# ITER Research Plan priorities for WP AC in 2022

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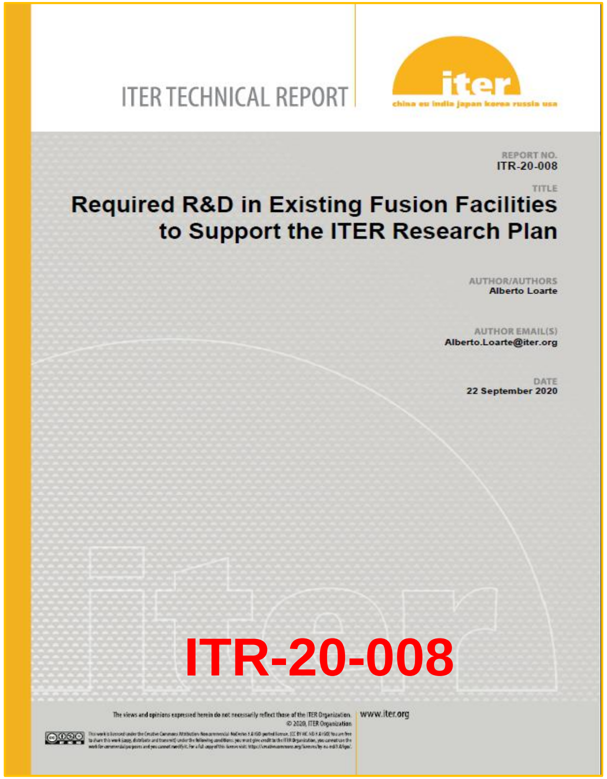
*The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.*

# Supporting R&D for the ITER Research Plan

- Presented in draft form to all ITPA Topical Groups in 2019 and released as ITER Technical Report in 2020
- 3 priority categories identified:
  1. Outcome of R&D can have major impact on system design or on the IRP (e.g. modifying overall experimental strategy in each phase or the objectives of the phases themselves)
  2. Outcome of R&D expected to have medium impact on system design or on the IRP (e.g. modifying significant details of experimental strategy to achieve objectives in each phase)
  3. Outcome of R&D expected to optimize details of IRP experimental strategy to achieve objectives in each phase by providing relevant experience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Required R&D in Existing Fusion Facilities to Support the ITER Research Plan

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# Workbook example: R&D for design completion

- R&D for design completion: Class A
- IRP implementation: Class B

| Ref. | System/ Issue | Required R&D | Category* | Required experimental facilities | Comment | Phase when system required/ Most impacted Phase |
|---|---|---|---|---|---|---|
| A. R&D for design completion | | | | | | |
| A.1 | SPI-single injector. Pellet injection optimization for RE avoidance (incl. TQ and CQ mitigation) | Optimization of shard size, velocity, amount, gas vs. shard fraction, composition (D + impurity) to achieve RE avoidance with optimum TQ, CQ (incl. wall loads) | 1 | Range of tokamaks with different sizes and plasma parameters to allow extrapolation to ITER (including high $I_p$ tokamak) and with appropriate measurement capabilities | More details on R&D work plan for DMS (https://user.iter.org/?uid=WEE89R) | PFPO-1 |
| A.2 | SPI-single injector demonstration for runaway mitigation | Determination of feasibility to dissipate the energy of formed runaway beams (amount, assimilation) and to improve scheme | 1 | Range of tokamaks with different sizes and plasma parameters to allow extrapolation to ITER and with appropriate measurement capabilities | More details on R&D work plan for DMS (https://user.iter.org/?uid=WEE89R) | PFPO-1 |
| A.3 | SPI-multiple injections | Determination of effectiveness of multiple injections to achieve RE avoidance with optimum TQ, CQ (incl. wall loads) compared to single injections (incl. timing requirements) | 1 | Range of tokamaks with different sizes and plasma parameters to allow extrapolation to ITER with at least two injectors from the same/similar locations (toroidal separation not required) and with appropriate measurement capabilities | More details on R&D work plan for DMS (https://user.iter.org/?uid=WEE89R) | PFPO-1 |
| A.4 | SPI-multiple injectors | Determination of effectiveness of multiple injection from different spatial locations to achieve RE avoidance with optimum TQ, CQ (incl. wall loads) | 1 | Range of tokamaks with different sizes and plasma parameters to allow extrapolation to ITER with at least two injectors toroidally well separated and with appropriate measurement capabilities | More details on R&D work plan for DMS (https://user.iter.org/?uid=WEE89R) | PFPO-1 |
| A.5 | DMS – alternative injections techniques | Demonstration of the feasibility of the technique to inject material in a tokamak and comparison of mitigation efficiency with SPI | 1 | Single tokamak demonstration and with appropriate measurement capabilities | More details on R&D work plan for DMS (https://user.iter.org/?uid=WEE89R) | PFPO-1 |
| A.6 | DMS – alternative disruption mitigation strategies | Exploration of disruption mitigation by schemes other than massive injection of $D_2$ and high Z impurities | 1 | Single tokamak demonstration and with appropriate measurement capabilities | More details on R&D work plan for DMS (https://user.iter.org/?uid=WEE89R) | PFPO-2 |
| A.7 | Laser Induced Desorption for in-situ T retention measurement | Demonstrate LIDS as quantitative in-situ diagnostic measurement for T retention in Be co-deposits at divertor | 1 | Demonstration in tokamak with Be/W environment | Required to provide in-situ measurements of T retained in divertor Be co-deposits (most likely after each operational day) | FPO |
| A.8 | Single crystal mirror testing | Performance of single crystal mirror with/without active cleaning | 1 | Demonstration in Be/W environment | Required for evaluation of performance of ITER diagnostics using plasma facing mirrors | PFPO-1 |
| A.9 | Laser Induced Breakdown Spectroscopy | Demonstrate LIBS as quantitative measurement for T retention in Be co-deposits on main wall | 1 | Proof of principle demonstration in Be tokamak environment | Can provide an in-situ measurement of T retention in the first wall during shutdown by installation in a robotic arm | FPO |
| A.10 | SPI-single injector. Pellet injection geometry optimization for RE avoidance (incl. TQ and CQ mitigation) | Optimization of injection direction to achieve RE avoidance with optimum TQ, CQ (incl. wall loads) | 2 | Range of tokamaks with different sizes and plasma parameters to allow extrapolation to ITER and with appropriate measurement capabilities | More details on R&D work plan for DMS (https://user.iter.org/?uid=WEE89R) | PFPO-1 |
| A.11 | Develop capabilities to measure fast ion losses | Demonstration of quantitative measurements in a tokamak environment (ICE) and/or of compatibility with ITER operation (FILD) | 2 | Demonstration in suitable tokamak with fast particles and under ITER-relevant conditions | Required to provide a direct measurement of fast ion losses in ITER | FPO (in present plans) |
| A.12 | Ammonia formation | Determination of ammonia formation during nitrogen seeded plasmas | 2 | Divertor tokamaks with metallic PFCs | Provides useful input to the fuel processing plant in ITER | FPO |
| A.13 | Neutron diagnostics | Demonstration of measurement capabilities for time of flight 14 MeV neutron spectrometer | 2 | Tokamaks with sufficient 14 MeV production | Provides input to diagnostic design to provide D/T ratio from neutron measurements | FPO |
| A.14 | IR measurement with reflections in metallic environment | Demonstration of reflection-robust IR temperature measurements of plasma facing components | 2 | Tokamaks with metallic PFCs and suitable IR systems | Provides input to diagnostic design/optimization and data processing to minimize consequences of reflections on PFC surface temperature | PFPO-1 |

# R&D topics

- R&D for design completion (DMS, Diagnostics, etc.)
- Disruption characterization, prediction and avoidance
- Stationary H-mode plasmas, ELMs, ELM control and impact on H-mode and power fluxes
- Characterization and control of stationary power fluxes
- Plasma material/component interactions and consequences for ITER operation
- Start-up, ohmic and L-mode scenario development
- Conditioning, fuel inventory control
- Basic scenario control and commissioning of control systems
- Transient phases of scenarios and control
- Complex scenario control during stationary phases
- Validation of scenario modelling and analysis tools
- Heating and Current Drive and fast particle physics
- Long pulse/enhanced confinement scenario issues

WPAC thrusts cover all these topics

# High Priority Cat. 1 and Cat. 2 R&D Topics (next ~3 years)

- Support of DMS baseline design (Shattered Pellet Injection, SPI)
- Resolution of diagnostic design issues
- He H-mode operation and/or H+10% He operation for Pre-Fusion Power Operation
- 3rd harmonic ECH heating validation for 1.8 T operation in PFPO
- Low $\langle n_e \rangle$ ECH heated H-modes for operation in PFPO-1
- Electron Cyclotron Wall Conditioning (ECWC) for use in PFPO-1
- ECH-assisted and ohmic start-up for First Plasma (FP) and PFPO-1
- Disruption loads characterization in PFPO
- Strategy for ELM control
- n = 1 and n = 2 error fields and correction
- Divertor lifetime appropriateness to allow operation until well into the Fusion Power Operation (FPO) phase with the first tungsten divertor
- 3-D field ELM suppressed H-mode as integrated scenario for ITER high Q scenarios
- Specific issues for Q = 5 steady-state scenarios in ITER with NBI + ECH

# B.10. Validation of scenario modelling and analysis tools

- B.10.1: Develop diagnostic and actuator models for control and validation of scenario modelling tools
  - Synthetic diagnostics/actuators are required for implementation of plasma control in ITER and for validation of modelling predictions
- B.10.2: Develop workflows to derive measurement for plasma parameters from multiple diagnostic inputs
  - Most key ITER parameters are determined by various simultaneous diagnostic systems. (Classified as primary, backup, and supplementary). Workflows are required to provide measurements of plasma parameters based on these multiple diagnostic inputs with the limitations/inaccuracies of each individual diagnostic contributing to the measurement taken into account.

# B.10. Validation of scenario modelling and analysis tools

- B.10.3: Develop (tokamak-independent) IMAS plasma reconstruction chains using measurements and their uncertainties, demonstrate their use at different facilities and compare performance with local tools
    - Plasma reconstruction chains are required to analyse ITER data. It is important to ensure that these tokamak-independent chains are developed and well tested before they are required for ITER
- B.10.4: Improve ITER IMAS scenario modelling capabilities by experimental validation
    - Reliable ITER pulse design requires validated plasma scenario simulators. The models in the simulator will be refined as result of ITER operation but an initial validation against experiment is required before their first application to ITER

# B.10. Validation of scenario modelling and analysis tools

- B.10.5: Develop faster than real-time plasma simulator to predict pulse trajectories and required control actions
  - Anticipation of control actions requires a reliable faster than real-time predictor in ITER. The models in the predictor will be refined as result of ITER operation but an initial benchmark against experiment is required before their first application to ITER

# Modelling & Analysis at ITER

- All physics modelling at ITER will use IMAS (by definition)
- IMAS is built around a standardized representation of data (Interface Data Structures, IDSs, described by a Data Dictionary) and an infrastructure to support data exchange and workflow development
- Physics codes come from ITER Members (IO has no resources for development)
  → WPAC can help refine/extend physics modelling capabilities to support predictions of ITER performance and contribute to future data interpretation
- Validation of physics codes and workflows also expected to be performed within ITER Members
  → WPAC can help validate models against data from EU devices and demonstrate portability through use of standard (IMAS) data representation

# High-Fidelity Plasma Simulator - I

- The IO is developing a HFPS (based around DINA and JINTRAC) able to perform coupled free-boundary and core-edge-SOL transport simulations of ITER plasmas

- A functional version is targeted for mid-2022 and a high-performance version for 2024

- Will form the pinnacle of a hierarchy of plasma simulation capabilities ranging from a rapid Pulse Design Simulator (PDS) used to design reference waveforms (pulse schedule)

- The HFPS will be used for ITER scenario design and performance predictions and in co-simulations with the Plasma Control System Simulation Platform (PCSSP)

# High-Fidelity Plasma Simulator - II

- Example areas where WPAC could contribute to HFPS development:
  - Improved (and validated) physics models
    - E.g. Impact of EP transport due to MHD, including AE, on CD
  - High performance (faster!) reduced/surrogate (ML) models enabling more extensive exploitation
    - E.g. Core/edge transport models for impurities (W, Be, He) and fuel ions (H, D, T)
  - Improvement to HFPS workflow design
    - E.g. Improvements to performance, flexibility, maintainability, portability

# Data Processing and Interpretation

- Example areas where WPAC could contribute to ITER's preparations for experimental data processing and analysis/interpretation:
  - Modelling to support diagnostic design (A.11)
    - Support decisions on fast ion loss detector design
    - Development of comprehensive model of Ion Cyclotron Emission (ICE) to support interpretation of (existing) observations and support development of a measurement of lost fast ions (A.11)
  - Development of synthetic diagnostics (B.10.1)
    - For diagnostic performance assessments, physics studies/data interpretation, and control studies

# IMAS Infrastructure

- Identification of technical limitations of present IMAS Data Model and infrastructure and collaborative development of solutions
  - Close collaboration with WP AC foreseen