2016-2017 ANNUAL REPORT
GEORGIA TECH FUSION RESEARCH CENTER
NUCLEAR & RADIOLOGICAL ENGINEERING PROGRAM
WOODRUFF SCHOOL, COLLEGE OF ENGINEERING
GEORGIA INSTITUTE OF TECHNOLOGY

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II. PLASMA PHYSICS RESEARCH PUBLICATIONS

Recent developments in plasma edge theory

W. M. Stacey

Abstract of paper published in Contrib. Plasmas Phys. 56, 495 (2016).

This paper reviews a concerted effort over several years by the Georgia Tech plasma group, in collaboration with colleagues at DIII-D and elsewhere, to develop a more complete physics model for the plasma edge. Recent work on i) the non-diffusive transport effects arising from electromagnetic particle pinches, ii) momentum-conserving pinch-diffusion theory, iii) the determination of the radial electric field, iv) the effects of 3D magnetic fields on edge rotation theory, v) determination of experimental deuterium rotation velocities and vi) ion-orbit-loss and X-loss/transport effects and intrinsic rotation are summarized.

Inclusion of ion orbit loss and intrinsic rotation in plasma fluid theory

W. M. Stacey and T. M. Wilks

Abstract of paper published in Phys. Plasmas 23, 012508(2016).

The preferential ion orbit loss of counter-current directed ions leaves a predominantly co-current ion distribution in the thermalized ions flowing outward through the plasma edge of tokamak plasmas, constituting a co-current intrinsic rotation. A methodology for representing this essentially kinetic phenomenon in plasma fluid theory is described and combined with a previously developed methodology of treating ion orbit particle and energy losses in fluid theory to provide a complete treatment of ion orbit loss in plasma fluid rotation theory.

A fluid model for the edge pressure pedestal height and width in tokamaks based on the transport constraint of particle, energy and momentum balance

W. M. Stacey

Abstract of paper published in Phys. Plasmas 23, 062515(2016).

A fluid model for the tokamak edge pressure profile required by the conservation of particles, momentum and energy in the presence of specified heating and fueling sources and electromagnetic and geometric parameters has been developed. Kinetics effects of ion orbit loss are incorporated into the model. The use of this model as a "transport" constraint together with a "Peeling-Ballooning (P-B)"instability constraint to achieve a prediction of edge pressure pedestal height and width in future tokamaks is discussed.

Improved Analytical Flux Surface Representation and Calculation Models for Poloidal Asymmetries

T. G. Collart and W. M. Stacey

Abstract of paper published in Phys. Plasmas 23, 052505 (2016).
An orthogonalized flux-surface aligned curvilinear coordinate system has been developed from an up-down asymmetric variation of the "Miller" flux-surface equilibrium model. It is found that the new orthogonalized "asymmetric Miller" model representation of equilibrium flux surfaces provides a more accurate match than various other representations of DIII-D discharges to flux surfaces calculated using the DIII-D Equilibrium Fitting (EFIT) tokamak equilibrium reconstruction code. The continuity and momentum balance equations were used to develop a system of equations relating asymmetries in plasma velocities, densities, and electrostatic potential in this curvilinear system, and detailed calculations of poloidal asymmetries were performed for a DIII-D discharge.

Confinement Tuning of a 0-D Plasma Dynamics Model

M. D. Hill and W. M. Stacey

Abstract of paper to be published in Fusion Science & Technology.
Investigations of tokamak dynamics, especially as they relate to the challenge of burn control, require an accurate representation of energy and particle confinement times. While the ITER-98 scaling law represents a correlation of data from a wide range of tokamaks, confinement scaling laws will need to be fine-tuned to specific operational features of specific tokamaks in the future. A methodology for developing, by regression analysis, tokamak- and configuration-specific confinement tuning models is presented and applied to DIII-D as an illustration. It is shown that inclusion of tuning parameters in the confinement models can significantly enhance the agreement between simulated and experimental temperatures relative to simulations in which only the ITER-98 scaling law is used. These confinement tuning parameters can also be used to represent the effects of various heating sources and other plasma operating parameters on overall plasma performance and may be used in future studies to inform the selection of plasma configurations that are more robust against power excursions.

Calculation of the Radial Electric Field from a Modified Ohm's Law

T.M. Wilks, W.M. Stacey, and T.E. Evans[1]

Abstract of paper published in Phys. Plasmas 24, 012505 (2017)
A modified Ohm's Law, derived from the conservation of deuterium and carbon ion and electron momentum and the requirement for charge neutrality, yields an expression for the radial electric field, E_r, in the edge pedestal region in terms of the motional electric field due to the carbon and deuterium ion rotation velocities as well as pressure gradients and the radial plasma current. This analytical Ohm's Law model for E_r is first shown to be consistent with the conventional "experimental" electric field calculated from the carbon radial momentum balance using experimental carbon rotation and pressure gradient measurements when experimental profiles are used to evaluate the Ohm's Law in three DIII-D [J. Luxon, Nucl. Fusion 42, 614, 2002] representative discharges (for L-mode, H-mode, and Resonant Magnetic Perturbation operating regimes). In order to test the practical predictive ability of the modified Ohm's Law, the calculations were repeated using rotation velocities calculated with neoclassical rotation models instead of measured rotation velocities. The Ohm's Law predicted E_r using theoretical rotation velocities did not agree with the "experimental" E_r as well as the Ohm's Law prediction using experimental rotation velocities, indicating that more accurate models for predicting edge rotation velocity are needed in order to have a validated predictive model of E_r in the plasma edge.
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Improvements to the ion orbit loss calculation in the tokamak edge

T.M. Wilks and W.M. Stacey

Abstract of paper published in Phys. Plasmas 23, 122505 (2016)
Existing models of collisionless particle, momentum, and energy ion orbit loss from the edge region of a diverted tokamak plasma have been extended. The extended ion orbit loss calculation now treats losses of both thermal ions and fast neutral beam injection ions, and includes realistic flux surface and magnetic representations, particles returning to the plasma from the scrape off layer, and treatment of x-transport and x-loss. Sensitivity to these ion orbit loss model enhancements is illustrated through application in a representative DIII-D H-mode discharge using fluid equations to predict neoclassical rotation velocities and radial electric field profiles, the structures of which are determined by radial particle fluxes and ion orbit losses.

Extended fluid transport theory in the tokamak plasma edge

W. M. Stacey

Abstract of paper published in Nucl. Fusion 57,066034 (2017).

Fluid theory expressions for the radial particle and energy fluxes and the radial distributions of pressure and temperature in the edge plasma are derived from fundamental conservation (particle, energy, momentum) relations, taking into account kinetic corrections arising from ion orbit loss, and integrated to illustrate the dependence of the observed edge pedestal profile structure on fueling, heating, and electromagnetic and thermodynamic forces. Solution procedures for the fluid plasma and associated neutral transport equations are discussed.

III. NUCLEAR DESIGN & ANALYSIS PUBLICATIONS

A Strategic Opportunity for Magnetic Fusion Energy Development

W. M. Stacey

Abstract of paper published in J. Fusion Energy 35, 111 (2016).

The realities of energy development and the perception of and support for magnetic fusion in the US are briefly summarized as background for proposing a strategic opportunity for magnetic fusion energy development as fusion neutron sources for subcritical advanced burner (transmutation) reactors for the destruction of long-lived transuranics in spent nuclear fuel.

Solving the Spent Nuclear Fuel Problem by Fissioning Transuranics in Subcritical Advanced Burner Reactors Driven by Tokamak Fusion Neutron Sources

W. M. Stacey

Abstract of paper submitted to Nucl. Technol.

The Georgia Tech concept of the Subcritical Advanced Burner Reactor spent nuclear fuel transmutation reactor and supporting analyses to date are summarized. SABR is based on the fast reactor physics and technology prototyped in EBR-II and proposed for the Integral Fast Reactor and the PRISM Reactor, and on the tokamak fusion neutron source physics and technology that will be prototyped in ITER. Preliminary fuel cycle calculations indicate that subcritical operation would enable a proliferation-resistant 100% TRU aggregate fuel reprocessing cycle, and that introduction of SABRs in a 1-to-3 power ratio with LWRs would reduce the required spent nuclear fuel High-Level-Waste-Repository capacity by a factor of 10

to 100. Preliminary dynamic safety calculations indicate that SABRs could be shut down to the decay heat level by turning off the plasma heating power without core damage in Loss of Heat Sink, Loss of Flow and Loss of Power accidents, but that additional decay heat removal capability is needed.in the case of total loss of primary or secondary system pumping power.

Dynamic Safety Analysis of a Subcritical Advanced Burner Reactor

Andrew T. Bopp, Weston M. Stacey

Abstract of paper submitted to Nucl. Technol.

A customized dynamic safety model is developed and used to analyze the safety characteristics of the Subcritical Advanced Burner Reactor (SABR), a fast transmutation reactor driven by a tokamak fusion neutron source. Loss of Flow Accidents, Loss of Heat Sink Accidents, and Loss of Power Accidents are analyzed along with the effects of feedback mechanisms, control rod insertion, and terminating electrical power to the neutron source. The core avoids fuel melting and coolant boiling without corrective action for 50% (failure of 1 of 2 pumps) Lost of Heat Sink (LOHSA) and Loss of Flow (LOFA). For 100% (failure of both pumps) LOFAs, LOHSAs, and LOPAs without corrective action, coolant boiling (1156 K)/fuel melting (1473 K) occur at about 25s/36s, 35s/84s, and 25s/36s respectively, after pump failure unless corrective control action is taken before this time, in which case the core power can be reduced to the decay heat level by shutting off the plasma power source. The present passive heat removal system is not sufficient to remove the decay heat and both fuel melting and coolant boiling ultimately occur in the 100% LOFAs and LOHSAs (failure of both pumps) unless some other means is provided for decay heat removal.

The SABR TRU-Zr Fuel, Modular Sodium-Pool Transmutation Reactor Concept

W. M. Stacey, A. T. Bopp, J-P. Floyd, M. D. Hill, A. P. Moore, B. Petrovic, C. M. Sommer, C. L. Stewart and T. M. Wilks

Abstract paper to be published Proc.2nd Int. Conf. Fusion-Fission Systems, ENEA (Frascati) 2016.

The updated Georgia Tech design of the SABR fusion-fission hybrid spent nuclear fuel transmutation reactor and supporting analyses are summarized. SABR is based on tokamak fusion physics and technology that will be prototyped in ITER and the fast reactor physics and technology proposed for the Integral Fast Reactor and the PRISM Reactor, which has been prototyped in EBR-II. Introduction of SABRs in a 1-to-3 power ratio with LWRs would reduce the spent nuclear fuel HLWR capacity requirement by a factor of 10 to 100.