Transport and Confinement ITPA Task Group Annual Report: 2009-2010
S.M. Kaye, PPPL

The Transport and Confinement Topical Group held two meetings this past year. The first was held on Oct. 5-7 in Princeton, NJ, USA following the IAEA TCM on H-mode and Transport Barrier physics. This meeting was joint with the Pedestal group, and the joint session included reviews and discussions on several L-H threshold physics topics, including species dependence, access to good confinement retimes, hysteresis, dependence of threshold on rotation, hidden variables and theory. Other topics discussed during this meeting were databases, specifically the momentum database, electron transport, transport model validation, and the status and plans for each JEX.

The second meeting was held at Culham Laboratory from March 31 to April 2, and the topics covered at this meeting included rotation and momentum transport, impurity transport, ITB physics, transport model validation, and hysteresis and access to H~1 regimes, including the I-mode. The next meeting is planned for immediately after the IAEA meeting on Oct. 18-20 in Seoul. The meeting will have joint sessions with Pedestal, IOS and DIVSOL.

The status of the Joint Experiments and Joint Activities are given in the table below. Note that during the year, three of the Joint Experiments were closed out. Several are being considered for 2010-2011.

JEX/JAC	Title	Comments
TC-1	Confinement scaling in ELMy discharges: β scaling	MAST expts before 3/10 Possible close-out in 2010
TC-2	Hysteresis and access to H-mode with H~1	AUG, JET, MAST, NSTX, TCV Analysis underway; reassess goals/approach in Fall 2010
TC-3	Scaling of low density limit to the H-mode threshold in H & D plasmas	AUG, DIII-D, JET, TCV Analysis of existing data
TC-4	Species dependence of L-H threshold	AUG, DIII-D, JET, NSTX Active area, more expts in '10 Close out after 2010?
TC-5	Determine transport dependence on T_e/T_i in hybrids and steady-state	DIII-D, JET Close out, incorporate in TC-7
TC-6	Effect of rotation on plasma performance	Close out
TC-7	ITG/TEM transport dependence on T_i/T_e, q and rotation in L-modes	Close-out; consider reopening for H~1 scenario development
TC-8	QH/QDB plasmas	Close-out; consider reopening for H~1 scenario development

TC-9	Scaling of intrinsic rotation with no external momentum input	C-Mod/TCV similarity expt.
TC-10	Expt'l identification of ITG, TEM, and ETG turbulence and comparison to codes	Ongoing Joint Activity Couple to TC-11, study ETG for electron transport
TC-11	He profiles and transport coefficients	Joint Activity; call for data
TC-12	H-mode transport at low aspect ratio	NSTX (low n*), MAST(q-scan)
TC-13	ITG critical gradient and profile stiffness	C-Mod (active), JET
TC-14	RF rotation drive with ICRH, LH and ECH	C-Mod, JET, DIII-D, AUG, JT-60U, EAST (?); LHCD/ECH
TC-15	Dependence of momentum and particle pinch on n^*	NSTX, DIII-D, JET, (AUG) Reassess in 2010
TC-16	Physics model validation during current ramp-up phase	Ongoing Joint Activity
Being considered	Determination of "residual stress"	DIII-D, NSTX, JET, JT-60U
Being considered	Effect of non-axisymmetric fields on L-H threshold (EF vs rotation dependence?)	DIII-D, JET, MAST, NSTX
Being considered	Electron transport induced by microtearing, fast-ion driven modes	NSTX, MAST, AUG
Being considered	Pellet fueling, pellet-induced particle transport	Cross-cutting working group topic

In addition to the above experiments and activities, database work is still ongoing, although to a lesser extent than in previous years. The status of the databases is given below:

1. Momentum database (M. Yoshida)
   Being developed with global and local parameters to enable gyrokinetic calculations to study source of momentum diffusivities and pinches.
   The first results were discussed at the Fall 2009 and Spring 2010 meetings.
      More data is needed to complete database, including a standardized computation of momentum diffusivity and pinch (discussed at the Spring 2010 meeting). M. Yoshida is working with K. Thomsen to turn into "standard" form for release to group (DB still private)
2. L-H threshold (J. Hughes)
   To be updated with profile information for model testing

and reducing uncertainties in P_{LH}. The plan is to discuss details (data, validation) at the Fall 2010 meeting

3. Profile database (C. Roach)

   Expanded to include data from Impurity/Helium transport experiments, although there have been no contributions yet. Still under discussion is whether to use the profile database as a resource to store ITER DEMO discharges for model validation work.

4. L- and H-mode databases

   Presently inactive but still being maintained.

   The databases still being maintained by K. Thomsen

Below are summaries of the work by the group in selected high priority topics.

L-H Transition Physics

On the topic of the species dependence, clear differences in L-H threshold between D and He plasmas have been seen in some devices (NSTX, JET, DIII-D, MAST, C-Mod), with the power threshold for He plasmas being up to 80% greater than that for D, while in AUG, the power thresholds for the two species are similar. Recent JET data showed no or very weak dependence of L-H power threshold as He concentration varies from 1 to 87 %. This is at odds with previous JET study in 2001, but does agree with AUG results in 2008. It is noted that different density ranges were explored at the same field in the two experimental campaigns at JET, 2001 and 2009. Given the difference in density range, the results are consistent with having the $n_{ciritical}$ for minimum threshold power be lower for D than for He. Results from both 2001 and 2009 discharges in JET show a reduction of confinement in He in the 60-70% range as compared with corresponding D plasmas. The power threshold for H is much higher than that for D (DIII-D). Results also suggest that the confinement in both H and He H-mode plasmas is less than that in D for the same discharge parameters.

Good confinement (H~1) access can be achieved, but for most devices powers have to be at least 30% above the power threshold. For powers less than this, Type III ELMs are typically obtained, and these result in a 10 to 20% lower confinement (H~0.8 to 0.9). At slightly higher powers, the Type III ELMs disappear and H~1 levels are restored, but the discharges are non-stationary. Stationary discharges are obtained, but only in the Type I ELM regime. It was recognized that this is a topic on which there has been relatively little dedicated work, and many more dedicated studies should be initiated, including considering the effect of gas puffing, differences at different densities or collisionalities at the transition to the H-mode and at the transition from Type III to I ELMs, and possibly most importantly developing scenarios, such as the QH mode, in which H~1 confinement is achieved without having to deal with the issue of Type I ELMs. It is dangerous to develop ways to access the Type I ELM regime when Type I ELMs cannot be tolerated. This work will be conducted within the framework of TC-2 through both dedicated experiments and analysis of data already obtained. It was felt by all that the priority of this ITPA work should be elevated to the highest level. The I-mode, observed on C-Mod, AUG and DIII-D was also discussed as a possible operation scenario for ITER. The I-mode has H-mode like energy confinement (0.8-1xH), but L-mode like particle confinement, and, therefore, no ELMs. The I-mode can be obtained only at high power in, so far, a counter-injection plasma; these powers are higher than those required for transition into the H-mode with co-injection, making the I-mode presently not relevant for reactor scenarios. It was felt, that there is much physics to be learned from the I-mode, specifically in its subsequent transition to the H-mode and possibly as the first step in the L-H transition process.

Hysteresis (L-H vs H-L conditions) is observed both in global and local edge parameters, but not in a universal fashion. C-Mod undertook a systematic study of the hysteresis in edge parameters for L-H and H-L years ago, showing how grad T changed in a systematic fashion across the bifurcation, which may allow understanding of the bifurcation in terms of limits on this parameter. JET experiments showed no change in $T_{e,knee}$ at the bifurcations. NSTX did examine hysteresis properties in RF-only heated discharges, and while there was some evidence of power hysteresis, large uncertainties in absorbed power prevented more definitive statements. It was recognized here too that more and more systematic studies are needed, although these would be lower priority than those experiments exploring access to good confinement regimes.

The effect of different rotation and torque on the L-H threshold is clearly observed in DIII-D, with lower thresholds at lower toroidal rotation velocities, as torque goes to zero and even becomes negative. This has nicely been tied into the effect that this rotation and rotation shear has on the edge radial electric field shear (increasing E_r shear as the rotation tends towards zero and lower), and has further been tied into the increase in Zonal Flows and reduction of GAM amplitudes as the L-H transition is temporally approached. On the other hand, when rotation is changed by changing the heating method (RF vs NBI), or by applying 3D edge magnetic perturbation fields or changing ripple amplitude, any effect on the threshold power is much less strong, and in some cases (JET, NSTX) is not even observed.

There is clear recognition that the set of global parameters used to describe the conditions necessary for an L-H transition is insufficient, that so-called “hidden parameters”, some of which are not so hidden, can play a major role. Among these are local edge parameter values and their gradients, E_r shear, grad B drift direction, wall conditioning (boronization, siliconization, lithiumization), divertor geometry (position of X-point, SN vs DN), plasma shape (triangularity, vertical position), recycling and fueling (including pellets), SOL flows and 3D effects (ripple, applied fields, stellarators vs tokamaks). Discussions were focused on the following questions:

1. Is the effect of wall and machine conditions due to impurities, recycling or both?
2. What is the source of the dependence on ion grad B drift direction and SN vs DN (E_r shear, recycling)?

3. Are low frequency fluctuations of the E_r shear important?
4. What is needed to understand the 3D physics effects?

Finally, there was discussion on the search for a theoretical model to explain the L-H transition. The presentation acknowledged that expecting a first-principles theory of the power threshold on a short time scale was unrealistic, and that descriptive scalings were still the best approach towards knowing just how close to the threshold the plasma conditions are, at least for the short-term. To this end, it is important to move away from the global parameters, and perhaps to move away from the threshold power itself, to a description that focuses on critical local parameters. As far as understanding the physics principles of the transition, any model has to explain both why the transition occurs at the plasma edge, and why the transition can be so fast (although it was pointed out that much information could be gained by understanding slow transitions, which are more accessible from the point of view of the often finite temporal resolution of diagnostics). It was suggested that understanding the turbulence during L-modes was one critical area. Another issue to bear in mind is that flow shear can be both stabilizing (perpendicular E_r shear) and destabilizing (parallel flow shear), and measuring or inferring the evolution of both is important. Understanding these may lead to an identification of the actual trigger mechanism for the transition.

Model validation during ramp-up/ramp-down phases

ITER scenarios developed with predictive transport simulation codes have established that the electron temperature in the outer half of the plasma column plays a critical role in current penetration (and the viability of a current ramp scenario), but simulations of ITER-similar current-ramp plasmas in C-Mod, DIII-D, JET with the most commonly used transport models are often incompatible with experimental measurements, particularly in the outer part of the plasma that is critically important for getting the correct internal inductance. This motivates our new transport model validation effort targeted at the outer half of plasmas with relatively high q_{95}, a part of parameter space that has previously been neglected. The joint activity planned at this meeting will involve ITER-similar experiments in C-Mod, DIII-D, JET (and possibly AUG) as well as transport simulation of these experiments by a number of transport codes. Experimental contacts and suitable data formats were established at the meeting, the details of shot selection, code benchmarking, and model testing will be worked out via e-mail with the goal of having test results in time for the next T&C ITPA meeting following the IAEA FEC this fall in Korea.

Predictions of several ITER-similar current-ramp plasmas in JET were carried out. The most important lesson learned is that complete documentation of the important physical parameters is required for a proper validation effort; missing measurements allow sufficient uncertainty in the predictions to frustrate the identification of good and poor transport models. The majority of the present results do favor the Bohm-gyroBohm model over the Coppi-Tang model, however. The numerically stable Coppi-

Tang model does not also have the virtue of reliably predicting the peripheral temperatures (although the central temperatures are frequently acceptable). Another important lesson is that superficially small differences in electron temperature profiles measured by different diagnostics can produce very significant differences in predictions of current penetration timescale (as determined by time of first sawtooth, for example). Solid documentation of all experiments will be needed for transport model validation.

Simulations of ITER-similar current ramps in DIII-D also demonstrate shortcomings of the Coppi-Tang model (again in the periphery), but simulations of current profile evolution based on measured T_e served to validate the neoclassical model for parallel conductivity (a validated conductivity model is also necessary for ITER predictions).

The EU ISM effort is led by a several people using three transport codes, which were said to have been benchmarked successfully against each other. This effort added data from Tore Supra and AUG to six JET shots (some of which are outside the set used above by Voitsekhovitch and Budny). Again the Coppi-Tang and GLF23 models did not fare well, while the Bohm-gyroBohm model was often acceptable. ITER projections of the internal inductance based on all these models were actually not far apart, but the specification of the edge temperature is outside the models, and uncertain, so these predictions are not definitive. One variation used in the study was based on the GLF23 model out to rho=0.8, and then having a constant electron thermal diffusivity between rho=0.8 and 1. This model gave closer estimates for the measured l_i, and this raises the question as to how sensitive this result is to the precise value of the edge diffusivity. Another question raised was why the Bohm-gyroBohm model used by one modeler led to often acceptable results, while the same model used by another, on a different discharge set, did not.

Simulations of a AUG current-ramp phase discharges that were *non*-ITER-similar were notable for their large radiated power and cold radiating mantle. The conditions are not relevant to ITER requirements, but the capability of the validation code is similar to the other work reported in this session. Once again, direct use of the measured T_e in a simulation of the current profile evolution validated the neoclassical model for parallel conductivity by giving a good fit to the evolution of the internal inductance. Using the usual suite of models for T_e predictions, however, did not lead to acceptable l_i agreement. Agreement could be improved by imposing a boundary condition farther in from the edge, but this eliminates any predictive capability.

Rotation and Momentum Transport Session

<u>Intrinsic Rotation</u>

Various aspects of intrinsic rotation (no external momentum input) were presented. Application of ECH in ASDEX-Upgrade plasmas leads to counter-current rotation. The shape of the velocity and density profiles depends on the deposition location, with peaking occurring only for on-axis heating with P_{ECH}>0.7 MW. Similar related observations have been previously seen in DIII-D and JT-60U. Intrinsic rotation in JET ICRF heated H-modes showed that the rotation was counter-current, and did not exhibit any scaling with plasma pressure. This result is a mystery. Studies on Tore-Supra used an approach which was to vary the edge ripple to control edge rotation in order to study the effect on v_{pinch} and intrinsic rotation. In the case of Tore-Supra, the ripple could be increased to 7%. By varying the plasma size to change the edge ripple, ion loss due to toroidal field ripple was found to induce counter-current rotation. The rotation was found to increase in this counter direction with both increasing P_{ICH} and P_{LH}, with no change in the edge rotation. Experiments on C-Mod were devoted to a TCV similarity experiment on rotation inversions which occur at a very precise density threshold. An L-mode rotation database is being populated for comparison with other devices, notably JET and TCV. Rotation in I-mode on C-Mod exhibits characteristics similar to H-mode. The core H-mode rotation was found to depend on the local pedestal pressure gradient, suggesting a role of the residual stress in driving the rotation. Direct measurements of vorticity fluctuations and intrinsic poloidal rotation were reported on CSDX, and the correlation with the residual stress. They were able to measure the total and diffusive stress, and subtract the two to find the residual stress that was related to collisional drift wave turbulence. Potential fluctuations in the edge velocity shear layer of TJ-II plasmas and a bifurcation of their propagation direction at the separatrix were found to depend on the density. A rotation sink in JET plasmas due to drag from neutrals was reported.

<u>Momentum Transport</u>

TC-15 is a Joint Experiment to study the effect of collisionality on momentum pinch and diffusivity. The Prandtl number is found to be independent of collisionality in JET plasmas, but that there is a correlation between collisionality and the momentum pinch that is opposite to the relation between particle pinch and collisionality. There is a weak relation between collisionality and the ratio between the momentum pinch velocity and diffusivity in DIII-D and NSTX plasmas. A method to determine the residual torque, believed to be related to residual stress, in discharges containing NBI torque steps was proposed. JET momentum transport coefficients determined with varying toroidal field ripple were presented, and a good correlation with the pinch from the Coriolis drift theory was found. Further, a smaller inward pinch with higher field ripple was found.

Impurity Transport

The session on core impurity transport has allowed us to review and compare recent and past observations in the different devices with particular emphasis on He transport. The aim was to identify common generic features which have to be understood and predicted by theoretical modeling. The session was introduced by pointing out key aspects of the modeling of turbulent impurity transport, in particular the fact that turbulent convection can reverse direction depending on the type of turbulence, and that a total convection directed outwards is usually difficult to obtain in simulations of plasma conditions at which it is observed, particularly for impurities like B or C. In addition, emphasis has been given to the role of turbulent diffusion of impurities, and it has been suggested to make specific comparisons between theoretical predictions and experimental observations on this parameter, applying proper normalizations, in particular the ratio of the impurity diffusivity to the effective heat conductivity.

past observations of He transport in DIII-D were reviewed. He density profiles have been measured for a variety of plasmas in stationary conditions, and transient transport experiments with He gas puffs have allowed the measurement of the He diffusivity and convection. The main result is that the He density profile is found to have the same shape of the electron density profile in all types of discharges, independent of the edge source or sink. Using He gas puffs to estimate the D and χ, it was found that both are in the range of a few m^2/s and a few m/s respectively. In particular, D was found to scale as gyroBohm in the core, but as Bohm farther out, similar to results for the thermal diffusivity. Present plans are to contribute with published cases to an ITPA He transport database, and to extend the investigations by means of joint experiments in the new DIII-D campaign.

It was found that no He and C accumulation is observed inside the ITB in JT-60U, whereas Ar is observed to accumulate. The He diffusivity is observed to be reduced to neoclassical level like the ion heat conductivity in the ITB region, whereas both the C and the Ar diffusivities are measured above the neoclassical levels (by one order of magnitude for Ar) even when the ion heat conductivity is neoclassical. In contrast, the measured convection velocities are observed to be in general consistent with the neoclassical predictions, therefore observed C and Ar density profiles remain less peaked than the neoclassical predictions.

Recent studies on impurity transport in different operational scenarios in JET were reported. It was found that the diffusivity of Ne, Ar and Ni is always significantly higher than the neoclassical level. Convection velocities inside r/a = 0.2 have the same sign as the neoclassical convection and comparable in magnitude in this central region, and determines the observed dependence of the global peaking on charge. Ongoing modeling activities are found in good agreement with the experimental observations in many cases, but fail specifically in predicting the observed flat or hollow density profiles of carbon.

Impurity transport studies in Alcator C-Mod, focused on the behavior in L-mode, I-mode and H-mode plasmas are compared. The measured impurity is usually Ca 18+, injected by laser blow off of CaF2. In L-mode plasmas, the impurity confinement time is shorter than neoclassical predictions, and is found to decrease with the ICRF heating power and to increase with the plasma current. It can be modeled as simple diffusion, without any significant convective term. In the EDA H-mode, the impurity confinement time is 5 times longer than in L-mode, and is also observed to increase with increasing plasma current. An inward convection in the region of the edge density pedestal is observed, smaller than the neoclassical prediction, where the diffusivity is of the order of the neoclassical predictions. In the inner region, the diffusion coefficient is almost one order of magnitude larger than the neoclassical value. Finally in the I-mode, impurity transport is observed to be similar to that in L-mode, although the energy confinement is like that of the EDA H-mode.

In Tore Supra, recent experimental studies focusing on the impact of the logarithmic electron temperature gradient, modified by the application of a total of 300 kW of ECRH at different radial locations (r/a = 0.35 and 0.6), on the Ni transport were reported. There is no dependence of the experimentally measured Ni diffusivity on this parameter in the region between the deposition locations; however, at r/a = 0.1, inside the innermost deposition, there is a clear increase of the diffusion coefficient with increasing logarithmic electron temperature gradient. The measured diffusivities are unambiguously larger than the neoclassical values. The theoretical interpretation is that the center of the plasma column is dominated by electron drift turbulence. Here the impurity diffusivity increases with increasing logarithmic electron temperature gradient, and it indicates a threshold consistent with gyrokinetic predictions. The convection is measured to be inward, independent of the logarithmic electron temperature gradient, and well predicted by linear gyrokinetic calculations with QuaLiKiz. The more outside region is dominated by ion turbulence, and in this region no dependence on electron temperature gradient is predicted, consistent with observations.

Experimental studies of impurity transport in NSTX were reported. Ne puffs have been studied on a tangential ME-SXR diagnostic array, exploring the transport behavior in rhostar and nustar scan experiments. Diffusivity levels consistent with the neoclassical predictions have been found, whereas a reversal of the convective velocity in the low field case indicates an anomalous effect. Different charge state distributions have to be taken into account when modeling the impurity transport, and may be responsible of the observation of a change in emissivity in the nustar scan experiments. Studies on the impact of rotation show enhanced core diffusivities, up to two orders of magnitude, which can be accounted for by the effect of rotation on the neoclassical transport.

A comparison of C density profiles between TCV and JET was presented. In TCV, C density profiles are observed to be more peaked than electron density profiles both in OH and in ECH L-mode plasmas,. In contrast, JET LHCD L-mode plasmas exhibit C densities with much lower peaking, although the electron density peaking is very similar to that in TCV. The electron density peaking in TCV is found consistent with the theoretical predictions obtained for TEM instabilities, while the C peaking, modeled by a combination of neoclassical and turbulent effects, is predicted significantly smaller than the experimental observations. This might suggest that the size of the predicted turbulent diffusivity is too large, or that some non-negligible collisional effect has been neglected in the neoclassical NCLASS calculations.

During the discussion session, some actions in the short future have been decided. The first is to include data on impurity density profiles and transport (particularly He from DIII-D and possibly JT-60U, while other devices can contribute with other impurities, e.g. C) in the ITPA profile database. In addition, several devices are or will in the next campaigns in the condition of addressing the problem of impurity transport with improved diagnostics to study different transport channels and directly diagnose turbulence characteristics. From the side of the turbulent transport theory validation, present theoretical models are required to predict both the diffusion coefficient and the convection velocity separately, not only their ratio. To this purpose, there was agreement on including new variables and radial profiles of both the experimentally measured diffusion and convection of impurities in the ITPA profile database.

ITBs

The ITB and profile stiffness session dealt with both electron ITBs and profile consistency and on ion ITBs and rotation. The session was introduced with a proposal to fill in a table listing for the different channels (ion, electron, particle) the physical parameters (e.g., rotation, negative s, s=0 and rationals) that are observed experimentally to be relevant for ITB formation and/or sustainment.

ITBs in various channels on NSTX were found not form at the same location. Electron ITBs form at minimum magnetic shear, ion ITBs at maximum ExB shear, toroidal rotation ITB seems slightly displaced inwards with respect to ion ITB (possibly linked with momentum pinch). High-k turbulence, whose characteristics are consistent with those predicted for ETG modes, is seen to be suppressed with strong negative magnetic shear, leading to a reduction in electron transport and formation of electron ITBs. Linear gyro-kinetic theory predicts unstable ETGs at the observed large R/L_{Te} values, which underscores the need for non-linear simulations.

Observation of a “bat ears” T_e profile in off-axis ECH H-mode discharges in were seen on DIII-D. Modulated ECH and fluctuation measurements clearly indicate existence of an electron ITB at q=1 surface preventing heat flow from outer regions to centre. It is not yet clear to which modified plasma parameter in H-mode (density, q profile) the ITB formation is due.

Joint observations of electron density ITBs in TCV, JET and JT60-U were presented. In the TCV dominant electron heating and weak rotation regime, correlated n_e and T_e ITBs occur in the region of negative magnetic shear, with a dominant role of inward thermo-diffusion for n_e ITBs. JET and JT60-U in $T_i \geq T_e$ and strong rotation regimes exhibit density ITB only with strong negative shear, with the location of maximum R/L_{ne} inside that of maximum R/L_{Te}. Density ITBs are not observed in optimized shear plasmas. From the JET and JT-60U analyses performed so far, while the NBI particle source in presence of a reduced diffusivity cannot be excluded, it appears not to be large enough to explain the observed values of R/L_{ne}, unless turbulence producing much larger (electron) heat transport than particle transport is at play.

ITB formation and evolution with co- and counter-NBI in MAST using high resolution kinetic and q profile diagnostics was discussed. With co-NBI, ITBs in the ion and momentum channels are very localized and form in the vicinity of q_{min}, although the momentum ITB forms at smaller radius than that of the ion ITB. ExB shear peaks at location of the ion ITB, while the electron ITB forms in the negative shear region. In counter-NBI, there is less power absorbed but similar torque due to broad prompt loss torque: broad ITBs in ion and momentum channels form outside q_{min}, with $\chi_i \sim \chi_i^{NC}$ over most of plasma radius.

ITB formation and control with ICRF heating in Alcator C-Mod plasmas was presented. ITB formation in C-Mod is found to be very sensitive to changes in B and to the location of the ICRF resonance, which has to be near |r/a|~0.5. Lowering the magnetic field results in the ITB foot moving outward. ITBs evolve from EDA H-mode on time scales longer then the energy confinement. During the H-mode before ITB, n_e and v_{tor} profiles are flat, but with ITB n_e becomes peaked (inward Ware pinch) and rotation becomes hollow (outward convection). A significant ExB shear is measured at the ITB foot location. ITBs are not formed in ELM-free H- modes. Ohmic H-mode ITBs are very similar.

The effect of ExB shear on core barrier formation near low-order rational q surfaces in DIII-D was studied by comparing co-injection and balanced injection. In the first case, with the ExB shearing rate is close to the ITG growth rate, an ITB is develops and is sustained after the initial transport reduction and v_θ excursion (consistent with a zonal flow structure) associated with the appearance of q_{min}=2. In the second case, the transient transport reduction at q_{min}=2 is still observed, but the ExB shearing rate is very low and the ITB does not develop. There is a decrease in the broadband turbulence when integer q enters the plasma. The absence of TAE activity in balanced injection cases shows that fast ion loss is not an essential ingredient for transport changes at integer q_{min}.

JET results on the role of rotation on ion ITB sustainment were presented. Ion ITBs are normally produced in JET with low or reversed magnetic shear and strong NBI driven rotation. When rotation is reduced by means of enhanced B_T ripple or dominant ICH, then ITB events are triggered by main rationals, they are not sustained. This is similar to what observed in DIII-D and JT60-U with balanced NBI. Therefore, strong ExB shear appears to be a necessary condition for an ion ITB AT scenario, underlying the importance of achieving a rotation gradient for such scenarios in ITER. Electron ITBs associated to ITG stabilization follow the same pattern, but pure electron ITBs associated to TEM stabilization can be obtained also without rotation in regions of negative magnetic shear. Further JET experimental observations of a reduction of ion stiffness when high rotation gradient and low magnetic shear are concomitantly present suggest that this physics could be at the origin of improved core ion confinement, such as ion ITBs or hybrids. The commonly used quenching rule of turbulence by ExB flow shear indicates only a threshold up-shift, and it was proposed to re-examine an alternative version of it that is supported by non-linear fluid turbulence simulations of Resistive Ballooning Modes This alternative version foresees also a change in stiffness, more consistent with JET experimental results.

Non-linear simulations of ITB formation due to ExB or magnetic shear were presented. Barriers are seen in codes with externally imposed ExB shear and also with self-generated zonal flows, but in slab cases and at rather large $\rho*$ only. The externally imposed or self-generated ExB shear is seen to affect stiffness, reducing growth rates by a factor $1/(1+a\gamma_{ExB}^2)$. In present simulations, however, the self-generated E_r is not consistent with neo-classical transport. Low magnetic shear is not generally seen to trigger barriers because of the presence of non-resonant modes. However in the case of low s and q_{min}=2, reduced transport was seen in GYRO. In the future we will be in better position to explore such issues with the availability of global, fixed flux codes including turbulent and neoclassical transport and achieving low r* (e.g. XGC, GYSELA, GT5D).

The behavior of transport and turbulence (measured with 2D-PCI) in high T_i ITB discharges in LHD plasmas with positive perpendicular NBI and negative parallel NBI were described. A relative reduction of ion thermal conductivity was observed inside the core region, where the enhancement of the turbulence was not observed with increase of Ti gradient , while outside the ITB, the ion transport and turbulence were enhanced with increase of Ti gradient. This enhanced turbulence was propagating in the ion diamagnetic direction in plasma frame. Preliminary results of GKV (Gyro kinetic Vlasov simulation) linear simulations indicated unstable ITG modes in regions where the ion transport and fluctuations were enhanced.

The discussion around the proposed table led to recognize the basic agreement of all devices so far in indicating rotation as a necessary ingredient for ion ITBs, with location of the ion ITB near the maximum ExB shear location and not necessarily in the negative s region. In addition, ion ITBs cannot be produced in steep q regions, although a quantitative analysis of a minimum s for ITB formation is not available. On the other hand, electron and density ITBs seem sensitive to negative s and can be formed also in absence of rotation. Rationals seem to play a role only in the triggering.

A few questions were formulated in view of future meetings.

On the physics side:

- Can we say that it is necessary to have also small s to develop large vpol?
- Identify right coefficient in regular Waltz rule! Now it ranges 0.5-1.6
- Global codes should investigate weight of $1/(1+g_E^2)$ correction
- Is a sustained ITG ITB attached to q_{min} or to the rational that triggered it?
- Is the ITB a 1st order transition as ETB or is a 2nd order critical gradient transition equally or even better compatible with data?
- Is there any role of heat pinches in ITBs?

On the operational side, since ITER needs core improved confinement for steady-state AT scenarios:

- In which channels is it reachable? Or wanted? ITG is dominant so rotation needed. More experiments trying to achieve ion improved confinement without NBI rotation?
- Which q profile is preferred? Strongly reversed, mildly reversed, flat? q_{min}~4 or q_{min}~2?
- Is a JT-60-like scenario with early heating, high q_{min}, strongly reversed q technically achievable in ITER? It is not in JET due to NBI shine-through
- Avoid impurity accumulation with RF in ITBs: more results in addition to JT-60?

Summary

The high priority items outlined in the ITER R&D document are still relevant, and the work plan for 2010-2011for the T&C group will not be significantly changed. We see more work done on transport model validation and L-H thresholds. In addition, we plan to develop more JEXs on electron transport and participate in a working group topic on pellet injection and fueling.