High Priority Research Tasks 2008-2009 (DRAFT for discussion at ITPA CC 2008)

Proposed by SOLDIV TG	Requested by IO

• **Improve understanding of Tritium retention and development of efficient T removal methods.**
Compile high-Z experience regarding hydrogenic retention in tokamaks and laboratory studies (new)
Initiate studies on neutron damage and how that leads to T retention (new)
• **High-Z operational experience (compatibility with core)**
Exposure of tungsten to He fluence and effects on surface properties (new)
Characterize the level and processes involved in RF enhancement of erosion (new)
	• A range of PWI issues will need to be resolved to build confidence that reliable operation can be sustained:
	  • establishment of requirements for carbon/ carbidic compound removal at divertor changeout (eg need to identify distribution of redeposited material)
	  • T-retention in W/ Be and their compounds, including neutron irradiation effects
	  • tungsten/ beryllium material damage and dust production rates (steady-state, transients)
	  • performance of Be-coated tungsten PFCs
	  • development of modelling capability for beryllium and tungsten PWI simulation
	• When are results required?
	  • early quantitative information on key safety-related questions (T-retention, dust production) would be important - ie 2-3 years
	  • should aim for a complete picture of W/ Be PWI issues on 5 year timescale

• **Understand the effect of ELMs/disruptions on divertor and first wall structures** Exploration of the effect on the SOL and power loadings of ELM mitigation (ongoing) Study runaway effects in disruptions and how to nullify them (new)	• a validated <u>modelling capability for runaway generation and loss</u> to allow an improved assessment of first wall energy deposition • An improved assessment of SOL width and local power deposition during disruptions/ VDEs, including limiter plasmas • improved data and analysis within the next 12 months would be valuable
• **Improve measurements & understanding of plasma transport to targets and walls to better predict heat loads and effects on the core** Code-code comparisons including impurities - specifically carbon (underway) Identify discrepancies between codes and experiment for SOL and divertor (new)	
• **High-Z operational experience (compatibility with core)** Exposure of tungsten to He fluence and effects on surface properties	

(new) Characterize the level and processes involved in RF enhancement of erosion (new)	

Proposed by PEDESTAL TG	Requested by IO
1. Improve predictive capability of pedestal structure 1-1: Test pedestal poloidal beta and ν^* scaling of pedestal width across devices and parameter regimes; develop the theoretical basis for this scaling 1-2: Establish pedestal conditions required for L-H transition through cross machine experiments and theory 1-3: Examine role of neutral penetration length on pedestal density width 1-4: Determine compatibility of divertor detachment and robust pedestal pressure 1-5: Incorporate comprehensive neoclassical and turbulence transport models into pedestal simulation codes	

2. Improve predictive capability for small ELM regimes, quiescent H-mode regimes and ELM control techniques
2-1: Validate physics basis for ELM control by pacing; i) minimum size and penetration for ELM triggering and ii) pedestal transport following high frequency pellets
2-2: Compatibility of high frequency pellet triggered ELMs with ITER operation; i) robust H-mode pedestal, ii) core fueling, and iii) divertor heat flux control
2-3: Validate physics basis for ELM control by Resonant Magnetic Perturbations (RMP); i) collisionality threshold, ii) rotation dependence, iii) magnetic mode spectrum optimization, iv) plasma response and v) effect on pedestal stability
2-4: Compatibility of RMP ELM control with ITER operation; i) pedestal degradation, ii) pellet fueling, iii) divertor heat flux control, and iv) L-H transition power threshold
2-5: Develop physics of ELM dependence on toroidal field ripple and rotation
2-6: Assess applicability of low collisionality small ELM regimes; Grassy ELMs and QH-mode
2-7: Develop and test nonlinear MHD and turbulence models of ELM evolution
	• It is essential to demonstrate that ITER will have adequate ELM control capability
	• An extensive R&D programme proposal has been prepared to address the key physics issues in this area, including:
	    • confirmation that the systems foreseen for ITER can provide required control at ITER parameters
	    • impact of control techniques on ITER fusion performance is acceptable
	    • exploration of alternative approaches to ELM control to provide backup techniques in case limitations found in primary techniques
	• When are results required?
	    • To give confidence that ITER has adequate ELM control capability, R&D results needed in next 2-3 years - feeds back to high level decision making
	    • If alternative approaches require system upgrades, results probably needed in next 2-3 years
	• Typical R&D questions in programme assembled by Pedestal TG:
	  • specification of requirements for RMP suppression of ELMs in ITER
	  • requirements for pellet parameters for ELM pacemaking in ITER
	  • interaction between different ELM control techniques

	• impact of ELM control on edge pedestal and resulting core plasma performance (Note: Psep/ PLH < 2) • analysis of potential deleterious effects on fuel, impurity and energy transport, core rotation, mode locking … • quantitative analysis of potential of alternative ELM control techniques

Proposed by Transport TG	Requested by IO
Develop an improved characterization of the L-H transition threshold: • Species • Toroidal field • Density, including low density limits • Effect of rotation on threshold power • Confinement enhancement above threshold	• Access to the H-mode in the non-active phase is problematic, with significant implications for overall structure of the ITER Research Plan: Timescale ~2 years – Robust H-modes probably not achievable in hydrogen plasmas – Confirmation of recent results from helium H-mode studies in JET (PLH,He ~ 0.7×PLH,H), would open access to H-mode operation in the non-active phase
Global Confinement • Determine effect of shape, edge stability on beta scaling of confinement • Determine confinement dependences in Hybrid discharges	•
Particle and impurity transport: • Define parametric dependences of density peaking over a wide range of conditions • Understand local particle transport and pinch processes • Examine correlations between impurity and main ion density profiles	
Electron transport: • Resolve role and importance of ETG vs coupled ITG/TEM/ETG • Assess role of electromagnetic fluctuations in driving electron transport (low- and high-frequency) • Demonstrate and understand through modeling and theory reduced electron transport regimes with dominant electron heating	
Ion thermal transport • Understand source of ion transport under various conditions, including regimes in which neoclassical transport dominates • Assess role of rotation in suppression of low-k turbulence • Increase test/model validity to plasmas with ITBs and other enhanced confinement regimes	
Momentum transport and plasma rotation: • Improve characterization and understanding of rotation sources, especially with regard to intrinsic rotation • Determine momentum pinch velocity and their relation to theory	

• Assess and understand effects of rotation on barrier formation	
Barrier formation • Assess rates of internal and edge barrier formation in support of ITER control system development • Develop understanding of triggering mechanisms (e.g., rotation vs q-shear)	
Model validation • Assess validity of physics-based transport models for basic understanding and in support of ITER scenario development • Incorporate turbulence measurements for comparison to synthetic diagnostics • Spans all regimes mentioned above	

Proposed by Integrated Operation TG	Requested by IO

Joint experiments: Focus on qualifying candidates for ITER scenarios. (2009, include full ITER scenario demonstrations)

The breakdown, current rise and ramp down of ITER. Joint experiments and code simulations : recommendations for ITER

- Extensive R&D required to establish physics basis for ITER reference scenarios with W/ Be PFCs:
    - development of current ramp-up/ ramp-down scenarios (with/ without additional heating and impurity seeding)
    - high performance H-mode scenarios with impurity seeding, ELM control etc
    - core impurity control, particularly in ITB scena***rios***

    Above three can be implemented in joint experiments. Needs collaboration with Transport and SOL/Div TGs.

    - impurity production with ICRF

    Needs to be discussed with SOL/Div TG.

    - control of ELM-produced impurities
    - operation with melt-damaged tungsten components

    Not in our scope.

- When are results required?
    - basic elements of operational scenarios should be assessed on 2-3 year timescale
    - more detailed aspects would need answers on 3-5 year timescale to allow time to analyze implications for ITER operation
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- Current ramp-up phase: timescale: <1 year
    - optimization of the current ramp-up is critical for preparing a plasma burn lasting ~400s
    - require validation of assumptions on plasma transport, impurity content, flux consumption, stable li operating space to validate redesigned reference scenario
- Current ramp-down phase: timescale: <1 year
    - careful balance involving current decay rate, flux consumption, li variation, auxiliary heating, density pump-out, power load on limiter after X-to-L transition
    - require experimental input on issues such as sustaining of H-mode in ramp-down phase, maintenance of X-point in decay,

Actuator code benchmarking with the emphasis on NBCD (code benchmark + joint experiments).	
Continue the focussed modelling-benchmark activity on ITER Hybrid, current rise and steady state scenarios, using common input data	

NEW?:
Scenario exploration: Use of actuators for ITER scenarios (also prepare for H/He phase of ITER?)
	• H&CD power mix: timescale: 2 years
	  • the Design Review stimulated a wide-ranging discussion on the most appropriate H&CD mix for ITER and priority of future upgrades
	  • This requires an improved experimental/ modelling analysis of role of various H&CD systems in sustaining ITER scenarios, particularly in relation to H-modes with low torque input and steady-state operation
	In our scope, have already started activities. We may need more specific request from ITER IO.

	• Specific H&CD issues:
	  • EC breakdown assist - proposed change from 126GHz to 170GHz
	  • are O1/ X2 breakdown assist equally efficient on HFS and LFS of field null?
	  • Is toroidal injection (20°) as efficient as perpendicular injection for O1/ X2?
	  • timescale: 6 months
	In our high priority research, have already started activities and been collecting data from various machines.
	
	  • NTM stabilization
	  • need to tie down power optimization based on importance of island width/ ECCD spot size, power modulation, uncertainties in tracking etc
	  • timescale: 12-18 months
	
	  • Sawtooth control - need figure of merit for power requirement for control of sawtooth frequency

	• timescale: ~ 2 years ***MHD TG should take lead with support from IOS.*** • Current profile control for ITB formation - need for counter-ECCD • final decision on equatorial launcher design is pending • is counter-ECCD a useful tool in ITER, in particular for control of current profile in ITB scenarios, more generally in decoupling ECRH and ECCD • timescale: 12 months ***Discussion in SSO TG closed. Answer =No.*** • ELM control - steering range of upper launcher could be adjusted • jECCD in ITER pedestal would be of same order as jbs, providing potential influence on ELM behavior if experiments indicate that this is worthwhile • timescale: 2 years ***Needs to be discussed with Pedestal TG.***

Proposed by MHD Stability TG	Requested by IO

Assess vertical stabilisation options for ITER, based on data on presently controllable vertical displacements and n=0 noise, and specify diagnostic requirements.	• Vertical stabilization: timescale: <1 year
	  ◦ determines AC losses in SS coils, base level of ohmic losses in internal coils
	  ◦ require characterization of noise in vertical stabilization system - amplitude, source etc

	• Plasma disturbance specification: timescale: <1 year • PF control system must maintain "headroom" for disturbance control to allow most common plasma disturbances to be controlled • require redefinition of characteristics of likely disturbances which ITER PF system should be capable of controlling - note confinement transitions (L-to-H, H-to-L, ITB collapse …) in particular

Develop ITER applicable disruption mitigation techniques. For massive gas injection, understand optimal gas mixtures, their assimilation properties and the influence of MHD on impurity penetration to the core. Study the ability to suppress secondary runaways. Develop reliable disruption prediction methods and understand diagnostic requirements.	• **There are several issues for which we would prefer to have the solution now (improved data and analysis within the next 12 months for Licensing):**
	  ◦ **a more complete validated modelling capability for VDEs, including halo currents, to strengthen the basis for predicting vertical and horizontal forces**
	  ◦ **a validated modelling capability for runaway generation and loss to allow an improved assessment of first wall energy deposition**
	• **An improved assessment of SOL width and local power deposition during disruptions/ VDEs, including limiter plasmas**
	• Three key questions:
	  ◦ is Rosenbluth density required for runaway suppression?
	  ◦ if so, is "killer pellet" a viable alternative to MGI (higher assimilation)?
	  ◦ are other alternatives, eg stochastic magnetic fields, effective and viable?
	• Need to understand:
	  ◦ quantitative extrapolation of technique to ITER
	  ◦ reliability of routine use
	  ◦ Implications for use in ITER - technology R&D? impact on operations?
	  ◦ first wall heat loads produced
	  ◦ Influence on runaway electron generation/ suppression
	• experimental demonstration that a technique or combination of techniques allows reliable mitigation of disruption effects
	• "mitigation" implies:
	  ◦ heat loads, runaway electrons: reduction by more than 1 order of magnitude

	• forces: reduction by factor of 2 to 3
	• key effects are:
	  • local heat loads
	  • vertical/ horizontal forces
	  • runaway electron currents (energies ?)
	• significant modelling development to provide basis for ITER extrapolation (specification of DMS in 2009:Procurement in 2012)

Continue development of the disruption DB to include pre-disruptive energy loss and halo current data.	
Study NTMs in Hybrid Scenarios, the effect of plasma rotation, validate ECCD control models against data (including modulation) and specify diagnostics for NTM detection.	
For RWMs understand mode damping particularly at low rotation. Continue benchmark tests of theory models for RWM feedback and experimentally study feedback control at low rotation. Study coil systems for RWM control in ITER and specify diagnostics.	
Quantify effects of non-resonant error fields, specify multi-mode error correction requirements and error field thresholds at high ß.	
ELMs?	

<table>
<tr><th>Proposed by Diagnostics TG</th><th>Requested by IO</th></tr>
<tr><td>Development of methods of measuring the energy and density distribution of confined and escaping α's.</td><td></td></tr>
<tr><td>Assessment of the calibration strategy for the neutron diagnostics and the calibration source strength needed.</td><td></td></tr>
<tr><td>Determination of life-time of plasma facing mirrors used in optical systems.</td><td>▪ Plasma facing mirrors and optical elements in divertor:
– these components will likely have a finite lifetime, which will impact on reliability of optical diagnostics
– several developments are needed, including
• models of erosion and deposition process
• mitigation of erosion and deposition by design
• development of shutters and baffles
• in-situ calibration techniques
– deliverable: recommendation on most rugged first mirror arrangement for ITER, based on experiment and modelling
– timescale: several years</td></tr>
<tr><td>Development of measurement requirements for measurements of dust, and assessment of techniques for measurement of dust and erosion.</td><td>▪ Dust: Timescale: 2-3 years (by end-2011)
• Validation of safe levels of dust in the vacuum vessel required for machine operation
• Need to test most promising diagnostic approach, a dust microbalance, in a tokamak
• Deliverable: develop, install, exploit and report on prototype

▪ Hot Dust: Timescale: 1.5 years (end-2009)
• Be dust on PFCs with T > 600°C must be limited to <6kg for safety
• Need to evaluate feasibility of significant quantities of dust being able to survive in regions of high heat flux using modelling and survey data from existing tokamaks
• Deliverable: provide an estimate of the quantity of hot dust in ITER, including quantitative evaluation of uncertainties

▪ Divertor Erosion: timescale: 2-3 years (by end-2011)
• divertor erosion is expected to be the major source of impurities</td></tr>
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	and dust, as well as limiting the divertor lifetime • need to test most promising diagnostic approach to remote divertor erosion measurements, based on laser ranging techniques • deliverable: develop, install, exploit and report on prototype remote divertor erosion measurement diagnostic using laser ranging
	▪ Hydrogen background: o In non-active phase, outgassing and DNB will affect base level of hydrogen, influencing fuel retention studies o need to assess evolution of hydrogen levels in existing devices and develop an appropriate model o deliverable: estimates of hydrogen background in initial phase of ITER operation and assessment of required accuracy of gas balance measurements to permit analysis of fuel retention in non-active phase o timescale: 2-3 years
	▪ Retained tritium: o require validated techniques for assessing level of retained tritium in vacuum vessel o need to select and prototype candidate diagnostic techniques, including extrapolation from local to global measurements; also need to determine accuracy in estimate of T-burnup o deliverable: validated technique for estimation of retained tritium in vacuum vessel o timescale: 2-3 years

Proposed for Energetic Particle TG by old MHD TG	Requested by IO
Measure damping rates of Alfvén waves (together with reliable mode identification: eigenfunction, frequency etc) and compare with theory	
Define benchmark test cases for fast particle stability codes	
Develop relevant diagnostics and make recommendations for ITER diagnostics	
Compare theoretical predictions with measurements of fast ion losses caused by magnetic field ripple and error fields in present day devices	▪ TF Ripple: timescale: 2 years • most significant ripple effects in ITER may be those associated with changes in pedestal parameters and H-mode performance • in ITER, aim to achieve $\delta TF < 0.4\%$ • require an improved predictive basis for confinement effects of TF ripple - in particular localized ripple such as that associated with TBMs • Localized ripple due TBMs:timescale : 2 years • ferromagnetic structural material used in TBMs will produce an additional component of at 3 locations • fast particle losses appear to be acceptable even in scenario 4 • will such localized ripple have a similar influence on H-mode performance as the global ripple used in JET experiments? • Such an effect would ideally be checked by a dedicated experiment
Predict the power loads to the ITER first wall caused by error fields, ferritic inserts, test blanket modules and perturbation fields (ELM mitigation coils)	