Transport and Confinement ITPA Task Group Annual Report: 2011-2012

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The Transport and Confinement Topical Group held two meetings this past year. The first was held on April 3-4 in San Diego, CA, USA just before the Joint US/EU Transport Task Force Meeting. Topics discussed at this meeting included 3D transport physics in stellarators and tokamaks, physics model validation during the current ramp up phase, understanding the transport and turbulence in the region of coupling between the core and pedestal/edge plasmas, and discussions of various JEX results.

The second meeting was held at IO in Cadarache, France on Oct. 5-7, 2011, with continuing discussions on the topics mentioned above. This meeting was held just before the H-Mode/ITB Workshop in Oxford, UK. In the ITPA meeting, there was a session on recent impurity transport results and detailed discussion of the 2011 JEX/JAC results and plans for 2012, including the proposal for three new JEX/JAC. Furthermore, poster reviews took place for the two presentations for the then upcoming H-mode workshop. The next meeting will be held in Hefei, China, April 2-5, 2012, and will be chaired by the new Chair of the group, Darren McDonald.

The status of the Joint Experiments and Joint Activities are given in the table below. Four, possibly five, of the Joint Experiments will be closed out (gray shading), and three new ones are being proposed (green shading).

JEX/JAC	Title	Comments
TC-1	Confinement scaling in ELMy discharges: β scaling	Close out with IAEA paper
TC-2	Hysteresis and access to H-mode with H~1	Close out with H-mode workshop paper
TC-3	Scaling of low density limit to the H-mode threshold in H & D plasmas	Close out with IAEA paper
TC-4	Species dependence of L-H threshold	Close out with IAEA paper
TC-9	Scaling of intrinsic rotation with no external momentum input	C-Mod/TCV similarity expt., data from other devices
TC-10	Turbulence and transport in the core-pedestal/edge coupling region	Ongoing Joint Activity
TC-11	He profiles and impurity transport	Joint Activity
TC-12	H-mode transport at low aspect ratio	NSTX ν^* scaling, MAST β scaling
TC-13	Ion and electron critical gradient and profile stiffness	JET, DIII-D, C-Mod, AUG
TC-14	RF rotation drive	C-Mod, JET, DIII-D, TCV,

		JT-60U, AUG
TC-15	Dependence of momentum and particle pinch on collisionality	Close out with IAEA paper
TC-16	Dependence of momentum pinch and diffusivity on β	AUG, DIII-D, JET
TC-17	ρ* Scaling of the Edge Intrinsic Torque	NSTX, DIII-D, JET, AUG, C-Mod, JT-60U
TC-18	Dimensionless Identity Experiments in I-Mode	C-Mod/AUG (DIII-D?) similarity expt.
TC-19	Characteristics of I-mode plasmas	C-Mod, NSTX, AUG, DIII-D
TC-20	Validation of transport models in ITER-similar current-ramp plasmas	Joint Activity
TC-21	Characteristics of the LOC/SOC transition	C-Mod, AUG, TCV New
TC-22	Evolution of transport during and immediately after H-L transtiions	Joint Activity, JET, C-Mod, AUG, New
TC-23	Physics of nonlocality phenomena	Joint Activity, KSTAR, LHD, HL-2A, C-Mod, MAST, DIII-D, Tore-Supra New

Publications and Presentations

H-mode Physics/Transport Barrier Workshop (Oct. 2011)

1. Momentum transport studies from multi-machine comparisons, M. Yoshida and the ITPA TC Group

2. Multi-Machine Analysis of the H-mode Confinement Close to the Threshold Power, Y. Martin and the ITPA TC Group

2012 Fusion Energy Conference (proposed)

1. Confinement scaling in ELMy discharges: b scaling (TC-1), C. Petty and the ITPA TC group

2. Scaling of low density limit to the H-mode threshold in H & D plasmas (TC-3), J. Hughes and the ITPA TC group

3. Species dependence of L-H threshold (TC-4), P. Gohil and the ITPA TC group

4. Dependence of momentum and particle pinch on collisionality (TC-15), T. Tala and the ITPA TC group

High Priority Issues

Below are summaries of the work by the group in selected high priority topics. More details can be found in the Topical Group Executive Summary for the two meetings.

Transport and Turbulence in 3D Systems

Following up joint activities of the stellarator/heliotron working group (CWG) with the T&C group, a session on joint activities and proposals for joint experiments and analysis was held. Specific requirements from current issues in tokamak transport and confinement benefitting from 3D experiments have been discussed aiming at specific actions. Some of the groundwork laid for developing joint activities and experiments include the following discussions:

- Influence of magnetic topology effects (stochasticity, rationals) in the interplay between equilibrium radial electric fields and zonal flows.
- Also utilizing the 3D configurational flexibility, investigations of joint probability distributions of fluctuations in gradients and radial transport (tokamaks vs stellarators) to reveal the role of edge magnetic shear and plasma parameters have been proposed.
    - Transport was found to be bursty along with the turbulence. PDFs of the turbulence and density profile showed that the strongest turbulence events occurred when the density gradient was either above or below its most probable value. This suggests a non-local mechanism is operative.
- Discussion of the role electron versus ion dominated transport of profile stiffness in stellarators showed the necessity of a more comprehensive revision of existent data and results.
- A comparative study of ELMy - ELM free transition in LHD and DIII-D was reported. Differences were found in the triggering mechanism of the transition: in LHD, plasma effects caused the transition whereas in DIII-D external perturbation suppressed the ELMs. Also differences in the particle transport were found: a reduction in LHD with reduced fluctuation level in contrast to by an increase in DIII-D with increased fluctuations.
- Comparisons between gyrokinetic calculation results and turbulence characteristics as measured by PCI in LHD were presented. An axis shift in LHD led to different density profiles, peaked and hollow, with the peaked cases showing electron--direction turbulence dominating and hollow profiles being associated with turbulence in the ion direction. GS2 calculations showed that

both ion direction, however, smaller real frequency toward the electron direction was found in peaked density profile indicating larger TEM contribution. This qualitatively agrees with the measurements. Non linear simulations of ion heat transport using GKV-X was done in core-edge transition region (rho=0.4-0.8). Good agreement was found between experiments and simulations.

- The complementary configurations of 3D field coils systems on various tokamak and ST experiments (DIII-D, NSTX, MAST & AUG) were surveyed, along with the similarities and differences in transport responses between the various experiments. The increase and spatially varying dynamical response of turbulence to applied 3D fields as measured in DIII-D with BES and DBS was presented, along with increased particle transport rates obtained from gas puff modulation and fast profile reflectometry.
- Open stochastic volumes from the 3D fields shared similarities on both tokamaks and stellarators in terms of the radial and poloidal transport. While applied RMPs caused particle pump-out in DIII-D, they could cause either pump-out or an improvement in particle confinement in TEXTOR, indicating the possible importance of the interaction between the RMPs and certain resonant flux surfaces. In LHD, the electron temperature is affected differently with different phases of the Local Island Divertor, indicating that the 1/1 island has a strong influence on confinement. There were lower turbulence levels in the case of a "healed" island. G. McKee gave a report on 3D turbulence and transport effects in DIII-D with applied RMP.
- With application of RMP, particle transport increased along with the low-k turbulence. The change in turbulence occurred on a fast time scale (~msecs) to the change in I-coil current, and it appears that the change in turbulence may be leading the change in gradients

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 a 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.

- Discharges from C-Mod, JET and DIII-D have been added to the database of discharges to be used for this model validation study.
- The TGLF and GLF23 models (with and without paleoclassical) were used as a basis to simulate ITER-similar current-ramp discharges in DIII-D. As is often reported for current ramps, the GLF23 model predicts higher peripheral temperatures than are measured, and the TGLF model has the same

characteristic. The TGLF transport model has insufficient thermal diffusivity in colder periphery of the DIII-D, JET, and C-Mod plasmas that were used as a basis for the simulations. Adding the paleoclassical model improves agreement, but additional thermal diffusivity is still needed near the edge.

- The activities of the EU's ITER Scenario Modeling (ISM) group were summarized. Current-ramp simulation has been used as a benchmark of the European Tokamak Solver (under development by the ISM group). While the Bohm-gyroBohm model works fairly well for hot JET discharges with slow current-ramp rates, it does poorly in discharges with higher density and lower Te. In simulations of current penetration based on measured electron temperatures, q(0) often falls faster than in the experiment if neoclassical resistivity is used together with a flat radial profile for Zeff. The q(0) evolution can be well modeled if the Zeff profile is centrally peaked in some ohmic JET discharges, but is peaked off-axis in some ICRH JET discharges; measured Zeff profiles are clearly needed for validation work.
- A computational strategy for self-consistent ITER simulations with L-H and H-L transitions with the goal of learning how shape-control systems respond to rapid changes in stored energy induced by the transport dynamics of L-H and H-L transitions was outlined. A limited study involving AUG, C-Mod, DIII-D and JET concentrating on 0D analysis of one to two shots from each machine was proposed as a Joint Activity for 2012.
- Time-dependent transport simulations of current ramps (up and down) for ASDEX Upgrade discharges found that GLF23 provides insufficient diffusivity in the colder plasma periphery, and several theoretically-motivated simple 'patches' were invoked to improve the fit to the data. The extrapolability of the patches to ITER is an open issue. The gyrokinetic linear stability analysis indicates that ITG modes are dominant across most of the plasma during most of the rampup; TEM dominates across the plasma early in the rampup, and in the central region when central ECH is applied.

Core-Edge Transition Regime

The focus of this subgroup is to attempt to understand the physics of the transition region between the core plasma and the plasma that forms the pedestal/edge. Are they two regions controlled by different processes, and how can we understand their connection? This is motivated by the observation that, still today, simulations in this plasma region, even with the most recent and comprehensive theoretical models often deliver fluctuation levels and heat fluxes which are well below those measured experimentally. This disagreement is likely to be the consequence of missing physical ingredients and/or not sufficient resolution at some scales in presently applied models. This problem is not only of high relevance for the understanding of turbulent transport, but it also implies a severe limitation in the transport modeling of many tokamak

scenarios, particularly those of current ramp phases, with evident negative consequences in our present prediction capabilities of critical parameters like the internal inductance during these critical phases of a plasma discharge.

- Results were presented from the EMEDGE3D code looking at the formation of a transport barrier at the edge and the stability in the presence of RMPs. The code predicts unstable RBMs in the edge in representative plasmas, with an increase in high frequency, but decrease in low frequency, turbulence in the presence of RMP. The RBM was able to reproduce relaxations similar to ELMs.
- The GENE code to assess the stability of RBMs in Tore-Supra L-mode plasmas. The RBM was found to be stable in these plasmas, except when collisionality was increased to high values. In this case, the mode was found only at the very edge, r/a~0.95.
- Theoretical work on the coupling of ETG modes to eGAMS were presented. eGAMs are induced by ETGs through energy cascades from short to long wavelengths. The eGAMS in turn set the radial scale of the ETG streamers, and can give an anomalous particle pinch in the edge pedestal of H-modes.
- Gyrokinetic analysis results of the evolution of the H-mode pedestal during an ELM cycle on MAST were presented. The simulations showed that the microtearing mode dominated in the edge of the core plasma, but KBMs dominate through the width of the pedestal. These modes appear to be unstable just before the ELM crash, but it is still believed that peeling-ballooning is still the ELM trigger.
- IT was proposed that a database of L mode discharges to be shared and analyzed with different tools be started. It was decided to choose well diagnosed L mode discharges in Tore Supra, DIII-D, JET, Asdex-Upgrade, trying to explore as much as possible the range of q at the edge and collisionality level. Indeed the ITG-TEM paradigm is thought to fail more in highly collisional cases and at higher q edge.

Impurity Transport

- Measurements of boron density profiles in ASDEX Upgrade, and related modeling with the gyrokinetic code GS2 and the neoclassical transport code NCLASS were presented. The B density profiles in NBI heated H-modes exhibit an increase of peaking with increasing additional ECH power, which correlates with the increase of Te/Ti, the reduction of toroidal rotation, and the reduction of the ion temperature gradient.
- First observations of He density profiles at JET in L-mode and H-mode standard and hybrid scenarios were reported, and are found to be more peaked than the corresponding C density profiles, and as peaked as or more peaked than the electron density.
- First measurements of B and He density profiles in C-Mod were presented. Boron measurements cover all confinement modes and show clearly non-

neoclassical behavior around mid-radius, where hollow density profiles are observed.

- Global nonlinear GYRO simulations of impurity transport were performed and demonstrated a modeling technique which allows the reconstruction of the impurity density profile over the entire simulation domain corresponding to zero flux. The results, obtained with C-Mod plasma profiles, show that predicted low Z impurities exhibit less peaking than hydrogen, but high Z impurities show significantly larger peaking in the more central region of the simulation domain.
- In the upcoming campaigns AUG, C-Mod, JET and TCV are planning to make new impurity measurements, which will be added to those already available from DIII-D. This will allow us to start a combined and comparative empirical characterization of the observations in the different devices investigating correlations with theoretically relevant dimensionless parameters. Modeling with turbulent and neoclassical codes will follow.

Summary

The high priority items outlined in the ITER R&D document are still relevant, and the work plan for 2012 for the T&C group will not be significantly changed. The focus on the current ramp-up model validation effort will be to reach a quantitative conclusion assessing the various models that presently exist, and the focus of the 3D Working Group will be to specify a Joint Expt or Activity that can be performed including both stellarators and tokamaks. Except for the modeling activity of the H-L transition, it is proposed that the L-H transition work be moved to the Pedestal group.

Transport and Confinement ITPA – Related Publications

2008

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