CoNF - 820345 - - 2

CONF-820345--2

DE82 009635

IMPURITY BEHAVIOR IN THE ISX-B TOKAMAK

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Any discussion of impurity behavior during neutral-beam injection in ISX-B is best formulated in terms of the distinctive differences observed between ohmically heated, co-injection, and counter-injection discharges.[1-3] In ohmically heated discharges both the production and the transport of impurities depend upon whether the working gas is hydrogen or deuterium. The influx of oxygen is almost the same for both cases, but the influx of metals is about a factor of 3 larger in the deuterium discharges. These results are consistent with the picture that oxygen gets into the plasma mainly through some process of chemical detachment, but that the metals are produced by neutral-particle sputtering at the walls. This conclusion pertains to discharges that are kept centered in the vacuum chamber so that the plasma limiter interactions are minimized. Under this condition the ion temperature near the edge of the current column is apparently low enough that charged particle sputtering of the limiter is a relatively small effect.

The most striking difference between operation in hydrogen and deuterium is the significant differences of impurity confinement. In hydrogen the impurities reach a quasi-steady concentration in the constant current part of the discharge, but in deuterium they continually accumulate, preferentially in the interior of the plasma, throughout the shot. This behavior is illustrated in Fig. 1. The Fe IX signal is calculated to originate at a radius of about 23 cm (a_ℓ = 27 cm) and is somewhat representative of the influx of iron. The Fe XVI and Fe XVIII lines come from the interior of the plasma and reveal a constant concentration of these ions in hydrogen but a steadily rising concentration in deuterium. Our present view of these results is that the impurity transport is controlled by a competition between neoclassical effects that cause peaking of the density in the center and anomalous effects that tend to counteract the formation of strong gradients. Because the mass difference between hydrogen and deuterium should not have an appreciable effect on the neoclassical phenomena, it appears that the anomalous transport rates must be strongly dependent on the mass of the working gas. In hydrogen, the anomalous processes are dominant, whereas in deuterium, the neoclassical processes control the transport of impurities. This dependence upon the mass of the plasma ions has been documented in the Alcator-A tokamak, although a transition to neoclassical dominance has not been observed.[4]

Neutral-beam injection alters both the production rate of impurities and their confinement in the plasma. Usually the metal concentration increases, as might be expected since the sputtering yields are increasing functions of temperature and the auxiliary plasma heating

*Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

produces more energetic neutral atoms and ions. It is not clear that the oxygen content rises even though the radiation may increase. In the one case that could be analyzed well, because the fully ionized oxygen was measured, we concluded that there was little additional influx during co-injection and that the increase of radiation was primarily the result of increased transport rates.[5] These discharges had significant MHD activity, and it is known from the work in ohmically heated plasmas that MHD activity can stop the tendency of impurities to accumulate.

In general, the confinement of impurities is strongly dependent upon the relative direction of beam current and plasma current. Figures 3 and 4 illustrate the behavior of radiation from O VIII and from several iron lines during co- and counter-injection in deuterium. The contrast of the spectral line evolution for the two cases is immediately apparent. Shortly following the onset of co-injection all the line intensities exhibit relatively low, quasi-steady-state levels; they do not continue to rise as in OH discharges. But in the counter-injection discharges the radiation levels grow rapidly. This growth is observed first in the inside ions that radiate from the interior. Then, as the plasma cools, the lower stages produced by recombination become strong radiators. This enhanced power loss during counter-injection is not caused primarily by a rapid influx of impurities from the edge; the low ionization stages do not begin to radiate appreciably until they are formed by recombination. Rather, there is an internal rearrangement that concentrates both the iron and the oxygen in the center of the plasma.

The differences between the impurity transport in the three different types of discharges that have been discussed may well be manifestations of recent neoclassical theories[6,7] that indicate that co-injection can inhibit inward transport but that counter-injection may enhance it. The possibility that strong anomalous processes, which would stop accumulation, are stimulated by co-injection cannot be dismissed, however. In general the energy confinement time in ISX-B co-injection discharges is only about 1/4-1/2 the confinement time in ohmically heated discharges, and perhaps the impurity behavior represents only one aspect of the general loss of confinement with auxiliary neutral-beam heating.

The influence of the beams in hydrogen plasmas is much the same as in deuterium plasmas. Accumulation is enhanced by counter-injection but not so strongly as in deuterium, a result that might be expected because the underlying transport anomalies are more effective in the lighter gas.

The power losses from impurity radiation do not constitute a serious problem for the co-injection cases. They are typically in the range from 12-20% of the total input[8] and are localized toward the periphery of the plasma where the O V and O VI lines are intense. This result is obviously quite gratifying, but, as noted, it may reflect the fact that the overall confinement properties of the plasma are degraded during the co-injection discharges. Radiation losses during counter-injection are intolerable for obtaining satisfactory heating and quasi-stationary operation. The plasma temperature drops steadily from the power losses because of the long impurity confinement times and the rapid accumulation in the interior of the discharges.

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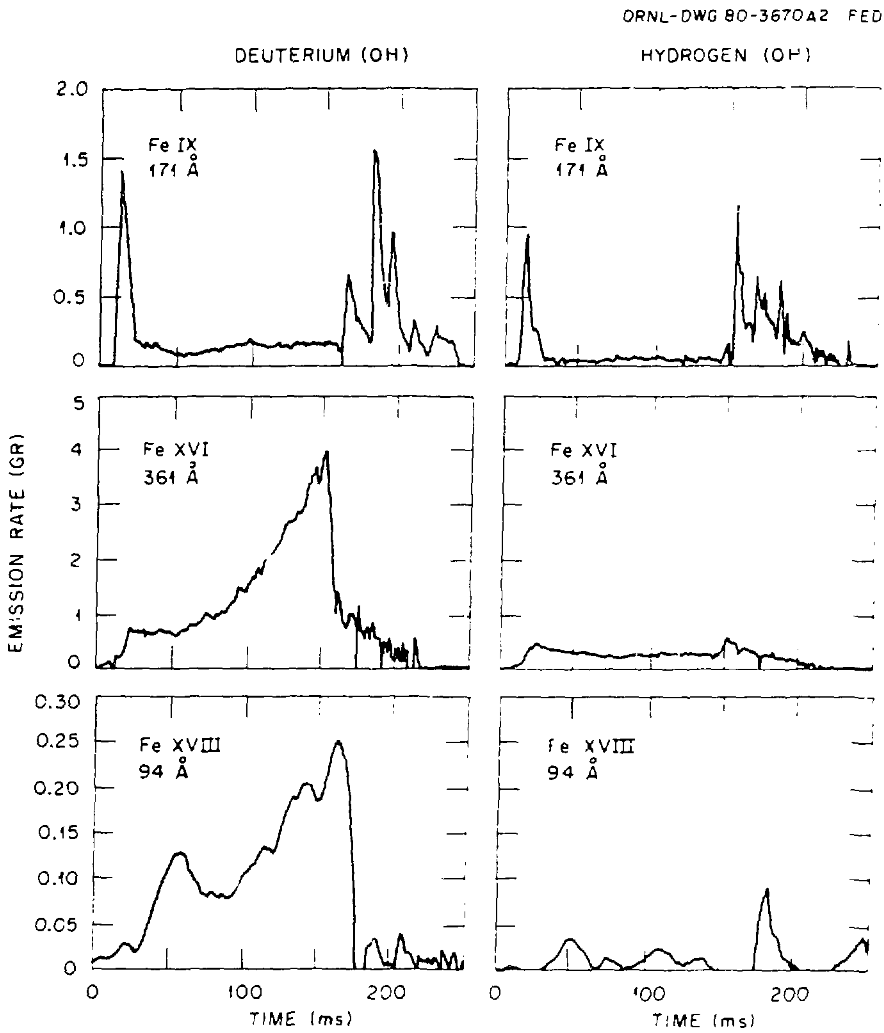

Fig. 1. Comparisons of emission rates from several iron lines during ohmically heated hydrogen and deuterium discharges.

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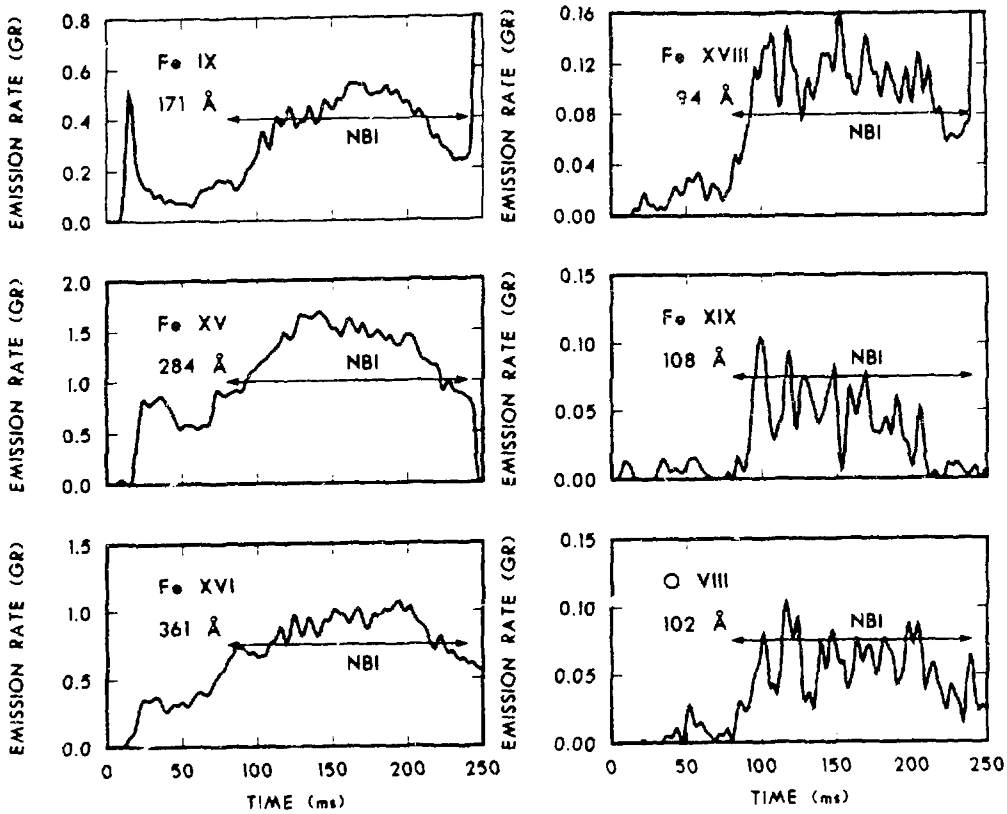

Fig. 2. Iron and oxygen emissions during co-injection.

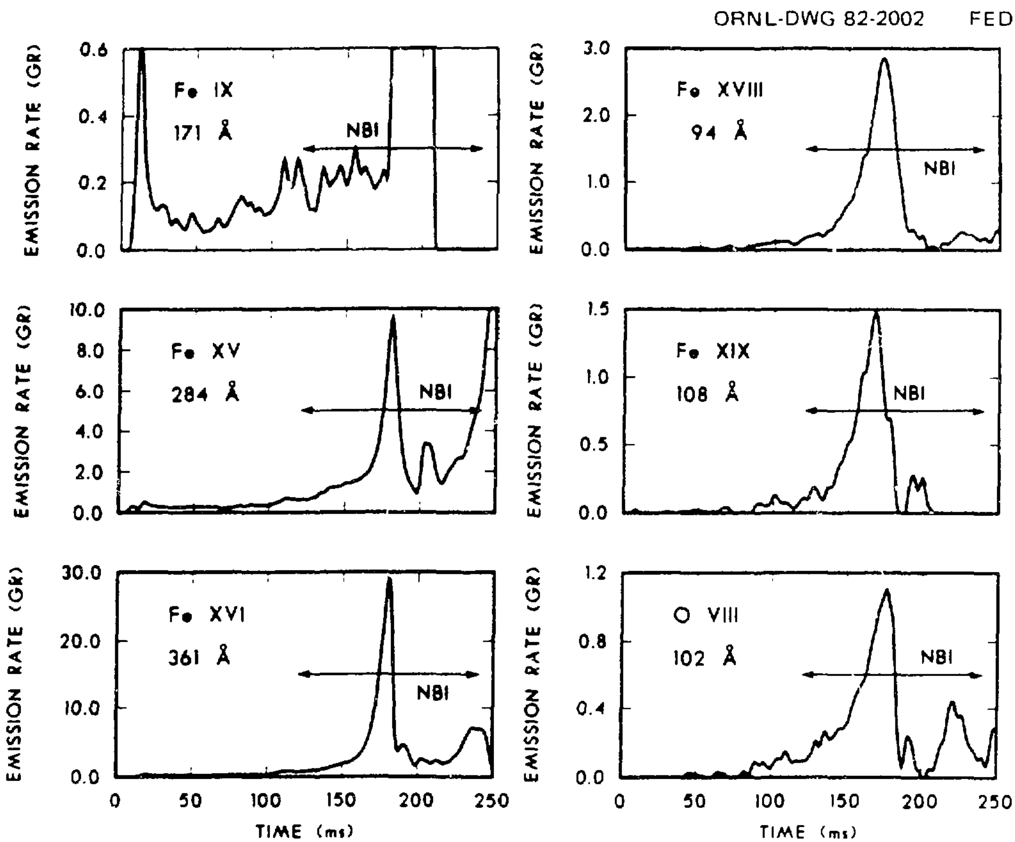

Fig. 3. Iron and oxygen emissions during counter-injection.