EIGHTEENTH FUSION ENERGY CONFERENCE

SESSION EX5

Saturday, 7 October 2000, at 11:10 a.m.

Chair: V.E. GOLANT (Russia)

SESSION EX5: Radiative Improved Mode, Divertor (provided by M. KIKUCHI, Japan)

Paper IAEA-CN77/EX5/1 (presented by M. Murakami)

DISCUSSION

B. COPPI: I wonder if you have considered the effects of the excitation of impurity driven modes in arriving at your interpretation.

M. MURAKAMI: The adiabatic response of impurity ions is included in both the gyrokinetic stability (GKS) analysis and the GLF23 modeling. The impurity branch of ITG mode is also included in both analyses. Regarding the latter, since the injected neon fraction (n_z/n_e=2%) is much smaller than the threshold fraction ($Z\cdot n_z/n_e$<50%) at which the impurity ITG becomes dominant, the effect of impurity ITG is very small. This was verified by turning off the mode in the GLF23 modeling.

A. ROGISTER: One of your main conclusion is that χ_i is neoclassical in the RI mode. These discharges are at high density. Did you estimate whether collisional dumping of the ITG instability could stabilize the mode?

M. MURAKAMI: The ITG growth rate is calculated in the GKS code with an appropriate collision frequency, so that I believe the collisional dumping of the ITG is included. However, I do not have specific information for that.

K. IDA: How important is the toroidal rotation shear in the improvement of confinement with N_e injection? In another word, do you observe the improvement of confinement in the discharge with balanced injection, ICRF, or Ohmic heating where there is no toroidal momentum input? What is the mechanism to drive toroidal rotation shear in neon injection experiments?

M. MURAKAMI: Most of the impurity injection experiments were carried out with co-injection (only a small number of shots with counter-injection). Toroidal rotation is the major (>80%) contributor for the total E x B shearing rate which is the essential part of the confinement improvement mechanism, as demonstrated in the GFL23 modeling. We have not done either balanced NBI or ICRF or Ohmic. As to the mechanism for driving rotation shear: the usual E x B shear feedback loop (increased E x B shear => reduced turbulence => reduced transport => increased rotation/pressure and/or their gradients => increased E x B shear) is amplified by two impurity driven effects, reduced growth rate and increased toroidal rotation gradient, as described in the talk.

Ph. GHENDRIH: The scenario that is used in this confinement improvement with N_e injection is typical of ITB's. What is the impact of magnetic shear in these results, both low shear in the core and increased shear at the edge?

M. MURAKAMI: By changing the impurity injection timing, we have changed the magnetic shear in the core from weak negative shear to weak positive shear. The neon injection effects did not change substantially. As for the edge shear (or global shear), we have carried out a q_{95} scan with neon injection. Lower q_{95} tended to have larger fluctuation suppression and confinement improvement, but these data need further analysis.

Paper IAEA-CN77/EX5/2 (presented by B. Unterberg)

DISCUSSION

J. SNIPES: In the high confinement cases with n/n_G ~ 1.4, what is the core Z_{eff} and the H factor relative to ITER89P?

B. UNTERBERG: Under best conditions at $n/n_{GW} = 1.4$ we obtain $H_{89} = 1.8$ with respect to the L-mode scaling, while Z_{eff} is = 2.

A. GROSMAN: You mentioned the importance of a careful control of the gas injection level. How does it compare with the recycling flux for the experiments you showed?

B. UNTERBERG: The recycling flux is strongly dominating the total flux to the plasma, the external fuelling rate is smaller than the recycling flux by a factor of about 50 corresponding to a high recycling coefficient. However, in case of a strong external fuelling rate, we observe an intermediate increase of the recycling flux together with the build-up of edge plasma density and neutral pressure, all together preceding the global confinement rollover.

R.J. TAYLOR: Can you diagnostically tell the improvements in fluctuation as electrostatic or magnetic or electromagnetic?

B. UNTERBERG: We don’t have diagnostics on core fluctuations available in TEXTOR-94 for the discharge conditions I described in my presentation. I can only refer to measurements made at DIII-D, where the reduction of fluctuations given with impurity injection, tends to be in agreement with a reduction of the electrostatic turbulence modeled with the gyrofluid code GFL23 as described by Dr. Murakami in his talk.

B. LIPSCHUZ: You mention that wall conditioning (and low mid-plane pressure) are important to achieve good confinement above $n/n_{GW} = 1$. Can you comment on what would happen in a steady-state machine where the walls are saturated? Will this technique work the same then?

B. UNTERBERG: Also in our discharges at $n/n_{GW}>1$ the walls are saturating during the plasma pulse, but we don’t observe a subsequent degradation in time or an increase of mid-plane neutral pressure if the external fuelling is moderate. We do observe degraded performance after discharges, which ended with disruptions, probably due to a release of particles from the wall yielding high neutral pressure at the edge from the beginning of the plasma pulse on.

Paper IAEA-CN77/EX5/3 (presented by H. Kubo)

DISCUSSION

V. PARAIL: How fast central ion temperature changes with Ar puffing? Does if follow the edge temperature change or does it change faster (in accordance with the idea of strong profile resilience)?

H. KUBO: It is difficult to recognize exactly whether the core improvement follows the edge improvement or the edge improvement follows the core improvement, since the improvement does not have a clear transition and appears with electron density increase.

B. COPPI: Referring to a fusion burning plasma like that proposed for ITER-FEAT, did you evaluate the conditions that would be obtained when the technique of injecting impurities is used to improve the energy confinement? As you pointed out, ITER-FEAT can be expected to have a problem with the energy confinement time, according to what is presently known, by choosing a density of operation that is too close to the density limit (i.e., $n/n_G=0.85$).

H. KUBO: Future experiments are necessary to evaluate quantitatively the condition in ITER.

T. ROGNLIEN: What is the role of the MARFE during argon injection and where is it located? Is the MARFE stable, or does it grow in time?

H. KUBO: The MARFE is located at the vicinity of the null point, and it does not grow.

F. ROMANELLI: What is the maximum plasma current at which this regime is achieved?

H. KUBO: Up to now, most of the experiments have been performed at a plasma current of 1.2 MA. Discharges with higher plasma current should be explored in future.

Paper IAEA-CN77/EX5/4 (presented by G.P. Maddison)

DISCUSSION

B. COPPI: Do you imply that your interpretation of the improvement in confinement and the change in the nature of turbulence, based on the characteristic of the modes you have detected, is at odds with that of Murakami? Also your final statement gives an optimistic outlook on using your technique to increase the energy confinement time in fusion burning plasmas. Can you give further comments on this?

G.P. MADDISON: (a) The comparison raised refers more to the transient confinement gains observed with neon injection into JET divertor L-modes. Analysis of data from these recent experiments is still on-going, and a proper comparison with the theoretical model of Dr. Murakami has yet to be made. However, a very preliminary statement which can be offered from first charge-exchange recombination spectroscopy inferences of toroidal rotation is that no sudden or steep spatial changes in this velocity component seem to be evident in the JET neon-seeded cases. Of course toroidal rotation increases as unbalanced neutral beam heating is applied, but no sharp features seem to accompany the neon input. (Magnetic fluctuation measurements presented pertained to different ELMy H-mode cases not closely resembling the DIII-D situation.)
(b) Regarding the optimism (deliberately) expressed with respect to application of impurity seeding beneficially to next-step plasmas - this is inspired by the apparent improvement in integrated plasma performance, rather than that simply in confinement time alone. In these terms, TEXTOR-94 RI-modes are most encouraging, and the early JET results shown in this presentation underline their possible scalability. It is integrated performance which matters most for next-step conditions. (Additional support for positive seeding effects have been shown in other presentations at this conference, e.g. those from JT-60U and DIII-D.)

O. GRUBER: What is the difference of your impurity seeded RI-mode discharges to the CDH mode of ASDEX Upgrade, published 5 years ago? ($H_{89P}=2$, $n=n_{GW}$, $P_{rad,main}/P_h \sim 0.5$, $Z_{eff} \sim 3$)

G.P. MADDISON: This is clearly an excellent question, and one to which we wish to give attention - time has not been sufficient yet. However, it should be noted that our best seeded "afterpuff" cases in JET tend to have low ELM frequencies (rather than high as in ASDEX-U CDH-modes. The JET cases are also obtained in "septum" and not diverted configuration, plus they have low central Z_{eff} ~2-3. It should be recalled that direct attempts to reproduce CDH states by impurity seeding of JET divertor plasmas were not successful, and tended to lead to degraded confinement with high central

Z_{eff}.) As noted, though, this is a comparison which we do need to examine.

R.J. GOLDSTON: In DIII-D, Mahdavi presented densities above Greenwald, but only possible in a narrow power range a bit above the L-H threshold, about 3 MW. Have you varied the beam power to look for this effect?

G.P. MADDISON: All of the ELMy H-mode data in JET presented were at 12-13 MW of neutral beam heating power, and were therefore well above the H-mode threshold (in fact above the Type I ELM threshold, too). This is accentuated by the experimentally known effect that the threshold power is lower for the "septum" configuration mainly used. The chief point to be stressed in the results shown is that good confinement was obtained simultaneously with high Greenwald fraction (but still $f_{Gwd}<1$), at a current of 2.5 MA, and with high heating power. Input power was varied in the lower Greenwald fraction divertor L-mode cases described - and there best confinement gains were found at highest heating level applied. (Some H-mode plasmas were executed at different power levels in earlier campaigns, but their "afterpuff" stages of the discharges were not being scrutinized.)

R. WEYNANTS: This is just a comment on the question made by B. Coppi several times during this session: Is this impurity seeding compatible with a burning plasma? My answer is -: In ITER, in order to "protect" the divertor, impurity injection to raise the main chamber radiation is foreseen, aiming at achieving P_{rad}/P_{tot} of typically 0.7. When doing this with krypton e.g. the Z_{eff} rise needed is shown by ITER to be completely compatible with a burning plasma.

Paper IAEA-CN77/EX5/5 (presented by A. Sakasai)

DISCUSSION

R. SCHNEIDER: Do you have any additional evidence for the interpretation of the puff and pump effect? It is very difficult to compete with the internal recycling fluxes, therefore the observed reduction of the carbon impurity might be just an effect of the improved recycling properties of the W-shaped divertor.

A. SAKASAI: Yes, we have measured the plasma flow (SOL flow) with a reciprocating probe at the outer divertor in OH, L- and H-mode plasmas with low power NB heating of 4 MW. However, the measurement in the ELMy H-mode plasmas with high power NB heating of 16 MW is difficult. So, we have not yet observed how much the plasma flow increases. We think the puff and pump effect includes the plasma flow and the improved recycling effects.

F. ENGELMANN: What can you say about the transport properties of He across (within) the internal transport barrier (ITB) and what were the values of τ_{He} in your experiment?

A. SAKASAI: The He flux Γ_{He} across the ITB is sufficient to reduce the density inside the ITB in reversed shear plasmas with $H^{ITER\text{-}89P} \sim 2$ if the pumping rate is improved. The value for the He-NB source is about 0.3 s.