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**Decadal Assessment of Advances in Plasma Physics** (at Georgia Tech)

by

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**Progress in Edge Plasma Transport (pinch velocity, ion orbit loss)**

The long-range electromagnetic forces have been included in a pinch-diffusion theory for particle, momentum and energy transport in the plasma edge (1,2). Retention of the pinch velocity required by momentum conservation incorporates long-range electromagnetic forces into a pinch-diffusion theory for particle, momentum and energy transport, which leads to significant changes in calculated edge particle, velocity and temperature distributions. Experimental evidence supports causative roles for i) a reduction in inward electromagnetic particle pinch due to Resonance Magnetic Perturbation (RMP) coils in the reduction of edge density caused by the RMP coils (3); for ii) the increase of inward particle pinch in rebuilding of the edge pedestal following an ELM (4); and iii) for increase in inward particle pinch contributing to the improved particle confinement following the L-H transition (5,6).

Models that treat the kinetic ion orbit loss of particles, momentum and energy by ions in the thermalized edge plasma ion distribution which can access loss orbits that exit the confined plasma have been incorporated into the plasma fluid equations and shown to significantly affect calculated edge radial distributions of ions, velocities and pressures (temperatures) (7-14). Calculations of DIII-D experiments (7-14) indicate a significant (order 50%) ion orbit loss in the edge plasma (ρ>0.95). Preliminary calculations indicate that ion return currents needed to maintain charge neutrality may determine the observed formation of a “well” structure in the radial electric field at the L-H transition (15).

The equations governing conservation of particles, momentum and energy are coupled, thus the fluid equations used to calculate the ion densities, rotation velocities and pressures (energies/temperatures) must also be coupled in order to conserve density, momentum and energy. A new set of fluid equations which conserve particles, momentum and energy (including particle pinch and ion orbit loss) have been developed (13, 14, 16-18). These advances in theory are being incorporated into the interpretation of experiments in DIII-D.

**Progress in Plasma Rotation (neoclassical gyroviscosity)**

Fluid rotation theory based on Braginskii’s gyroviscosity (extended to toroidal flux surface geometry and arbitrary collisionality) has been under intermittent development at Georgia Tech since 1985. Gyroviscosity, the dominant component of the toroidal velocity damping in neoclassical theory, depends predominantly on the poloidal asymmetry in rotation velocity, density and electrostatic potential, and much of the development has revolved about calculating this poloidal asymmetry. The present state of the art is a calculation based on a “Miller model” flux surface geometry, a low-order Fourier series (sin, cos) in ɵ and a separation of variables approximation (19), which over-predicts measured toroidal rotation about 20% in the plasma core, but with greater error in the plasma edge. We are working with higher order Fourier series expansion of the poloidal dependences and removal of the separation of variables to obtain substantial improvements, except in the plasma edge (20).

The Braginski viscosity theory is based on axisymmetric magnetic field lines. We believe that our difficulty in predicting rotation in the plasma edge may be due to the presence of non-axisymmetric magnetic fields in the plasma edge, which change the form of the axisymmetric Braginksii viscosity tensor (21) and give rise to a variety of additional “non-axisymmetric” viscosity components (22,23). Both the axisymmetric and the non-axisymmetric viscosities can be cast in the same “drag frequency” form, and hence are readily combined in a fluid theory for the prediction of toroidal rotation (24).

**Progress in Understanding and Controlling D-T Fusion Thermal Excursions**

The fact that the D-T fusion cross-section increases as the plasma temperature squared in the probable operating temperature range of ITER and other future D-T fusion reactors implies the possibility of a thermal runaway and the need for passive or active thermal feedback mechanisms. We have found (25) that the physics that has been used to investigate this problem in the past is faulty in not taking into account the different spatial locations and time scales of the various physical mechanisms that would be involved in a thermal excursion and its quench. In particular, the use of the measured temperature dependence of interpreted steady-state values of plasma energy confinement times to characterize the global dynamic response of the plasma may severely misrepresent the response of the hot plasma core to a temperature change. (Note that dynamics calculations in DIII-D using the ITER98 scaling law required substantial “tuning” to match experiment [26].

A thermal excursion would most likely be initiated in the hot central core of the plasma, where an increase in temperature would produce additional energetic alpha particles. These fast alpha particles would initially transfer their energy to plasma electrons and slightly later to the plasma ions. The heated electrons in the plasma core would immediately produce electron cyclotron radiation (ECR), which would transfer much of the fusion energy from the plasma core to the plasma edge electrons or surrounding wall essentially instantaneously. Much of the energy that went to the surrounding wall would be reflected and absorbed in the plasma edge or core. The fusion alpha energy transferred to the core ions and the energy transferred to the core electrons that did not go into ECR but was collisionally transferred to the core ions would both heat the core ions on a collisional timescale and thereby produce additional hot alpha particles in the core to drive a thermal excursion. This spatially-distributed, multi-timescale dynamics (25) must be modeled to calculate the effect of thermal excursions in a D-T plasma.

**Progress in Burning Transuranics in Spent Nuclear Fuel and Breeding Fissile Material**

The possibility that a follow-on extended ITER could be used as a neutron source to “drive” a subcritical fast nuclear reactor fueled with the transuranics remaining in spent nuclear fuel has been studied in a series of conceptual design, fuel cycle and dynamic safety studies for a SABR fusion-fission hybrid reactor (27,28). Such a SABR would have several inherent safety and fuel cycle advantages, relative to a critical fission reactor, that would enable SABRs to more efficiently extract the nuclear energy remaining in these fissionable transuranics while reducing their ultimate high-level waste storage requirements by a factor of 10. A similar SABrR hybrid reactor design was developed (29) for the breeding of fissionable Pu239 from U238 (28) when shortage of fissionable U235 becomes a problem for the nuclear fuel cycle in the future.

**Progress in Neutral Particle Transport**

The computationally efficient Georgia Tech neutral particle transport code GTNEUT was found to predict similar results as a Monte Carlo code requiring orders of magnitude more computation time for the analysis of neutral particle recycling in a full-chamber DIII-D model (30). The previous difficulty in inputting an appropriate flux surface based computational grid structure has recently been resolved by using an extended Miller model flux surface representation extended to represent the divertor, together with a triangular grid structure generator (31).

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