ITER priorities for WEST Phase 2

Outline of talk

- ❑ **High priority R&D topics for the ITER Research Plan**
- ❑ **WEST experiments →support IRP high priority R&D topics**
- ❑ **Specific Agreement on ITER-like divertor plasma facing unit tests**

R&D issues for ITER Research Plan

- **Extensive list of prioritized ITER Research Plan refinement issues elaborated and refined with comments from to ITER Members' fusion communities**

- **High impact IRP issues in next years:**

  - **Impact on remaining components' design or specific IRP options/choices**

  - **Addressing "strategic assumptions" in IRP for experimental programme development**

Impact on components' design and IRP options/choices

1. Support of DMS baseline design (SPI)
2. Diagnostic design
3. He H-mode operation or H+10% He (PFPO)
4. 3rd harmonic ECH heating validation (1.8 T) (PFPO)
5. Low <n_e> ECH heated H-modes and ELM control power supply optimization (PFPO-1)
6. ECWC conditioning (PFPO-1)
7. ECH assisted and ohmic start-up (FP and PFPO-1)

→ Affect component design and early stages of IRP-related decisions (e.g. connection of 9 PS to ELM control coils, possible ECH upgrade, ….) → timely input for decisions required

Strategic assumptions of IRP

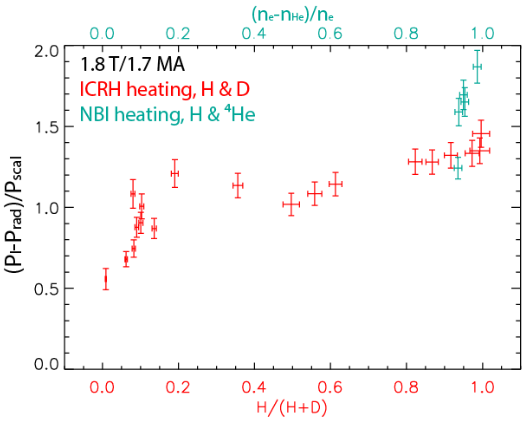
1. Disruption loads characterization in PFPO
2. Strategy for ELM control
3. n = 1 and n = 2 error fields and correction
4. Divertor lifetime appropriateness until well into FPO programme
5. 3-D field ELM suppressed H-mode as integrated scenario for ITER
6. Specific issues for Q = 5 steady-state scenarios in ITER with NBI + ECH

→ Address open issues in IRP strategy which, if not resolved, may require new R&D that needs time to produce solid results

IRFM/WEST R&D impacting PFPO-1/pre-PFPO-1 decisions - I

- **He H-mode operation or H+10% He**

- **Evaluation of pro's and con's of He vs H+10% He with W divertor**
  - ✓ Lower P_{LH} and $P_{type\text{-}I}$ in He compared to H+10% He ☺
  - ✓ Stronger deterioration of W divertor surface with He ☹
  - ✓ Higher W sputtering → W contamination of core plasma with He ☹



J.C. Hillesheim 2016 IAEA

JET

Impacts possible decision on ECH upgrade and development of specific ICH schemes for PFPO

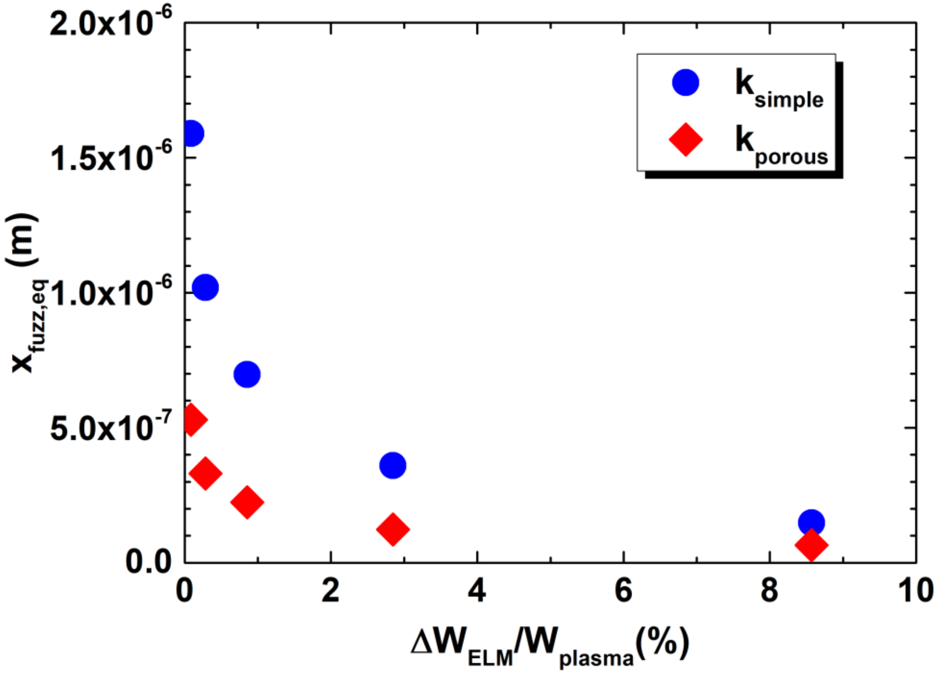
IRFM/WEST R&D impacting PFPO-1/pre-PFPO-1 decisions - II

- W fuzz growth due to He plasmas strongly hindered by the presence of ELMs
  - In the no-ELM case, fuzz grows with ~$t^{0.5}$ dependence

- ITER Research Plan foresees need for full ELM suppression
  - Even very small ELMs seem to allow fuzz mitigation

Need for experimental validation

De Temmerman – PSI 2018



G. De Temmerman et al, NME, submitted

IO-CEA Agreement on Divertor PFU tests

- **Agreement on testing activities of ITER-like Divertor plasma facing units (so-called WEST elements) in WEST signed between IO and CEA**

- **Establishment and implementation of work program to tests units in WEST for IO → Joint Team (IO and CEA representatives + ITER and/or WEST partners, if needed) to implement activities:**
  - ✓ **specifications of the procedures and experiments to be executed**
  - ✓ **execution of the experiments**
  - ✓ **analysis of results and reporting**

- **IO will receive the elements from F4E and provide them for tests at WEST**

Conclusions

- The ITER Research Plan provides the experimental strategy to progress from First Plasma through to the achievement of Project's goals: Q = 10 (300-500 s), Q = 5 (1000 s) & Q = 5 steady-state consistent with the Staged Approach

- Details of the IRP are subject to refinement following results of R&D → R&D is required to address outstanding issues

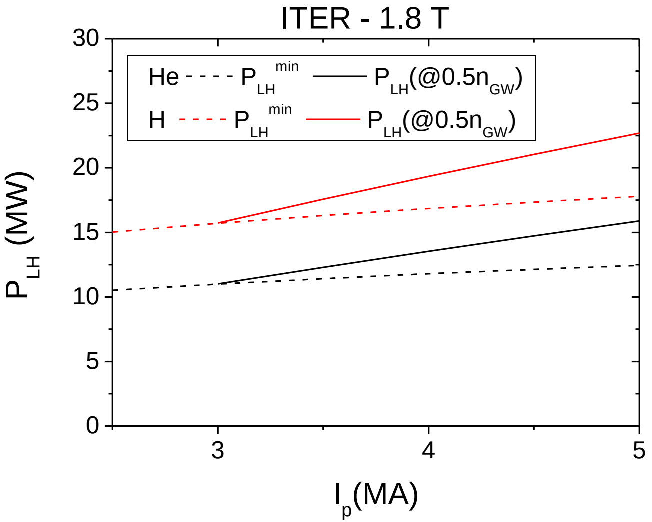
- WEST can make important contributions to R&D in support of ITER Research Plan thanks to its specific capabilities and expertise of the WEST team

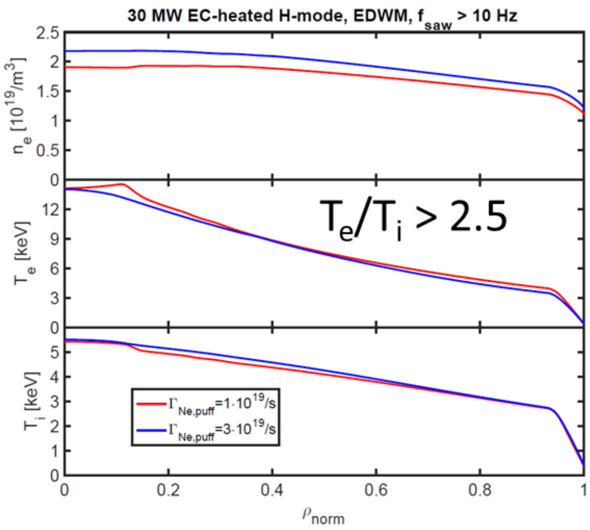
Reserve Material

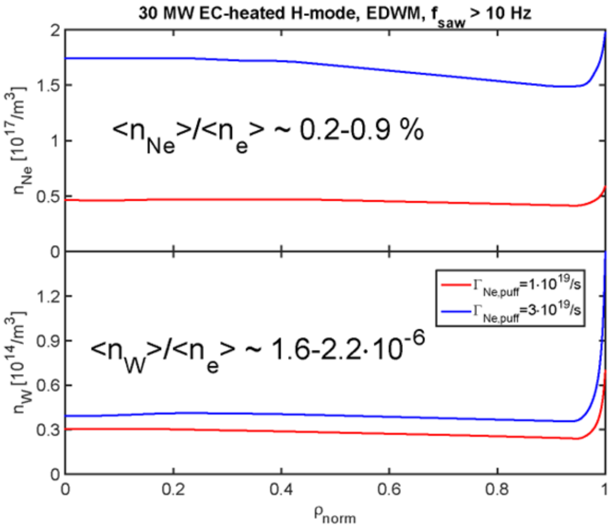
IRFM/WEST R&D impacting PFPO-1/pre-PFPO-1 decisions - III

❑ Low $<n_e>$ ECH heated H-modes

- ECH heated H-modes at low $<n_e>$ for 5 MA/1.8T scenario for PFPO-1
  - Access issues → validity of physics basis P_{LH} ($<n_e>$ for H, He, H+10%He ?)
  - H-mode properties (T_e/T_i) and particle transport (main ion, W)

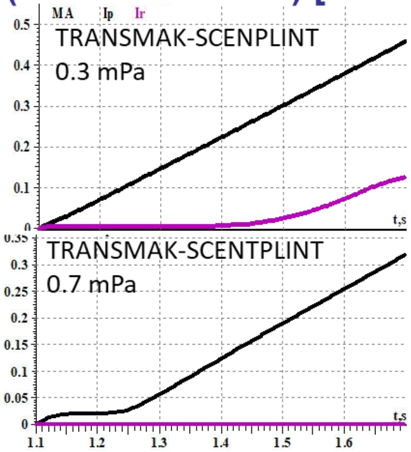


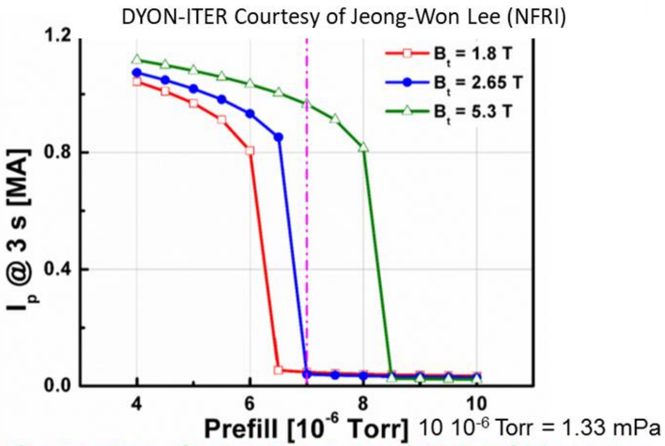




Plasma start-up in ITER

- First Plasma and Engineering Operation Phase
  - 100 kA/ 100 ms milestone with ECH assisted start-up
  - Studies of ohmic start-up (start-up at 1.8 T)
    - ECH (170 GHz) 3rd harmonic assist not effective→1.8 T Ohmic start-up with V_{loop}~0.3 V/m?
    - Modelled 1.8 T Ohmic plasma start-up OK within narrow pressure window (similar to 2.65 T) [burn-through ←→ runaway avoidance]





10 10^{-6} Torr = 1.33 mPa

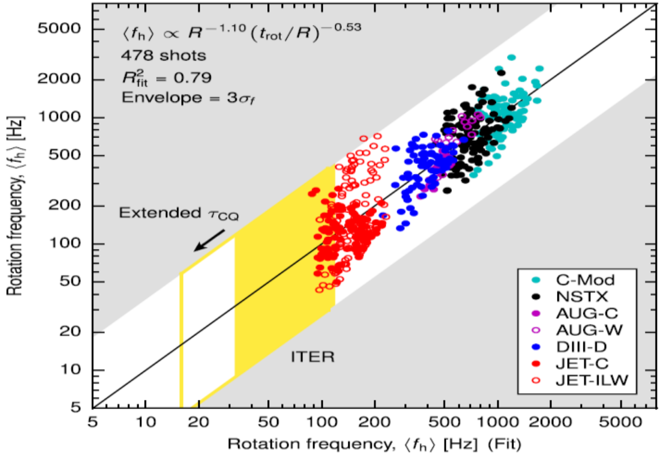
Ohmic plasma start-up in FP and Engineering Operation → decision on 1.8 T ECH assist

IRFM/WEST R&D impacting strategic assumptions of IRP - I

Disruption loads characterization in PFPO

- **Main issues are related to long CQ to assess rotation effects on forces → lack of C leads to longer CQs**
  - Experimental scaling indicates ITER frequencies in the resonance range with $N_{rot} > 2$
  - No scaling of sideways forces or vessel displacement available (static or rotating)
  - Several theories are available, but experimental basis not sufficient for validation

- Measurement required to aid discrimination:
  - *sideways forces and VV displacement*
  - *current paths inside FW components and VV*
- Impact on operation strategy and disruption management

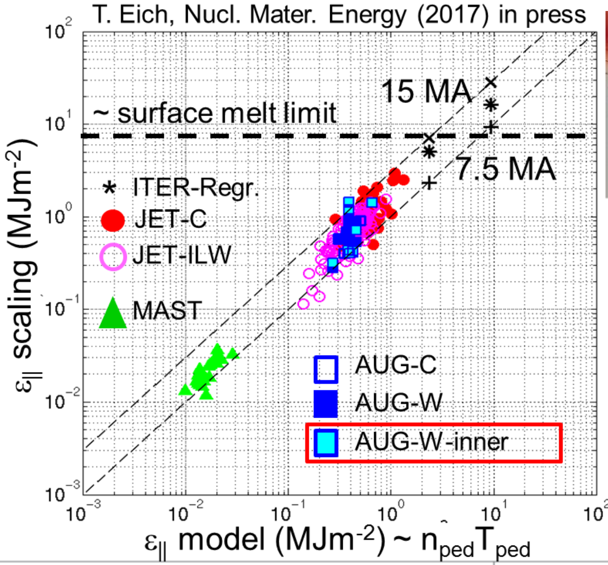


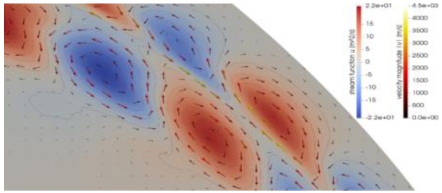
IRFM/WEST R&D impacting strategic assumptions of IRP - II

❑ Strategy for ELM control

- ➢ **ELM mitigation (f_{ELM} increase) may not reduce peak power loads**
- ➢ **ELM mitigation (f_{ELM} increase) may not provide W exhaust in low grad-n$|_{ped}$**

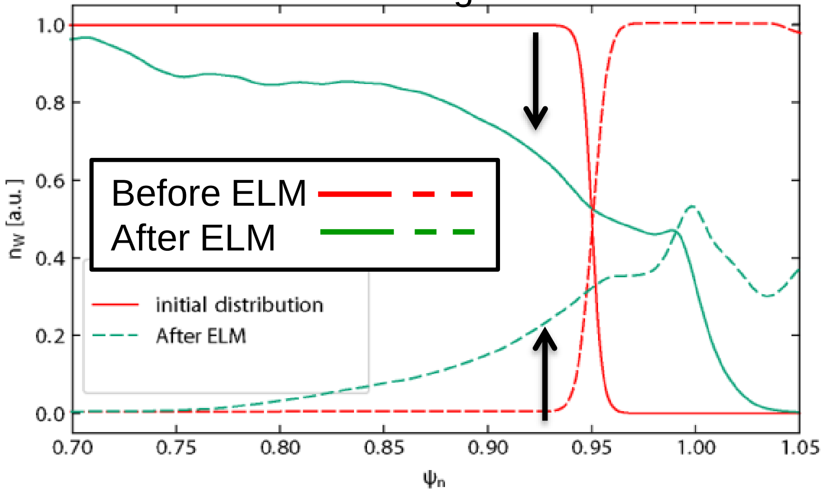
$\varepsilon_{ELM,div} \sim n_{ped}T_{ped}$ (weak ΔW_{ELM}, f_{ELM} dependence)





W well screened in pedestal → not expelled by ELMs

JOREK - Van Vugt EPS 2018

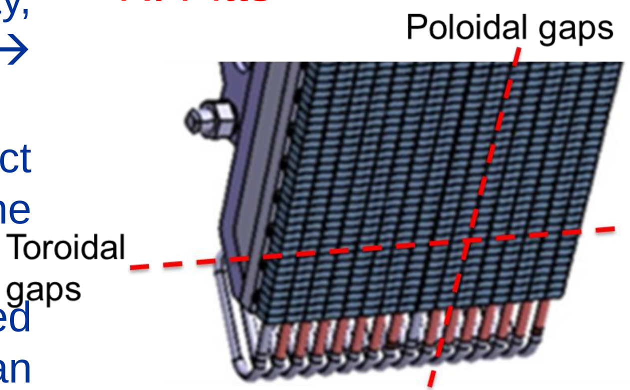


IRFM/WEST R&D impacting strategic assumptions of IRP - III

- **Divertor lifetime appropriateness until well into FPO programme**

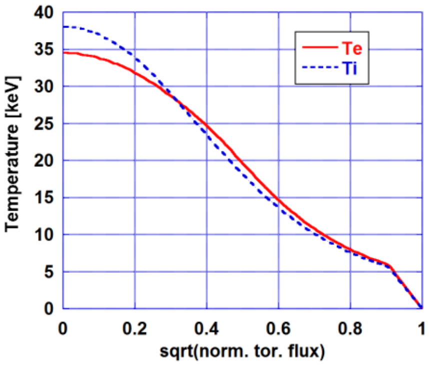
- **Consequences of He operation on lifetime**
- **Refinement of effect of power fluxes (stationary and transient) on lifetime required → can affect decision for early procurement of 2nd W divertor**
- **Consequences for operation of degraded PFCs (e.g. small scale localized melting over many PFCs) needs to be assessed**
- Need for small, discrete components for high heat flux density, water cooled ITER divertor targets leads inevitably to gaps → tens of thousands of them in high heat flux areas
- ITER will use toroidal bevels on monoblock surfaces to protect poloidal gap leading edges in the high heat flux regions of the vertical targets
- Toroidal gaps cannot be hidden → edges will be exposed according to 3-D ion orbit modelling and PiC simulations → can small ELMs melt TG edges ? → implications divertor lifetime ?

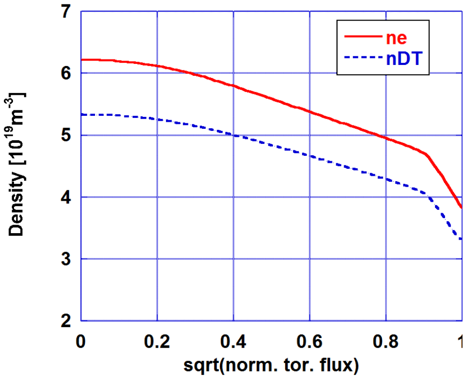
R. Pitts

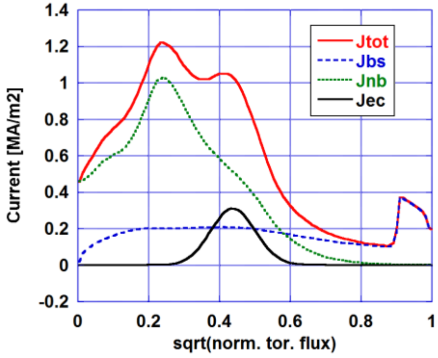


Strategic assumptions of IRP - IV

- **Issues for Q = 5 steady-state scenarios in ITER with NBI + ECH**
  - **H&CD and upgrade path already defined → $j_{CD}(r)$ dominated by NBICD**
    - **NBI+ECH steady- state scenarios have q_{min} < 1.5 and l_i > 0.8 (low j_{ped}) with q(0) ~ 1.5 - 3.0 (avoiding ITBs)**
  - **Understanding of achievable confinement with this current profile (H ~ 1.5 required for steady-state) and MHD stability**

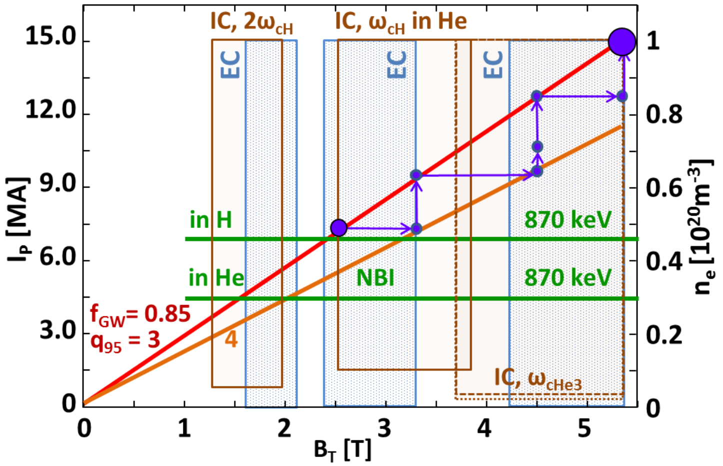






Additional issues of interest to IRP

- **Controlled termination of discharges without core particle source (NB) (i.e. avoiding radiation collapse issues driven by W)**
- **Operational space in L-mode with off-axis heating**
  - Development of favoured set of I_p/B_t steps in PFPO in preparation for D/DT phase
  - Assessment of impact of fuelling, H&CD mix, ECRH on-/off-axis on L-mode plasma confinement/transport/impurity transport
  - R&D → eed for central heating to control central transport (W accumulation avoidance) in L-mode



- **Diagnosis of disruption loads on divertor (essential to determine if W lifetime affected by stationary loads or transient loads in WEST)**

Integrated Modelling and Analysis Suite development and validation

- **Successful implementation of IRP requires high quality integrated modelling of ITER plasma discharges and experimental data analysis**
- **IO has developed the IMAS platform to standardize experimental and modelling data and to provide framework for integrated modelling**
- **IMAS must be tested and refined in present experiments well in advance of FP**
  - **Mapping of experimental data to IDSs**
  - **Development/testing of device independent IMAS analysis workflows**
  - **Validation of IMAS integrated modelling tools with experiments from as many as possible devices**