Status Report for WPW7X

WPW7X Board Meeting | 15.03.2022

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WPW7X Board Meeting

- Our thoughts are with our friends and colleagues in Ukraine. The Russian attack and the unjustified war is utmost condemned.

- Since the ISHW is the most knowledgable specialist's forum relevant to Mission 8, I kindly encourage all participants of WPW7X to participate in the 23rd International Stellarator-Heliotron Workshop Instytut Fizyki Plazmy i Laserowej Mikrosyntezy - Home (ifpilm.pl)

- This presentation has annexes with information presented in the WPW7X stakeholder meeting (10.03.22)

Project Board presentation topics - Spring

#	Project Board
1	**[max. 5 min]** WP Organization
2	**[max. 20 min]** WP Main Objectives & Summary of Achievements (previous year) Status of Grant Milestones & Grant Deliverables (previous year)
3	**[max. 5 min]** Risks & Mitigations Register: Current Status
4	**[max. 10 min]** Project Change Requests & Other Items for Decision/Approval by PB
5	AOB

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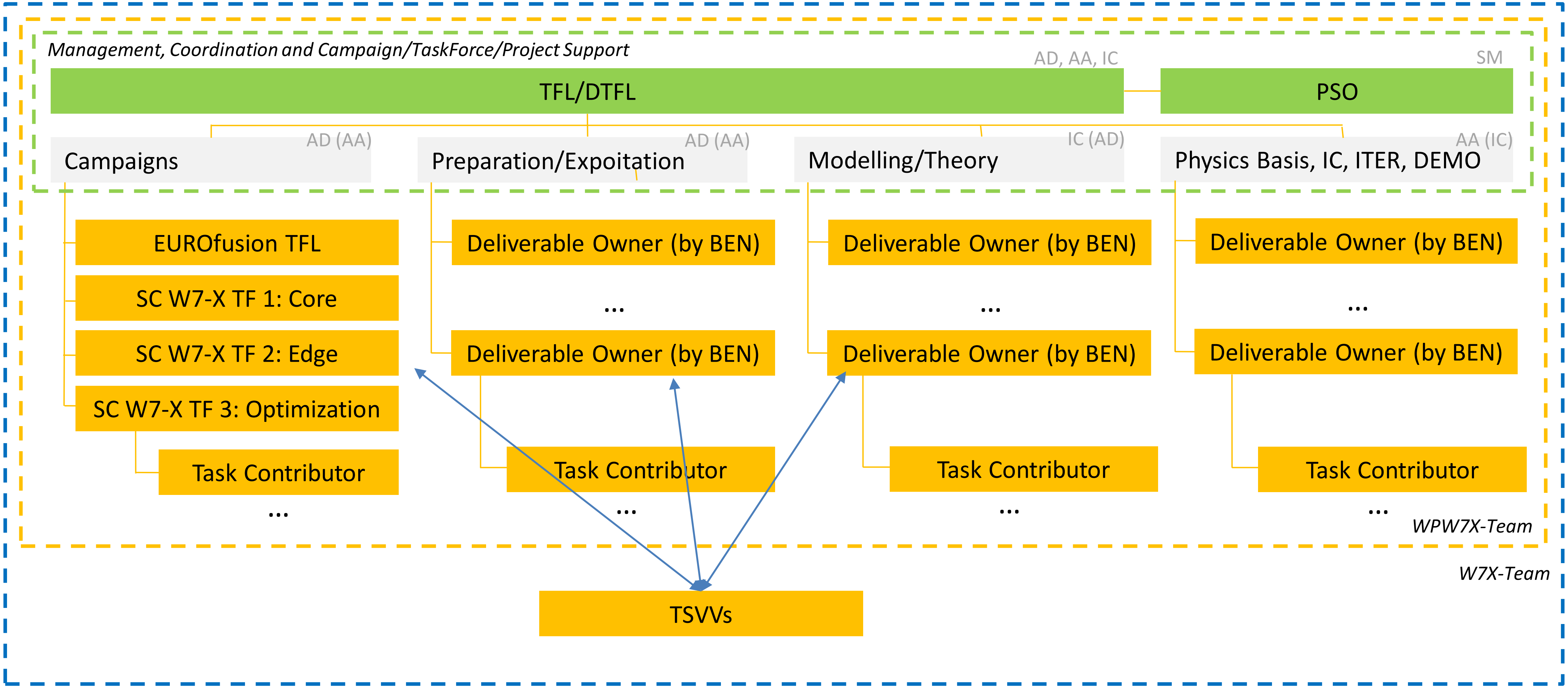
- max. duration of WPL's presentation (incl. discussion): 40+5 min
- max. duration per item indicated between square brackets
- Additional documents will be available to the PB members well ahead of the meeting


Management, Coordination and Campaign/TaskForce/Project Support
AD, AA, IC
TFL/DTFL
SM
PSO
AD (AA)
Campaigns
AD (AA)
Preparation/Expoitation
IC (AD)
Modelling/Theory
AA (IC)
Physics Basis, IC, ITER, DEMO
EUROfusion TFL
SC W7-X TF 1: Core
SC W7-X TF 2: Edge
SC W7-X TF 3: Optimization
Task Contributor
…
Deliverable Owner (by BEN)
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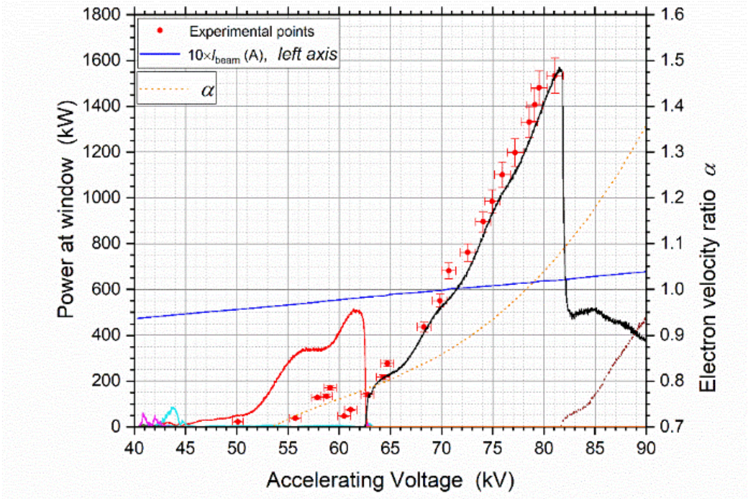
Deliverable Owner (by BEN)
Task Contributor
…
WPW7X-Team
W7X-Team
TSVVs

2 – WP Main Objectives & Summary of Achievements (previous year)

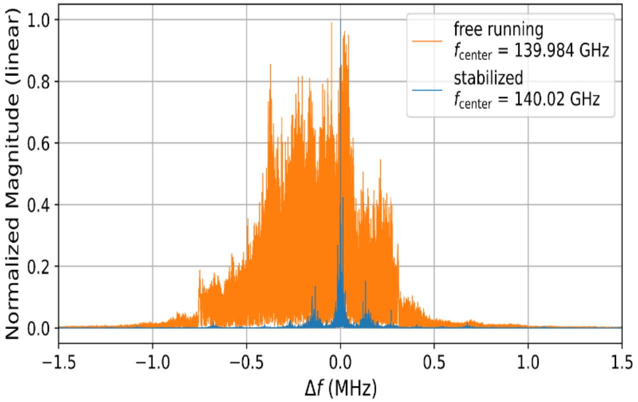
WPW7X-2021.O1: Continue the development of heating and fueling system upgrades and prepare their installation on the device

Substantial upgrades of the heating systems have been performed as planned. The electron cyclotron resonance heating (ECRH) system has been upgraded and the infrastructure for the 1.5MW gyrotron has been prepared as planned. The ICRH system has been delivered to Greifswald and the ICRH antenna was installed.

ICRH antenna inside the W7-X plasma vessel



Test results from 1.5MW short pulse gyrotron



Frequency stabilization of gyrtron emissions

2 – WP Main Objectives & Summary of Achievements (previous year)

WPW7X-2021.O2: Initiate collaborations with TSVV-12 on stellarator optimization and lay out plans for the project with the goal of producing highly optimized designs by 2025

WPW7X-2021.O3: In collaborations with TSVV-13, enhance the capabilities of micro-turbulence modelling in W7-X via development of the currently available gyrokinetic codes, their verification and their application to specific transport problems

TSVV 12: Stellarator Optimization

- The variational MHD equilibrium code SPEC, capable of including magnetic islands, can now also be used to assess stability.
- The fast neoclassical code KNOSOS was upgraded, and now it can be applied to any large-aspect-ratio stellarator.
- Several codes (SIMPLE, GORILLA, ASCOT5, KNOSOS-MC) for assessing fast-particle confinement in stellarators were developed.
- Technique for rapidly assessing the linear stability threshold of ITG instabilities.
- Implementation of the gyrokinetic code `stella` in the optimization suite STELLOPT has started.

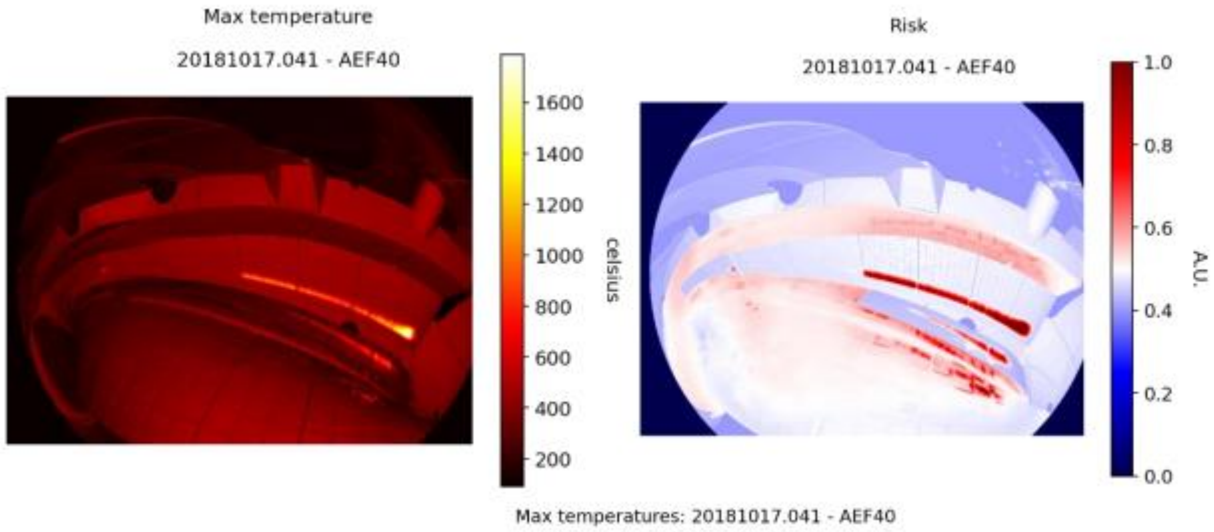
TSVV 13: Stellarator Turbulence Simulation

- Thorough verification activities and benchmarking between different gyrokinetic codes.
- Routine, self-consistent gyrokinetic simulations of multispecies W7-X plasmas with the flux-tube version of `stella`.
- Inclusion of collisions in `stella` and development of a full-flux-surface version.
- Development of and electromagnetic version of GENE-3D.
- Development of the stellarator transport suite GENE-3D/KNOSOS-Tango.

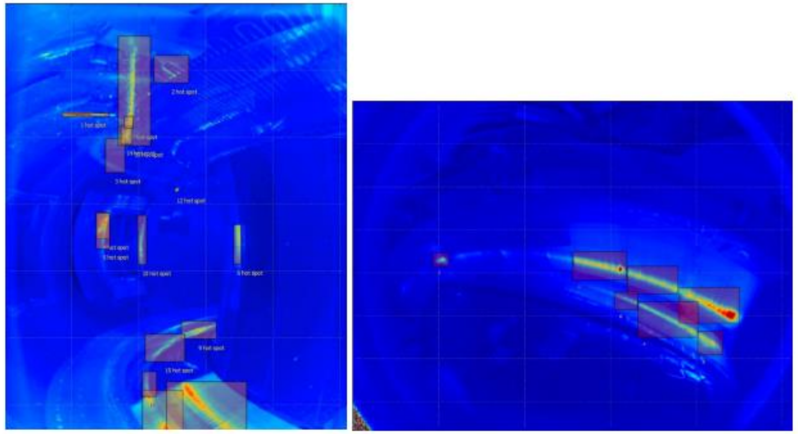
2 – WP Main Objectives & Summary of Achievements (previous year)

WPW7X-2021.O4: Prepare safe long-pulse, high-power operation by implementing safety interlocks and developing strategies for wall conditioning

FPGA-based interlock systems for magnetic diagnostics were developed as planned. Wall conditioning techniques were qualified and studies for low field plasma startup were conducted within international cooperations with LHD (Toki, Japan). With Interaction with WPPriO, imaging tools were developed incorporating techniques employing artificial intelligence.



Risk map for plasma facing components in W7-X

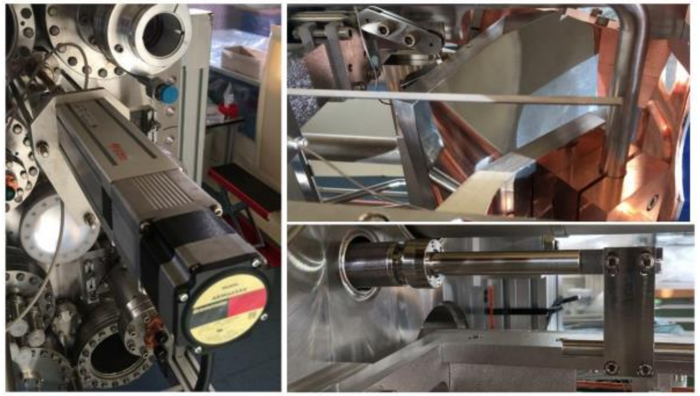


Identification of hot spots with AI (W7-X *learning* from WEST)

ITER relevance: PFC surveillance and hot spot detection (2 EEGs w/ PrIO)

WPW7X-2021.O5: Continue to develop and implement diagnostic systems and upgrades in support of the scientific objectives of Mission 8 in OP2

The activities included **spectroscopy** systems, **manipulators**, **probes**, upgrades of an **Alkaline metal beam**, **reflectometer** and upgrades of **an impurity pellet system**. Moreover, immersion tubes were hardened to get them ready for long-pulse plasma exposure. Software developments required for **safe operation** (control systems, interlocks) were developed.



Components of the AEA21 W-band mirror steering system

WPW7X-2021.O7: Prepare longer-term upgrades of the W7-X divertor and plasma facing components in collaboration with other EUROfusion work packages (WPPWIE, WPDIV)

Tungsten PFCs in W7-X

A concept for a **transition to metal plasma-facing components** operation was worked out in collaboration with WPDIV and WPPWIE. TZM tiles procured by the ECRH group were installed. Sandblasting was applied to increase the emissivity of the W or W alloys baffle tiles. Tungsten transport studies in 3D configuration are prepared for OP2.1.

WPW7X-2021.O6: Advance the analysis of OP1 experimental data, develop and validate physics models and codes to (a) prepare OP2 experimental scenarios and (b) continue to construct the physics basis and the design and simulation tools for next-step devices

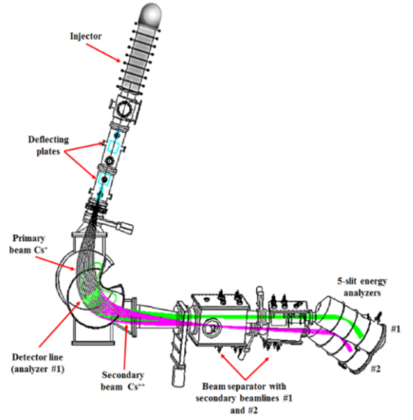
The investigation of induced plasma instabilities (**sawtooth crashes**) revealed the impact of distortions in the rotational transform and resulted in the specification of safety margins to avoid instabilities. The physics of **plasma flows** was pursued. Pellet fuelled discharges were assessed to **prepare high-performance discharges** in the forthcoming campaign

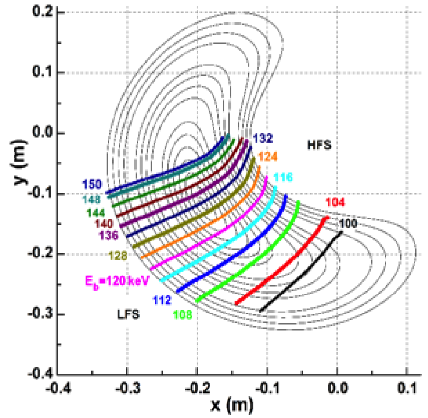
As a highlight, a Nature article was published about the demonstration of **reduced neoclassical transport** in W7-X due to the stellarator optimization concept (C.D. Beidler et al., Demonstration of reduced neoclassical energy transport in Wendelstein 7-X, Nature **596,** 221 (2021)). This result constitutes a scientific milestone towards the assessment of the HELIAS line as an alternative route to fusion electricity (Mission 8 of the Roadmap).

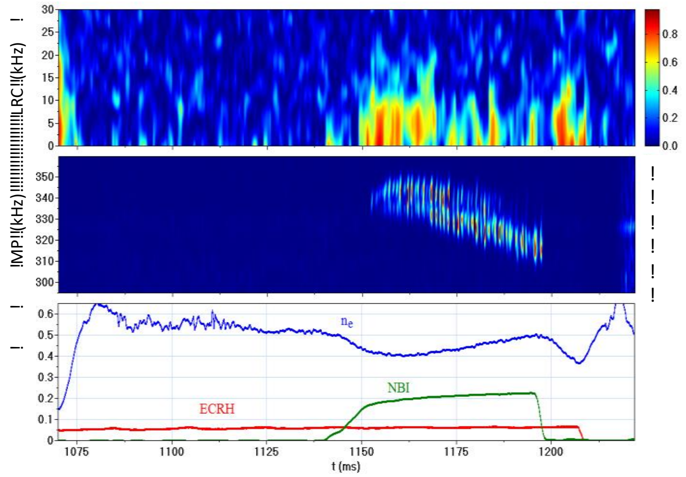
Moreover, the documentation of **detached discharges** provided an approach to operate W7-X at large heating power in long pulses. Finally, the role of density peaking and its impact on turbulent transport was linked to ITG and TEM instabilities which limit the ion temperature in gas fuelled, ECR heated plasmas. Accompanying gyro-kinetic simulations indicated that density gradients lead to **turbulence suppression**.

WPW7X-2021.O8: Support the preparation of the HELIAS physics basis, ITER first plasmas, ensure information exchange with the EUROfusion FTD and continue international collaborations in support of the Mission 8 objectives

WPW7X organized the working group meeting 2021 of the **IEA Stellarator-Heliotron Technology Cooperation Program**. **Experiments on LHD** were conducted in order to qualify experimental techniques and to complement experiments on W7-X. Important progress was attained in start-up experiments which is directly transferable to ensure plasma break-down at low magnetic fields. This qualification extends capabilities to achieve higher plasma beta. For **ITER**, dedicated studies on experimental techniques (depolarization and two-color Thomson scattering, development of pressure gauges) and dedicated actions for **ITPA** tasks were conducted. Meetings with **FTD-PRD** have been held to explore experiments required for the physics basis of a HELIAS reactor.







2D potential and fluctuation measurements: fast ions and potential fluctuations

2 – WP Main Objectives & Summary of Achievements (previous year)

Main issues and deviations/insufficient progress

The **COVID pandemic** led to deviations in the workplan. The majority of deviations were resolved by a reorganization of tasks, e.g. to synchronize the delivery of components with the assembly schedule of W7-X. Few tasks were shifted to 2022 (analysis of probe data for OP2.1 preparation) but did not lead to critical delays.

The delivery of the **cw pellet injector** (led by DoE) was delayed. The EUROfusion contribution (support actions) were conducted in time. The resulting delay is accepted and the experimental program will be arranged to bring forward different deliverables. Pellet fuelling is critical for the attainment of high plasma performance. The pellet injector is expected during the W7-X campaign OP2.1.

2 – Status of Grant Milestones & Grant Deliverables (previous year)

GA Deliverable No.	Title	Due Date	Status	Details on Status (in case of delays or issues)
D03.01	Report on conducted scenario & campaign preparation (focus: optimization studies, wall conditioning procedures)	31/12/2021	Completed	

GA Milestone No.	Title	Due Date	Status	Details on Status (in case of delays or issues)
M03.01	1.5 MW gyrotron infrastructure Completed	31/12/2021	Completed	

3 – Risk & Mitigation Register: Current Status – page 1

Description of Risk	**Severity**	**Likely hood**	**Proposed Mitigation Action**	**Risk materialized ?**	**Mitigating Measures applied?**	**Comments**
Assembly of actively cooled in-vessel components (WCIVC) is late or W7-X is unavailable	H	M	Shift of machine time, bring forward preparatory actions, enforce international cooperation, reorganize campaign schedule	y	y	delay of ~ 6 weeks adaption of planning risk analysis w.r.t. AWP after CfP
Delays in the commissioning of WCIVC	M	L	Shift of machine time, bring forward preparatory actions	see above	see above	
Delays in the commissioning of heating systems of W7-X	M	M	Reorganisation of the building blocks of the scientific program, shift of machine time	n		
Preparatory action (any for W-7X) not conducted in time	M	M	Parallelization, reorganisation of work with shift of resources, close monitoring	y	y	Work shifted
W7-X machine status along milestone not achieved	H	M	Develop alternative scientific program, bring forward programmatic elements meeting with the achieved machine status, conduct experiments within international collaborations where viable and fundable	n		To be assessed during/after OP2.1
Missing expertise in 3D modelling and stellarator specific theory	M	M	Initiate build-up of expertise and close monitoring of human resource development (within required lead-times), attract interest within EDU instruments (grants), monitoring/change of scope in related TSVV and ER	n	y	EMC3-EIRENE group expert groups of edge modellers and reiteration of their sci. strategy

3 – Risk & Mitigation Register: Current Status – page 2

Description of Risk	Severity	Likely hood	Proposed Mitigation Action	Risk materialized ?	Mitigating Measures applied?	Comments
Delay in the preparation of metallic wall operation for W-7X	M	H	Close monitoring of strategic planning (with large lead times), revision of resource allocation, cooperation with WPs in FSD and FTD	y	n	**Lack of resources, long-term impact, reiteration of resource loaded WBS initiated**
Delay in the provision of the HELIAS physics basis	H	L	Close monitoring with FTD, support of database activities, enforcement of international collaborations	n		
Lack of resources for Mission 8 activities	H	H	Risk assessments and revision of resources, changes in the scope	y	n	Risk analysis **being** conducted **(cf. Annex)**, **planning budget is smaller than assumed for CWP**, planning is pursued with conservative assumptions
Lack of management resources	**H**	**H**	**Rebalancing responsibilities, e.g. travel budget accounting, revision of ToRs with load balancing**	**y**	**n**	**See management report WPW7X**

4 – Project Change Requests & Other Items for Decision/Approval by PB

Decisions on PCRs

PCR Number	PCR Title	PCR Status	Comments
1	Budget change/specification AWP2022	new	• Task planning and resource allocation as to meet with the task specifications
2	Budget change request: balancing indicative resources 2023-25	announced	• Updated indicative resources being worked out

5 – AOB (including lessons learnt)

Management report: https://idm.euro-fusion.org/?uid=2PGGG7

Some lessons learned are:

- *Management:* Unexpected long-lead times led to uncertainties → Working efficiency affected, (exponentially) increasing management effort, overload on working level → First priority of any timeline should be to make BENs able to conduct tasks from Jan. 1st (which is expected to be not met at the time this report is created).

- *Budget:* BENs need to allocate their resources/know about expectable resources → Clear commitments/communication on working level required (level-3 tasks and their specifications, campaign allocations, special cases) by Jan. 1st (already impossible for 2022).

It is noted that the present reimbursement scheme for missions (per actual costs, not per unit costs) does not allow for a precise mission planning (since the costs for individual missions fluctuate even within one BEN) and results in large but ineffective workload for the mission monitoring both for the TFL and the PSO. *In consequence, planning risks emerge* for the 2022 (campaign) as well as time risks due to the absorption of resources needed otherwise. The present overall management workload is too high. The science-oriented conduct of management could not be continued as in FP8. An analysis of resulting risks is planned for 2022.

2021 was an exceptional year

- Mission management -> micromanagement
- Resource loaded planning affected by unknowns/uncertainties
- Information flow to BENs requires improvements (WPW7X Stakeholder Meeting)
- Depreciation actions require more administrative support
- More details in bi-weekly WPW7X reports in GENERAL Meetings · Indico (euro-fusion.org)

End of PB-Presentation slides

Feed-back from the stakeholder meeting and Conclusion

- Do we want to have a Stakeholder Meeting in advance to each WPW7X Board Meeting to enhance the information flow? – Yes, the information is highly relevant and necessary for the conduction of the work and to get an overview and possible interfaces with other tasks.

- Which information is requested in addition to this meeting? – The information content is at the right level.

- Feed-back for the WPW7X Board Meeting: - The attendees agree with the task specification and the plan forward for 2022. Minutes of the Stakeholder Meeting are found in IDM.

Status W7-X https://w7x-info.ipp-hgw.mpg.de/

- **Commissioning: progress as planned**
  - *24.01.22 W7-X completion phase 2 has been finished and device pump down has started*
  - *07.03.22 plasma vessel vacuum 2.2e-07 mbar reached; water filling of cooling circuits has started*
- Key dates

Phase/milestone	date	remark
device pump down start	24.01.22	as of 24.01.22
baking	15.08.22 – 26.08.22	
Plasma commissioning OP2.1.1	27.09.22 – 26.10.22	
Contingency	27.10.22 – 21.11.22	
Scientific Operation OP2.1.2	22.11.22 – 15.12.22	Covered by 2022 budget
Scientific Operation OP2.1.3	15.01.23 – 27.03.23	Covered yb 2023 budget
Milestone/phase		
Call for proposals	07.02.22	
Proposal submission	04.04.22 – 30.04.22	Endorsed by Int. Prog. Comm.
Prioritization	03.06.22	
EUROfusion call for particpation	15.06.22	
W7-X Program Workshop	05-06.09.22	
EUROfusion selection	15.09.22	
Program OP2.1.2 and 3, initial session planning	15.10.22	

Budgetary situation WPW7X - overview

- The total FP9 budget consists of *HR preparation and exploitation*, *Operation costs W7-X (incl. HR for operation) and hardware depreciation*
- In Spring 21 the GA decided to add budget to WPW7X for *human resources for preparation and exploitation* conditional on funding contributions from the UK and Switzerland
- As for now, UK has not been associated and unallocated budget (provisionllay added to the WPW7X Human Resources) was removed from WPW7X

- Status: for *HR preparation and exploitation*, the total budget 2022-25 is 5.237 M€-CC. A flat spending profile results in 1.3M€-CC per year. If UK entered EURATOM and the fusion program received the additional funds as expected in Spring 2021, additional funds of ~0.4M€ per year for *HR preparation and exploitation* was the impact.

- For 2022, 1.484M€-CC are foreseen for HR preparation and exploitation (using unused travel budget ~ 0.18M€-CC) thus keeping a conservative planning with a flat spending profile

- Mission costs: weeks*(6days/week*Average Mission Costs PMU/day*0.7 +5days/week*Salary rate*0.5)*1.25 vs PM calculation makes 100k€ difference
- Still large difference between average mission costs as from PMU and findings from WPW7X in 2021 (EK-CER: 210 vs. 140 €/day, FZJ: 120 vs. 144€/day, IPPLM: 81 vs 169 €/day ERM: 171 vs 153 €/day)

Budgetary situation WPW7X - summary

- Complicated situation resulting from budgetary constraints requires balancing:
  - coverage of urgently needed resources/work before OP2.1
  - need to distribute the available budget up to the end of FP9 with a good particpiation in the campaigns and their scientific exploitation, keep long-term developments
  - Need to integrate preparation and conduction of campaign
- Planning uncertainties:
  - *Budget scenario (BREXIT) -> HR preparation and exploitation ~ 30% -> prioritization*
  - Uncertainties of travel estimates ~8% + largely unknown actual costs per BEN -> monitoring
- Strategy:
  - keep uncertainties under control and react in due course
  - important work to be reinitiated/speed-ups reducing risks is identified)

  - Allocate now resources preparation actions (incl. Commissioning/OP2.1.1)
  - Incorporate the planning of the proposal driven parts of operation (OP2.1.2 and OP2.1.3)

Planning methodology and derived strategy

Deliverables table		Year	Type	Dissemination Level
W7X.D.01	Report on conducted scenario & campaign preparation (focus: optimization studies, wall conditioning procedures)	Dec. 2021	R	PU
W7X.D.02	Non-linear stellarator gyrokinetic code(s) treating at least entire flux surfaces (not limited to single flux tubes)	Dec. 2022	OTHER	SEN
W7X.D.03	Report on conducted scenario & campaign preparation OP 2.1 (focus: wall conditioning, divertor exhaust and core heating/fast-ion confinement, preparation of steady-state scenarios, preparation of plasma exhaust scenarios with divertor heat load control)	Dec. 2022	R	PU
W7X.D.04	Stellarator optimization code including algorithms with reduced sensitivity to local minima in parameter space	Dec. 2022	OTHER	SEN
W7X.D.05	Assessment report on fast-ion generation and divertor exhaust (energy limit 1 GJ)	Dec. 2023	R	SEN
W7X.D.06	Report on conducted scenario & campaign preparation OP 2.2 (focus: preparation of steady-state scenarios turbulent and core neoclassical transport)	Dec. 2023	R	PU

Milestones Table		Year	Type	Dissemination Level
W7X.M.01	1.5 MW gyrotron infrastructure completed	Dec. 2021	DEM	PU
W7X.M.02	**Commissioning of W7-X enhancements incl. commissioning with plasma OP2.1. First operation without use of water-cooled PFCs (although these are installed)**	**Dec. 2022**	DATA	SEN
W7X.M.03	Operation OP 2.1 with water-cooled PFCs completed	Dec. 2023	DATA	SEN
W7X.M.04	Operation OP 2.3 completed and 1 GJ energy turn-around achieved.	Dec. 2024	DATA	SEN
W7X.M.05	High-beta HELIAS operation at low collisionalities	Dec. 2025	DATA	SEN
W7X.M.06	Operation OP 2.4 with High-power and long-pulse completed and 6 GJ energy turn-around achieved (pulse lengths up to 600 s, long-pulse detachment).	Dec. 2025	DATA	SEN

- Workplan priorities as outlined in the CWP

- **Prioritization decision:**
  1) Scientific commissioning of components and upgrades
  2) Campaign (roughly 50/50 in 2022 and 23) as outlined
  3) Other preparatory actions (preparation of proposals, diagnostics, metallic-wall etc.)
  4) ITER, PRD, ITPA, InCo, etc.

- Impact of budget reduction (w.r.t. Spring 21)
  - Reduced scope for divertor scenarios
  - Reduced preparation of ICRH/FI program
  - Reduced scope for high-beta program
  - Reduced scope for long-pulse investigations
  - Reduced exploitation of long-term EU investments
  - Reduced scope of advanced heat-load control
  - Delayed availability of high power gyrotrons
  - Delays in the design of metallic divertor

- All-in-all: delays, increasing risks for not attaining the required physics basis for bringing the stellarator line to maturity

Budget overview: plan for 2022 and OP2.1: 6.219M€-CC, HR E&P 1.484 M€-CC

BEN	Total CC	Travel CC	HR CC	IMS 15.03	Travel 15.03.	HR 15.03	IMS 15.09 (indicativ)
CEA	32,0381282	2,583	29,45512821	25,89785897		25,03687	6,1402
CIEMAT	254,075262	55,7865	198,288762	142,5941659		128,0411	111,4812
CIEMAT@70 %	62,265	12,1275	50,1375	62,265		50,1375	0
CIEMAT U Seville	17,90625	0	17,90625	17,90625		17,9062	0
CIEMAT UPC	11,9375	0	11,9375	11,9375		11,9375	0
CIEMAT BSC	5,96875	0	5,96875	5,96875		5,9687	0
DTU	27,3716827	4,22625	23,14543269	18,22295192		16,5324	9,1487
DTU SDU	9,55208333	0	9,552083333	9,552083333		9,5520	0
EK-CER	132,526298	78,2775	54,24879808	31,07475962		14,5372	101,4515
ENEA	25,2807885	4,788	20,49278846	10,65625		10,6562	14,6245
ENEA RFX	5,16979487	0,798	4,371794872	5,169794872		4,3717	0
ENEA UC	10,65625	0	10,65625	10,65625		10,6562	0
EPFL	22,2933333	0	22,29333333	22,29333333		22,2933	0
FZJ	429,125337	68,04	361,0853365	278,4976442		250,7776	150,6276
IPPLM	137,582974	47,9115	89,67147436	67,3814359		54,9599	70,2015
IST	13,5919872	4,725	8,866987179	13,59198718		8,8669	0
KIPT	69,7757051	31,2725	38,50320513	60,0999359		36,3349	9,6757
KIPT KINR	3,41666667	0	3,416666667	3,416666667		3,4166	0
KIT	160,723083	21,546	139,1770833	160,7230833		139,1770	0
LPP-ERM	268,101923	116,9	151,2019231	155,7348462		71,1538	112,36707
MPG	0	0	0	0		0	0
MPG 70%	105,9625	0	105,9625	105,9625		105,9625	0
NCSRD	14,34375	0	14,34375	14,34375		14,3437	0
OEAW	11,984375	0	11,984375	11,984375		11,98437	0
VTT	25,1557115	1,6485	23,50721154	19,84375		19,8437	5,3119
				1265,774922	221,326	1044,4489	591,0302
							217,7479
				1483,522895			373,2822

Preparation Comm. OP2.1.1 (w/ indicative travel CC)

1day on-site + travel

OP2.1

OP2.1.2

OP2.1.2

1day on-site, 1day off-site + travel

	Status in IMS	Planning	
Allocated HR:	1044,428	see WBS:	1044,449
Unallocated OP2:	425,000	see WBS:	217,748
Secondment:	46,085	see WBS:	12,128
Mission Budget w/o INCO:	131,523	see WBS:	209,199
Total:	1647,036		1483,523
ENH:	180,000	see IR Grid:	180,000
OP&Maint:	4346,788334	see IR Grid:	4346,788
Total Annual Budget in IMS:	6219,825		