Task 1: Transport and ITB Physics

Collaborative work on ITPA-IEA joint experiments was performed for the following topics.

TC-5: Determine transport dependence on Ti/Te ratio in hybrid and steady-state scenario plasmas.

Enhanced transport was also observed during ECH in AUG as well as JT-60U and DIII-D. In AUG, R/LTi variation in NBI and NBI+ECH phases agrees with ITG threshold, provided both ExB shearing and Te/Ti stabilizing effects are taken into account. Experimentally, causality of increase in Te/Ti and enhancement of transport is not clear from responses of Te and Ti after ECH switch on. Summary of work presented at H-mode workshop.

TC-7: ITG/TEM transport dependence on Ti/Te, q profile and rotation in L-mode plasmas.

Experiments on JET shows importance of stiffness at low rotation, profiles less stiff at high rotation. R/LTi threshold shows modest dependence on Te/Ti at low rotation. Discussions to be held with DIII-D to see what experiments can be done before shutdown. Do not restrict analysis to stiffness paradigm.

TC-9: Scaling of intrinsic plasma rotation with no external momentum input.

JET experiment on L-mode plasmas at higher β_N shows strong current dependence of core rotation with plasma current observed in C-Mod. Rotation inversion experiments performed in TCV using C-Mod similar plasmas, results agree with previous TCV experiments (sense of rotation inversion opposite in limited vs diverted, rotation directions relative to C-Mod opposite). Continue to populate H-mode database, expanding to include profiles, and start L-mode database with C-Mod, JET and TCV data.

TC-13: ITG critical gradient and profile stiffness

The JET result that ion stiffness is high at low rotation shear and is reduced for increasing rotation shear (a mechanism not theoretically foreseen) calls for confirmation by performing similar experiments in other machines.

TC-14: RF Rotation Drive.

LHCD causes increase in counter rotation in C-Mod. Rotation direction changes across ECH deposition layer in JT-60U. Rotation directions opposite for MCFD (Mode Conversion Flow Drive) in C-Mod and JET (grad-B direction different). Rotation data of ECH experiments will collect from DIII-D, AUG, TCV, LHD.

TC-15: Dependence of momentum and particle pinch on collisionality.

Experiments performed on JET, DIII-D and NSTX to quantify effect on collisionality and relation between momentum and particle pinch. Pellets used on DIII-D to decouple R/Ln effect from collisionality. Preliminary analysis from NSTX shows transition of momentum pinch from inward to outward as collisionality decreases. Results also show possible outward pinch for impurities as n=3 fields applied in NSTX. Good exchange of physicists on these experiments was performed.

Task 2: Transport and Confinement

Task 2: Transport and Confinement (S. Kaye)

TC-1: Beta Dependence of Confinement. Experiments on NSTX showed a weak dependence on beta and little dependence on shape. In JET, hybrid discharges were found to have a weaker power dependence, $P^{-0.34}$, than normal H-mode scaling, $P^{-0.65}$. This actually yields a stronger beta scaling than standard $H_{98(y,2)}$.

TC-2: Hysteresis and access to H-mode with H~1. In JET experiments no hysteresis was reported. In NSTX, it was found that hysteresis was calculated to be present if one did not include the dW/dt term in the power, but was absent if one did. It was concluded that ITER should not rely on hysteresis to access high density H-mode regimes.

Access to H~1 regimes was found to depend on the ELM type and power: Near P_{th} type III ELM's led to H~0.8. At $P>>P_{th}$ H~1 but accompanied with type I ELMs. At intermediate power levels H~1 can be obtained in ELM free regimes, but these are not stationary.

TC-3: Scaling of low density limit of $P_{th,\,min}$. JET performed experiments at 1.8 T and 3T but did not access densities low enough for a definitive conclusion. NSTX results indicated that total B may be the governing parameter.

TC-4: Species dependence of L-H power threshold. A significant amount of work was performed on a number of devices to assess this very important ITER issue.

Device	Heating Method	H^+	He^{++}	Comments
AUG	H,D-NBI, ECH		1 x D	
C-Mod	ICRH		1.2-1.8 x D	
DIII-D	D,H, He-NBI, ECH	2 x D	1.3-1.5 x D	
JET	D,H,He-NBI, ICRH	2 x D	1.3 x D	Need to determine He/D mix
MAST	D-NBI		1.4 x D	
NSTX	HHFW		1-1.4 x D	Uncertainty in η_{HHFW}, definition of P_{th}

A wide variety of results were obtained. In all cases it appears that Helium will have a lower threshold than Hydrogen but it will probably be larger than for deuterium. In addition a number of 'other' variables are observed to significantly affect the threshold power level. These include, grad E_r, wall conditioning techniques (Boronization or Li evaporation), Divertor geometry and x-point location, location of fueling, SOL flows and rotation, as well as 3D effects.

TC-5: Transport dependence on T_i/T_e in hybrid and steady state scenarios
TC-6: Transport dependence on ExB shear and momentum input

Enhanced transport has been observed at low values of T_i/T_e during ECH heating. Difficult to separate this effect from rotation changes. The experimental r/L_{Ti} is found to follow ITG threshold scalings. Need experiments that can decouple Ti/Te, v_{phi} and grad v_{phi}.

TC-7: ITG/TEM transport dependence on T_i/T_e, q and rotation in L-mode plasmas.

JET performed experiments scanning q at high and low rotation values. Opposite behaviors of the R/L_{Ti} threshold with s/q were observed at high and low rotation.

TC-8: QH/QDB plasmas.

DIII-D was able to produce QH modes with co-NBI and extend the duration of QH plasmas at lower target densities. Mast was unable to obtain QH mode discharges with counter-injection.

TC-9: Scaling of intrinsic rotation with no external momentum input.

Additional data added to database from JT-60U, DIII-D, NSTX, JET and AUG. Trend remains the same, M ~ β_N. L-mode data base exhibits a different scaling, M~ I_p/n_e . Rotation inversion in L-modes was studied. Inversion observed when q~3. Inversion was found to change sign between limited an diverted discharges.

TC-10: Experimental identification of ITG/TEM/ETG turbulence and comparison with codes.

DIII-D experiments were performed in TEM dominated discharges. Also, a kappa scan was performed and n/T fluctuation cross phases were measured. Transport fluxes were underpredicted in the first two study. In the later study, cross phases consistent with the experimental measurements were found for the outer half of the plasma. On NSTX ETG predictions match the transport but not the observed k-spectra. On Tore-Supra, reasonable agreemnet between GYRO predictions and Doppler reflectometry and derived χ_{eff} were found in a standard case discharge.

TC-11: He profiles and transport coefficients.

New task which has begun with input from JET where He profile evolution with He gas puffing experiments were performed.

TC-12: H-mode transport at low aspect ratio.

New data from MAST are consistent with NSTX for I_p , B_T and ν^* scaling. Compared to conventional aspect ratio devices, stronger B weaker I and inverse ν scalinds are found. On NSTX χ_e was found to strongly deoend on j(r).

TC-13: ITG critical gradient and profile stiffness.

JET experiments used ripple to change and decouple Ω, grad Ω during ICRF heating. Indications of low stiffness in the behavior of R/L_{Ti} and q_i were found.

TC-14: RF rotation drive with ICRF, LH and ECH.

In C-Mod LHCD was found to drive a counter current rotation proportional to teh driven current. Also in C-Mod, mode conversion flow drive via IBW waves led to peaked co going v_ϕ and higher core T_i. On JET the same heating regime was found to drive a counter current rotation $\sim P_{rf}$. On JT-60U, the rotation direction was seen to change across the ECH absorption layer.

TC-15: Dependence of momentum and particle pinch on ν*

NSTX and D-IID studied the dependence of particle pinch on collisionality with a stronger dependence observed on NSTX although both sets of data were in agreement on the diffusivity.

Task 3: MHD, Disruptions and Control (Now ITPA TG on MHD Stability)

Resistive Wall Modes

NSTX observations of RWM onset at intermediate plasma rotation, and the measured rotation dependence of the n=1 plasma response in DIII-D, are both consistent with MISK code predictions of weaker RWM damping in the gap between precession and bounce frequencies. A DIII-D experiment (joint activity with JAEA) addressed the possible nonlinear relation between energetic particle-driven modes and RWM onset.

Non-resonant Magnetic Braking

Non-resonant magnetic braking results are becoming available from a wide range of machines, and validation of Neoclassical Toroidal Viscosity (NTV) models for rotation damping is in progress at DIII-D, JET, MAST and NSTX. In DIII-D, the NTV torque from n=3 perturbations can maintain a QH-mode even with zero NB injection torque. The n=3 torque shows a strong peak at low plasma rotation, in good qualitative agreement with NTM theory. On NSTX, significant variations were made to the ExB frequency to examine the effect on NTV braking, in plasmas with lithium wall preparation. The required criterion for $1/\nu$-regime torque scaling was examined with data over a wide range of the ratio $\nu_i/nq\omega_E$. With sufficient lithium, rotation damping at rational surfaces does not appear to cause surfaces to lock, suggesting an NTV torque effect. In MAST NTV torque from a naturally occurring mode removes the shear in the core rotation - a result that is quantitatively consistent with NTV theory.

Neoclassical Tearing Modes

Data is now available on the aspect ratio dependence of NTM behaviour from a joint IEA/ITPA experiment on AUG, DIII-D, MAST and NSTX. On AUG-MAST (3/2) and (2/1) NTM onset data have been collected, while on DIII-D-NSTX mainly (2/1) mode data has been collected. Onset β and marginal β-values are consistent with present theories relating the marginal island width and the ion banana width. On DIII-D, pre-emptive ECCD at q=2 was used to maintain stability of ITER demonstration discharges at ITER collisionalities and low rotation. Experiments in AUG and HL-2A have demonstrated ECCD destabilisation of fast ion-stabilised sawteeth (that could otherwise trigger NTMs); the AUG experiments used steerable ECCD. Experiments and modelling show ICRH destabilisation of NB-stabilised sawteeth in JET is a fast ion effect, not due to ICCD. Cross-machine scalings (DIII-D, NSTX and JT-60U) show a dependence of the 2/1 β-limit on rotation – the theory is not yet resolved.

Disruptions

Massive Gas Injection (MGI) experiments, for disruption mitigation, have been undertaken on AUG, DIII-D, MAST, JET and TEXTOR. The experiments on MAST show a 70% reduction of the power at the outer divertor strike point, using 10% Ar in He. TEXTOR experiments show a clear reduction in energy deposited on the limiter with Ne and Ar MGI, compared to He MGI and natural disruptions. A common feature is that the fuelling efficiency is found to be low for heavy gases, such as Ar. AUG achieved 24% of the critical density for runaway avalanche suppression. First results on injection of shattered cryogenic pellets were reported from DIII-D, with densities in the current quench comparable to the best MGI cases. The radiated power during MGI in C-Mod, JET and DIII-D shows strong poloidal/toroidal asymmetries at the start of gas injection, but the power soon symmetrises. Analysis of the plasma current decay time during JT-60U disruptions shows the importance of the time derivative of l_i for positive and reversed shear plasmas.

With regard to future plans from June 2010 to May 2011, it is expected that joint experiments on Disruptions, Neoclassical Tearing Modes, Resistive Wall Modes and non-resonant magnetic braking will continue, together with the related exchanges of personnel.

Task 4: Edge and Pedestal Physics (Now ITPA TG on Pedestal)

Collaborative work on ITPA-IEA joint experiments was performed for the following topics.

PEP-1 + 3: **Dimensionless identity experiments in JT-60U and JET: studies of ripple effects and rotation** No new experiments have been carried out, but analysis has continued. In particular, under the IEA/LT framework (JE152), H. Urano (JAEA) visited JET for the analysis and discussion of results inter-machine experiment between JET and JT-60U. The comparison of JET and JT-60 results highlights that pedestal conditions may be crucial for ripple effects, consistently with JET results showing that low collisionality plasmas are more sensitive to ripple. Tests of models for the interpretation of the particle pump-out are ongoing. *The results of the analysis will be presented at the coming IAEA conference under a joint paper Comparison of pedestal characteristics in JET & JT-60U similarity experiments by H. Urano, G. Saibene, N. Oyama, V. Parail, P. de Vries, R. Sartori, Y. Kamada, K. Kamiya, A. Loarte, J. Lönnroth, Y. Sakamoto, A. Salmi, K. Shinohara, H. Takenaga, M. Yoshida, the JT-60 Team and JET EFDA Contributors*.

PEP-2: Pedestal gradients in dimensionally similar discharges and their dimensionless scaling

In 2009 PEP-2 experiments were carried out in all three devices. Both JET and DIII-D have finished a full ρ* scan at low triangularity (~0.25) and high triangularity (~0.4). AUG has carried out initial experiments to match the JET and DIII-D plasma shapes. Main results are that (a) T_e and n pedestal widths do not depend (or only very weakly) on ρ*, misalignment of the pedestal density with respect to pedestal T observed, but only in DIII-D, (b) DIII-D experiments show a strong positive ρ* scaling of ELM size; this is not observed in JET. The effect of input power (relative to the L-H threshold power) is being investigated. *In 2010, experiments are planned in AUG (ρ* scan) and in, DIII-D. DIII-D will study scaling of ELM size with ρ* by investigating the effect on ELM size of proximity to the L-H threshold power, as well as further experiments (fine β scans) to clarify the dependence of pedestal width on βp and other variables.*

PEP-6: Pedestal Structure and ELM stability in DN No new results were reported.

PEP-19: Basic mechanisms of edge transport with resonant magnetic perturbations in toroidal plasma confinement devices

Experiments on DIII-D, MAST, NSTX and TEXTOR have been performed to address the basic transport physics issues associated with resonant magnetic perturbation fields. These experiments and the experimental comparison focused on three topics:

(a) Pedestal structure and transport with RMPs and relation to ELM suppression: A reduction of the pedestal electron pressure was measured in ITER-shaped H-modes in DIII-D, consistent with a field line pitch resonance. Based on vacuum magnetic field modelling it was shown (consistent with TEXTOR results that the resonant feature of this pressure reduction is driven by a near field pitch angle alignment of the magnetic field lines with the RMP coil leading to a resonant change in the edge magnetic topology and a strongly q_{95} resonant pedestal temperature reduction while the density pump out does not show a strong q_{95} sensitivity within the $3.2<q_{95}<4.1$ range investigated. This provides further support for the applicability of this paradigm as an effective modelling approach for extrapolating RMP effect to ITER. However, the ELM suppression window does not match the widest extension of the stochastic layer and the resultant strongest pedestal pressure reduction. On the contrary, ELMs can be suppressed for rather moderate pressure reduction and considerably smaller stochastic layer extent. MAST attempts to suppress ELMs in double null H-mode plasmas with a RMP spectrum causing island overlap just below the DIII-D engineering design Chirikov criterion did not show ELM suppression and furthermore, no noticeable reaction of the plasma in terms of density pump out, strike point splitting or rotation was observed *Further experiments comparing DIII-D and MAST experiments are planed with the completed internal coil set at MAST and increased NB heating capabilities.*

(b) Density pump out with RMP: At MAST density pump out was found in L-mode plasmas accompanied or caused by enhanced edge turbulence and an increase in the radial electric field. Modelling of these experimental observations qualitatively reproduced the density pump out in L-mode and shows a clear dependence of the pump-out magnitude on density. At DIII-D a series of L-mode experiments in high field side limited, weakly shaped and lower single null, high triangularity plasmas with the RMP spectrum typically applied for ELM suppression have been performed. Density pump-out was measured in both shapes, but only if τ_p* is used to quantify particle confinement. This was suggested by TEXTOR studies on density pump-out and the dependence of τ_p on the detailed RMP spectral properties and related field line trajectories. Here it was shown that at high local resonant field amplitudes on the dominant resonant surfaces a density pump-out is obtained which grows above a threshold linearly with the perturbation field. Below this threshold an increase in the density and τ_p was measured connected to an increase in the radial electric field shear and a decrease of the turbulence on this resonance. Plasma fluid and neutral transport modelling with the EMC3-Eirene code based on the vacuum paradigm was accomplished after 2 years of development and revealed in detail the reflection of the three-dimensional magnetic topology in the plasma structure and the non-turbulent particle flows. The impact of RMP driven transport changes on heat and particle exhaust have also been modelled with this code. Detailed experimental investigation of RMP effects on particle transport and changes in the global particle balance were carried out in high purity helium (He) plasmas at TEXTOR and subsequently at DIII-D. Initial analysis indicates control of the exhaust properties, i.e. the external pumping efficiency without wall pumping by the perturbed magnetic boundary. Evidence for mitigation of ELMs in helium H-mode plasmas at DIII-D was found as an important input for ITER, planning on using helium as operating gas during the non-active phase.

(c) Particle and heat flux measurements on the divertor surfaces in relation to the magnetic topology: The striation of the divertor heat and particle fluxes was investigated at all devices involved. In L-mode plasmas at TEXTOR, DIII-D and MAST, striation of heat and particle fluxes was found and the relation of the location of the striated fluxes and the width of the splitting was compared to vacuum magnetic field line tracing. At DIII-D the measured fluxes are in fair agreement with vacuum field line tracing for low collisionality H-mode plasmas and in lower single null L-mode discharges. However, high collisionality H-mode plasmas show a significant wider experimentally measured splitting in the divertor heat flux. This apparent contradiction is still under analysis. At MAST, striated heat flux patterns were observed in L-mode and the width and location matches the vacuum predicted location. At NSTX, heat flux striation was also observed. Detailed comparison between machines is planned for future to reveal the exact information which can be extracted from the separatrix lobes occurrence in terms of magnetic and plasma transport response.

PEP-21: The spatial and temporal structure of Type II ELMs

The operational space for access to small ELMs on MAST has been established. This parameter space is very similar to the region in which Type II ELMs are observed on ASDEX Upgrade so there is a strong likelihood that the two ELM types are linked. Following repairs to the EZ4 flywheel generator on AUG the Type II ELM regime has been re-established. The radial propagation of the ELMs on both devices has been measured and analysis is ongoing.

PEP-22: Controllability of pedestal and ELM characteristics by edge ECH/ECCD/LHCD

No report received; no new experiments carried out.

PEP-23: Quantification of the requirements for ELM suppression by magnetic perturbations from internal off mid-plane coils

ELM suppression has not been established on MAST, but it has been possible to increase the frequency of Type I ELMs by a factor of 5 and mitigate the ELM energy loss by carefully tuning q_{95}. Vacuum modelling shows that the q_{95} scan performed has little effect on the Chirikov parameter profile but rather that it maximises the normalised component of the resonant field suggesting that on MAST this may be the more critical parameter. ELM suppression experiments on DIII-D in April 2010 (see also PEP-19 report) used balanced double null (DN) plasmas (similar to the MAST CDN configuration). Previous attempts to obtain ELM suppression in DIII-D DN plasmas were unsuccessful although ELM mitigation (increased frequency low amplitude ELMs) was obtained. The goal of this experiment was to maintain very well balanced discharges during the RMP pulse since previous experiments suffered from difficulties with precision control of the shape in the DN configuration. Although very good shape control was successfully maintained, no ELM suppression or density pump-out was observed. Although it is possible that some indications of an ELM suppression window were seen at high q_{95}, well outside the usual ELM suppression window in ITER. Similar Shaped plasmas. In general, when RMPs are applied to these DN plasmas there is a large density pump-out and small high frequency ELMs (possibly Type IV ELMs) appear in place of Type I ELMs. *Comparisons of the DIII-D and MAST RMP experiments in DN plasmas will be performed to see if the density pump-out and ELM behaviour is similar in the two machines.*

PEP-24: Minimum pellet size for ELM pacing

At AUG, penetration to at least the pedestal top was found necessary for small LFS injection to trigger ELMs. The HFS centrifuge launch system is under re-commissioning. A study on room temperature solid pellets showed C and B are good materials to mimic Be pellets in ITER. JET confirmed pellet pacing in a large tokamak. Smallest achievable pellets were found already below a size threshold for ELM triggering. This threshold was reached in the baseline scenario for 1-3 10^{19} D pellet particle content, correlating with pellet penetration to about pedestal top. The first ELM filament was found to develop from the ablation plasmoid. This filament can cause an additional impact zone in the divertor and the first wall. DIII-D confirms this finding, higher spatial resolution of the camera system showed filament formation in front of the LFS pellet. This is interpreted by the steeper pressure gradient causes the trigger. Small pellets were found to increase the intrinsic ELM frequency even beyond the pellet rate. Pellet ELMs show less energy losses than spontaneous ELMs during this phase. Penetration of only about 1cm was required to release the ELM.

AUG plans until the end of 2010 to bring the centrifuge system for pacing using modest pellet sizes but high repetition rates back into full operation. As well, tests for launching single room temperature pellets in order to investigate their ELM trigger potential is planned. JET has requested re-commissioning of the HFPI in order to reach design criteria (50Hz repetition rate for pacing size pellets) before March 2011. Experiments for the campaigns following Restart with the new ITER-like Wall expected from summer 2011 are under discussion. DIII-D intends to modify the existing injector by spring 2011 to obtain smaller pellets at higher rates. An additional injection line will be installed to mimic the ITER approach. MAST envisages installation of a launcher capable to inject rather fast (>250m/s) LFS pellets but limited to ~3 pellets per pulse.

PEP-25: Inter-machine comparison of ELM control by magnetic field perturbations from midplane RMP coils

ELM control experiments have been performed on JET aiming at a better understanding of the plasma response to the magnetic perturbation: (a) splitting of the outer strike point in L-mode plasma has been observed with n=2 fields on JET when field penetration occurs; (b) compensation of density pump-out has been achieved with either gas fuelling or pellet injection. However, no recovery of energy confinement has been observed; (c) complete ELM suppression was not obtained by application of n=1 or n=2 fields with a Chirikov parameter larger than 1 at $\Psi_{pol}^{1/2} > 0.925$ which is one of the important criteria for the design of ITER ELM suppression coils; (d) multi-resonance effect on q_{95} in ELM control with a low n (1 and 2) magnetic perturbation field has been observed. The mechanism of edge ergodisation, which is used to explain the results of ELM suppression with n=3 field on DIII-D, may explain the global effect of the n=1 field on ELM frequency, but it cannot explain the multi-resonance effect observed with the low n fields on JET; (e) the amplitudes of the observed torque are between the NTV torque in the $1/\nu$ and ν regimes. The collisionality dependence of the observed RMP torque is similar to the NTV torque in the $1/\nu$ regime; (f) a new in-vessel ELM control coil system (8+24 coils) has been designed. The NTV torque calculated from both MAST (n=3 field) and TEXTOR (m/n=6/2 field) are small, which is consistent with the experimental observations. A large plasma rotation braking has been observed on MAST with n=2 field induced by EFCCs. A quantitative measure of spectral quality (Figure of merit) has been used for comparison with different devices. *Additional joint experiments for completing the database are planned. These include (a) the investigation of the q_{95} dependence (the multi-resonance effect) on ELM control with RMP fields on other devices (MAST, AUG, NSTX, TEXTOR); comparison of the plasma braking by the low n perturbation fields with NTV theory in the super-banana plateau regime for JET, MAST, AUG, TEXTOR; and (c) investigation of the magnetic spectrum dependence of ELM control for JET, DIII-D, MAST, NSTX, AUG, TEXTOR. Combining the experimental results with modelling and making a more detailed comparison of the experimental results on the devices will be carried out in parallel with experiments over the next years.*

PEP-26: Critical edge parameters for achieving L-H transition
Experiments have been performed on several devices in 2009/2010. On ASDEX Upgrade the influence of decoupling electrons and ion has been studied in ECR heated low density discharges. On Alcator C-MOD the pedestal saturation mechanisms in EDA H-modes has been investigated during L-H transitions in discharges with high plasma and neutral density. On MAST the evolution of profiles before and during the L-H transition has been measured with high time resolution on the order of 200µs for Te, ne and Er. There is evidence that the ne profile evolves on a faster time scale than the Te profile, and fluctuations seem to be suppressed on even faster time scales. On NSTX L-H transitions at low power have been studied showing that the differences of edge parameters before the L/H transition are subtle at best. *Analysis of these experiments is on going with more experiments on all devices planned or proposed*.

PEP-27: Pedestal profile evolution following L-H transition
The aim of this PEP is to characterise the build-up of the density and temperature pedestals, their saturation and associated evolution of core plasma parameters with P_{in}/P_{thr}~1. In these experiments, special emphasis is required on fluctuation measurements. Currently existing data are analysed (not from dedicated experiments).
AUG: Experiments in the Oct-Dec 2010 campaign. MAST: Experiments with increased spatial resolution in 2011. JET, C-MOD, DIII-D: Proposals for 2011 will be submitted.

PEP-28: Physics of H-mode access with different X-point heights
The effect of X-point height and divertor structure has been observed on many devices. In 2009/2010 dedicated experiments were done on MAST and circumstantial evidence was collected on Alcator C-MOD, DIII-D and NSTX. On MAST an increase of the power threshold by about a factor 2 to 3 higher injected power is needed to access H-mode if the X-point height is increased by about 10cm in 0.75MA SN discharges. *Data analysis remains to be completed and experimental proposals will be put forward for the experimental planning of ASDEX Upgrade, C-MOD, JET, MAST, and NSTX for their forthcoming campaigns.*

Task 5: SOL and Divertor Physics

The LTA report on confinement SOL and divertor physics consists of the description of reports on ITPA led activities in this area. Below are the major ITPA elements associated with this task agreement, spanning the period June 2009 – April 2010.

Recovery of tritium from co-deposits. For H/Be co-deposits with low C fractions (below a few %) the co-deposits act like pure Be in that ~90% of the H can be desorbed at bakes of 350C. Oxygen baking at 350C results in C and H removal from co-deposits but no removal of Be. Heating of surfaces to high temperatures (1000C) may be feasible by moving the plasma wetted surface around the chamber, strike point sweeping and heating during disruptions (planned and unplanned). Oxygen-radicals produced by ECR discharges appear to be efficient at removing C from gaps (as opposed to surfaces where O bake is more efficient).

Dust behaviour. Dust injected on a number of tokamaks (e.g. MAST, DIII-D, TEXTOR) indicate a dependence of the trajectory on the mass/Z of the material. Initial modelling studies reproduce a number of the dust trajectory characteristics but apparently there are still too many unknowns. For proper comparison with modeling more effort is needed to develop injection at a known velocity/direction and to make sure a 3D trajectory can be followed by appropriate stereoscopic views. The study of the mechanisms for dust generation is in much poorer state due to lack of diagnostics. Examination is needed of how the dust collected correlates with events in the plasma.

Be sputtering yield database. The ITPA DIVSOL TG reviewed all available information on Be erosion derived from studies in tokamaks and in dedicated laboratory experiments. The results are in poor agreement which means predicting the lifetime of the Be wall in ITER and the contribution of wall erosion to tritium co-deposition has very large uncertainties. Further laboratory studies are required, together with the upcoming work within the JET ILW programme. An informal collaboration was initiated between UCSD, Sandia-Livermore and FOM to investigate Be erosion mechanisms. In addition, the wall migration experiments planned for EAST (driven by the IO) should help bring new information to benchmark code material migration calculations being performed for ITER.

Tungsten melting. Regarding use of W at the ITER strike point region, where melting is very likely, the question of melt layer dynamics and effect of eroded W on the core plasma has received more emphasis recently. Modelling of melted W surfaces observed in TEXTOR are consistent with thermal emission current moving the melted W up the tile (i.e. against gravity) as seen experimentally. The poloidal movement of the W is consistent with JxB motion, with no bridging of gaps observed. The re-solidified W exhibits poor structure (e.g. holes inside). Initial experiments on the effect of a divertor-localized W source (ASDEX-Upgrade) show minimal effects on the core plasma but there is no way at present to scale this small source to a melted tile in ITER. More experiments are required both in melt layer dynamics and effect on the core. A number of new W materials (alloys, or specially prepared W) are available on which more research is needed.

Disruptions. Even though several tokamaks have recently expanded their IR coverage of the main chamber, the results are sparse on power flows during disruptions. In addition, the variation of power and energy deposition can be very large, even within one machine; DIII-D reported a range of 3 orders of magnitude in the divertor power loads during the thermal quench for different kinds of disruptions with beta limit disruptions being the worst. It is now becoming clearer that for many major disruptions, (but not including high-β cases), a significant amount of the disruptive energy is not deposited in the divertor. This is encouraging for ITER since the thermal load specifications for the divertor can be somewhat relaxed, but worrying for the main chamber, where the ITER Be surfaces have lower damage thresholds under transient loads. An example of such observations is provided by the new IR system on JET, which indicates that first-wall energy deposition during a disruption can approach that of the divertor as the power flow profile in the SOL broadens.

Disruption mitigation. There has been a significant enhancement of diagnostic capability over the last year, resulting in studies of toroidal and poloidal asymmetries in the induced radiation following massive gas injection (MGI). There is overall agreement that MGI can significantly reduce localized, conducted heat loads to the first wall and divertor. AUG, JET, and DIII-D all report that the injected impurities are swept by poloidal drifts over the top (crown) of the plasma toward the inner wall. This raises the concern that a repeatable "hot spot" may form. ITER currently envisages the most intense radiative activity to be concentrated around the gas injection location, which these new results appear to contradict to some extent. Nevertheless, results presented from C-Mod showed clearly that the toroidal asymmetry of the thermal quench radiation flash is quite variable, suggesting that repeated radiation flash heating of a single wall location during the TQ is unlikely. More fast bolometry of MGI shots should be performed. Simultaneous MGI at two different toroidal locations should be attempted if possible - this has not yet been done and would help ITER verify that radiation flash heat loads can be distributed by going to more than one MGI port.

Limiter plasma SOL profiles. On the basis of SOL profile measurements (Tore Supra and DIII-D dedicated experiments) the important ITER assumption of significantly broadened profiles for inboard versus outboard limiter configurations is clearly verified. However, the scaling of power widths with key plasma parameters assumed by ITER is not found in these experiments. The Tore-Supra results, which included excellent edge T_i data, demonstrate how important this quantity is in determining the power flow channel.

Unmitigated ELM loads. More information is needed on ELM power flows to main chamber surfaces, including the scaling of this power flow with relative ELM size. Dedicated experiments have been performed upon ITER request in the last year to look at secondary divertor power deposition. Results are still under analysis (from DIII-D and TCV), but do show that ELM filaments can deposit energy far from the secondary strike line, in accord with the ITER assumption. New main chamber ELM energy deposition data from JET (higher temporal resolution) are consistent with the previous findings of a rough $(\Delta W_{ELM}/W)^{1/2}$ dependence of wall energy deposition. Impressive new JET divertor IR measurements also indicate a broadening of the heat flux profile with ΔW_{ELM} consistent with the main chamber observations, though this is seen to occur only for much higher relative ELM sizes than ITER can tolerate. The question of how these observations scale to ITER (high density, but low collisionality) remains open.

Task 6: Steady State Operation

The following joint experiments are coordinated by the IOS-TG:
IOS-1.1: ITER baseline, at q_{95}=3, β_N=1.8, $n_e \leq 0.85 n_{GW}$
IOS-1.2: Study seeding effects on ITER baseline discharges
IOS-2.1: ECRH breakdown assist at 20^o toroidal angle
IOS-2.2: Ramp-down from q_{95}=3
IOS-3.1: Beta limit for AT with ITER recommended q-profile.
IOS-3.2: Define access conditions to get to SS scenario
IOS-4.1: Access conditions for advanced inductive (hybrid) scenario with ITER-relevant restrictions
IOS-4.2: ρ* dependence on transport and stability in hybrid scenarios
IOS-5.1: Ability to obtain and predict off-axis NBCD
IOS-5.2: Maintaining ICRH coupling in expected ITER Regime
IOS-6: Modulation of actuators to qualify real-time profile control methods for hybrid and steady state scenarios

Significant progress was made in the period June 2009 to May 2010 in view of development of integrated operation scenarios for ITER.

For the ITER baseline scenario (**IOS-1.1 and IOS-1.2**), JET operation in stationary type-I ELMy H-mode at q_{95}=2.7-3 was extended to 4.5MA with H_{98}=0.9-0.95, where 1.3-2 times the L-H threshold power P_{L-H} was required. DIII-D long pulse operation at q_{95}=3 showed n=1 modes appearance after 2τ_E and stability boundary for the modes can be measured by neither β_N nor l_i. P_{L-H} in helium was ~1.3-1.5 times larger that in deuterium in DIII-D and 1-1.4 in JET. Confinement was significantly lower in helium by 40-50% than in deuterium in JET and DIII-D. Ar seeded radiative divertor was studied in combination with ELM control by RMP in DIII-D. Re-emergence of ELMs at higher gas-puff rates may account for the apparent similarities in core argon accumulation between RMP and comparable non-RMP discharges. With nitrogen seeding in JET, ITER-acceptable type III ELMs were realized.

On ECRF assisted startup (**IOS-2.1**), ECRH assisted breakdown in X2-mode was found to be possible with toroidal injection angle of 20^o in DIII-D, AUG, KSTAR and TJ-II. The required power was similar or slightly higher as compared to perpendicular injection.

On ramp-down from q_{95}=3 (**IOS-2.2**), JET performed a series of ramp-down experiments in helium, since experiments in deuterium was already done in 2008. Plasmas with moderate heating power kept l_i(3) below 1.3 and in some examples ramp down with H-mode phase was obtained. ITER-proposed ramp-down scenario starting with a slow ramp-down in H-mode was performed in DIII-D. The DIII-D experiments show that the proposed ramp-down rate must be increased to avoid flux consumption in CS. DIII-D results also show the importance of an aperture reduction to the reduction in density to avoid density limits. DIII-D did a 17 MA simulation discharge for ITER with no additional problems to ramp-down.

For the ITER steady-state operation scenarios (**IOS-3.1 and IOS-3.2**), existing data from 2008 JT-60U experiments (H_{98}~1.7, β_N~2.7, f_{BS}~0.92, f_{CD}~0.94, $n_e/n_{Greenwald}$~0.87, q_{95}~5.3) was analyzed. The q profile is similar to the ITER scenario except higher central q~10 due to transient phase. Stability analysis using MARG2D indicates ideal wall beta limit was 2.9. On DIII-D, systematic scans on q_{min} and q_{95} were performed, investigating dependence of the temperature and density profiles on the q profile. Systematic variation of temperature profile with q was found while density profile seemed to be determined primarily by the H-mode pedestal. The maximum achieved β_N decreased from 3.8 to 3.1 as q_{min} was increased from 1 to 1.7 at q_{95}=6.8 and decreased from 3.6 to 3.4 as q_{95} decreased from 6.8 to 4.5 at q_{min}=1.5. Maximum achieved β_N was mostly 10-20% below the n=1 ideal wall stability limit. In JET, both q_{min}~1 and q_{min}~2 scenarios using I_p overshoot technique was investigated. Stability and confinement was reproducibly good in q_{min}~2 (H_{98}~1.25 and β_N up to 3), and very good at q_{min}~1 (H_{98}~1.4 and β_N up to 3). The beta limits in both high and low q_{min} scenarios do not appear to be due to RWM, but NTM at m/n=2/1 and 3/2, respectively.

For the ITER hybrid (or advanced inductive) operation scenarios (**IOS-4.1 and IOS-4.2**), access condition (new for 2009) in terms of q profile is independently investigated in various devices. JET used I_p overshoot technique to broaden the q profile, while DIII-D used a change of shape. DIII-D is going to test the I_p overshoot in 2010. On transport and stability (IOS-4.2), specific joint experiments were performed on DIII-D (May 2009) and JET (October 2009). The combined JET and DIII-D range in ρ^* was about 3 with these experiments. The on-going analysis shows that a similar plasma regime (type I ELMs, no ITB etc.) has been achieved on both DIII-D and JET despite differences in operation techniques and comparable H_{98} was observed. The preliminary indication from the 0-D analysis is that the ρ^* dependence is closer to the Bohm scaling. Local transport analysis using the database is progressing.

On off-axis NBCD (**IOS-5.1**), analysis of experiment in 2008 in AUG showed anomalous fast ion transport. Analysis of 2008 JT-60U experiment showed peak in the off-axis NBCD roughly agreed with calculation. DIII-D finished analysis in 2008.

On ICRF coupling (**IOS-5.2**), it was found in JET that coupling perturbation was minimized during ELMs at larger antenna-plasma gap and that coupling was improved by injecting D_2 gas. In DIII-D ELMy H-mode plasma, no evidence that ionization due to antenna near fields is significant and difference between results obtained by puffing from near antenna and plasma top were subtle.

On modulation of actuators for real-time profile control (**IOS-6**), data analyses were completed in JET and JT-60U, and there was no new experiment. DIII-D experiment was performed using co-/ctr-/balanced-NBI, ECCD and possibly loop voltage as independent actuators, and it appears that sufficient data for system identification was obtained.

Concerning personnel exchange, C. Challis and E. Joffrin (EU) visited DIII-D for IOS-3&4 in March and May 2009, P. Politzer and T. Luce (US) remotely participated in JET for IOS-4.2 in October 2009, D. Moreau (EU) visited DIII-D for IOS-6 in

November 2009 and J. Hobirk (EU) visited JT-60U for IOS-5.1 in January 2010.

Task 7: Tritium and Remote Handling Technologies

The practical development of methods for de-tritiation of first wall components has concentrated on the nature of the by-products of the process. Removal of films by laser ablation results in the generation of dust from film break-up containing part of the fuel originally in the film; this dust will have to be collected, for example with a vacuum cleaner. Developments are being co-ordinated between EFDA-JET and the EFDA Emerging Technology and System Integration Task on dust and tritium control. In June 2009 laser ablation was used in the JET Beryllium Handling Facility to remove films from mirrors exposed to JET discharges during the period 2004-2007. The laser power thresholds for removing deposited films and substrate material had been explored previously, so that power levels were set nominally to remove deposits but not damage the substrate. Up to 90% of the reflectivity was restored in the near infra-red, but only 20-30% at 400nm. Some substrate damage was observed, so more optimisation of laser parameters is required.

Surface analysis of plasma facing components from JET

Tiles removed during the 2007 Shutdown have been analysed by Ion Beam Analysis and SIMS; amounts of deposition (including ^{13}C) have been assessed. A successful $^{13}CH_4$ puffing experiment was carried out on the last day before the 2009/10 Shutdown for the installation of the ITER-like Wall (ILW). It has already been determined that 33% of the injected $^{13}CH_4$ did not react inside the vacuum vessel but was pumped by the divertor cryopumps. During the Shutdown, all the plasma-facing surfaces will be removed, giving the opportunity for a more comprehensive analysis of the retained ^{13}C. Tiles removed from the vessel will also be analysed for erosion, deposition and H-isotope retention.

A programme of dust collection from the JET divertor was completed at the start of the ILW Shutdown. The dust samples collected from various regions of the divertor will be weighed separately; the samples will then be available for further characterisation. This provides an opportunity for a detailed assessment of deposition in a carbon-based tokamak, for a future comparison of deposition with a metal-walled tokamak, and to provide data for the ITER Safety Case.

Marker layers for the ILW W-coated divertor tiles (a 4µm Mo layer on the W coating with a 4 µm top-coat of W) have been produced and characterised, and the marker tiles for Be substrates (using a Be coating on a nickel interlayer) are being progressed. Be tiles with a ^{10}Be tracer have also been developed. All the markers are designed to assist in measuring erosion/deposition and transport in the ILW to support modelling for ITER.

Task 8 Other: Negative Ion Neutral Beam Technology

Dr. Grisham made four trips to collaborate with the negative ion beam groups at JAEA during the course of the past year. As in previous years, the principal thrust of this collaboration is to understand the physical mechanisms which have limited the performance of negative ion neutral beam systems, and to use this knowledge to improve future systems.

Most of the work this year was focused on finding ways to improve the voltage holding in accelerators of the sort being developed for the ITER and JT-60SA negative ion neutral beam systems, and on the design and validation of a beamlet steering concept for the JT-60SA and ITER accelerators. Improved modeling of accelerator geometries planned for these devices is now showing that, with the large acceleration gaps required for voltage holding in high voltage negative ion accelerators, each beamlet is influenced by the electric fields from many other beamlets as well as from the accelerator support structure. This means that any change to any part of the accelerator structure can easily affect the overall focusing of the total beam envelope. This requires either very careful control and optimization of the accelerator and the accelerator support structure, or alternatively, finding a way to reduce the size of accelerator gaps through improved voltage holding. A concept, magnetic insulation, was developed for doing this, as well as improving the operability of accelerators such as those needed for ITER, but it requires testing on a high voltage component test facility before it can be incorporated into accelerator designs.