PSD brainstorming meeting for 2026-2027, December 10, 2024

Plans for WP TE in 2026-2027

E. Tsitrone, N. Vianello for TE TFL

E. Tsitrone, N. Vianello, M. Baruzzo, J. Garcia, A. Hakola, V. Igochine, D. Keeling, B. Labit

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High level objectives

ITER Physics

- Urgent issues related to ITER full W using TE metallic devices: boronisation, W transport, RE damage in W component, startup, far SOL heat and particle load
- Improve understanding in missing ITER relevant physics and extrapolation: full-integrated modelling (interpretative, predictive), pedestal physics (interpretative, predictive)

DEMO Physics

- Qualification of no-ELM regimes and ADCs at high P/R : definition of metric and integrated qualification. Exploitation of TE devices and corresponding interpretative/extrapolative modelling

JT-60SA

- Contribution to Scientific Exploitation in OP2 and OP3: JT-60SA ET has provided candidate scenarios for these Phases (Baseline up to 4.5MA, Hybrid and ITB) together with high-level priorities. Ensure proper EF contribution and verify global coherence of the scientific program
- Prepare the physics basis for transition to W

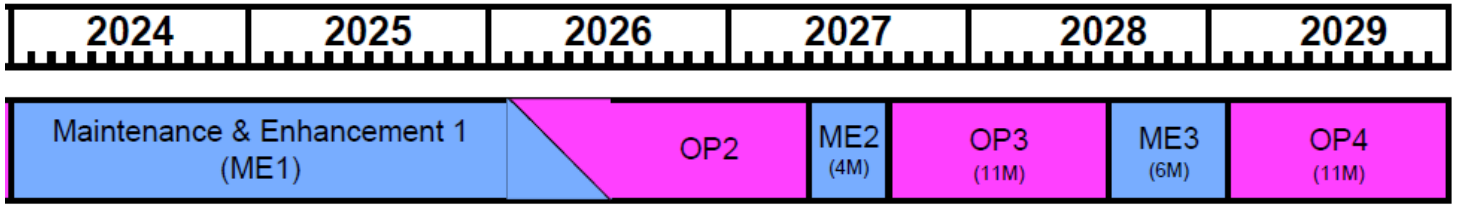
JET

- Complete JET scientific exploitation over the period

General consideration: Intensify modelling effort for extrapolation of results from TE devices to ITER / DEMO, using TSVV tools

Boundary conditions

JT-60SA timeline



TE under grant extension

- Availability of TE devices to be consolidated with machine representatives over 2026-2027

Expected upgrade to TE devices :

- TE enhancements
- Machine enhancement:
  - AUG : new upper divertor (already during 2025 campaign)
  - MAST-U : EBW and higher NBI power
  - TCV : tight baffle, additional power
  - WEST : ECRH, TWA, new first wall

International collaborations :

- US no ELM (e.g.: QCE extended to DIII-D, NT, XPR)
- KSTAR (RMPs with W divertor and long pulse operation, QCE in long-pulse operation…)
- China (implication of TE devices following work on BEST RP ?)

DTT and COMPASS-U not expected to come into operation over the period, but integration to be prepared (or not under TE?)

Proposed Grant deliverables

Proposed as GD

Kept as guidance for the program

2026	GD-RT01-2026: Provide full integrated simulation of high current partial detachment plasma scenario including assessment of PFC erosion in D and DT plasma
	GD-RT-05-2026: Validate reduced model for plasma reattachment on multiple devices and wide operational space
	GD-RT06-2026: Provide input on design and operation of conditioning systems for next step full W devices, with a focus on standard boronization systems

2027	GD-RT01-2027: Quantify, via experiment and modelling, the difference in pedestal turbulence induced transport between peeling and balloning limited plasma
	GD-RT02-2027 Qualification with experiment/modelling the most promising no-ELM scenario in term of confinement, exhaust capabilities, Plasma Wall Interaction (RT02/RT07)
	GD-RT02-2027: Provide a range of possible NT shapes for EU-DEMO leveraging sufficient core confinement with an exhaust solution
	GD-RT03-2027: Qualify the best analytical model for 3D forces based numerical interpretative model of current WPTE device
	GD-RT-04-2027: Based on knowledge gain on TE device, provide integrated modelling of ITER startup on W limiters (RT04/RT06/TSVV11)
	GD-RT-05-2027: Extend XPR operation to H-mode grade confinement and with dominant electron heating
	GD-RT-05-2027: Provide Validation to full 3D simulation of XPR in H-mode with self-consistent transport included
	GD-RT07-2027: Heat and particle loads in DEMO-type fusion devices for down-selected alternative divertor configurations
	GD-RT-08-2027: Qualify flux-pumping as viable q profile control mechanism for DEMO, via data analysis and modelling
	GD-RT09-2027: Demonstrate efficacy of measurements techniques for diagnosing energetic alpha population in ITER DT plasmas
	GD-RT09-2027: Produce prediction of EP-driven MHD in ITER baseline scenarios and resulting EP redistribution/loss.
	GD-JT-60SA-2027: Document the impact of N-NBI on plasma behaviour and extrapolation to ITER
	GD-JT-60SA-2027: Provide physics based requirement for ECHR system enhancement on JT-60SA
	GD-JT-60SA-2027: Established expected heat and particle load in relevant W scenario to inform proper divertor design

Proposed Grant Milestones

- GM-RT01-2026: Peeling limited pedestal in metallic device achieved
- GM-RT02 2026: Proper figure of merit for cross-scenario comparison among no-ELM/ADC defined
- GD-RT05-2026: First wall particle and heat fluxes quantified in XPR in metallic devices
- GM-RT07-2026: ADCs characterized in H-mode conditions in all relevant TE devices (RT-07)
- GM-RT03-2027: Modelling of SPI experiment on JET and ASDEX-Upgrade completed
- GM-JET-2027 : JET data validation requested by WP TE completed (including T accountancy for DTE2 and DTE3)
- GM-JT-60SA-2027: OP2 successfully run with adequate EF contribution

Back up slides (RT)

High-level objectives – RT01

- Peeling limited pedestal investigation should complete most of the experimental work in within 2025. Focus should be on all the appropriate modelling including high-fidelity GK strengthening the link with TSVV
- Experimental investigation on W screening and transport will probably extend in 2026 and this will benefit the understanding of low-collisionality pedestal. Will benefit from simulation in relevant JT-60SA foreseen scenario at full power
- Medium and High Z impurity transport should be properly assessed (experimentally and modelling in pedestal relevant condition no-ELM (in view of DEMO), peeling limited plasma (in view of ITER), partial detached plasma
- Extend present pedestal investigation to JT-60SA
- Gap to be filled: understanding edge (pedestal/separatrix/far SOL) transport in partial detachment with seeding
  → The integrated scenario might be completed by the end of 2025 but spillover in 2026 is not impossible

Possible GD – RT01

- GD-RT01-2027: Provide full integrated simulation of high current partial detachment plasma scenario including assessment of PFC erosion
- GD-RT01-2027: Quantify, via experiment and modelling, the difference in pedestal turbulence induced transport between peeling and balloning limited plasmas
- GM-2026: Achieve peeling limited pedestal in full metallic device

High-level objectives – RT02

- Quantify plasma-wall interaction for QCE and W sputtering – Assess compatibility with next step device
- Understand and simulate impurity transport for no-ELM regimes
  - Data collected in 2025, essentially on AUG
  - Analysis in 2026-27
- Increase the level of maturity of low nu* ELM free regime (RMP, QH-mode)
  - One should understand if QH-mode is possible in W-environment.
- Increase the level of maturity of the Negative Triangularity route
  - The final report of the ad-hoc group from DCT posed several questions. Some of them can be answered by 2027 (including DIII-D results)
  - Reduced model for edge transport in NT
- Prepare scenarios to investigate QCE and QH-mode in JT-60SA
  - Shape is favorable for QCE
  - Low nu* (and NNBI) is favorable for QH-mode

Possible GD – RT02

- GD: Propose a refined multi-parameters metric to identify the best ELM free regime for EU-DEMO
- GD: Provide a range of possible NT shapes for EU-DEMO leveraging sufficient core confinement with an exhaust solution

RT-03 Strategies for disruption and run-away mitigation

The possible projects are :

1. Post-disruption runaway electron impact on W wall.
   - Experiments on WEST/…
   - Collaboration with RT06
2. Modelling of non-axisymmetric disruptions with JOREK code with realistic boundary conditions (both are ongoing activities)
   - Coupling with CARIDDI (realistic 3D wall) and study of the 3D forces to clarify which analytical model is correct and should be used for predictions.
   - Modelling of the existed SPI experiments on JET & AUG

High-level objectives – RT04

- Integrate multiple active controllers in MIMO schemes for ITER, demonstrate their effectiveness including actuator sharing logics.
- Develop active control schemes in view of DEMO, including controllers with limited diagnostic sets.
- Develop dynamic error field control strategies for ITER and DEMO
- Based on existing experiments, develop predictive capabilities for ITER start-up and current ramp-up on W limiters with and without Boronization, including integrated scenario modelling
- Continue development of physics based disruption prediction/avoidance tools, with focus on portability to ITER

High-level objectives – RT05

- Extend RT05 relevant scenarios towards higher performances while keeping appropriate exhaust solution in view of DEMO
- An “evaluation metric” will be implemented to properly compare all DEMO relevant scenarios (no-ELM/small-ELM/XPR)
- Complete/validate reduced model validation for attachment/re-attachment and XPR access
- Quantification of First wall fluxes and possible foreseen erosion at different recycling condition
- Qualification of detachment towards slow transients still to be completed and proved on multiple-machine: include ramp-up, H-mode entry, H-mode exit, strong MHD activity and saw-toothing
- Scalability of buffering capabilities
- Integrated and high-fidelity edge code in XPR

Possible GD – RT05

GD-RT-05-2026: Validate reduced model for plasma reattachment on multiple devices and wide operational space
GD-RT-05-2027: Extend XPR operation to H-mode grade confinement and with dominant electron heating
GD-RT-05-2027: Provide Validation to full 3D simulation of XPR in H-mode with self-consistent transport included
GD-MT-05-2026: Quantify expected first wall particle and heat fluxes in XPR in metallic devices

High-level objectives – RT06

- Provide input for ITER R&D issues related to the new ITER baseline
  - Assessment of effciency / lifetime of standard boronization, impact on fuel retention/removal and implications for designing the system for ITER
  - Execution of experiments / validation of modelling tools for RE impact on W first wall

- Assess ITER grade divertor lifetime under tokamak conditions (high particle fluence, off normal events ...)

- Continue effort on understanding W migration pathways and impact on core contamination, extending results to no ELMs scenario

- Assess fuel retention and consolidate strategy for fuel removal in next step full W devices

NB : no major impact expected from JT60SA for RT06 over the period 26-27

Possible GD and GM – RT06

- GD1 : Compare high particle fluence impact on ITER grade PFC and plasma operation under attached / detached divertor conditions (Dec 2027)
- GD2 : Provide input on design and operation of conditioning systems for next step full W devices, with a focus on standard boronization systems (Dec 2026)
- GD3 : Validate the suite of codes used to predict RE impact on W PFC in ITER on full W Te devices (AUG, WEST) (Dec 2026)

- GM1 : full set of boronization probes available in WEST (TE enhancements)
- GM2 : LIBS system operational on WEST (TE enhancements)
- GM3 : T accountancy completed by UKAEA (in 2025 ?) and T balance assessed for JET DTE2 and DTE3

High-level objectives – RT07

- Compare downselected ADCs to conventional divertor configurations for their technical requirements, exhaust capabilities and core performance
  - ✓ Addresses the aspects of technical complexity, physics basis and various pros and cons
  - ✓ Proper metrics should be developed (e.g., spider plot) for all the three aspects listed above
- Determine possible benefits of reactor-relevant ADCs at high P/R ratios in terms of heat-flux profiles both at the divertor and in the main chamber
  - ✓ Focus on configurations relevant for AUG (XD, CRD, SF,…), comparison to the SXD established on MAST-U DEMO feedback
  - ✓ Emphasis on small/no-ELM regimes (QCE, EDA,…)
- Quantify transport in the SOL of selected ADCs via experiments and high-fidelity modelling
  - ✓ Should include coupling of SOLPS-ITER/SOLEDGE3X to turbulence codes (like GBS)
  - ✓ Make predictions for reactor-relevant conditions
- Extend the ADC studies to long pulses and different types of transients
  - ✓ WEST would be the crucial contributor to this objective
  - ✓ Transients would include besides ELMs, e.g., strong sawteeth activity and all types of filaments

Possible GD and GM – RT07

- GD: Heat and particle loads in different regions of DEMO-type fusion reactors for downselected alternative divertor configurations
- GM: ADCs characterized in H-mode conditions in all TE devices Dec. 2026/2027

High-level objectives – RT08

- Assess Flux pumping as viable q profile control mechanism for DEMO, via data analysis and modelling.
- Pursue integration of high Beta, high bootstrap fraction scenarios with high greenwald fraction, small ELMs radiative divertor
- Assess large radius ITB scenarios as viable scenario concept for DEMO
- JT60-SA

Thoughts on EP research into 2026/27

Comment from Roman Ochoukov (RTC):

- My suggestion for the future direction of the EP research in 26-27 would be to study more EP physics in the D-T / fusion reactor relevant plasma mixtures.
- We now generally run with high single ion species (all deuterium or all hydrogen) fractions, however, the WPTE machines can certainly mix up the ion species and impurities to simulate reactor like ion mixtures. This is more important now in the absence of JET.

Current set of deliverables

- D1. Provide high quality diagnostic information for the characterization of confined and lost fast ions in plasmas relevant for ITER and JT60-SA
- D2. Quantify ion heating and core turbulence stabilization by ICRF-generated fast ions in view of ITER and DEMO
- D3. Quantify the impact of fast ions and fast ion MHD driven instabilities on core transport
- D4. Integrate the available heating, fast-ion and transport modelling tools for interpretation of experimental results in view of ITER and DEMO
- D5. Quantify fast-ion losses and associated heat load from edge perturbations (ELMs and RMPs)
- D6. Quantify neutral beam current drive and make predictions for ITER
- D7. Identify AE control actuators and preliminary assess for ITER

- RT-09 D1-7 are aimed at
  - Documenting and modelling EP←→MHD interaction and subsequent redistribution/loss effects
  - Quantifying turbulence stabilisation by Eps
  - Determining how the above can be controlled

What's missing, how should these evolve?

- What we don't have in here is explicit research aimed at quantifying how the presence of large alpha population will affect plasma stability
  - Can't be done by experiment – analysis of JET DTE2/3 data?
  - Also alpha diagnostic technique – AUG expt. by Yevgen but insufficient AUG time to do it completely
  - Could also be done on WEST with introduction of EP diagnostics
- Effect of ITER NNBI at ~1MeV
  - Current machines have low energy NBI or high energy ICRH
  - Some proposals looking at novel heating scheme (e.g. 3-ion schemes) that produce different energy spread from ICRH – more explicit focus on the deliverables to investigate such schemes?
  - Partially accounted for by inclusion of JT-60SA in several deliverables – could make it explicit that we want to research effects of EPs at 500-1000keV
- RMP
  - Need any investigations of "FI interaction with edge" to focus on down-selected ITER scenarios. If these are "RMP suppressed ELMy scenarios" then such scenarios must be the basis of experiments rather than simply documenting effects of RMPs at various n and phase settings – what scenarios result from RT-01 (and possibly 02 if naturally ELM-free scenarios become more prominent in ITER RP) that need further understanding of their EP behaviour?

Modelling needs

- D4 already focussed on this: integrated modelling of FI transport in view of being ready for interpretation of ITER results. What do we need in terms of predictive capability?
- Need to demonstrate interpretive capability also through the high energy NNBI expts to be done on JT-60SA, ensure workflows are established and validated through 2025/26 ready for benchmarking activities in 26/27
- Ensure required predictive capability is there for transfer of experience to ITER.

Uses of TE devices

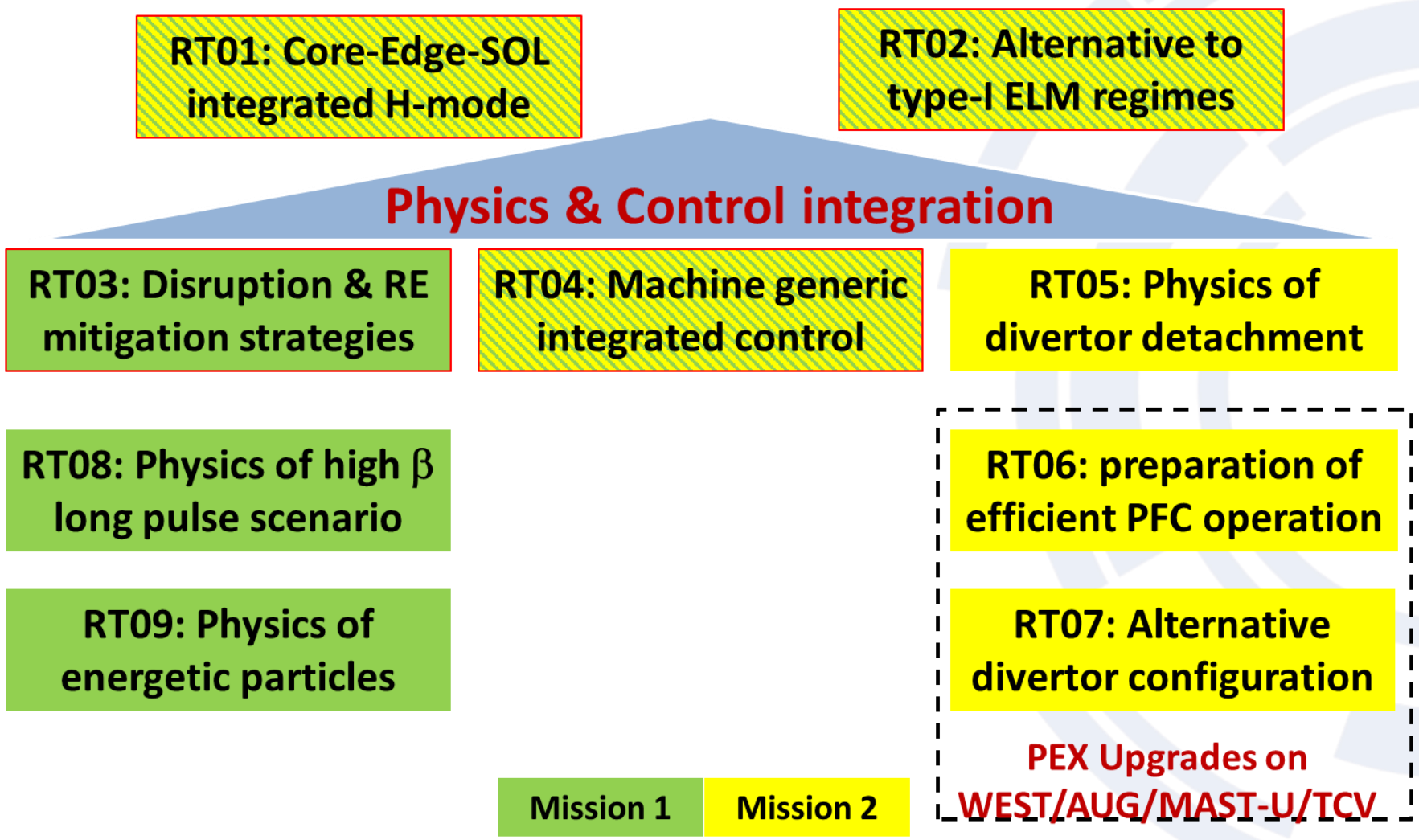
- TCV
  - Thorough testing of FI dynamics in down-selected scenarios (RSAE/monotonic q-prof, NT, …)
- MAST-U
  - Additional NBI/EBW power… shaped q-profs with current drive in higher beta plasmas, RMP studies
- AUG
  - W-environment + Boron scheme (see earlier comment), RMP studies
- WEST
  - What FI diagnostics planned? Long-pulse, wall loading from FI losses in extended pulses.
- JT-60SA
  - NNBI directly relevant to ITER – intermediate energy FI experiments (intermediate in sense of PNBI < NNBI < ICRH)

Proposed GDs

1. Demonstrate efficacy of measurements techniques for diagnosing energetic alpha population in ITER DT plasmas
2. Produce prediction of EP-driven MHD in ITER baseline scenarios and resulting EP redistribution/loss.

Back up slides (other)

2024 Research Structure in continuity



Status of grant deliverables

"Title" in Sygma	Title in CWP	Initial due Date	Expected deliverable date	Status	Comments/Reason for delay
TE.D.08	Balance between gross and net erosion of W under different operational conditions in full-metallic toroidal devices	Dec 2023	Dec 2024	To be completed this year	Good data set in L mode and H mode. Modelling for H mode + W prompt redep still ongoing
TE.D.09	Establishment and comparison of N and Ne-seeded partially-detached divertor in high-power operations in view of ITER radiative scenario.	Dec 2023	Dec 2025	Proposal to defer to 2025	Proper GK analysis concerning impurity effects on pedestal not yet available
TE.D.14	The radiation asymmetry during disruption mitigation and SPI disruption dynamics using improved power balance, radiation diagnostics capability and fast cameras characterized and documented.	Dec 2024	Dec 2024	To be completed this year	JET and AUG data published. JOREK modelling
TE.D.12	The physics basis for the decision for an alternative divertor configuration for DEMO.	Dec. 2024	Dec 2025	Delayed	Upper divertor of ASDEX Upgrade delayed and considered important
TE.D.13	Recommendation on the seeding impurity mix in view of a future reactor.	Dec. 2024	Dec 2025	Delayed	Data exists – but analysis progress by end of year unclear

Enhancements : new projects launched in 2024 to continue

Device	Project
AUG	FIRE&GO - Fast Ion Research Enhancements and Gamma-ray Observations [at ASDEX]
AUG	Ultra-fast-swept profile reflectometer on AUG
AUG	Direct Digital Synthesis for the O-mode Profile Reflectometer at ASDEX Upgrade
AUG	Real-time spectroscopy at ASDEX Upgrade
AUG	Real-time control system for ELM buffering at ASDEX Upgrade
COMPASS-U	Tungsten impurity monitoring and control at the COMPASS-U tokamak
COMPASS-U	Characterisation of advanced confinement modes at COMPASS-U
COMPASS-U	PFCs and diagnostics for power exhaust studies at COMPASS-U
MAST-U	Neutron Detectors suite for 14 MeV neutron triton burnup and 2.5 MeV neutron spectroscopy measurements at MAST Upgrade
MAST-U	ONCOMING-Optimized taNgentially spaCe resOlved geM ImagiNG [at MAST-U]
MAST-U	Collimated gamma-rays detector for HXR measurements of runaway experiments on MAST Upgrade
~~SMART / TCV~~	~~Development of a Co-spatial Ion and Electron Spectroscopy (CIES) diagnostic [initially implemented in SMART diagnostic then TCV~~
TCV	New 100-Hz Laser for the TCV Thomson Scattering System
TCV	Runaway Electron Mitigation Coil for TCV
TCV	Upgrade of the TCV LHPI antenna
TCV	Implementation of the 4th dual-frequency gyrotron for TCV
TCV	Collective Thomson Scattering (CTS) diagnostic for TCV
TCV	Runaway electron mitigation and velocity analysis by magnetic-ripple manipulation [at TCV]
TCV	Upgrade of the TCV ECRH high voltage power supply
~~WEST~~	~~QCM for boronisation and material migration studies in a full W environment [at WEST]~~
WEST	A RETARDING FIELD ANALYZER FOR ION TEMPERATURE MEASUREMENTS IN THE SOL OF WEST
WEST	Boronization Probes for WEST
WEST	LIBS4FUSION: in-vessel fuel Inventory and deposited layers composition in a full tungsten device
WEST	Fast Ion Loss Detector in WEST
WEST	IRBO IR Bolometry for WEST
WEST	High DEfinition Visible Endoscope for WEST

- 2 projects cancelled (CEA and CIEMAT) : impact on ENH budget ?
- Implementation under responsibility of PMU : monitoring process ?

Proposed scheme for assessing participation to JT-60SA

- **Proposal:** Call for participation to be evaluated at EUROfusion level by a combination of ET EU Topical Group Leaders and WPTE TFLs → this will help consistency of staff selection with EF priorities

	Topical Groups	Proposed assessment
TG01	Operation Regime Development	J. Garcia
TG02	MHD Stability and Control	G.Pucella/V. Igochine
TG03	Transport and Confinement	L. Garzotti/B. Labit
TG04	High Energy Particle Behaviour	Y. Kazakov/D. Keeling
TG05	Pedestal and Edge Physics	Y. Liang/N. Vianello
TG06	Divertor, Scrape Off Layer and Plasma-Material Interaction	G. Falchetto/E. Tsitrone
	Integrated data validation and data access with IMAS	F. Imbaux /M. Baruzzo

- Final review of the staff selection by J. Garcia
- Need to nominate an EU contact person for non-EU Topical Group leaders (Divertor and SOL)
- Responsability for data access / "IMASification" of JT-60SA to be clarified (link with DSD ?)

WP TE coordination team for 2025

Research Topics	Research Topic Coordinators	Ref TFLs
RT-01: Core-Edge-SOL integrated H-mode scenario compatible with exhaust constraints in support of ITER	Carine Giroud, Lorenzo Frassinetti, Sven Wiesen, Damian King	Nicola Vianello, Benoît Labit
RT-02: Physics understanding of alternatives to Type-I ELM regime	Mike Dunne, Michael Faitsch, Olivier Sauter and Eleonora Viezzer	Benoît Labit, David Keeling
RT-03: Strategies for disruption and run-away mitigation	Ondrej Ficker, Cedric Reux, Umar Sheikh	**Valentin Igochine**, Antti Hakola
RT-04: Physics-based machine generic systems for an integrated control of plasma discharge	Adriano Mele, Lidia Piron, Charles Vincent	Matteo Baruzzo, **Valentin Igochine**
RT-05: Physics of divertor detachment and its control for ITER, DEMO and HELIAS operation	Matthias Bernert, Holger Reimerdes, Nicolas Fedorczak, Stuart Henderson	Nicola Vianello, Emmanuelle Tstitrone
RT-06: Preparation of efficient Plasma Facing Components (PFC) operation for ITER, DEMO and HELIAS	Yann Corre, Karl Krieger, Anna Widdowson	Emmanuelle Tsitrone, Antti Hakola
RT-07: Physics understanding of alternative divertor configurations as risk mitigation for DEMO	Dominik Brida, Christian Theiler, Kevin Verhaegh	Antti Hakola, **Benoît Labit**
RT-08: Physics and operational basis for high beta long pulse scenarios	Fulvio Auriemma, Alexander Bock, Chiara Piron	Matteo Baruzzo, **Valentin Igochine**
RT-09: Physics understanding of energetics particles confinement and their interplay with thermal plasma	Yevgen Kazakov, Joaquin Galdon, Anton Jansen van Vuuren, Roman Ochoukov	David Keeling, Matteo Baruzzo
RT-11:Analysis and modelling of DTE2 related experiment on JET		David Keeling, Matteo Baruzzo