Multi-scale Transport Behavior Working Group

Paul Terry, Chairman
Earl Marmar, Vice Chairman

Questions T4 - T6

T4: How does turbulence cause heat, particles, and momentum to escape from plasmas?

T5: How are large-scale electromagnetic fields and mass flows generated in plasmas?

T6: How do the magnetic fields in plasma rearrange and dissipate their energy?

Complex dynamical processes over full spectrum of spatial, temporal scales

⇒Grand challenge problem

Longstanding, unsolved, important, recognized and of interest outside plasma physics

Community Participation (May 1, 2004 - present)

Key contributors to report: P. Terry, E. Marmar, M. Greenwald, E. Synakowski, J. Sarff, R. Groebner, J. Drake

Electronic forum: Subscriber-based bulletin board
multiscale_transp@lists.psfc.mit.edu - 41 subscribers

Number of persons contributing written comments

T4	10
T5	8
T6	8

Public discussions

TTF (Salt Lake, May, 2004)	3.5 hours on T4, T5
ICC (Madison, May, 2004	3 hours on T4 - T6

Special venues
Experts conference call on T6 (reconnection)
Dynamo experts meeting

Community involvement limited relative to TTF transport initiative

T4: How does turbulence cause heat, particles, and momentum to escape from plasmas?

OFES: Historically central problem, sizable fraction of activity

Turbulence: fundamental, unsolved, ubiquitous, many applications

Fluid dynamics, weather and climate, industrial processes, astrophysical systems

Burning plasma: Turbulent transport must be managed

H-mode required, pedestal height (high Q), impurity control, particle transport (high density), profile control with limited external leverage, predictive pre-discharge modeling

Practical fusion: Turbulent transport must be managed

Control of pressure, density, temperature, flow profiles for fueling, exhaust, long pulse, in compact, economically viable devices

IPPA: Predictive model benchmarked against comprehensive experimental data base

T4: Turbulent transport research thrusts

- Investigate transport governed by ion gyro-scale fluctuations, including ion heat, momentum, and particle transport
- Study transport governed by fluctuations affecting electron heat loss, including electron gyro-radius scale fluctuations and magnetic turbulence
- Transport in the edge region

Goals (cross cutting)

Understand

Characterize

Control

T4 Thrust 1: Investigate transport governed by ion gyro-scale fluctuations, including ion heat, momentum, and particle transport

Ion heat transport is most developed area but validation required

Momentum, particle transport crucial, not as well developed

Required

New diagnostic approaches for fluctuations in *n*, *T*, *v*, and for profiles

Approaches = hardware, analysis techniques, presentation, for improved resolution, sensitivity, coverage

Inclusion of electromagnetic, nonadiabatic electron effects in ion transport theory

Simulations for long wavelength ion turbulence with synthetic diagnostics compared with multifield, multidimensional fluctuation measurement

Comparisons must meet established standards

T4 Thrust 2: Study transport governed by fluctuations affecting electron heat loss, including electron gyro-scale fluctuations and magnetic turbulence

Cause of electron heat loss not identified

Mechanism, scale of fluctuation, electrostatic or electromagnetic, collisional?

Required

Develop, implement new diagnostic capabilities

- Fluctuations at electron gyro-scale
- Magnetic fluctuations, multiple fields
- On many devices (Scanning β)
- Detection of energy transfer direction, spectrum anisotropy, structures

(Present diagnostics are for ion-scale, electrostatic)

Develop theory for disparate scale interactions, anisotropies, nonlinear state of magnetic turbulence

Identify mechanisms for electron thermal transport barriers

T4 Thrust 3: Transport in the edge region

H-mode, pedestals routinely produced, but no predictive capability for threshold, pedestal parameters, and scalings (despite many attempts)

Required

Learn how to replace failed 1-effect models with comprehensive, integrated, multi-effect models

Including: Transport fluxes (heat, particles, momentum), nonlinear macroscopic instability, atomic processes, boundary effects, collision-driven transport, x-point topology

Acquire capability for high resolution (time, space) edge data for comparisons

Measure radial electric field and its shear, time-, space-resolved transport fluxes, fluctuations, neutral fueling profiles, current density, magnetic field structure

T5: How are electromagnetic fields and mass flows generated in plasmas?

Self-organization of large scale structure is fundamental problem in complex systems

Flows: plasma rotation, planetary flows, astrophysical flows

Magnetic field: relaxed plasmas, bootstrap current, planets, stars, etc.

Burning plasma

Flow shear and transport barriers, bootstrap current, current drive

Practical fusion

Compact confinement schemes with relaxed fields

This issue is strongly coupled to T4

T5: Flow and field generation research thrusts

- Understand and harness the generation of large-scale flows
- Understand and control the generation of large-scale magnetic fields

Goals (cross cutting)

Understand

Characterize

Control

T5 thrust 1: Understand and harness the generation of large-scale flows

Despite crucial role in barriers, flows (with/without driving source) cannot be predicted (understanding, characterization, control lacking)

Required

Measure large scale and small scale flows

Measure turbulence that drives flows (Reynolds stress, bispectra)

Develop, implement flow visualization diagnostics

Develop new analysis techniques for visualization data

Develop comprehensive theory of flow generation and drive

- Understand transfer between turbulence and organized flows
- Model appropriate turbulent correlations (Reynolds stress, bispectra)

T5 thrust 2: Understand and control the generation of large-scale magnetic fields

Variety of nonlinear mechanisms may operate to generate large-scale magnetic field via fluctuations (MHD, two-fluid, kinetic)

Required

Profile measurements of mean flow, current, pressure, magnetic field

Profile measurements of fluctuating flow, current, pressure, magnetic field

Develop and validate models of observations for extropolation to future
  fusion conditions, non fusion applications (astrophysics)

Characterize natural scaling of transport associated with generation
  Manipulate associated turbulence to improve confinement

T6: How do magnetic fields in plasmas rearrange and dissipate their energy?

Reconnection is dynamical archetype in plasmas

Unstable modes, disruptions, relaxation oscillations, solar flares, magnetic substorms

Burning plasmas

Classical, neoclassical tearing modes, resistive wall modes, ELMs, sawtooth oscillations, field error penetration limit or disrupt confinement, threaten device hardware

Practical fusion

Reconnected, relaxed plasmas are less constrained - offer advantages of simplicity, compactness, lower fields, provided associated transport can be controlled

T6: Magnetic reconnection and relaxation research thrusts

- Characterize the spatial structure and temporal evolution of reconnection

- Understand the initiation of reconnection and its nonlinear evolution through modification of its environment and energy source

- Develop external means by which reconnection can be manipulated

T6 thrust 1: Characterize the spatial structure and temporal evolution of reconnection

Anomalously fast dynamics result from spontaneous creation of narrow reconnection layer

Required

Experimentally characterize structure, scale of reconnection

Expand diagnostic resolution, expand parameter regimes by diagnosing range of devices, measure flows, assess non MHD effects

Determine role of instabilities in forced reconnection

Measure fluctuations in layer, develop theories for linear, nonlinear evolution of instabilities

Characterize reconnection energetics

Fast particle generation, heating, energy budgets

T6 thrust 2: Understand the initiation of reconnection and its nonlinear evolution through modification of its environment and energy source

Operation of fusion devices requires prediction of conditions under which reconnection occurs, and its consequences once initiated

Required

Threshold and initiation

NTM threshold and seeding, models for onset of reconnecting modes, improved profile diagnostics (resolution, fields detected)

Structure of evolving reconnecting modes

Measurement of temperature, density, flows in magnetic islands

Nonlinear Evolution

Incomplete reconnection in sawteeth, kinetic codes/theories

T6 thrust 3: Develop external means by which reconnection can be controlled

Long pulse operation, devices with relaxed plasmas require external control

Required

Deploy external stabilization and feedback hardware

Internal, external non-axisymmetic coils, linear amplifiers, RF current drive, energetic particle beams

Implement and test feedback stabilization for reconnecting modes

Resistive wall modes, neoclassical tearing modes, sawteeth, dynamo modes in relaxing plasmas