EUROfusion E-TASC General Meeting

Perspective of the Plasma Science for ITER, DEMO and stellarators department

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Objectives of the Plasma Science for ITER, DEMO and stellarators Department (likely changes name to Fusion Science Department)

- Address physics gaps for ITER with the priority on the ITER re-baselining→MoU that contains a technical specifications document with the mutual reporting as deliverables
- Support the FoaK physics programme → as DEMO terminology will be removed, DEMO parameters serve as a proxy for a First of a Kind, FoaK, to provide orientation to the physics programme (e.g. need of no/small ELM regimes as e.g. QCE or combined with exhaust solutions such as XPR now both part of ITER considerations)
- A draft version of a physics gaps document towards a stellarator-based reactor is being circulated among the physics gap working group and includes SSRLs
- BEST research plan published in Nov 2025 → now assess where essential/beneficial for programme
- Expect that increased focus on interpretative modelling required (challenging to sustain in 2026 and more so in 2027 with reduced funds compared to the high funding available for 2025)
- *Aiming at addressing uncertainty quantification for interpretative modelling & in extrapolations for ITER and DEMO (moving start of activity to 2026 as discussion not concluded how to most efficiently initiate and drive the community – essential as the uncertainty determines the confidence and thus speed with which ITER could progress towards its goals, major impact on discussion about VNS and plays a crucial role in the discussions around the DEMO LAR gate 2 review → presently ITER needs to learn a lot on its path as reliable extrapolation is not expected to be available in time)*

The role of Subjective Scientific Readiness Levels

Level	Criteria
Emerging	Little or no understanding yet on WP TE devices
Exploratory	Physical process is assessed on WP TE devices, transposing to ITER or DEMO is uncertain
Judgemental	Controlling physical processes has been assessed on WP TE devices, but extrapolation to ITER/DEMO requires scalable parameters and further investigation
Mature - needs underpinning	Good understanding of controlling physical processes on WP TE devices, but major uncertainty in view of transposing ITER/DEMO
Mature - needs support	A good understanding has been achieved on WP TE devices, further research exploring ITER or DEMO relevant parameters
Established	Understanding is well developed and can be applied to ITER or DEMO

Definition established within WP TE in 2021 and monitored since then, to be extended to PWIE end of 2024 and W7-X in 2026/2027 (towards stellarator DEMO physics gaps)

Status and Changes in SSRLs for 2024 (update for 2025 soon)

Level	Emerging	Exploratory	Judgemental	Mature-needs underpinning	Mature-needs support	Established

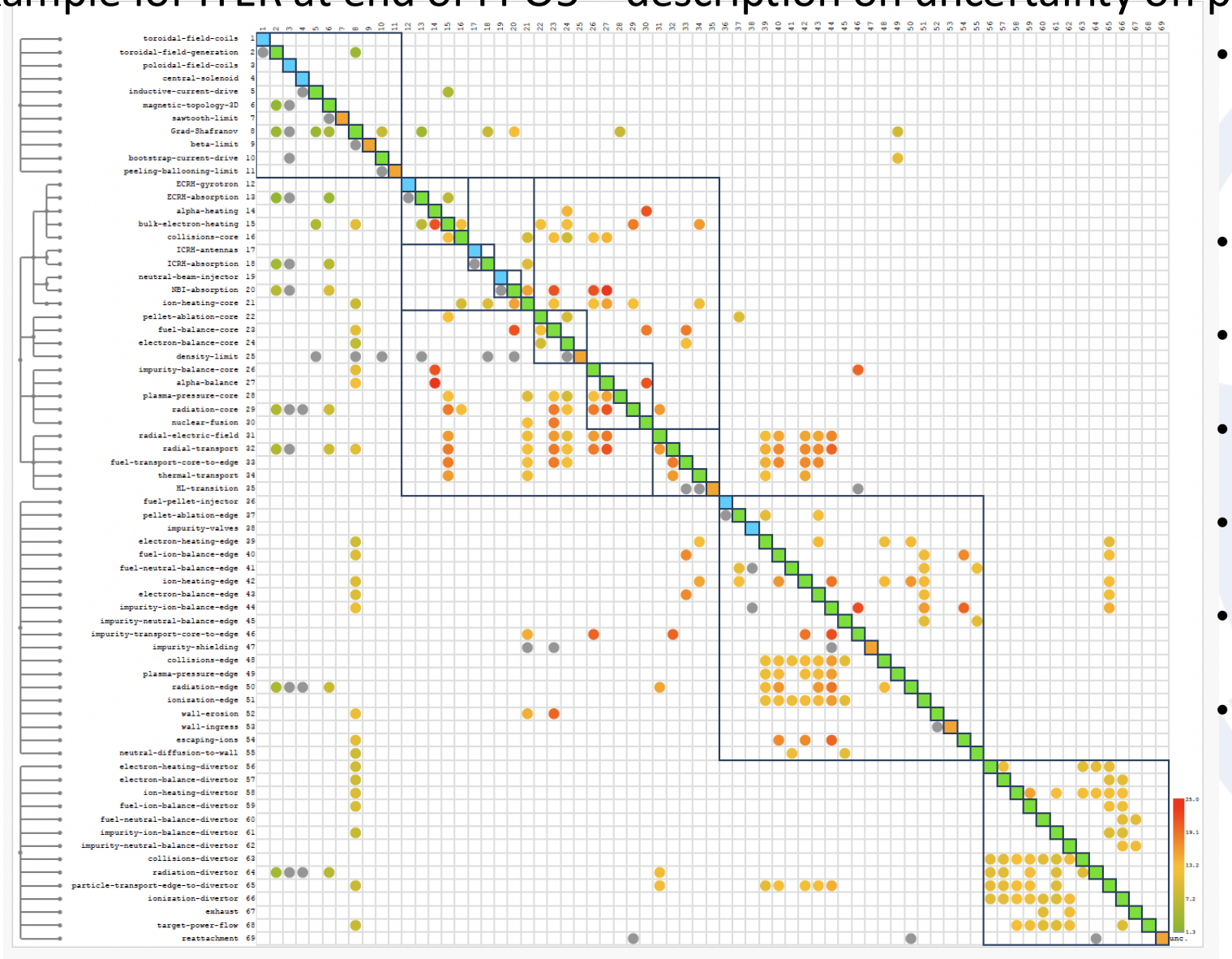
RT	*Title*	*D1*	*D2*	*D3*	*D4*	*D5*	*D6*	*D7*
RT01	Core-Edge-SOL integrated H-mode scenario compatible with exhaust constraints in support of ITER		x		x			
RT02	Physics understanding of alternatives to Type-I ELM regime			x	x		x	
RT03	Strategies for disruption and run-away mitigation						x	
RT04	Physics-based machine generic systems for an integrated control of plasma discharge	x	x		x			
RT05	Physics of divertor detachment and its control for ITER, DEMO and HELIAS operation			x				
RT06	Preparation of efficient Plasma Facing Components (PFC) operation for ITER, DEMO and HELIAS		x					
RT07	Physics understanding of alternative divertor configurations as risk mitigation for DEMO			x				
RT08	Physics and operational basis for high beta long pulse scenarios	x		x	x	x		
RT09	Physics understanding of energetics particles confinement and their interplay with thermal plasma		x	x	x			

DX: Numerator of deliverable or scientific objective

"X" marks a scientific objective of an RT with a change of the SSRL in 2024 compared to 2023 based on the level 3 reporting

Developed a Design Structure Matrix to assess areas of largest uncertainty

Example for ITER at end of FPO5 – description on uncertainty on processes

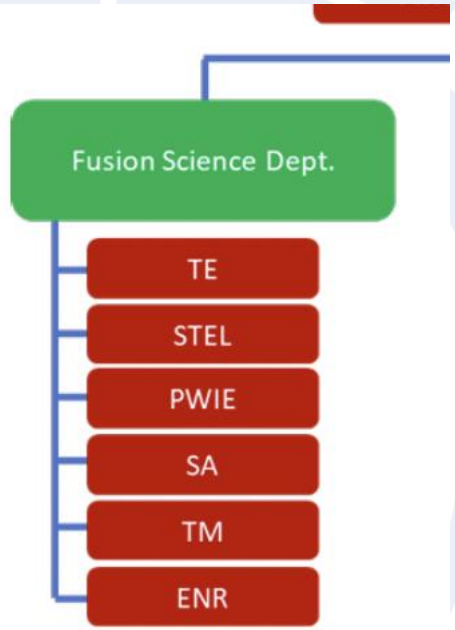


- EUROfusion pilot plant working group, sub-group 2 for physics (chaired together with M. de Baar) w. A. Loarte for ITER as a member
- Idea of a concept agnostic approach: tokamaks and stellarator
- DSMs were produced for 3 main phases of ITER (SRO, FPO-3 and FPO-5)
- DSM was also produced for W7-X towards a stellarator FoaK
- Discrete events have not been addressed (yet)
- Outcome: at least one intermediate device required towards Stellarator FoaK
- ITER likely to attain most TRL 7 (@FPO-3) during operations with *remaining uncertainties in the continuous physics associated with the alpha physics, impurities, wall erosion and edge transport*

Organization in 2026 → will change name to Fusion Science Dept.

Organized in 5/6 Work Packages:

- WP TE Tokamak Exploitation (N. Vianello, E. Tsitrone, call for participation end of year, with most of participation resources aimed for January 2026 - as in past years),
- WP STEL Exploitation (follow up of WP W7-X + conceptual aspects towards stellarator reactor, M. Jakubowski)
- WP PWIE Plasma Wall Interaction & Exhaust (S. Brezinsek (+ new tbd Deputy))
- WP SA JT-60SA Enhancements & Commissioning (WP SA, C. Sozzi)
- WP TM: Theory and Modelling (X. Litaudon, contains all 11 TSVVs & to provide link with DSO and other WPs in PSD, recommendation expected by early November)
- WP ENR (np WP leader, PIs, most essential element in this context is contact to Theory)



Idea in Autumn 2024 PB of a “Future Devices WP” not being followed up

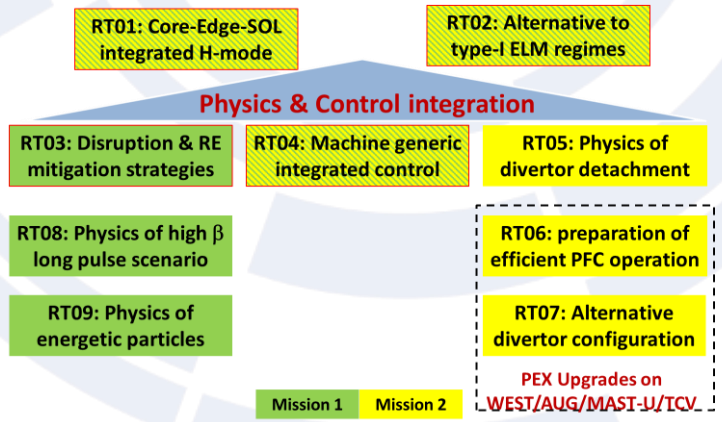
WPTE - Strongly streamlined programme for WP TE in 26-27

High level objectives for 26-27

- Address urgent R&D issues related to the new ITER baseline / Research Plan (full tungsten wall) : far SOL physics and wall loads; tungsten sources, transport and screening; startup on tungsten limiters; runaways damage of tungsten first wall components and efficiency of boronisation in full tungsten devices.
- Provide a full qualification of the most promising no ELM scenario, focusing on X-point radiator (XPR) and quasi-continuous exhaust (QCE) now considered as a viable option for ITER / DEMO.
- Support modelling efforts for interpretation of available data from TE devices (including JET DD and DT last campaigns)
- Prepare the JT-60SA scientific exploitation in the OP2 and OP3 campaigns

Same structure retained for WP TE in 26-27

- 9 “programmatic” Research Topics (RT01 to RT09)
- 2 Research Topics dedicated to JET (RT10 for data validation, RT11 for analysis of JET campaigns performed before 2022 and related work)
- 8 Research Topics (RT12 to RT18) mapping the existing Topical Groups of the JT-60SA EU-JA Experimental Team.



WPTE - List of Grant Deliverables 2026-2027

ID	Deliverables Table	Date	Relevant TSVV
TE.D.16	Report on fully integrated simulation of high current partially detached plasma scenario including assessment of PFC erosion in D and DT plasma	Dec 2026	TSVV-A, TSVV-B&C, TSVV-D, TSVV-E, TSVV-H
TE.D.17	Report on reduced model validation for plasma reattachment on multiple devices and wide operational space	Dec 2026	TSVV-B
TE.D.18	Report on providing input on design and operation of conditioning systems for next step full W devices and focus on standard boronization systems	Dec 2026	TSVV-D
TE.D.19	Report on qualification with experiment/modelling of the most promising no-ELM scenario in terms of confinement, exhaust capabilities and plasma wall interaction	Dec 2027	TSVV-A, TSVV-B, TSVV-D, TSVV-E, TSVV-H
TE.D.20	Report on optimized scheme for “benign termination” of runaway beams documented in view of possible applicability for ITER	Dec 2027	TSVV-F

+ GD for TE diagnostic enhancements

* Pending resources are made available for JT-60SA related work

WPSTEL High-level objectives in 2026–2027

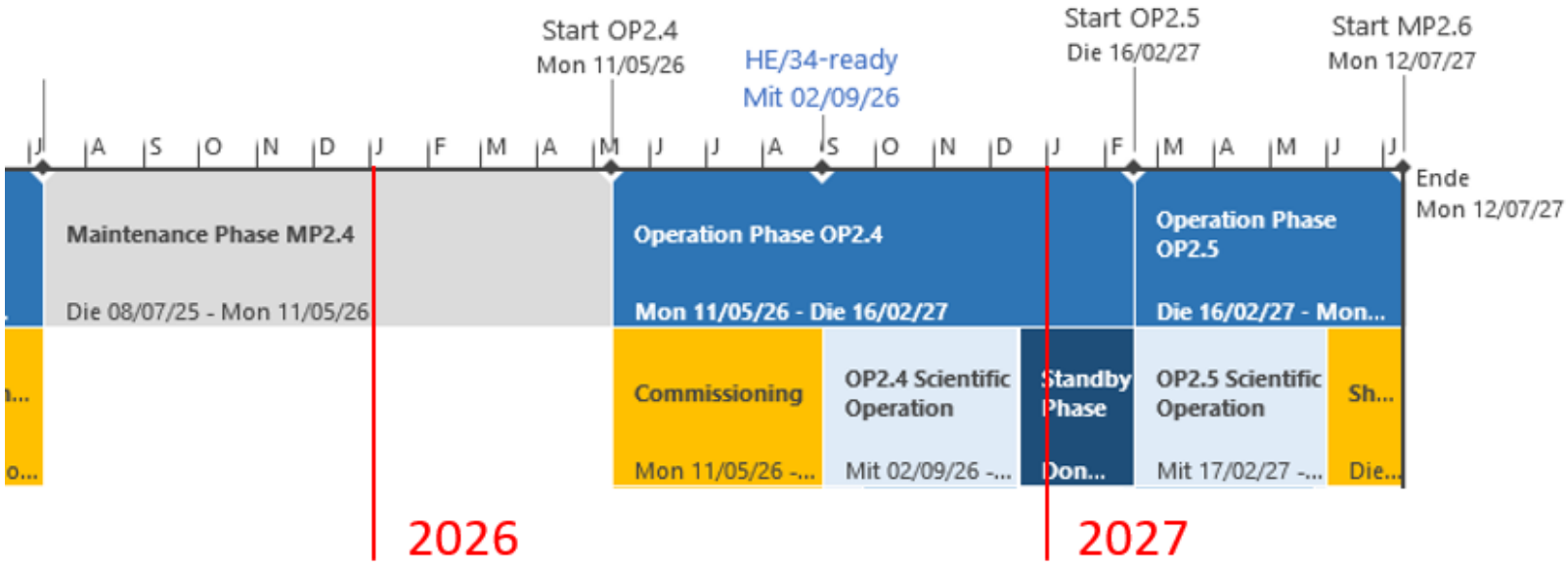
WPSTEL covers the EUROfusion contribution to the exploitation of Wendelstein 7-X and stellarator reactor studies.

- *Overarching goal:* Provide a physics and technology basis for the assessment of stellarators as reactor candidates.

Next, (very) high-level objectives for 2026–2027, grouped into **three main areas, A1, A2 and A3.**

A1. Preparation, execution and exploitation of W7-X campaigns in 2026–2027

- Long pulse, high-performance scenarios based on profile control at reactor-relevant ν and β.
- Assessment of the optimization of the magnetic configuration at reactor relevant parameters on: fast particle behavior, MHD equilibrium and stability, etc.



WPSTEL High-level objectives in 2026–2027

A2. Assessment on physics gaps for the development of stellarator reactors

- Identification and analysis of key physics uncertainties between present-day stellarators and a future reactor.
- Determination of which ones can be addressed within WPSTEL, and develop recommendations.

A3. Stellarator reactor studies

- Identify and further analyse a small set of the most advanced next-generation optimised stellarator configurations and associated coil designs, in close coordination with engineering studies.
- Adapt and assess blanket concepts for 3D stellarator geometries.
- Outline remote maintenance needs and constraints for stellarator reactors.

PWIE: Main Objectives for 2026/2027 I

- WPPWIE covers high priority activities for ITER (new baseline), supports pilot power plant and reactor-class devices, supports tokamak and stellarator exploration, and addresses open physics questions in are of plasma-wall interactions, plasma boundary and particle exhaust
- WPPWIE core program of 2025 continues in 2026 and 2027 addressing these priority items
- Support program for ITER: W sources, transport, influx, and deposition at the first wall and divertor |T retention, quantification, and removal from B | (temporary) first wall material qualification
- Support program for pilot and fusion plant activities: (novel) material qualification | transients and high fluence | PWIE simulations (e.g. lifetime) | retention/diffusion/permeation in PFCs/blanket (W/steel)
- Support program for JT-60SA/Wendelstein7-X: transfer from C towards W PFCs | power handling | material migration | divertor functionality optimization| long-pulse PWI operation aspects

PWIE: Main Objectives for 2026/2027 II

- PFC qualification and lifetime: synergistic effects in loading and operation beyond damage | RE beam damage analysis / interpretative modelling / predictions
- PWIE code development and benchmark experiments: pedestal⇔ plasma-wall interface ⇔ material using linear machines, laboratory experiments, reference experiments in full-W devices (ASDEX Upgrade, WEST and incl. EAST collaboration for CXN)
- PWIE simulations for novel tokamak scenarios QCE, XPR| first wall vs. divertor W sources | material migration studies | benchmark experiments
- Completion of JET components analysis: tungsten, steel, RE-damaged PFCs, T and He retention
- Benchmark of CRM with A&M data for H, D, T (atoms and molecules) | W collisional-radiative models | B chemistry, MD calculations
- In-operando diagnostics optimisation for material composition and retention | lessons learned from LIBS and LID-QMS at JET towards next step devices |analysis stations in hot cells | simulation and fast analysis tools
- Support in surface analysis for toroidal devices and linear plasma experiments
- First exploration of PEX JUDITH-3/PSI-2 with tungsten samples (end of 2027)

WPSA objectives in 2026-27

- The overall objective of WPSA is to support the scientific exploitation of JT-60SA through the development of machine enhancements, operational tools and operational expertise in cooperation with the EU implementing agency F4E.
- This work is being performed in close connection with the JT-60SA Experiment Team for the assignment of priorities in the enhancements program

Scope=>

OP1: first plasma

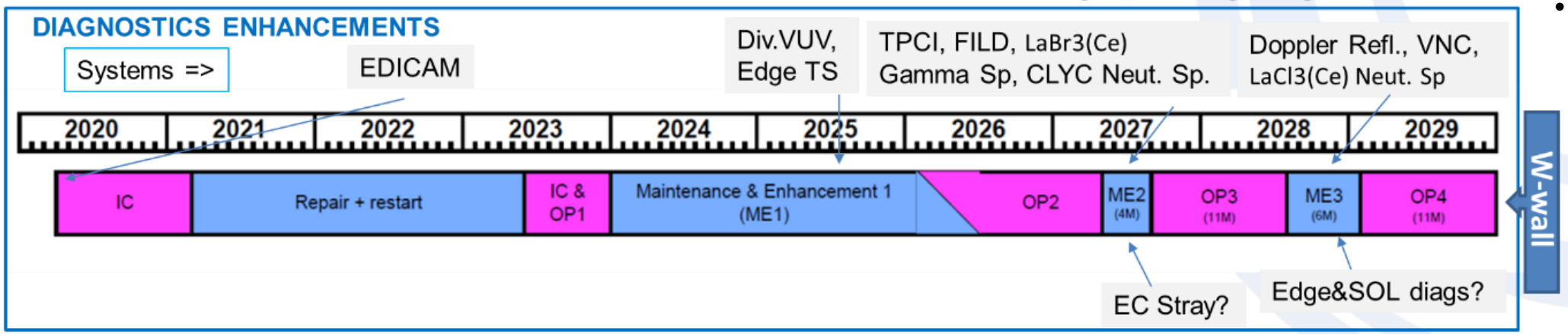
EC assisted breakdown at low $E_{//}$
Plasma control with SC coils
Disruption characterization

OP2: high Ip operation

Extension of the operation domain (high Ip, H mode, Beta, collisionality, …)
Disruptions and Runaway control, Error field
Heat transport L mode with dominant Electron heating
Shine through, Fast ion losses, LH transition, ELMs,
SOL scaling at high IP, Divertor characterization

OP3: H mode development

ITER relevant H-mode and high beta scenarios
High Beta non-inductive steady-state scenarios
NTM, RWM, ST control
Heat transport L mode with dominant Electron heating
Fast ions and turbulence, Alpha particles in D-3He plasma
ELMs regimes, W screening, Seeding



- Most of 2026: JT-60SA through Machine Enhancements 1
- Most of 2027 dedicated to OP2: significant participation expected (running diagnostics and related data processing and validation)

Grant Milestone	Commissioning of the Edge Thomson Scattering diagnostics in JT-60SA completed	31.12.2026
Grant Deliverable	Report on first measurement of the pedestal density and temperature at sub-cm spatial resolution in JT-60SA	31.12.2027

WPSA Code Management activities in 2026 (~1ppy)

Main objective: consolidation, test and provision of operational tools for use in Naka control-room, in support to the scientific exploitation

- JT-60SA Pulse Design Simulator [E Joffrin et al. submitted to Nuclear Fusion] consolidation: computing time optimization and application to JT-60SA hybrid scenario
- Magnetic control integrated tools demonstrated on a relevant scenario
- Intrashot data visualization and analysis tools adapted to OP-2 (eg automated profile fitting tool)
- Consolidation of EC HCD and ECE modelling tools
- Consolidation of tools in support of OP-2 magnets operation (in collaboration with F4E)
- TPCI synthetic diagnostics tested on a relevant scenario

➢ Training for users on the Pulse Design Simulator, ATEP workflow, MHD chain