Progress in analysis of PWI issues for ITER and research needs

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With contributions from ITER Scientist Fellows on Fuel retention management

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Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

Quick overview of ITER progress

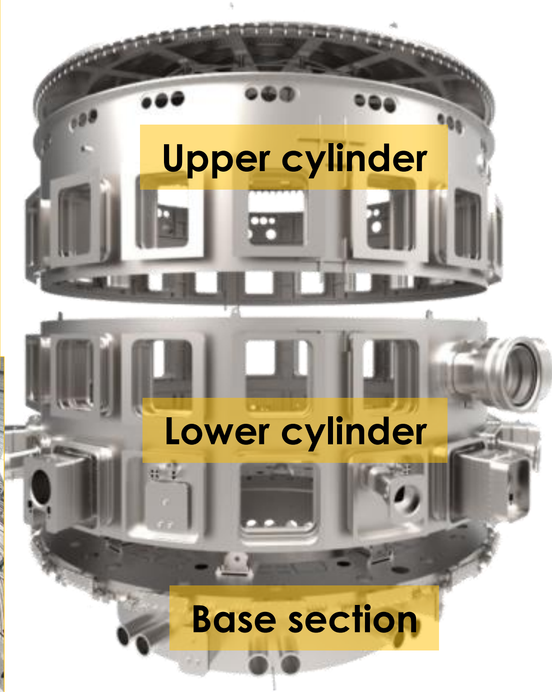

Cryostat cylinders in storage
Cryostat Workshop
PF Coil Winding Facility
Assembly Hall
Cryoplant
400 kV Switchyard
Heat Rejection System
Magnet Power Conversions Bdgs.
Contractors area
Tokamak building
Tokamak Complex
June 2020

6 years of progress

April 2014

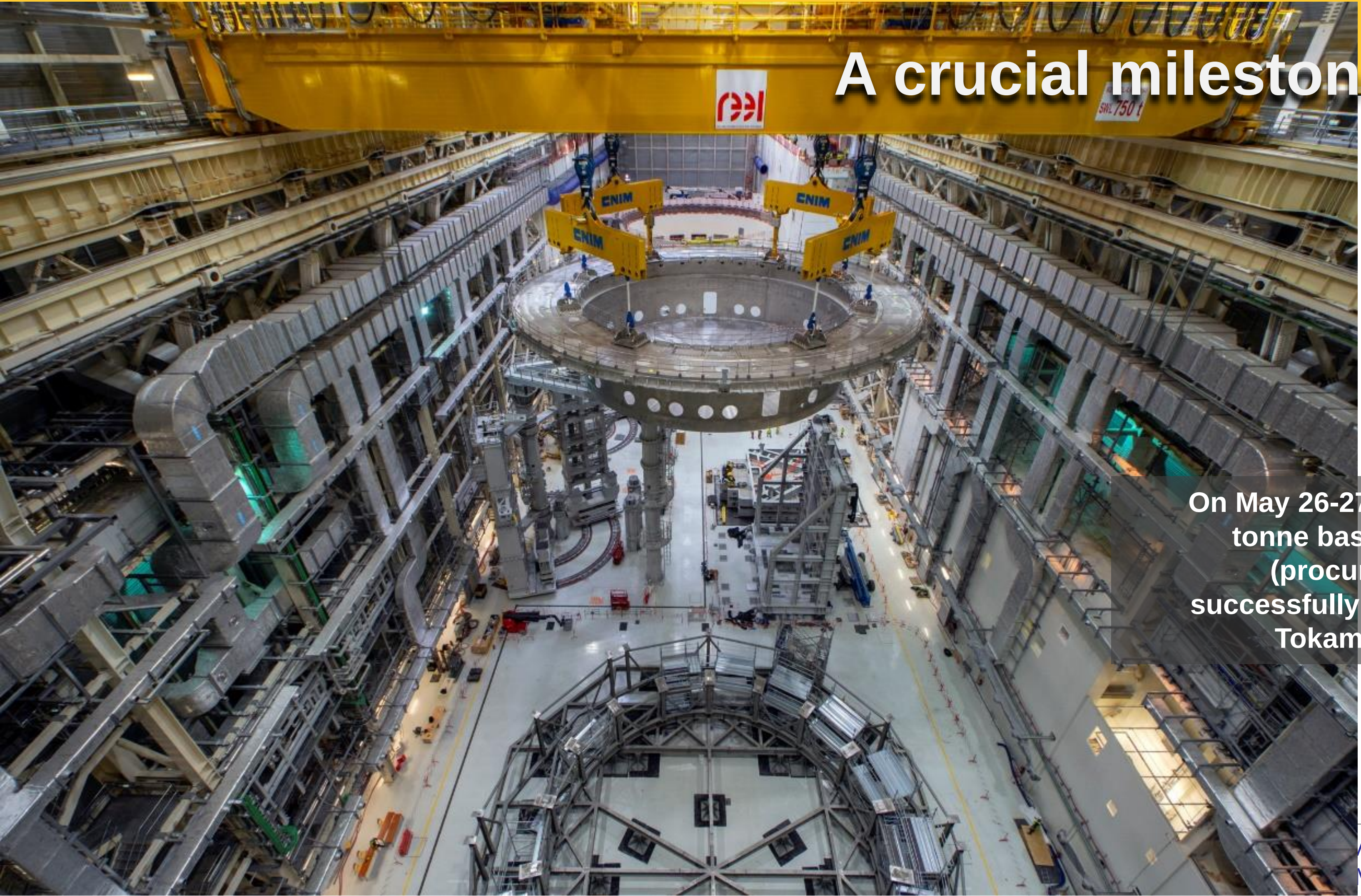
March 2020

Tokamak assembly



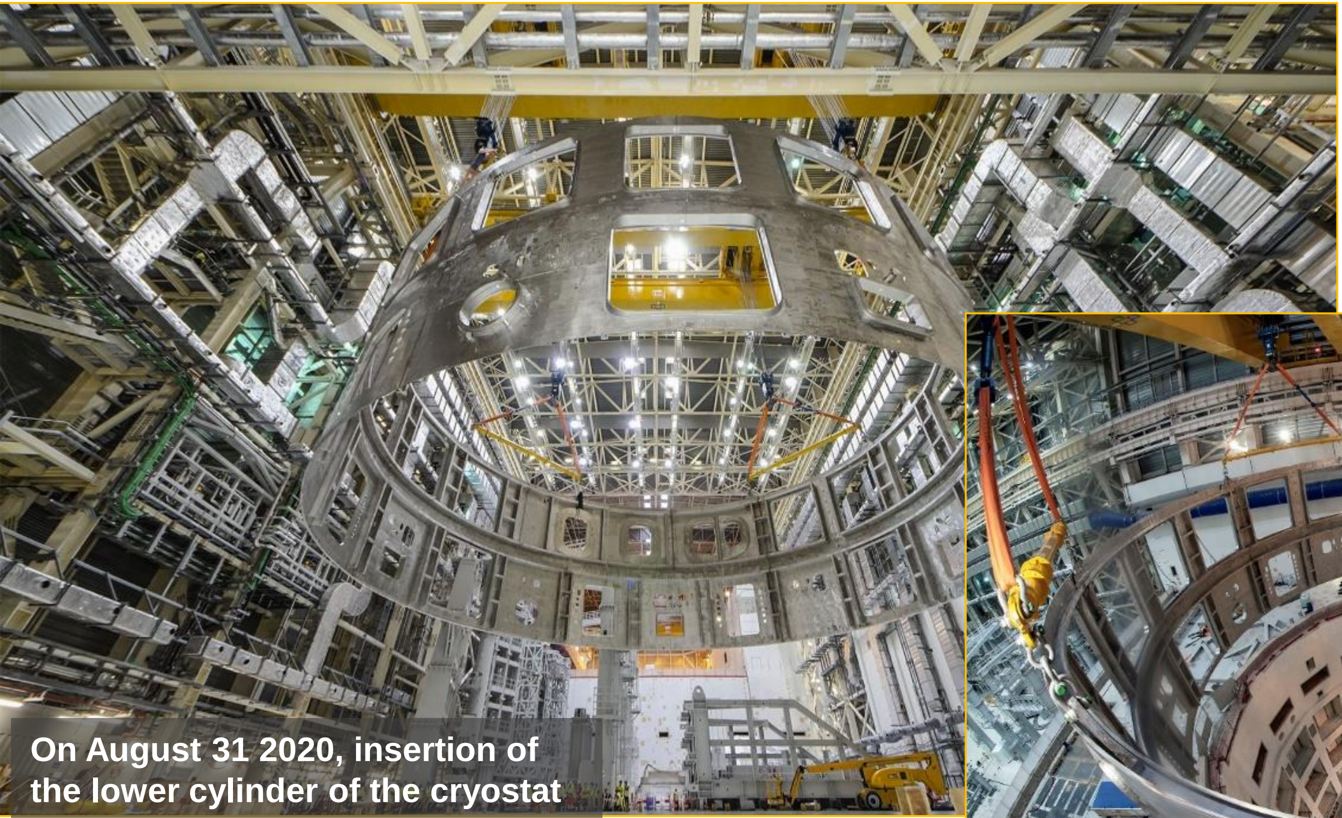
Manufactured in pieces in India, the 30 m x 30 m Cryostat is then welded together onsite

A crucial milestone

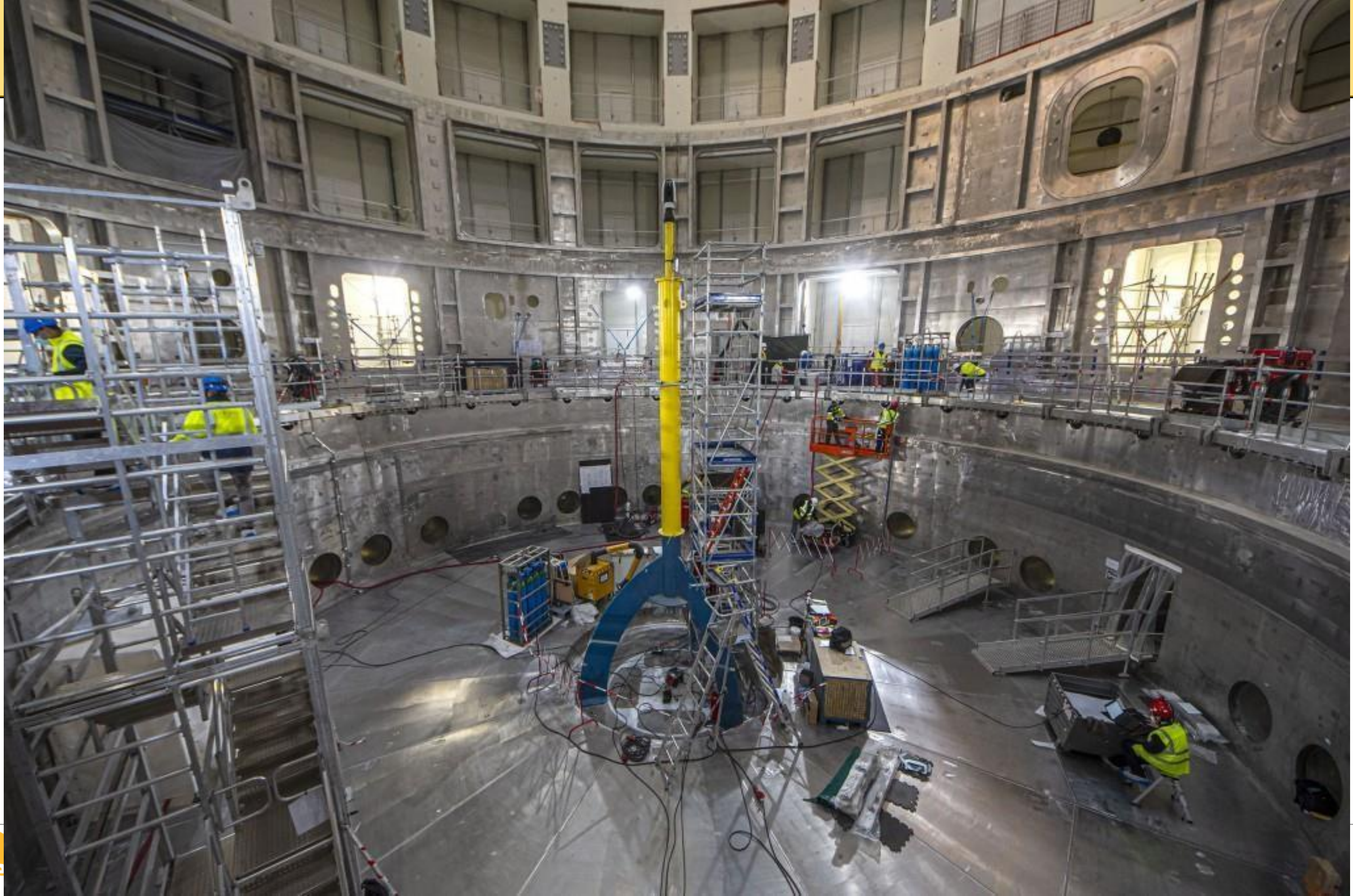


On May 26-27 2020, the 1,250-tonne base of the Cryostat (procured by India) was successfully inserted into the Tokamak Assembly Pit.

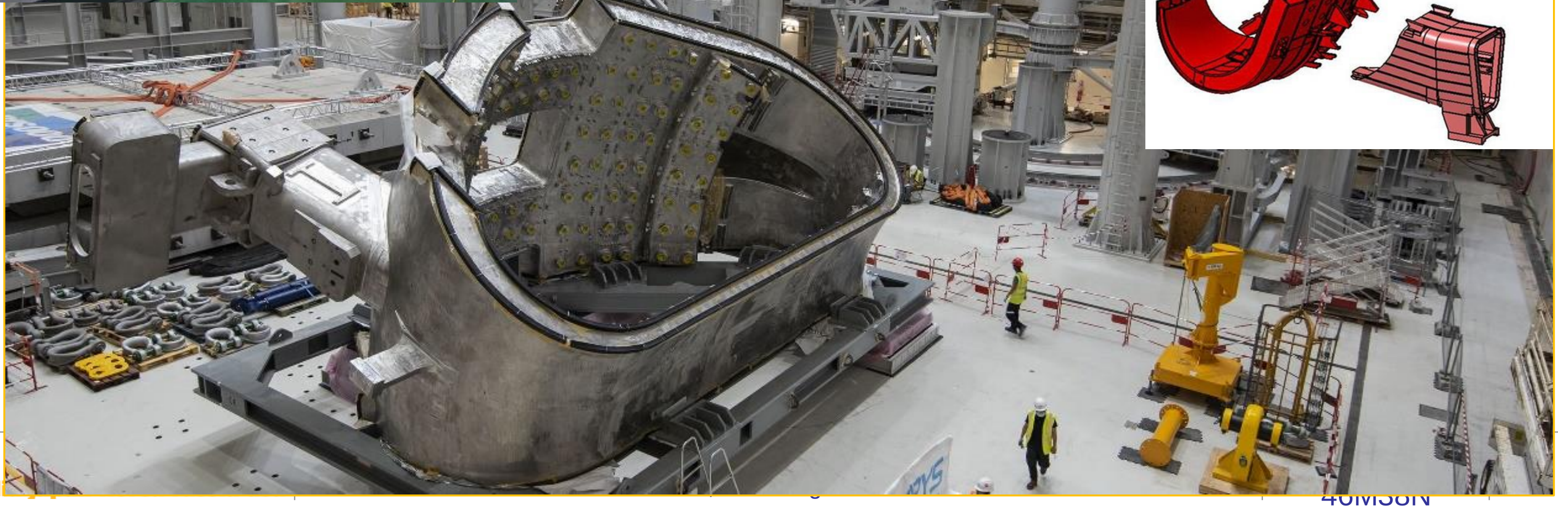
Cryostat assembly

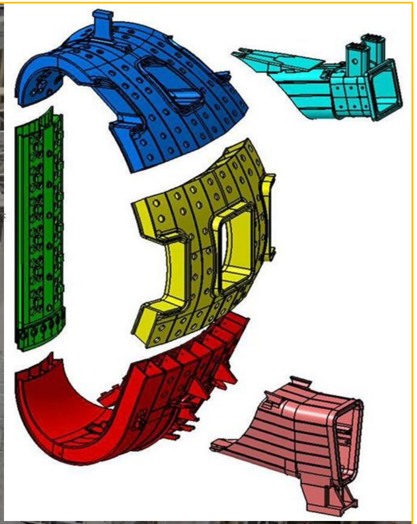


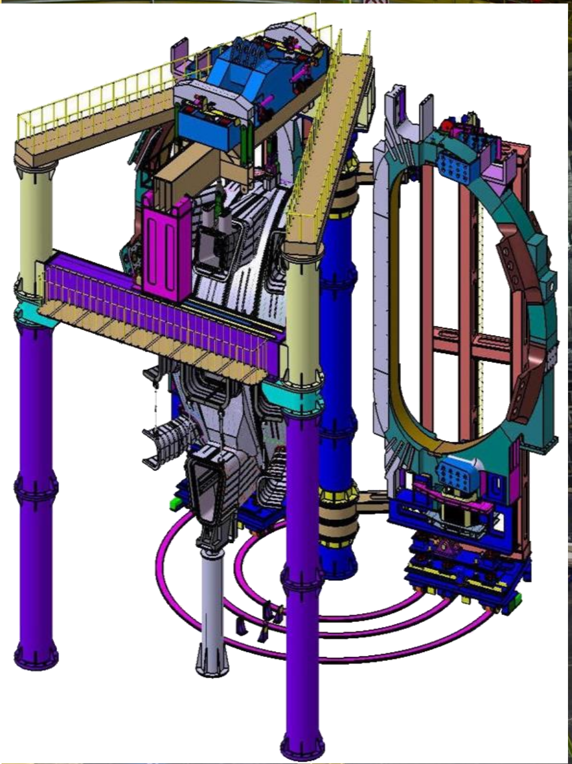
On August 31 2020, insertion of
the lower cylinder of the cryostat



Vacuum vessel

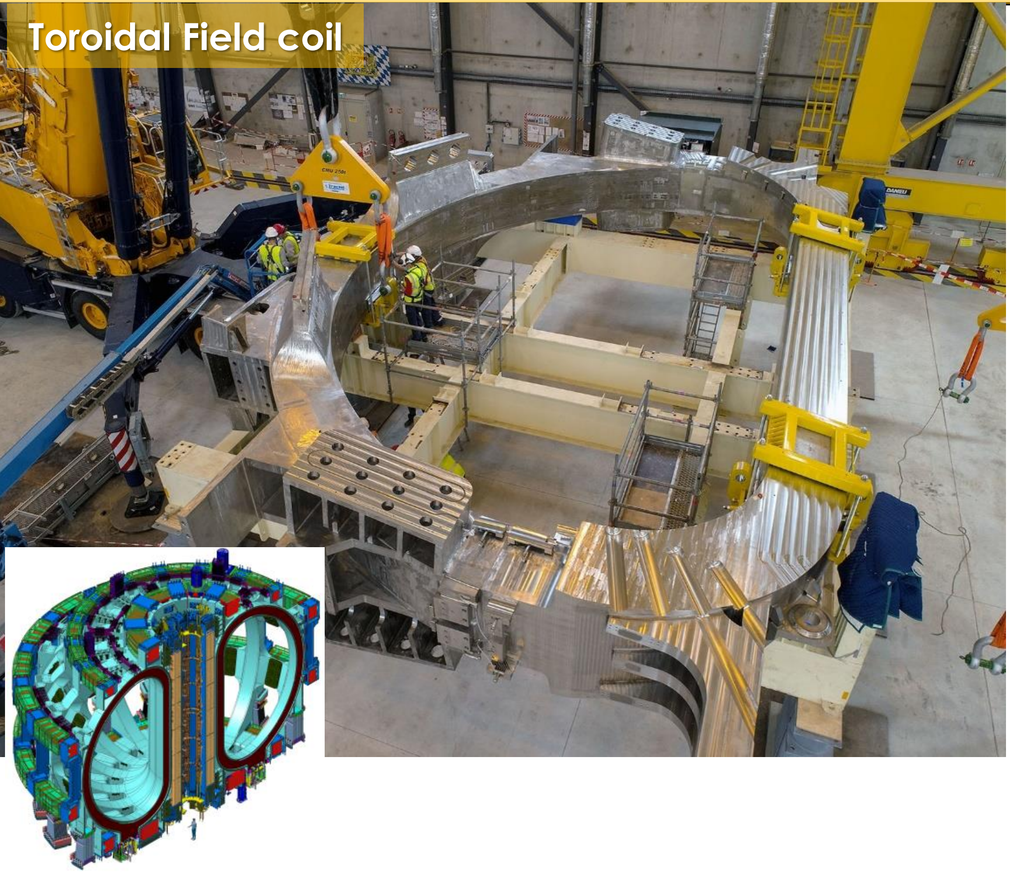




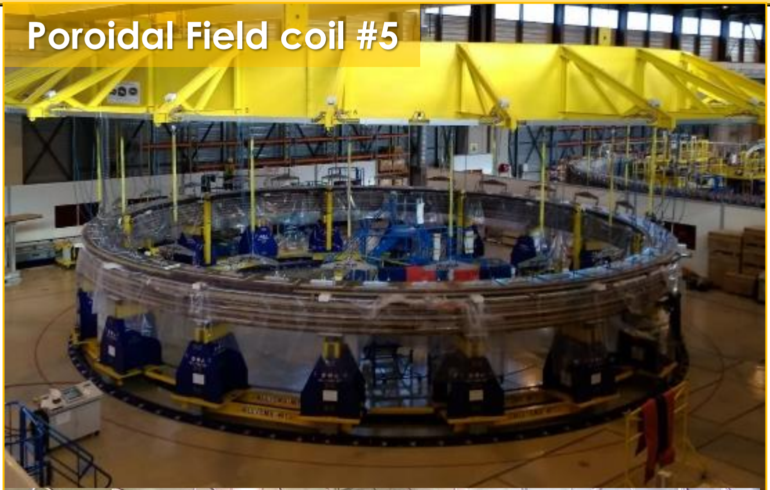



6000 m^2, 60 m high, double overhead travelling crane with 1500 ton lifting capacity

TF and PF coils



Toroidal Field coil



Poroidal Field coil #5

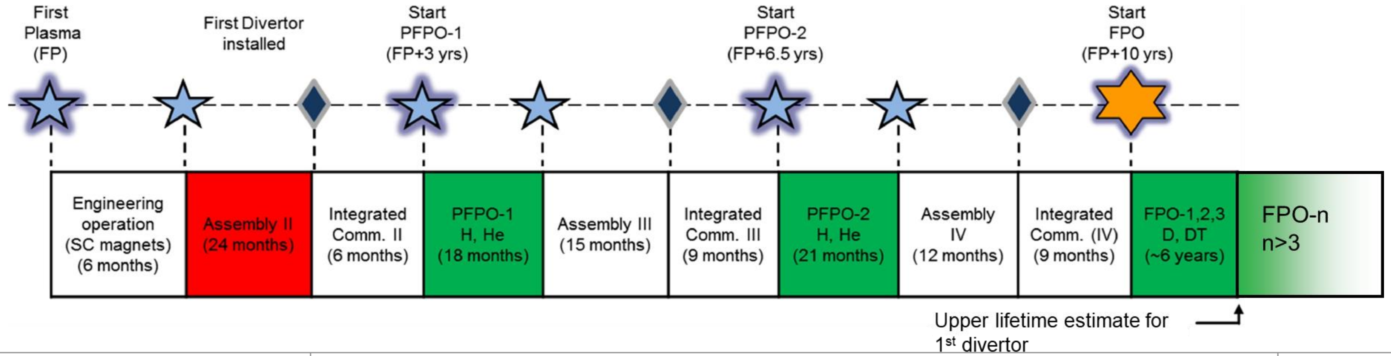
Poroidal Field coil #6

Deliveries keep coming

ITER PWI progress and priorities

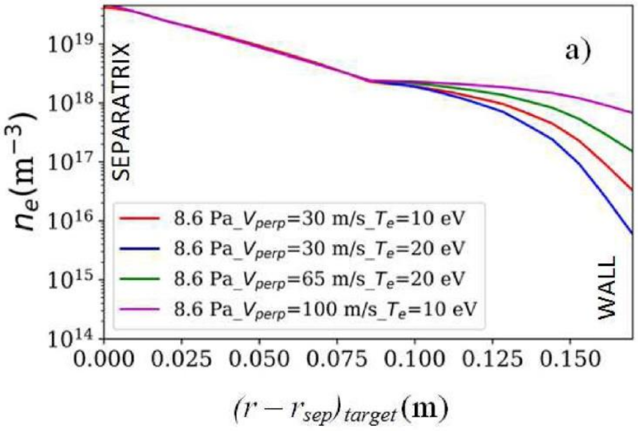
RPrS update

- Preparation work for the update of the RPrS which is due in 2023
  - Review of progress since previous version for dust and T inventory
  - Identification of gaps and required R&D to fill gaps
- (conservative) Estimates of dust performed for different operations phases
  - Number of discharges and duration derived from ITER Research Plan
  - Erosion from WALLDYN and melting/splashing during disruptions assumed as main mechanisms



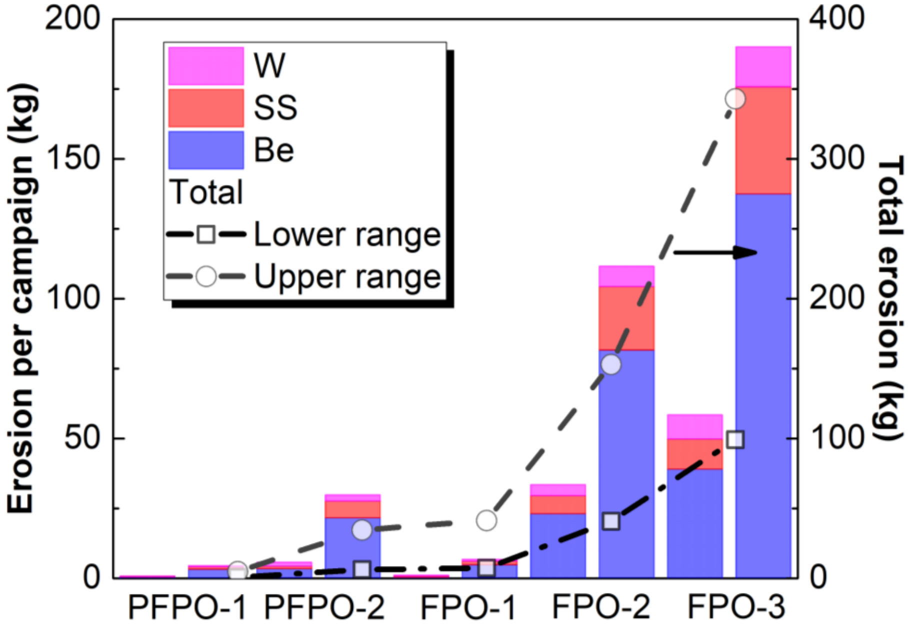
Total wall erosion

- For the different phases, different assumptions are made for edge plasma properties



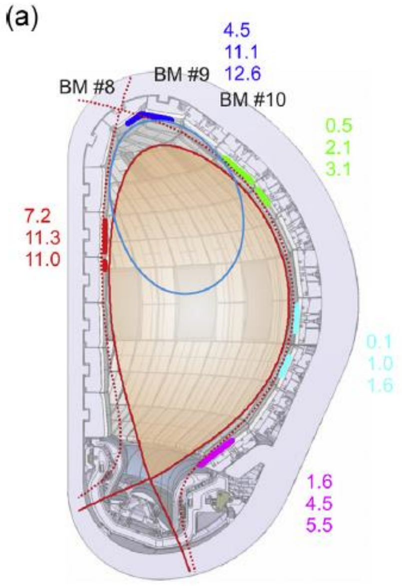
A. Khan et al, NME 20 (2019)

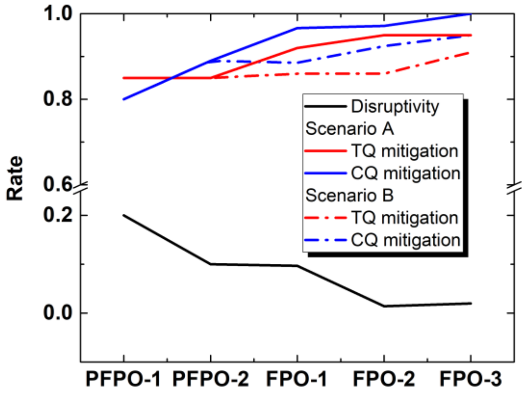
G. De Temmerman et al, to be submitted

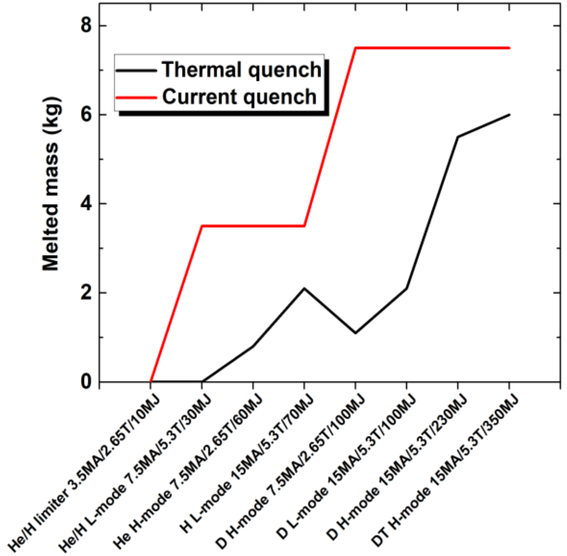


Total wall melting and splashing

- Amount of melted and evaporated material evaluated as a function of plasma current and stored energy
  - Disruptivity: 0.2 for PFPO-1, 0.1 for PFPO-1
  - 25% of molten material ejected as droplet (very conservative)







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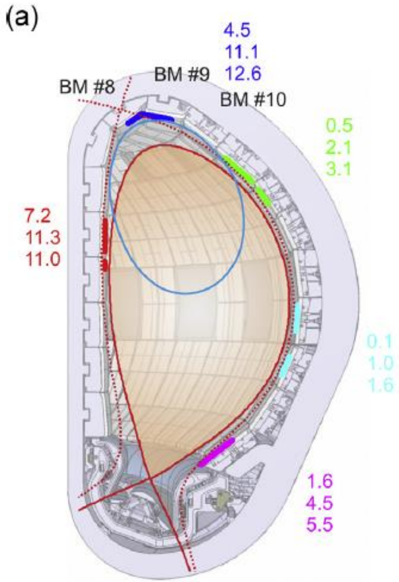
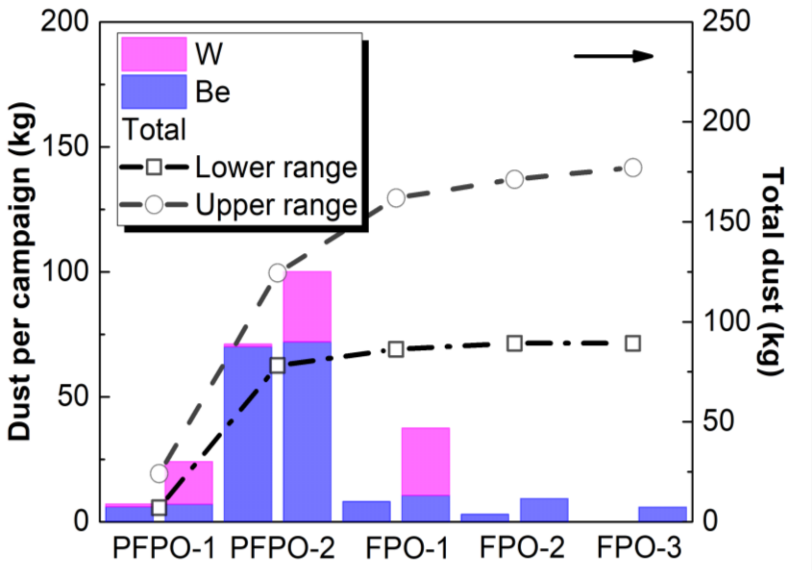
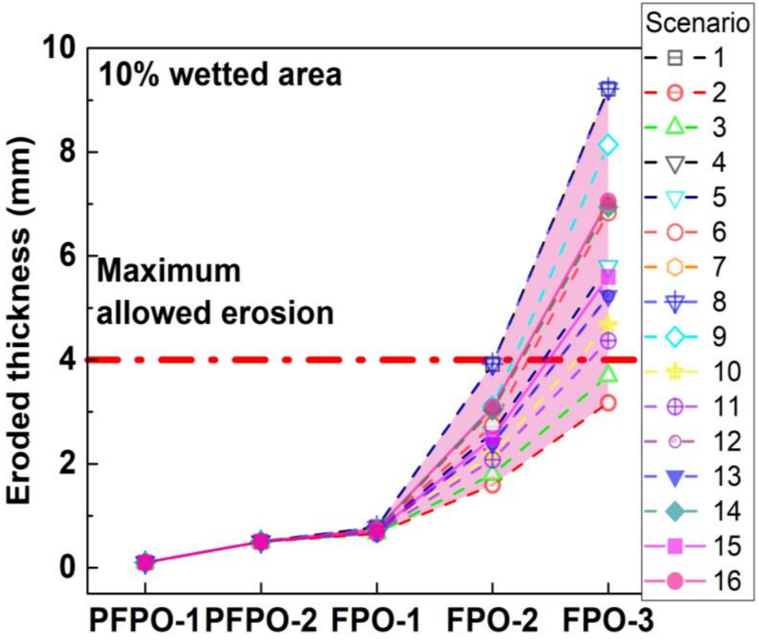


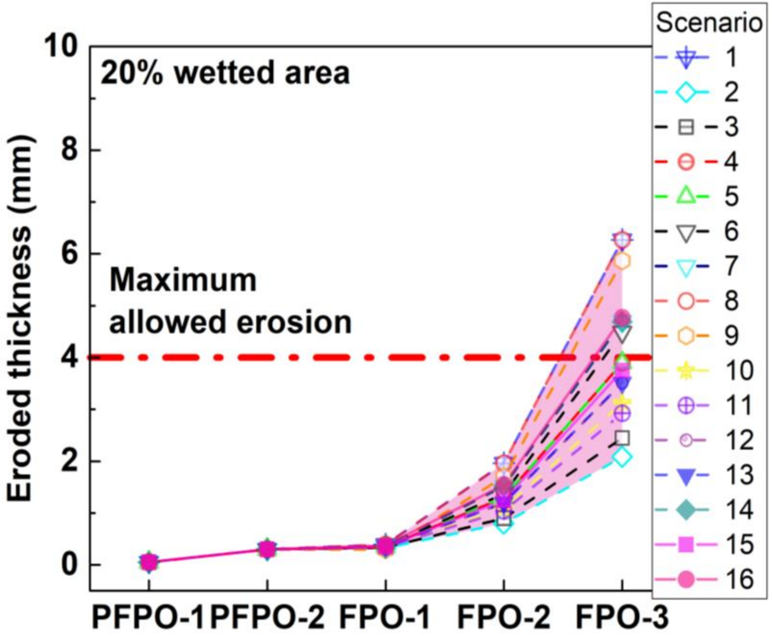


G. De Temmerman et al, to be submitted

Taking into account component lifetime

- Above estimates do not take into account the maximum allowable component erosion
  - Operations will have to be adapted to ensure sufficient erosion lifetime

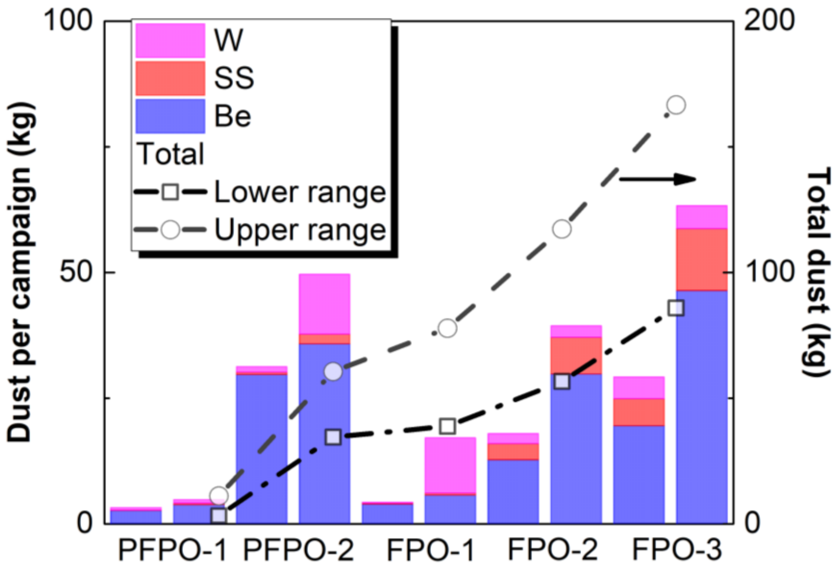




G. De Temmerman et al, to be submitted

Total dust production

- Assume 50% conversion factor from erosion to dust (43% highest number from JET)
- 10% of melted material is dust (less than 1% in JET, but difficult to extrapolate)



G. De Temmerman et al, to be submitted

OPERATING PHASE	LOWER ESTIMATE (KG)			UPPER ESTIMATE (KG)		
	Be	W	SS	Be	W	SS
PFPO-1	2.65	0.49	0.07	3.8	7	0.28
TOTAL	3.2			11.1		
PFPO-2	29.7	1.14	0.45	35.7	11.9	1.92
TOTAL	31.3			49.6		
FPO-1	3.9	0.15	0.2	5.7	11	0.4
TOTAL	4.3			17.2		
FPO-2	12.75	2	3.2	29.8	2.3	7.3
TOTAL	18			35		
FPO-3	19.5	4.3	5.4	46.4	4.6	12.2
TOTAL	29.2			63.2		

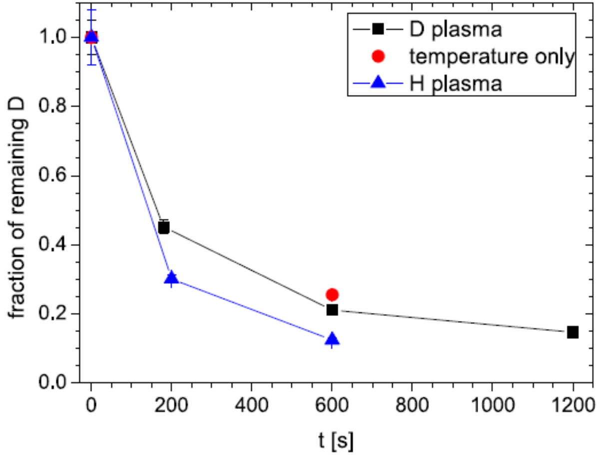
Recommendations from NSAR

- **Validation of the ITER predictions will require detailed dust collection during the first few years of operations making use of the progressive start-up of the machine foreseen in the ITER Research Plan. This includes the determination of :**
  - Amount, composition, hape and specific surface area, location of dust accumulation, adhesive and cohesion properties, mobilisable dust vs re-solidified dust
- **Provisions for dust analyses (on-site preferable) necessary**
- **Removal of divertor cassette(s) during each long-term maintenance appears to be the only way to check for dust below the divertor**
  - **Not currently foreseen. Recommendation to plan for this now**
- **Continuing R&D program in current devices and development/improvement of predictive capabilities**

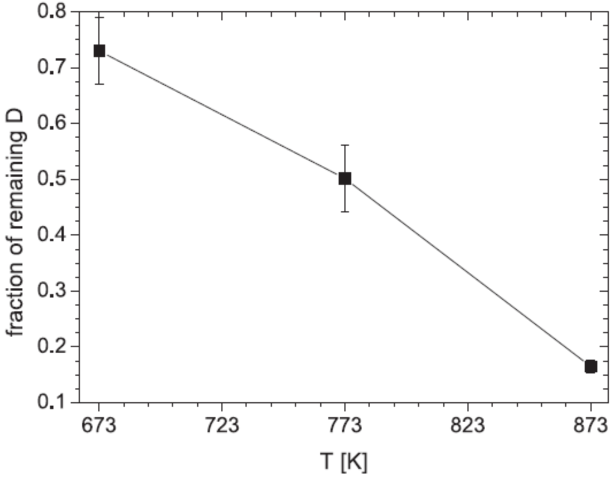
Plasma-induced outgassing

- Series of experiments at PISCES-B to investigate possibility of T-removal through strike-point sweep
  - 3-µm thick Be/D co-deposits formed by magnetron sputtering and exposed to H plasmas in PISCES-B

T=773K



t=180s



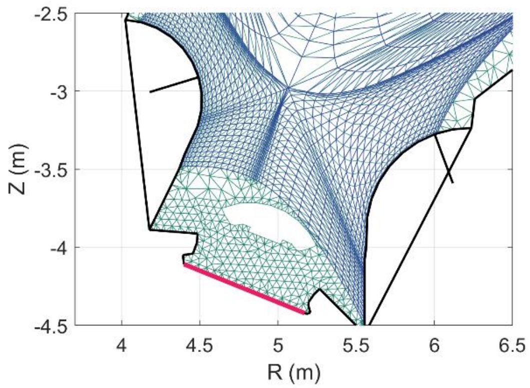
A. Zaloznik, et al, NME (2020)

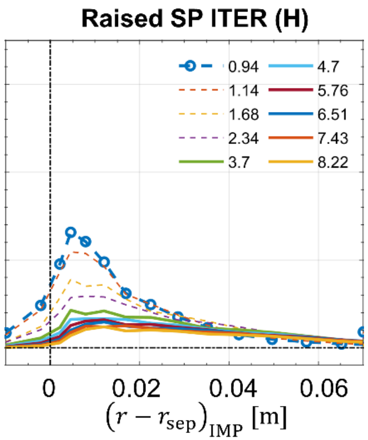
Raised strike-point operations in ITER

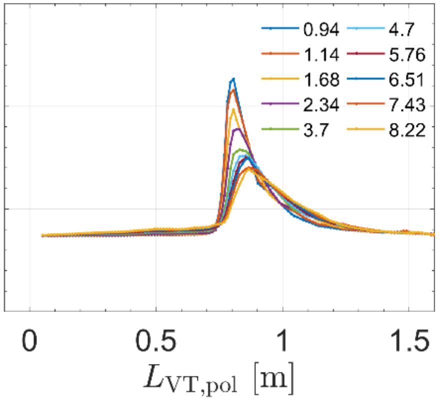
- Possibility and prospects for raised strike-points operations in ITER?
  - Equilibrium identified. 10MA L-mode, 20MW ECH
- SOLPS simulations showed that high enough temperature could not be obtained without too high T_e: active cooling, limited heat fluxes

SOLPS grid for raised strikes

J.S. Park et al. NF in preparation and AAPS-DPP



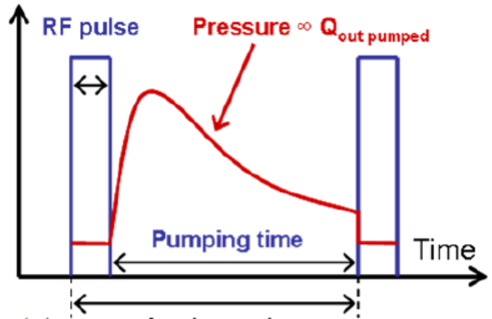


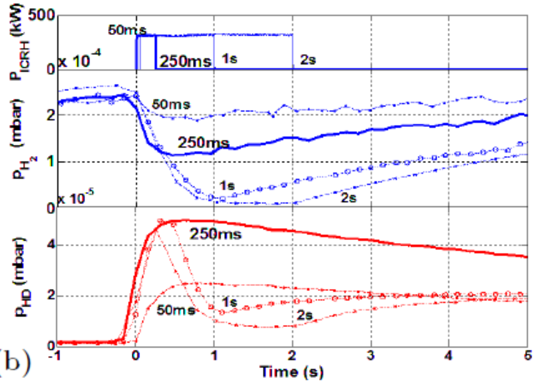


- Difficult to get high enough temperatures with nominal cooling
- Baffle region not optimized wrt misalignment, needs to be considered

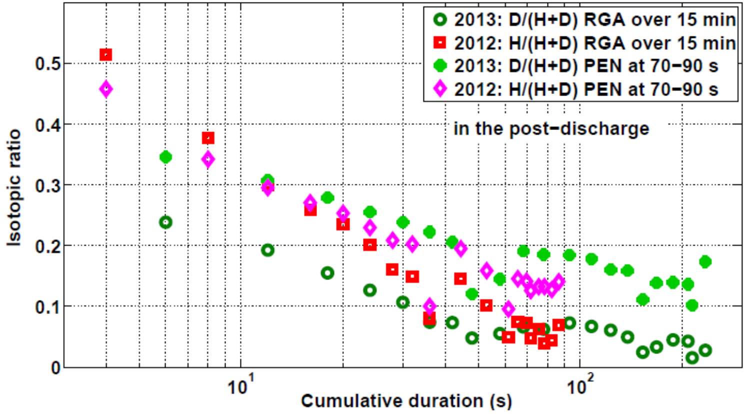
ICWC: removal efficiency?

- ✧ ICWC typically uses a series of pulses to induce outgassing and allow efficiency pumping without re-ionization





D. Kogut, PhD thesis

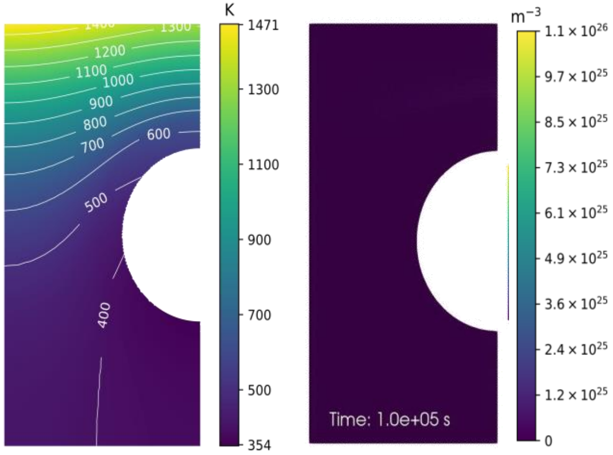


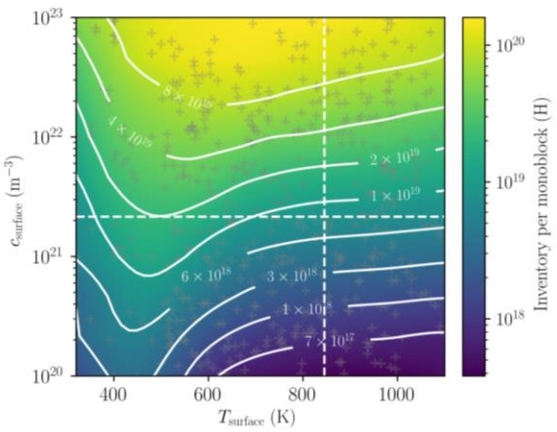
- ✧ High removal efficiency observed in JET
- ✧ Extrapolation to ITER still unclear
- ✧ Series of experiments ongoing at TOMAS

ISF: development of diffusion/trapping codes

- **Treatment of diffusion/trapping of species included in existing FEM codes**
  - **ABAQUS, COMSOL**
  - **Benchmark against TMAP7 for simple 1D case**

- **Application of machine learning to simulate retention in the ITER divertor**



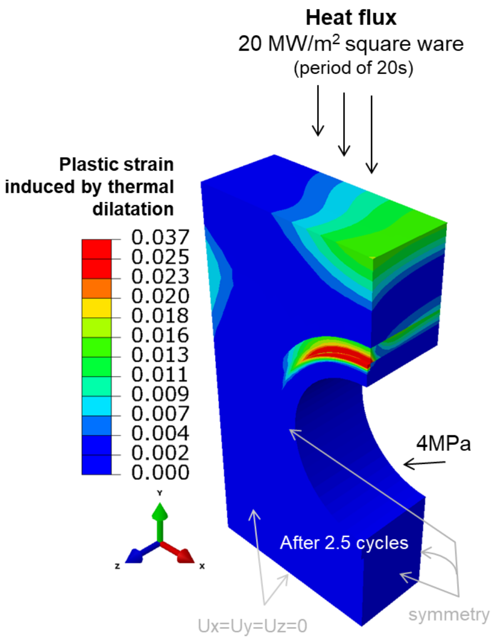


Papers:

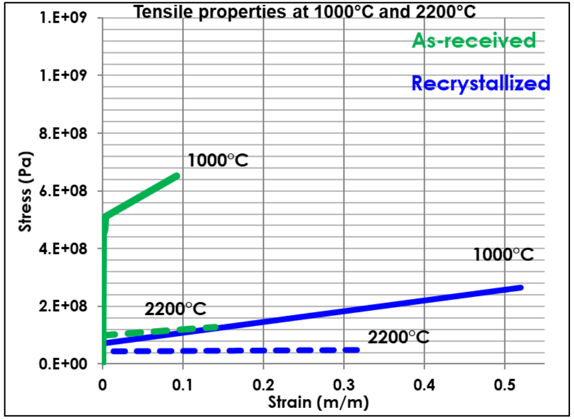
- Delaporte-Mathurin *et al*, NME (2019)
- Delaporte-Mathurin *et al*, SREP (2020)
- Delaporte-Mathurin *et al*, PSI2020, NME (submitted)

ISF:Coupling between thermal and plasma effects

- MB geometry implies strong thermal gradients (stress and strain…)
  - 3D effects important for D diffusion…



J. Mougenot et al, TRANSAT 2019



Trap versus strain derived from Terentyev et al

$$N_t = 1.8328 \times 10^{15}\,(1 - e^{-60\varepsilon_p})$$

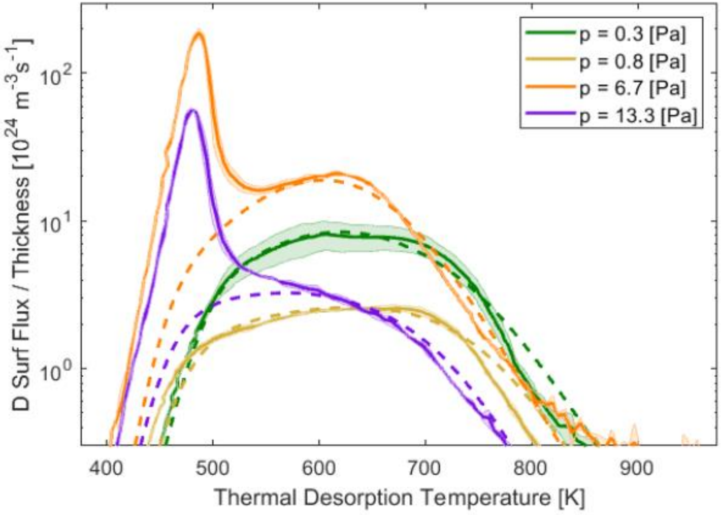
Up to 10^{-5} at. fr. after 2.5 cycles could become non negligeable on HI migration

J. Mougenot et al, TRANSAT 2019

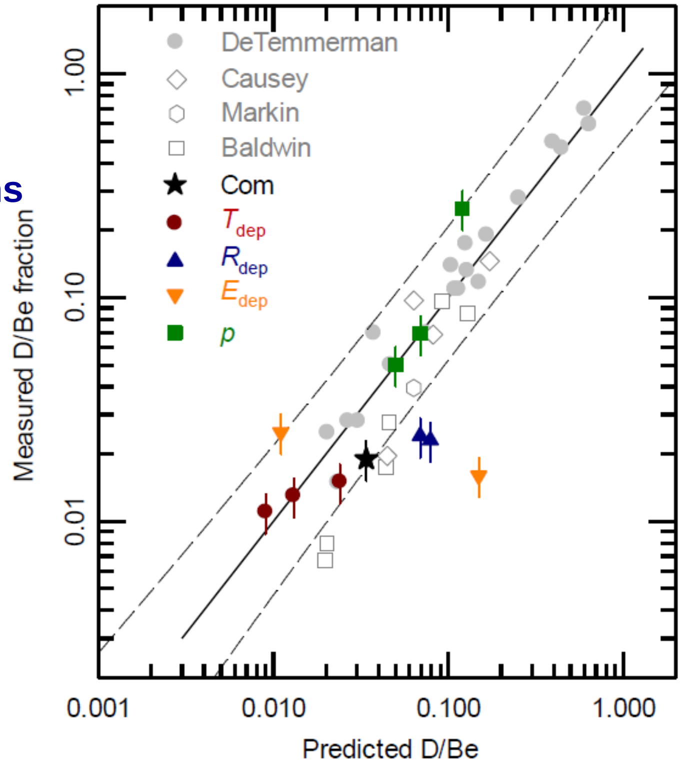
Important to consider geometry effects on thermal gradients and trapping

Tritium retention in Be co-deposits

- IO service contract with UCSD to investigate D trapping in Be co-deposits versus deposition conditions
  - Extension of "De Temmerman" scaling
  - Energy dependence unclear
  - Systematic study of trapping versus deposition conditions



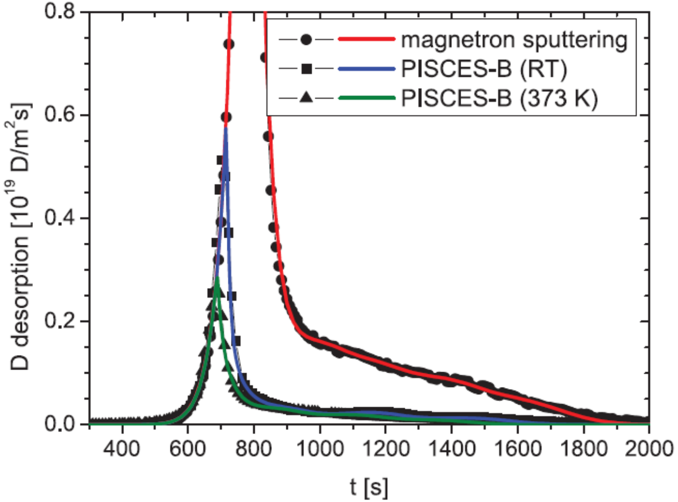
M.J. Baldwin et al, Phys. Scr. accepted



T removal techniques: open questions

- Need to revisit T retention management to integrate recent results
  - Baking efficiency, ICWC, raised strike-point operations

New diffusion/trapping model for co-deposits



A. Zaloznik et al, Nucl. Fusion, 59 (2019)

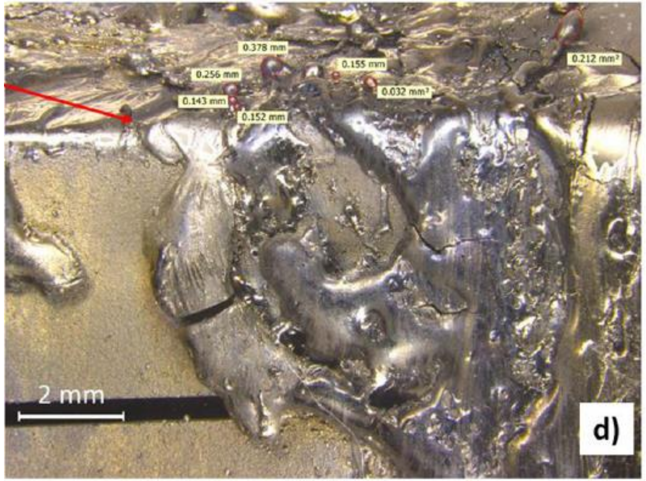
Fuel removal efficiency of:

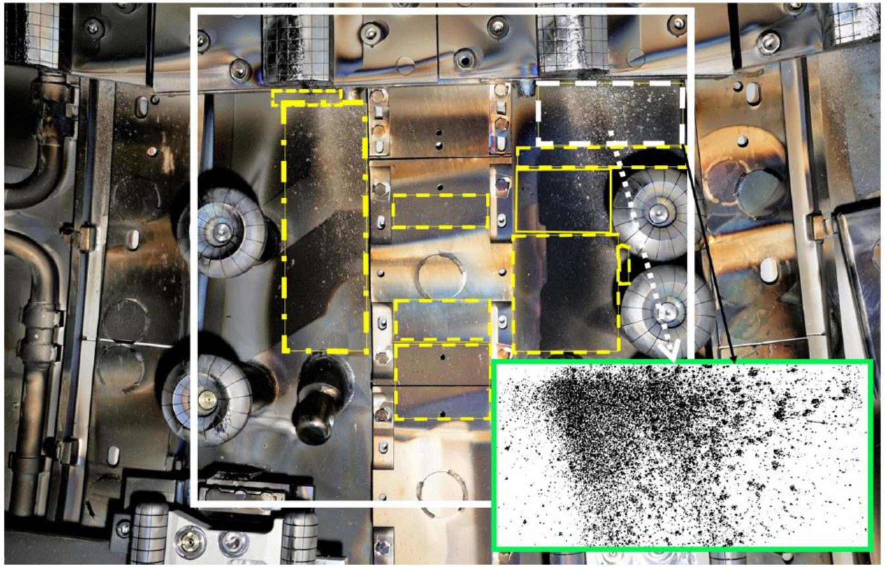
- Operation with raised strike-points to locally heat deposit areas: encouraging results from PISCES-B (UCSD)
- ICWC/ECWC: modeling? Recent isotopic exchange modeling from Matveev et al
- Baking: influence of sharp release peak and new surface recombination treatment

Plan is to develop an initial T management strategy (recovery frequency, …) in 2020-2021

Dust or droplets?

- **Conservative assumption for ITER: re-solidified droplets are dust**
  - **Unlikely to be re-mobilized by LOVA**
  - **Characterization (even if qualitative) of droplet adhesion for RPrS update needed**

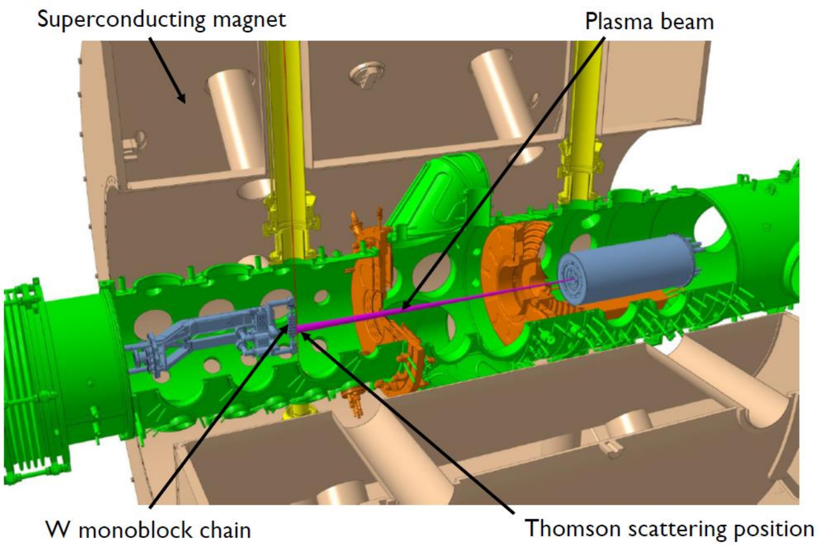


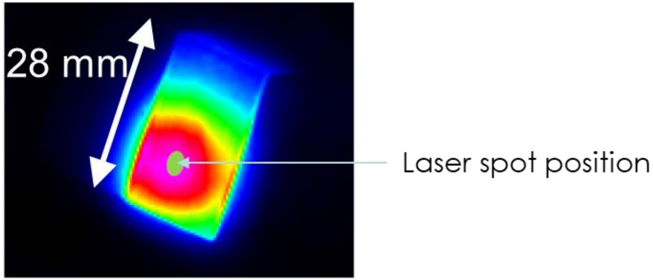


I. Jepu et al, Nucl. Fusion, 59 (2019)

High fluence experiments

- Continuation of high fluence experiments on Magnum-PSI
  - Accelerated lifetime tests (high flux)
  - This year: add transient heat fluxes using a high power laser



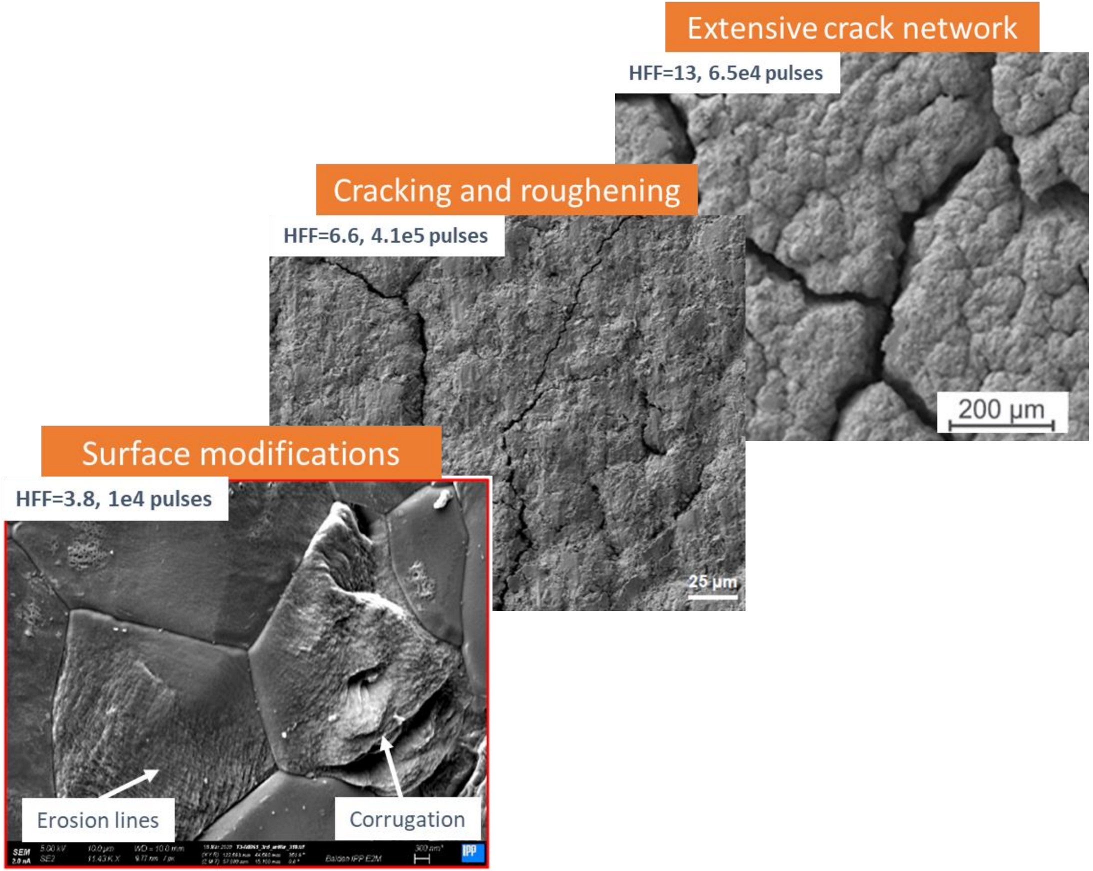


T.W. Morgan, Phys. Scr (2020)

What happens long term to monoblocks with simultaneous plasma and transient loading around damage threshold?

High fluence experiments

Variable	Options
Ion species	H, H+He, H+Ne, H+He+Ne
Pulse HFF	2.2-13 MW m^{-2} $s^{0.5}$
Pulse number	10,000 to 1,000,000
Base temperature	750 °C
q	12-13 MW m^{-2}
Φ	~2-2.5×10^{28} m^{-2}

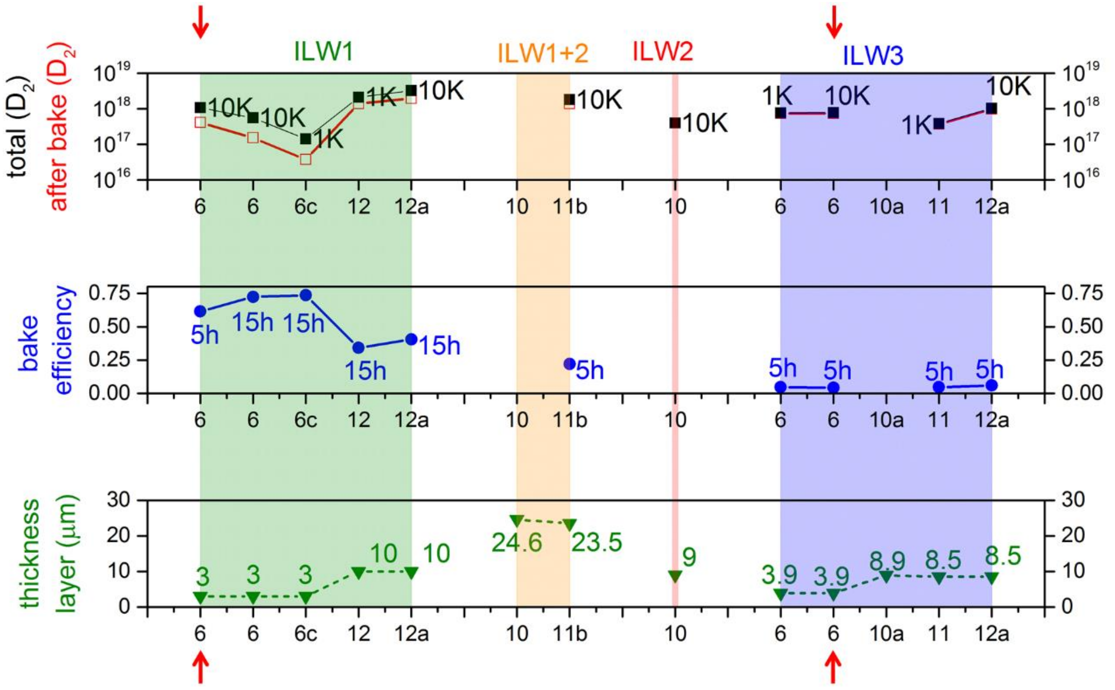


T.W. Morgan et al, PSI 2021

Understanding D trapping in JET

- TDS analysis of D release from JET co-deposits (from tile 1 mainly)
  - Ongoing work to try and understand D trapping in JET co-deposits from different campaigns
  - Complicated by the lack of data and sample-to-sample variations

D. Matveev, unpublished



Summary/conclusions

- **WP PFC and JET2 in general well oriented and address to a large extent ITER R&D priorities**
- **Highest priority areas currently are:**
  - **High fluence PWI on W**
  - **Diffusion/trapping data and modeling**
  - **Be splashing**
  - **T retention and removal**
  - **Delamination of Be layers**

The end of a journey… (2003-2020)

Thanks for all those years of collaboration!!!

The end of a journey… (2003-2020)

greg@zenonresearch.org

…marks the beginning of a new one