

FSD Project Board 16 March 2026

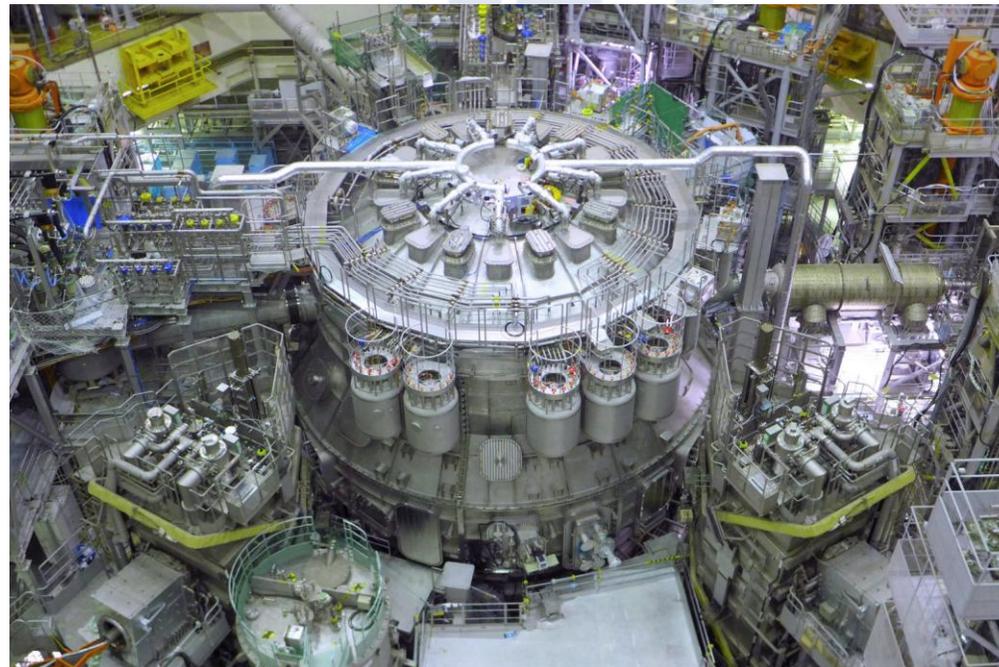
Enhancement and Commissioning of JT-60SA (WPSA)

Status summary

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With contributions of Gloria Falchetto (Code Management, CEA), Matteo Iafrati (Operations, ENEA), Juan Ayllon (Enhancements, CIEMAT), Alessandra di Bastiano (ENEA, PSO), Joao Figueiredo (PMU)

ISTP-CNR (ENEA)



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WPSA scope

& hand over between SA, F4E and operations in JT-60SA

WPSA supports:

- proposals for enhancements (mainly diagnostics to achieve the scientific and operational objectives of JT-60SA), until scientific acceptance (JT-60SA Experiment Team priority) and until a degree of development (detailed conceptual design) such that a Procurement Agreement by the EU implementing agency (F4E) can be signed.
- Installation and commissioning of the developed systems until final acceptance (first data production for diagnostics)
- NB: “Regular” operation of subsystems is at present outside the budget and horizon. Likely might happen for OP3 (late 2027), if an agreement for EU participation in operations is achieved.
- Development and test of operational oriented software tools (synthetic diagnostics, control room analysis, control tools). Does not support their exploitation (use for analysis or experiment design by a non-developer)



2025 objectives

- Prepare and assist machine integration of the EU-led diagnostic systems (OP, ENH) in 2025/26
- Prepare commissioning and first operation of the EU-led diagnostic systems for “delivering” to the scientific community (Experiment Team) in 2026/2027 (OP area, Matteo lafrati)
- Prepare and verify a suite of tools and codes for the Scientific Exploitation, including operation-oriented tools, synthetic diagnostics, simulation workflows preparing the subsequent validation on data or benchmarking with/in WPTE (Code Management Area, Gloria Falchetto)
- Support new users in data analysis, leveraging experience gained during commissioning
- Support training for control room tools
- Develop feasibility, design, assist procurement of new subsystems according with the JT-60SA scientific plan (ENH), in particular concerning diagnostics for plasma edge and plasma-wall interaction (Enhancement Area, Juan Ayllon-Guerola)
- Foster coordination and exchange of information for the Eurofusion contribution to the transition to W divertor and wall.
 - Core and impurity transport (WPTE)
 - Modeling of heat load on PFCs (WPTE)
 - Modeling for PFCs shape optimization (WPPWIE)
 - Test of PFCs (WPPWIE)
 - Development and qualification of PFCs (WPDIV)
 - Diagnostics upgrade for W monitoring, wall and divertor protection
 - Upgrade of the heating systems
 - Upgrade of the protection system
 - Review of the wall cleaning systems and procedures
 - Review of the gas injection system



Background

- JT-60SA tokamak through Machine Enhancements 1 for the whole year 2025
- (Remote) data access unavailable until September 2025
- JT-60SA data server and analysis cluster transferred to IFERC network for easier remote access as one of the actions taken after the OP1 experience

OP1: first plasma

Scope=>
 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

DIAGNOSTICS ENHANCEMENTS

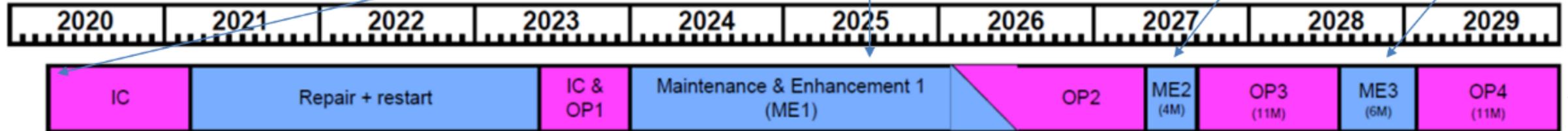
Systems =>

EDICAM

Div.VUV,
Edge TS

TPCI, FILD, LaBr3(Ce)
Gamma Sp, CLYC Neut. Sp.

Doppler Refl., VNC,
LaCl3(Ce) Neut. Sp



RE monitor

Edge&SOL diags?

W-wall



2025 main achievements: installation

- Edge Thomson Scattering (ETS): The ETS laser was successfully repaired, restoring full functionality, and its downstream optical path was modified to meet QST requirements.
- The mechanical structure (including the ramp, trolley, and jigs) was installed and aligned at Naka.
- Additionally, a comprehensive synthetic diagnostic was developed, confirming that the system meets the required accuracy and spatial resolution for pedestal and separatrix measurements.

- VUV Spectrometer: A detailed alignment procedure based on a laser footprint and a hexapod geometry was established.
- Final Acceptance Test was completed in ENEA Frascati and system shipped to Naka.

Present status:

- installation of the port plug successfully completed the
- optics arm connected to the trolley

Next steps:

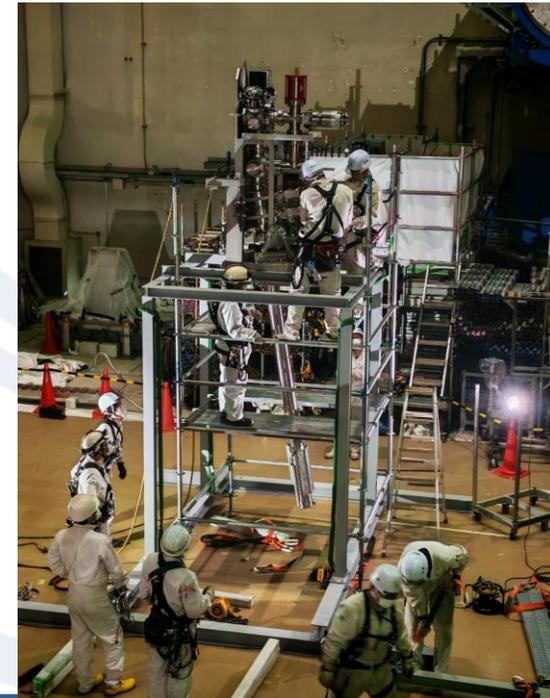
- installation of the optical fiber bundles
- calibration

Present status

- Damages occurred during transportation were repaired by the EU team in Naka with no delay on the installation schedule
- System installed in JT-60SA and successful leak test

Next steps:

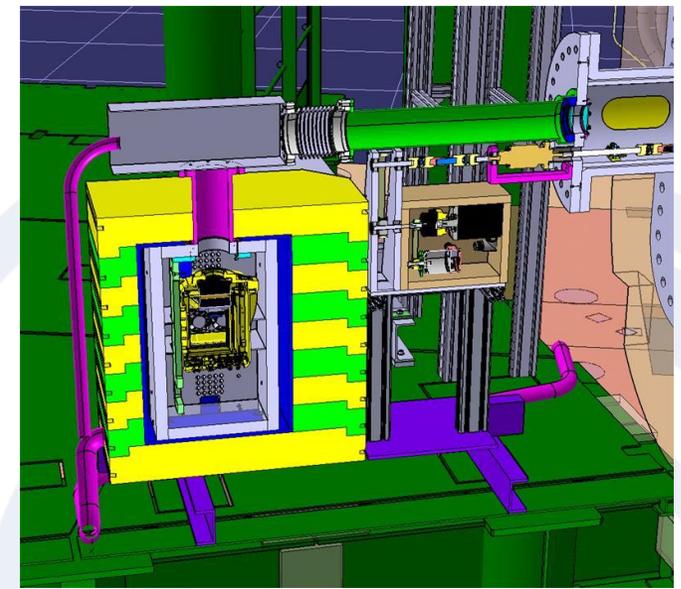
- Completion of the cabling, installation of the second detector and checking of the alignment





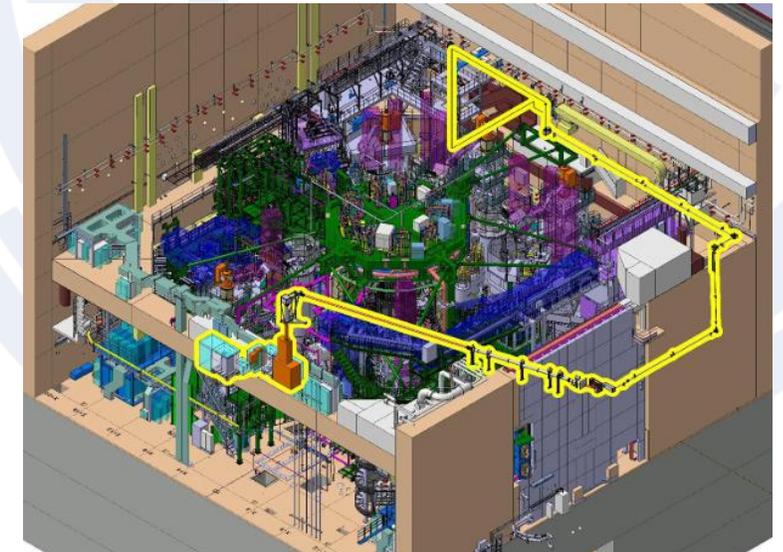
2025 main achievements: diagnostics in preparation

- Fast-Ion Loss Detector (FILD): The ex-vessel design was consolidated and adapted to port 18, with a neutron shielding concept validated via simulations to provide the required reduction factor (**installation for OP3-2027**)
- TPCI: Preparation of the formal Procurement Agreement that was signed in September 2025, and modified optical supports were delivered to QST to ensure compatibility with other systems (**installation for OP3-2027**)
- Gamma-ray Spectrometer (GRS): The design phase was completed, with LaBr₃(Ce) selected for its superior energy resolution and fast response (**installation for OP3-2027**)
- Neutron Diagnostics: Physics performance was validated for the Compact Radial Neutron Spectrometer (CRNS) based on LaCl₃ and Vertical Neutron Camera (VNC), confirming their ability to distinguish between different neutron contributions
- Doppler Reflectometry: The conceptual design for the Doppler Reflectometer (DR) in-vessel optics finalized (EP09).
 - 3-D ray-tracing confirmed that a bottom-launch geometry provides optimal clearance.
 - A single-axis steering mirror adopted, covering relevant plasma scenarios with high S/N.
 - Mechanical design with cantilevered structure for full extraction during remote maintenance.
 - A viable route for ex-vessel waveguides identified.



Design of the FILD radiation/magnetic shielding box

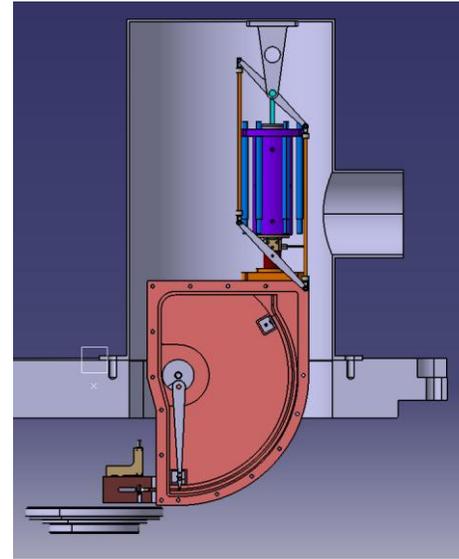
TPCI complete path of the laser from the laser room to the detection boxes.





2025 main achievements: Pellet Launching system

- An early version of a storage cryostat has been designed to produce a pellet source capable of supplying fuelling pellets to JT-60SA
- This cryostat is intended to be connected to a batch extruder and integrated into the centrifuge accelerator model. A pellet cutter designed is also part of the pellet source.
- The design process was supported by a numerical model describing the extrusion process.
- Scientific and technical support to the manufacturing and test of the accelerator system for the completion of the centrifuge and auxiliaries (procurement under F4E contract).
- The testbed at IPP Garching is now fully operational, including gas handling and power supplies, and is ready for hardware integration.



Integration of the pellet source with the centrifuge.



Centrifuge Factory test

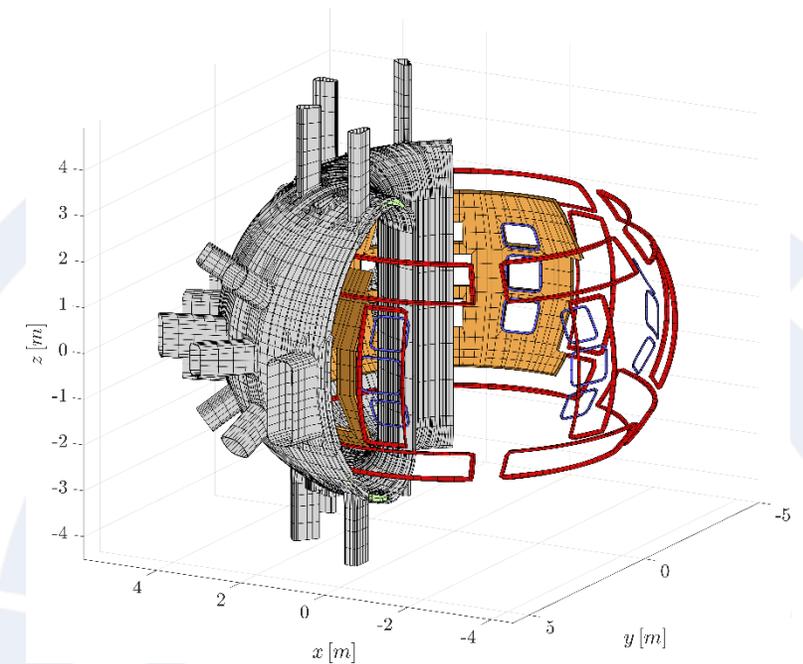
Present status

- F4E tender for development and procurement of 2 pellet sources (fueling and pacing)
- Final factory test of the launching centrifuge ongoing this week



2025 main achievements: Code Management

- Resistive Wall Mode (RWM) Control: The simulator was translated into a modular Python environment for easier implementation and running, and a Model Predictive Controller (MPC) designed for the mode stabilization was successfully demonstrated to be superior to traditional PID controllers.
- Pulse Design Simulator (PDS): This tool demonstrated a full discharge simulation (start-up to termination) for a reference 4.6MA/2.25T scenario. Inclusion of kinetic controllers.
- Breakdown Modelling: A reduced numerical model for pre-ionization was developed, offering a computationally efficient framework for start-up optimization. The model was validated through comparisons with full-orbit simulations, guiding-center simulations, and experimental results.
- Two simulation tools for EC waves have been installed on the Naka server: GRAY, for EC Heating and Current Drive (H&CD) computation, and SPECE, for Electron Cyclotron Emission (ECE) diagnostics data analysis. A model of the JT-60SA EC heating system has been provided, both for the Integrated Commissioning phase and for the complete EC launchers.
- Magnetic Control: Interfacing was achieved of the MECS simulator on the Naka server with CREATE control algorithms built in Matlab. Assessment of MECS versus CREATE-NL, showed overall good agreement, with some discrepancies in the eddy currents. CREATE-NL computational speed resulted about 1000 higher than MECS.
- Operational Training and Tools: Training presentations were delivered regarding machine protection for a full tungsten (W) machine (addressing runaway electrons and overheating) and the requirements for real-time control diagnostics.



Computational mesh for JT-60SA for RWM control

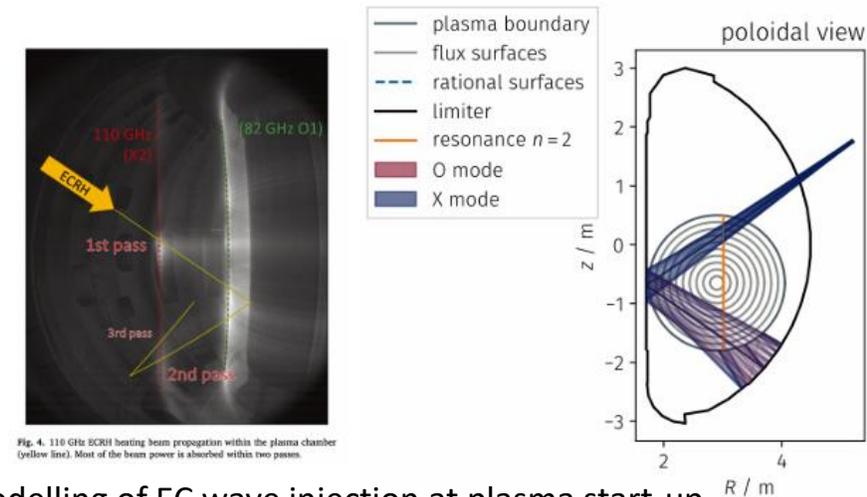


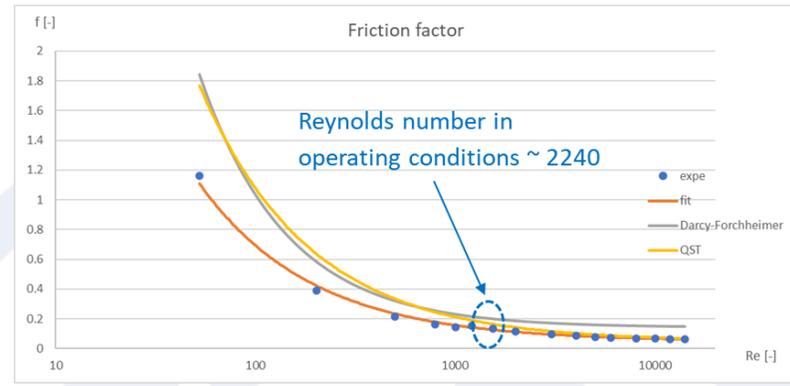
Fig. 4. 110 GHz ECRH heating beam propagation within the plasma chamber (yellow lines). Most of the beam power is absorbed within two passes.

Modelling of EC wave injection at plasma start-up.
Left: EDICAM image right: beam path computed with GRAY.

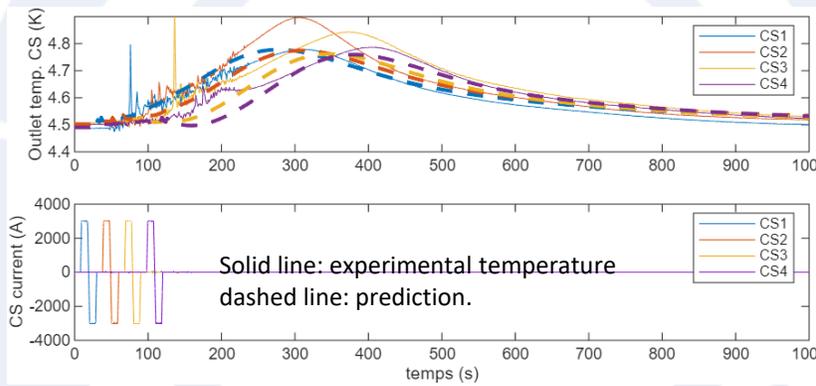


2025 main achievements: cryo-magnet system assessment

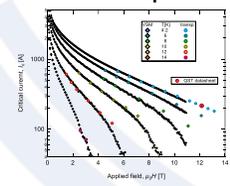
- Hydraulic Characterization:** Three conductor samples (EF-H, EF-L, and CS) were successfully characterized at the **OTHELLO test facility** using pressurized nitrogen. These tests allowed for the deduction of **experimental friction factor correlations**, which were found to be a close match to reference correlations for Reynolds numbers above 1000.
- Model Development and Validation:** The **STREAM-STAM thermal-hydraulic model** was implemented for the EF coil and validated against experimental commissioning data (5 kA ramp-up/down), showing **good agreement** in predicted fluid outlet temperatures and circulating flow time constants. Additionally, the **Loop 2 cryogenic model** was updated to include **inter-pancake thermal contact**, which proved mandatory for accurately reproducing the system's thermal-hydraulic behavior.
- Strand Characterization:** Detailed magnetic and transport characterization was completed for **Nb₃Sn superconducting strands**. This included the determination of the $I(B, T)$ critical surface and the discovery that the **effective filament diameter**—essential for AC loss modeling—is temperature-dependent and approximately six times larger than the geometrical diameter due to inter-filament coupling.
- Software and Design Tools:** A software tool was developed and optimized to automate the retrieval, filtering, and **realignment of Quench Detection Voltage (QDV)** data from distinct databases (PMDB and EDDB). Furthermore, the design for the **CS joint testing tool** at the SELFIE facility was finalized, resulting in the delivery of **38 construction drawings** two months ahead of the original deadline.



Comparison of the experimental fit with the reference correlation for the CS



current input from 2023 / 10 / 26 experimental data, associated with experimental and simulation results in term of temperature.



Critical current density, I_c , of the JT60-SA Nb₃Sn strand as a function of applied magnetic field B at several temperatures.



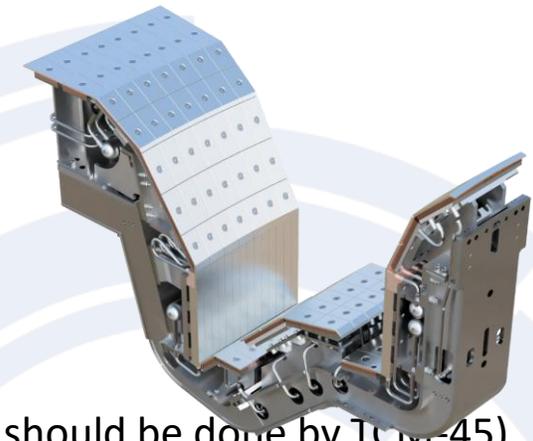
2025 main achievements: Feasibility Studies of diagnostics in preparation of the Tungsten Transition

- As part of the preparation for the W transition, additional diagnostics are taken into consideration (a further assessment of the diagnostics plan should be done by TCM-45 – late May 2026) – Call for feasibility studies of “Edge and SOL” diagnostics, 2025.
- A comprehensive set of feasibility studies has been carried out in 2025 aimed at supporting high-power operation phases and the transition from carbon to tungsten wall.
- The studies evaluate the feasibility, formulate a preliminary conceptual design, and explored the integration in JT-60SA,
- 9 Promising output from the preliminary assessment (out of 15 received proposals)
 - High-resolution visible overview camera with real-time and multispectral capabilities
 - MANTIS multispectral visible imaging
 - RE monitor (installation for OP3-2027)
 - SOL-Pedestal Imaging Vacuum-Ultraviolet spectrometer
 - Thermal Helium Beam
 - EU-DEMO like real-time detachment control diagnostics for JT-60SA
 - Neutral Gas Analyser
 - Quartz Crystal Microbalances
 - Directional Electron Probe
- Detailed reports available in IDM
- Further assessment phase at the next JT-60SA Technical Coordination Meeting



Summary Update on JT-60SA W wall timeline

- Modeling:
 - Ar/Ne seeding (SOLEEDGE, SOLPS-ITER):
 - Power flux peak is not a major concern, H-mode access ok
 - W erosion is the showstopper
 - detachment threshold is most stringent limit, not feasible at low density
 - low pumping throughput likely given by neutral trapping (=> suggested to rise the strike points)
 - ECRH power below 5 MW is predicted to be sufficient to avoid central accumulation (ASTRA-FACIT)
- Additional diagnostics for the W phase under discussion (a further assessment of the diagnostics plan should be done by TCM-45)
- Upgrade of the ECRF systems: 9=>12 sources (≥ 1 MW each) by 2031
- Additional systems being designed
 - Boronization
 - requirements on cryopumping and vacuum system
 - Additional control systems and real time diagnostics
- W divertor and PFCs (F4E)
 - High Heat Flux full scale mockup procured and tested (10 MW/m² 2600 pulses, 15 MW/m² 100 pulses, 20 MW/m² 15 pulses x 2 s) => release of series production in Q2/2026
 - Cassette frames being manufactured
 - ITER grade tungsten under procurement (Q3/2026)
 - On board divertor diagnostics and components (Langmuir probes, Halo current coils, Thermocouples, Gas puff pipes,...) being integrated in the design
- Tungsten First wall – design activities (F4E/QST)
 - Drop-in replacement to C wall
 - Reuse of stabilizing plate → priority
 - Assessment of the possible need of in-vessel work for stabilizing plate and water manifolds modification
 - PFC technology based on NHF design, but possibly simpler/cheaper (e.g. W coated SS or CuCrZr tiles)
 - Remote handling compatible (RH studies to be started in parallel to W wall design)
 - Potential issue for the top PFCs (top strike points) being considered





Grant deliverables

| Deliverable. Sygma ID. | Deliverable title | Delivery due date | Date of completion | If delayed: Expected delivery date | Status % Reached If not reached % of milestone reached for the reporting year | Comments If applicable, reasons why deliverable was not achieved |
|---------------------------|--|-------------------|--------------------|------------------------------------|---|---|
| D2.5 | Delivery and final tests of EU-REC Completed | 30/06/2024 | | 30/09/2026 | 70% | Activity performed in conjunction with QST and F4E and in pace with the schedule of the machine preparation for next operational phase (2026). |
| D2.6 | Installation of the EU systems before the OP2 campaign | 31/12/2024 | | 31/07/2026 | 80% | The installation plan is strongly dependent on the schedule of the shutdown for the Machine Enhancement 1 (now ongoing). Installation of the in-vessel components of the EU procured systems started in July 2025 with scheduled completion in July 2026. |
| D2.10 | Delivery of EU procurements (TBD) for the campaign 2026 Completed. | 31/12/2025 | 28/02/2026 | | 100% | Delivery of the EU procurements for OP2 in time for the scheduled installation |

