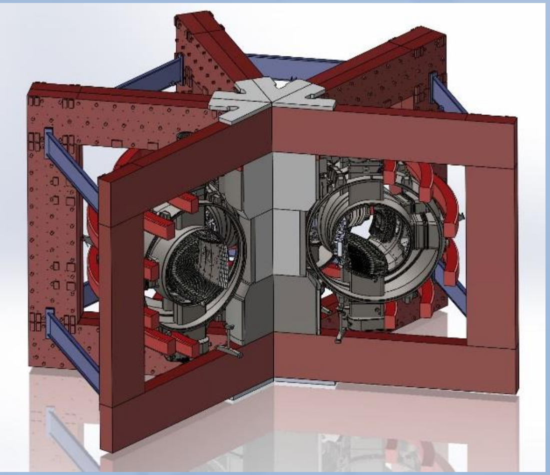
EUROfusion

He-W Plasma-Wall Interaction Studies in WEST



Sebastijan Brezinsek for WP PFC and WEST team

Project Leader WP PFC

JÜLICH Forschungszentrum

DE LA RECHERCHE À L'INDUSTRIE cea

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Outline

- Need for a He campaign in a metallic tokamak
- ITPA DivSOL activity: He-W plasma-wall interaction in metallic tokamaks
- PWI studies in WEST

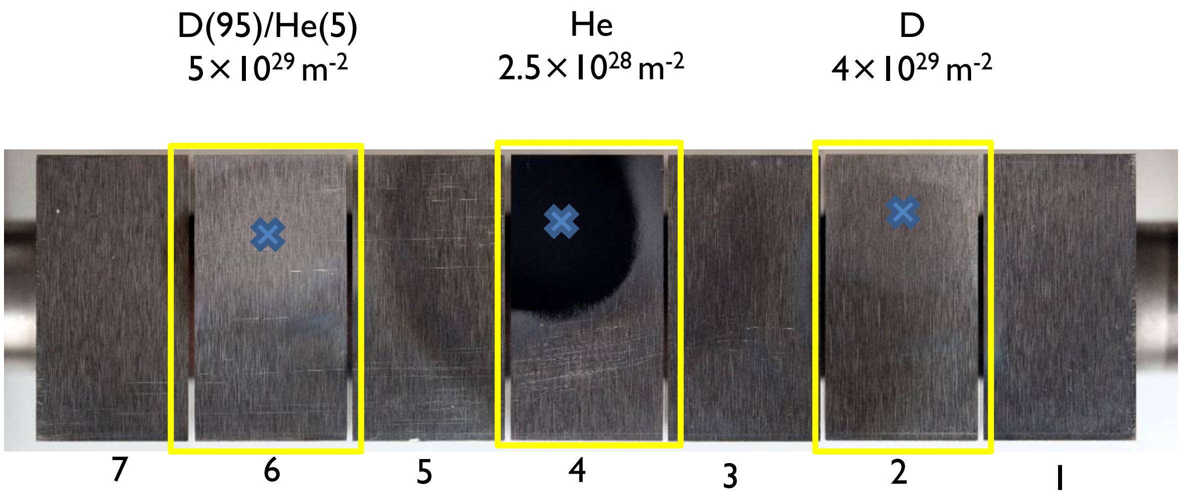
	Experiment title	Scientific Coordinator	Allocated time
WEST-6	Fuel exchange experiment: deuterium to helium plasma	T. Wauters (ERM-KMS) D. Douai (CEA)	3 sessions
WEST-7	Scrape-off layer width in helium plasmas	R. Dejarnac (IPP.CR) N. Fedorczak (CEA)	3 sessions
WEST-8	Tungsten sources in helium plasmas	G. van Rooij (DIFFER) A. Gallo (CEA)	4 sessions
WEST-9	Helium-Tungsten Plasma-Wall Interaction studies	T. Dittmar (FZJ) B. Pégourié (CEA)	5 sessions

- He plasmas in WEST: a testbed for physics understanding, diagnostics qualification, and plasma & PSI modelling

- Successful EUROfusion Call for participation:
~8 ppy onside and ~2ppy offside from 13 partners

Need for a He campaign in a tokamak?

- He is the fusion ash and will interact with the main chamber wall and divertor
  - Studies with ~10% c_{He}: assess plasma performance, fueling, and exhaust in He
  - Investigate accumulative effects of He in W wall and divertor PFCs
- Pre Fusion Power Operation in ITER will use He or He/H mixed plasmas
  - Assessment of ELM mitigation/ schemes in H-mode (mandatory for DD, DT)
  - He-W PSI and accumulative effects of He in W divertor PFCs (lifetime, operation)

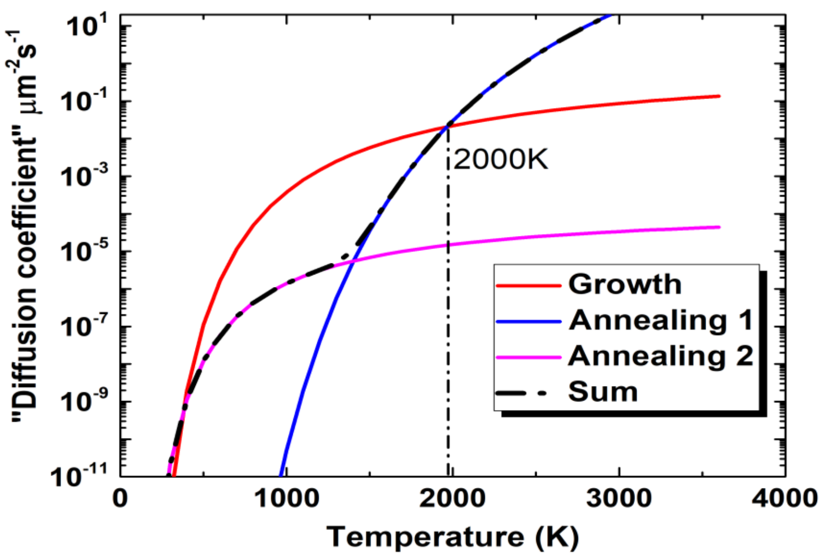


Mimic expected ITER PFPO fluence in MAGNUM-PSI on ITER W monoblocks in H, He, (D, D+He)

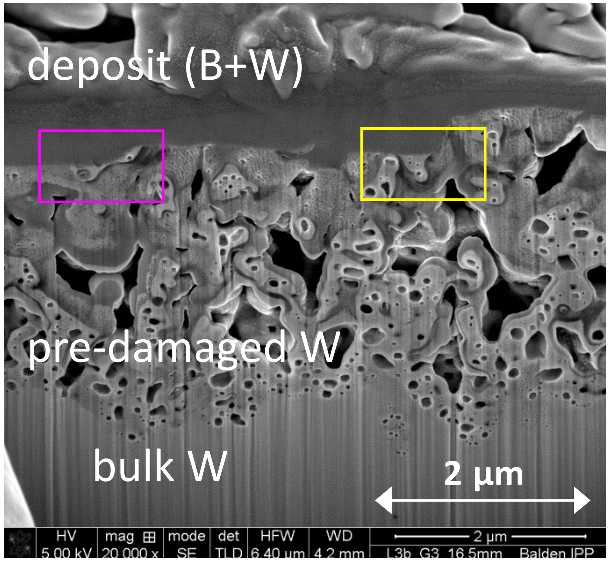
T. Morgan PFMC 2019

Need for a He campaign in a tokamak? II

- PSI between He and W potentially challenging for first ITER divertor operation
  - Avoid/minimise critical surface modifications and change of material properties (hardness, crystallization, retention, brittleness etc.)
  - W PFC lifetime estimates: He role on W erosion and power handling
- Complex toroidal geometry, shallow impact angles, re-deposition at high mag. field
- Test of models concerning W fuzz formation / annealing / erosion / deposition



G. De Temmerman NME 2018



S. Brezinsek NME 2018

ITPA DivSOL task 33:
He operations in metallic devices

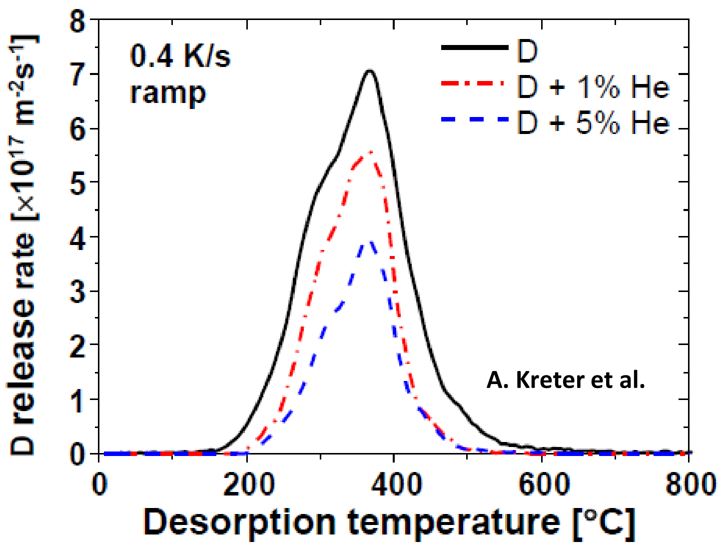
- *Investigate W nanostructure formation, growth, or re-erosion in divertor conditions with high magnetic field in toroidally confined (He) plasmas.*
- *Study re-erosion of pre-formed W nanostructure by ELM-impact.*
- *Assessment of the potential risks concerning the W PFC properties with full He operation in ITER during restart.*

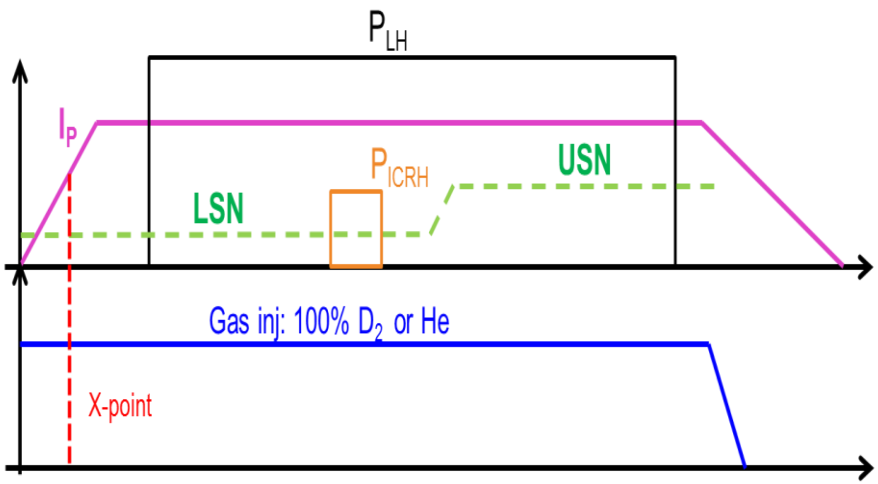
Device	2016-2018	2019	
AUG*	Exp. done	Yes	W samples in divertor manipulator
EAST	Not done	Yes (?)	W samples in midplane manipulator
WEST*	Not done	Yes	Analysis of ITER-like W PFUs after campaign
JET*	parasitic	parasitic	Spectroscopy and gas balance only

- WEST experiment will connect tokamak and linear plasma experiments owing to the high achievable fluence. Essential step towards predictive modelling for ITER

WEST-6: Fuel exchange experiment between deuterium and helium plasma

- He implantation in W documented and observed in ASDEX Upgrade (GDC)
- Short- or longterm retention of He in W

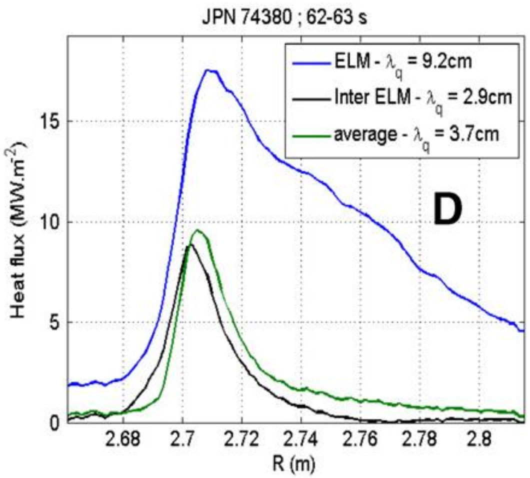


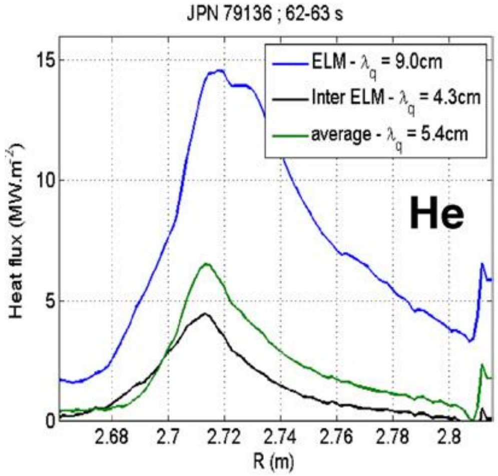


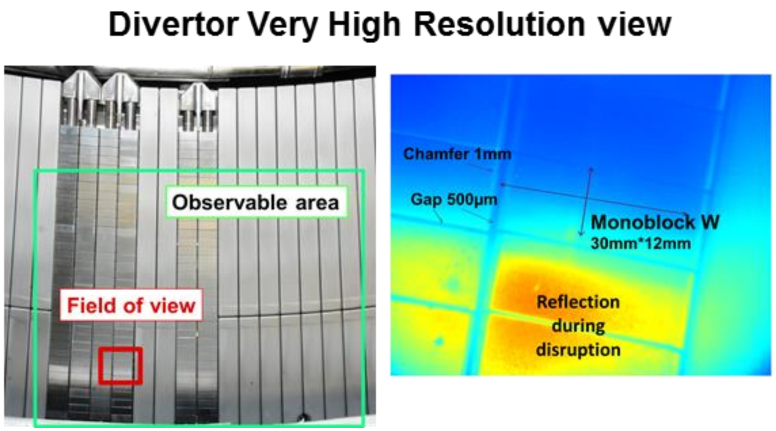
- Assessment of accessible "reservoirs" (D and He) through plasma experiments
  - assess He trapping / D fuel recovery while switching from D to He
  - assess He recovery and minimse He retention during He to D changeover
- Evaluation of the characteristic time (flux and) fluence for changeover in a W device

WEST-7:
Scrape-off layer width in helium plasmas

- Difference in SOL width reported in JET experiments: $\lambda_q^{He} > \lambda_q^{D}$
- Power-decay length models (incl. Eich scaling) suggest a dependence on aspect ratio => WEST unique device world wide to test





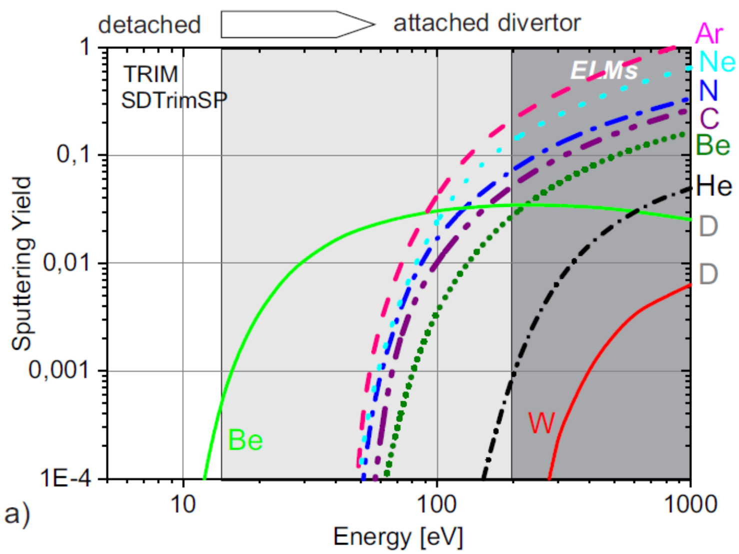


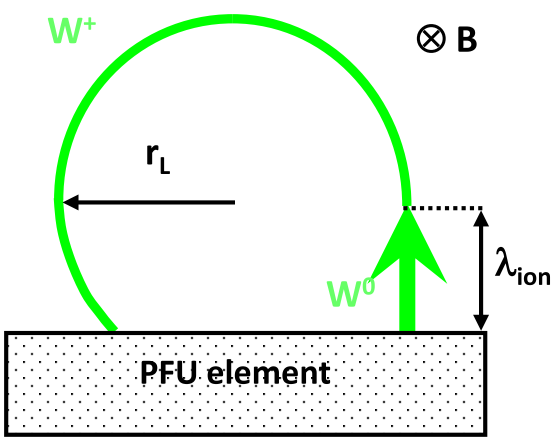
Fundamenski NF 2011

- Scan in plasma current, x-point height, flux expansion and power
- Comparison with reference plasmas in deuterium
- If H-mode reached: inter and intra-ELM analysis

WEST-8: Tungsten sources in helium plasmas

- In general: W sputtering determined by impurities in L-mode plasmas
- Enhanced W sputtering in main chamber in He plasmas
- Increased W migration from main chamber W PFCs into the W divertor (DEMO)



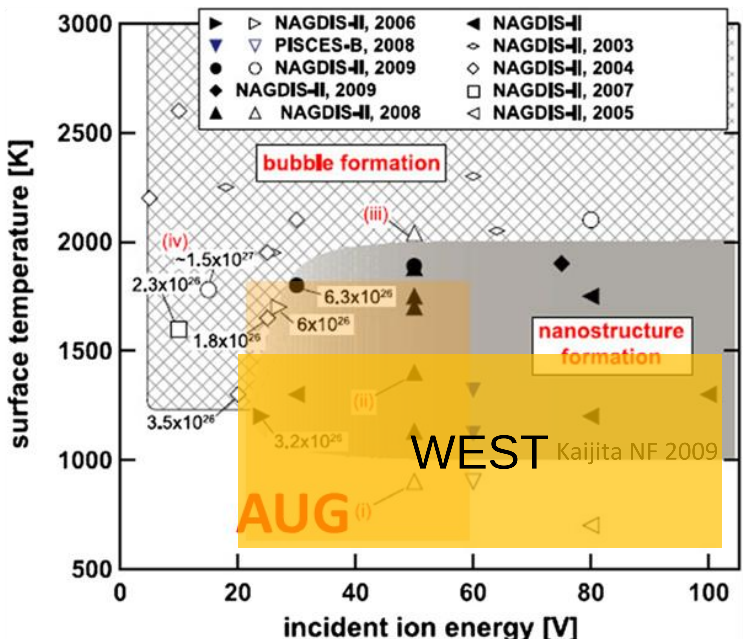


- In-situ spectroscopic analysis
- Post-mortem analysis
- PSI model validation (ERO)

- Prompt redeposition on rough and smooth surfaces
- W sputtering with He implanted

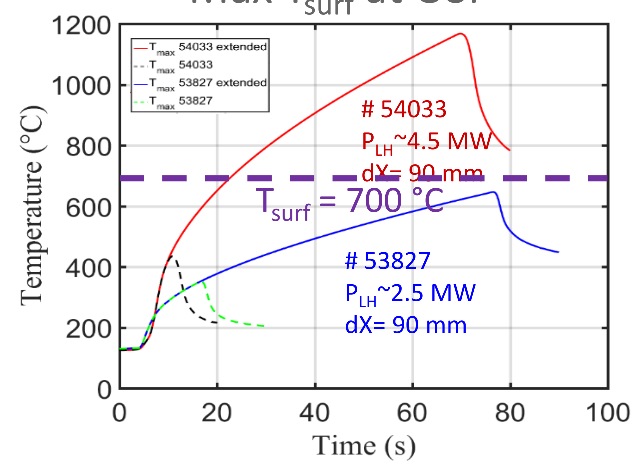
WEST-9:
Helium-Tungsten Plasma-Wall Interaction

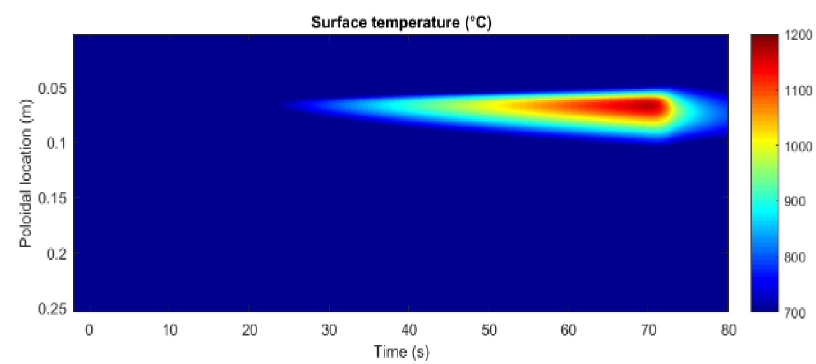
Conditions for W fuzz formation can be achieved in WEST long pulse discharges
(i) Impact energy >20 eV (ii) Surface temperature 1000-1800 K
(iii) He fluence > 2×10^{24} m^{-2} at uncooled W-coated PFUs



- In-situ diagnosis
- Post-mortem analysis

Max T_{surf} at OSP



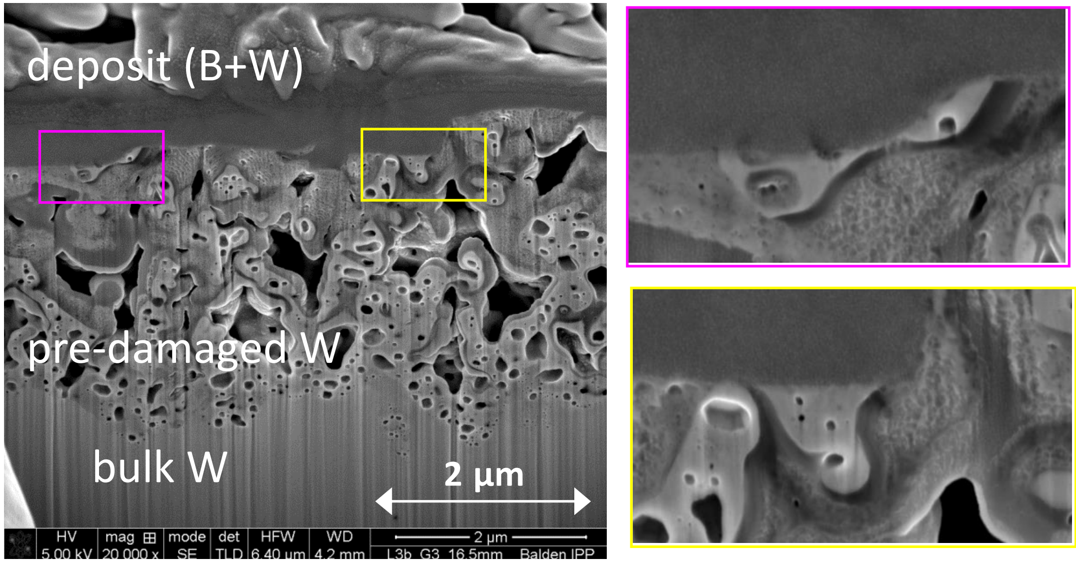


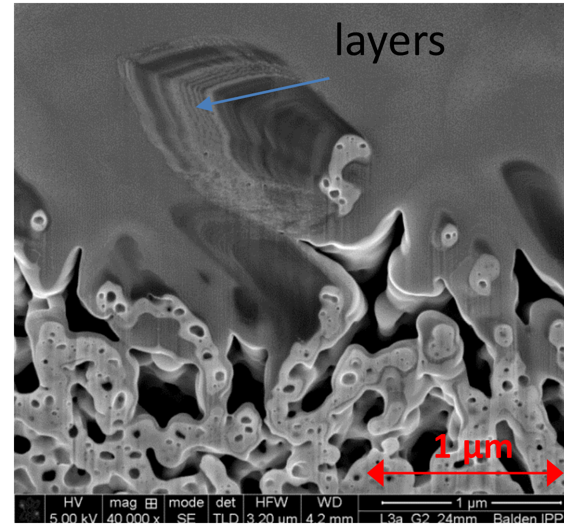
Expand L-mode: I_p=0.5MA P_{LH}=4.5MW

We are ready for the EUROfusion He campaign in WEST…

… international partners are welcome to participate with us and CEA

DSOL-33 experiment in ASDEX





S. Brezinsek NME 2017

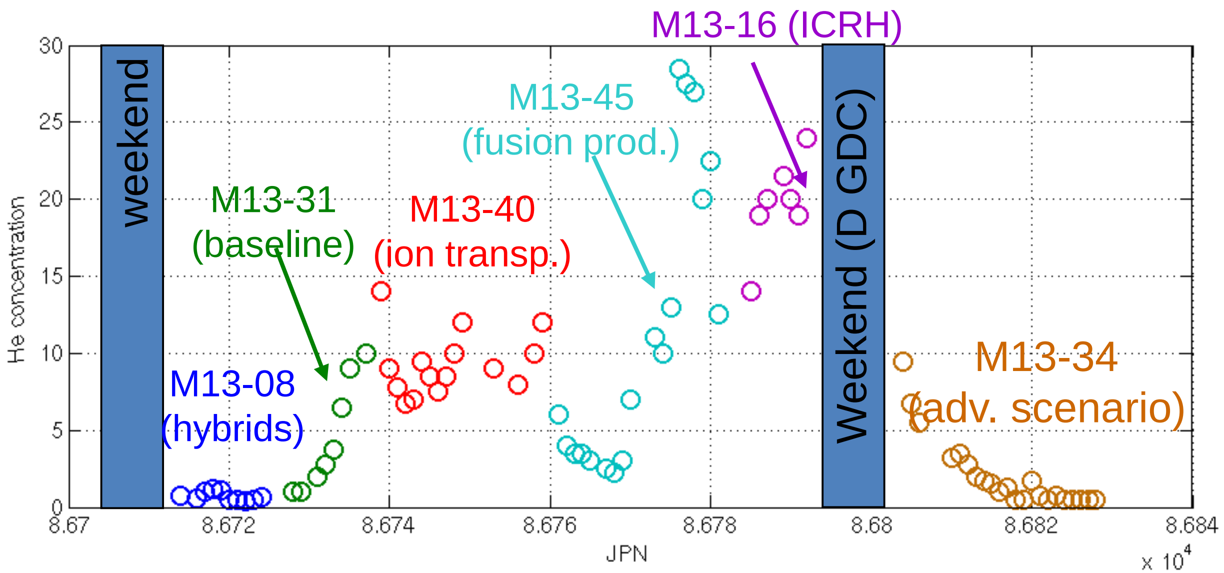
- **D-plasmas**: Outer divertor under similar plasma conditions is a **net erosion** zone for W
- **He plasmas**: Outer divertor transferred on W samples into a **net deposition** zone
- Coverage of the W samples surfaces by B, C, and some W
  - B mainly from previously performed boronisations in AUG
  - W results mainly from main chamber W source and minor local re-deposition of W

⇒ Determination of (light) ion flux mix (He, B, C) impinging onto the W divertor
⇒ Study the role of W eroded from main chamber entering the W divertor (in D & He)
⇒ Study W divertor surface morphology evolution in WEST at higher He fluence with dedicated IR and VIS imaging (e.g. AIA)

DSOL-33 experiment in JET

- No dedicated operational time in JET-ILW for He operation currently foreseen
- In case of JET prolongation – full He campaign is granted

- One day of L-H threshold studies in He plasma during restart scheduled
- Parasitic measurement for DSOL-33 possible
  - Study retention of He in W and Be and fuel exchange time
  - Regular monitoring pulse to document change of conditions (restart)
  - Study surface modification on bulk W if high plasma fluence can be reached
  - Determine impurity influx increase from Be wall and W sputtering in divertor

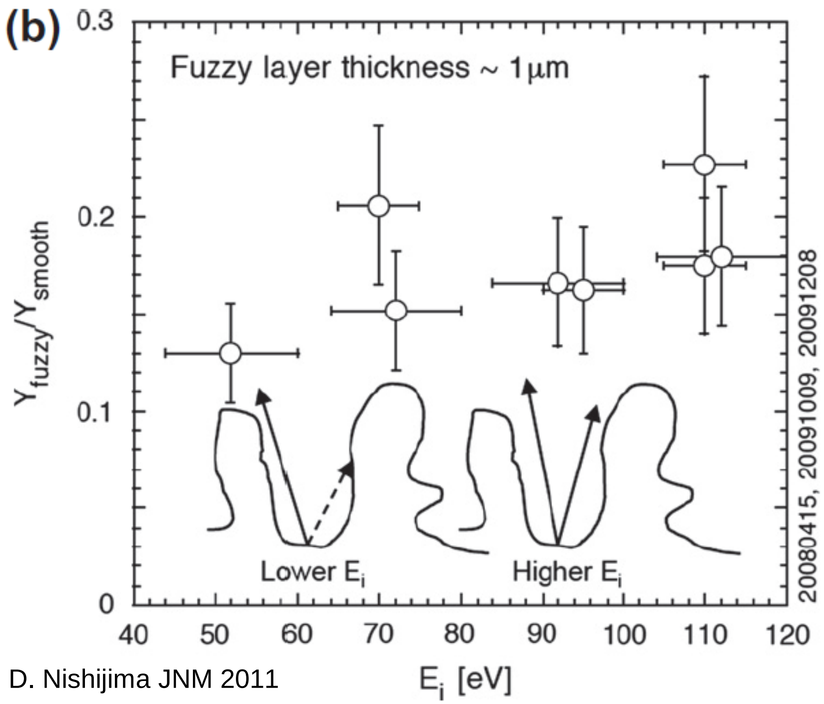


Earlier ^3He studies in JET-ILW indicate residence time of He In W and Be

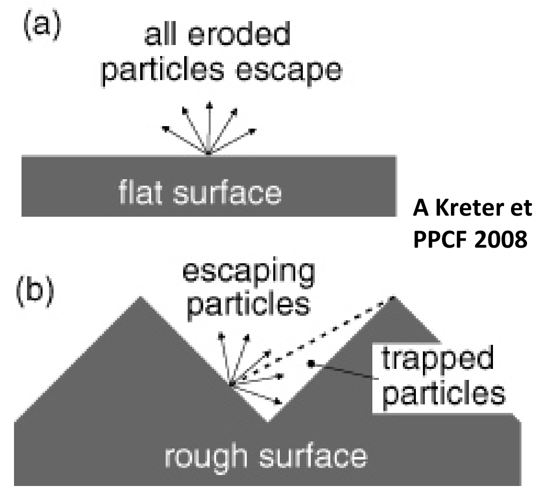
E. Lerche et al.

W main chamber wall sources / Surface roughness enhances net deposition

- Enhanced W main chamber source due to He^{2+} impact in contrast to D^{+} impact
- Flux of W ions impinging divertor is challenging to measure (e.g. W isotopes)
- High W self sputtering erosion yield needs to be considered (in modelling)



D. Nishijima JNM 2011



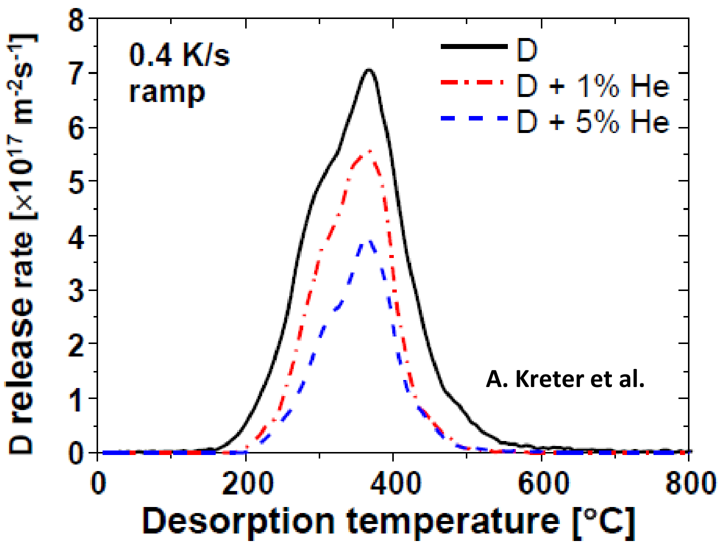
A Kreter et al. PPCF 2008

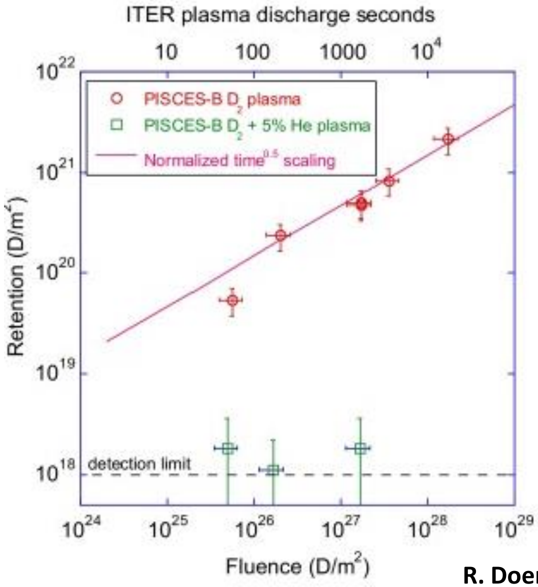
Enhanced W re-capturing of already high prompt redeposition

- W sputtering yields for perfect W surfaces well described (BCA): E_{thres}~150 eV
- Technical surface has significant roughness: re-capture of eroded W enhanced
- Surface can switch from erosion to deposition zone (same plasma conditions)

He retention in W: quantification and release

- TEXTOR, ASDEX-Upgrade, and JET-ILW showed He retention in W PFCs
- AUG He-GDC lead to >30% He in subsequent D plasmas!
- In D/He mixtures can the retention of D in W be reduced owing to He in the near surface [PISCES, PSI-2 etc.] => depends strongly on surface temperature
- He nanobubbles might lead to open porosity network => quick release of D



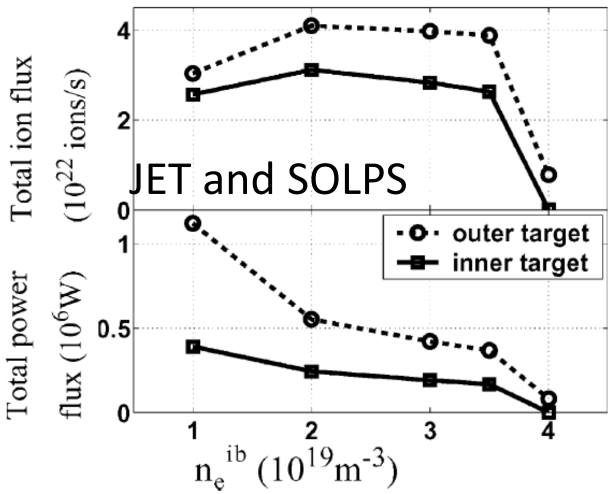


R. Doerner et al.

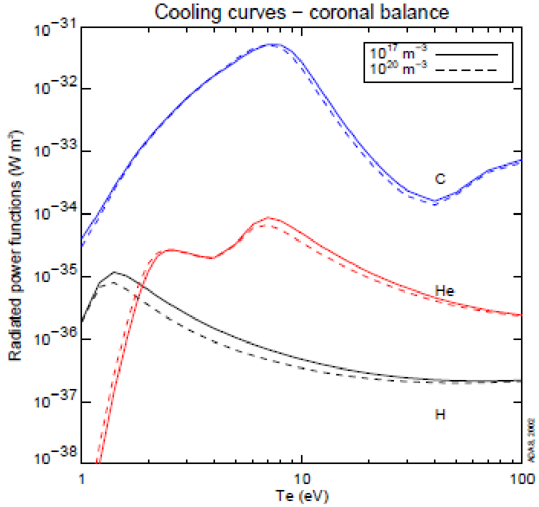
- Comparative gas balance in 100% D_2 and 95:5 D/He mixture in WEST (and EAST)
- Isotope exchange experiment to quantify dynamic He content in WEST (and EAST)

Detachment: absence of hydrogenic molecular physics in He plasmas

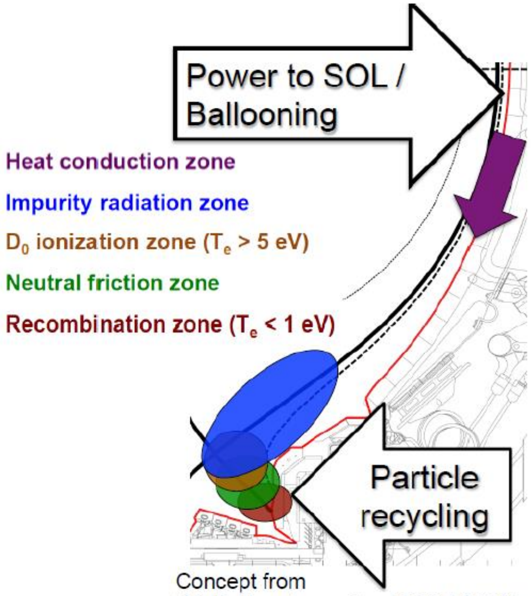
- In-out asymmetry in detachment modelling not yet resolved
- Metallic walls eliminated the "free radiation" parameter used in C walls
- Further step forward by comparing He and D plasmas and elimination of the complex deuterium molecular physics => reduce uncertainties



M. Wischmeier JNM 2003



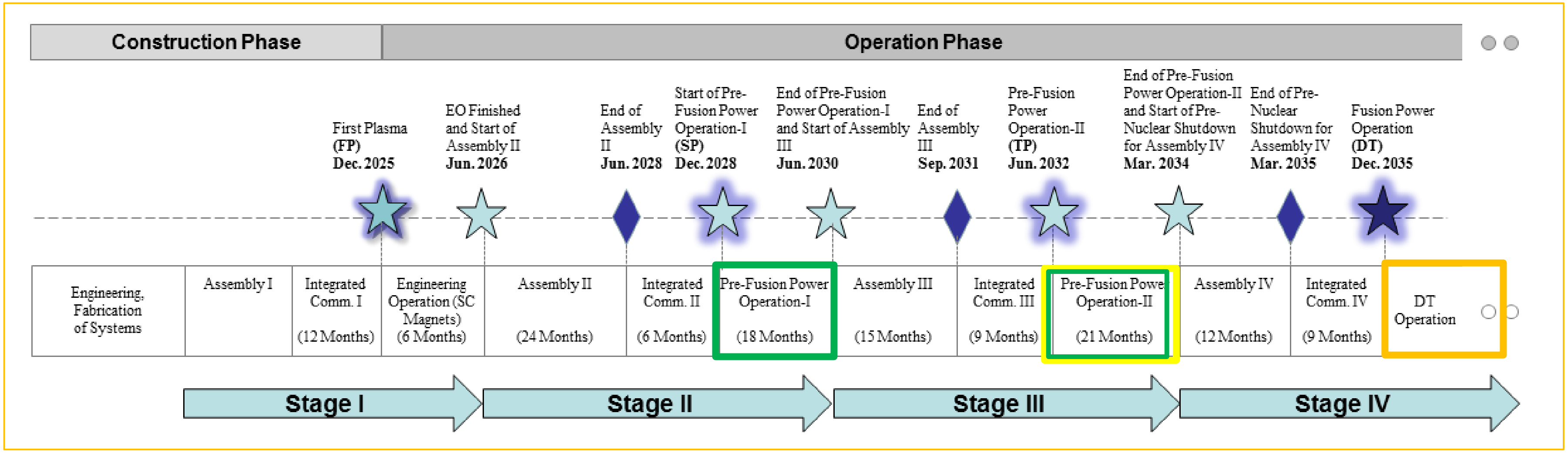
M. O'Mullane ADAS 2002



Concept from [M. E. Fenstermacher, PPCF 1999]

- Compare divertor detachment in L-mode in D and He in WEST
- Benchmark of SOLPS-ITER and SOLEDGE-EIRENE
- Provide plasma background for ERO2.0

MAGNUM tests – ITER Monoblocks



ITER operational phase

PFPO1/2

PFPO1/2

FPO1

FPO1/2/3

Block	Front/back	Plasma species	Max T_{surf} (°C)	Max Fluence (m^{-2})	Max Flux ($s^{-1}\ m^{-2}$)
1	None				
2	Back	D	1215	4.1×10^{29}	1.0×10^{25}
3	Front	H	615	1.0×10^{29}	1.2×10^{24}
4	Back	He	840	2.5×10^{28}	2.9×10^{24}
5	Front	D	1225	1.0×10^{30}	1.5×10^{25}
6	Back	D:He (95:5)	1205	5.0×10^{29}	1.3×10^{25}
7	Front	D:He (95:5)	1220	2.8×10^{29}	1.2×10^{25}