WEST in FP9

On behalf of WPs PWIE, PrIO, TE
Volker Naulin

WEST GB 07-05-2021

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Horison Europe: Fusion Science

A targeted, integrated and prioritised physics programme

- **Preparation of ITER operation and exploitation**
  - (ITER Research Plan & ITPA CC)
- **Target and solve DEMO physics issues**
- **Understand, explore physics, blue sky research**

EUROfusion connects input from the users to a coherent programme towards fusion energy by 2050!

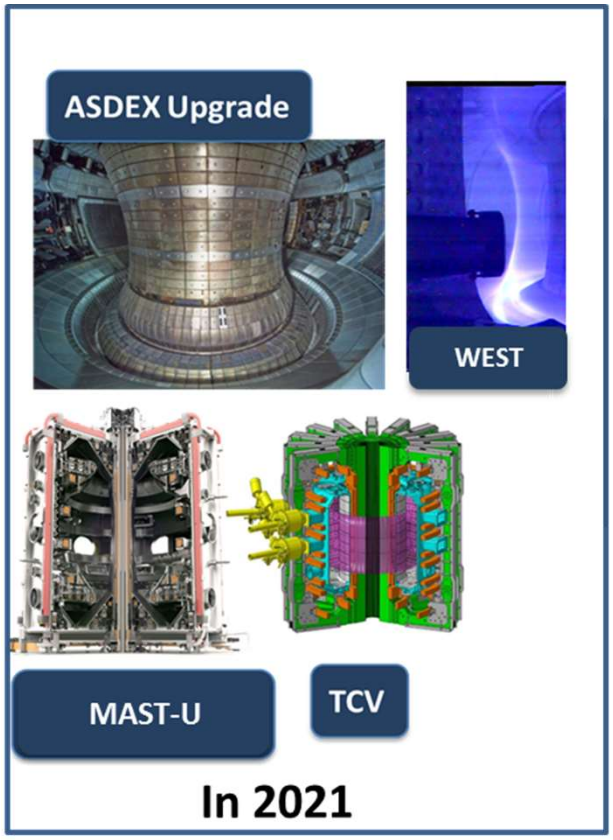
Overarching priorities for WP TE in FP9

- Prepare **ITER exploitation**
- Provide *Physics Basis* for guiding **DEMO design**
- Exploit recent **machine enhancements**, i.e. related to **PEX** (Plasma EXhaust)

Follow the Roadmap and address objectives of:

- Mission 1: Plasma Regimes of Operation
- Mission 2: Heat exhaust System

Participation of 4 devices in 2021:
ASDEX Upgrade, TCV, MAST-U, and **WEST**



Tokamaks available in TE

- **AUG**
  - SPI potentially available second half of 2021
  - Preparation for upper divertor, PEX
- **TCV**
  - Divertor upgrades
- **WEST**
  - First time available for TE
  - Exploitation of actively cooled divertor
  - Many elements in 2021 and 2022 prioritized for Mission 2: strong integration with PWIE
- **MAST U**
  - First time available, operation starting
  - Super X divertor

Overview of the received TE proposals and allocated pulses for WPTE

Request for pulses is **largely oversubscribed**

	AUG	TCV	MAST	WEST
Total	1223	1741	978	1305
Budget	380	806	360	270

	AUG	AUG	AUG	TCV	TCV	TCV	MAST	MAST	MAST	WEST	WEST	WEST
TOTAL for M1	979	45,7%	207	1163	34,0%	339	624	34,4%	165	663	17,4%	50
TOTAL for M2	244	22,0%	97	603	30,7%	306	354	27,9%	134	707	62,5%	180
TOTAL			304			645			299			230
Budget			380			806			360			270
Contingency pulses left			76			161			61			40
Contingency left in %			20			20			17			15

WP TE exploitation of WEST in 2021

2021	Title	ITER	DEMO	Total	AUG	AUG	AUG	TCV	TCV	TCV	MAST	MAST	MAST	WEST	WEST	WEST
RT1	IBL scenario towards detachment and low collisionality							39	5,0%	40	104	5,6%	20	209	5,6%	15
RT2	H-mode entry and pedestal dependence with impurities and isotopes	2	1	283	76	7,4%	28	116	6,7%	54	70	6,9%	25	21	0,0%	0
RT3	RF-assisted breakdown and current ramp-up optimization									0	5	0,0%	0	51	3,7%	10
RT4	Disruption avoidance development for ITER and DEMO	2	2	239	74	3,9%	15	140	3,7%	30	5	0,0%	0	20	0,0%	0
RT5	Run-way generation and mitigation	1							4,3%	35	10	0,0%	0	91	3,7%	10
RT6	ELM mitigation and suppression in ITER/DEMO relevant condition	2	1	180	78	5,8%	22	32	3,2%	26	70	6,9%	25	0	0,0%	0
RT7	Negative triangularity	NaN	1	166	31	0,0%	0	135	0,0%	0	0	0,0%	0	0	0,0%	0
RT8	I-Mode and QH-mode studies					3%	20	140	5,0%	40	10	4,2%	15	41	5,6%	15
RT9	Extension of EDA and QCE performance towards DEMO	2	1	335	113	9,2%	35	102	6,7%	54	80	5,6%	20	40	0,0%	0
RT10	Fast-ion losses with dominant IRCH	2	3	86	56	2,9%	11	0	0,0%	0	10	0,0%	0	20	0,0%	0
RT11	Impact of MHD pertubations on fast ion losses	3	3	330	118	2,9%	11	92	3,7%	30	120	9,7%	35	0	0,0%	0
RT12	Development of the steady state scenario	3	3&1	577	82	0,0%	0	185	3,7%	30	140	6,9%	25	170	0,0%	0
	TOTAL for M1							1163	42,1%	339	624	45,8%	165	663	18,5%	50
RT13	X-point radiation and control							48	6,2%	50	45	4,2%	15	30	5,6%	15
RT14	Physics of plasma detachment / impurity mix/ heat load patterns	2	1	395	89	9,2%	35	86	9,9%	80	157	9,7%	35	63	0,0%	0
RT15	SOL transport	2	1	299	81	5,3%	20	119	6,2%	50	65	5,6%	20	34	0,0%	0
RT16	PFC ageing under tokamak conditions														33,3%	90
RT17	Material migration, fuel retention, dust formation and conditioning				33	2,6%	10	30	3,2%	26	0	0,0%	0	370	27,8%	75
RT18	Alternative divertor configuration	NaN	DTT	307	0	0,0%	0	220	12,4%	100	87	17,8%	64	0	0,0%	0
	TOTAL for M2			1908	244	25,5%	97	603	38,0%	306	354	37,2%	134	1370	66,7%	180

~1 session, L-H transition (Er)

~1 session, ICRH assisted breakdown

~1 session, run away generation

~1 session, I mode

~1 session, X point radiation

~5 sessions, W migration, ammonia formation, H/D changeover

~4 sessions

WP TE proposed programme for M1 until 2025 (I)

Programme aspects in Mission 1 & Mission 2	2021	2022	2023	2024	2025
Development of the H-mode regime with ITER constraints (electron heating, low torque, L-H/H-L phases, impact of impurities, fuelling, exit and entry in H-mode, operation near LH threshold, etc. …)	AUG, TCV, MAST-U,	AUG, TCV, MAST-U,	TCV, MAST-U, WEST	AUG, TCV, MAST-U, WEST, JT-60SA	AUG, TCV, MAST-U, WEST, JT-60SA
Identify isotope impact on plasma scenario (L-H, detachment, transport, including low level of He, mixed plasmas)	AUG, TCV, MAST-U	AUG, TCV, MAST-U	AUG, TCV, MAST-U WEST	AUG, TCV, MAST-U, WEST, JT-60SA	AUG, TCV, MAST-U WEST
Disruption and RE mitigation (with a focus on D2 injection) and prepare physics based generic disruption avoidance system	AUG, TCV, WEST	AUG, TCV, WEST	AUG, TCV, WEST	AUG, TCV, WEST, JT-60SA COMPASS-U	AUG, TCV, WEST JT-60SA COMPASS-U
Develop scenarios with mitigated ELMs or ELM-free	AUG, MAST-U, WEST, TCV	AUG, MAST-U, WEST, TCV	AUG, MAST-U, WEST, TCV	AUG, MAST-U, WEST, TCV JT-60SA COMPASS-U	AUG, MAST-U, WEST, TCV, JT-60SA COMPASS-U
Understand the impact of fast ions on plasma transport and stability	AUG, TCV MAST-U	AUG, TCV MAST-U	AUG, TCV MAST-U	AUG, TCV MAST-U JT-60SA	AUG, TCV MAST-U JT-60SA
Develop the physics and operational basis for steady state scenario (high beta, metallic wall, control, non-inductive current optimisation and stability)	MAST-U, TCV	MAST-U, TCV	AUG, MAST-U, WEST, TCV	MAST-U, WEST, TCV	MAST-U, WEST, TCV JT-60SA

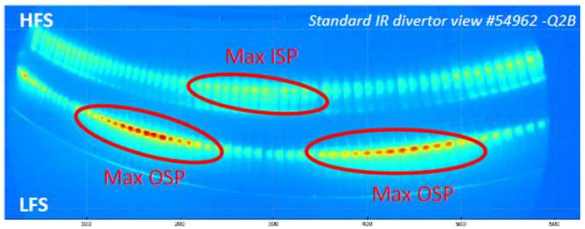
WP TE proposed programme for M2 until 2025 (II)

Objectives	2021	2022	2023	2024	2025
Test **detachment control schemes** and their robustness with respect to transients and radiation stability	**AUG, WEST, TCV**	**AUG, MAST-U, WEST, TCV**	**AUG, MAST-U, WEST, TCV**	**AUG, MAST-U, WEST, TCV JT-60SA**	**AUG, MAST-U, WEST, TCV JT-60SA**
Develop the physics basis for integrated particle and heat exhaust control for ITER and DEMO (Impurity mixes, re-attachment, ELMs impact, isotope impact, non-stationary phases)	**AUG, MAST-U, WEST, TCV**	**AUG, MAST-U, WEST, TCV**	**AUG, MAST-U, WEST, TCV**	**AUG, MAST-U, WEST, TCV COMPASS-U JT-60SA**	**AUG, MAST-U, WEST, TCV COMPASS-U JT-60SA**
Test plasma facing materials/components for ITER and DEMO in a tokamak environment (long pulse / high fluence conditions for D and He, potential PFC failure modes, impact of PFC ageing on plasma performance, develop first wall protection schemes)	**AUG, WEST**	**AUG, WEST**	**AUG, WEST**	**AUG, WEST**	**AUG, WEST**
Migration and erosion of material of PFCs (including transients such as ELMs and with different divertor configurations)	**AUG, WEST**	**AUG, WEST**	**AUG, WEST**	**AUG, WEST**	**AUG, WEST**
Investigate fuel retention in metallic machines and develop fuel recovery and conditioning schemes relevant for next step fusion devices	**AUG, WEST**	**AUG, WEST**	**AUG, WEST**	**AUG, WEST**	**AUG, WEST COMPASS-U**
Qualify alternative advanced divertor configuration (core confinement, transients, detachment, stability, scenarios, etc.) in view of DTT and DEMO *	**TCV, MAST-U**	**TCV, MAST-U**	**TCV, MAST-U**	**AUG COMPASS-U**	**AUG COMPASS-U**

WEST addressed key areas of PSI with EUROfusion support in FP8

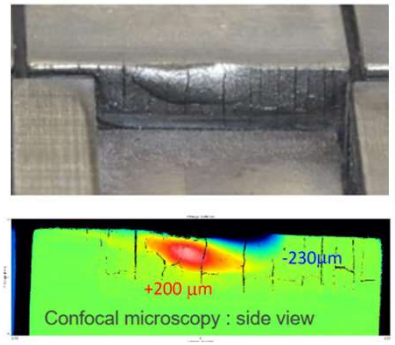
- ITER-like W divertor qualification and exploration under plasma particle and heat load
  - Pre- and post-mortem assessment of W monoblocks
  - Power-decay length determination | heat load variations due to ripple | role of W emissivity
  - W PFU damage evolution with plasma fluence: “natural” damage and pre-damaged PFUs
- Dedicated steady-state W melting experiment on modified W-coated PFUs
- W divertor and main chamber source quantification and the role of plasma impurities (O,C)
- Interpretive plasma boundary (SOLEdge2D-EIRENE), PSI (ERO), and transient modelling (MEMOS-U)

IR thermography: ripple effect



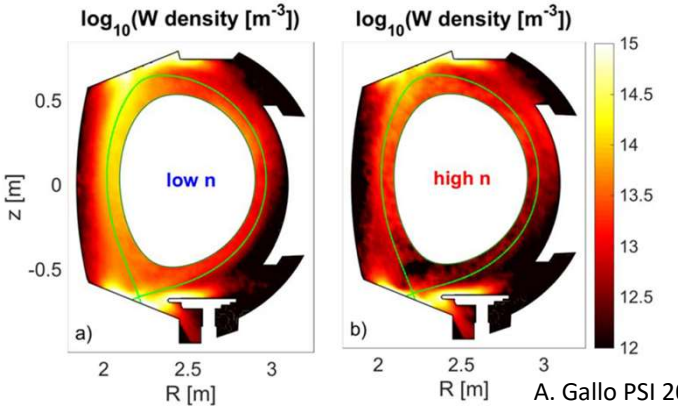
E. Tsitrone PFMC 2021

Dedicated W melting



Y. Corre PFMC 2021

ERO2.0 modelling of W



A. Gallo PSI 2021

Courtesy: S. Brezinsek | PFC/PWIE

- **ITER like PFCs**
- **High heat flux**
- **High fluence/long pulse capability**

FP9 WEST contributions to PSI studies

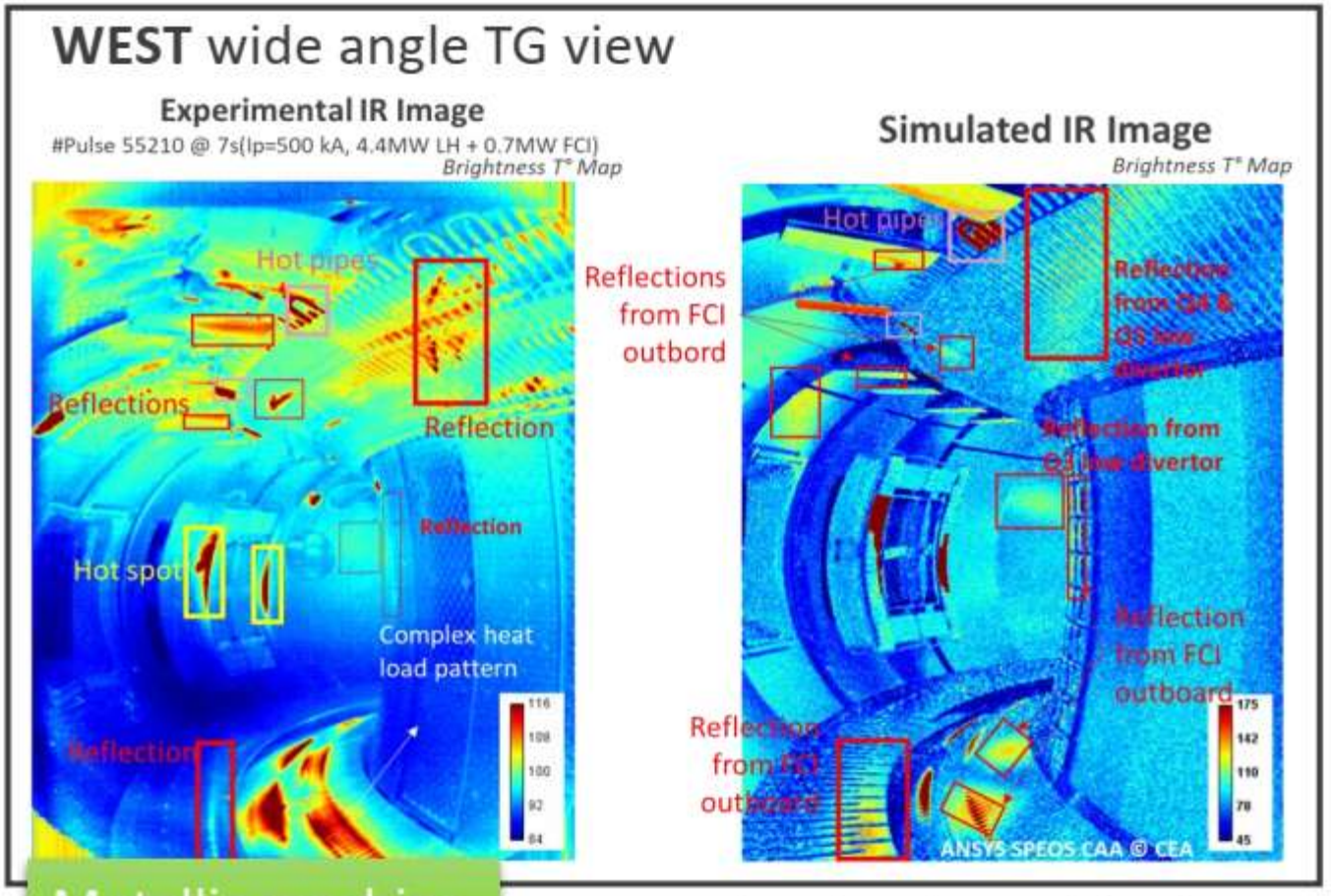
- Continue and complete post-mortem analysis and its complex interpretation
  - PFU damage evolution (e.g. cracks/arcs) and melting at (misaligned) edges
  - Erosion and deposition pattern studies (e.g. with marker layers) / role of impurities / W migration
  - W morphology changes due to He operation (nanobubbles in W)

- New dedicated PSI studies with pre-/inter-/post-characterization of PFC and its interpretation:
  - Qualification of ITER-like PFUs at high fluence (Phase II) and comparison with high fluence exposures in MAGNUM
  - Impact of recrystallization on the power handling of PFUs / comparison with laboratory studies
  - Steady-state fuel retention and fuel removal studies in full-W toroidal devices / role of impurities
  - Global W balance in steady-state conditions / role of W prompt re-deposition in WEST high field operation

- Continue plasma-edge and PWI modelling of dedicated PSI experiments
  - Benchmark experiment for PWIE codes related to global migration, melting, and fuel retention in view of DEMO
  - Benchmark experiment for plasma boundary codes related to W transport and divertor operation

Courtesy: S. Brezinsek | PFC/PWIE

WEST in PrIO



MH. Aumeunier et al., Nuclear Materials and Energy 26 (2021) 100879

WEST in FP9

- **Continued results for WP PWIE**
  - ITER like actively cooled divertor
  - Layer formation
  - Long term high fluence

- **A new machine welcomed into the portfolio of tokamaks in TE**
  - Already fully involved in the TE programme
  - Wide user interest
  - Contributing to TE research topics
  - Will be joint in 2022 by JET and Compass Upgrade
  - In good shape for facilities review

- **Relevant expertise developed for WP PrIO**
  - IR measurements, Wall monitoring system, machine protection

Fusion Science

A targeted, integrated and prioritised programme

We will not be able to

do all we want,

all we think we need,

all that is exciting.

We might be able to do a number of things that we NEED

WEST in WP PWIE

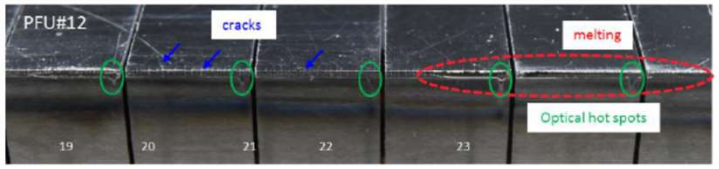
- Behaviour of PFC components
- High heat flux
- High fluence/long pulse capability

On the plasma side :

- Steady progress in divertor heat flux (5 MW/m^2)
- Net erosion @ OSP/ISP (≥ 0.1 nm/s), sharp transition erosion / redeposited layers on HFS
- First He campaign and W melting experiment performed ➔ post mortem analysis / modelling underway

On the component side :

- No failure but first damages observed on ITER divertor prototypes
- Optical hot spots : predicted to happen in ITER, evidenced in WEST
- Current understanding : brittle cracking of cold W surfaces due to transient heat loads
- Same phenomenon to be expected with the ITER divertor



ITER like divertor sector for WEST phase 2

Question : does it matter ? ➔ Phase 2 of WEST

- Set of ITER like divertor prototypes ➔ full ITER like divertor with toroidally bevelled PFU (456 ITER like PFU, 1000's of optical hot spots)
- Phase 2 operation to start in summer 2021
- Enabling full long pulse / high fluence capability of WEST (target 10 MW/1000s)

Talk by Tsitrone
PFCM-18

M. Richou, PFMC 2021