SEVENTEENTH IAEA FUSION ENERGY CONFERENCE

SESSION OV1

Monday, 19 October 1998, at 10.45 a.m.

Chairman: D.C. ROBINSON (United Kingdom)

OVERVIEWS 1

Paper IAEA-CN-69/OV1/1 (presented by S. Ishida)

DISCUSSION

J.G. JACQUINOT: What is the definition of P_{NB}^{abs} used in the calculation of Q_{DT}^{eq} and how does it relate to the beam power going through the port? What is the multiplier used to convert Q_{DD} to Q_{DT}?

S. ISHIDA: P_{NB}^{abs} is defined as injection power minus shine-through. Since the shine-through rate is very low, the P_{NB}^{abs} is actually the same as the beam power going through the port. The ratio of the equivalent DT power to the actual DD power is ~ 200.

D.M. MEADE: The standard definition of fusion gain, Q, is the ratio of the fusion energy produced in a given time interval to the injected plasma heating energy during the same period. In 1957, J.D. Lawson showed that the injected energy must include the energy needed to raise the plasma to operating temperatures. This was the definition used by JET, JT-60 and TFTR in the mid-1970s design proposals. What is the highest equivalent Q_{DT} ($200\,Q_{DD}$) in JT-60U?

The Lawson diagram shown in Figure 2 is incorrect. The JT-60U points achieve Q_{DT} (equiv.) $\simeq$ 0.7 and do not reach break-even. The $n\tau$ values for the shaded break-even curve should be increased, raising the $n\tau$ required for break-even by about 70% for this JT-60U case.

S. ISHIDA: If Q is simply defined as $P_{DT}^{eq} / P_{NB}^{abs}$ even for the transient state, the Q value is calculated to be ~ 0.73, where no α-power or ripple loss power are extracted from the beam absorption power.

Figure 2 is used to show the potential of high-performance deuterium discharges. For instance, a step-down of injection beam power could make the present Q_{DT}^{eq} value possible in a quasi steady state (dW/dt = 0), but we have not yet done this.

B. COPPI: You refer to your experimental results as being in "reactor regimes". However, igniting plasmas have characteristics such as Z_{eff}, the ratio of the electron collision frequency to the diamagnetic frequency, and the central pressure, which are different from those produced in your experiments. Do you plan to improve some of these parameters in your experiments with a view to simulating ignition regimes?

S. ISHIDA: You are right. We intend to better approximate reactor regime plasma conditions by means of divertor modifications, and through the use of the N-NBI system and the planned ECH system.

R.J. GOLDSTON: Do you plan to combine high-power NBI (> 20 MW) with LHCD to sustain high-performance reversed shear plasmas?

S. ISHIDA: Yes. High-performance reversed shear discharges combined with LHCD could be sustained mainly by using four tangential positive beams (~ 10 MW) at off-axis and N-NBI (≤ 10 MW), whereby ripple losses would be reduced.

R.J. GOLDSTON: What is τ^*_{He}/τ_E in your more advanced regimes with H > 2?

S. ISHIDA: For reversed shear discharges where H ~ 2, τ^*_{He}/τ_E is about 10. These results are discussed by A. Sakasai et al. in another paper (IAEA-CN-69/EX6/5).

Paper IAEA-CN-69/OV1/2 (presented by M.L. Watkins)

DISCUSSION

I.H. HUTCHINSON: Congratulations to the JET Team on the outstanding results in D-T. Your claim to have clearly observed alpha particle heating does not seem to be justified by the supporting data, however. It seems that the variation of the stored energy with tritium fraction is fractionally no larger than the possible variation of energy confinement time (at least within error bars). It cannot therefore be unequivocally attributed to alpha heating, even though such heating is probably present.

M.L. WATKINS: Thank you for your kind remark. The alpha particle heating, which is strongly peaked on axis, goes almost entirely into increasing the stored energy, as the timescale is too short to lead to increased losses. Furthermore, the pure deuterium and almost pure tritium ends of the alpha particle heating scan show that the confinement is independent of isotope mass. The increases in stored energy and central electron temperature are therefore proportional to the alpha particle heating power, being maximized when the alpha particle heating is a maximum, that is, with 60% tritium in deuterium.

D.M. MEADE: The highest Q_{DT} achieved transiently in JET is ≈ 0.6 using the standard definition of Q. As first shown by J.D. Lawson in 1957, the energy required to increase the plasma energy (dW/dt) should be included in the energy input. It is misleading to state that Q_{tot} ≈ 0.9 was achieved. Only Q_{DT} = 0.6 was achieved. The JET Team argues that Q ≈ 0.9 might be achieved if plasma conditions could be extended to steady state. However, in nine years the parameters have not been extended to ~ $5\vartheta_E$, and the highest Q_{DT} achieved for 5 τ_E is ≈ 0.2.

M.L. WATKINS: The full power balance for the record fusion power pulse has been published, so you can construct whatever ratio of fusion power to input power you wish. The JET Team has quoted Q_{in} = 0.62 (ratio of fusion power to input power) and $Q_{tot} = 0.94 \pm 0.17$ (calculated to take account of the non-stationary nature of these hot ion ELM-free H-modes in which plasma parameters increase until the terminating MHD). If the same plasma parameters as those obtained in these transient discharges could be maintained into steady state, Q_{in} would be equal to Q_{tot}, and this is confirmed by power step-down experiments, albeit at lower performance.

Paper IAEA-CN-69/OV1/3 (presented by T.S. Taylor)

DISCUSSION

R.J. GOLDSTON: Your plot for the theory of off-axis ECCD in Fig. 6(b) shows exactly zero efficiency at r/a = 0.5, and is presumably negative at larger r. How does this extrapolate to future DIII-D experiments and reactors where one would like to drive current at r/a = 0.7 and beyond?

T.S. TAYLOR: The collisionality in present experiments on DIII-D is comparable to that expected in ELMing H-mode fusion power producing plasmas (e.g. ITER), but the β is significantly lower. The consequence of the relatively low β is that the EC waves interact with electrons near the trapped particle boundary and can diffuse rapidly from the co-current side to the counter current side of the velocity distribution. This is the Ohkawa effect and can result in net negative current. At higher β, the wave particle interaction occurs much farther from the trapped particle boundary as a consequence of relativistic effects on the electron cyclotron resonance and, from the same linear theory, significant co-current drive is predicted.

B. COPPI: To verify whether the toroidal ITG mode (called ion ubiquitous mode when we found it) is excited, the threshold conditions and the most probable wavelength ($\sim 1/3\ \Delta_i$) can be evaluated from fluctuation measurements. What are your observations?

T.S. TAYLOR: The fluctuation measurements shown (Fig. 8), which clearly indicate a reduction in turbulence strongly correlated both spatially and temporally with the reduction in transport, are from the beam emission spectroscopy (BES) at r/a $\simeq$ 0.7. The peak in the turbulent spectrum is at $k_\perp \sim 1.7\ cm^{-1}$, or $k_\perp\ \Delta_i \sim 0.4$ or $k_\perp\ \Delta_{i1} \sim 3$, where Δ_i is the toroidal gyroradius, and Δ_{i1} is the poloidal gyroradius. Assuming you mean the poloidal gyroradius, the measured turbulence spectra are not inconsistent with your prediction, but generally at a somewhat longer wavelength.

R.J. BUTTERY: Is the basis of future work on DIII-D still likely to be reactor relevant physics?

T.S. TAYLOR: Yes, our future plans are very reactor relevant, since they are focused on optimizing steady-state tokamak performance. This physics research plan includes: optimization of the current profile for advanced tokamak scenarios using reactor-relevant electron cyclotron current drive for both axial and localized off-axis current drive; active feedback stabilization of the resistive wall mode to increase the beta limit of high-performance discharges using n = 1 feedback coils located outside the toroidal field coils; and improved impurity and particle control in high-triangularity advanced tokamak plasmas, with the addition of an ITER-relevant private flux baffle and a private flux cryopump.

M.C. ZARNSTORFF: In your long pulse experiments, how much current is driven externally and how much is from the bootstrap current? To what extent are the monotonic q-profiles you showed for these experiments compatible with high bootstrap fraction steady-state operation?

T.S. TAYLOR: For the cases shown with normalized beta just below 4, the confinement enhancement with respect to ITER 1998 thermal ELMing H-mode scaling, H_{98y}, just below 2, and $q_{95} \sim 4$, the bootstrap fraction is approximately 50% and the total non-inductive current drive is approximately 70%. A further increase in beta to $\beta_N \sim 5.5$, which might be possible with wall stabilization, would increase the bootstrap current to ~ 70%. The alignment and the magnitude of the bootstrap are improved if q_0 is increased to give a reverse shear profile. The edge bootstrap current driven by the H-mode pedestal is well aligned with the total edge current, but stability would be improved if this edge current were reduced.

Paper IAEA/CN-69/OV1/4 (presented by A. Iiyoshi)

DISCUSSION

R.J. GOLDSTON: I would like to congratulate you and your team on the spectacular technical achievement of bringing LHD on line, and also the fine initial physics results reported here.

A. IIYOSHI: Thank you.

J.D. CALLEN: What types of heating have you used in your experiments to date?

A. IIYOSHI: We have used ECH and NBI, and plan to add ICRF soon.

F. WAGNER: I should also like to congratulate you on the successful start of LHD and wish you success with it in the future. Do you have any information yet on the development of the density profile with ECRH and, more specifically, does the profile become hollow?

A. IIYOSHI: Thank you for your kind words. We appreciate all the support and collaboration we have received from the international helical community. The profile, as you have surmised, is hollow. We have concentrated on generating target plasmas for NBI by ECRH. It should be noted that the behaviours in the ECRH phase are transient.