EUROfusion

WPW7X AWP2024

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Wendelstein 7-X

FSD Meeting | Culham | 20.09.2023

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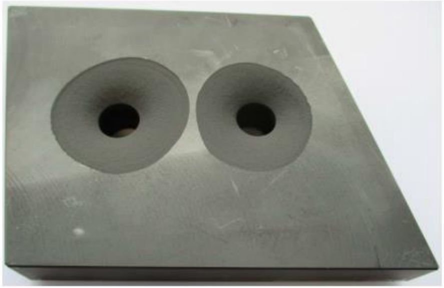
Status 7-X, technical risks: plan is stable



NBI beam dump

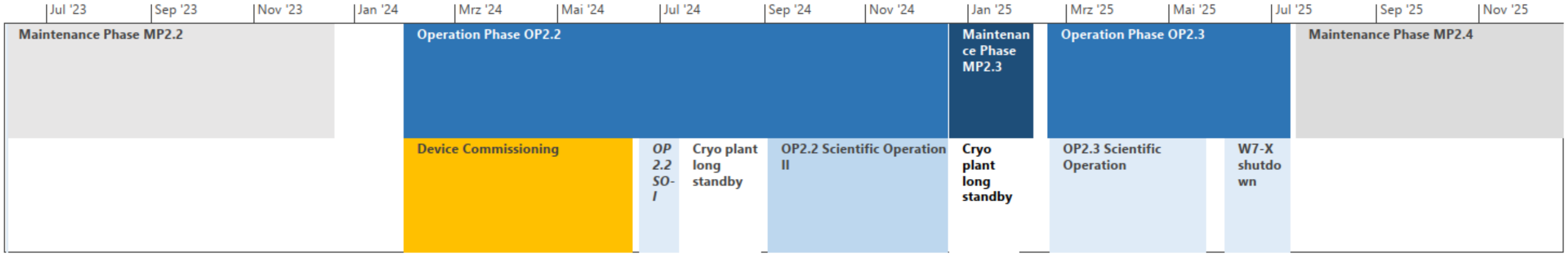
- Reason for lost tile
- Stresses from poor head conduction; malfunction of screw
- Fixed with replacement

Transformer replacement

- Replacement/repair is difficult and is a schedule risk for OP2.2
- Risk recently mitigated: company confirmed delivery plan compatible with OP2.2 planning

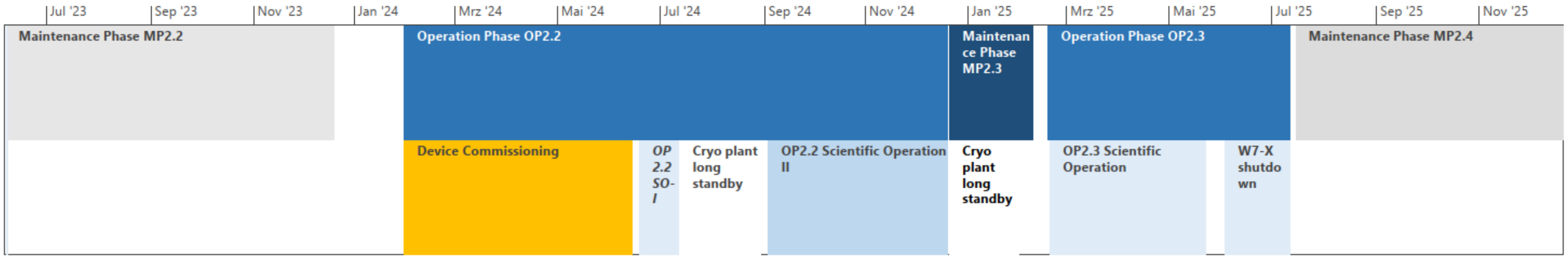
Status W7-X

Operation schedule



17.06. – 12.07.2024	plasma operation SO-I OP 2.2	• 4 weeks to bring systems up
15.07. – 30.08.2024	operation pause	• main vacation period (school break) • magnets remain cold, PV under vacuum • TH accessible
02.09. – 13.12.2024	plasma operation SO-II OP 2.2	• 15 weeks of operation • proposal-based • continue with 2/3 days alternating rythm
20.12.2024 – 14.02.2025	maintenance phase MP 2.3	• magnets remain cold, PV under vacuum
17.02. – 23.05.2025	plasma operation SO-II OP 2.3	• no time allocated for system commissioning • 14 weeks of operation • same scheme as OP 2.2
14.07.2025	start maintenance phase MP 2.4	

WPW7X Plan 2024 - Campaign



Workshop OP2.1	27./28.11.23 (zoom)
Call for Proposals	**Jan. 24**
Proposals	Feb. 24
W7-X Program Workshop	Apr. 24
Call for Participation	**Apr. 24**
Session Plan	Jul. 24
Response to BEN	**Jul. 24**

23/24 D‘s & M‘s

W7X	D3.5	Assessment report on fast-ion generation and divertor exhaust (energy limit 1 GJ)	31.12.23		on track
W7X	D3.6	Report on conducted scenario & campaign preparation (focus: preparation of steady-state scenarios turbulent and core neoclassical transport)	31.12.23		on track
W7X	M17	First Operation with water-cooled PFCs Completed	31.12.23	30.03.23	completed
W7X	M18	1 GJ energy turn-around achieved.	31.12.24	15.02.23	completed
W7X	D3.7	Report on the modelling of plasma heating schemes, plasmas with fast-ions and transport regimes for long steady-state high-beta operation (energy limit 2 GJ)*	31.12.24		Unknown
W7X	D3.8	Report on conducted Scenario & campaign preparation (focus: turbulent and neoclassical transport, high-power steady-state operation)	31.12.24		Unknown
W7X	D3.9	Assessment report on scenarios with optimized transport and high-beta operation (energy limit 6 GJ)*	31.12.24		Unknown

*specification of energy limits to be revised with operator. Heating capabilities are extended slower than expected at the beginning of FP9.

I. 2024 Campaign

EUROfusion Machine Time W7-X			
2022	2023	2024	2025
18%	23%	30%	30%

- HR for Participation in the campaign
  - Physics commissioning
  - Qualification of instruments and software
  - Conduction of experiments

TF-I: Core scenario development

Summary TF-I: OP2.1 Results vs. Deliverables

Results O1: *High Performance Scenarios*

D1: Steady State High Performance	√	*4 Scenarios developed*
D2: Density Profile Control	√	*Pellets missing*
D3: Impurity Accumulation	√	*No impurity accumulation*

Results O2: *Heating Scenarios*

D4: Effective Ion Heating	√	*Break of T_i clamping w/ 3 NBI + pure ECRH*
D5: W7-X Operational Map	√	*Max heating powers not available (4 NBI + 9.5 MW ECRH)*
D6: Fast Ion Losses	√	*No unexpected wall loads, initial FILD data*

Results O3: *High Beta Scenario*

D7: Plasma Startup at low B	√	*ICRH Breakdown, NBI+X3 takeover missing*
D8: Improved Confinement at High Beta	X	*No low field scenario developed*
D9: B Field Dependencies	X	*No low field scenario developed*

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TF-I Core Scenario Development | 24.04.2023 26

TF-II: Edge Scenario development

Summary (I/II)

- ***O1: Integrated scenarios for long-pulse operation with PFC heat load control, efficient particle exhaust, and impurity screening:***
  - D1: Demonstration of safe divertor scenarios to avoid overloaded plasma-facing components, — √ multiple scenarios with > 100 MJ energy or > 6 MW heating
  - D2: Determination of trim and/or control coil currents required to correct error fields, — √ current dataset incomplete
  - D3: Demonstration of effective pumping, high divertor compression, and qualification of fueling actuators, — √ pellets missing; need to feed back on more signals
  - D4: Demonstration of long-pulse operation. — √ 1 GJ with low performance

- ***O2: Development of long, stationary divertor detachment scenarios with and without impurity seeding:***
  - D5: Demonstration of scenarios with long, stationary divertor detachment; in particular, for the high-mirror, high-iota and standard configurations, — √ no high-iota to date
  - D6: Characterize the conditions under which detachment is possible, — √ higher performance and more sophisticated feedback desired
  - D7: Achieve rapid transition to detachment. — X need dedicated scenarios

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TF-II: Edge Scenario development

Wendelstein 7-X

Summary (II/II)

- ***O3: Exploration of scenarios compatible with carbon-free operation and tungsten PFCs:***
  - D8: Definition of the operation limits associated with plasma-facing components containing tungsten materials,
    - √ limits for ECRH (O2-misalignment)
  - D9: Characterize the scrape-off layer retention for tungsten impurities (eroded from baffle and heat shield),
  - D10: Determination of erosion effects due to seeding impurities,
    - X no spectroscopic data in SOL (D9 and D10)
  - D11: Characterize enrichment/accumulation for low-Z and high-Z impurities.
    - √ HEXOS calibration with TESPELs
    - √ no accumulation observed in the core plasma
- ***O4: Development of wall conditioning procedures:***
  - D12: Condition walls to enable plasmas with high density gradients necessary for high performance
    - √ boronization, GDC
    - √ ECWC (systematic study pending)
    - X ICWC (not conducted)
    - X conditioning ⇔ profiles
- ***O5: Reference discharge:***
  - D13: Regular performance of a standardized discharge with defined diagnostic coverage throughout the campaign
    - √ accomplished
    - √ gas balance analysis required

TF-III: W7-X Optimization

Summary of OP2.1 for TF-III deliverables

- **O1: Core transport and stability**
  - D1: Documentation of profiles for transport analysis and modeling — data taken, analysis pending
  - D2: Turbulence in plasma scenario and MC space — accessible scenarios well covered
  - D3: Impurity transport and perturbative experiments — largely limited by technical issues
  - D4: Neoclassic optimization at increased T_i — not attempted for lack of scenario
  - D5: Reduced equilibrium currents at higher beta and in MC space — accessible scenarios well covered
  - D6: MHD stability and modes in the MC space — accessible scenarios well covered

  (D1–D6: lack of robust high beta scenario)

- **O2: Edge and SOL transport**
  - D1: Transport across LCFS and in island divertor SOL — good (though not complete) coverage
  - D2: Validation of edge transport codes — good (though not complete) coverage
  - D3: SOL width and target heat flux scalings — low field scenarios missing
  - D4: Asymmetries and mapping of diagnostics in 3D SOL — data taken, analysis pending (some diagnostics missing)

- **O3: Low-field high beta scenarios**
  - D1: Optimization criteria at increased beta
  - D2: High-beta plasma profiles, magnetic fluctuations
  - D3: Field stochastization and implications for SOL / divertor

  (D1–D3: no low field scenario; some investigations into intermediate beta were done, assessment pending)

II. Preparation and Exploitation

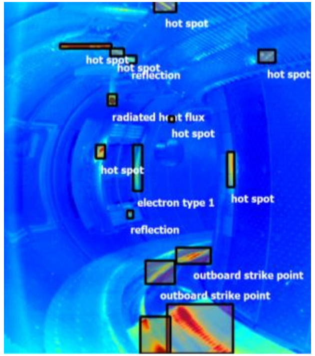
- HR for Preparation
  - Upgrades and hardening of EU diagnostics contributions (PHA, reflectometry, EDICAM, C/O Monitor)
  - Software for safe operation (imaging software)
  - Development of components (MATEO)
  - Development, engineering, tests and qualification of components (gyrotrons, metallic PFCs)
  - Qualification of instruments and software
- HR for Exploitation
  - Analysis and modelling along the achieved progress (see slides above)

WP Milestones

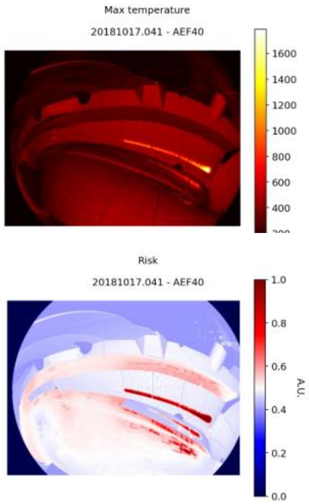
Sequential WP-M ID	WP Milestone Title
WPW7X-2024.M.1.	Call for Participation issued (15.04.24)
WPW7X-2024.M.2.	EU Manning for Task Forces detected (31.07.24)
WPW7X-2024.M.3.	Campaign conducted (15.12.24)
WPW7X-2024.M.4.	low-*B* plasma demonstrated (15.03.23 -> 15.12.24)
WPW7X-2024.M.5	Campaign preparation conducted (31.12.24)

WPW7X Prog. Headline I: Safe long-pulse operation

Safe machine operation, PWI and divertor operation:
surveillance, wall conditioning, detachment
→ long-pulse, high-density operation
→ preparation for reactor relevant PFCs (WPPWIE, WPDIV)



Grelier et al., SOFT (2022)
Puig-Sitjes, Appl. Sci. 2022



R. Mitteau (w/PrIO)

Short term needs addressed by CINECA (summer 23)

Long term needs

Storage 1 .. 10TB
Dataset management tool
<80000 GPU hrs

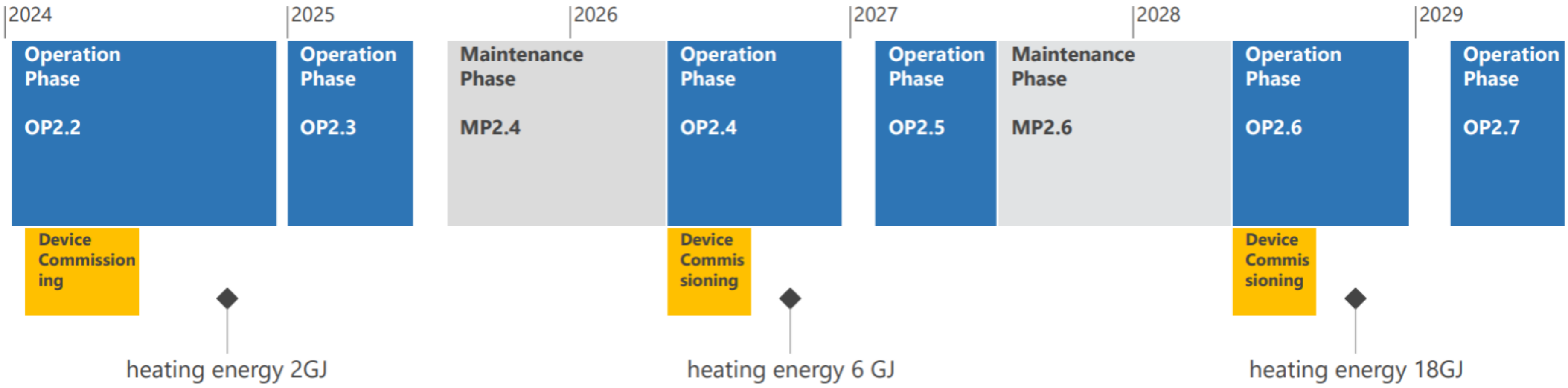
Communicated to ACH

PCR requests WPW7X 2024 (2025 the same)

Manipulator development	Construction and lab test of the original MATEO manipulator	Avoidance of delays Strategic opportunity	35PM (FZJ)	= 154,04
Gyrotron development	• Cavity cooling design • Window qualification • Tests	Avoidance of delays Strategic opportunity	11PM (NCSRD) 4PM (ENEA-PoliTo) 3PM (KIT) 11PM (KIT)	= 27,79 = 13,94 = 14,06 = 51,56
Divertor physics design	• Neutral gas calculations • Additive manufacturing of heat sinks	Avoidance of additonal delays Avoidance of missing design	4PM (KIT) 10PM (DTU)	= 18,75 = 45,31
Interpretative Modeling and experimental data analysis of OP2.1 and preparation of OP2.2	Interpretative modeling for high-current OP2.1 discharges; • Comparison of HINT/EMC3-EIRENE calculations at recycling rollover point to detachment experiments; • Modeling of island localized modes in FMM & beta-effects in lowshear configurations; • New integrated probe head building on success of RFA, DEP, and thermocouple measurements (also incl. Langmuir probe); • 2D distribution inversion for endoscope filter cameras (4 endoscopes, 20 filter cameras, 2 IR cameras, 12 spectrometers); • Cross-validation of reflectometer profiles against other upstream edge diagnostics. • Analysis and upgrades of PHA and CO Monitor • Analysis of Reflectometry and Modeling • Preparation of Pellet Injection • Reflection model for PFC surveillance, safety and AI extensions • Analysis of dual wavelength Thomson scattering and probe measurement	Completion of the exploitation of campaigns, Completion of W7-X physics basis Avoidance of delays	25 PM (FZJ) 10PM (IPPLM) 25PM (CIEMAT) 4PM(CEA) 3PM (ENEA)	= 110,03 = 18,02 = 79,82 = 20,42 = 13,94
Campaign	• Scenario development • Long pulse operation • Turbulence/NC transport entanglement	Avoidance of delays Full exploitation of EU components Strategic opportunity	20PM	= 92,81
			in total	660,48 k€-CC = 13ppy

Facilities Review: WPW7X View

- W7-X: Indispensable and unique, clearly addressing the objective of Mission 8: bringing stellarators to maturity exploiting the HELIAS concept.
- FULGOR KIT (ECRH test facility): indispensable to avoid time risks for heating upgrades on W7-X
- TJ-II: important – high benefit for the preparation of W7-X experiments, complementary magnetic configuration (code validation)
- Turbulence optimized QI stellarator: next-generation QI stellarator optimized for fast-ion confinement and turbulent transport: proof-of-concept fills an important aspect of the gap of magnetic configurations that can be extrapolated to reactor scale.
- URAGAN-2M: important – preparation of W7-X experiments (wall conditioning and start-up)
- TOMAS: important – preparation of W7-X experiments (ICWC)
- LHD, Heliotron-J (both Japan), HSX (US): complementary magnetic configurations (code validation) – pursued in International Collaborations within the IEA Technology Cooperation Program on Stellarators and Heliotrons


2024
2025
2026
2027
2028
2029
Operation Phase OP2.2
Operation Phase OP2.3
Maintenance Phase MP2.4
Operation Phase OP2.4
Operation Phase OP2.5
Maintenance Phase MP2.6
Operation Phase OP2.6
Operation Phase OP2.7
Device Commission ing
Device Commis sioning
Device Commis sioning
heating energy 2GJ
heating energy 6 GJ
heating energy 18GJ