Summary of MHD Breakout Group at the Dec. 2005 USBPO Workshop

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The macroscopic stability discussion was divided into eight topical areas: neoclassical tearing modes, resistive wall mode/external kink stability, m = 1/sawteeth, ELM/pedestal modeling, disruptions, error fields, 3D equilibrium and responses, and ICC BP issues. A brief summary of the discussion in each of these topical areas follows.

In ITER, NTMs are predicted to be less stable than in present day devices. If left unmitigated, 2/1 NTMs could prevent ITER from achieving its goals. Recent advances include the demonstration of complete stabilization of m/n = 2/1, 3/2 NTMs with unmodulated ECCD leading to improved beta. However, it remains to demonstrate ECCD stabilization in tokamaks with $q_{95} \sim 3$ and rotation similar to that for ITER. Additionally, tests of modulated ECCD and tests of broad deposition current profiles relative to threshold islands remain to be performed. These tests are crucial as modulated ECCD with broad deposition profiles are the relevant regime for ITER. Improved theoretical modeling in the areas of seeding physics and self-consistent coupled MHD-RF modeling remains to be carried out.

Plasma rotation cannot be relied upon to stabilize resistive wall modes in ITER operation in the wall-stabilized regime. Since Snowmass, RWM stabilization by plasma flow has been demonstrated. The theory of resonant field amplification has been discovered and provides a plausible explanation for rotation damping above the no-wall limit. Dynamic error field correction has been shown to sustain rotation and allow access to the ideal beta limit. RWM induced plasma rotation is global and non-resonant; this observation is essentially consistent with neoclassical toroidal viscosity theory. Demonstration of RWM stabilization in low rotation plasmas remains to be performed. The establishment of the stabilization physics required for predictive scaling is not present. The US experimental facilities are uniquely equipped to address RWM physics and mode stabilization. The US community can lead the design of optimal control coil geometry for ITER's RWM stabilization system.

Large m = 1 modes/sawteeth are expected in standard ITER operation. These modes are expected to have large inversion radii, could excite other MHD modes (in particular, NTMs) and enhance disruptivity and energetic particle loss. Since Snowmass, the Porcelli-Boucher-Rosenbluth model has been largely validated, but technical details remain. This is a concern for ITER as the energetic particle contribution to this theory are to be substantially larger than in present day tokamaks. While this model has proven useful, a number of physical effects are not properly accounted for in the theory and require further study. A unique US contribution to the physics understanding of the sawtooth can be pursued through the Simulation of Wave Interaction with MHD (SWIM) project which can study the combined role of m = 1 MHD physics, energetic particles, collisionless reconnection processes and the application of RF waves.

Understanding ELM physics is crucial for ITER operation. The standard paradigm for the onset of ELMs is given by the ideal MHD stability of intermediate wavelength (n ~ 3-30) ballooning-peeling modes. Since Snowmass, one of the most important developments is a method to suppress ELMs using resonant magnetic perturbations (RMPs). A number of physics issues related to ELM physics require further exploration. These include a determination of the physics that sets the pedestal width, an understanding of ELM dynamics and heat deposition, the physics of passive ELM-free operation, and an understanding of the plasma response in the presence of RMPs. A unique opportunity for the US program is the evaluation of resonant magnetic perturbations for ELM control on ITER.

ITER will be the first MFE experiment where the avoidance and the mitigation of disruption damage must be an integral part of all plasma operation. Significant progress has been made using high-pressure gas jets to mitigate disruptions on a number of large tokamaks. Issues include the development and benchmark of the gas jet problem with predictive numerical codes. Elucidation of the role of neutrals, gas flow and radiation physics remains.

The tolerable error field for mode locking in ITER is still uncertain. However, recent C-MOD data suggests that the critical magnetic field perturbation is much more optimistic that earlier experimental projections. However, no reliable predictive theory explains the observations and hence, it is difficult to project to ITER. Non-resonant magnetic perturbations may play an important role in plasma braking and mode locking. Non-resonant magnetic fields are not shielded out at the rational surface and produces plasma flow damping throughout the plasma region. Due to this effect, it may be that magnetic error correction coils must account for both resonant and non-resonant components.

Three-dimensional magnetic perturbations are increasingly used to control tokamak stability and performance. These include compensation coils for error fields, resistive wall mode feedback and ELM stabilization. There is a need to develop analysis tools to describe the effect of 3D perturbations on equilibrium and to subsequently understand the effects on stability and transport. In this area, there is substantial overlap with the physics of stellarators; the application of stellarator-specific analysis tools to tokamaks may prove valuable.

For many issues, the benefits to ICCs and burning plasmas (in both directions) will occur through the validation of MHD theories and codes that can be applied to other configurations. A number of MHD issues are common to many magnetic fusion concepts. The ICC portfolio provides an experimental test bed for understanding the role of fundamental configuration variables that are difficult to vary in any particular experiment. Predictive science valid over a wide range of configuration space will most convincingly allow an "alternate" substitution for DEMO, even if the substitution is not very different from a present-day concept.

An emerging theme in the MHD breakout group is the role of external magnetic coils for the control of MHD modes. Hence, the MHD breakout group recommends that a task group will formed to spearhead the design of ITER coils for control of RWMs and ELMs. This could be a joint effort from the MHD and boundary topical groups.