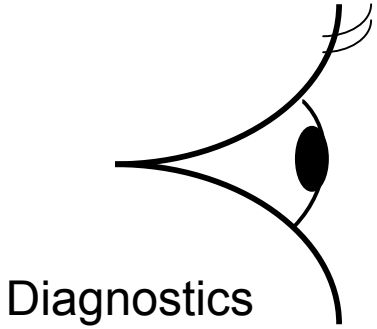
Plasma Wall Issues on ITER - Diagnostic Impacts.

Charles Skinner et al.,
Princeton Plasma Physics Laboratory

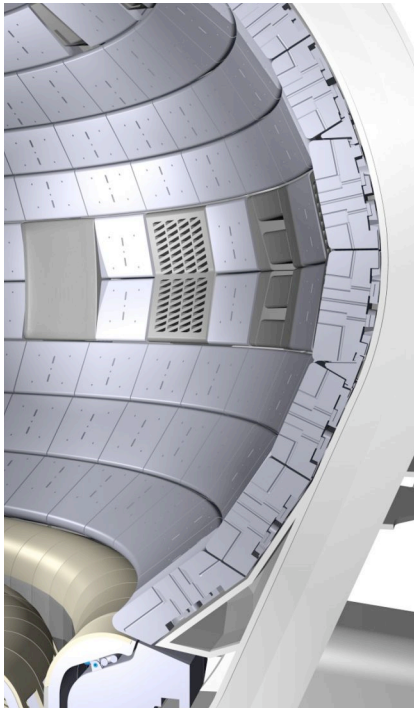
12th Meeting of the ITPA Topical Group on Diagnostics, PPPL 26-30 March 2007.

Two way street:



Diagnostics of PWI:
- Influx of Be/C/W
- H/D/T gas balance
- Deposition
- Erosion diagnostics
- Dust diagnostics (Wed)

Effects of PWI on diagnostics:
- Erosion/deposition of mirrors
- Dust on 1st mirrors (Wed)
- [CHERS without carbon]


ITER

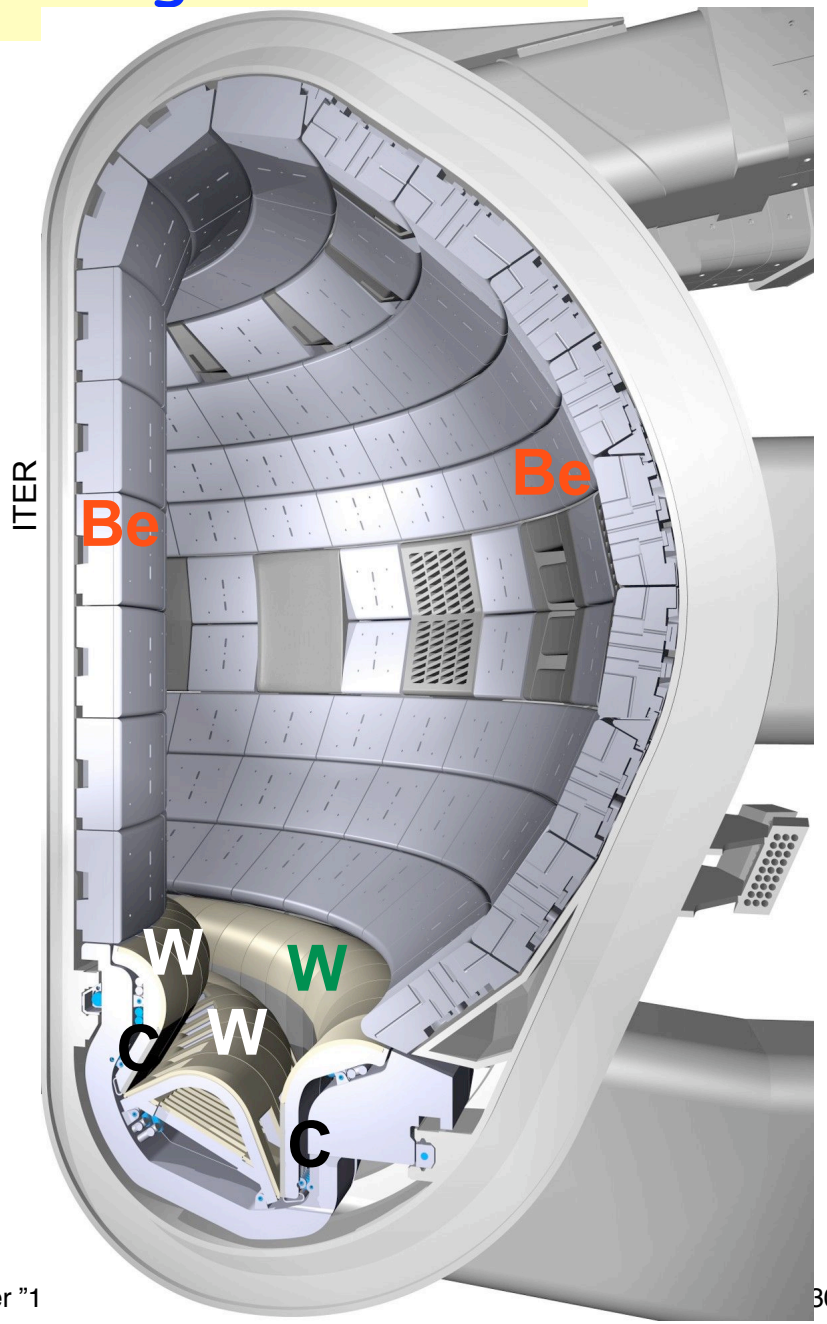
With contributions from many colleagues

ITER plasma facing materials

Beryllium wall
(low Z = low radiation losses, oxygen getter, but low melt temperature)

Tungsten baffle and dome
(high melt temp, low erosion, low T retention, but high rad. losses)

Carbon divertor target
(does not melt, good radiator for plasma detachment, but T retention is major issue)

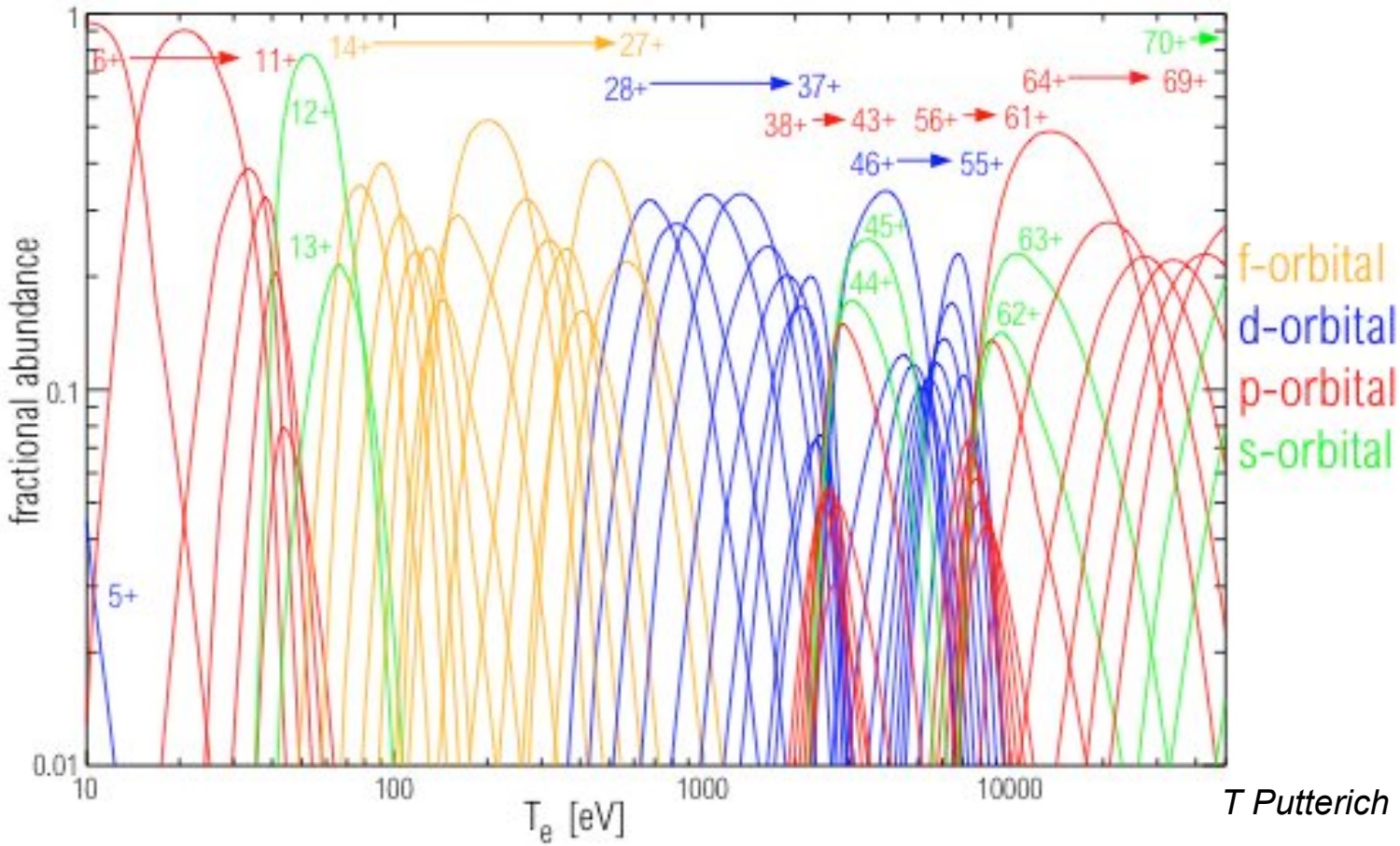


- Plasma:
  - 3-year Hydrogen,
  - 1-year Deuterium
  - then DT
  - Argon ≈ 0.12% of electron density to control detachment
  - Ne, N_2 also possible
  - Be impurities est. ≈ 3% of Ne
  - Core He ash 15%
  - Zeff < 1.6

Important to track the creation of mixed material surfaces:
Be on W, W on Be etc.

Be is backed by copper so spectral information on Cu important too.

Tungsten will be principal high-z impurity



T Putterich

Asdex-U | ITER

W influx must be controlled, core concentration << than 10^{-4}
W atomic data used to interpret emission measurements.

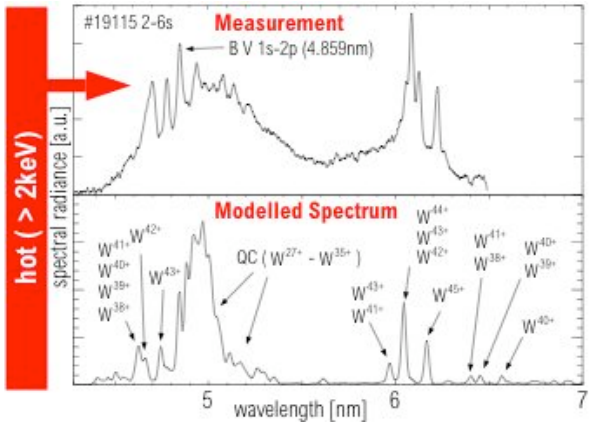
C. H. Skinner "12th Meeting of the ITPA Topical Group on Diagnostics, PPPL 26-30 March 2007".

Atomic data needs for tungsten:

Measurement Requirements:

- Nw/ne range 1e-6 to 4e-4
- W influx 4e14 - 2e17 /s
- Ne,Ar,Kr /ne 1e-4 to 2e-2
- Ne, Ar, Kr influx 4e16 - 8e18 /s
- Ti 0.05 - 40 keV

±10%



T Putterich

- W influx gauged by W I 400.8 nm line with known photon efficiency (S/XB) but there is potential interference from WII line at nearly same wavelength
- Ionized tungsten has small gyro radius so major fraction is promptly recycled back to wall on the first gyro orbit after ionization.
- NIST Database for 450-1000 nm shows 2186 lines for W1, 35 lines for WII but remarkably nothing for W III and up at any wavelength.

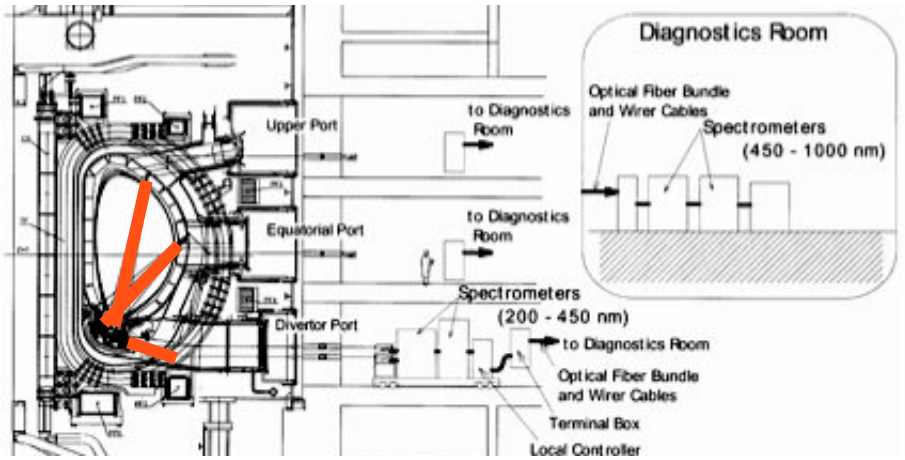
Recommend:

1. Search for emission lines > 450 nm
2. Identifying emissions of charge states for ionization states below about W^{26+}
3. Corresponding S/XB (emission /mass loss) measurements.

'Forbidden' magnetic dipole emission lines

- Line of sight from upper port passes through plasma core.
  - potential to observe forbidden
  - lines in 450-1000 nm region.
  - Could temperature and density of highly charged ions be conveniently obtained using high throughput visible region spectrometers / fiber optics ?

Sightlines in red



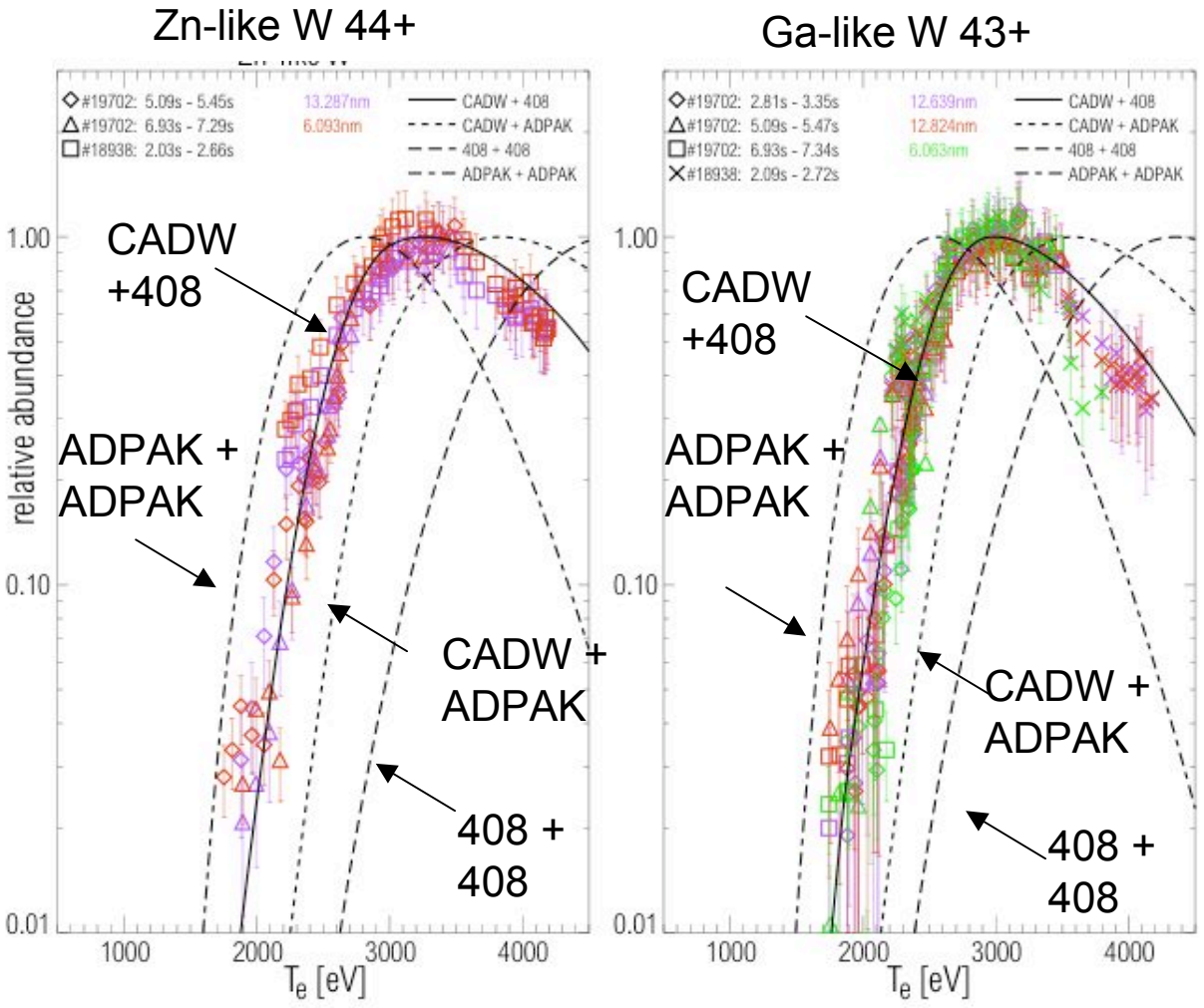
T. Sugie et al., J. Plasma Fusion Res. 79 (2003) 1051

- Ti-like Tungsten^{+52} M1 transition at 3627.13Å reported from EBIT measurements [Utter, Beiersdorfer & Brown (PRA 61 (2000) 030503(R))]
  - (not seen so far on Asdex but maybe insufficient Te).

- Recommendation:
  Search for magnetic dipole emission lines from highly ionized tungsten (up to Li-like).

Ionization Balance data needed.

- Ionization balance calculations need improvement
- Baseline ADAS (408 + 408) not good enough.
- CADW+408 has 'fudge' factor



Putterich Asdex-U data

Acknowledge very helpful discussions with M Putterich, R Neu, D Stuttman, P Beiersdorfer, D Stotler, K Hill

Summary of areas where W data is needed:

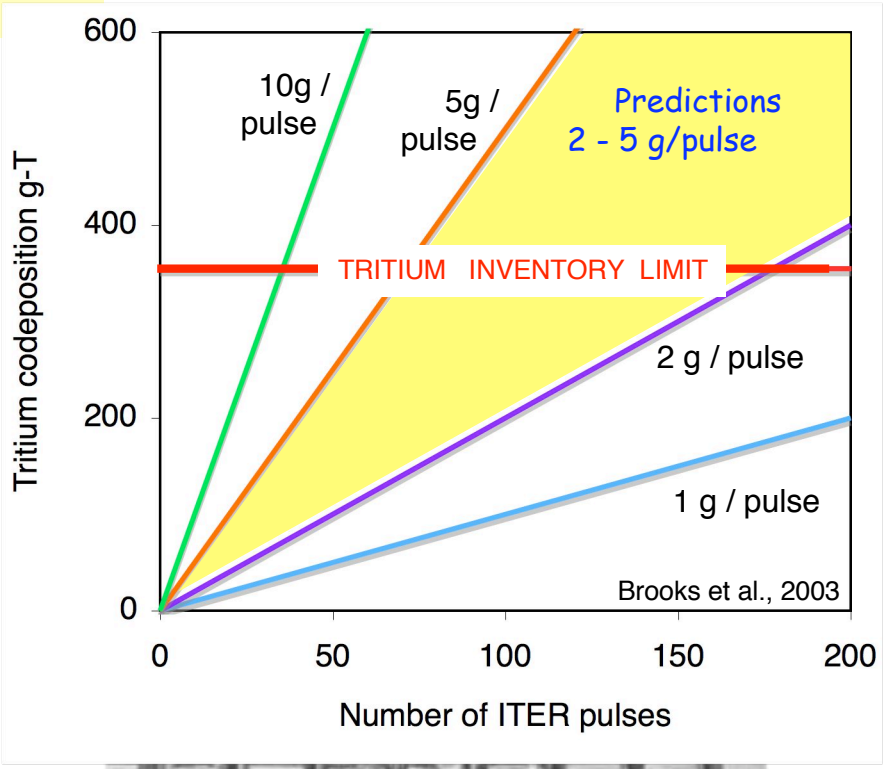
1. Search for W emission lines > 450 nm
2. Identifying emissions of charge states for ionization states below about W^{26+}
3. Corresponding photon efficiency (S/XB) measurements
   -> measure of influx after recycling.
4. Identification of emission lines from neon-like tungsten for ITER temperatures 10-30 keV.
   - Use data for JET in 2009 with W PFC and 35 MW NBI.
5. Improve ADAS - energy dependence of ionization equilibria and excitation rates for W. Look at spectral lines, where strong discrepancies between codes and experimental spectra appeared (such as 0.793 nm of Ni-like W^{46+}).
6. More identified lines always desirable to measure W density gradients and transport barriers.
7. Ne, Ar, Kr, Cu lines also…
8. EBIT measurements of charge exchange spectra…

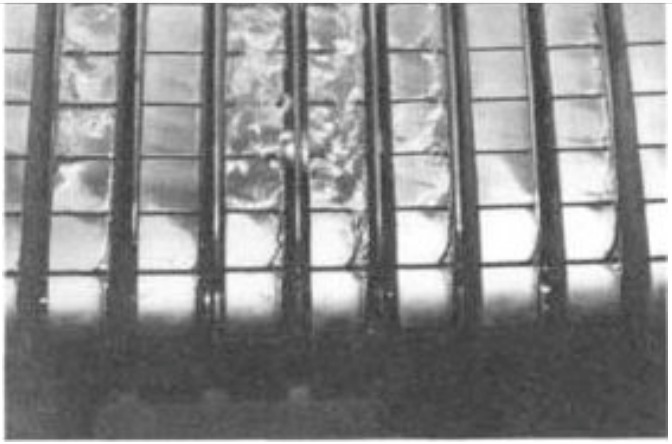
Retention Diagnostics needed

- ITER's plasma facing materials dilemma:
  - Carbon does not melt, but retains T
  - W does not retain much T but melts.
  - No contemporary tokamak has used ITER's mix of PFC materials (coming up: Asdex-U 100% W this year and JET ILW in 2009)
  - No contemporary tokamak has used ITER's conformal wall geometry (no limiters)

- Present plan is to begin H phase with Be/C/W and assess:
  - Retention level
  - ELM mitigation for decision on C or W divertor target plates for DT.
- Diagnostics to support this plan are not in 2001 design.

Number of ITER pulses before tritium inventory limit is reached



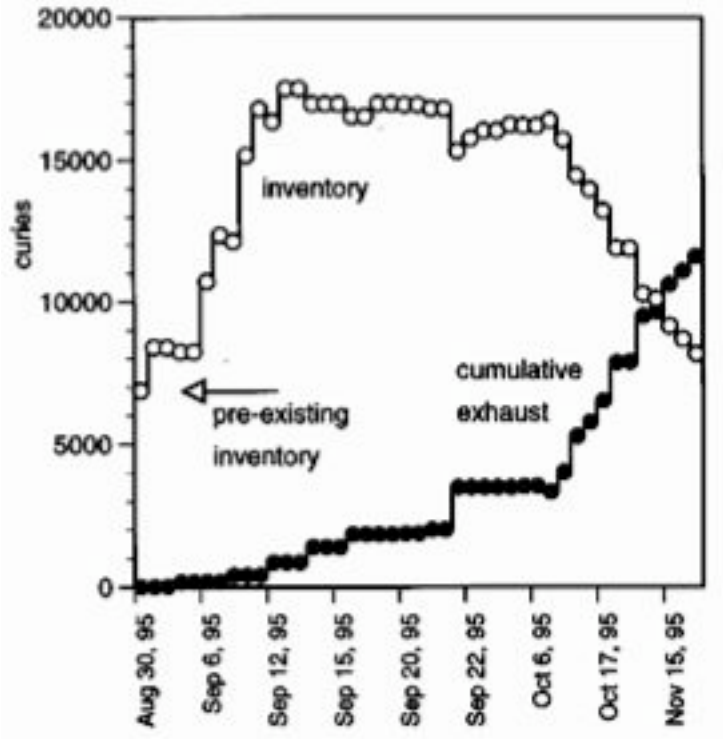


Be limiter damage observed on JET (Loarte PSI-16)

H/D/T Gas balance diagnostics

- ITER FUELING:
  50 g-T / pulse, 20 pulses/day, 10 days operation = 10,000 g-T
- Tritium Limit ≤ 330 g-T in vessel
  ~ 3% of 10 day fueling.
- Operation > 10 days needs retention << 3 % or fast, efficient T removal (by unproven techniques).
- Need to measure retention in H phase to < 1% accuracy for C/W decision.

TFTR tritium balance 1995



- 2001 baseline proposes 1-week shutdown to measure T inventory
- Issue card ITPA FW6 proposes on-line diagnosis of H, D, T inventory.
- Needed accuracy < 3% problematic (was 5-7% on TFTR) but could indicate upper limit.
- Trace D useful if injected for longer than the plasma-wall equilibration time.

Deposition Diagnostics Needed

To establish ~ < 1% retention need to measure H/D/T retained in deposits:

H phase:

- manned intervention possible but assessement complicated by pre-existing H_2O
- Trace D ?

DD and DT phases

- Periodic removal of divertor cassette ?
- remote retrieval of coupons by general purpose maintenance arm ?

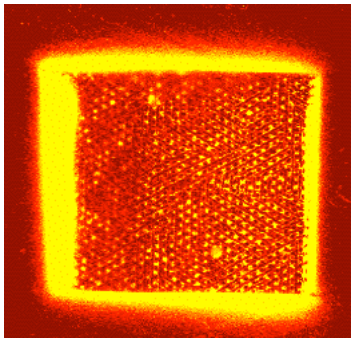
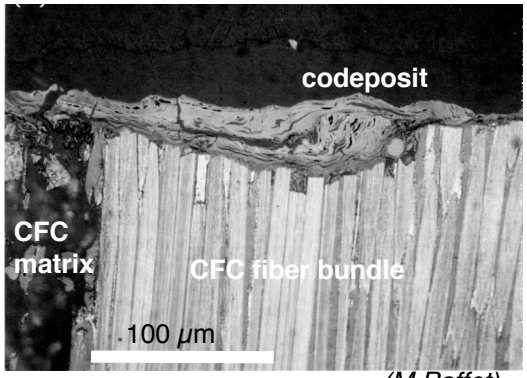
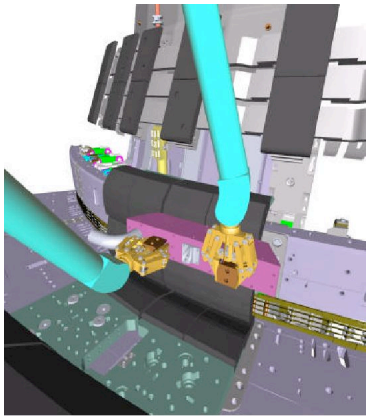


Image of tritium on TFTR tile. Note most T is on sides. *(T. Tanabe)*

Microstructure of TFTR codeposit



(M Paffet)



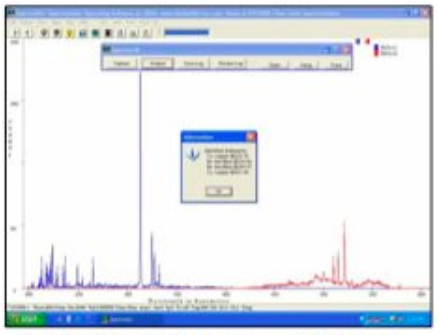
JET remote handling

MIXED MATERIALS DIAGNOSIS:

- Be erosion of blanket module could lead to mixed material ($Be_{22}W$) alloys in divertor with ~ 1,500 C melting ! (not 3,680 C for W)
- Laser ablation spectroscopy could be applied to diagnose this

PORTA-LIBS-2000 can be useful for a variety of applications. Here's just a few:

$20,000



Spectral ID of 1.9% Beryllium + 98.1% Copper

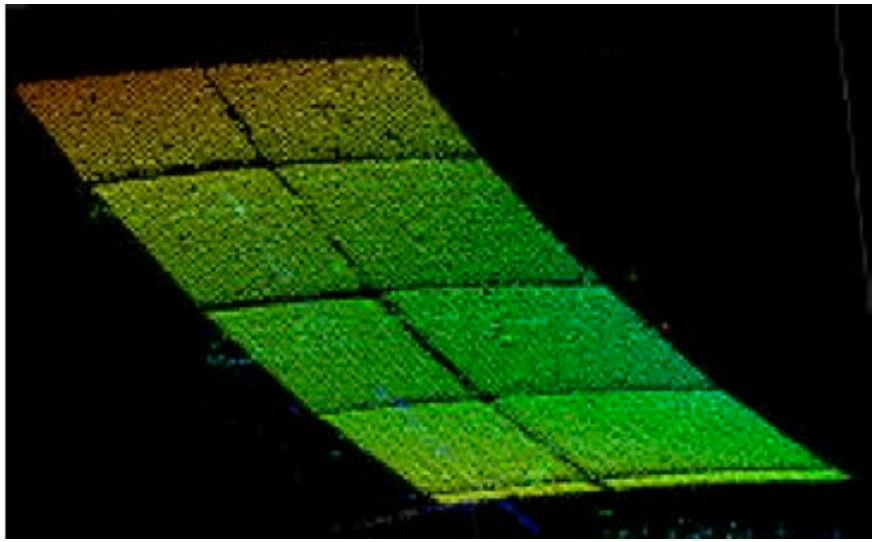
Spectral ID of 1.9% Be/98.1% Cu

Erosion Diagnostics Needed

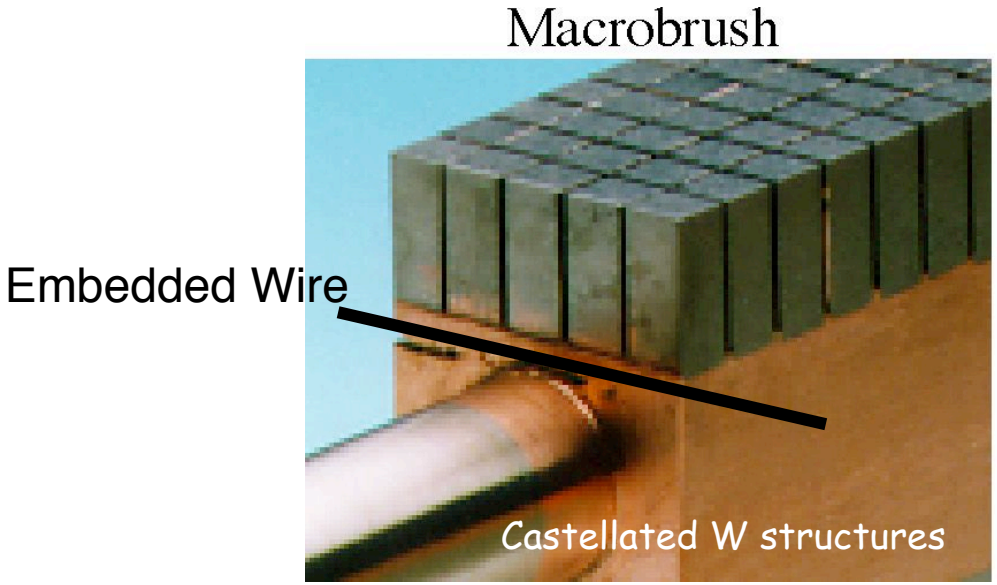
Erosion diagnostics needed to ensure PFC integrity.
Erosion monitor is in the list of uncredited diagnostics.
The EU, JA, and US have expressed interest in it.
Most of the work to present has been done in JA (reports posted on ITPA Diagnostics website).

Embedded wires could be used as well for difficult-to-view areas such as apex of lower divertor.

Erosion would lead to loss of electrical continuity and warn of potential LOCA (loss of coolant accident).



Laser rangefinder scan of 8 TFTR tiles (Menon et al.)

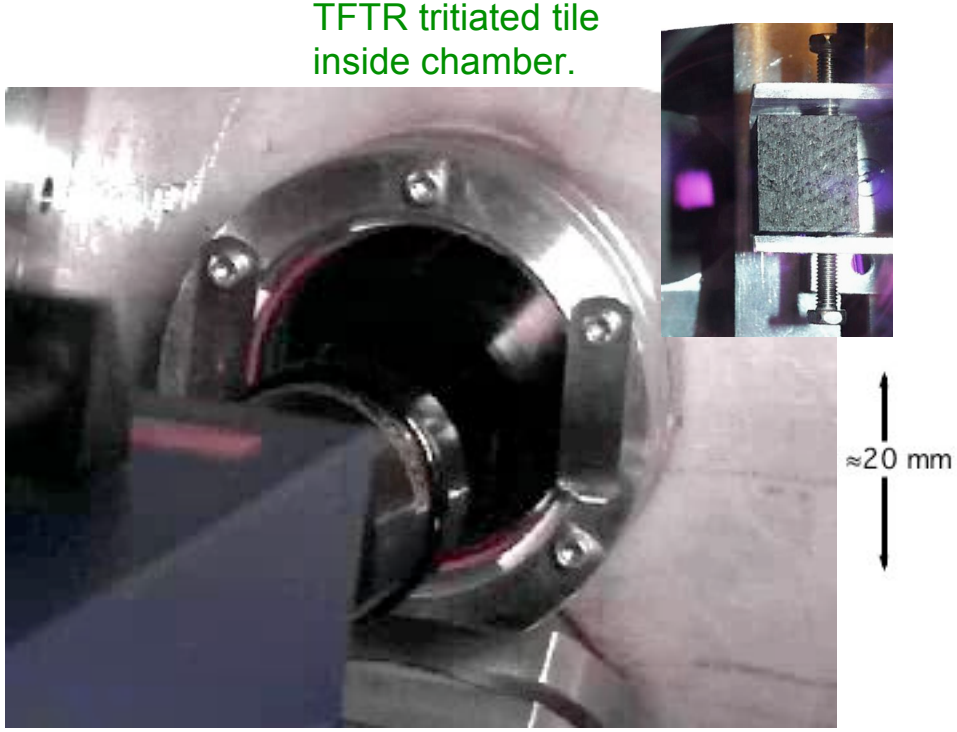


Dust and deposition removal from diagnostic mirrors ?

Divertor target plate will be eroded ~1 cm at strike point over 3 year lifetime.

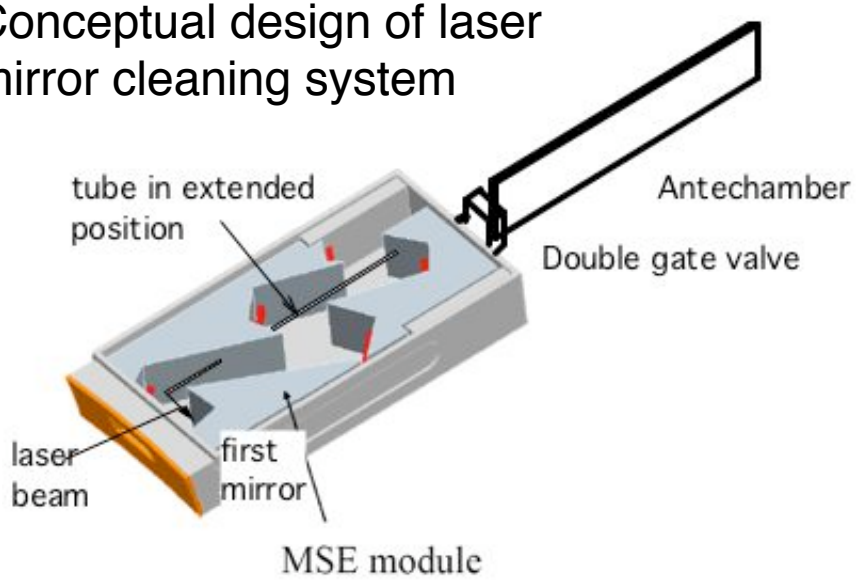
Material will go somewhere !

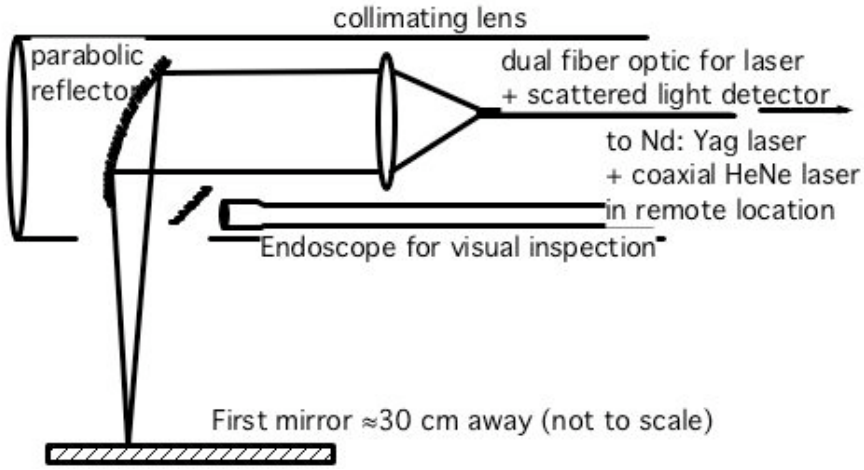
7/8" cube cut from TFTR tritiated tile inside chamber.



From prior laser detritiation work

Conceptual design of laser mirror cleaning system



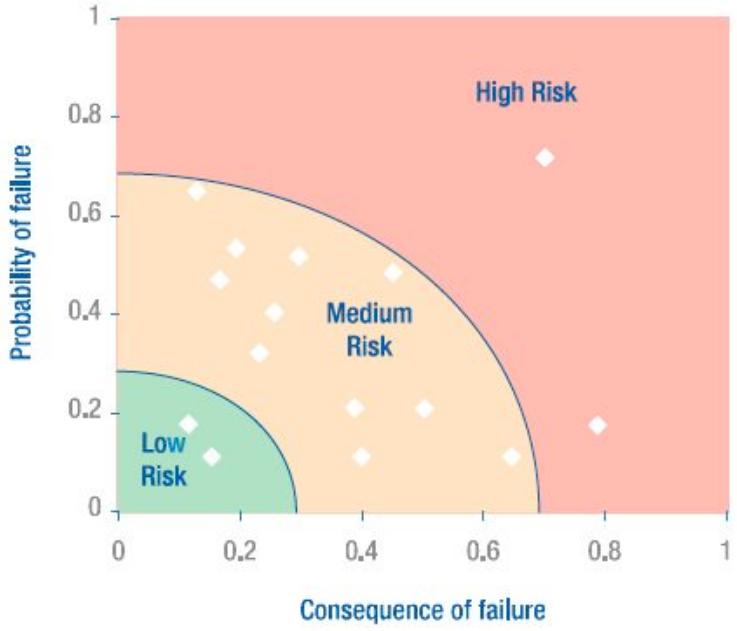


Risk analysis

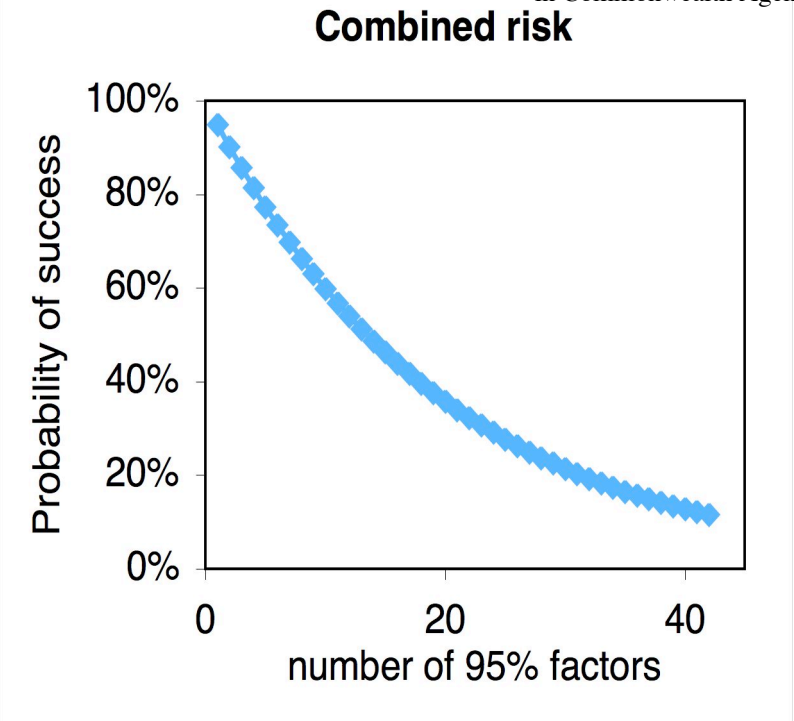
Final Point:

- Management of risk intrinsic in any large project.
- 95% probability of success in a number of individual but essential systems is not sufficient.
- ITER has many many systems.
- Risks in fusion are hard to quantify, but can only be reduced through dedicated R&D.

- Recommend ITER enlist risk management experts from e.g. space missions to identify areas of highest risk and consequences and use this to quantify R&D needs.

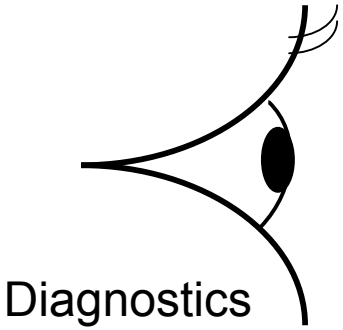


Management of Scientific R&D in Commonwealth Agencies



Summary:

- ITER's mix of Be/W/C materials and conformal in-vessel geometry (no fixed limiters) has not been tested in contemporary tokamaks !
  - PWI area has high risk and high consequences for ITER operations and diagnostics.
  - Only R&D can mitigate risk (e.g. JET ILW experiment)
  - Most items below are not even 'uncredited' !

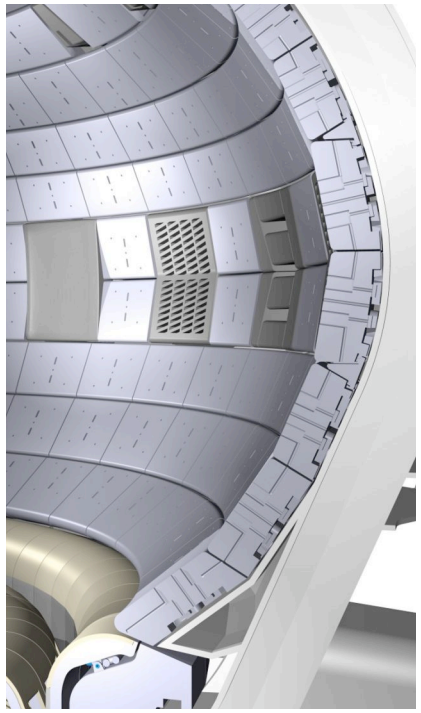


Diagnostics of PWI:

- Tungsten atomic data needed
- Deposition/gas balance diagnostics needed to support C/W target plate decision for ITER's DT phase.
- Erosion diagnostics for PFC protection
- Dust diagnostics (Wed talk)

Effects of PWI on diagnostics:

- Mirror cleaning technology highly prudent
- Dust on 1st mirrors (Wed)



Cumulative risk assessment overdue