**Integrated stability control**

Numerous instabilities with the potential to degrade or disrupt plasma performance have been identified for magetic confinement devices. Whereas feedback mechanisms capable of stabilizing these instabilities have been identified in many cases, the simultaneous control of all plasma instabilities is an unsolved problem. The list of instabilities that will be considered here are:

The resistive wall mode
The neoclassical tearing mode
Edge localized modes
Fast particle driven instabilities (many)

The plasma configurations to be considered in this document will be limited to the stellarator and the tokamak (including low aspect ratio devices).

The methods proposed to stabilize these instabilities consist of two basic mechanisms: applied non-axisymmetric magnetic fields, and applied radio frequency current drive to control the current profile.

**Major issues for integration of these methods are:**

1) Nonlinear interactions between the feedback schemes.
2) Complex dependencies of the instabilities on plasma parameters – extrapolation issues
3) Compatibility of the feedback schemes with reactor conditions

**Non-linear interactions:**

Several potential non-linear interactions can be conceived of that could complicate the simultaneous use of multiple feedback schemes. In particular, the use of non-axisymmetric fields to control RWMs could directly couple to the ELMs and drive the, unstable even in the presence of ELM mitigation fields. The lack of a established predictive theory that can explain ELM mitigation makes testing this hypothesis through modeling difficult. The effects of non-axisymmetric fields on fast particle driven instabilities is an unexplored field. Non-axisymmetric fields are known to affect the stability of neoclassical tearing modes. Although ELM mitigation fields are not expected to be resonant, applied fields intended to correct RWMs could deleteriously affect NTM stability (so far this has not been observed).

**Extrapolation of current understanding to reactor conditions:**

The growth rates and/or stability thresholds of all instabilities listed above have parametric dependencies that are the subject of active research. Given the uncertain nature of the scaling these instabilities with plasma parameters, it difficult to be certain when discussing the likelihood of success of integrated control in future devices. Important areas of research are: kinetic effects on resistive wall mode stability, threshold scaling with $\rho^*$ for NTMs, description of the mechanism for ELM mitigation using non-axisymmetric fields, and saturation mechanisms for fast particle driven instabilities. It is also possible that these uncertainties can interact with each other. For example, one of the mechanisms for triggering NTMs is coupling to fast particle driven instabilities. Whether this problem becomes more severe in a device which is self-heated remains uncertain. Some of the scaling uncertainties are likely to resolved by ITER (e.g. scaling of NTM thresholds), but advances in theoretical understanding will be required in other areas.

**Compatibility of feedback schemes with reactor conditions:**

The mechanisms that are envisioned for control of the RWM, the NTM, and ELMs are likely compatible with reactor conditions. However, since the physics of fast particle instabilities is a major research thrust on ITER, it is not clear what the requirements for any future stability control mechanism would be. Potential control opportunities involve using plasma waves to control the current profile to affect stability, and also using these waves to tailor the fast particle distribution function by direct interaction. It is possible upgrades to ITER could address these issues.

**Thrusts**

For tokamaks, in addition to the current program to understand the physics of the instabilities themselves, it is important to start investigating the cross-linkages between the various feedback schemes. Some work has been performed in this regard with NTMs in the presence of saw-teeth for example, but further work needs to be done. In particular, A scenario that simultaneously stabilizes the RWM, the NTM and ELMs needs to be be developed in a regime that is relevant for steady-state tokamak operation – i.e at high normalized $\beta$, and and high bootstrap current.