EUROfusion

WPW7X: 2022 programme goals and strategy (AWP2022)

A. Dinklage (TFL), A. Alonso (DTFL), I. Calvo (DTFL)

eurofusion-wpw7x@ipp.mpg.de

Wendelstein 7-X

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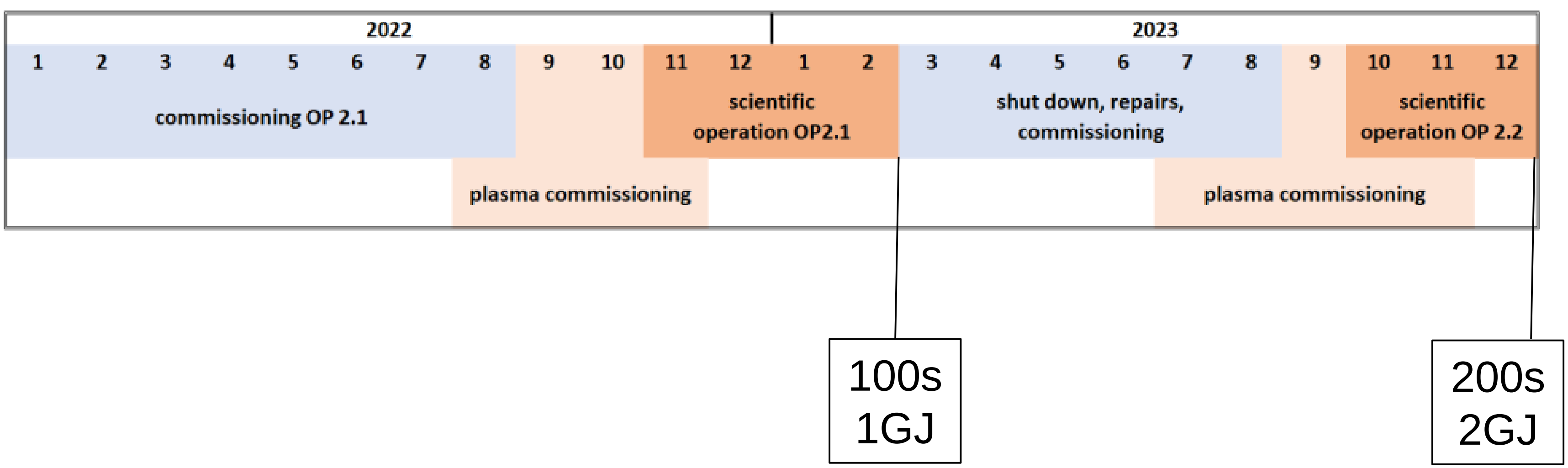
Grant Deliverables & Milestones 2022

	Description	Due date	Type	Dissemination
W7X.M.02	Commissioning of W7-X enhancements incl. Commissioning w/ plasma **OP2.1. 1st operation** of W7-X w/o use of water-cooled PFCs	Dec. 2022	Data	Sensitive
W7X.D.03	Report on conducted **scenario & campaign preparation OP2.1** (focus: wall conditioning, divertor exhaust and core heating/fast-ion confinement, preparation of steady-state scenarios, preparation of exhaust scenarios with divertor heat load control)	Dec. 2022	Report	Public
W7X.D.02 *TSVV*	Non-linear stellarator gyrokinetic code treating at least entire flux surfaces (not limited to flux tubes)	Dec. 2022	Other	Sensitive
W7X.D.04 *TSVV*	Stellarator optimization code including algorithms with reduced sensitivity to local minima in parameter space	Dec. 2022	Other	Sensitive

Timeline and AWP2022 in a nutshell

Priorities: campaign OP2.1

1. Preparation of campaign OP2.1
2. EUROfusion manning to OP2.1
3. Long-term developments, HELIAS physics basis, INCO, industrial collaboration & ITER



SMART WPW7X Milestones 2022

- WPW7X-2022-M.1: Program meeting
  Physics program (aligned with Mission 8 objectives) ready
- WPW7X-2022-M.2: CfP evaluated
  Manning for campaign OP2.1 organized
- WPW7X-2022-M.3: Plasma commissioning phase conducted
  ICRH antenna in operation
- WPW7X-2002-M.4: Scientific operation
  First plasma (w/ water-cooled PFCs installed, not operating) in campaign OP2.1

Now: objectives to arrive at the WPW7X Milestones

2022 Objective 1: EU components ready

Operate and exploit EU components in the W7-X experimental campaign OP2.1 and prepare OP2.2.

objective

a. Conduct the scientific commissioning, operate and participate in experiments using video cameras, IR surveillance, AM Beam, PHA, Reflectometry, CO monitor, probes, pressure gauges, manipulators, spectroscopy and software/control systems

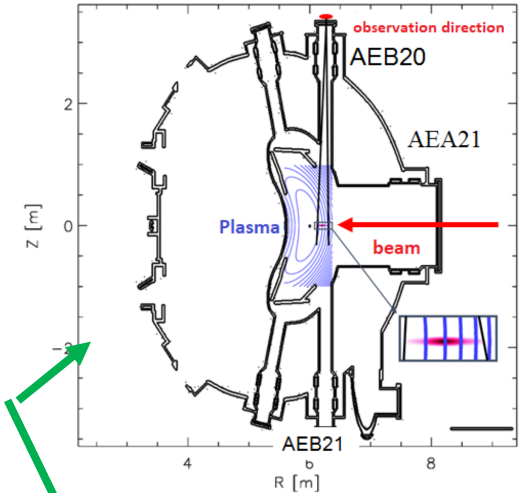
b. Prepare and conduct impurity transport studies with TESPEL and LBO

examples

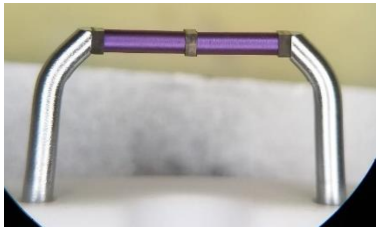
description of work

synergy potentials

Upgrade AM-Beam:
SOL/edge densities
→ integrated SSO scenarios



New design LaB6 pressure gauges
gas balance
→ divertor operation



2022 Objective 2: technical preparation OP2.1

Technical preparation of OP2.1: finalize the development of heating and fueling system upgrades as well as diagnostics upgrades, prepare their installation on the device, conduct system qualification and technical commissioning

a. Heating upgrades

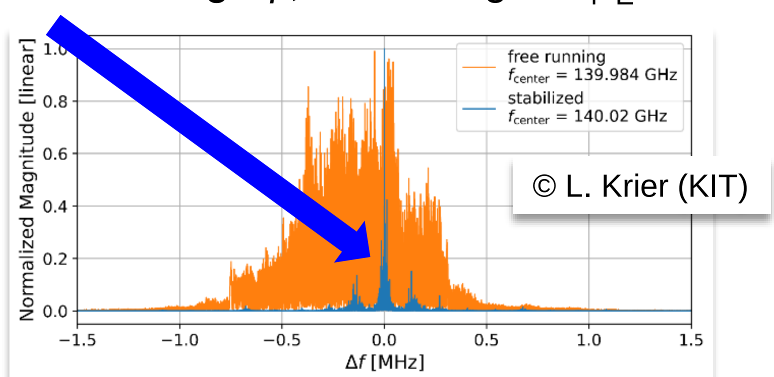
b. Fueling systems and density control

c. Divertor and wall heat-load surveillance

d. Diagnostic commissioning (upgrades and enhancements, also from FP8)

(MW)	ECRH	NBI_{inj}	ICRH	P_{tot}
OP1.2	7.8	3.2	---	**7.8**
2022	9.3	6.4	~1.0	**>10.8**

Heating upgrades: performance increase
→ high-β, low ν*, high $nT_i\tau_E$



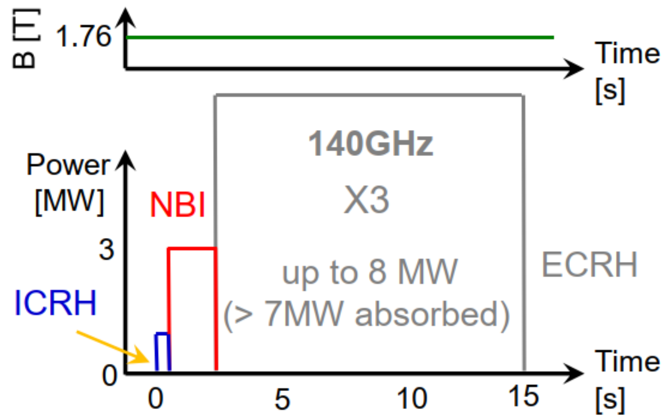
ECRH frequency stabilization

2022 Objective 3: preparation of operation

Preparation of operation: prepare safe long-pulse, high-power operation by implementing safety interlocks and develop strategies for wall conditioning

a. wall conditioning schemes (incl. ICH, w/ WPPWIE).
b. safe operation schemes.
c. heating scenarios (ICH, ECH, NBI)
d. generation of fast ions (ICH, NBI).
e. Low-B start-up (ICH, NBI, ECRH) and X3 plasma heating
f. long pulse operation
g. pellet injection, gas puff scenarios
h. steady-state detachment (seeding)

X3 heating and ICH/NI startup: high-β operation
→ stellarator optimization



T. Stange et al

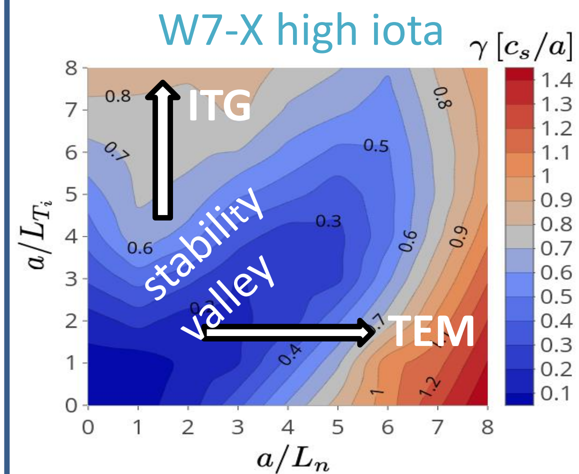
WPPWIE TSVV 12 TSVV 13

2022 Objective 4: Experiments in Campaign OP2.1

Prepare and conduct experiments along the high-level objectives of WPW7-X

a. neoclassical optimization at high-β
b. turbulence mechanisms (fluctuations, zonal flows)
c. transport reduction in high-performance regimes
d. H-mode, HDH-mode, …
e. detachment (exploration of the accessible operation range, active cooling, seeding, pumping)
f. confinement in the extended configuration space
g. SOL transport & wetted areas (in view of potential reactor scenarios).
h. MHD optimization: low-B, high-beta and configuration variation.
i. qualification of fast-ion confinement
j. impurity transport
k. particle transport for scenarios (density peaking)

Taming 3D turbulence: Improve confinement → high-performance



Alcusson et al., PPCF (2020)

WPPRD TSVV 12 TSVV 13

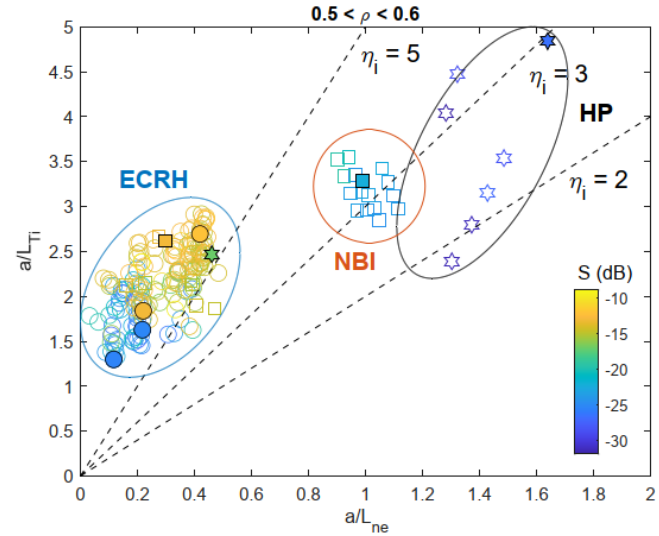
2022 Objective 5: scientific preparation

Scientific preparation of OP2.1: Advance the analysis of OP1 experimental data to develop and validate physics models and codes to prepare OP2 experimental scenarios, experiment proposals and to construct the physics basis and the design and simulation tools for next-step devices.

a. Exploit OP1 data for OP2 operation

b. Integrate validation activities from the associated TSVV tasks

Fluctuation reduction in different OP1.2 scenarios:
Expectations for OP2.1
→ swift qualification of upgrades



Carralero et al., submitted (2021)

TSVV 12 TSVV 13

2022 Objective 6: long-term developments

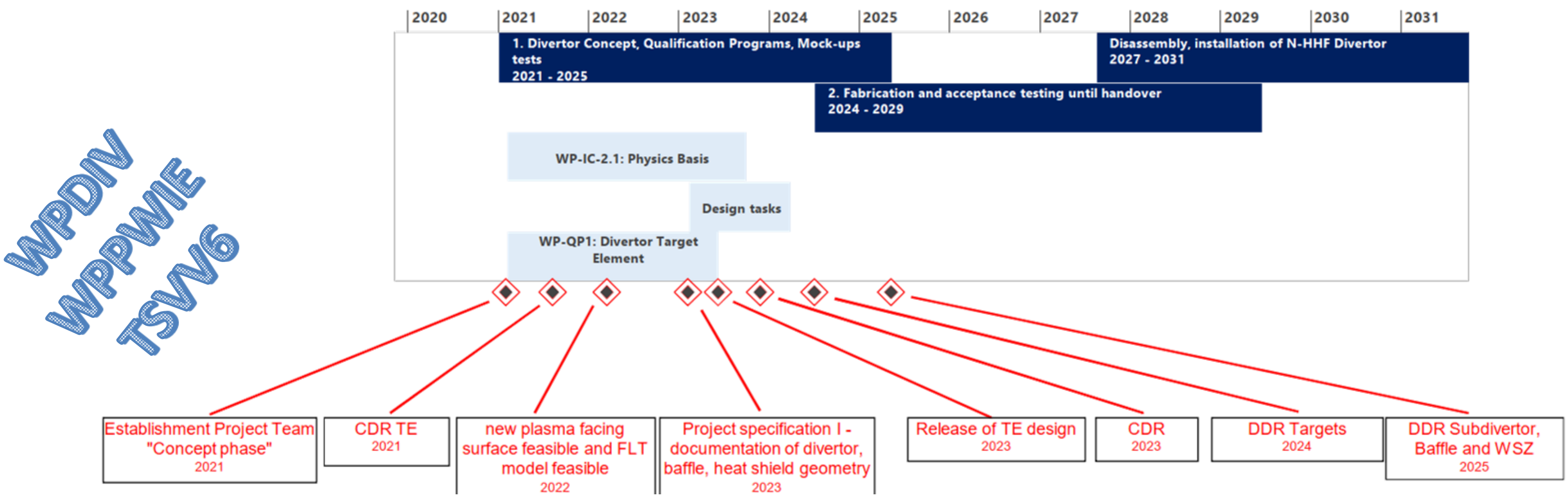
Preparation of longer-term upgrades of the W7-X divertor and plasma facing components in collaboration with other EUROfusion work packages (w/ WPPWIE, WPDIV).

a. EMC3/EIRENE/ERO2.0 validation

b. Develop metallic wall operation and divertor concepts.

c. Experiments for metallic wall operation & validation of material migration

W-divertor project
prepare metallic W7-X:
→ HELIAS reactor



2022 Objective 7: HELIAS basis, ITER support

Support the preparation of the HELIAS physics basis, ITER first plasmas, ensure information exchange with WPPRD and continue international collaborations in support of the Mission 8 objectives.

a. International collaborations (IEA Technology Collaboration Programme on Stellarators and Heliotrons)

b. Integration of stellarator databases into the EUROfusion database

c. Specific support actions (e.g. ITER ECRH stray radiation model and material testing) and ITPA contributions.

Mistral stray-radiation test facility: material/component test
→ hardening, safe operation

TSVV 12: Stellarator Optimization

GA Deliverable no.	Title	Due Date (mm/yyyy)
D03.04	Stellarator optimization code including algorithms with reduced sensitivity to local minima in parameter space	12/2022

Other specific objectives for 2022 (selection)

- Evaluation of improvement on ideal MHD stability using **CAS3D** within optimization framework.
- Interface between the neoclassical code **KNOSOS** and optimization code.
- Interface between the gyrokinetic code **`stella`** and optimization code.
- Benchmark and early estimate of the accuracy and speed of bootstrap codes.
- Benchmark of existing fast ion codes – validation of existing features.
- Application of new diagnostics in the MHD code **SPEC** to assess magnetic topology and robustness of stellarator equilibria against pressure and current perturbations.

Developments in this TSVV are not only relevant for the **design of next-generation stellarators**, but also for their **application to W7-X campaigns** (e.g. assessment of fast ion confinement, assessment of robustness of magnetic configuration, efficient evaluation of neoclassical transport, etc.).

TSVV 13: Stellarator Turbulence Simulation

GA Deliverable no.	Title	Due Date (mm/yyyy)
D03.02	Non-linear stellarator gyrokinetic code(s) treating at least entire flux surfaces (not limited to single flux tubes)	12/2022

Other specific objectives for 2022 (selection)

- Benchmark of the full flux surface version of **`stella`** vs GENE-3D run in full flux surface mode.
- Interface between **KNOSOS** and gyrokinetic codes.
- Development of **synthetic diagnostics** that provide meaningful numerical input for the interpretation of OP2 turbulence data.
- Assessment of the turbulent transport of the different species, with emphasis on impurities. Assessment of the relative weight of turbulent to neoclassical transport.
- Development of adjoint methods for linear gyrokinetics to be applied to turbulence optimization.

Developments in this TSVV are of the utmost importance for W7-X campaigns. The **calculation of turbulent transport** is essential to interpret, predict and, hopefully, control total transport in W7-X.

Synergies within EUROfusion

- FTD.WPPRD: see Warmer (reactor relevant proposals)
- FSD.WPPrIO: Database (IMAS), specific support actions, ITPA coordination?
- FTD.WPDIV: coordination W7-X, WPDIV, WPPW
- FSD.WPPWIE: wall conditioning, TG PWI @ W7-X

- TSVV6: W7-X validation cases being discussed
- TSVV12: tools ↔ validation ↔ proposals
- TSVV13: tools ↔ validation ↔ proposals
- … thrust meetings underway

Opportunities for industrial collaborations

THALES

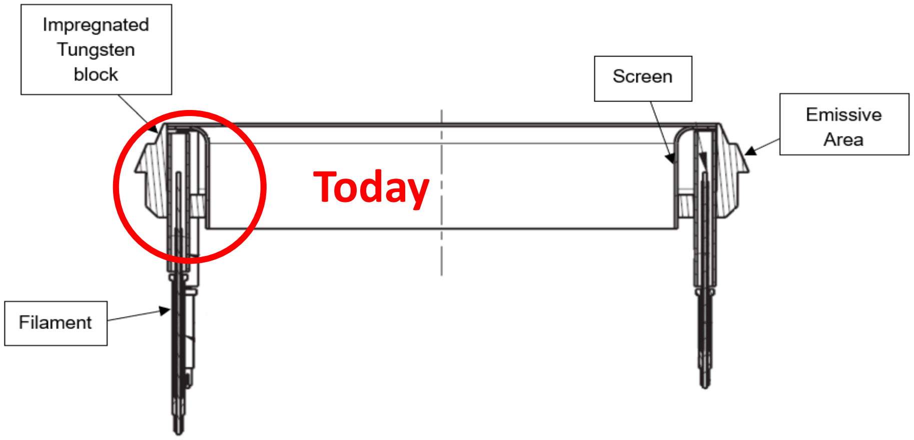


Figure 1 : TH1507 Gyrotron Cathode

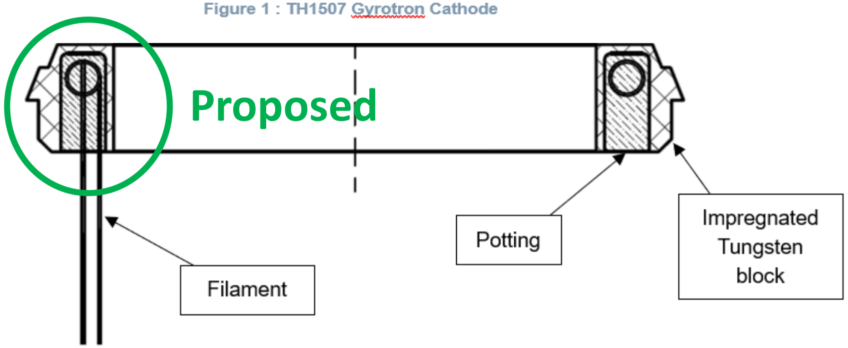


Figure 2 : Example of a potted gyrotron cathode

Present technology:

- heating is based on confined radiation from heated filament
- isolation by the ceramic beads.

New proposal (Thales):

back of emissive area in potting of alumina.

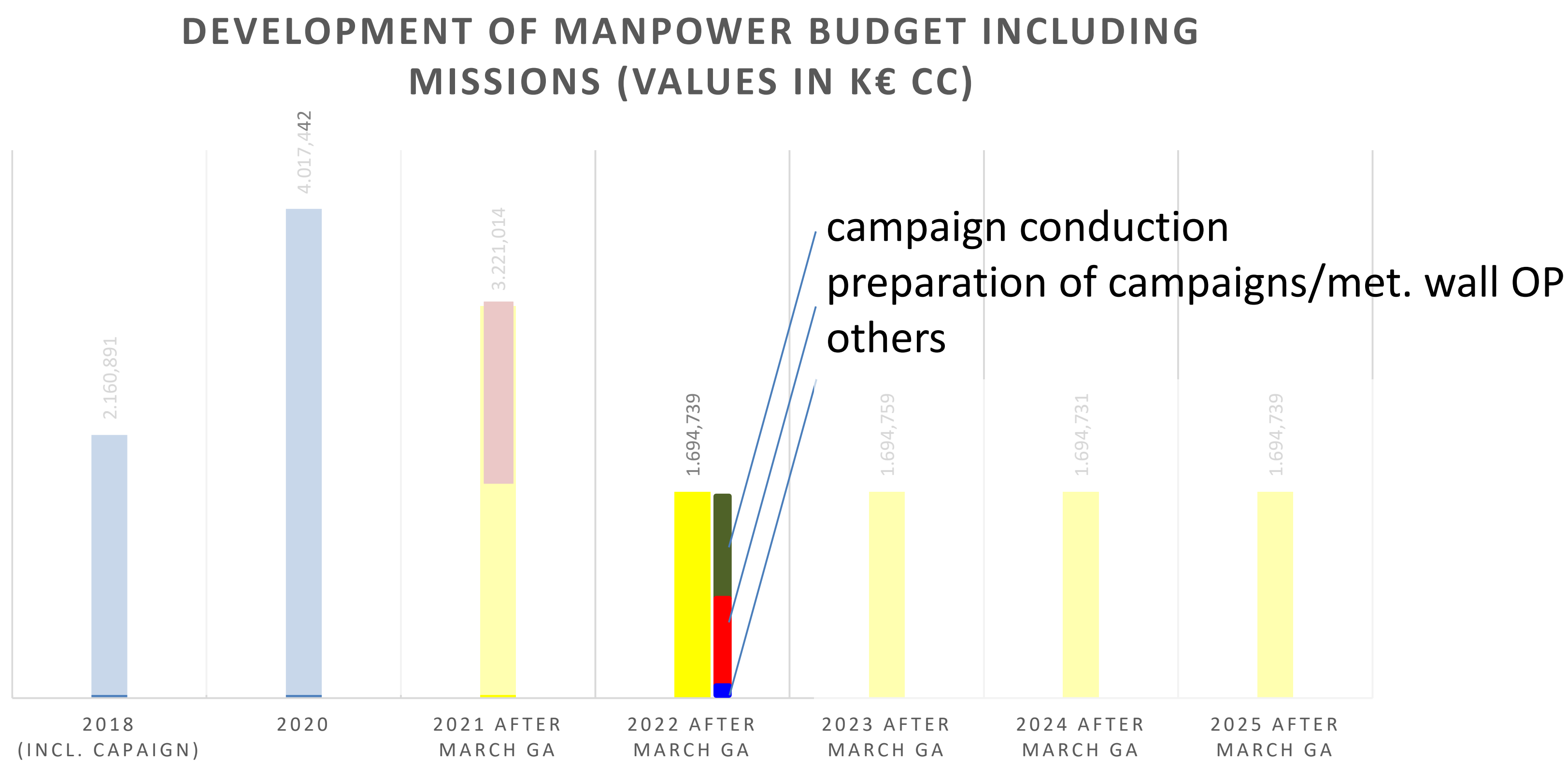
Advantages:

- enhanced heat transfer to emissive area
- overall electrical isolation
- better thermal homogeneity

→ enhanced longevity & robustness
→ RAMI

Enable a leading European technology for production of thermal emitters for MW-class gyrotrons by introduction of potted emitter technology.

Resource allocation



Budget unknown (~50%): results in high-impact risks for the exploitation of large EU investments.

Risks

- Resources too low: critical reduction of scope
- Lack of manning: critical reduction of scope
- Machine delayed: delays
- COVID: delays
- Resoruces for HELIAS reactor studies too small: Mission milestones cannot be attained

- Pace of energy increase too low: delayed program
- PI not available: reordering of program required
- Heating ICRH coupling: reduction of scope
- NBI: lack of ion heating
- ECRH: lack of cw heating/SSO performance

INCO

- Due to COVID restrictions, travelling to the main cooperation partners (Japan, US) cannot be conducted
- INCOs continued by remote participation but at lower pace and efficacy
- Propose to keep INCOs ‚on hold' and to resurrect them once the conditions change

Summary and conclusion

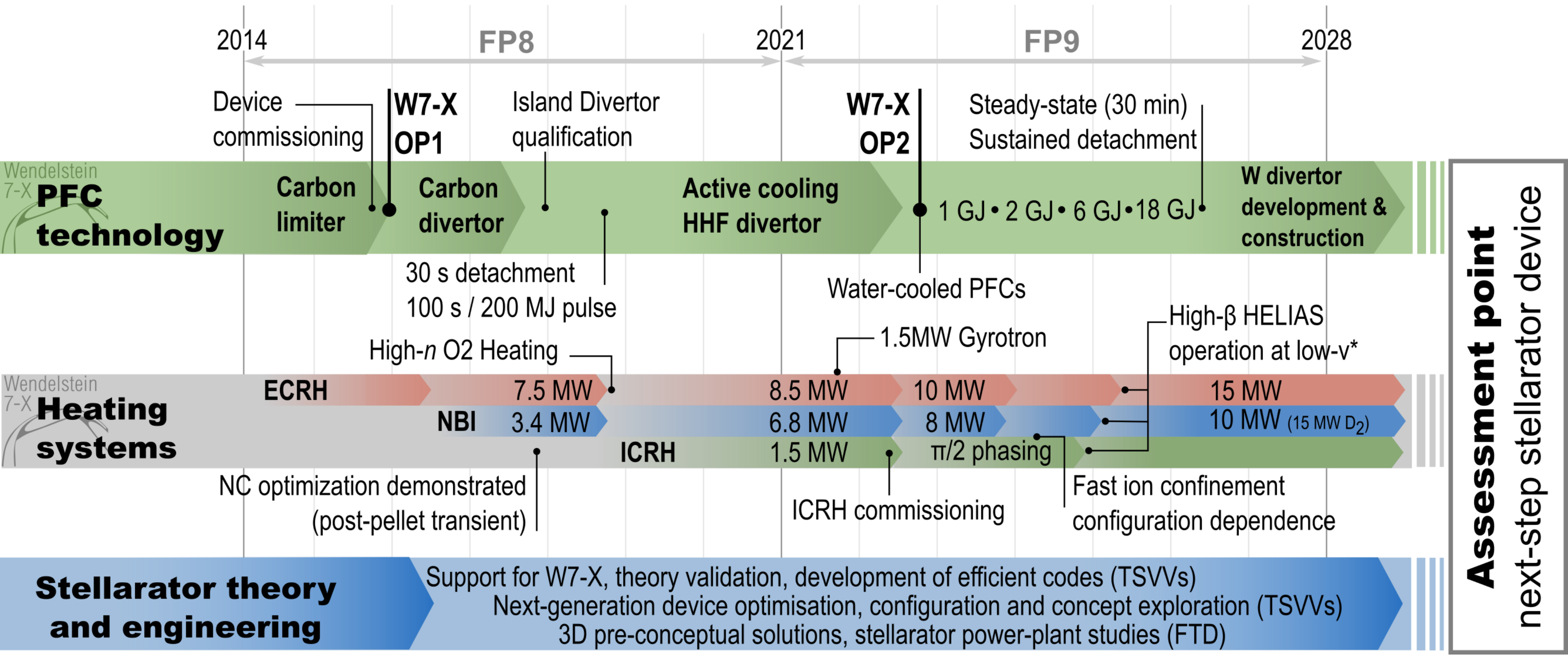
- Programme 2022: focus on OP2.1

Shift to more and more campaign oriented work

EUROfusion Machine Time W7-X				
2021	2022	2023	2024	2025
0%	18%	23%	30%	30%

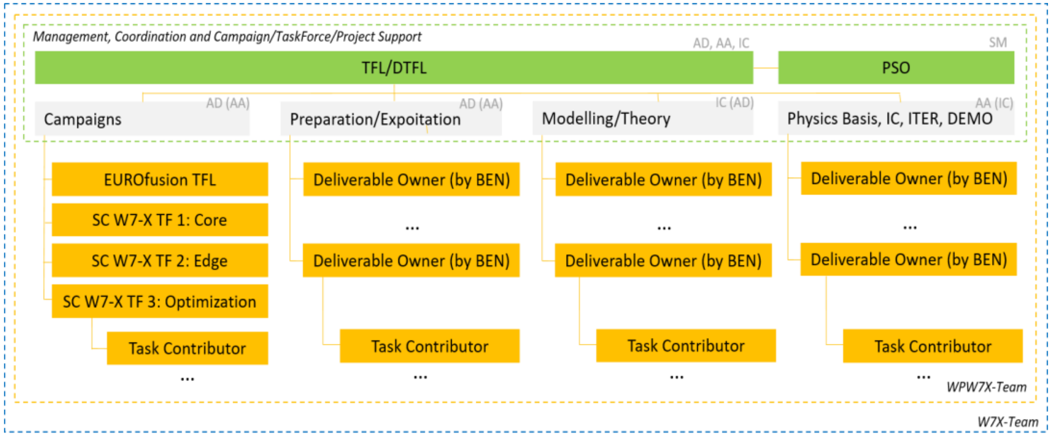
- make enhancements (FP8-EP etc.) ready for OP2
- exploitation prioritized along high-level objectives of M8
- INCO, HELIAS physics basis, TSVV, ITER support
- synergy potentials (FSD, FTD, etc.) worked out and exposed

W7-X in FP8 and FP9



EUROfusion Machine Time W7-X				
2021	2022	2023	2024	2025
0%	18%	23%	30%	30%

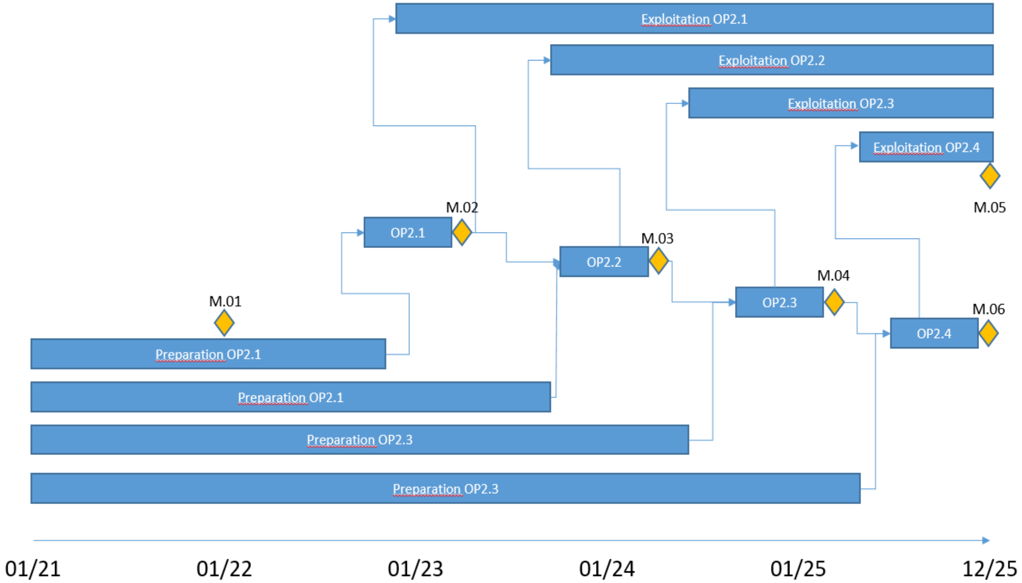
Management WPW7X



Structure

- ➢ flat hierarchies
- ➢ full integration into the W7-X Team

One-Team: leverage of resources



Simple overall workflows: format follows function

- ❖ Preparation
- ❖ Campaigns
- ❖ Exploitation

Exceptions:

- ➢ support HELIAS/ITER/DEMO
- ➢ International Collaborations

Today‘s Situation and Target of the Industrial Collaboration

- **Today‘s situation:**
  - ➢ European Gyrotron Manufacturer, Thales, relies on Semicon, USA, as single source supplier. *(It is assumed that Russia is relying on Semicon too).* On the other hand, Thales is leading manufacturer of smaller size emitters for Klystrons and TWTs already using advanced potted emitter technology.
  - ➢ Semicon announced to discontinue the manufacturing of large hollow emitters as required by European gyrotrons as Semicon faces severe issues with manufacturing of large sized emitters of proper quality.
  - ➢ Semicon uses a heating technology for thermal emitters that is not optimum. It is prone to thermal inhomogenity, hence low quality electorn beams, and it causes „emitter cooling“ that leads to a significant change in beam current during start-up phase.

- **Target:**
  - ➢ Enable Thales for doing the initial steps for moving to an inhouse production of large-size gyrotron emitters.
  - ➢ Enable a leading European technology for production of thermal emitters for MW-class gyrotrons by introduction of potted emitter technology.

Proposal for Enabling Technology

Today's technology currently used for heating is based on confining the radiation from the heated filament inside the tungsten block using a screen. The electrical isolation between the different parts of the filament is provided by the addition of ceramic beads.

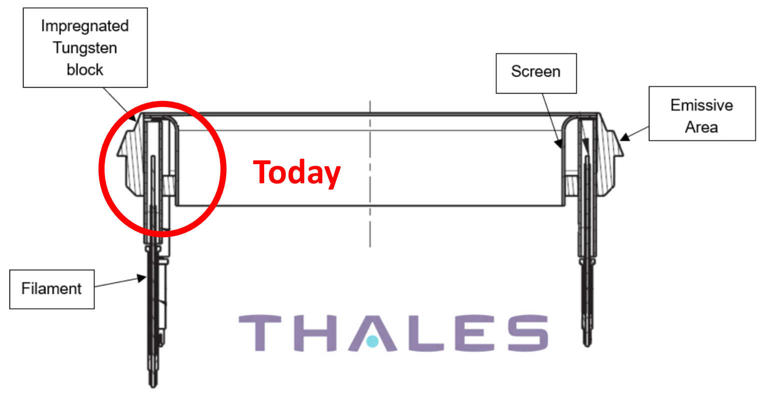


Figure 1 : TH1507 Gyrotron Cathode

Thales proposes to put the filament on the rear face of the emissive area by trapping it in a potting of alumina. This system plays a double role: an electrical isolator to avoid the shorts between the different spins of the filament for example and a thermal conductor in order to transmit the thermal power to the emissive area.

- Better heat transfer to the emissive area
- Electrical isolation at any points of the filament
- Better thermal homogeneity

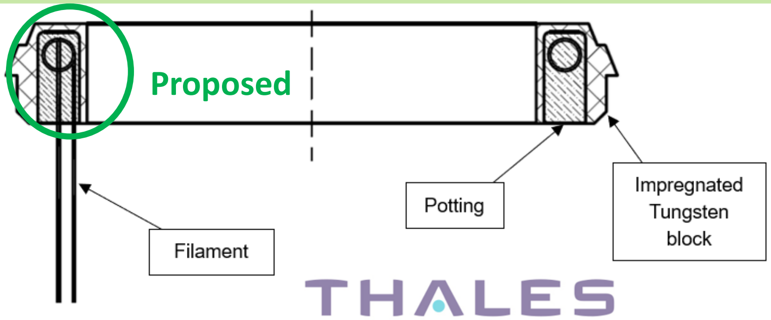


Figure 2 : Example of a potted gyrotron cathode

Development Plan

1.) Achieve technological feasibility

- 2 emitter rings (A & B) will have to be manufactured
- 1 emitter will be thermally cycled and expertized in Thales

2.) Perform thermal and emission tests for initial qualification

- 1 emitter (A or B) will be assembled in cathode to be tested in SP at KIT
- This emitter will be expertized at Thales after operation in SP

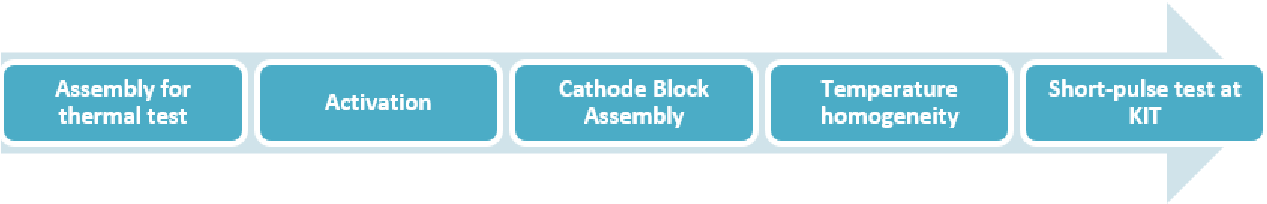


Figure 4 : Thermal and emission tests

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