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REVIEW OF ITER PHYSICS ISSUES AND POSSIBLE APPROACHES TO THEIR SOLUTION

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Review of ITER Physics Issues and Possible Approaches to Their Solution* IT

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ITER will demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes by nominal operation of 500 MW fusion power for 400 seconds. With its all superconducting coil technology, ITER will be capable of moving toward steady-state, high gain operation for fusion power. While the physics basis for ITER's nominal inductive operation is well established, the physics basis for steady-state is currently being developed (ref PIPB). Ongoing tokamak research programs must continue to contribute strongly during ITER construction to various physics issues whose resolution will improve both the inductive and steady-state operation of ITER.

Stability — The resistive wall mode (RWM) limits the plasma beta in advanced tokamak regimes. Wall stabilization of the RWM by plasma rotation has been shown. For steady state with high bootstrap fractions, ITER will need the higher β_N made possible by wall stabilization. However plasma rotation in ITER is estimated to be just below the threshold for rotational stabilization. Consequently research is ongoing on direct feedback stabilization without rotation. The rotation estimate, balancing neutral beam momentum input against diffusive loss, is questionable since plasmas rotate without momentum input; more research is needed on plasma rotation physics. But a factor of two more momentum input into ITER might double the plasma rotation at the q=2 surface and put it above the threshold. More RWM research is needed coupled to designs of RWM stabilization coils that can be added to ITER.

The neoclassical tearing mode (NTM) is expected to be unstable at low beta in ITER so stabilization or avoidance (by high q_{min}) is important. Stabilization by localized ECCD works but we need to quantify the power needed in ITER and whether modulated ECCD must be used, given how well the launchers in ITER can focus the EC waves.

Disruption mitigation with massive gas injection has been shown to work. The injected gas apparently does not penetrate far but fast MHD mixing of the ionized gas into the core may be occurring. ITER needs assurance how to extrapolate an MHD mixing process. The liquid jet is a backup option.

Edge localized modes (ELMs) may cause excessive erosion of the divertor plates in ITER. The best solution is to eliminate ELMs while retaining the H-mode edge. The physics of the ELM-free Quiescent H-mode needs to be understood sufficiently to specify how to achieve this mode in ITER. ELMs can also be suppressed by edge resonant magnetic perturbations. The physics of this suppression by edge coils must be understood to specify a coil set that can be added to ITER. Approaches to limit ELM size by pellet pacemaking or plasma shaping must be further developed.

Alfvén mode studies in present machines are expanding owing to better diagnostics revealing modes in the plasma interior not previously seen. However ITER will make the

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dominant contribution in this area but an area of concern is the adequacy of the alpha diagnostics, especially for escaping alphas.

Confinement at low ρ******* *and* ν** can only be studied in ITER.* The adequacy of ITER's turbulence fluctuation diagnostics is a concern. Research needs to focus on transport in the electron channel, cases with $T_e = T_i$, and how stiff the transport really is. Dimensionless scaling results and the ITER global database scalings disagree, particularly in beta dependence. With a stiff transport model, the energy gain is controlled by the height of the edge pedestal pressure. We can calculate the limiting edge pedestal pressure gradient, but we need research on what determines the pedestal width. The L-H transition threshold physics needs renewed effort, perhaps illuminated by internal transport barrier formation studies.

First wall. The best mix of first wall materials is a crucial issue. Research is needed on the tritium codeposition issue for carbon and on the melting, cracking, and plasma impact issues for metals, and on the mechanical and chemical properties of mixed material redeposition layers.

Divertor physics. *Only ITER* can operate at absolutely high densities with low collisionalities. Results in current machines vary from laminar type SOL flow and divertor recycling at ITER's collisionality to clumpy cross-field transport with substantial main chamber wall interaction at ITER's absolute density. Comparison of data from ITER to smaller tokamaks is needed to resolve how divertor properties can be extrapolated.

Pellet fueling. How to get fueling deep into the core plasma is still an issue.

Advanced, steady-state scenarios. Current research is making exciting progress. Hybrid modes in which the OH transformer supplies some current drive extrapolate to ITER's fusion power in several thousand second pulses. Discharges equivalent to ITER's true steady-state Q=5 mode with 100% noninductive current drive have been demonstrated. Prospects look good for even higher performance, but wall stabilization will be needed. The study of the complex feedback loops involving the current profile, bootstrap current, alpha heating, transport barriers, instabilities, etc. in high performance steady-state plasmas will be a *unique research contribution of ITER*. Steady-state poses diagnostics challenges.

The auxiliary heating systems on ITER were chosen when plasma heating was the main concern. Alterations of the mix of systems or additions to perhaps a total 130 MW might focus on optimizing current drive and current profile control by more ECCD, adding LHCD, and increasing the momentum input for RWM stabilization to enable higher bootstrap fraction with high fusion gain. The compatibility of LH with advanced modes, including H-mode, if the LH launcher is closely coupled to the outer midplane plasma needs research or methods must be shown to couple power with a large gap between plasma and launcher. The physics of coupling of ICRF waves through edge plasma needs work.

A comprehensive simulation code including both engineering and physics should be developed to integrate the physics elements discussed above and to assess planned operation. Extensive validation of the code against existing experiments will be required and ITER might play a central role in coordinating the international efforts in this area.

[1] Progress in the ITER Physics Basis, being prepared by the ITPA.