RT13 – programme priorities in 2027

(JT-60SA TG: MHD Stability and Control)

WPTE General Planning Meeting

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Main MHD research items for OP2 and OP3

- JT-60SA has produced its first plasma in October 2023 as part of **OP1**. The future experimental campaigns are expected to start in 2027. The discussions in the topical group and with the ELs allowed to provide the main MHD research topics for **OP2**:

[MHD-1]	Error field characterization/correction and impact on locked modes
[MHD-2]	Disruption studies and creation of disruption databases
[MHD-3]	Runaway electrons generation/dissipation and control studies
[MHD-4]	Sawtooth activity and modification by ECRF and impact on NTM

- These studies will continue in **OP3**, with the addition of new topics:
  - ✓ Tearing Modes during ramp-up, flat-top, and ramp-down phases
  - ✓ Neoclassical Tearing Modes stabilization/control with ECH/ECCD
  - ✓ Characterization of MHD activity in high beta plasmas
  - ✓ Resistive Wall Mode studies

Summary of MHD experiment proposals for OP2

- Call for Proposals launched at the end of 2025: the experiment proposals received (42) cover the main MHD research topics indicated as priorities in OP2 and widely discussed at the MHD TG meetings. Four programs selected for OP2.
- For each program, it will be important to verify the existence of the required target scenarios and monitors, or to plan their development within the experiment itself.
- Regarding the methodology, some programs may include an initial piggyback phase, linked to scenario development, and a second phase with dedicated pulses.

Research topics		# proposals	# sessions
[MHD-1]	Error field characterization/correction and impact on locked modes	13	17
[MHD-2]	Disruption studies and creation of disruption databases	15	23
[MHD-3]	Runaway electrons generation/dissipation and control studies	9	27
[MHD-4]	Sawtooth activity and modification by ECRF and impact on NTM	5	7
		42	**74**

Selected OP2 MHD experiments

OP2 experiment	EC	Co-EC	No. of sessions
[M03] Error-field characterization and correction	L. Pigatto (RFX)	Y. Ko (QST)	4
[M05] Initial disruption studies and disruption database	T. Yokoyama (QST)	G. Pucella (ENEA)	2
[M06] Initial runaway generation and control studies	U. Sheikh (EPFL)	A. Matsuyama (Kyoto Univ.)	2
[M11] ECRH/ECCD control and impact on sawteeth*	E. Alessi (CNR-Milan)	H. Yamazaki (QST)	2
			10

**M11 is a joint experiment shared by JT-60SA ORD and MHD TG. To simplify the selection process, participants interested in contributing to M11 should provide their IMS responses only to RT12 (TG-ORD).*

Discussions on deliverables, extended goals, preparation activities, analysis and modelling tools, OP2 experiment execution, and the exploitation of results will represent the focus of our activities in 2027.

M03: Error-field characterization and correction

Deliverables and Extended goals

D1: Characterize error-field and locked mode detection with conventional compass scan
D2: Characterize error-field and locked mode detection with non-disruptive compass scan
D3: Test and demonstrate error-field correction with EFCC (ohmic / ECRF-only plasmas)
D4: Provide data to identify and characterize a critical MHD mode in the baseline scenario
D5: Compare the measured error-field penetration thresholds with existing numerical models and ITPA scalings

E1: Initial assessment of β_N and rotation effects on the error-field penetration
E2: Validation of frequency-dependent plasma response model using active MHD spectroscopy

Programme with a clear progression: measurement, understanding, correction, and validation

- D1 and D2 are essential for error-field and locked-mode characterization
- D3 is the key operational deliverable, demonstrating effective EFCC performance
- D5 closes the scientific loop through comparison with numerical models and ITPA scalings
- E1 may provide interesting physics results through β_N and rotation studies
- E2 is ambitious, but highly valuable for plasma-response validation

EC	Leonardo PIGATTO (RFX, EU)
Co-EC	Yongtae KO (QST, Japan)

Cycle #1	Cycle #2	Cycle #3	Cycle #4
0	**4** (1 with NBI)	0	0

M03: Error-field characterization and correction

Preparation activities foreseen

- Locked-mode detection: definition and implementation
- Vacuum modeling of structures, actuators and sensors
- Design gas-puff feedforward control
- Discuss and assess feasibility of feedback for non-disruptive compass scan
- Develop scenarios with expected conditions (low rotation, EC-heated plasma, NBI, shaping)

Analysis and modelling tools expected to be used

- Change finder: automatic locked-mode detection
- Post-shot diagnostic analysis (MHD, SXR, CXRS, TS) and control room tools
- Equilibrium reconstruction with diagnostic constraints
- Equilibrium and controllability: MECS, CREATE-L / -NL, CHEASE […]
- MHD stability, screening and penetration: R2F, RFX-locking, MARS-Q, MARG2D, GPEC, NTVTOK […]
- Integrated transport codes: TOPICS, METIS and Pulse Design Tool […]
- Vacuum and eddy current codes: SPRED, CARIDDI, FRIDAvac, FIESTA

M05: Initial disruption studies and disruption database

Deliverables and Extended goals

D1: Characterize disruptions in low- and high-current experiments in OP2
D2: Validate vessel sideways forces for ITER
D3: Create disruption database and modelling validation and test of disruption predictors
D4: Test MGI for disruption mitigation studies at low plasma current

E1: Real-time disruption (edge cooling) mitigation experiment

Strategic programme for building JT-60SA disruption management capabilities

- D1 provides the essential baseline characterization of disruptions
- D2 offers high impact for ITER through vessel sideways-force validation
- D3 is arguably the core deliverable: disruption database development, model validation, and predictor testing
- D4 represents a realistic first step toward disruption mitigation using MGI
- E1 is a natural progression toward real-time mitigation experiments

EC	Tatsuya YOKOYAMA (QST, Japan)
Co-EC	Gianluca PUCELLA (ENEA, EU)

Cycle #1	Cycle #2	Cycle #3	Cycle #4
0	1	1	0

M05: Initial disruption studies and disruption database

Preparation activities foreseen

- Define criteria for disruption database creation and structure design
- Develop target scenario for MGI injection experiments
- Determine MGI gas amount and species for scan studies
- Identify diagnostics for evaluating VDE-induced heat loads and MGI radiation
- Perform MHD stability analysis in high-density plasmas
- Implement anomaly detection tool for real-time MGI trigger experiment

Analysis and modelling tools expected to be used

- Linear MHD codes (MISHKA, CASTOR, MARS) for stability analysis
- Nonlinear MHD codes (INDEX, JOREK) for disruption dynamics
- MECS code to design VDE target scenarios and analyze associated loads
- Sideways force models (JOREK-STARWALL, ATEC) to support vessel force validation for ITER
- Data processing & DB tools for disruption database creation, MGI radiation analysis, and heat load evaluation

M06: Initial runaway generation and control studies

Deliverables and Extended goals

D1: Characterize runaways in OP2
D2: Develop a reproducible scenario for runaway generation studies on JT-60SA
D3: Characterize initial post-disruption runaway beam control and benign termination
D4: Validate modelling of runaway generation and mitigation

E1: Characterize plasma instabilities driven by runaways
E2: Characterize spectral evolution of runaways under different conditions

<u>High-risk programme with potentially outstanding scientific return</u>

- D1 efficiently builds the runaway database through piggyback observations
- D2 is the critical deliverable, establishing a reproducible runaway-generation scenario
- D3 addresses runaway-beam control and benign termination, a key ITER issue
- D4 enables validation of runaway-generation and energy-dissipation models
- E1 and E2 investigate runaway-driven instabilities and spectral evolution

EC	Umar SHEIKH (EPFL, EU)
Co-EC	Akinobu MATSUYAMA (Kyoto Univ., Japan)

Cycle #1	Cycle #2	Cycle #3	Cycle #4
0	0	2	0

M06: Initial runaway generation and control studies

Preparation activities foreseen

- Multi-machine database analysis for RE scenarios:
  - Characterize large startup RE seed populations
  - Investigate seed generation during disruption
- Adapt MGI system for low injection amounts (discussions already underway with MGI team)
  - Prepare scenario with injection from seeding valves as backup
- Set current limits and safety thresholds with machine operators, develop path to high current RE operation
- Diagnostics and threshold settings: evaluate HXR influence on neutron detectors and thresholds to signify clear RE generation

Analysis and modelling tools expected to be used

- RE generation optimization using startup models (e.g., STREAM - Molina-Cabrera, EPS 2026)
- RE beam generation modeling with MECS, DREAM and eventually JOREK (also capable of final termination modeling in OP2)

M11: ECRH/ECCD control and impact on sawteeth

Deliverables and Extended goals

D1: Characterize electron temperature and current profile controllability with ECRH/ECCD
D2: Test the impact of ECRH/ECCD on sawteeth
D3: Validate ECRH control-room modelling tools
D4: Conduct a test of ECRH power modulation

E1: Purity of EC polarization modes
E2: Long-period sawtooth modification by ECRH/ECCD (studies with N-NBI)
E3: Test high-power gyrotron operation for future applications in JT-60SA

Programme focused on ECRH/ECCD control, with impact on sawteeth (shared by ORD TG)

- D1 is the fundamental prerequisite for demonstrating profile control
- D2 evaluates the direct impact of ECRH/ECCD on sawtooth behavior
- D3 validates control-room modelling tools
- D4 validates ECRH power-modulation capability
- E1 is required to assess power deposition localization and prevent power dispersion
- E2 is likely the most interesting extended-goal physics activity. E3 is a test for future applications

EC	Edoardo ALESSI (CNR-Milan, EU)	Cycle #1	Cycle #2	Cycle #3	Cycle #4
Co-EC	Hibiki YAMAZAKI (QST, Japan)	**0.5** (ctg.)	**1**	**0.5**	0

M11: ECRH/ECCD control and impact on sawteeth

Preparation activities foreseen

- Development of algorithms for the detection of ST period and inversion radius on available diagnostics (Mirnov, ECE, SXR), in perspective of their use in control room.
- Characterize sawtooth activity in OP1 pulses
- Modelling of ST period and of ECRH/ECCD deposition in OP1 pulses
- Predict impact on the ST period changing the ECRH/ECCD deposition (inside/outside q=1)

Analysis and modelling tools expected to be used

- Detection of ST period and inversion radius from SXR (ECE).
- Code and graphics for crossing between Mirnov and SXR (ECE) to evaluate 1/1 inter-ST fluctuations
- Code and graphics to evaluate optimal ECRF polarization
- ETS, JETTO-JINTRAC codes including Porcelli-Sauter models for analysis of ST period and inversion radius and design of experiments
- Beam tracing codes (GRAY) to evaluate ECH/ECCD deposition

Support for future operations and W-PFC transition

- **WSA-RT13-D1**

  Preparation of future C-PFC phase TG-MHD activities to improve capabilities for runaway control and disruption mitigation in support of the W-PFC transition

- **WSA-RT13-D2**

  Support W first-wall design through predictive modelling of heat loads during disruptions and the assessment of runaway electron mitigation and impact, leveraging cross-machine insights strictly focused on validating JT-60SA predictive tools and operational boundaries

Competences

Data analysis and Interpretation

Magnetic sensors
CO2 laser interferometer (tangential)
Visible TV cameras
Fast camera EDICAM
Divertor Langmuir probes and thermocouples
Soft X-ray detector intensity
Visible spectrometer (tangential)
Quadrupole Mass Spectrometer
Magnetic (flux loops, magnetic probes, Rogowski coils, diamagnetic loops, AT probes)

Modelling

Linear MHD (MISHKA, CASTOR, MARG2D, MINERVA…)
Nonlinear MHD (JOREK, NIMROD, MEGA, XTOR…)
Resistive Wall Modes (CARMA, STARWALL, RWMaC,…)

Group meetings

- **Topical Group meetings**, held regularly throughout the year, will continue to be the heart of our activities, offering the opportunity to:
  - ✓ discuss scientific topics of interest to the group
  - ✓ present updated studies on OP2 experiments
  - ✓ discuss proposals for OP3 experiments
  - ✓ present the development of control room tools
  - ✓ conduct rehearsals for conferences and paper reviews

Presentations uploaded to the MHD folder: MHD Stability and Control (sharepoint.com)

- **Dedicated rehearsal meetings** will be organized to discuss the content of MHD-related contributions to major international conferences (such as IAEA, EPS, APS, and AAPPS).

1st TGM (13.10.2022)

2nd TGM (02.03.2023)
3rd TGM (06.12.2023)

4th TGM (26.03.2024)
5th TGM (22.07.2024)
6th TGM (14.11.2024)

7th TGM (04.02.2025)
8th TGM (26.05.2025)
9th TGM (30.06.2025)
10th TGM (12.09.2025)
11th TGM (06.10.2025)
12th TGM (16.12.2025)

13th TGM (09.04.2026)
14th TGM (23.07.2026)
15th TGM (29.09.2026)

ITPEA contribution

- The **International Tokamak Physics and Engineering Activity** (ITPEA) provides a framework for internationally coordinated fusion research activities.

- Many of the ITPEA discussions are relevant for the JT-60SA scientific exploitation. The JT-60SA contribution to the ITPEA TG on "**MHD, Disruptions and Control**" (MDC) will cover several aspects:

  - ✓ [MDC-19] Error field control at low plasma rotation
  - ✓ [MDC-25] Sources and scalings of non-axisymmetric "Sideways"
  - ✓ **…**

2027 MHD objectives & OP2/OP3 roadmap

- **OP2 Preparation, Execution & Control Room Support**
  - ✓ Finalize pulse plans and drive joint EU–JA experiment execution in the Naka control room
  - ✓ Consolidate control-room tools for real-time and fast MHD experimental analysis

- **Core MHD Physics & Model Validation**
  - ✓ Error Fields: quantify and correct error fields for scenario optimization
  - ✓ Disruptions & Runaways: expand disruption physics/prediction strategies and develop runaway electron mitigation & control schemes
  - ✓ Sawtooth Control: demonstrate ECRH/ECCD-driven sawtooth control capability
  - ✓ Validation: benchmark OP2 experimental data against numerical models and ITPA scalings

- **Reporting and OP3 Preparation**
  - ✓ Timely delivery of WPTE milestones and presentation of OP2 results at international conferences
  - ✓ Initiate physics assessment and scenario design for OP3 topics (NTM control, high-β, RWM studies)