5th Physics Project Board

2025 AWP WP*PWIE*: *P*lasma-*W*all *I*nteractions and *E*xhaust

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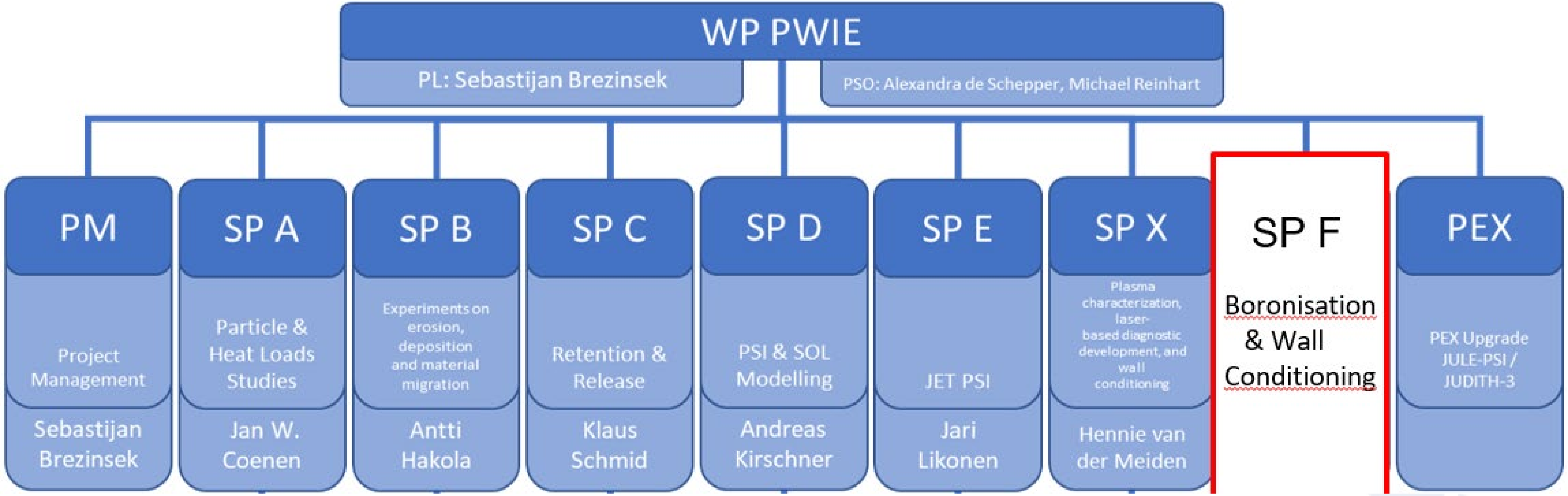
This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

JÜLICH Forschungszentrum

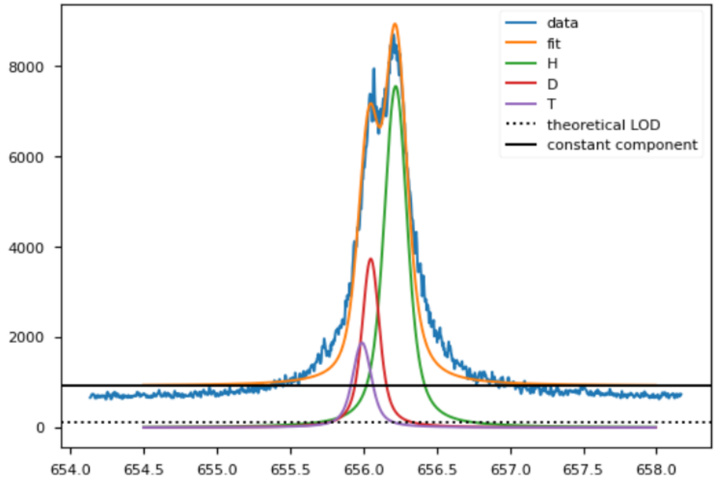
AWP 2025 – Revision of the original program / WBS WPPWIE

- Main structure and activities for reactor remain as in initial 2021 plan with some adaptions
- In view of the ITER re-baselining changes to indicative plan
  - General activities related to Be (LIBS, fuel recovery assessment, ITER simulations etc.) were closed in 2023
  - Remaining activity is the JET-DT tile analysis (LIBS and ex-situ) with Be and W tiles to assess retention, migration, dust formation. Data feeds into benchmark of PWIE codes to validate physics models (low Z can be exchanged)
  - Number of new activities to high priority ITER items related to clean W first wall operation and usage of Boron added
- PCR in July 2024 provided initial support for new critical activities for DEMO, ITER and COMPASS-U

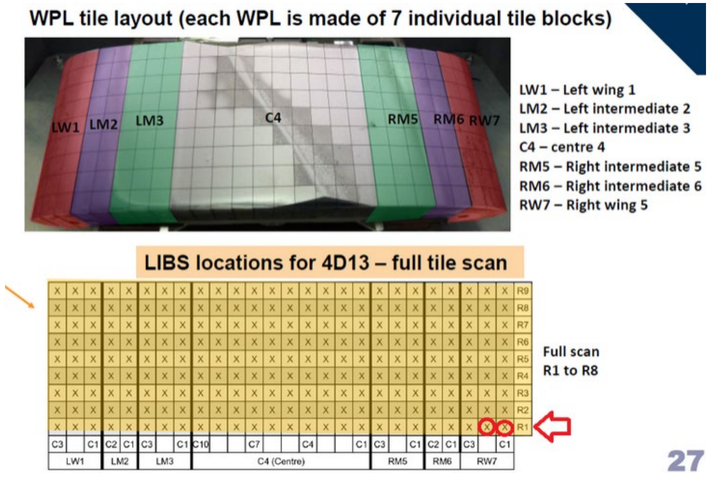


JET-LIBS data on RH (October 2024!)

little D and T – no W at this place



Bulk-Be part with Be deposit



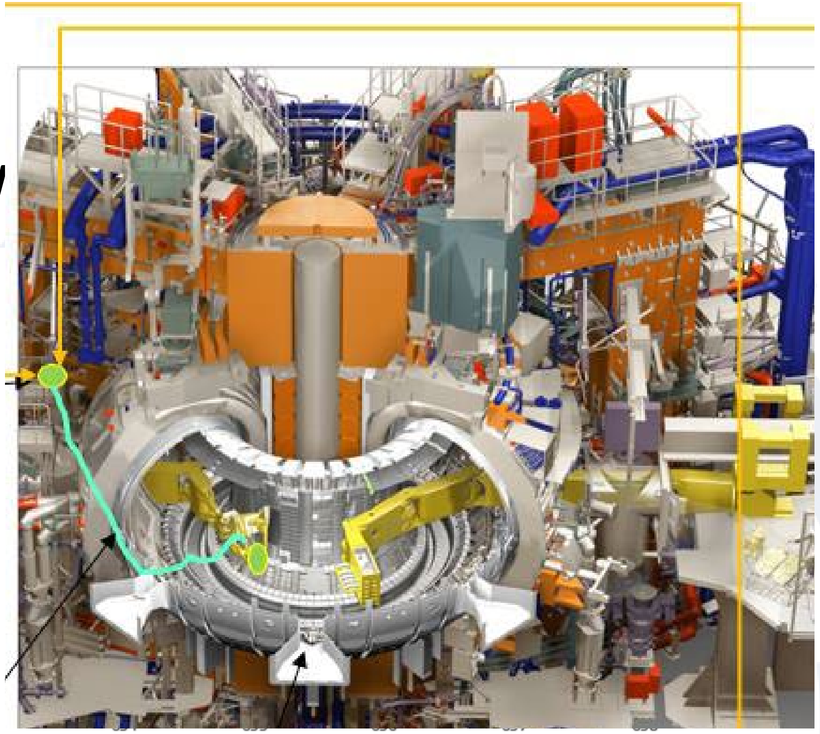
Technical demonstration of LIBS on RH arm in a nuclear activated device
SUCCESSFULLY PERFORMED!!
Grant Deliverable fulfilled!

Opens new area of in-situ material composition and fuel content analysis!

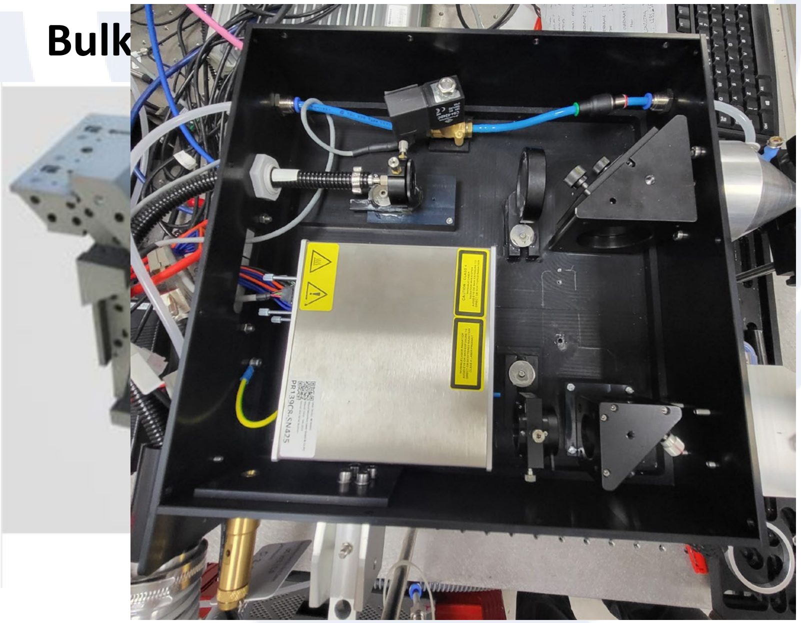
Thanks to Jari Likonen and SPE team… as well as the JET RH-team and UKAEA!

Several 10 000 of spectra to be analysed using also AI
⇒ 2025 analysis campaign
⇒ Input to PWIE modelling

W



Bulk



AWP 2025 – Main objectives I

- Material qualification for DEMO and other facilities with plasma and combined load, damage evolution, limits
- Support of WEST and ASDEX Upgrade experiments, analysis, and interpretative modelling (PWIE aspects only e.g. migration, 3D aspects, layer formation, stability) => TSVV-6, PWIE-AI-SOL
- Address T-retention by trapping/diffusion/permeation in damaged tungsten/EUROFER PFCs
- Prompt re-deposition physics of W and properties of re-deposited W (experiments and modelling) => TSVV-7
- Analysis of JET-LIBS data and prepare/start for post-DT tile analysis => PWIE-AI-LIBS
- Support of W7-X PWIE in long-pulse operation, wall conditioning, material migration, dust, transfer to W
- Properties of cold, recombining plasmas in view of molecular assisted processes in H,D => TSVV-5
- Development and application of laser-based technologies for in-situ and in-operando studies (W, steel, B)
- Support of COMPASS-U (and JT60SA regarding transfer to W) by modelling, divertor design, and PFC test

In general very strong links with: WPTE and WPW7X as they offer platform to bridge: laboratory results with tokamak / stellarator via modelling

Links in specific areas with WPAC, WPMAT, WPDIV, WPPRIO, WPSA, WPDC….

AWP 2025 – Main objectives II

- **Supporting ITER re-baselining and addressing critical question in experiments / modelling:**
  - Simulation of first wall W erosion, W deposition, and W screening in limited, start-up and diverted plasmas
  - Boronization and B layers: homogeneity, B layer properties, lifetime, and impact of B on wall conditions
  - T retention (scaling law), T removal techniques (ICWC, ECWC), T quantification (laser-techniques), active removal of B layer by erosion, dust formation, dust properties, and dust removal (=>TOMAS and other facilities)
  - Advanced modelling of B physical and chemical erosion process as input for PWIE models (MD simulations)
  - Qualification of ITER TFW design solutions in HHF devices (inertial and actively cooled) PFCs
  - W PFCs damage predictions under VDE and RE impact in ITER
  - Supporting ITER first mirror performance in the presence of boron (boronization / boronization + plasma)

Linked to ITPA activities and needs of revised ITER research plan

New/updated activities in 2025: Focus on WEST support

- SP B : Understanding the formation of WEST-like deposits with W
  - Final analysis of WEST-like deposits from long-pulse operation: stability and dust conversion factor
  - Mimic WEST-like divertor plasma conditions and pulses in MAGNUM-PSI (and PSI-2)
    - Thermal cycling of actively cooled W PFCs in NAGNUM-PSI and secondary upstream W source
    - Role of surface temperature, thermal stresses, impurities, oxide formation, duty cycle etc. as parameters
    - Pre- and post-characterisation and spectroscopy
  - ERO simulations for linear plasma experiments (same A&M data for WEST)
  - Dust formation and characteristics
- SP D: Simulation of WEST long-pulse plasmas in full 3D geometry (incl. ripple)
  - Plasma boundary simulation with SOLEDGE3X-EIRENE
  - ERO2.0 simulation of WEST long-pulse devices incl. W local redeposition and monoblock shaping
  - Dust simulation
- SP A: HHF exposure of W monoblocks exposed in WEST
  - Damage evolution under e-beam loading
  - Deposit stability assessment

Joint Meeting WPTE/PWI in Aix in September

MAGNUM-PSI: Simulation of WEST high fluence campaign

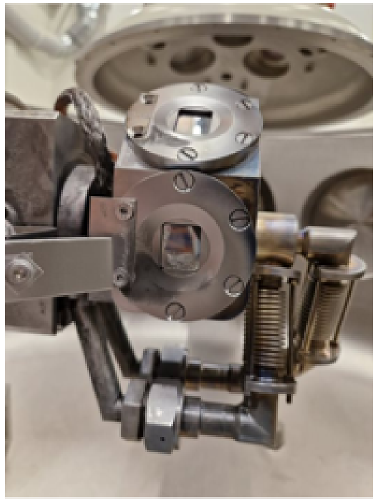
- Mimic high W influx from WEST main chamber into W divertor by artificial impurity source
- Test experiments in Ar plasma to get high W source in plasma
- Final step: try to mimic ITER conditions => Lower W flux from wall into divertor => different balance of W erosion/deposition

Method- initial experimental testing

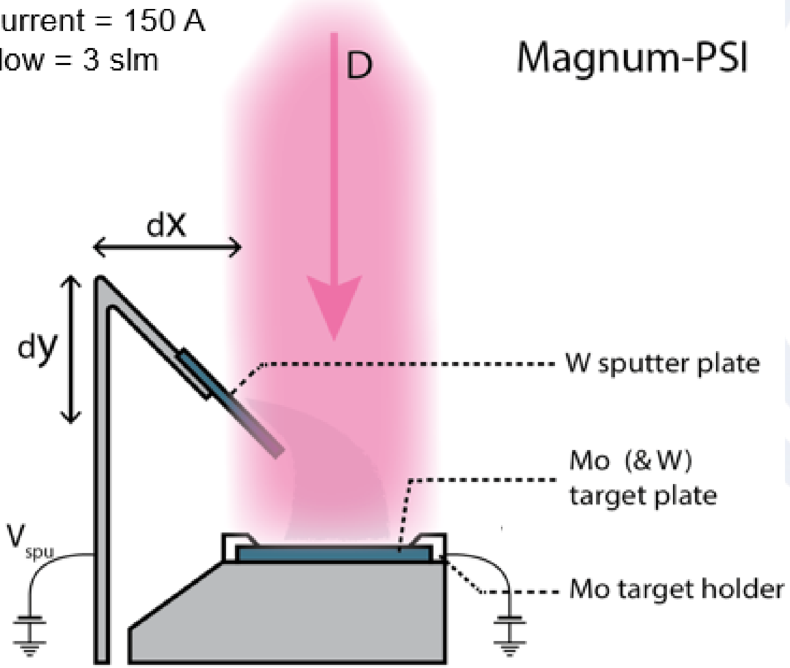
Sputter & redeposition using Ar plasma

Initially use Mo sputtering target (availability)

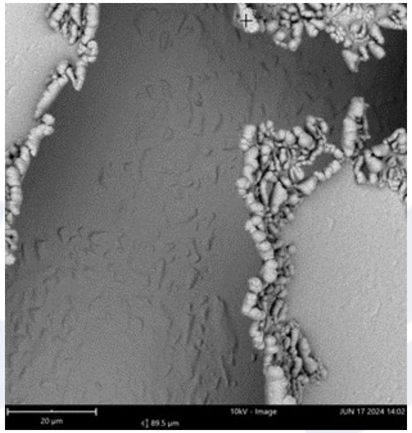
- Biased Mo sputtering target mounted above sample
  - (~15mm wrt center of plasma)
- Sputtered Mo entrained and redeposited on Mo sample and steel witness plate.
- Changing V_{spu} to impact sputter Yield & deposition rate



H plasma
B = 1.2T
Current = 150 A
Flow = 3 slm



Flaking Mo layers observed



New/updated activities in 2025: Focus on first wall W erosion

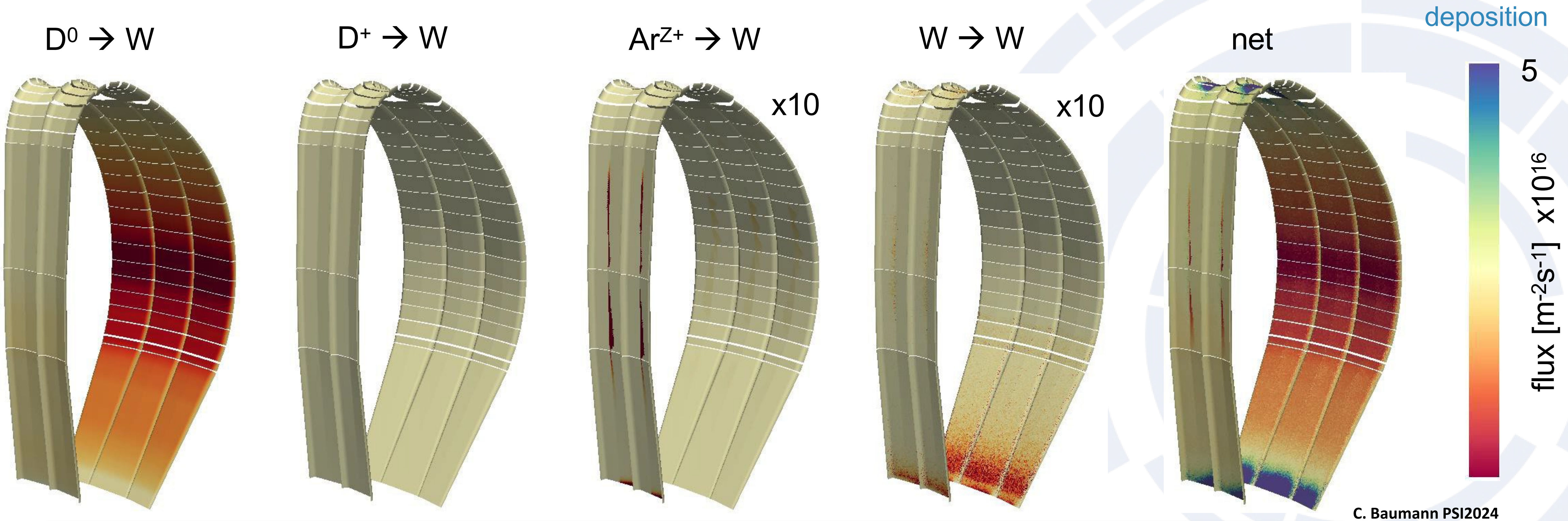
- SP D : Simulation of fluxes to the first wall and W sputtering
  - CXN and ion flux composition in simulations for COMPASS-U, AUG, (JET), ITER and DEMO
    SOLPS-ITER H-mode plasma simulations (ELM-averaged)
  - Poloidal distribution of CXN with energy and angular distribution (universal EIRENE solution)
  - Role of inner and outer wall W source variation with change of CXN, D+, impurity ionisation level
  - ERO2.0 simulations / WallDYN-3D simulations for AUG, JET, ITER
  - Comparison of cases with extended grid to the wall and normal grid to assed far-SOL profiles
- SP B: Gross and net W erosion at the first wall (manipulators) jointly with WPTE
  - Experiments with wall clearance variation and light impurity seeding
  - Pre- and post characterisation of materials with different sputtering threshold and FIB cuts
  - Comparison with PSI-2 plasma experiments

⇒WPTE/PWIE Proposal of dedicated W (and B) migration experiment in AUG at high fluence (1-2 days identical plasmas)

Joint Meeting WPTE/PWI in Aix in September

Example of DEMO first wall erosion simulations with ERO2.0

Assumption: Te=2eV at wall

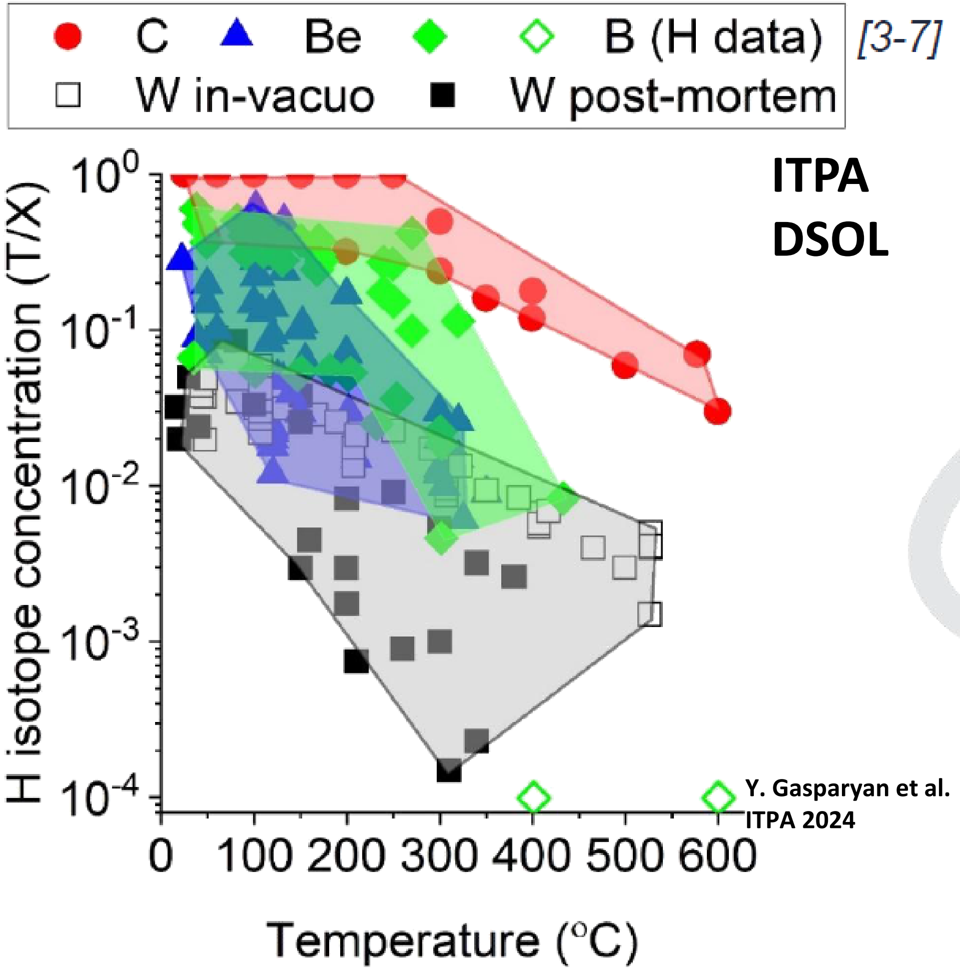


C. Baumann PSI2024

- Main chamber erosion by D-CXN; divertor erosion by seeding impurities and self-sputtering
- Uncertainties about plasma conditions at wall (turbulence, shoulder, energy threshold)
- Strong deposition at remote areas above outer divertor and at top of the machine (upper X-point)
- Impact of main chamber source on core plasma pollution depends on screening efficiency
- Need for a benchmark experiment in full-W device with impurity seeding and semi-detached divertor

New/updated activities in 2025: Focus on boronisation and retention

- SP C+ SP F : B layer database
  - Development artificial B layers for physics studies and comparison with tokamak samples
  - Matrix about fuel content: impact energy, temperature, material mixing, stability, fuel content, release as function of temperature
  - Use of TOMAS (upgrade), new facilities in IAP, and other abs to create variety of B layers with and without D content as reference
  - Magnetron-sputtering or laser-ablation-induced deposition used as replacement for boronization (later not possible in labs)
  - Transfer knowledge from Be to B => need for B database with D content in B layers

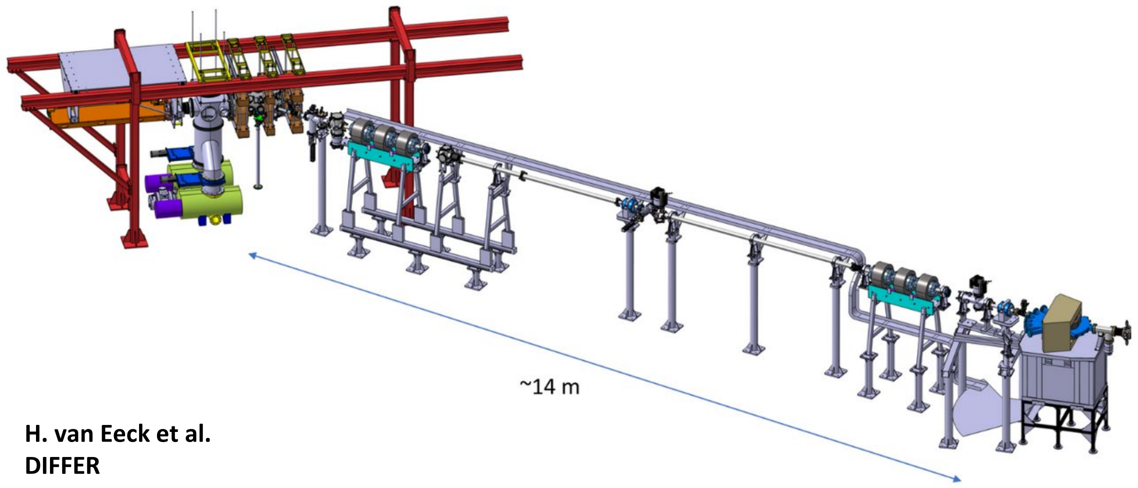


Joint Meeting WPTE/PWI in Aix in September

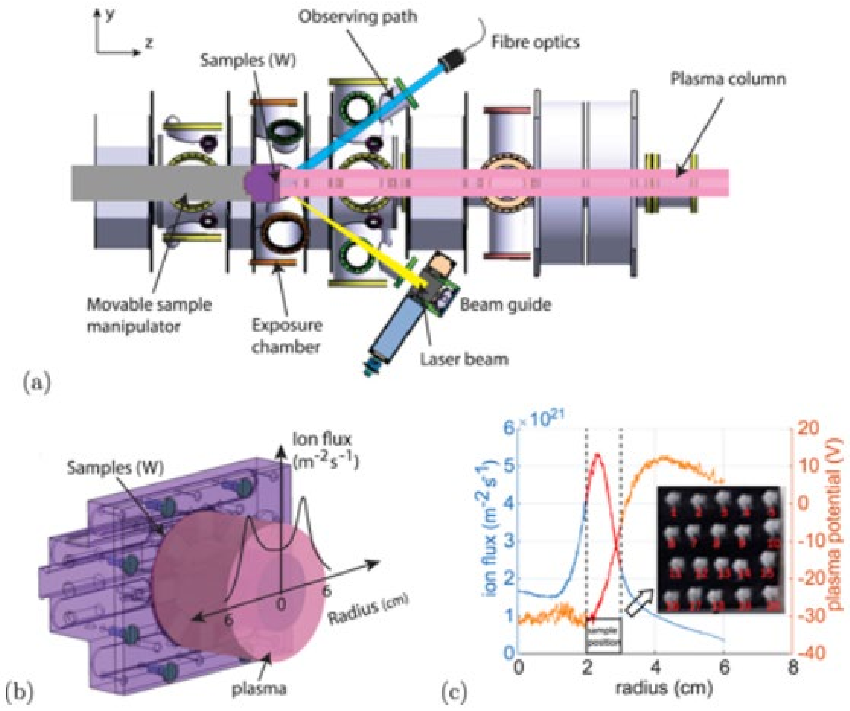
Boron-related in-situ/vacuo fuel retention and recovery studies

SP C + SP F + SP X (in-vacuo)
- Fuel retention and release properties of B layers exposed to fuel species and build with fuel
- Simulation related to fuel trapping and release
- Ion-damage W material studies

SP C + SP F + SP X (in-operando)
- Fuel retention and release properties of B layers exposed to fuel species and build with fuel
- Simulation related to fuel trapping and release
- Recycling-studies on surface



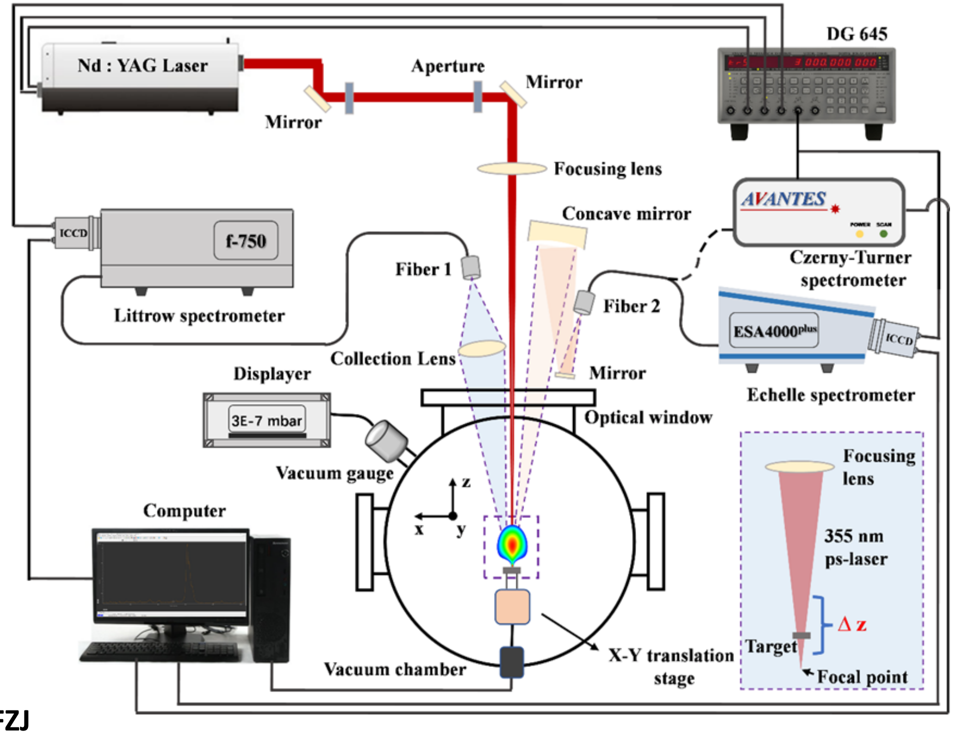
H. van Eeck et al.
DIFFER



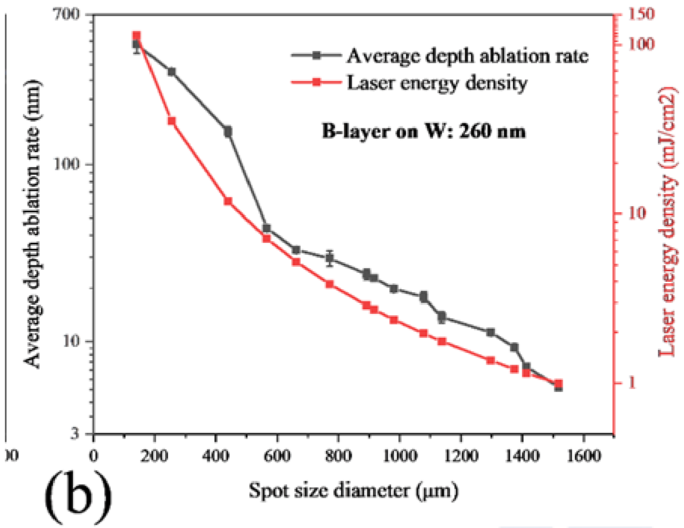
In-situ deuterium content measurement by in-operando LIBS (PSI-2) or in-operando NRA (UPP) in 2025 foreseen without breaking vacuum and controlled B+D interaction

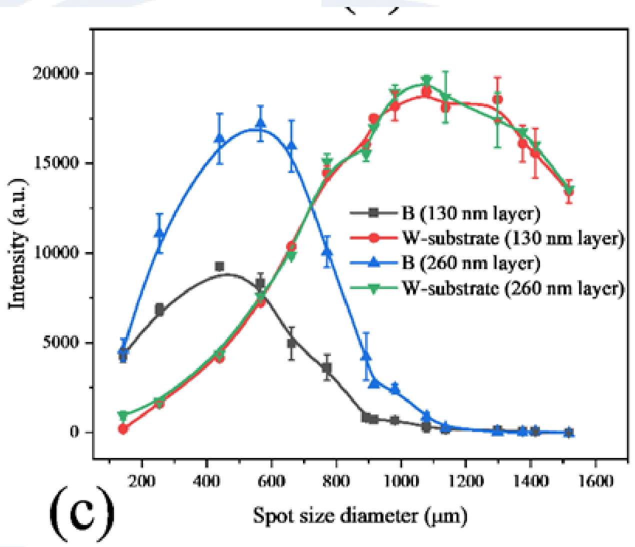
Examples: Development of LIBS to measure thin B layers (>5 nm) in 2024

SP X:
- Qualification of LIBS on thin B-layers
- Qualification of LID-QMS on B-layers with fuel



FZJ





H. Wu et al. submitted to NME

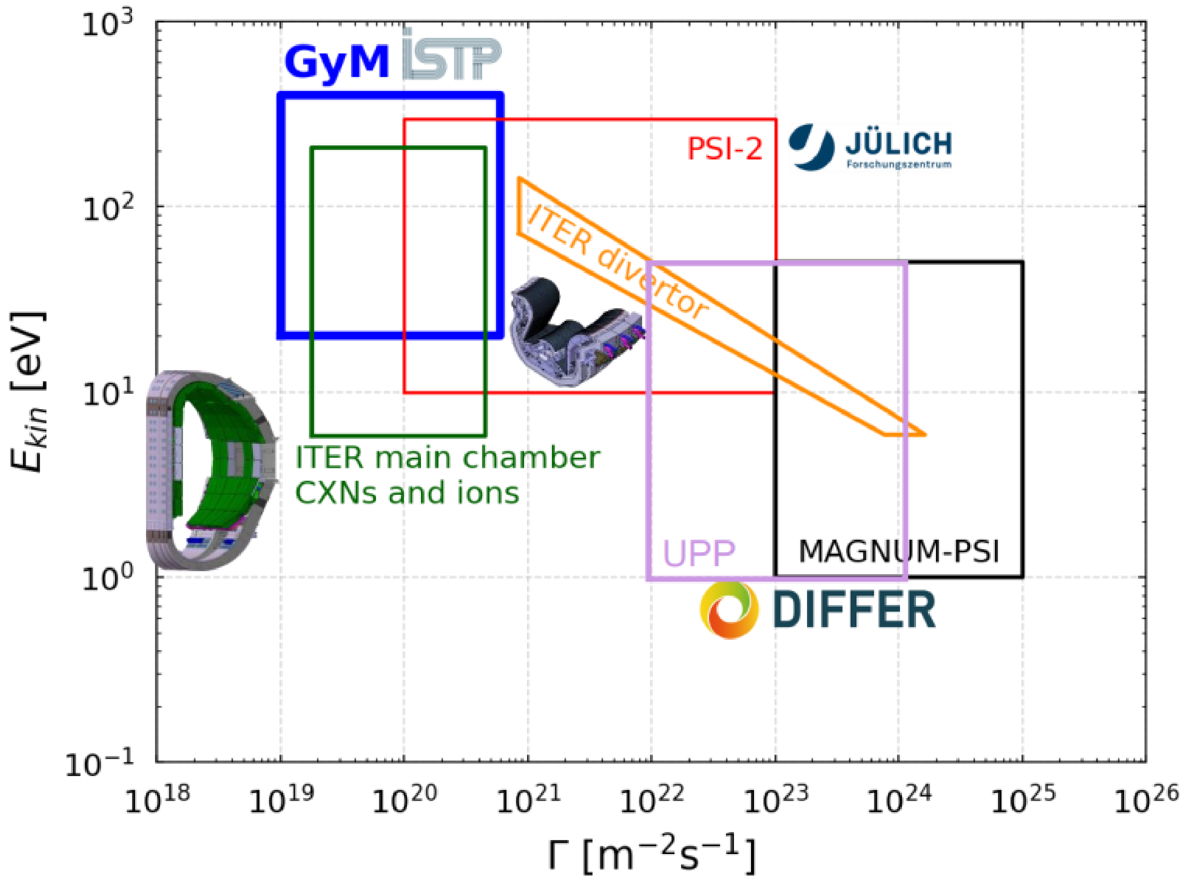
- ps-LIBS technique optimized to measure thin B layers on W substrate
- Thin deposits can be studied considering thin layer effects (reflection)
- Tests on boron layers from magnetron sputtering (130/260 nm)
- Successful test on boron layer samples from Wendelstein7-X pure boronization exposure with deposits below 10nm on W samples
- Limitations due to B and W line overlapping
- Parallel recording of O, H, C and other impurities possible

=> Diagnostic tool for fast in-situ or ex-situ studies of boron layers

Risk Mitigation Proposal => Refocus on boron and WEST-related studies

Proposal to re-use indicative JULE-PSI budget [40 days] for other linear facilities (all 70% funding rate):

- Increase the experimental days in PSI-2 in 2025 to cover substantial studies on boron layers on boron PWI including in-situ LIBS for fuel retention and fuel removal [add ~45 days => 90 days]
- Increase budget of experimental days in UPP in 2025 to include substantial studies on boron PWI with in-operando NRA for fuel retention and removal from layers [add ~30 days => 40 days]
- Residual budget for additional MAGNUM days on existing subjects => priority WEST W simulation [add ~10 days => 50 days]
- Additional 100 k€ to be converted to mission under WPPWIE for 2025 (also 70% funding rate). Mission for experiments and associated analysis meetings



PCR Request Summary

- Facility costs increase and hardware increase: 140 k€ CC
  - Includes cost for TOMAS (40 days) with about 35 k€ in addition
  - Includes cost for GYM (30 days) with about 35 k€ in addition
  - Includes cost for ion beam facilities and new facilities to analyse samples with about 50 k€
  - Includes cost for additional materials (e.g. bor,, gas) beyond what is in stock (bought by FZJ as lead lab) ~ 20k€
- Mission cost increase: 100 k€ CC
  - No mission money from initial indicative budget left (additional cost for JET-LIBS transferred into 2025, additional cost meetings, end of 5-years-project essential) => 50 k€
  - Mission costs for extensive use of TOMAS exploitation by ERM-KMS team to FZJ => 30 k€
  - Mission costs for COMPASS support (was not in the PCR) => 20 k€ (including training)
- Human resource increase: 1ppy
  - Support in analysis and interpretation of boron retention analysis matrix and new sets of experiments and diagnostics
- Reuse of 2025 JULE-PSI budget for in-situ boron studies

Grant Deliverables FP9

SyGMa ID	Title	Due Date	Status
PWIE.D.01	Post-mortem analysis of plasma-facing components exposed in W7-X (graphite) and WEST (ITER-like tungsten PFUs) in FP8. Reports on campaign integrated material migration pattern and modelling in both devices.	31.12.2021	Done
PWIE.D.02	Diffusion and trapping modelling in W PFCs under combined D+He impact and ion-induced self-damage for ITER / DEMO-like conditions. Report on underlying physics and fuel recovery strategies.	31.12.2021	Done
PWIE.D.03	Optimization of laser-based diagnostics for ITER and other long-pulse devices regarding material composition and fuel retention quantification. Selection of most suitable approaches [report].	31.12.2022	Done
PWIE.D.04	Interpretative PSI modelling of material migration and fuel retention in WEST, JET, ASDEX Upgrade and initial predictive PSI modelling for W7-X with full-W PFCs [report].	31.12.2022	Done
PWIE.D.05	Initial assessment on the impact of material damage (pre-irradiation) on fuel retention in W [report].	31.12.2022	Done
PWIE.D.06	Damage matrix from the exposition of advanced W materials in HHF and plasma devices [report].	31.12.2023	Done
PWIE.D.07	PSI modelling of DEMO main chamber erosion, deposition and fuel retention. PIC modelling of the sheath in the DEMO divertor (with TSVV-7)	31.12.2023	Done
PWIE.D.08	Neutral gas kinetics modular code upgraded and midterm verification/validation (with TSVV-5).	31.12.2023	Done
PWIE.D.09	Initial PSI modelling of W sources, screening, transport and core concentration in full W-devices (with TSVV-6)	31.12.2023	Done
PWIE.D.10	Recommendation to IO on Material Research Laboratory on the ITER site regarding T, Be and neutron-activated materials: minimum requirement and auxiliary systems	31.12.2023	Delayed to 2024 with reduced scope (no Be)
PWIE.D.11	Comprehensive catalogue on dust in metal devices: generation, migration, quantity, impact of moisture on dust generation	31.12.2023	Done
PWIE.D.12	In-situ fuel inventory assessment with the use of laser induced desorption techniques to monitor T retention in JET.	31.12.2023	Done
PWIE.D.13	Report on the demonstration of LIBS as T detection technique in JET using remote handling.	31.12.2024	On track
PWIE.D.14	Properties of JET bulk tungsten and beryllium after extensive test under reactor conditions	31.12.2024	On track

Grant Deliverables FP9

SyGMa ID	Title	Due Date	Status
~~PWIE.D.15~~	~~Initial exploration of HML (PEX Upgrade) capabilities regarding JUDITH-3 and JULE-PSI usage~~	~~31.12.2024~~	Withdrawn => 2026
PWIE.D.16	Exploitation of experiments (WEST, JET, ASDEX Upgrade) related to material migration, fuel retention, and fuel recovery including interpretative plasma-edge and PWI modelling	31.12.2024	On track
PWIE.D.17	Assessment of LID-QMS as in-situ fuel retention technique in JET and extrapolate to ITER conditions.	31.12.2024	On track
PWIE.D.18	Simulation of JET and PEX Upgrades results in view of ITER divertor and DEMO/DTT alternative configurations. Quantitative comparison of potential benefits alternative configurations with respect to conventional solutions in view of exhaust performances and core compatibility (input to overarching PEX.M1 milestone).	31.12.2024	PEX Upgrades under WP TE in exploitation.
PWIE.D.19	Characterization and predictive modelling of plasma-wall interactions in He und He/H mixed plasmas for ITER in Pre-Fusion Power phase	31.12.2025	On track, but scope reduced
PWIE.D.20	High fluence exposition of mono blocks made of references W and advanced W materials for DEMO, JT60-SA, DTT in MAGNUM-PSI and UPP including pre- and post-characterisation	31.12.2025	On track, apart from JT60-SA done
~~PWIE.D.21~~	~~Fuel retention studies in self-damaged and neutron-damaged materials exposed in JULE-PSI~~	~~31.12.2025~~	Withdrawn => 2027
PWIE.D.22	Comparison of in-situ (LID-QMS in JET) and ex-situ examination (FREDIS, TDS) of the laser-irradiated components regarding fuel/tritium content	31.12.2025	Already done
PWIE.D.23	PSI modelling of DEMO main chamber erosion, deposition and fuel retention. PIC modelling of the sheath in the DEMO divertor (with TSVV 7)	31.12.2025	On track
PWIE.D.24	Neutral gas kinetics modular code upgraded and final verification/validation report (with TSVV 5).	31.12.2025	On track
PWIE.D.25	PSI modelling of W sources, screening, transport and core concentration in full W-devices (with TSVV 6)	31.12.2025	On tracl

Grant Milestones FP9

SyGMa ID	Title	Due Date	Status
PWIE.M.01	Initial tile analysis of WEST PFUs and W7-X TDU PFCs completed	31.12.2021	Reached
PWIE.M.02	Comparative modelling of first set of revised advanced divertor solutions executed.	31.12.2021	Reached
PWIE.M.03	Modelling of fuel retention in W under combined D+He exposure and self-damaged W by diffusion and trapping executed.	31.12.2021	Reached
PWIE.M.04	High fluence experiments in deuterium (L-mode) discharges on ITER-like PFUs in WEST executed.	31.122023	Reached
PWIE.M.05	Incorporation of turbulence in multi-fluid calculations using physics-based diffusion coefficients (with TSVVs).	30.06.2022	Reached
PWIE.M.06	Comparative experiments of different LASER-based techniques on W and other reference samples executed.	31.12.2022	Reached
PWIE.M.07	Interpretative modelling of W migration and D retention in WEST high fluence discharges completed.	31.12.2022	Delayed
PWIE.M.08	Exposition of initial set of reference and advanced W materials for DEMO and JT-60SA in HHF and plasma devices executed.	31.12.2023	Reached, apart from JT60-SA
PWIE.M.09	3D Modelling of first wall erosion and fuel retention in the DEMO-1 reference scenario completed (TSVV7).	31.12.2023	Reached
PWIE.M.10	Initial neutral particle code development done and interface to plasma boundary code coupling specified (TSVV5).	31.12.2023	Reached
~~PWIE.M.11~~	~~FZJ PEX facility with JULE-PSI and JUDITH-3 is fully operational and ready for scientific exploitation.~~	~~31.12.2024~~	~~Cancelled => 2026~~
PWIE.M.12	Exposition of initial set of reference and advanced W PFCs for DEMO and JT-60SA to fluence up to $10^{30}m^{-2}$ in MAGNUM-PSI and UPP executed.	31.12.2024	Reached, apart from JT60-SA
PWIE.M.13	Helium plasmas and fuel/He recovery experiments in WEST executed and samples removed.	31.12.2024	Reached
PWIE.M.14	Potential PFCs solutions for an all-W W7-X identified and reference samples exposed in HHF and plasma devices to stellarator relevant power loads and fluence.	31.12.2025	
~~PWIE.M.15~~	~~Exposition of neutron-damaged and self-damaged W samples in JULE-PSI.~~	~~31.12.2025~~	~~Cancelled => 2027~~

International Collaboration

ID	International Collaboration in WP Activities	Planned year(s) of engagement	Status
IC01	SP D.3: EU-Japan (LHD, NAGDIS)	2021-2025	Running
IC02	**SP D.3: EU-US (UCSD, PISCES)**	2021-2025	Renewed
IC03	SP D.3: EU-China (EAST)	2021-2025	Running
IC09	SP E.2: EU-Japan (Rokasho/Broader Approach F4E)	2022-2023	F4E visit needed
IC10	SP B.1: EU-US (UCSD, PISCES)	2022-2025	Renewed
IC12	ITER collaboration (e.g. SP D and SP E)	2021-2025	Running
IC13	ITPA collaboration (e.g. SP A and SP X)	2021-2025	Running
IC14	IAEA collaboration (e.g. SP C and SP X)	2021-2025	Running

Spare

Status PEX-FZJ Upgrades

- PEX-FZJ upgrades include JULE-PSI (plasma) and JUDITH-3 (e-beam) in the hot material laboratory (HML) in FZJ. Controlled area, licensed for activated and toxic materials.
- FREDIS with LID-QMS analysing JET tiles is installed in the HML.
- Main plan for JULE-PSI in PWIE when FP9 was set-up for 2024+:
  - Study of neutron-damaged materials for DEMO regarding properties, retention, power handling, erosion, etc.
  - Study of (damaged) Be materials for ITER – as the only facility running after closure of JET
  - Jule-PSI plasma operation with limited tritium amount possible

- JULE-PSI device is built and operates in Argon / Hydrogen in FZJ outside of the hot cell
  - Deuterium measurements this year with plasma characterisation foreseen
  - Analysis and simulation of the plasma started (SOLPS-ITER) + EIRENE (alone)
- JUDITH-3 constructed and operates outside of the hot cell
- Three required new hot cells are not yet installed due to substantial cost increase (Corona/Inflation/…)
- Construction in 2025 => Transfer of facilities in 2026 => Full operation in 2027.
- Grant deliverable withdrawn. No operation with activated or toxic materials in 2025 => Shift 2026/27

Status PEX-FZJ Upgrades II

- Situation changed with respect to start of FP9: ITER decision to abandon Be!
- Focus of PEX-FZJ Upgrades now purely on activated, neutron damaged materials, and tritium
  - Neutron-damaged materials from fission application for plasma exposure also delayed (WPMAT)
  - Studies with boron in principle possible, but PSI-2 and JUDITH-2 exist and are easier accessible (cheaper)
- Delay of hot cell has only moderate impact on the mid-term research program

- Risk of not having PEX Upgrade in time in risk register tabulated:

  Use other linear plasma facilities if applicable for physics studies
  - No other facility for activated, neutron damaged materials, and tritium available => delay
  - Operation with Be not required anymore => need to study B => other facilities
- Note, operation of PSI-2 in the indicative plan for 2025 reduced to half of 2021

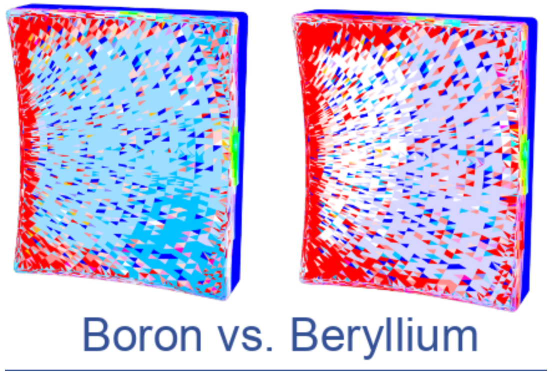
Examples/needs: Simulations about B erosion, transport, deposition

SP D:
- Modelling of toroidal devices w/wo boronization, W and B sources and migration
- Global fuel retention simulations
- Production of atomic and molecular data with B

- JET with Be used as reference for Be and fuel retention studies with ERO2.0 and WallDYN-3D => C30C reference experiment
- In-situ spectroscopy, gas balance, and post-mortem analysis used to benchmark those codes => ITER predictions for Be/W ITER

- Predictive modelling of full-W ITER with B done under IO lead

ITER first Mo mirror: B vs. Be depostion



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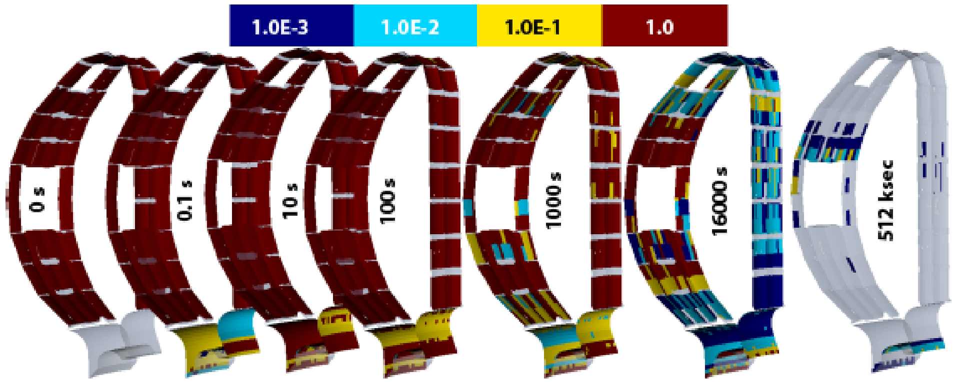


K. Schmid et al. PSI2024

Figure 13: Qualitative time evolution of the B surface concentration starting with a 100 nm B layer on the main chamber wall during a total of 512×10^3 s of steady state plasma exposure for OSM case 00g.

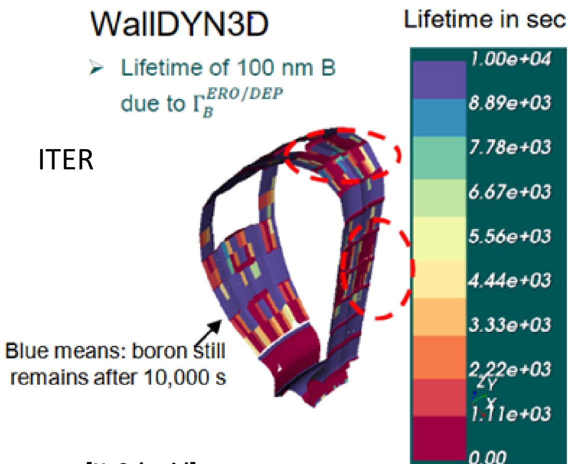
- Simulations strongly linked with IO activities/tasks
- Example to compare: Be vs. B in ERO2.0
- Impact of boronization on mirrors => linked to mirror studies under WPPWIE
- Boron chemistry not considered => data missing

- Benchmark experiment in full-W device after ITER-like boronization (100nm), in-situ characterisation and sample removal is missing.
- Next step: predictive modelling for AUG or WEST with the same codes

Scope: Work Package Plasma-Wall Interactions and Exhaust

Focus on ITER and DEMO materials, H and isotopes, He, seeding gases, and impurities

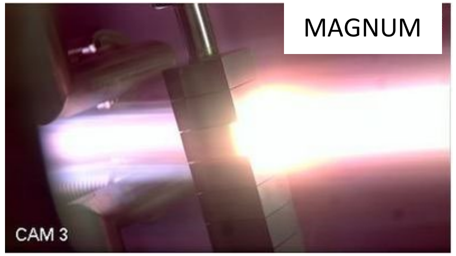
Goal: steady-state operation



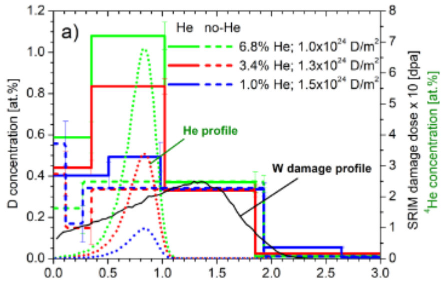
[K. Schmid]

3D erosion & deposition modelling **Tungsten, (Beryllium), Boron**

Particle and heat flux **Tungsten + Deuterium**



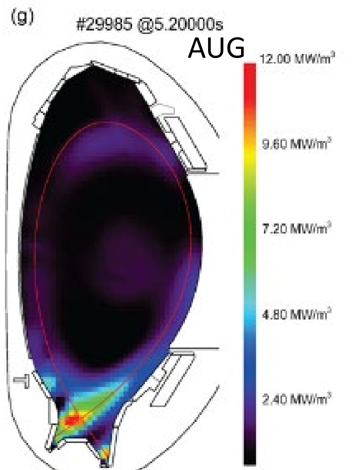
[T. Morgan]



[S. Markelj]

Fuel (**Tritium**) retention **Tungsten + Deuterium/Helium**

Cold divetor operation **Tungsten + seed gas (Ne, Ar, Kr)**

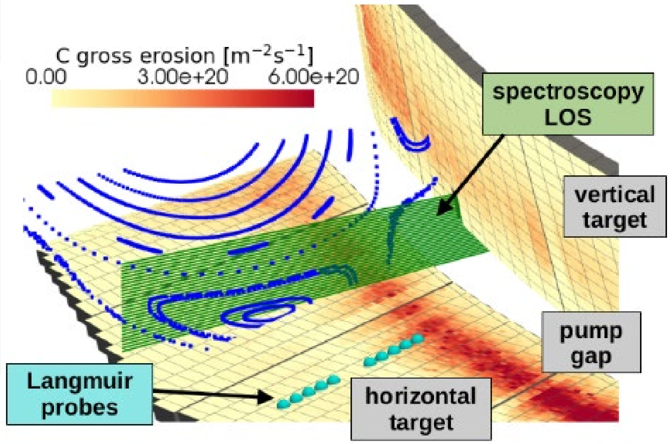


[M. Bernert]

Recombining plasmas in PSI-2 and MAGNUM-PSI

Support in WPTE exploitation In AUG, WEST and JET in PWIE area with metallic PFCs

Support in WPW7X exploitation operating with Graphite towards Tungsten PFCs



[J. Romazanov]

Material qualification and synergistic effects of W and advanced W materials

PWI diagnostic development

Tokamak Experiments + Plasma boundary modelling + Global PWI modelling + Local PWI modelling →

Laboratory experiments + PWI modelling →

ITER, DEMO predictions

WPPWIE 2025 Activities (Tasks) List

ID	Title
SP A.1	Synergistic Load Studies of Plasma-Facing Materials for ITER & DEMO
SP A.2	High Particle Fluence Exposures of Plasma-Facing Components for ITER
SP A.3	Advanced Materials under thermo-mechanical and plasma loads
SP A.4	High Temperature performance of Armour Materials: Recrystallization and Melting
SP A.5	COMPASS-U – Materials Assessment
SP B.1	Physics of erosion and deposition
SP B.2	Material migration in toroidal devices
SP B.3	Characterization of plasma-exposed materials
SP B.4	Reference coatings for ITER and DEMO
SP B.5	Production of metallic dust in toroidal devices
SP B.6	B-deposition on diagnostic mirrors
SP C.1	Transport of Hydrogen through the first wall of fusion devices
SP C.2	T retention Release from B layers
SP C.3	Influence of He, high-flux D and impurities on Hydrogen retention and transport
SP C.4	Influence of n-damage on Hydrogen retention and transport
SP C.5	T-permeation experiments in 316L

WPPWIE 2025 Activities (Tasks) List

ID	Title
SP D.1	Plasma Boundary Modelling
SP D.2	Production of Atomic/Molecular and Surface Data
SP D.3	Impurity Migration Modelling
SP D.4	Neutral Particles Modelling
SP D.5	COMPASS-U
SP E.1	LIBS at JET
SP E.2	Comparison of hydrogenic retention quantification by different techniques and fuel removal assessment
SP E.3	Post-mortem analysis of PFC and other objects in JET
SP F.1	Coordination
SP F.2	Boronisation
SP F.3	TOMAS
SP X.1	Atomic and molecular processes in attached/detached plasma
SP X.2	Optimization of laser-based surface analysis diagnostics
AIP.1	AIP: LIBS data-processing with Deep Neural Networks and Convolutional Neural Networks for chemical composition quantification in the wall of the next step-fusion reactors
AIP.2	AIP: AI-augmented SOL modelling for capturing impact of filaments on transport and PWI in mean field codes simulations
PEX	PEX commissioning of hot cells and test facilities

PCR July 2024 - reprise

WP	PCR proposal description	2024 [k€ CC]	means of expenditure	2025 [k€ CC]	means of expenditure	Implement 2024/2025
PWIE1	Support in the analysis of the impact of boronization on the new ITER re- baseline (O getter, fuel retention and removal, lifetime, properties) and associated A&M data calculations / modelling (SP B, SP C, SP D, SP X, SP F)	100	21PM 11.5k€ mission 15k€ use of facilities	100	21PM 11.5k€ mission 15k€ use of facilities	**Fraction done!** **SPF HR open**
PWIE2	Analysis of JET tiles including some extracted post DT tiles (2025) and JET RH LIBS analysis completion [Note containers call done after first PCR in April – not yet allocated]			200	46PM 23k€ mission	**2024 na** **2025 prep**
PWIE3	SPA: Experiments and modelling of W recrystallisation and impact on power handling and retention. Support for W samples and OG&S (different SPs)	50	9.5 PM 25k€ HW	50	9.5 PM 25k€ HW	**2024 in** **2025 prep**
PWIE4	SPB: dust studies for DEMO with W (and B dust)	75	16 PM 25 k€ use of facility	75	16 PM 25 k€ use of facility	**2024 in** **2025 prep**
PWIE5	Charaterisation of ITER/DEMO Mo mirrors exposed to B flux [Note mirrors also in PCR April – allocated and used]			77	20 k€ HW, 15.5PM 2 k€ Mission 10k€ use of facilities	**2024 in** **2025 prep**
PWIE6	SPC: increase ressources for permeation / retention studies with real T (T-lab in USPPL) incl facility costs	29	7.5PM	70	18PM	**2024 in** **2024 prep**
PWIE7	Support to COMPASS-U PFCs selection, qualification and W source estimation.	200	50 k€ use of HHFF 25 k€ use of an. facilities 25 k€ use of plasma facilities, 38.5PM	200	50 k€ use of HHFF 25 k€ use of an. facilities 25 k€ use of plasma facilities, 38.5PM	**2024 in** **2025 prep**

Proposal: PWIE1 => 12 PM unallocated to shift into 2025 for (delayed) boronisation activities => Call for a person and activites

EUROfusion

Plans of SP A for AWP2025

Jan Willem Coenen

Forschungszentrum Juelich – IFN-1

PWIE Leadership

S. Brezinsek (PL) J.W. Coenen, A. Hakola, K. Schmid, A. Kirschner, J. Likonen, H. van der Meiden. M. Reinhart (PSO), and D. Douai (CO)

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SPA.1 Main Objective and Activities

ACTIVITY: continuation of 2024 work

Scientific question: This task contributes to the qualification of current baseline materials and beyond by different heat load treatment techniques and quantifying the difference in damage behavior by the different loading techniques as well as the additional impact of fuel species and other fusion relevant conditions.

What shall be done:

- **Material Testing and Qualification**: Develop a test matrix for ITER and WEST materials like tungsten, focusing on synergistic loads and high-cycle, impurity exposure. Qualify materials across various devices (DIFFER, FZJ, MPG).
- **Damage and Behavior Analysis**: Perform post-mortem analyses to assess surface damage and material properties like crack propagation and recrystallization (FZJ, MPG, DIFFER).
- **Plasma Load Synergies and Fatigue Studies**: Study synergy effects of sequential plasma loads and fatigue damage in tungsten materials under pulsed and steady-state loading (FZJ, DIFFER, MPG, KIPT).

Main Goals:
Qualification of Baseline Materials for use in Current and Future Devices / Synergistic Load Studies of Plasma-Facing Materials for ITER & DEMO

Involved RU: FZJ,DIFFER,CIEMAT,MPG,KIPT
Status: Continuation

Special resources: PSI-2,JUDITH,MAGNUM-PSI,OLMAT, Accelerator (FZJ), UPP, GLADIS, QSPA
WP collaboration: WPW7X / WPTE

SPA.2 Main Objective and Activities

ACTIVITY: continuation of 2024 work

Scientific question: This task is envisioned to utilize existing high fluence devices such as MAGNUM-PSI, but also in future e.g. machines under construction to allow extrapolation of data from existing materials studies towards the effect of high flux and fluence on materials and components.

What shall be done:

- Recrystallization behavior of DEMO tungsten grades and other releveant materials under high flux/fluence plasma loading
- Pre- and post-analysis of materials and components (MPG)

Further analysis linked to facilities and staffing in SP B

Main Goals:
Qualification of Baseline Materials for use in Current and Future Devices / High Particle Fluence Exposures of Plasma-Facing Components for ITER

Involved RU: DIFFER, MPG
Status: continuation

Special resources: MAGNUM, UPP
WP collaboration: WPDIV, WPMAT in FTD

SPA.3 Main Objective and Activities

ACTIVITY: continuation of 2024 work

Scientific question: Develop qualification methods for advanced materials for ITER & beyond by different thermos-mechanical test procedures, heat load treatment techniques, and laboratory experiments as well as linear plasma devices.

Apply advanced test and characterization techniques to validate advanced materials for PFC use. Contribute to long-term activities in WPPWIE to mitigate limitations in PFCs currently available.

What shall be done:

• **Plasma Qualification**: Test advanced materials (e.g. Wf/W, SMART alloys) under thermal and plasma loading to assess plasma-facing properties (FZJ, KIPT, DIFFER, MPG).
• **Thermo-Mechanical Studies**: Examine thermo-mechanical properties of divertor materials, including W-yarn testing and neutron-irradiated sample comparison (LPP-ERM/KMS, SCK-CEN, MPG).
• **Surface and Damage Analysis**: Investigate surface and structural changes, focusing on recrystallization, cracking, and fatigue under plasma loading (FZJ, MPG, KIPT).

Main Goals: Qualification of Advanced Materials for use in Current and Future Devices / Advanced Materials under thermo-mechanical and plasma loads

Involved RU: FZJ, DIFFER, KIPT, LPP_ERM/KMS, MPG
Status: continuation

Special resources: PSI-2,JUDITH,MAGNUM-PSI,OLMAT, Accelerator (FZJ), UPP, GLADIS, QSPA
WP collaboration: WPW7X etc.

SPA.4 Main Objective and Activities

ACTIVITY: continuation of 2024 work

Scientific question: Melting and its effect on plasma performance and PFC lifetime in particular melting under relevant conditions or ITER and DEMO is still a partly unanswered issue. Here both, experiments in controlled environments and dedicated modelling shall be connected, Via Modelling. The lifetime of PFUs for ITER / WEST is crucially linked to operation near and close to the point of recrystallization. Thus, the study of recrystallization in linear plasma devices including the role of the plasma composition shall be further explored.

What shall be done:

- **Microstructural Characterization**: Investigate tungsten-based materials exposed to plasma, analyzing mechanical and microstructural profiles to identify heterogeneities and restoration mechanisms (DTU).
- **Plasma Exposure and Heat Load Effects**: Study tungsten exposed to giant ELMs and plasma heat loads, assessing surface melting, recrystallization, and microstructural changes (KIPT, CEA, VR).
- **Recrystallization and Joint Activities**: Assess the effects of H and He on tungsten recrystallization, and conduct experiments on damaged components, linking with WP TE and SP A1 (FZJ, DTU, VR).

Main Goals: Qualification of ITER/DEMO Relevant Materials with respect to High Temperature performance of Armour Materials: Recrystallization and Melting

Involved RU: CEA, DTU,VR,KIPT,FZJ,VR

Status: continuation

Special resources: PSI-2,KIPT, Accelerator

WP collaboration: WPTE

SPA.5 Main Objective and Activities

ACTIVITY: continuation of 2024 work and addition of HIVE in 2025

Scientific question: Task under SP A5 include the preparatory work on assessing and analysing the material candidates for COMPASS-U this includes particularly heat flux performance as well as material evolution on microstructure, and surface condition.

What shall be done:

- **Material Pre-characterization and Exposure**: Nine candidate tungsten materials will undergo pre-characterization, with down-selection to main suppliers (Plansee, ALMT, AT&M). Exposures will be conducted at facilities such as JUDITH, PSI-2, OLMAT, and Magnum.
- **Disruption Simulation and Damage Threshold**: Disruption simulations on COMPASS-U W armor will focus on damage thresholds in terms of power density (up to ~7 GW/m^2) and pulse number, especially at the edges. This data will help assess mild or mitigated disruptions expected in DEMO (~30 GW/m^2).
- **Post-characterization and Nano-crack Detection**: Pre- and post-characterization using advanced techniques will include nano-crack detection in the first wall surface using IR laser heating and scanning. Comparative material analysis will follow across multiple techniques.

Main Goals: Particle & Heat Load Studies in preparation of the exploitation of ITER and DEMO based on COMPASS-U material mix

Involved IPP.CR, CIEMAT,CU,DIFFER,ENEA,FZJ,IPPLM, UKAEA
Status: New and continuation

Special resources: MAGNUM, PSI-2,OLMAT, HIVE
WP collaboration: WPTE

Plans of SP B for AWP2025

A. Hakola

VTT

PWIE Leadership

S. Brezinsek (PL) J.W. Coenen, A. Hakola, K. Schmid, A. Kirschner, J. Likonen, H. van der Meiden. M. Reinhart (PSO), and D. Douai (CO)

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WPPWIE

SPB.1 Main Objectives and Activities

Physics of erosion and deposition

Scientific questions to be addressed

- Assess the erosion characteristics of reference coatings simulating re-deposited W layers in metallic fusion devices
- Determine the erosion and formation rates for W- and B-based co-deposited layers (with SP F)

What shall be done?

- Expose reference coatings to D plasmas in linear devices and laboratory setups (production and pre-characterization under SP B.4) – vary plasma and target parameters, including thermal cycling
- Determine sputtering rates of the exposed samples and properties of co-deposited layers on witness plates – data for modelling under SP D, post exposure analyses under SP B.3
- Investigate the role of dust impacts on sample erosion – vary the size distribution and speed of the dust particles

Main Goals

- Database on the erosion/deposition rates for representative layers expected in ITER and DEMO – comparison to bulk W
- Cross-comparison between different machines and against data from fusion devices (AUG, WEST, W7-X – under SP B.2)
- Understand the formation of WEST-like thick deposits consisting of B and W

Involved RU: **DIFFER, ENEA, FZJ, OEAW**

Status: **continuation from 2024**

Special resources: **MAGNUM-PSI, PSI-2, GyM, accelerator usage**

WP collaboration: **WPMAT, WPDIV, WPTE**

SPB.2 Main Objectives and Activities

Material migration in toroidal devices

Scientific questions to be addressed

- Understand erosion of W components and formation of W- and B-containing co-deposited layers in tokamaks and stellarators under conditions relevant for future fusion reactors
- Identify material migration pathways for W and B with the focus on the main chamber

What shall be done?

- Procure/produce and pre-characterize specific marker samples for dedicated experiments in fusion facilities (AUG, WEST, W7-X) – reference coatings to be developed under SP B.4
- Post exposure analyses of the exposed samples after experiments or experimental campaigns (long-term samples) – data for modelling under SP D, part of the analyses under SP B.3
- Analyse deposition of B on samples exposed during boronizations

Main Goals

- Gross and net erosion profiles for the exposed B- and W-based samples – comparison against SP B.1 data
- Roles of different mechanisms in eroding W in the main chamber – including remote areas and CX neutrals
- Effect of boronization procedures on material migration and deposition patterns

Involved RU: CEA, MPG, RBI, FZJ, VTT

Status: continuation from 2024

Special resources: usage of accelerator and SEM facilities

WP collaboration: WPTE, WPW7X

SPB.3 Main Objectives and Activities

Characterization of plasma-exposed materials

Scientific questions to be addressed

- Identify changes in the surface characteristics of selected samples and plasma-facing components removed from tokamaks and stellarators (AUG, WEST, W7-X)
- Determine erosion, deposition, and fuel-retention patterns on samples following extended exposure in fusion facilities or specific experiments in linear plasma devices

What shall be done?

- Post exposure analyses of the available samples or wall components – AUG, WEST, and W7-X wall tiles (partly under SP B.2), reference samples from MAGNUM-PSI, PSI-2, and GyM experiments (under SP B.1)
- Comparing the results of individual analyses, in particular for WEST components removed after Phase 1 and Phase 2

Main Goals

- Erosion and deposition patterns of the analyzed components – to be compared against sputtering data from SP B.1 and results from individual migration experiments under SP B.2
- Structure and morphology of co-deposits on the analysed components
- Retention of D on the components – to be used for benchmarking retention studies in SP C

Involved RU: CIEMAT, ENEA, FZJ, IAP, IPPLM, IST, JSI, MPG, NCSRD, RBI, VR, VTT

Status: continuation from 2024

Special resources: usage of accelerator and SEM facilities

WP collaboration: WPTE, WPW7X

SPB.4 Main Objectives and Activities

Reference coatings for ITER and DEMO

Scientific questions to be addressed

- Develop methods to produce and pre-characterize reference coatings to simulate re-deposited W layers, B/W-based co-deposits, and B layers originating from boronizations
- Produce marker layers for agreed experiments under SP B.1 and SP B.2

What shall be done?

- Production of B, W, and B/W layers with pre-defined specifications for the SP B.1 and SP B.2 experiments as well as for studies under SP A, SP C, SP F, SP X, WPTE, and WPW7X
- Pre-characterization of the produced layers before their exposure

Main Goals

- Established recipes to produce B, W, and B/W layers – inlcuding controlling their O content and surface morphology
- Qualified workflow for characterizing the produced samples – especially critical for the B layers

Involved RU: CEA, CIEMAT, ENEA, FZJ, IAP, IST, IPPLM, JSI, NCSRD, RBI, VR, VTT

Status: continuation from 2024

Special resources: usage of accelerator and SEM facilities

WP collaboration: WPTE, WPW7X

SPB.5 Main Objectives and Activities

Production of metallic dust in toroidal devices

Scientific questions to be addressed

- Assess the amount and properties of dust produced in metallic (W) fusion devices during varying operational conditions
- Investigate parametric dependencies in producing particles resembling dust observed in fusion devices

What shall be done?

- Characterization of dust samples removed from fusion devices (AUG, WEST, W7-X) for their structure and composition
- Production and characterization of W and B dust particles in laboratory conditions for comparison against dust removed from tokamaks and stellarators
- Carry out remobilization experiments for big W/B dust flakes in linear devices – if necessary for modelling under SP D

Main Goals

- Database on the analyzed dust samples from tokamaks and stellarators – identify the underlying physics determining the properties of the dust generated and make predictions towards ITER and DEMO
- Established recipes to produce B, W, and B/W dust particles in laboratories – focus on air/water leaks to extrapolate to ITER and DEMO
- Fracture and strentgh properties of B and W reference layers (produced under SP B.4) – role in dust production

Involved RU: CEA, FZJ, IAP, IPPLM, MPG, RBI, UKAEA, VR

Status: continuation from 2024

Special resources: accelerator and SEM facilities, possibly MAGNUM-PSI

WP collaboration: WPTE, WPW7X

SPB.6 Main Objectives and Activities

B-deposition on diagnostic mirrors

Scientific questions to be addressed

- Determine possible changes in the properties of Mo-mirrors upon exposure to boronizations (AUG, W7-X)

What shall be done?

- Post exposure characterization of Mo-mirrors following their exposure to boronizations

Main Goals

- Information for deciding if B contamination is an issue for diagnostics mirrors in ITER and making proposals for cleaning solutions

Involved RU: **FZJ, MPG**

Status: **continuation from 2024**

Special resources: **N/A**

WP collaboration: **WPTE, WPW7X**

EUROfusion

Plans of SP C for AWP2025

K. Schmid

IPP-Garching

PWIE Leadership

S. Brezinsek (PL) J.W. Coenen, A. Hakola, K. Schmid, A. Kirschner, J. Likonen, H. van der Meiden. M. Reinhart (PSO), and D. Douai (CO)

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WPPWIE

SPC.1 Transport of Hydrogen through the first wall of fusion devices

ACTIVITY: continuation of 2024 work

Scientific question:

The transport of **H**ydrogen **I**sotopes (HIs) through the first wall of fusion devices is the driving process for HIs retention but also for permeation to the coolant. Both of these processes have fundamental implications for the safety and the tritium self-sufficiency of a fusion reactor.

What shall be done:

- Investigate kinetics of H-transport across multi material interfaces both in experiment and modeling
- Measure H-transport trough W heavy alloys in permeation experiments
- Perform co-permeation experiments of D and H in W

Main goals:

- Obtain arrhenius paramters for kinetic interface modeling
- Determine the dominant transport channel through W heavy alloys
- Determine the influence of isotope exchange on retention and transport speed in W

Involved RU: MPG, CEA, JSI, IPP_LM, ÖAW, VR
Status: Continuation

Special resources: N. A
WP collaboration: N. A.

SPC.2 T retention Release from B layers

ACTIVITY: continuation of 2024 work

Scientific question:

The retention in and release from B co-deposition layers, expected in ITER due to the foreseen need for boronization in an all W ITER, needs to be quantified to asses their effect on the in vessel T inventory.
Different layers are expected depending on whether they should shield the underlying W from erosion or getter impurities

What shall be done:

- Co-deposit B + D as function of temperature at fixed particle energy and layer growth rate
- Measure influence of different boronization layer types on permeation as function of temperature

Main goals:

- Temperature dependence of D/B ratios. First step to derive scaling laws
- Measure boronization layer permeability to assess their influence of H uptake

This will collaboration between different WP-PWIE SP‘s for layer deposition and characterization

Involved RU: MPG, FZJ, DIFFER, CEA
Status: Continuation

Special resources: MAGNUM
WP collaboration: WP-TE

SPC.3 Influence of He, high-flux D and impurities on Hydrogen retention and transport

ACTIVITY: continuation of 2024 work

Scientific question:

The n-bombardment of armor and structural materials in the first wall of DEMO and ITER leads to formation transmutation products (e.g. He, Re). Due to self-trapping in metals He tends to form bubbles which in the bulk act as trap sites for T and form open porosity close to the surface.

What shall be done:

- Create He based defects in the bulk of EUROFER and W at high temperture
- Characterize the created defects by decoration with D and by TEM
- Measure retention in W/Re mixtures and compare to pure W

Main goals:

- Evolution of He based defects in EUROFER and W at high temperatures
- Retention on He based defects created at high temperature
- Influence of Re on retention in W

Involved RU: JSI, MPG, FZJ, IPP_LM
Status: Continuation

Special resources: PSI-2
WP collaboration: N. A.

SPC.4 Influence of n-damage on Hydrogen retention and transport

ACTIVITY: continuation of 2024 work

Scientific question:

The n-bombardment of armor and structural materials in the first wall of DEMO and ITER leads to formation open volume defects by displacement damage. These open volume defects are strong traps for T.

What shall be done:

- Create displacement damage in W at high temperture
- Search (TEM) for large cavitites that may allow for T storage in molecular form

Main goals:

- Measure D_2 molecule retention in large cavities
- Correlate D retention with void size from TEM

Involved RU: JSI, MPG, FZJ, IPP_LM
Status: Continuation

Special resources: MAGNUM, GLADIS etc.
WP collaboration: WPW7X etc.

SPC.5 T-permeation experiments

ACTIVITY: continuation of 2024 work

Scientific question:

To make predictions about the permeation of T to the coolant the metal/water interface needs to be understood.

What shall be done:

- T-gas-permeation experiments through steels with downstream side immersed into water compared to inert gas.

Main goals:

- Compare permeated amount into water & atmosphere above it to permeated amount into inert gas
- Characterization of surface state

Involved RU: ISSP-UL, CEA
Status: Continuation

Special resources: N. A
WP collaboration: N. A.

EUROfusion

Plans of SP D for AWP2025

SPL Andreas Kirschner

FZJ – IFN-1

PWIE Leadership

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WPPWIE

SPD PSI and SOL Modelling

SP D.1: Plasma boundary modelling

Scientific question: Plasma ($T_{e,i}$, n_e, flows, …) and sheath parameter are needed as input for impurtiy migration and PSI modelling and have to be provided in 2D or 3D by simulation codes.

What shall be done: Modelling (SOLPS-ITER, EMC3-EIRENE, SOLEDE3X, …) of plasma background parameter, including tokamaks, W7-X and linear devices. Modelling of sheath parameter (PIC-based codes).

Main Goals: Provide plasma background parameter and sheath characteristics, which can be used for impurity migration and PSI modelling in SP D.3.

Involved RU: CEA, DIFFER, ENEA, FZJ, IPP.CR, VTT
Status: continuation

Special resources: HPC requests
WP collaboration: WPW7X, WPTE, TSVVs, IO, ITPA DivSOL

SPD PSI and SOL Modelling

SP D.2: Production of atomic/molecular and surface data

Scientific question: Ionisation, dissociation, recombination data are needed for impurity migration modelling. Erosion yields and reflection coefficients are needed for PSI modelling.

What shall be done: Focus on the production (MD, SDTrimSP) of erosion and reflection data for W-B-O-H(D,T) surfaces for varous projectiles (fuel, seeding species, …). Development of missing interaction potentials.

Main Goals: Provide erosion yields and reflection data in dependence on impact energy and angle.

Involved RU: CEA, ÖAW, VR, VTT, MPG
Status: continuation

Special resources: HPC requests
WP collaboration: WPTE, TSVVs

SP D.3: Impurity migration modelling

Scientific question: Erosion and redeposition is critical issue in fusion devices. Life time of wall components, possible dust sources from deposited layers, main plasma impurity content.

What shall be done: Modelling (ERO2.0, WallDYN) of impurity transport, erosion and deposition characerestics in comparison to experiments (spectroscopy and post-mortem data from tokamaks, W7-X, linear devices). Predictive modelling for ITER. Focus on full-W devices, consideration of boronisation.

Main Goals: Understanding of erosion and deposition by means of modelling in comparison to experimental results e.g. from WEST, AUG, linear devices, W7-X. Predictions for ITER.

Involved RU: CEA, ENEA, FZJ, MPG, VTT, VR
Status: continuation

Special resources: HPC requests
WP collaboration: WPW7X, WPTE, TSVVs, IO, ITPA DivSOL

SP D.4: Neutral particles modelling

Scientific question: Performance of particle exhaust. Neutral fluxes as erosion sources in particular at main wall areas.

What shall be done: Modelling (DIVGAS) of particles gas dynamcis and exhaust for W7-X and DEMO. Modelling (EIRENE) of neutral wall fluxes (including energy and angular distribution) for various devices – to be used in impurity migration codes.

Main Goals: Optimisation of particle exhaust systems. Assessment of erosion due to neutral wall fluxes.

Involved RU: KIT, VTT
Status: continuation

Special resources: HPC requests
WP collaboration: WPW7X, WPTE, TSVVs, IO, ITPA DivSOL

SPD PSI and SOL Modelling

SP D.5: Plasma background and PWI modelling for CAOMPASS-U

Scientific question: Erosion and deposition assessment in COMPASS-U. Evaluation of COMAPSS-U PFCs.

What shall be done: Plasma background modelling (SOLPS-ITER, SOLEDGE3X, PIC-based codes) for COMAPSS-U with drifts and currents. Impurity migration and PSI modelling (ERO2.0) for COMAPSS-U.

Main Goals: Assessment of W erosion and redeposition in COMPASS-U.

Involved RU: IPP.CR, CEA, FZJ
Status: continuation

Special resources: HPC requests
WP collaboration: WPTE, TSVVs, IO, ITPA DivSOL

EUROfusion

Plans of SP E for AWP2025

Jari Likonen

VTT

Involved RUs: CU, ENEA, FZJ, IAP, IPP_LM, ISPP_UL, IST, UT, VR, VTT

PWIE Leadership

S. Brezinsek (PL) J.W. Coenen, A. Hakola, K. Schmid, A. Kirschner, J. Likonen, H. van der Meiden. M. Reinhart (PSO), and D. Douai (CO)

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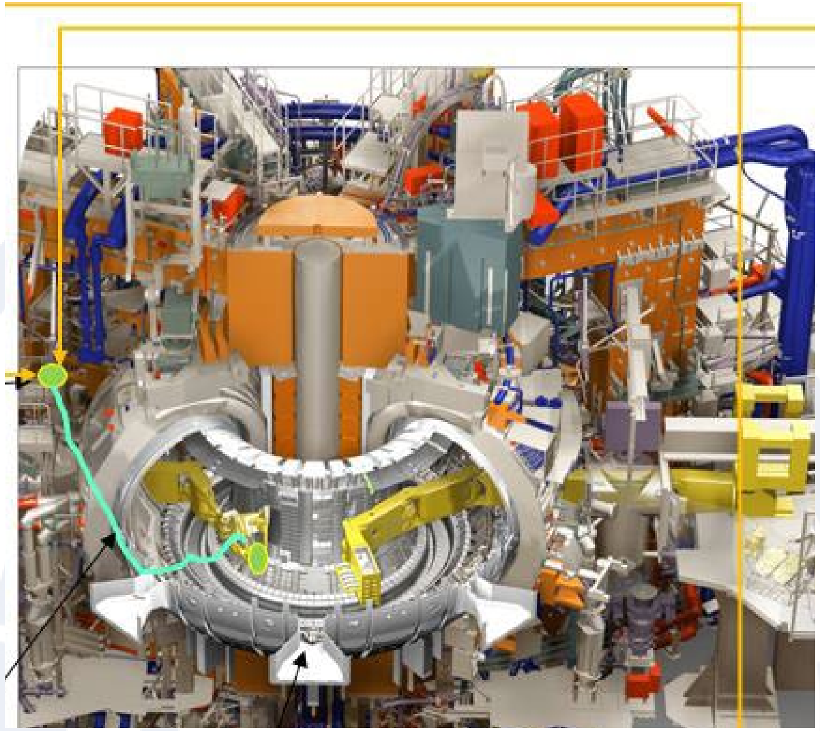
WPPWIE

SPE.1 LIBS at JET Main Objective and Activities



Scientific question:

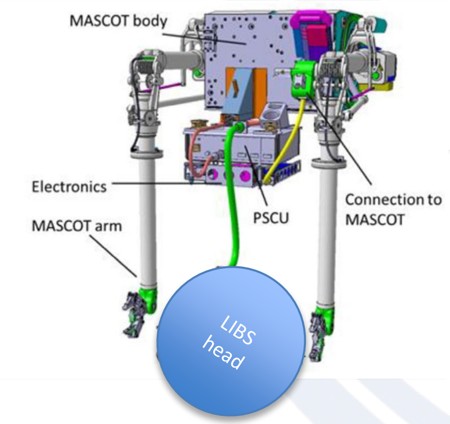
- Task will concentrate on in-vessel analysis (H isotope retention, composition of layers) using LIBS on a remote handling arm at JET

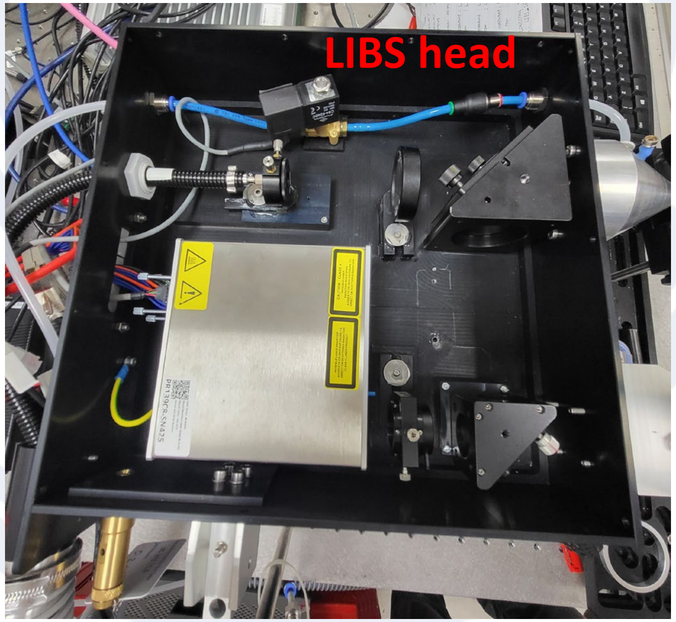
What shall be done:

- LIBS experiment at JET in October 2024
- Over 900 locations inside JET vacuum vessel will be analysed

Main goals:

- Data analysis of LIBS spectra
- Determine H isotope ratios and composition of co-deposited layers





Involved RU: CU, ENEA, FZJ, IPP_LM, ISPP_UL, UT, VTT

WP collaboration: UKAEA

Status: Continuation

SPE.2 Cutting of DTE3 tiles and sample distribution

Main Objective and Activities

Scientific question:

- The Task will concentrate on coordination (VTT), sample preparation and sample distribution for DTE3 divertor and limiter tiles, and diagnostics components removed during the 2024 shutdown.

What shall be done:

- Samples from W-coated CFC divertor tiles will be prepared using coring technique (VTT)
- IAP will cut samples from Be limiter tiles and metallic diagnostic components
- Samples will be distributed between RUs participating in SPE programme

Main goals:

- Completion of sample preparation and distribution of samples

Involved RU: IAP, VTT, FZJ

WP collaboration: UKAEA

Status: New

SPE.3 Completion of ILW3 post-mortem analyses and first analysis of DTE3 samples

Main Objective and Activities

Scientific question:

Investigation of material migration from the limiters and the main wall towards the divertor resulting in formation of co-deposited layers on the divertor tiles, and characterisation of hydrogen isotope retention including tritium.

What shall be done:

- Post-mortem analysis of ILW3 and DTE3 samples and components using various analysis techniques (ion beams, TDS, electron microsopy…)

Main goals:

- Completion of characterisation of remaining ILW3 tiles and metallic components, and first analyses of JET DTE3 divertor and limiter samples.

Involved RU: FZJ, IAP, IPPLM, ISPP_UL, IST, VR, VTT **WP collaboration: UKAEA**

Status: New

Plans of SP X for AWP2025

Hennie van der Meiden

DIFFER

PWIE Leadership

S. Brezinsek (PL) J.W. Coenen, A. Hakola, K. Schmid, A. Kirschner, J. Likonen, H. van der Meiden. M. Reinhart (PSO), and D. Douai (CO)

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WPPWIE

SPX.1 Main Objective and Activities

Scientific question:

- Determine distribution of ro-vibrationally exited states of H2 and isotopes

What shall be done?

- Passive spectroscopy: VUV-flux measurements with SI VUV diode system (MPG) and VIS/VUV spectrometer (FZJ, MPG, DIFFER)
- Active spectroscopy: Continuation CARS and VUV-LIF development (DIFFER)
- Continuation development of Machine learning algorithms for LIBS analysis

Main goal:

- Obtaining the missing atomic and molecular ro-vibrational data as input for modelling for understanding energy and momentum losses in detached plasma

Involved RU: MPG, FZJ, DIFFER, CU
Status: partly new other continuation

Special resources: MAGNUM, GLADIS etc.
WP collaboration: WPW7X etc.

SPX.2 Main Objective and Activities

Scientific(technical) question:

- Can we realize a laser based techniques for quantitative determination of composition and fuel content in W, B and C layers with depth resolution close to 10 nm

What shall be done?

- LIBS performance tests on relevant layers with varying thickness
- Comparizon performance different LIBS based methods: ns/ps-LIBS, res-LIBS, sp/dp-LIBS and other methods
- LIBS performance tests for He detection(?)
- Test *in situ* LIBS in linear devices, using NRA/RBS or LIA-QMS/EDX as a reference
- Continuation development of Machine learning algorithms for LIBS analysis

Main goal:

- Understanding LIBS physics and realizing of LIBS as a tritium monitor for fusion devices

Involved RU: CEA, DIFFER, ENEA, FZJ, IPPLM,
CU UT, ISSP UL, VTTMPG, FZJ, VTT
Status: continuation

Special resources: MAGNUM, PSI-2, UPP, Accelerator
WP collaboration: WPTE, WP7X, ITER and ITPA DIAG

Joint WPTE and WPPWIE Technical Meeting on
Plasma-Wall Interactions in full-W devices

2024-2025 Summary and Plans for Boronisation Studies within WPPWIE

Sebastijan Brezinsek

Forschungszentrum Jülich
Heinrich-Heine-Universität Düsseldorf

J.W. Coenen, A. Hakola, K. Schmid, A. Kirschner, J. Likonen, H. van der Meiden. M. Reinhart (PSO), and D. Douai (CO)

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Revised ITER first wall material selection and new research plan

Old ITER plan: Use full-W first wall in ITER at the later stage of exploitation once main ITER goals (Q=10 and 400s & Q=5 and 5000s) with Be/W material mix were achieved!
New ITER plan: Start with full-W first wall, demonstrate plasma compatibility and control, demonstrate low retention and low dust production for the regulator, and show as soon as possible Q=10 for 100s (=> compensate the delay)

See T. Wauters et al.

Basic scientific input to the ITER decision to change the first wall:

- Successful operation in full-W and full-C devices (with boron for wall conditioning)
- Experience from JET operation with W divertor
- Experience from AUG operation in full-W PFCs with start-up “without” boronisation
- Progress in knowledge regarding operation with W (ECRH, RF design etc.)

Identified issues:

- Tungsten first wall requires a new wall conditioning strategy in ITER as main technique „use Beryllium“ gone
- Be gettered oxygen and ensured low pollution of the plasma core, has a moderate erosion source due to absence of severe chemistry (contrast to C) and has a low radiation potential (contrast to W)
- Residual O in the vessel and associated W sputtering can thread start-up and Q=10 due to high core radiation

ITER strategy:
ITER reached out to community to address open questions, develop risk mitigation strategies, cure problems, make predictions => ITPA, EUROfusion WPs, ITER partners … => results feed into ITER new Research Plan

General observation:
(i) JET with “W divertor + Be wall” behaves in general like AUG “with W divertor + W wall + transient B coverage”
(ii) ITER has made enormous effort to predict PWI with Be and a lot of knowledge can be translated to B

New WPPWIE focus on revised ITER first wall material selection and new ITER research plan needs

Open issues:

- Initially no boronisation system in ITER foreseen => design done in 2023 => number of anodes and gas valves sufficient?
- Huge volume and large surface area in ITER vessel => homogeneity of protective layers? => full coverage needed?
- Lifetime of the boronisation? Short-term and long-term effects => weeks or days? => start-up location coverage or O getter?
- Boronisation or boron dropper as key tool to be used? => reliability after 15 years of operation required
- Impact of B on fuel retention and removal? => fuel accounting, mixed layers with O => impact on "safety case" of ITER
- Impact of B on material migration and dust formation? => safety issue as dust, if boronisation permanent in use
- Will boronisation cause deposition on first wall mirrors in ITER => need to use shutters, redesign, clean mirror techniques?

Required changes and critical issues for ITER identified by the PWIE team in 2023 and implemented into initial 2024 plan

- Closure of Be activities by end of 2023, apart from JET-LIBS, JET post-DT sample analysis, and associated modelling
- Identification of critical questions, physics processes and folding those with capabilities of PWIE team and facilities
- Parallel review of existing knowledge, publications, reports regarding B / W / D / O complex (studies in 2000s done)
- Set-up of a physics program within the capabilities of WPPWIE to study basic processes related to B
- Main issue: no facility to handle B_2H_6 for boronisation and boron layer change properties and oxidise if exposed to air
- Strong link to toroidal devices with boronization capabilities and short as possible exposure to air mandatory
- New dedicated facilities or upgrades of existing facilities with in-situ diagnostics considered (co-funding is not sufficient!)

Additional funding in January and July 2024 for 2024 and 2025 granted / 2025 program details in preparation

- Majority of initial planed laboratory activities now in plan; possibilities to modify program to tackle observed issues
- Joint proposals with WPTE and WPW7X have been "granted" time: pre- and post-characterisation and PWI simulation
- New tasks in liaison with IO included in the plan (first wall mirrors)

Restructuring of WPPWIE and Tasks related to B

Existing subprojects with additional focus on boron

SP B:
- Characterisation of B layers (techniques)
- Production of artificial B layers with D and/or O content and associated characterisation

A. Hakola et al.

SP C:
- Fuel retention and release properties of B layers exposed to fuel species and build with fuel
- Simulation related to fuel trapping and release

D. Matveev et al.

SP D:
- Modelling of toroidal devices w/wo boronization, W and B sources and migration
- Global fuel retention simulations
- Production of atomic and molecular data with B

SP X:
- Qualification of LIBS on thin B-layers
- Qualification of LID-QMS on B-layers with fuel

Existing teams, good existing knowledge, well progressing

New subproject F with focus on wall conditioning

SP F1:
- Coordination of activities related to wall conditioning and boronisation with strong links to activities of machines in TE/W7-X
- Recapitulation of existing knowledge
- Benchmark in TE/W7-X experiments: manipulator / full device

SP F2:
- Activities at TOMAS with test of ITER conditions and needs: ECWC, ICWC, GDC
- Cleaning activities of B-layers from lab or tokamaks in TOMAS
- Application of in-situ LID-QMS or LIBS in those systems

A. Goriaev et al.

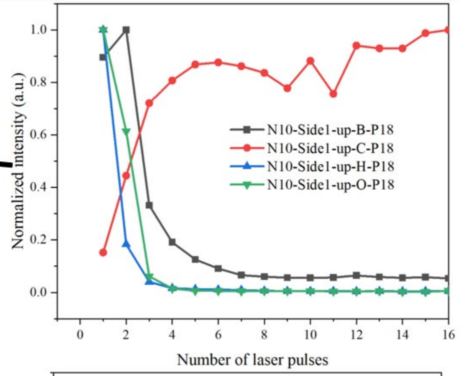
SP F3:
- Laboratory experiments with B layers (PSI-2, MAGNUM, GYM) focus on B erosion, deposition, retention within capabilities
- Generic wall conditioning studies

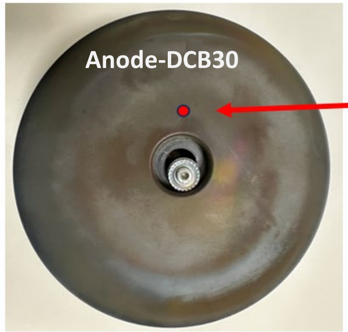
A. Goriaev et al.

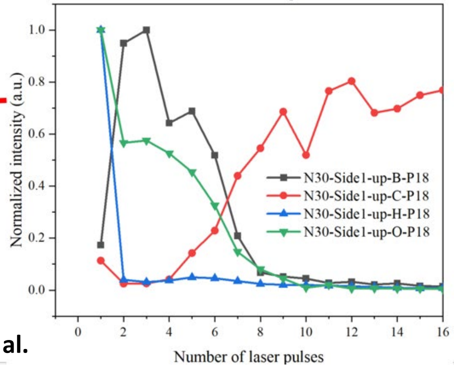
F1 challenging as experts are „machine experts“ and „no time“
F2 challenging if „infrastructure“ needs to be implemented
Still open issues and human resources required!

Examples: Analysis of anodes for boronisation in W7-X

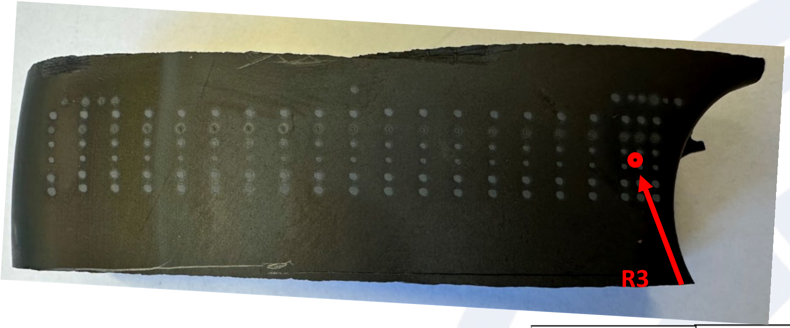
SP B:
- Characterisation of B layers (techniques)
- Production of artificial B layers with D and/or O content and associated characterisation



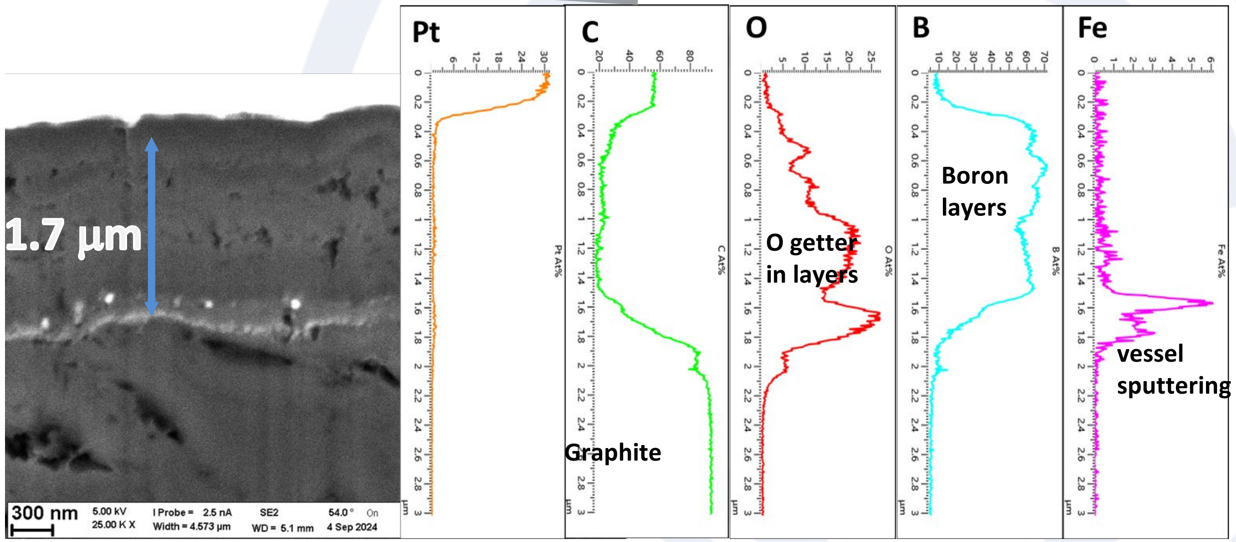




H. Wu et al.



SEM & FIB



MPG & FZJ

M. Rasinski et al.

- 4 anodes for boronisation used in W7-X analysed
- Toroidal asymmetry: Local B thickness 2µm
- Global B deposits on FW: <30nm (campaign)
- Local B deposits in divertor: µm (campaign)

M. Mayer et al.
D. Zhao et al.

- W7-X analysis studies planed before ITER considered B
- Materials available to study boronization homogeneity, role of valve, and anode
- O gettering capability quantification

=> New dedicated experiments in W7-X foreseen (with C.P. Dhard as contact):
thick B layer on W, Mo (mirror) and steel