The Real Mission of ITER

A White Paper for ReNeW, by G. A. Wurden, Los Alamos National Laboratory 2/24/2009

First consider a partial table of tokamaks, looking at plasma energy content, pulse length, plasma current, heating capability, and plasma volumes:

Machine	Stored Energy *	Pulse Length	Current	Cooling	Aux Heating	Volume
DIII-D	3.5 MJ	6 sec	2-3 MA	inertial	25 MW	21 m^3
TFTR	7 MJ	5 sec	3 MA	inertial	40 MW	30 m^3
JT-60U	10.9 MJ	20-60 sec	3-5 MA	inertial	50 MW	90 m^3
JET	10 MJ	10-30 sec	3-7 MA	inertial	20-40 MW	95 m^3
Tore Supra	0.3-1 MJ	400 sec	1.7 MA	water	3-9 MW	20 m^3
ITER	200-450 MJ	300-3000 sec	15-17 MA	water	70-100 MW	837 m^3
DEMO	600 MJ	steady	10-20 MA	helium	100 MW	500-1500 m^3

*The poloidal magnetic field energy is typically 2-3x bigger than the plasma kinetic energy.

The Issue

For future machines, the plasma stored energy is going up by factors of 20-40x, and plasma currents by 2-3x, while the surface to volume ratio is at the same time decreasing (the problem when comparing elephants to mice). Therefore the disruption forces, even for constant B, and associated possible localized heating on machine components, are more severe. Notably, Tore Supra has demonstrated removal of more than 1 GJ of input energy, over nearly a 400 second period. However, the instantaneous stored energy in the Tore Supra system (which is most directly related to the potential for disruption damage) is quite small compared to other large tokamaks. In ITER, the divertor plate surface area is ~40 m^2. If the plasma energy during a disruption was uniformly deposited there, the energy per unit area corresponds to about 10 MJ/m^2. Clearly this is why in the case of a disruption, radiating the plasma energy across a larger area of the main chamber is highly desirable. But uniform deposition isn't likely. Expected energy and current deposition peaking factors are crucial knobs driving the design of internal components in ITER.

The Goal

The goal of ITER is routinely described as studying DT burning plasmas with a Q ~ 10. In reality, ITER has a much more important first order mission. In fact, if it fails at this mission, the consequences are that ITER will never get to the eventual stated purpose of studying a burning plasma. **The real mission of ITER is to study (*and demonstrate successfully*) plasma control with ~10-17 MA toroidal currents and ~100-400 MJ plasma stored energy levels in long-pulse scenarios.**

Before DT operation is ever given a go-ahead in ITER, the reality is that ITER must demonstrate routine and reliable control of high energy hydrogen (and deuterium) plasmas. The difficulty is that ITER must simultaneously deal with several technical problems: 1). heat removal at the plasma/wall interface, 2). protection of the wall components from off-normal events, and 3). generation of dust/redeposition of first wall materials. All previous tokamaks have encountered hundred's of major disruptions in the course of their operation. The consequences of a few MA of runaway electrons (at 20-50 MeV) being generated in ITER, and then being lost to the walls are simply catastrophic. They will not be deposited globally, but will drift out (up, down, whatever, depending on control system), and impact internal structures, unless "ameliorated". Basically, this represents an extraordinarily robust e-beam welding machine, capable of deep penetration into any armor tiles, to the cooling channels which are embedded less than 1 cm below the tile surface. When energy is deposited in a fraction of a second on (or in) a tile, the presence of underlying water cooling does no good for the purposes of heat removal.

Events of this nature have been seen in TFTR (for example, shot 103681, http://wsx.lanl.gov/ricky/disrupt.htm) with only about 300kA of runaways. In that case, an ICRF antenna carbon tile protection limiter simply exploded and disappeared. Because TFTR was inertially cooled, there were no water leaks, but nevertheless plenty of dust and debris were produced. The armor was discovered missing a few months later, at an inspection during a vacuum opening. Recovery from a major disruption in TFTR typically took a day. Recovery in ITER could take much longer.

Suggested Research Thrust

In the years leading up to ITER, **it is absolutely essential to study high heat load plasma operations in long-pulse tokamaks, with multi-Megajoule stored energy content**. The obvious machines to do this are KSTAR and EAST. If they lack the heating, plasma control, first wall assemblies, and diagnostic systems, then they should be rapidly upgraded through aggressive American contributions to international collaboration. Ultimately this research thrust could evolve into an American NHTX type of platform, but the relative benefits, costs, and schedule of an American machine need to be considered carefully.

Finally, a balance with other ITER issues (second order effects) must be maintained. Considerations of radiation damage, neutron shielding, test blanket module development, tritium retention, diagnostic hardening (against radiation) are all vitally important for DEMO, but will be unlikely to be explored in ITER if the basic problem of demonstration of disruption avoidance, mitigation, amelioration, and survival isn't solved first. Similar statements can be (and have been) made about the importance of developing routine ELM suppression techniques. The reasoning for this necessary prioritization is that the other things simply won't matter (for ITER), if the control and survival problems aren't solved.