Transport in 'transient' conditions: current ramp-up & ramp-down, between sawtooth crashes

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Simulations of ITER operating scenarios have revealed the need for careful initiation and termination of plasma discharges. The planned capabilities of the PF coil power supplies are easily exceeded during plasma current ramp-up and ramp-down. Furthermore, higher than desirable values of internal inductance are frequently encountered with purely ohmic heating, so some level of auxiliary power is desirable to slow down current penetration. It is therefore important to reliably predict the thermal electron confinement in ohmic and low-power L-mode regimes in order learn how to ‘thread the needle’ during the ramp-up and ramp-down phases.

Studies of plasma transport typically focus on high-power, high-performance discharges in quasi-steady-state conditions, however, and the transport models that are successful may or may not be suitable during plasma current ramp-up and ramp-down. Note that the radial profile of the current density will not be ‘relaxed’ during ramps, and the values of “q” tend to be higher, so the transient phases are outside the parameter range found during typical current flat-top operation.

This issue is also considered by other ReNeW groups: “Startup, flat-top, and ramp-down scenarios” is a topic in the “Creating a self-heated plasma” panel in Theme I, and “Start-up and ramp-up” is critical for the “Spherical torus” panel in Theme 5 for reasons peculiar to spherical torii as well as those stated above. Any eventual research thrust including this issue should cover the needs identified by all three panels.

Temperature recovery between sawtooth crashes is another ‘transient’ condition that may be of more in importance in ITER than in current devices. The sawtooth mixing region may be a larger fraction of the plasma than is usual in current experiments and the time between crashes is likely to be delayed by suprathermal alpha stabilization, which may thereby allow for more current relaxation - which would affect the size of the mixing region. The evolution of the current and the pressure profiles will together determine the sawtooth period and the modulation amplitude of the fusion power.

There are several types of transient events that need not be considered by the panel on "Extending Confinement to Reactor Conditions" because they are dealt with by other ReNeW panels such as the “Mitigating Transient Events in a Self-Heated Plasma” Panel in Theme I, and the “Off-normal events panel” of Theme II. For example, the impact of ELMs on the plasma is not really a ‘transport’ process in the usual meaning of that phrase.

What is needed to resolve the issues?

Uncertainty concerning thermal transport during current ramp-up and ramp-down can be greatly reduced by coordinated research on this topic in current tokamaks; the present level of ignorance is primarily caused by lack of attention, not intrinsic difficulty. Recognition of the issue's importance in 2007 motivated new experiments and transport analysis, coordinated by two ITPA groups: Integrated Operation Scenarios, and Transport & Confinement. Continued effort, especially the application of all the customary transport diagnostics should clarify the situation well before ITER operates. In order to be most relevant to ITER it is desirable to use wave heating in place of neutral beam heating during the current ramp-up and ramp-down.

Better understanding of transport within the sawtooth mixing region in high performance plasmas will be more difficult because it is quite complicated. Diagnostic time resolution may marginal for measurements of magnetic pitch angle, ion temperature and flow speed; however, plasmas with very long sawteeth are likely to be most relevant to ITER. Measuring and simulating the time dependent heating profile will often be quite difficult because it will be affected by the periodic redistribution of plasma at each sawtooth crash. The analysis complications could be minimized by avoiding heating via fast ion populations because they will have complicated histories caused by the mixing; ECH and ohmic heating would therefore be favored for simplicity. Models of sawtooth mixing could be tested by using central current drive to vary the current distribution within the mixing region. However, stabilization by suprathermal alphas is expected in ITER, so it will also be important to be able to also vary the fast ion population in order to validate models of this effect. Much more effort than is currently expended is required to make progress in understanding both the inter-crash transport and the details of the mixing.

What elements of a research thrust will resolve the issues.

Resolution of the physics issues discussed above could fit into the research plans of current and any new tokamaks. However, it will be desirable to upgrade 'purely' electron heating systems (such as electron cyclotron and lower hybrid) and some diagnostic capabilities; in particular, better spatial and temporal resolution in measurements of the poloidal field in the sawtooth mixing region are probably highly desirable. More detailed data will also be needed to maximize what can be learned from sophisticated time-dependent nonlinear MHD codes (and, possibly, to motivate further code development).