphery as expected. At 267 ms, 10 ms before the start of the collapse, a second peak ostensibly appears in the center of the plasma. No tenable physical explanation for such a central peak has been found, however. It is believed that a strongly radiating, poloidally localized source located in the midplane may be giving a false impression of the radial distribution.

Summary

Vessel cleaning techniques have reduced the low-Z content to about $0.02n_e$ and allowed quasi-steady operation of ECH plasmas. Impurities still present a problem in NBI plasmas which eventually collapse to a low temperature where 100% of the input power is radiated. It is still uncertain whether the impurity radiation can initiate the collapse. Reduction of island widths by correcting field errors should provide more insight into this problem.

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