PSI Issues in ITER

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1st NIFS-CRC International Symposium and 1st Korea-Japan Workshop
on Edge Plasma and Surface Component Interactions
in Steady State Magnetic Fusion Devices
21-22 May, 2007, National Institute for Fusion Science

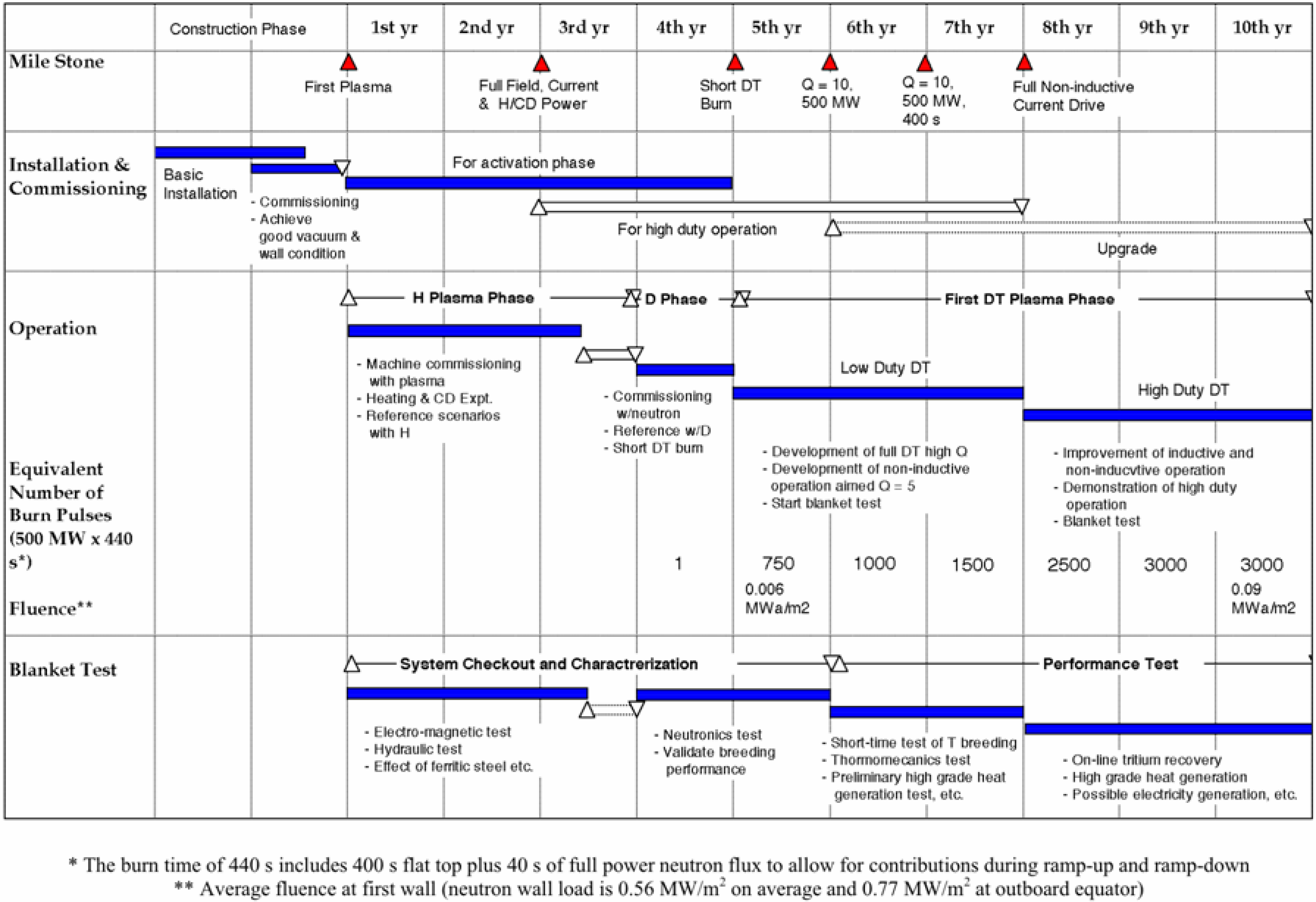
ITER

- Unique fusion device with long DT burn ~500 MW(Q>10), inductive pulse length ~400s
- Ultimate aim of steady state operation (Q>5)
- Significant alpha heating: p(r) will be determined by plasma
- Steady state operation : j(r) will be determined by plasma
- Plasma stored energy 1-2 orders of magnitude larger than in present devices
  - Heat loads at disruption and ELM expected to be at least x5 higher than present devices; which could shorten the lifetime of PFC
- Large nuclear project
  - Requires long-term planning and coordinated R&D

Strategy

- Conservative design
- Step-wise programme (HH, DD, DT, Ip, heating power, etc)
- Flexibility (wide operation space, replaceable divertor, H&CD)
- Diagnostics
- Experimental tools (e.g. gas injection+neural network/disruption, frequent pellet/ELMs)
- Physics R&D will be continued during construction and operation

ITER Operational Plan



	Construction Phase	1st yr	2nd yr	3rd yr	4th yr	5th yr	6th yr	7th yr	8th yr	9th yr	10th yr

Mile Stone

- First Plasma
- Full Field, Current & H/CD Power
- Short DT Burn
- Q = 10, 500 MW
- Q = 10, 500 MW, 400 s
- Full Non-inductive Current Drive

Installation & Commissioning

Basic Installation

- Commissioning
- Achieve good vacuum & wall condition

For activation phase

For high duty operation

Upgrade

Operation

H Plasma Phase

- Machine commissioning with plasma
- Heating & CD Expt.
- Reference scenarios with H

D Phase

- Commissioning w/neutron
- Reference w/D
- Short DT burn

First DT Plasma Phase

Low Duty DT

- Development of full DT high Q
- Developmentt of non-inductive operation aimed Q = 5
- Start blanket test

High Duty DT

- Improvement of inductive and non-inducvtive operation
- Demonstration of high duty operation
- Blanket test

Equivalent Number of Burn Pulses (500 MW x 440 s*)	4th yr	5th yr	6th yr	7th yr	8th yr	9th yr	10th yr
	1	750	1000	1500	2500	3000	3000
Fluence**		0.006 MWa/m2					0.09 MWa/m2

Blanket Test

System Checkout and Charactrerization

- Electro-magnetic test
- Hydraulic test
- Effect of ferritic steel etc.

- Neutronics test
- Validate breeding performance

Performance Test

- Short-time test of T breeding
- Thormomecanics test
- Preliminary high grade heat generation test, etc.

- On-line tritium recovery
- High grade heat generation
- Possible electricity generation, etc.

* The burn time of 440 s includes 400 s flat top plus 40 s of full power neutron flux to allow for contributions during ramp-up and ramp-down

** Average fluence at first wall (neutron wall load is 0.56 MW/m^2 on average and 0.77 MW/m^2 at outboard equator)

Plasma-Facing Components on the day one (reference)

First wall and limiter: beryllium

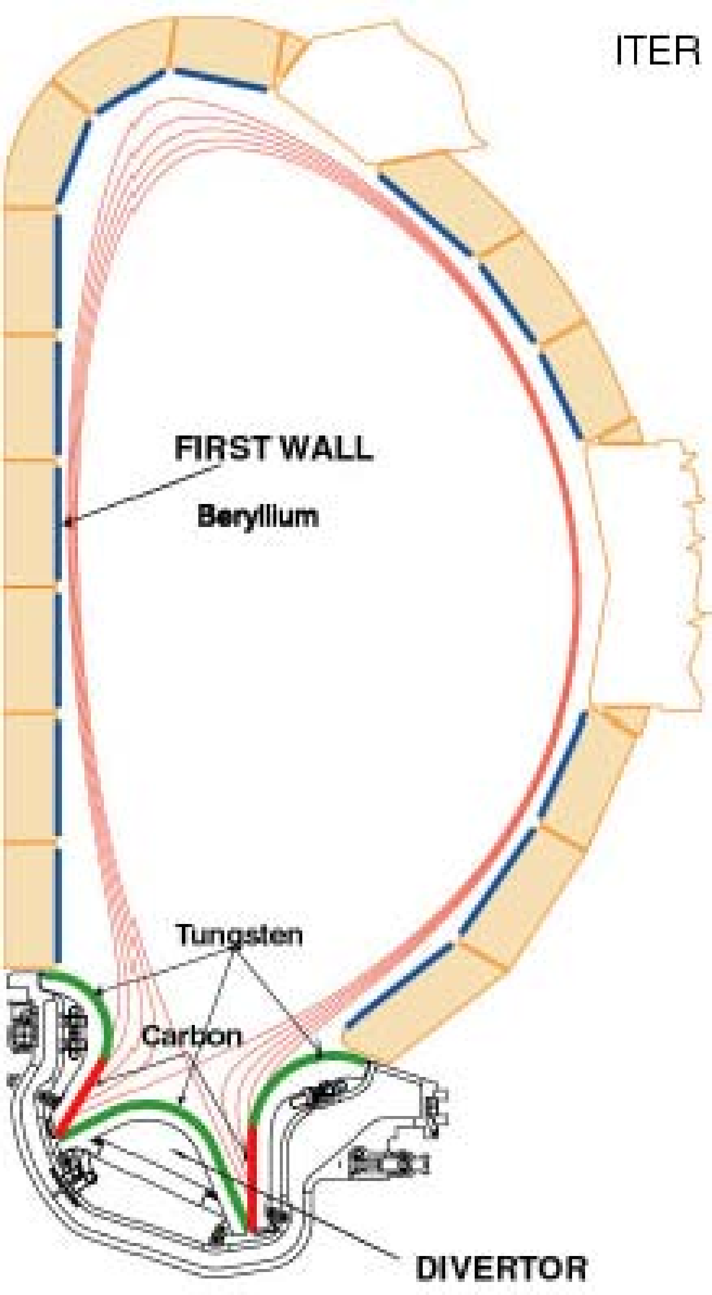
- Low Z, getters oxygen
- Retains T, but releases T at lower temperature

Separatrix hit point: CFC

- withstands a wide range of plasma parameters
- T retention problem

Divertor dome and baffle: W

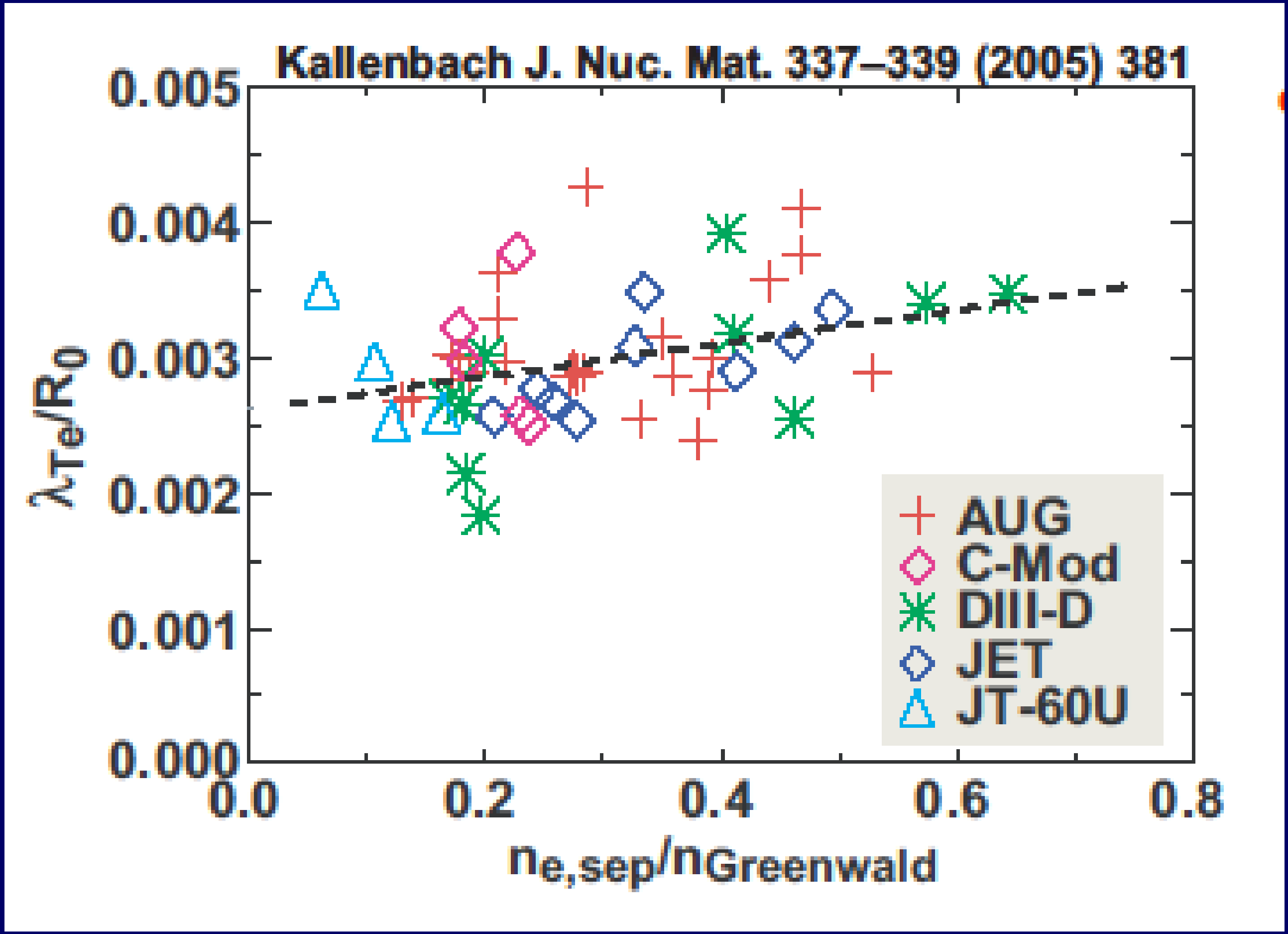
The divertor has a modular structure, replaceable within 4 months
The final selection of 1st divertor PFC will be made in 2010



Major uncertainties in PWI

- Sol/divertor transport model (D, χ, v, P_{rad}, Z_{eff}), A&M data (high Z, C_mH_n)
- T retention, dust, mixed material effects
- Disruption, ELMs, blobs
- Steady state control
- High Z PFM

Sol measurement suggests sol heat flux decay length ~ 5 mm



Major uncertainty: sol flow and impurity transport

blob

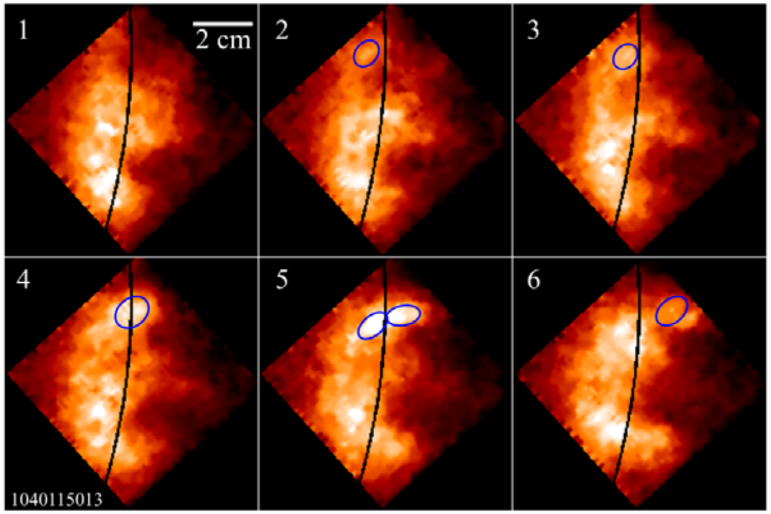


Figure 5. Movie frames of edge turbulence at $n/n_{\mathrm{GW}} = 0.8$. The ovals locate the 'birth' and motion of a blob. The separatrix is also shown. The emission is He I, and the time between frames is 4 μs.

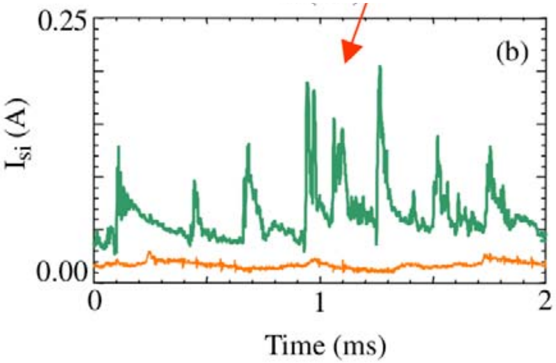


Figure 4. SOL density profiles in LSN L-mode discharge
$I_p = 1$ MA and $I_p = 0.8$ MA (a); time traces of the ion sat
currents in far SOL ($R = 233$ cm) of the two discharges (

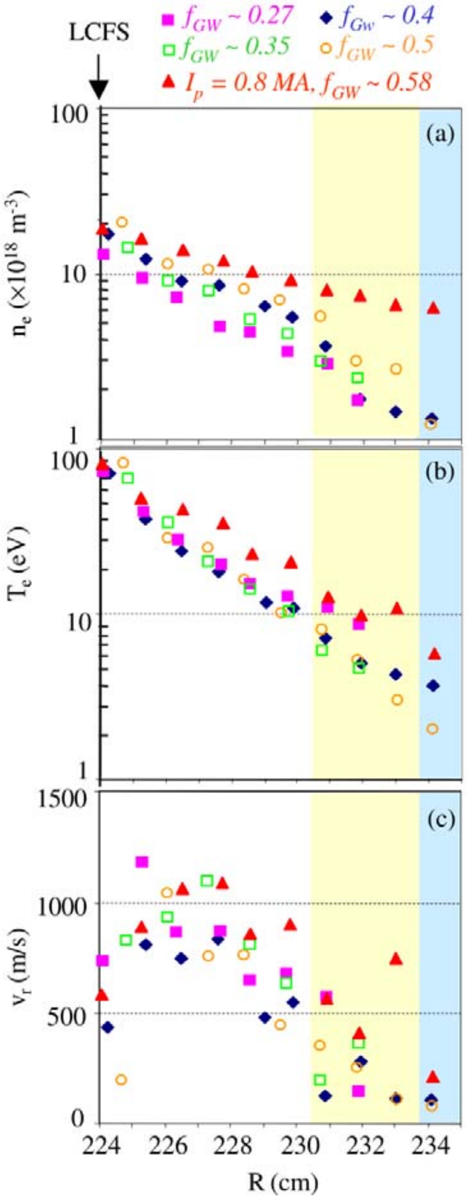
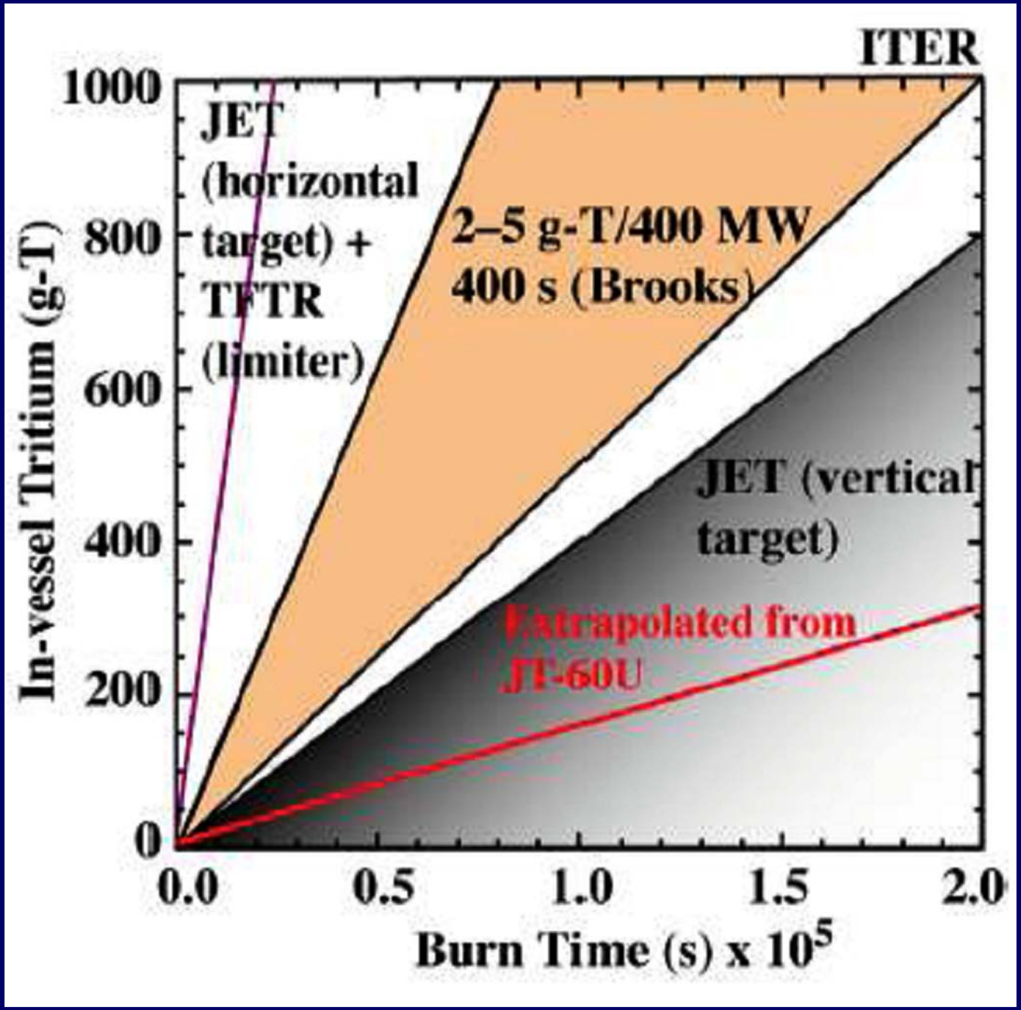


Figure 7. Radial profiles of the blob peak densities (a), temperatures (b) and radial velocities (c) in SAPP discharges at $I_p = 1.0$ MA with varying average discharge densities. Data from the $I_p = 0.8$ MA discharge of figure 3 are shown as well.

N_e and T_e decay as the blob move radially. T_i decays as rapidly?

Tritium retention issue



- Assumption of in-vessel mobilisable tritium = 1kg
- Extrapolation from exp. Is highly uncertain
- Use of CFC is limited in ITER
- small addition of Be reduces T retention

Tritium retention

- Safety assumption : in-vessel mobilisable tritium of 1 kg
- Hard to measure in-vessel mobilisable tritium
- $W_{\text{in-vessel}} = W_{\text{in-plant}} - W_{\text{out-vessel}} - W_{\text{decay}} - W_{\text{burn}}$
- Burned tritium ~ 4.6 kg
- The error of fusion power measurement ~ 10%
- The other error < 100 g
- The global power balance and He-4 measurement could be useful

Wall conditioning

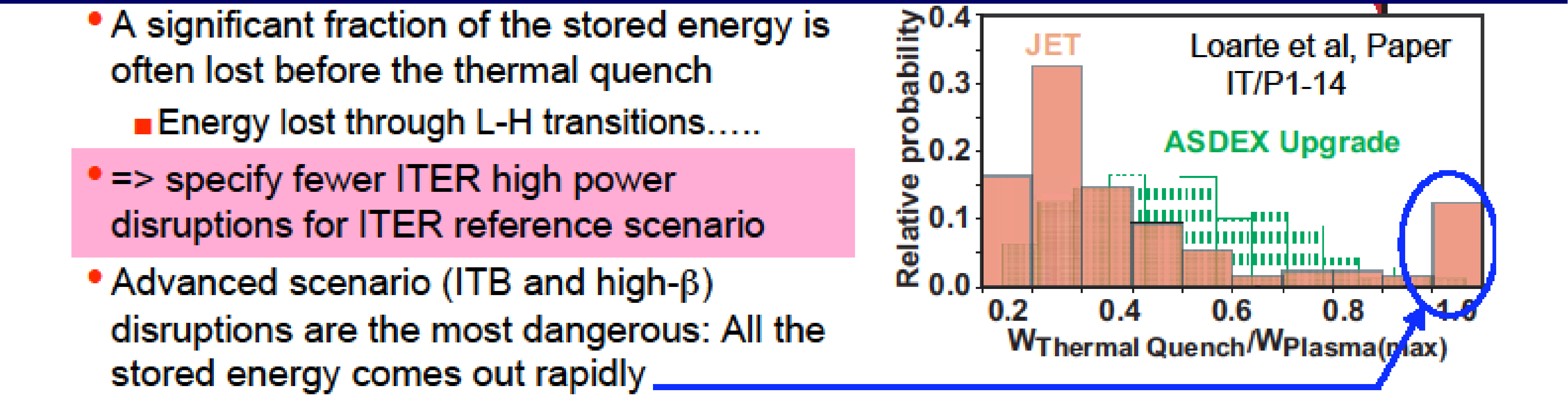
- Wall conditioning is required to maintain low levels of impurity and particle recycling and to control tritium retention
- Steady magnetic field will preclude GDC during operation
- During operation, ICWC, ECWC and low Ip discharges will provide wall conditioning
- High temperature baking of divertor cassettes (~350 C) is under study
- The possibility of baking with oxygen is under study

dust

- Size:10’s nm~10 μm
- Possibly radiative, chemically reactive
- Formation mechanism need to be understood
- Measurement methods and removal methods need to be developed
- Electrostatic collection could be useful

Disruption mitigation

- At the thermal quench, most of the stored energy will be lost and transported to PFC
- Runaway electron could damage the first wall

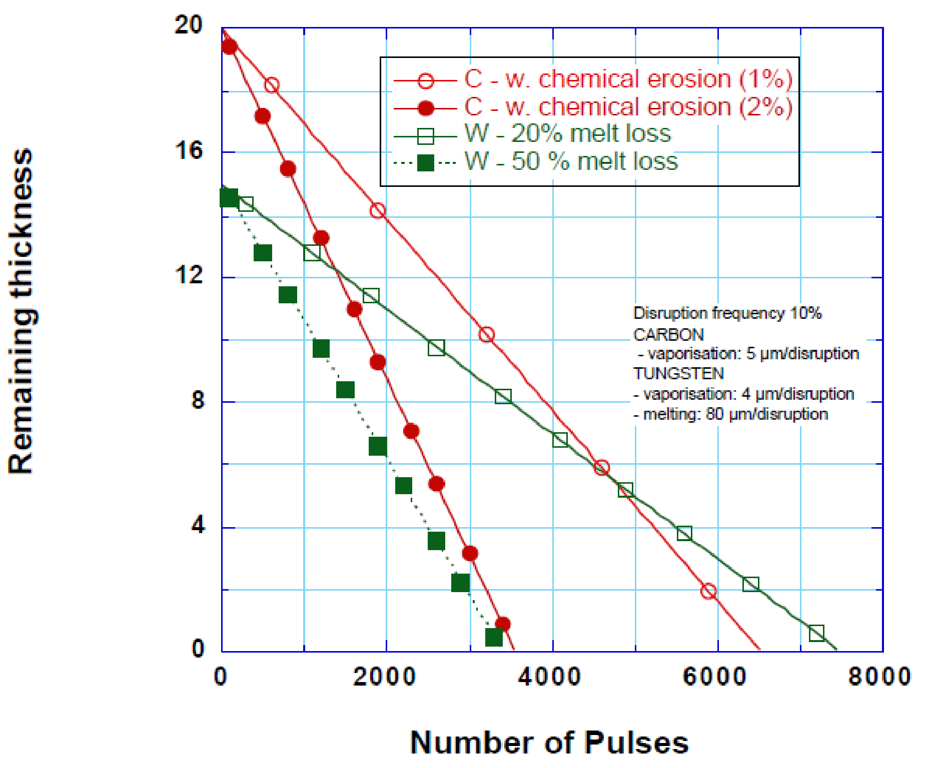


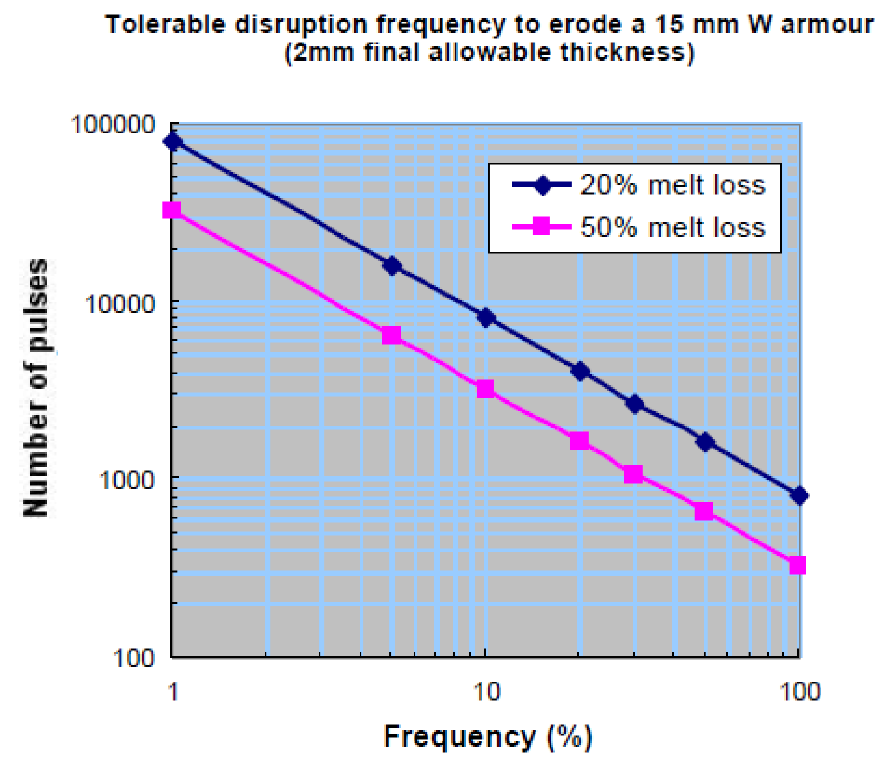
- A significant fraction of the stored energy is often lost before the thermal quench
  - Energy lost through L-H transitions…..
- => specify fewer ITER high power disruptions for ITER reference scenario
- Advanced scenario (ITB and high-β) disruptions are the most dangerous: All the stored energy comes out rapidly

Loarte et al, Paper IT/P1-14

- The disruption would shorten the lifetime of PFC
- The disruption should be mitigated by a system e.g. neural network + massive impurity gas injection
- Suppression of runaway ele should be demonstrated

Disruption should be mitigated or avoided for longer PFC lifetime



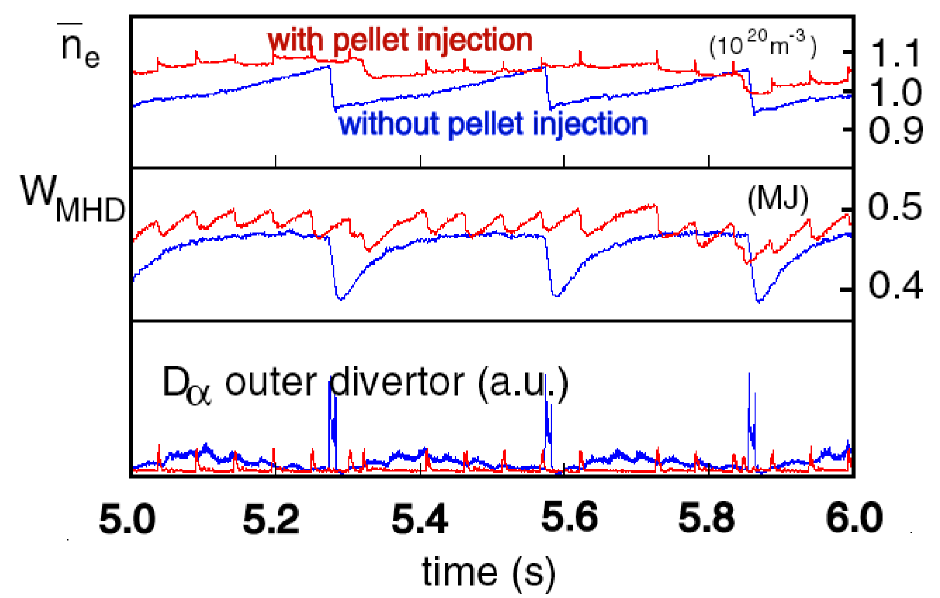


Vertical displacement event

- VDE occurs when the vertical position control is lost (e.g. malfunction of power supply, sensors…)
- At the thermal quench, FW will melt
- The movement of plasma is slow (~0.5 s), which enables early detection and mitigation

ELM mitigation

- Heat flux associated with unmitigated type-I ELMs could shorten the lifetime of PFC
- Pellet pacemaking could provide efficient ELM mitigation



- Discharge scenarios free of type I ELMs are developed
- ELM mitigation/elimination with external coils is under investigation

High Z PFM

- Adoption of high Z PFM would preclude some operation regimes (e.g. peaked density, infrequent ELMs, low n_{sep})
- Disruption avoidance/mitigation should be developed

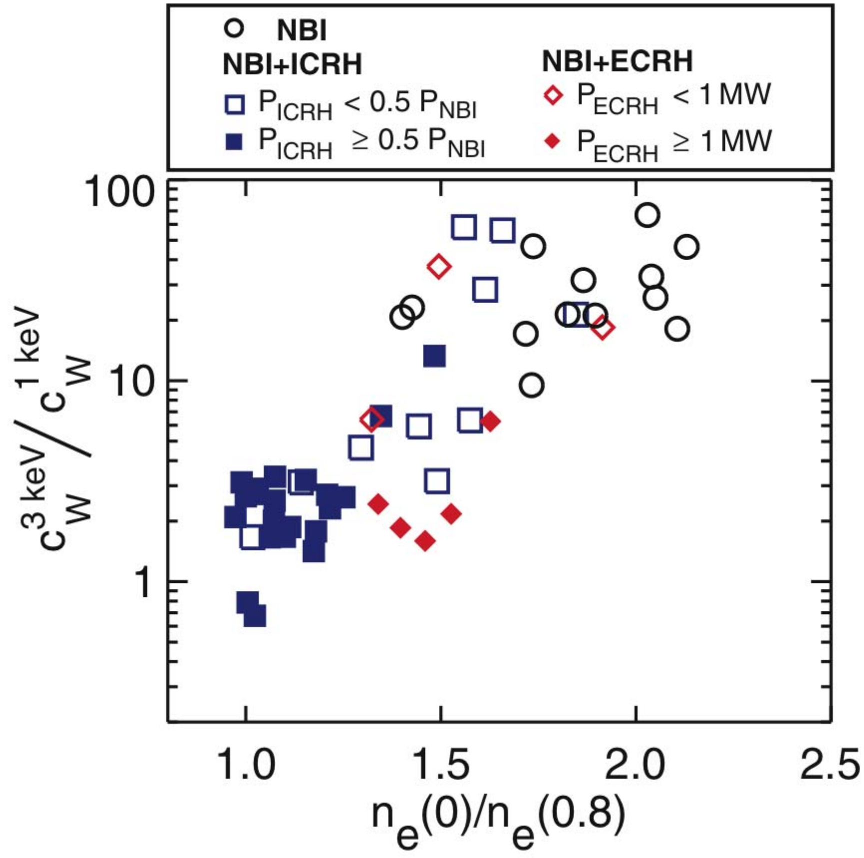


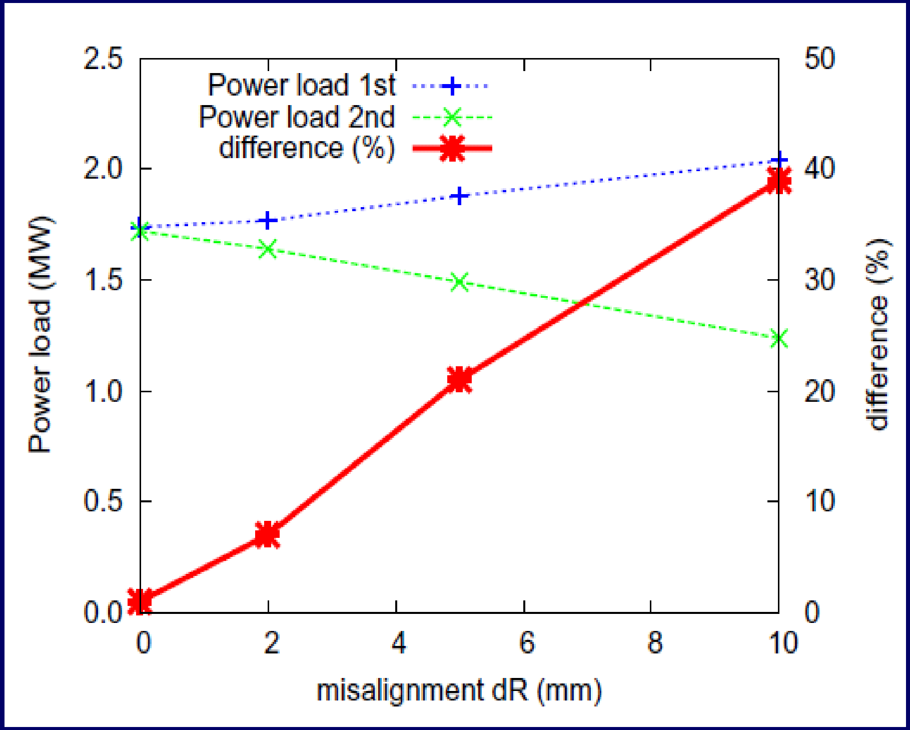
Figure 13. Peaking of the W concentration (c_W) as a function of background density. Discharges with pure NBI heating (black circles) show the strongest peaking, whereas central ECRH reduces the c_W peaking significantly already at low additional heating power.

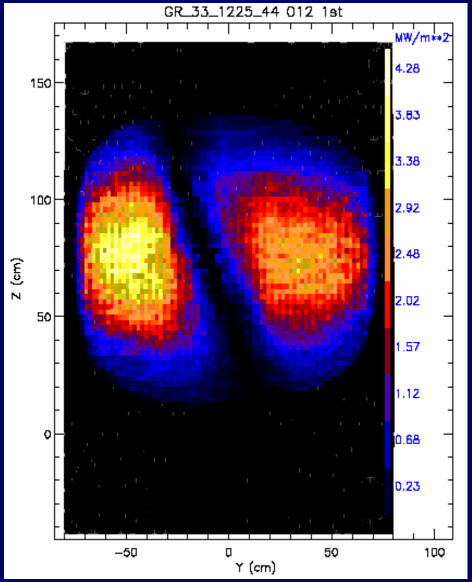
PWI in steady state

- Heat and particle control is very important for steady state operation
  - Impurity control and heat exhaust with peaked density and low separatrix density
  - Heat load due to high energy particles expelled at TAE could be an issue

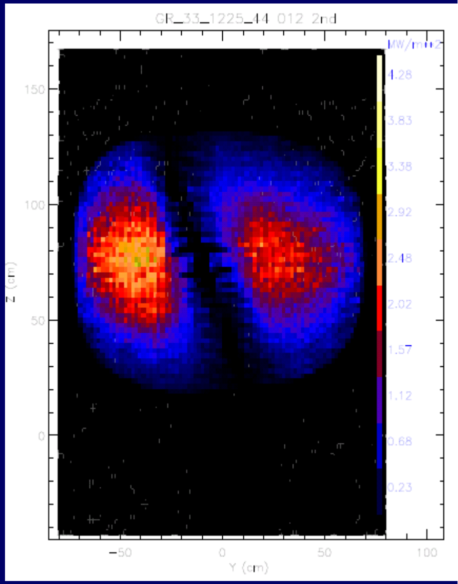
Example of successful collaboration

Design assessment of limiter using 3D sol code





First limiter



Second limiter 10mn behind of the first limiter

M. Kobayashi / G. Federici

Summary

- Issues:
  - Disruption control(prediction, mitigation, avoidance)
  - ELM mitigation (pellet, external coils, discharge scenarios)
  - Tritium retention(understanding, removal)
  - Dust (understanding, removal)
  - Sol transport (blob), impurity transport (high Z)
  - Steady state control
  - Wall condiitoning (with steady B)
- Most of these problems are common across the different confinement schemes