Transport and Confinement ITPA Task Group Annual Report: 2008-2009

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The Transport and Confinement Topical Group is a newly formed group, subsuming the Transport Physics and Confinement Database and Modeling groups. The formation of this group was based on both suggestions by the ITPA management and members of each of the groups themselves. It was felt by these members that merging these groups made sense due to a) the large overlap between them, and b) the de-emphasis of global studies in the CDBM group. Consequently, the new group was initiated in June 2008, and the membership represents several of those who were in the original TP and CDBM groups as well as many new members. As indicated, while global studies, including those that involve global databases will not be abandoned, but will become subdominant to studies that focus more on local, profile information. Further, since there is a great deal of cross-over between the T&C groups and others on various topics, efforts will be made to hold joint meetings with other TGs and focus some part of those meetings on topics that are of common interest. The most obvious groups are Pedestal (L-H transition physics) and IOS (physics model validation). This will be discussed later on.

Two meetings have been conducted this past year. The first was held on Oct. 20-22 in Milan, Italy following the IAEA Fusion Energy Conference. This meeting was joint with the Pedestal group, and it covered L-H threshold physics (the joint topic of interest), Particle and impurity transport (most notably density peaking), rotation and momentum confinement, core transport and modeling, and it also had a discussion of Joint Experiments and Activities in order to summarize what has been done and plan for the future. The second meeting was held in Naka from March 31 to April 2, and this meeting was joint with the IOS group. The joint topic of interest was transport modeling and physics model validation, but it also addressed the effect of rotation on performance, momentum transport and electron transport. The next scheduled meeting is for Oct. 5-7 at PPPL, and the meeting will be joint with the Pedestal group.

One of the main challenges for the newly formed T&C group, especially in the first meeting, was to re-assess the Joint Experiements (JEXs) and Joint Activities (JACs). The T&C group inherited 19 JEX/JAC from the two predecessor groups (8 from CDBM and 11 from TP), and in our discussions, 10 were closed out. However, 6 new ones were developed (with ideas for even more), so it is clear that there is still some reduction necessary. Below are tables giving the present status of the JEX/JAC. The first table gives the status of JEX/JAC from the CDBM group:

Previous	Present	Title	Comments
CDB-2	TC-1	Confinement scaling in ELMy discharges: b scaling	NSTX, JET, MAST, DIII-D
CDB-4	Closed	Confinement scaling in ELMy discharges: n* scans at fixed n/nGW	C-mod not yet able to achieve required bN
CDB-6	Closed	Improving condition of database: low aspect ratio	Combine with TP-9 for TC-12
CDB-8	Closed	r* scaling along ITER relevant path at both high and low beta	C-mod unable to match ne; JET expts not planned
CDB-9	Closed	Density profile peaking as a function of collisionality	Completed
CDB-10	TC-2	Hysteresis and access to H-mode with H~1	AUG, JET, MAST, NSTX, TCV
CDB-11	TC-3	Scaling of low density limit to the H-mode threshold in H & D plasmas	AUG, DIII-D, JET, TCV
CDB-12	TC-4	Species dependence of L-H threshold	AUG, DIII-D, JET, NSTX

The next table gives the status from the TP group:

Previous	Present	Title	Comments
TP-3.1	TC-5	Determine transport dependence on Te/Ti in hybrids and steady-state	DIII-D, JET
TP-3.2	Closed	Determine transport dependence on Te/Ti in L-modes	No expts planned on TEXTOR, T-10, HL-2A
TP4	TC-6	Effect of rotation on plasma performance	Full session in Spring 2009; Closing out - 2009
TP-5	TC-8	QH/QDB plasmas	AUG, DIII-D; close out in 2009?
TP-6.1	TC-9	Scaling of intrinsic rotation with no external momentum input	C-Mod/TCV similarity expt.
TP-6.2	Closed	JT60U/DIII-D Mach number scan identity experiment	Overlap with PEP-18; see if can combine
TP-6.3	Closed	Momentum transport with NBI input	More specific test of theory proposed in TC-15
TP-7	TC-10	Expt'l identification of ITG, TEM, and ETG turbulence and comparison to codes	Ongoing Joint "Activity"
TP-8.3	Closed	JT60U/JET ITB similarity experiment	Completed; data being analyzed
TP-8.4	Closed	T-10/TEXTOR/HL-2A ITB similarity experiment	No experiments planned
TP-9	Closed	Aspect ratio dependence of H-mode confinement	Combine with CDB-6 in TC-12

The third table indicates the newly developed JEX/JAC:

Previous	Present	Title	Comments
New	TC-7	ITG/TEM transport dependence on Te/Ti, q(r) and rotation in L-mode	DIII-D, JET
New	TC-11	He transport in hybrid, AT, ITB scenarios	Joint Activity (?); first do some data mining
New	TC-12	H-mode transport at low aspect ratio	MAST with high power, NSTX with Lithium, DIII-D similarity
New	TC-13	ITG critical gradient and profile stiffness	C-Mod, JET
New	TC-14	RF-driven rotation	ECH on AUG, DIII-D, EAST, TCV; mode conversion on C-Mod, JET
New	TC-15	Dependence of momentum and particle pinch on collisionality	DIII-D, JET, NSTX, TCV
Being considered		Test of residual stress	DIII-D, ?
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	To be discussed Fall '09
Being considered		Pellet fueling, pellet-induced particle transport	Cross-cutting working group topic? Discuss Fall '09

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. H-mode database (K. Thomson)
   DB4v5: Preliminary hybrid data from JET, AUG, DIII-D in addition to other hybrid data has already been put in, and an earlier version (DB4v3) combined with Pedestal db (DB3v3)
2. L-mode database (F. Imbeaux)
   Problems with parameter values were identified several years ago and subsequently fixed. There is no activity presently
3. L-H threshold (Y. Martin → J. Hughes)

To be updated with profile information for model testing and reducing uncertainties in PLH.

4. Momentum database (M. Yoshida)

   A database is being developed that will contain both global and local parameters. These will enable gyrokinetic calculations to study source of momentum diffusivities and pinches.

5. Profile database (C. Roach)

   There is no activity presently. This database could be used as resource to store ITER DEMO discharges for model validation work.

The activity of the T&C group over the past year was broad, but it did address parts of all the High Priority Issues identified in the ITER R&D document. The transport-related high priority issues include:

1. Transport and confinement in transient phases
2. Access to high confinement regimes during steady-state and ramp-up/down H, D, and DT phases (including L-H threshold physics)
3. Characterization of proposed schemes for ELM control, compatibility with scenario requirements (to be addressed by Pedestal group)
4. Determination of ripple effects on ITER plasma performance and on fast particle confinement (some was addressed by T&C, but mostly will be addressed by the Energetic Particle TG)
5. Particle transport and fueling in ITER reference scenarios

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

Particle and impurity transport: density peaking

The flattening of the density profile with increasing collisionality has been well documented and is a persistent feature among most conventional as well as low aspect ratio tokamaks. The behavior is seen in both Deuterium and Helium plasmas. The empirical extrapolations to ITER collisionalities would suggest that density peaking in that device would be $n_e(\rho=0.2)/\langle n_e \rangle \sim 1.5$. The dependence with collisionality is also see in stellarators (LHD) in configurations with a smaller radius magnetic axis, where ripple/neoclassical transport is reduced. At larger radius, with larger ripple, the dependence is inverted, raising the question of the source of the particle pinch that gives rise to the density peaking behavior in stellarators (i.e., turbulent vs neoclassical pinch). The question can pertain to tokamaks as well.

There has been progress in understanding the physics of the density peaking, especially in light of the question posed above. In particular, is there a connection between density profiles and ITG-range turbulence. Measurements from JT-60U indicate longer density gradient scale lengths when the turbulence in the ITG-range exhibits smaller correlation lengths, supporting the conjecture of turbulence-driven pinches. LHD results indicate greater density pump-out with increased turbulence.

There has been also a great deal of theoretical progress towards understanding the source of the peaking, which can put predictions for ITER on a physics basis rather than one that is based on empirical characterizations. Gyrokinetic calculations that include both TEM and ITG modes have shown that the particle fluxes are a complex combination of inward and outward contributions at different wavenumbers and energies of trapped particles in phase space, and that a dependence on collisionality is exhibited. Most of the inward transport is caused by slower trapped electrons, while the faster ones give rise to the outward transport. GS2 ITG simulations were also used to parameterize the normalized density gradient scale length as functions of collisionality, T_e/T_i and neutral beam particle flux. These calculations also showed that the density peaking is primarily a function of collisionality. Experimental data was used to compute expected R/L_n values, which were then compared to theoretical predictions, and good agreement between the two was found. Given this agreement, theory was used to predict the density peaking for ITER, and it was found to be ~1.5, which is consistent with empirical estimates, and which puts this prediction for ITER on a firmer, and a physics-based, ground.

L-H Transition Physics

Three JEXs have been devoted to this high priority area, but the important results obtained during the last year extended beyond the established JEXs. The first topic concerns hysteresis effects, and experiments on JET exhibited mixed results. Initial results from density ramp and power step-up and step-down experiments indicated little difference in power threshold for L-H or H-L transitions, with the power threshold being $\sim 1.2P_{scaling}$, where $P_{scaling}=0.3n_eBR^{2.5}$. This result indicates no hysteresis. More recent experiments showed mixed results. In power ramp-up experiments, the H-mode is maintained at power levels less than $1.2P_{scaling}$; the increase in heating power across the transition due to intentional ramping is less than the increase in density due resulting from the transition. This indicates that there is hysteresis, that the plasma can stay in H-mode even at heating powers less than the threshold power. On the other hand, during the ramp down of power, the plasma back-transitioned to the L-mode at precisely $1.2P_{scaling}$, indicating no hysteresis. While the analysis is just beginning on these discharges, the initial results are certainly mixed, and questions as to the validity of density as a scaling parameter are raised.

Results from both ASDEX-U and JET indicate that a Type I ELMy regime is required for achieving H-factors of ~1 at powers just above the threshold power. For ASDEX-U, Type I ELMs can occur when $P \sim P_{LH}$; however, on JET, $P \sim 1.5P_{LH}$ is required. At lower powers, smaller, Type III ELMs are observed, and these degrade confinement by ~20%. This is true as well on ASDEX-U; H<1 when Type III ELMs occur.

Experiments on ASDEX-U indicate that the species dependence of P_{LH} is favorable for an ITER He phase, with power thresholds for He the same as those for D plasmas. ASDEX-U used ECH heating to perform these experiments, maintaining the purity of the respective thermal plasmas. Experiments on DIII-D indicated much higher thresholds for Hydrogen than for Deuterium plasmas.

Other issues have affecting the L-H transition have been identified and will be pursued during the next year. The density of the minimum power threshold has been observed to scale with B_T from a collection of data from various devices, although at different rates. JT-60U results show that there is no difference in P_{LH} with positive or negative neutral beams. NSTX has shown that there is a strong reduction in P_{LH} with application of Lithium wall coatings. A very important consideration has emerged with respect to applied external fields for ELM suppression, that is, the effect that these applied fields have on the power threshold, and whether or not this effect is related to changes in plasma rotation or the applied field itself. Preliminary results from JET, NSTX and MAST were presented, and this topic is likely to be the subject of a new JEX for 2010. *This could have a significant impact on ITER.*

Model validation during ramp-up/ramp-down phases

The objective of this work is to identify physics-based models that can be used for ITER scenario development and to understand the plasma evolution during the early and late discharge phases. This has particular application to determining whether the planned hardware provides sufficient flexibility for plasma control and achievement of performance objectives in light transport and heating uncertainties. The approach is to validate models at a high level (e.g., T_e, l_i agreement) in ITER "DEMO" discharges on various devices such as ASDEX-U, C-Mod, DIII-D and JET. This work is cross-cutting with the IOS group.

Many simulations have been performed, and they have met with a wide variety of "success", even for the same models. The obvious conclusion from the work so far is that the models and simulations do NOT provide a robust prediction for ITER. The Coppi-Tang-Redi model has been used as a basis for modeling the ramp-up phase, and this model, as published, leads to overestimates of T_e in the core, and underestimates near the edge, leading to more rapid current penetration and higher l_i than desired. A reduction in the model diffusivity in the outer regions gives somewhat better agreement locally, but even worse agreement farther in. This work has been carried out in JET, DIII-D and C-Mod plasmas. To date, no other physics-based models have been tested for ramp-up phases. The EFDA ISM group has focused on an empirical model, but claim that simulations using GLF23 are underway. It was shown from work on JET, however, that the results of the simulations are extremely sensitive to assumptions made about non-measured quantities such as Z_{eff} profiles and specific impurity content.

The results of these efforts so far do not give a robust and confident picture for ITER simulations, and the groups held a discussion as to whether too much is expected from the modeling. In particular, an actual prediction for the L-H transition is not imminent, and there is a need for a physics-based prediction of pedestal temperature. A prediction of the edge T_e based on peeling-ballooning mode theory is presently being developed, however. It was felt that although we should not stop these benchmarking efforts, we do need to redefine and refocus it, perhaps taking an alternative approach. This approach would be to adopt a set of T_e profiles from existing experiments' ramp-up phases, and adjust the magnitude of the profiles in response to changes in heating power. Then, without needing to predict the T_e, one could still assess whether an acceptable l_i can be obtained with the available heating power.

The model benchmarking effort has met with several issues that will hinder completion of this work on the ~2 year time scale requested by ITER. These have to do with data sharing, modeler resources and coordination. The various groups, understandably and justifiably want to make sure they have analyzed, verified and published their data before releasing it. There is a need to identify a number of individuals to do this work and make sure they have the resources and time to do it. At present, there are a number of groups around the world performing modeling, but they are all performing their tasks in a disparate manner. A specific task that is clearly defined, along with common input, specified tools and models and a common set of metrics need to be developed and, they also accepted and followed by these groups. The various groups essentially have to buy in to the importance of these specific tasks, and be prepared to participate. This direction needs to come from the member organizations; the ITPA TG Chairs do not have this influence.

Summary

The high priority items outlined in the ITER R&D document are still relevant, and the work plan for 2010 for the T&C group will not be significantly changed. We see more work done on modeling momentum transport (including intrinsic rotation and residual stress) 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.