Theme I: Achieving and Understanding the Burning Plasma State in ITER

Understanding alpha particle effects

Study alpha heating effects
Understand instabilities driven by alpha particles

Extending confinement to reactor conditions

Understand transport in the burning plasma regime
Control how the ITER plasma spins
Use transport barrier physics to achieve high gain
Achieve a sufficient edge pedestal for high gain
L-H transition and pedestal characterization
Sawtooth activity
Toroidal field ripple effects
Transport and confinement in transient phases

Creating a self-heated plasma

Startup, flat-top, and rampdown scenarios
Achieve high gain in ITER
Achieve modest gain steady-state capability
Optimize gain in non-inductive plasmas
Establish integrated simulation model
Achieve 100% non-inductive operation of ITER
Use RF systems to control ITER plasmas
Provide central fueling in ITER
Impacts of H-mode issues on operation and modifications
Impacts of wall interaction issues on operation and modifications
Error field correction
Breakdown
Ramp-Up
Flat-top
Termination
Impacts of scenario development issues on operation and modifications
Plasma facing materials - scenarios
Refined set of ITER reference plasma scenarios
Develop a comprehensive modeling capability
Execute necessary R&D to prepare for upgrades to H&CD
Handle unprecedented power exhaust challenge
Operate with sufficiently low tritium inventory
Tritium retention
Dust
PFC lifetime
Plasma facing materials - PWI
Assess the performance of power-plant-scale superconducting magnets

Theme I: Achieving and Understanding the Burning Plasma State in ITER

Controlling and sustaining a self-heated plasma

(Joint with Theme II Control panel)

- Control complex, burning plasmas
- Stability pressure-limiting instability
- Suppress confinement limiting instabilities in ITER
- Neoclassical tearing modes
- Resistive wall modes
- Error field effects
- Breakdown
- Define requirements for plasma control system
- Impacts of MHD stability control on operation and modifications

Mitigating transient events in a self-heated plasma

(Joint with Theme II Off-normal plasma events panel)

- Disruption/VDE/runaway mitigation
- Implement edge stability suppression in ITER
- ELM control/mitigation

Diagnosing a self-heated plasma

(Joint with Theme II Measurement panel)

- Deploy turbulence and alpha particle measurements
- Diagnostics

Theme II: Creating Predictable High-Performance Steady-State Plasmas

Plasma modification by auxiliary systems

- Neutral Beam Injection
  - Long pulse megavolt accelerator operation
  - Long pulse megavolt power supply operation
  - Long pulse negative ion source operation
  - Long pulse positive ion source operation
  - Neutron shielding of insulators
  - Steady state neutral beam operation (lithium jet neutralizer)
- Fuelling
  - Steady state fueling technology
  - Fueling efficiency and isotope mixture control
  - Fueling method compatibility with ELMs
- Theory
  - Pellet fueling (including ablation and flows)
  - Wave and wave particle interactions from antenna to separatrix
  - How RF drives flows and currents
  - Efficient RF current drive
- ICRH
  - Launchers; Steady state high power, large gaps
  - Elm resilience with arc protection
  - Impurity production and sheath formation
  - Physics of breakdown and conditioning
  - ICRF seed current drive in AT scenarios
  - Antenna performance at high density
- Lower Hybrid
  - Steady state launchers
  - AT scenario control; rotation, current profile, pedestal, NTM
  - Edge fast electron production
  - Density limit
  - Optimal frequency in high density burning plasmas
  - Penetration through high temperature pedestal
- ECRH
  - Effect of dominant electron heating and Te > Ti on confinement.
  - Steady state high power gyrotrons with improved efficiency
  - Frequency tuning of gyrotrons
  - Multiple frequency transmission lines
  - Steady state high power launchers and components
- Additional issues for alternate configurations
  - Heating in over dense plasmas

Theme II: Creating Predictable High-Performance Steady-State Plasmas

Control

(Joint with Theme I Controlling and sustaining a self-heated plasma panel)

- Operating Regime
- Plant Startup and Shutdown
- Kinetics
- Fusion plant
- Stability
- Off-normal control
- Reliability and Certification
- Modeling and Design
- Algorithms and Approaches
- Experimental demonstrations

Integration of high-performance steady-state plasmas

- Assessing ARIES/DEMO requirements
- Core performance requirements.
- SOL/divertor compatibility
- Heating and current drive
- Control needs
- Diagnostics
- Modeling requirements for DEMO era

Note: Above topics include assessment of integration issues for 3-D/stellarator devices

Validated predictive modeling

- Predictive tritium retention
- Pedestal and ELMs
- Prediction of core plasma pressure, current, flows
- Stability, including effects of intrinsic rotation
- Disruptions
- RF and fast particle physics (including interactions)
- Integrated modeling needs

Theme II: Creating Predictable High-Performance Steady-State Plasmas

Measurement

(Joint with Theme I Diagnosing a self-heated plasma panel)

- Measurement Capability for steady-state burning plasmas
- Measurement Compatibility with S-S BP conditions and Diagnostic Access
  - concerns about radiation field, fluxes, fluences
  - 1st-wall footprints for measurements
- Reliability and Calibration of Measurements under steady-state burning plasma conditions
- Interpretation and analysis of measurements
  - Sensors for plasma control

Magnets

- Reliability
- Maintainability
- Demountability
- Alternate magnet geometries
- Materials-conductor, insulation, structural

Note: Panel is considering multiple magnet types and configurations.

Off-normal plasma events

(Joint with Theme I Mitigating transient events in a self-heated plasma panel)

- Disruptions
- Runaway electrons
- Large ELMs
- Energetic Alphas

Note: Above topics include assessment of issues for 3-D/stellarator devices

Theme III: Plasma-Material Interface

Plasma-wall interactions

- SOL and Divertor Plasma
  - Turbulent heat and particle transport
  - SOL particle flows
  - Impurity transport
  - Radiation transport
  - He pumping
- Erosion & Redeposition
  - Impurity generation
  - RF sheaths
  - Dust production
  - Morphology changes
  - Component lifetime
  - Energetic a effects
- ELMs & Disruptions
  - Off-normal heat flux
  - Energetic electrons
  - Impurity injection
- Tritium Retention
  - Safety
- Innovations
  - High radiation frac'n
  - Flux expansion
  - Stellarator edge
  - Material development
  - Liquid surfaces
  - Active coating

Plasma facing components

- Solid Surface PFC
  - Heat transfer development
  - Materials Development
  - Integrated PFC Development
  - Integrated Component Testing
  - Chamber Geometry Optimization
  - NDE technique development
- Liquid metal surface and design
  - Temperature limits
  - MHD Effects
  - Heat Removal
  - Materials Development (pipes, nozzles, etc.)
  - Diagnostics
  - Hydrogen and impurity retention, removal

Theme III: Plasma-Material Interface

- Integrated Testing
- PFC Maintenance
  - Tools and Techniques Development
  - Off-line Testing
  - Integrated Testing

Internal components

- Measurement Systems
- RF Antennas (ICRF, LH)
- Microwave launchers
- Control Coils
- Innovation (materials, active coatings)

Theme IV: Harnessing Fusion Power

Fuel cycle

Needs for DEMO
Need to adequately process fusion fuel
Need to provide torus vacuum and fueling
Need to adequately contain and handle tritium
Need to adequately perform tritium accountability and nuclear facility operations
Need to breed tritium
Need to extract tritium from the breeding system
Need to characterize, recover and handle in-vessel tritium

Power extraction

Helium coolant flow control and heat transfer enhancement at coolant/wall interfaces in highly parallel, non-isothermal systems

Magneto-thermo-fluid dynamics in the blanket utilizing lithium-bearing, liquid metal alloys as the coolant/breeder

Development, characterization, and licensing of suitable plasma facing armor, heat sink, structure material combinations, fabrication, and joining methods for high fluence fusion environment

Development, function and long term stability of ceramic functional materials and beryllium multiplier materials under combined highly non-isothermal thermomechanical loads and neutron irradiation

Compatibility and interactions among structures, coolants, and functional materials: corrosion, erosion, sintering, embrittlement, etc.

Integration, maintenance, and replacement high temperature, activated power extraction modules, cassettes and sectors and ancillary equipment

Permeation, inventory, residence time, transport through and removal of tritium from high temperature materials and coolant systems

Control of plasma power deposition on surfaces including spatial control like strike point size/sweeping and control/mitigation of ELMs and disruptions

Magnitude and impact of error fields from blanket MHD effects and ferritic steels

Engineering diagnostics development for measurement of key power extraction operations in high fluence, fusion environmental conditions

Accurate/Characterized nuclear field and nuclear response function simulations and nuclear data in complex, heterogeneous, deep structures

Theme IV: Harnessing Fusion Power

Development and validation of integrated models and predictive capabilities simulating synergistic phenomena and performance in fusion in-vessel systems including: nuclear field and response functions, thermofluid MHD, heat/mass transfer, structural mechanics, electromagnetics, chemical reactions, system thermalhydraulics, etc.

Identification, quantification and amelioration of individual and synergistic failure modes, effects, and rates under combined and prototypic thermal/mechanical/EM/chemical/nuclear loadings and multiple blanket module interactions

Transport, deposition and dose of activated products in the ancillary piping, HXs, pumps: tritium, transmutation products, corrosion products

Selection and optimization and integration power conversion system for multiple temperature helium streams including heat exchangers

Chemical control systems development for liquid metal chemistry and lithium-6 enrichment, and purge/coolant gas chemistry and tritium cleanup

Materials science

Alloy Development
Chemical Compatibility
Design Criteria
Erosion
Fabrication & Joining
Plasma-Material Interactions
Radiation Effects
Safety, Licensing, RAMI
Thermal Creep & Fatigue
Tritium Inventory
Tritium Permeation

Safety

Need for an international Fusion Safety Standard Framework
Need for an Integrated Management Strategy for Activated

RAMI

It is difficult (or impossible) to extrapolate the reliability of some fusion core components to next generation devices

Realistically, the expected availability of DEMO is modest

The availability of DEMO will need to be high enough to make the economics of fusion attractive

High reliability and availability are the products of purposeful design

Theme IV: Harnessing Fusion Power

Achieving high availability on DEMO requires a readily maintainable configuration for the tokamak core which must be developed as part of an integrated design

DEMO Requirements relevant to RAMI

Primary requirement

Availability is adequately high (A=50-75%) for the power producers to commit to building a commercial fusion plant

Implementing requirements

Integrated design. An integrated design for the tokamak core components and balance of plant which provides adequate reliability and maintainability (A=50-75%) while meeting performance requirements

Component reliability and maintainability. Component reliability and maintainability adequate to provide high availability (A=50-75%). Probability of an investment-critical failure adequately low.

Component lifetimes. Component lifetimes are adequate for achieving high availability (A=50-75%)

Maintenance system. An effective maintenance system that is proficient in monitoring equipment health, detecting and isolating failures, providing spares, effecting and verifying repair, refurbishing failed components, and processing radwaste.

Disruptions and off-normal events. DEMO must be tolerant of any disruptions or off-normal events which could occur

Theme V: Optimizing the Magnetic Configuration

Compact toroid

- FRC
  - Stability at large s (normalized ion gyroradius)
  - Transport mechanisms and scaling
  - Current drive and sustainment
  - Fast particle effects on current drive, stability, confinement
  - Heating methods
- Spheromak
  - Sustainment and confinement
  - Efficient formation techniques
  - Transport mechanisms and scaling
  - Beta limiting mechanisms
  - Particle balance and density control
  - Fast particle effects on sustainment, stability, confinement
  - Resistive wall mode control
  - Technology for long pulse operation

Reversed-field pinch

- Transport mechanisms and confinement scaling
- Current sustainment
- Integration of current sustainment and improved confinement
- Plasma boundary interactions
- Energetic particle effects
- Beta limiting mechanisms
- Self-consistent reactor scenarios
- Optimized resistive wall mode control for a fusion environment

Spherical torus

- Start-up and ramp-up
- Plasma-material interface
- Electron energy transport
- Integration at high beta
- Magnets
- Stability and steady-state control
- Disruptions
- RF heating and current drive
- Ion scale transport
- Fast particle instabilities
- Neoclassical tearing modes
- Continuous neutral beam injection systems

Theme V: Optimizing the Magnetic Configuration

Stellarator

Simpler coil systems
Integrated high performance of Quasi-Symmetric optimized stellarators
Confinement predictability
Divertors
Operational limits
Impurity and fusion ash accumulation
Reduction of anomalous transport
Energetic particle instabilities
Disruptions (limits on plasma current generated rotational transform)
ELM-free high performance
Profile sensitivity of operational limits
Superconducting stellarator coils