ITER R&D Needs, Challenges, and the Way Forward

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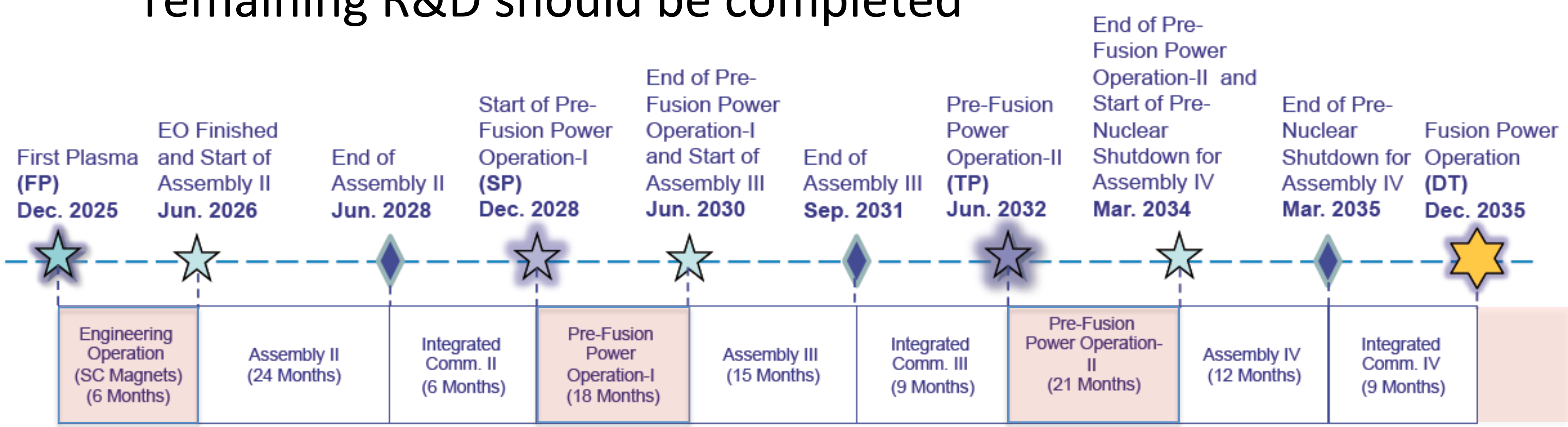
Context of ITER R&D Needs

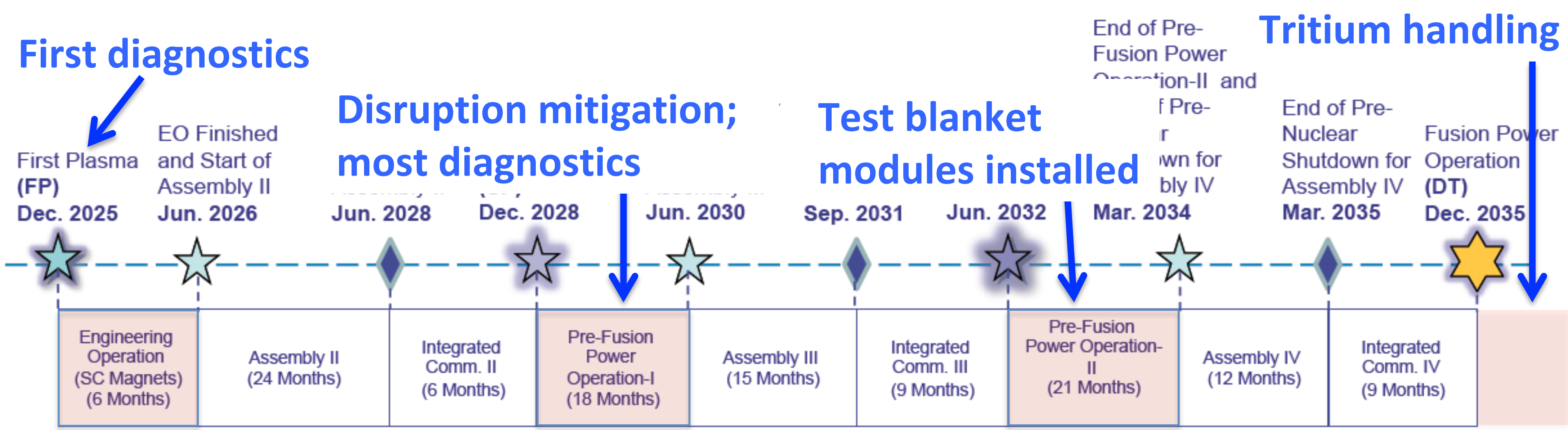
- By internal measures, >85% of design activity is complete
  - This implies most of the technology R&D is complete; however, some issues remain and have to be considered;
- The size and geometry, maximum magnetic field strength, and divertor design of ITER are fixed
  - This implies the remaining physics R&D focuses on the effective use of ITER;
- The ‘staged approach’ schedule for ITER defines when the remaining R&D should be completed



Areas of Technology R&D

- Disruption Mitigation
- Diagnostics
- Remote Handling
- Test Blanket Modules
- Tritium Handling

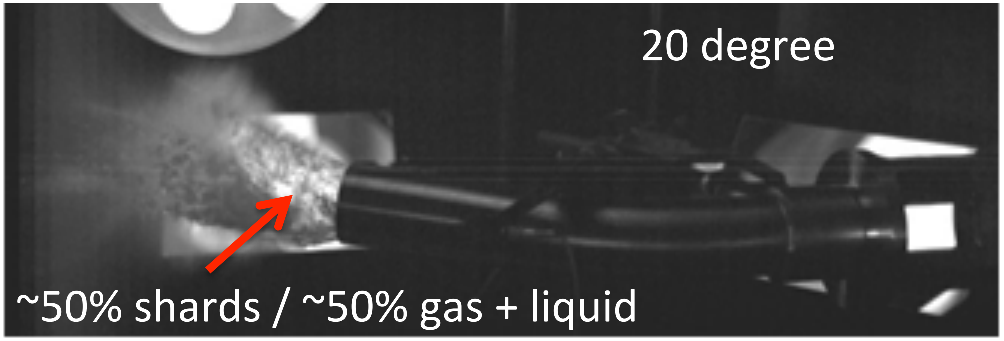
R&D must be complete in time to enable integration into design and implementation for ITER needs



Disruption Mitigation

The baseline disruption mitigation approach for ITER is Shattered Pellet Injection (SPI)

Neon + Deuterium *T. Gebhart, to be published*



Key R&D needs for SPI are:

- Reliable and uniform pellet formation and release;
- Understand and control variability in size distribution of shards from the shatter of the pellet;
- Minimize the variability of timing of the pellet (critical for multiple injectors);
- Develop diagnostics to monitor reliability and facilitate commissioning;

In addition, there is a need for technology development of alternate disruption mitigation methods

Diagnostics

ITER R&D needs in the diagnostic area reflect the challenges of the nuclear environment:

- Robust and maintainable vacuum barrier windows that transmit visible or IR radiation;
- Robust and accurate neutron counters;
  - Goal is 1% accuracy for fusion power with maintainable sensors
- Accurate reflectometry for position control;
  - Mitigates risk of loss of magnetics diagnostics
- Design optimization with low-activation materials and remote handling capacity;
  - Critical for reduction of occupational radiation exposure
- Diagnostics with steady-state capability (ITER pulse capability up to 3000 s).

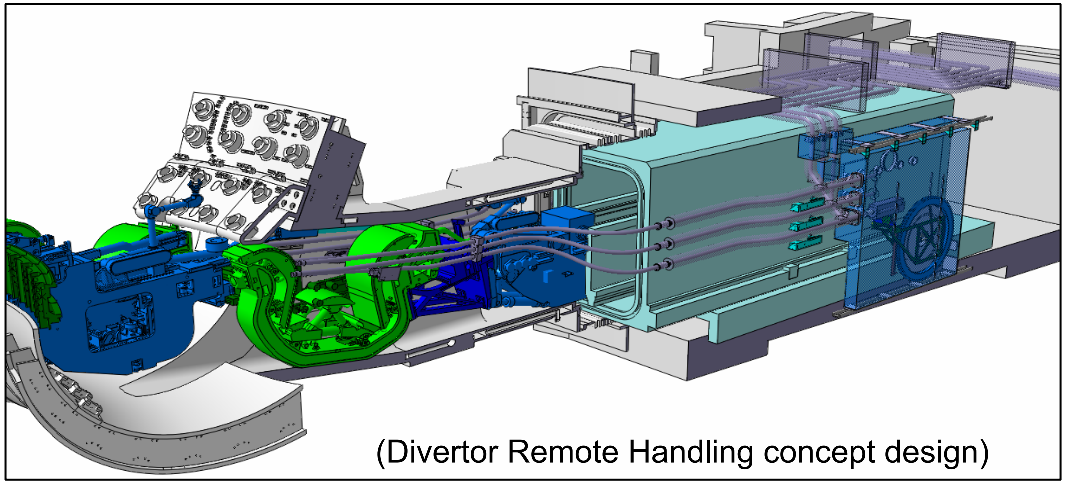
ITPA Diagnostics group (under CTP TCP) plays a critical role

Remote Handling (1)

Mock-ups of ITER systems would allow testing and timing of maintenance procedures:

- Required to know the intended time planned for routine maintenance is adequate;
- Would guide decisions to repair or proceed without systems that require maintenance unexpectedly during operational periods.

Areas of interest are in-vessel, ex-vessel, hot cell, and waste processing maintenance activities



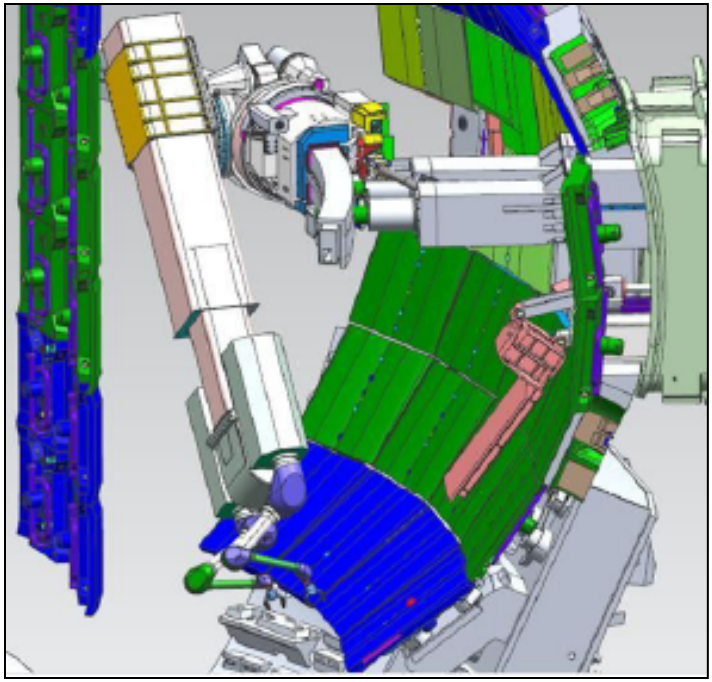
(Divertor Remote Handling concept design)

ITER mock-up development contributes directly to DEMO design—ITER validates the transfer from mock-up to real use

Remote Handling (2)

Decontamination of the remote handling equipment for hands-on maintenance is an area of uncertainty and risk:

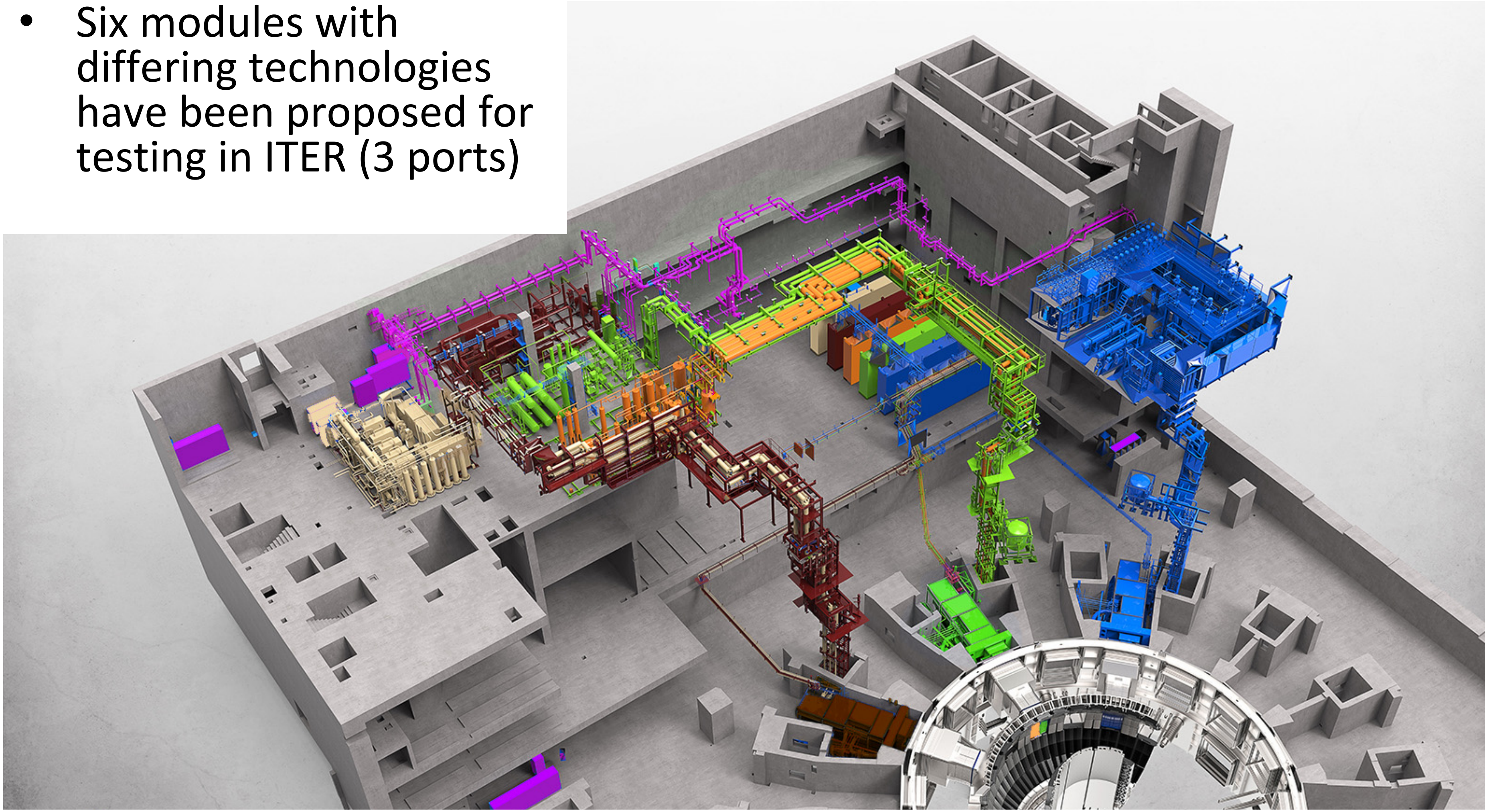
- Primary concern is dust (especially beryllium);
- Simulations in the lab would need to test particle size and composition relevant to ITER with expected ITER remote handling tool materials.



Systems affected would be the remote handling casks and remote handling systems for the blanket modules, divertor, neutral beam, and the hot cell

Test Blanket Module Testing in ITER

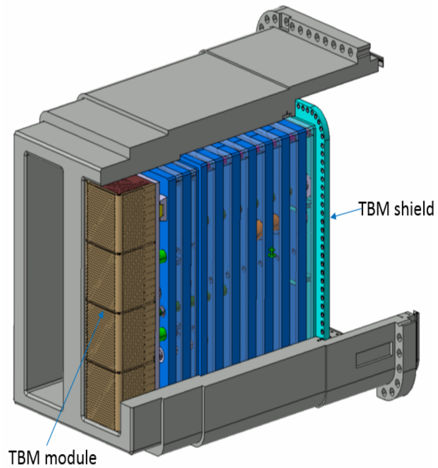
- Six modules with differing technologies have been proposed for testing in ITER (3 ports)



Test Blanket Module R&D

Significant R&D is needed for design and implementation of the test blanket modules in ITER:

- Structure material development, including manufacturing technology and qualification under neutron irradiation;
- Breeder material development, including characterization of thermo-mechanical properties, hydrodynamics for fluid breeders, and tritium release;
- Diagnostics to measure the performance of the modules;
- Simulation tools to be validated for future design and safety analysis.



Recall that TBM operation in ITER is itself part of the TBM R&D program

Tritium Handling

Tritium handling in ITER differs from existing facilities due to:

- Larger magnitude than previous tokamaks
- More complex waste/input stream than non-fusion facilities
- Demands of tokamak operations

R&D needs in this area include:

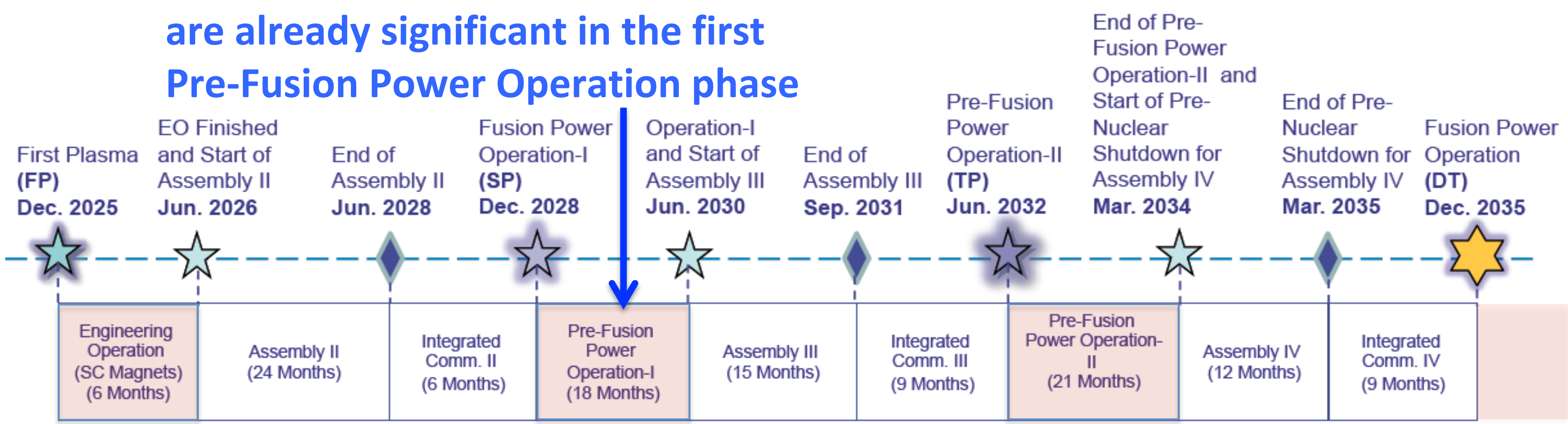
- Development of tokamak leak localization and repair methods for a tritium environment
- Diagnostics for detection of tritium and monitoring of concentration in cooling and waste water
- Diagnostics for rapid analysis of surface tritium concentration
- Understanding of system performance in the presence of hydrocarbons, ammonia, halogens, and fire gases
- Development of larger capacity tritium-compatible pumps

Areas of Physics R&D

- Disruption physics
- Plasma-wall interactions
- Plasma performance
- Real-time control

Note: This is a subset of ITER's physics R&D needs—a comprehensive prioritized list will be available later this year

Most of the topics discussed here are already significant in the first Pre-Fusion Power Operation phase

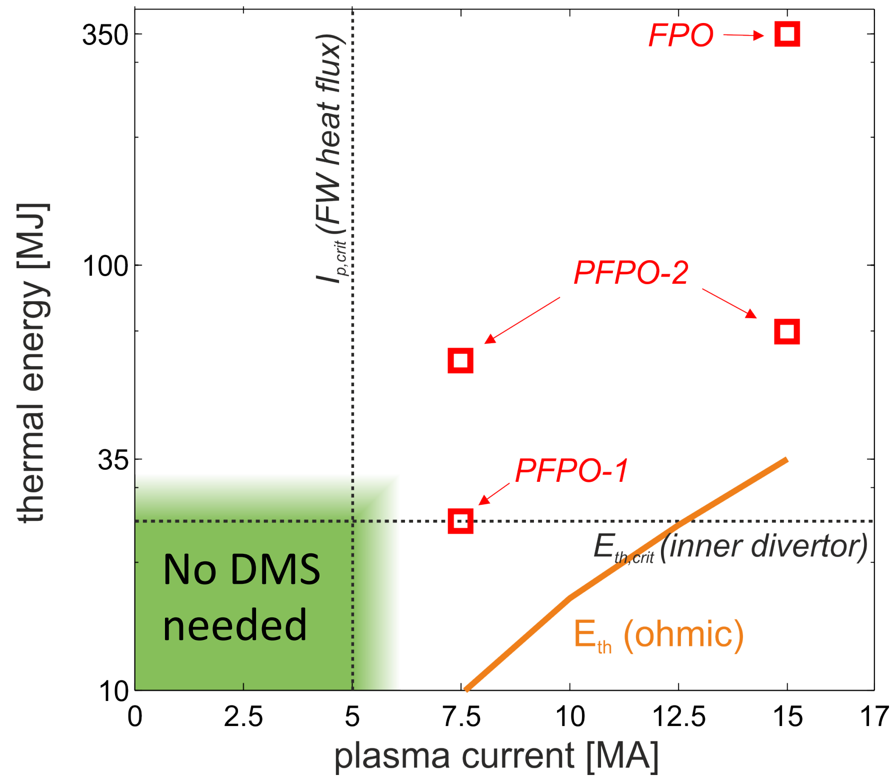


Disruption Physics (1)

Disruption mitigation is needed in the first operational phase of ITER

Key R&D needs:

- Measure effectiveness of SPI to mitigate the thermal loads and forces in larger machines
- Establish reliable schemes to predict and detect disruptions



One type of disruption (rotating asymmetric VDE) has the potential for large forces on in-vessel components due to resonance between the plasma rotation and the vacuum vessel

- Critical issue is predictive capability for the rotation frequency

Disruption Physics (2)

In addition to the issues just discussed, understanding high energy ‘runaway’ electrons generated during a disruption and how to suppress them is critical

Key areas of research:

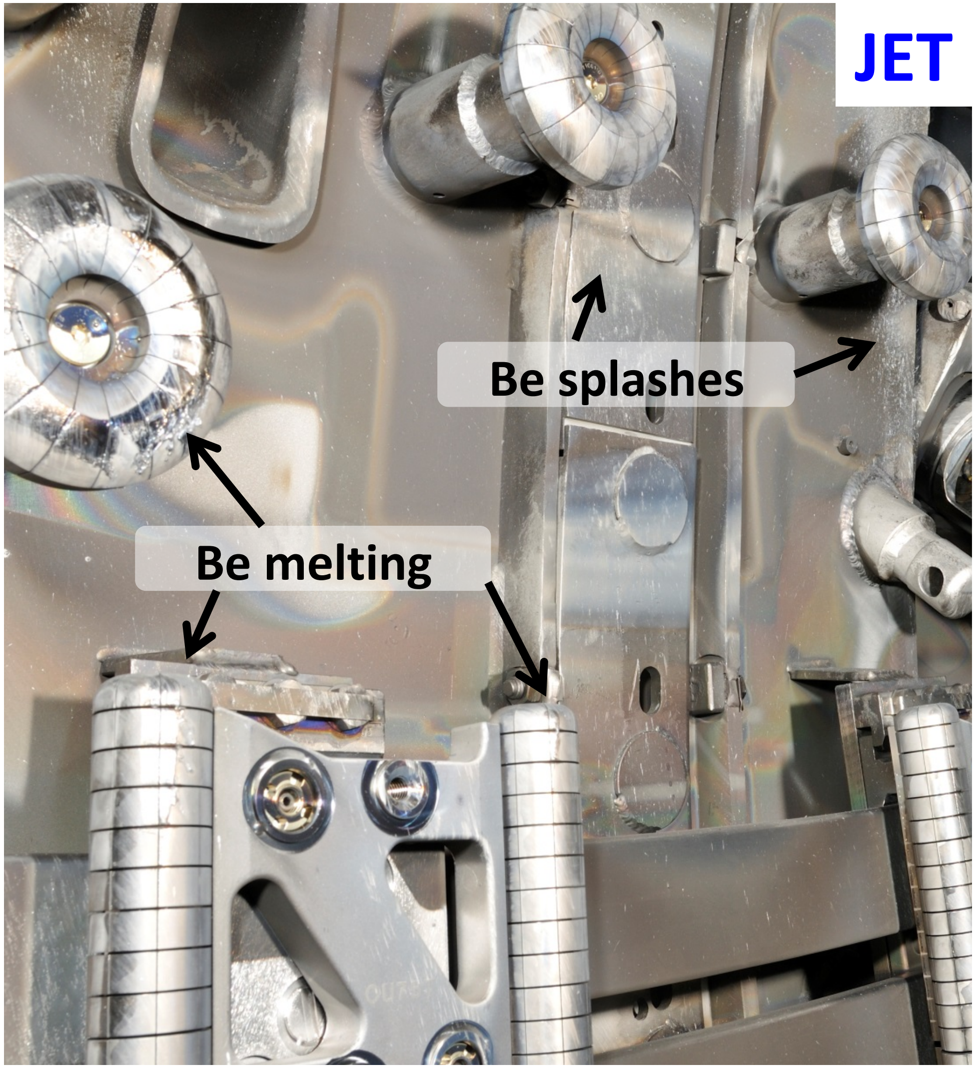
- Validation of a physics model for the runaway generation mechanism, including the effect of currents in the vacuum vessel
- Experimental optimization of pellet composition and timing for runaway suppression by SPI
- Simultaneous optimization of SPI to mitigate thermal load, forces, and runaway generation
- Physics model for penetration of shards from SPI into the plasma as a function of size and plasma parameters

Plasma-Wall Interactions (1)

Generation of beryllium dust is a prime concern for ITER

Key research areas:

- Validate the cause of melting (suspected to be disruptions;
- Benchmark quantitative models of melting, material migration, and dust production.



M. Rubel et al., ITPA DivSOL Naka, October 2016

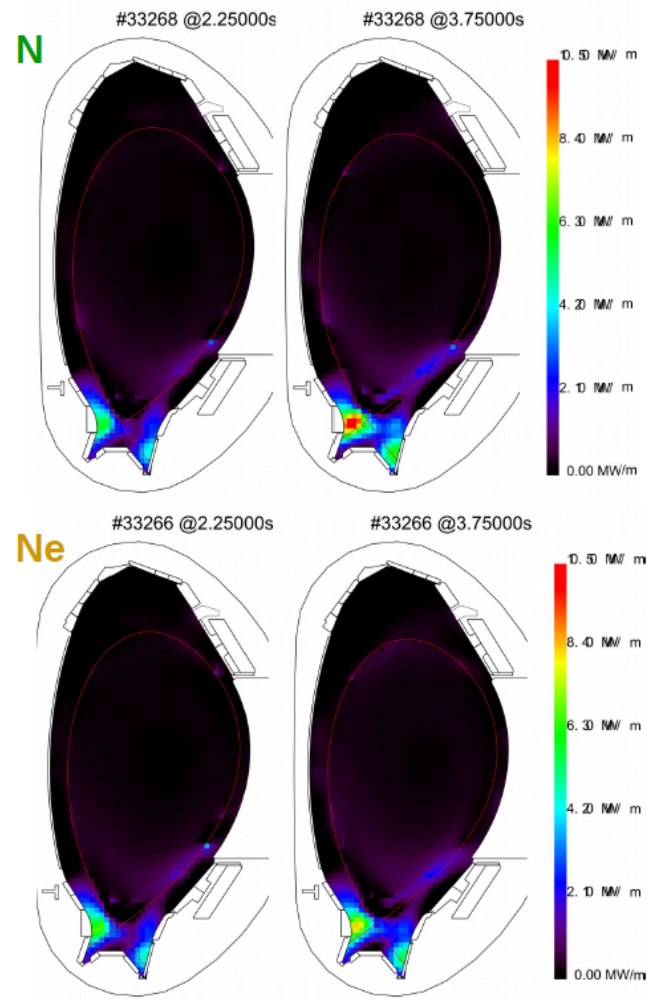
Plasma-Wall Interactions (2)

ITER requires reduction of power flow to the divertor in full-performance operation

- Radiation inside and outside the plasma edge is envisioned

Key R&D needs:

- Optimization of impurity species to radiate at the correct location
- Understanding of impact on fusion performance, including dilution
- Quantification of ammonia production for nitrogen seeding (impact on tritium plant)



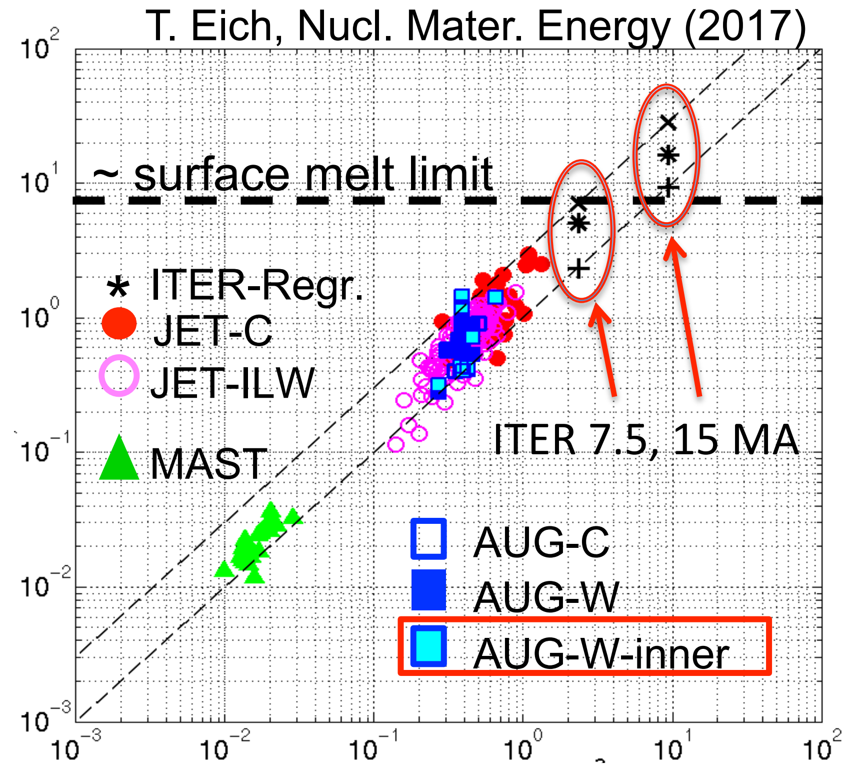
F. Reimhold et al., ITPA DivSOL, York, UK June 2017

Radiation patterns in AUG for nitrogen and neon injection

Plasma-Wall Interactions (3)

Control of Edge Localized Modes (ELMs) is necessary for high-current operation in ITER to limit erosion of the divertor

- Application of asymmetric magnetic fields is the primary control method for ITER

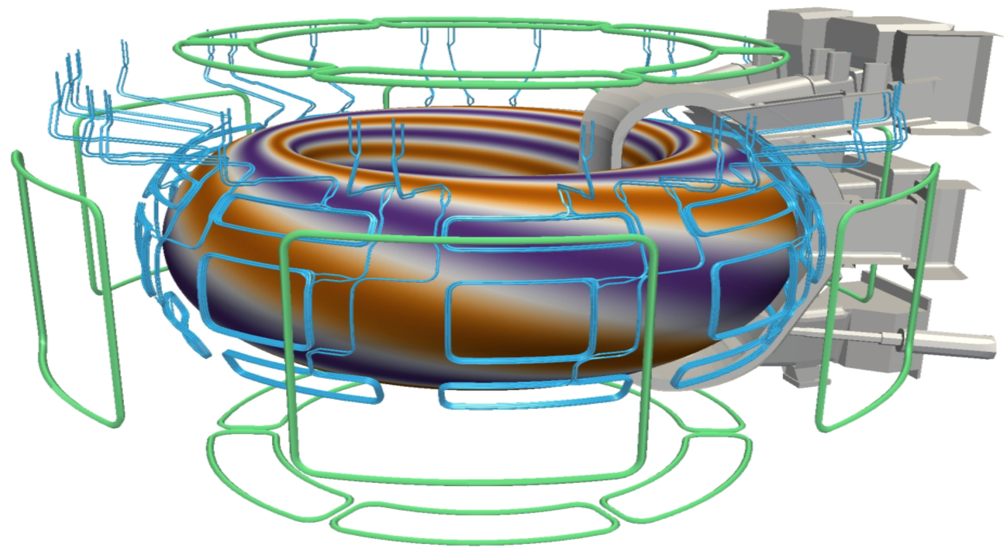


Key R&D needs:

- Quantitative understanding of the applied field needed for suppression in ITER;
- Measurement of impact on fusion performance;
- Testing of alternate methods of ELM mitigation (e.g., pellets, small-ELM operating regimes).

Plasma Performance (1)

Correction of toroidally asymmetric external ('error') magnetic fields is needed to optimize ITER plasma performance, especially at low rotation



Key R&D needs:

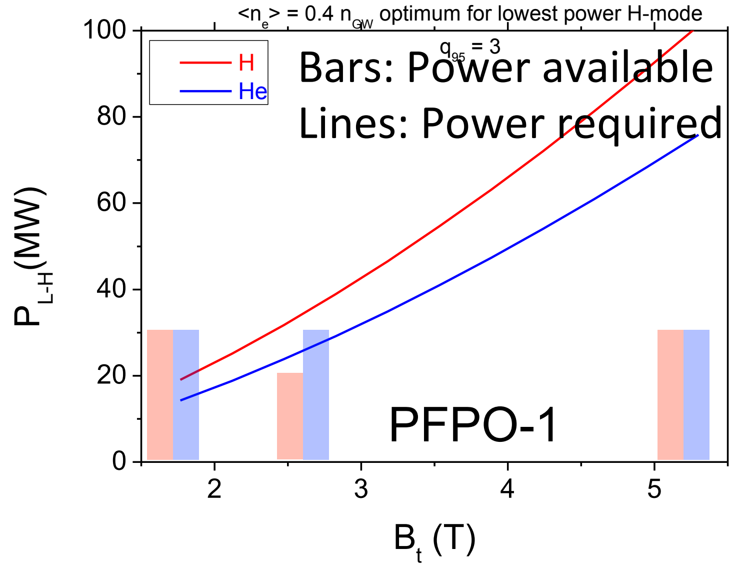
- Quantify what level of resonant and non-resonant error field is acceptable for ITER at each stage of operations
- Determine whether upper and lower coils are both needed for error field correction

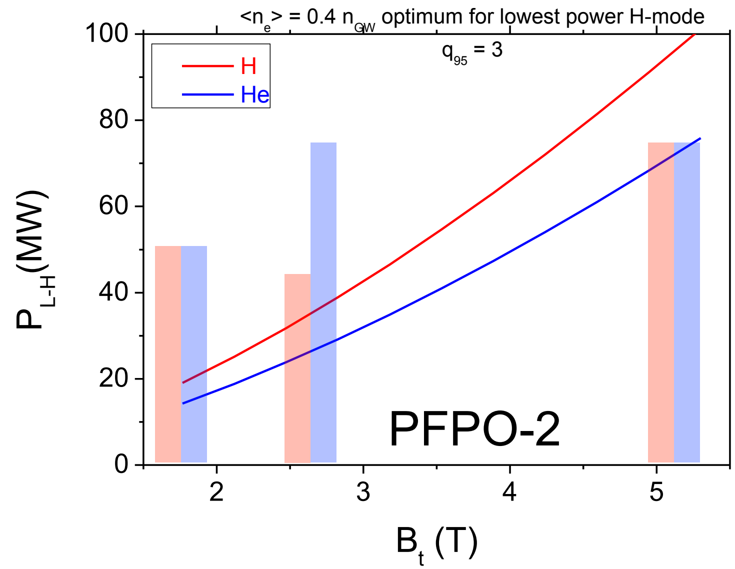
Plasma Performance (2)

Knowledge of how the H-mode power threshold and confinement vary with hydrogen species and helium is critical to optimizing the ITER Research Plan

Key R&D needs:

- Quantify the variation of the H-mode power threshold, especially in mixed hydrogen/helium plasmas
- Validate the predictive capability for plasma performance, including the pedestal, for the expected gas mixtures of each operating phase





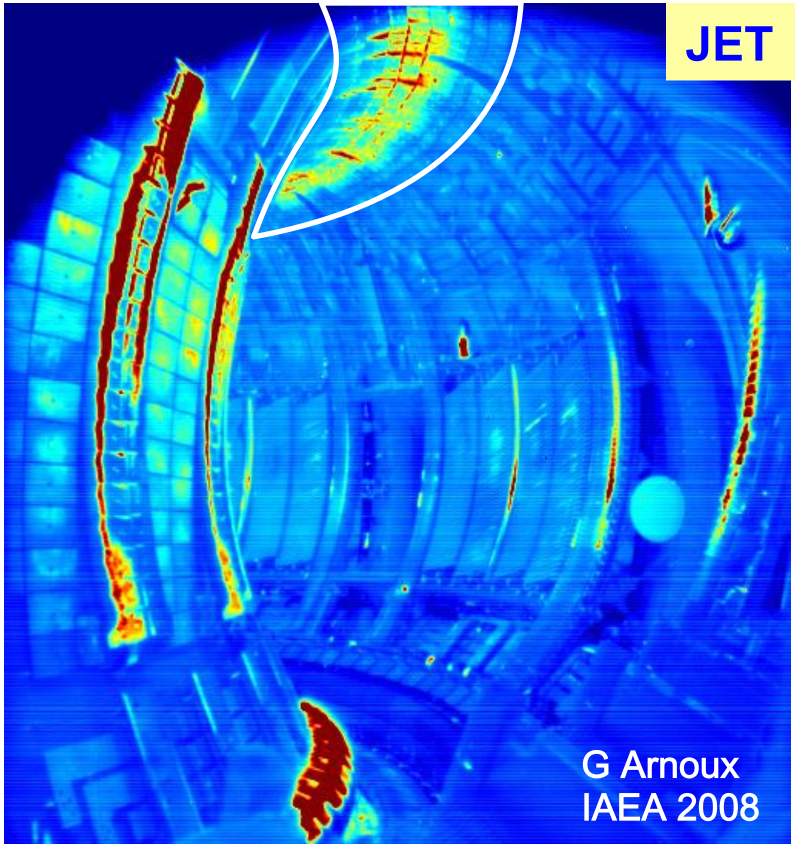
Real-time Control (1)

Protection in real-time is needed to prevent damage to internal components

Key R&D needs:

- Development of adaptive algorithms, including forecasting, to separate non-physical signals from those requiring action
- Demonstration of closed-loop control of divertor heat flux reduction by radiation
- Development of arc detection for ICRF antennas

Real-time Hot Spot Detection



Real-time Control (2)

The potential consequences of disruptions in ITER motivate development of strategies to avoid rather than mitigate them

- The plasma control system is the first line of defense

Key R&D needs:

- Demonstration of active control of instabilities with ITER-relevant tools
- Generation of maps of operating space where instabilities likely to lead to disruption are found (empirical or theoretical)
- Development of robust protocols for safe termination of the plasma when approaching unsafe operating conditions

The Way Forward

- ITER is reviewing its Physics R&D needs to prioritize and to identify unique capabilities to address them jointly with IO
  - Goal is to complete by mid-2018, routinely update, and make available to all the ITER members
  - A process for making an MOU with laboratories in ITER Member states is in place for new collaborations
- ITER makes extensive use of the ITPA process
  - Co-operation on Tokamak Programmes TCP is a framework for these collaborations
  - This meeting is an opportunity to engage the other TCPs in contributing to ITER R&D needs, especially technology
- ITER recently launched the ITER Science Fellow program to enhance modeling capability
  - Program is highly successful—more than 30 fellows now participate with many more associated scientists