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IPP

Recent analysis of Key Plasma Wall Interactions Issues for ITER

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with contributions from

ITER PWI Team, EFDA PWI TF, F4E, ITPA SOL/DIV,

Outline

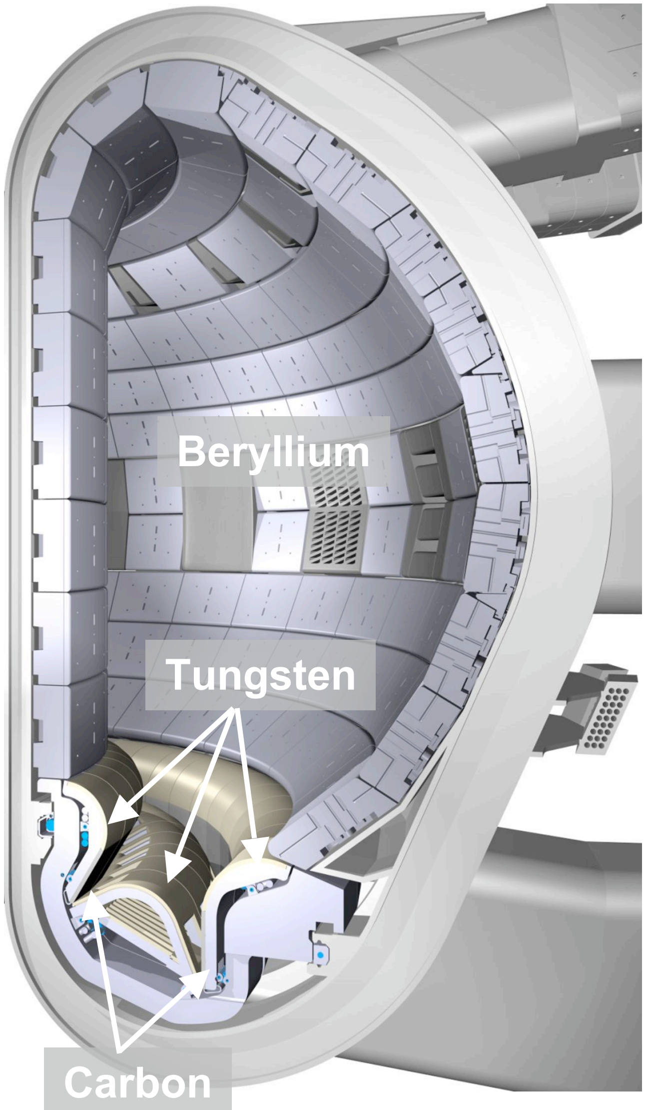
Operational parameters and limits of ITER

High priority issues:

- **Lifetime of plasma-facing components**
- **Dust**
- **Tritium inventory**

Consequences for plasma scenarios and material choice

ITER PFC Environment



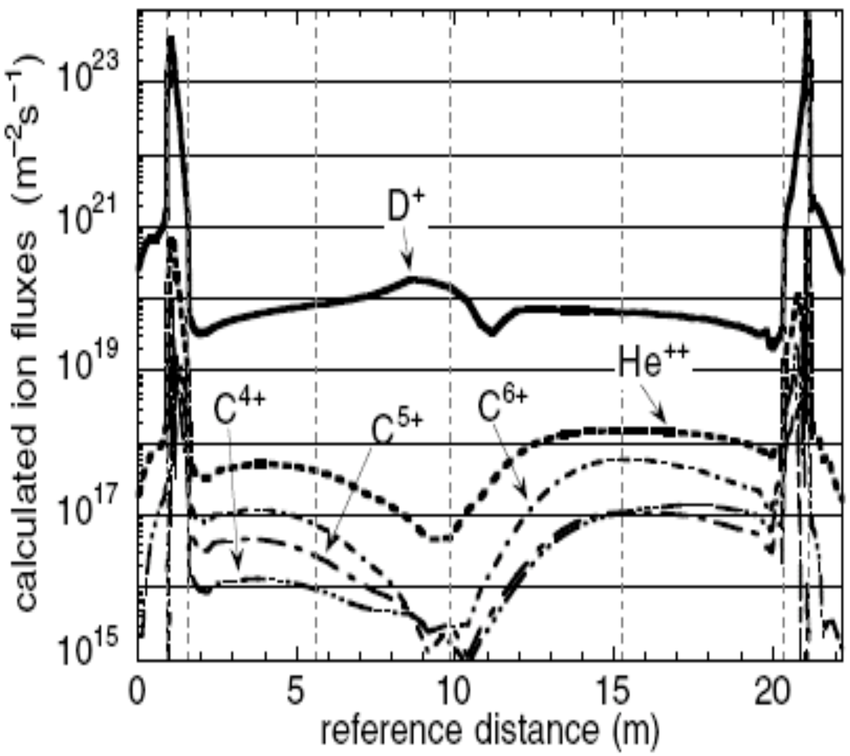
Initial reference material mix (H, D phases):

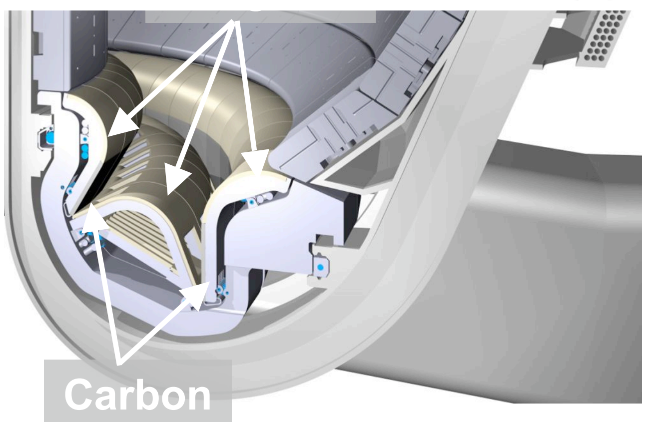
- **700m² Be** first wall and start-up limiter modules
- **100m² W** divertor dome and baffle region
- **50m² Carbon Fibre Composite** (CFC) for the divertor strike point areas

Present strategy for ITER operation

- change to a **full W-divertor** before DT operation
- Decide on specific time for change on the basis of experience on hydrogen retention and dust
- **all-W** as future DEMO relevant choice

ITER PFC Environment





Predicted edge plasma conditions:

- ❑ B2-EIRENE simulations (A. Kukushkin)
  ⇨ total wall flux $8x10^{22}$ (D+T)/s
- ❑ power flux scaling (A. Kallenbach)
  ⇨ total wall flux $1\text{-}5x10^{23}$ (D+T)/s
- ❑ scaling with n_{SOL}, λ_n and v_{conv} (B. Lipschultz)
  ⇨ total wall flux $\leq 7x10^{23}$ (D+T)/s
- ❑ used here:

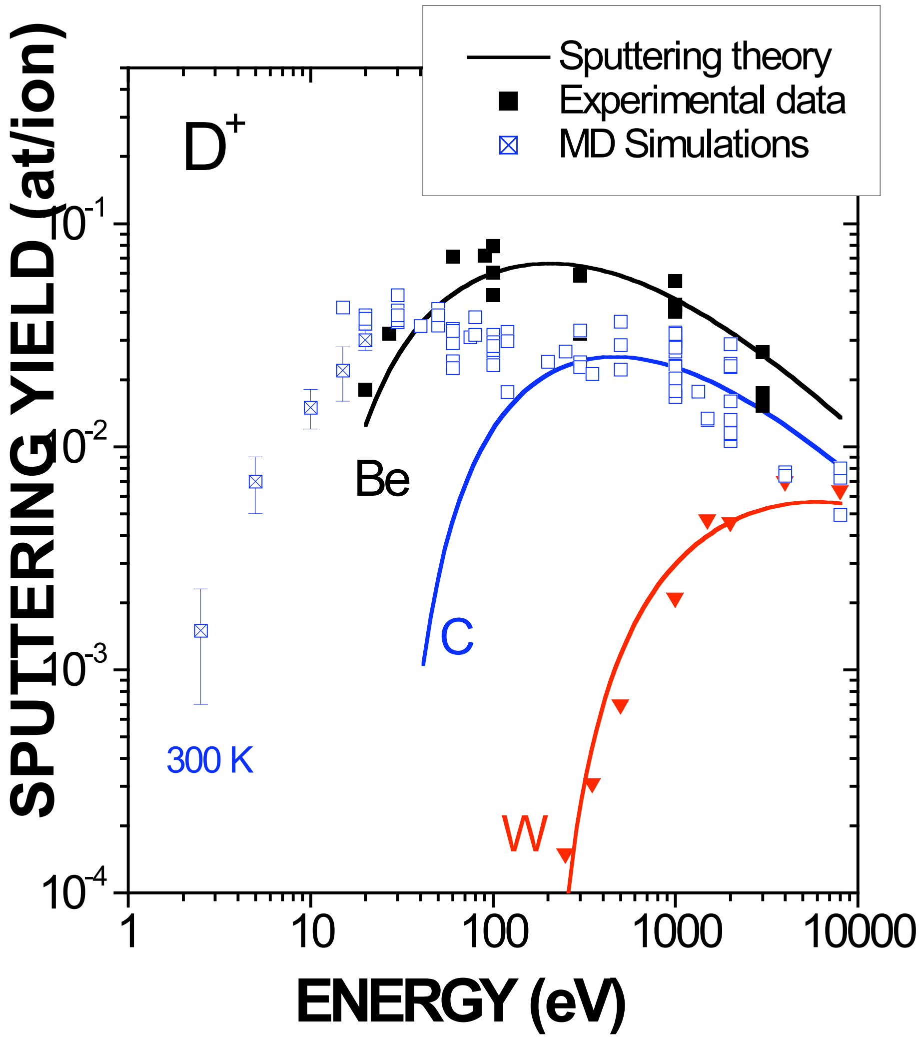
total wall flux $1\text{-}5x10^{23}$ (D+T)/s

divertor flux $5x10^{24}$ (D+T)/s

flux distribution from B2-EIRENE

Lifetime of PFCs

Erosion assessment from laboratory data:



Physical sputtering understood and well predictable

Chemical sputtering widely investigated and well described

The multi-step process can be strongly modified by material mixing

E. Salonen, Phys.Rev.B 2001, M. Balden, J.Nucl.Mat. 2000

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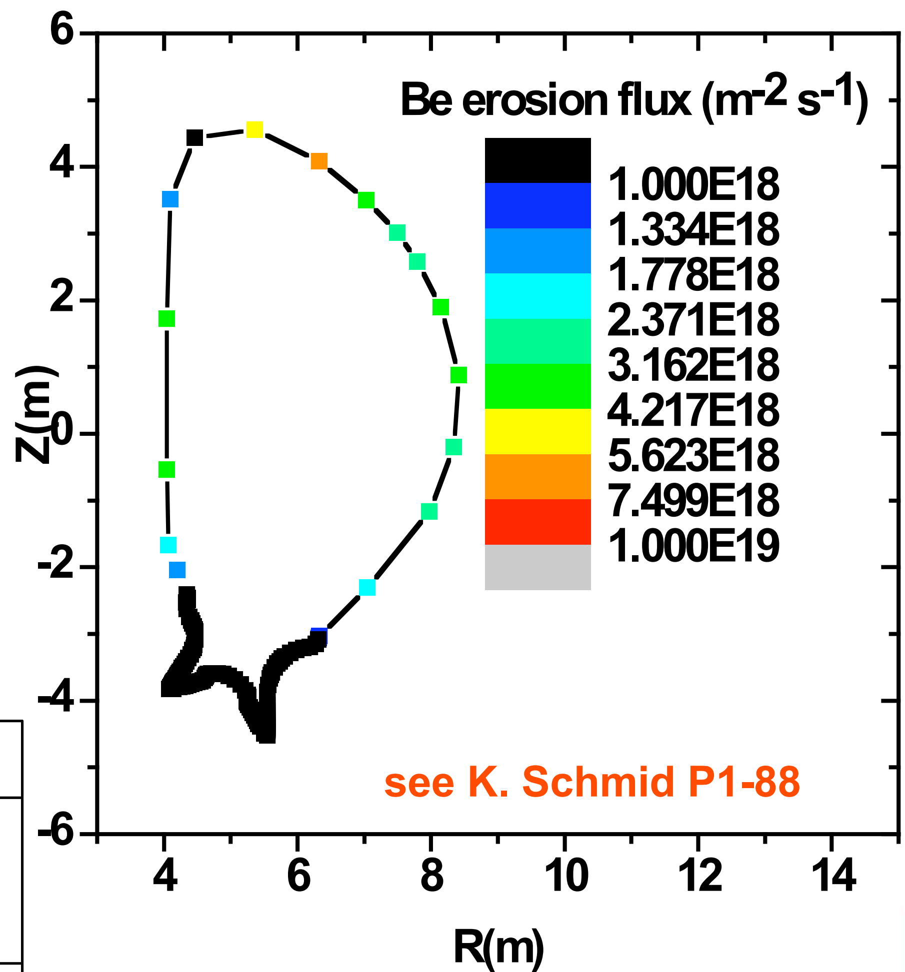
Lifetime of PFCs

Wall erosion in steady state:

Be first wall erosion is calculated based on B2-Eirene results
Toroidal peaking may reduce wetted area to ≈ 50m²

For **W** erosion due to impurity sputtering is taken into account;
here: 0.1% Ar in SOL plasma

Wall material	nm/s	atoms/s	g/shot
Be average	**0.12**	**8x10²¹**	**48**
peak 50m²	**8**		
W average	**0.05**	**2x10²⁰**	**26**
peak poloidal	**0.12**		



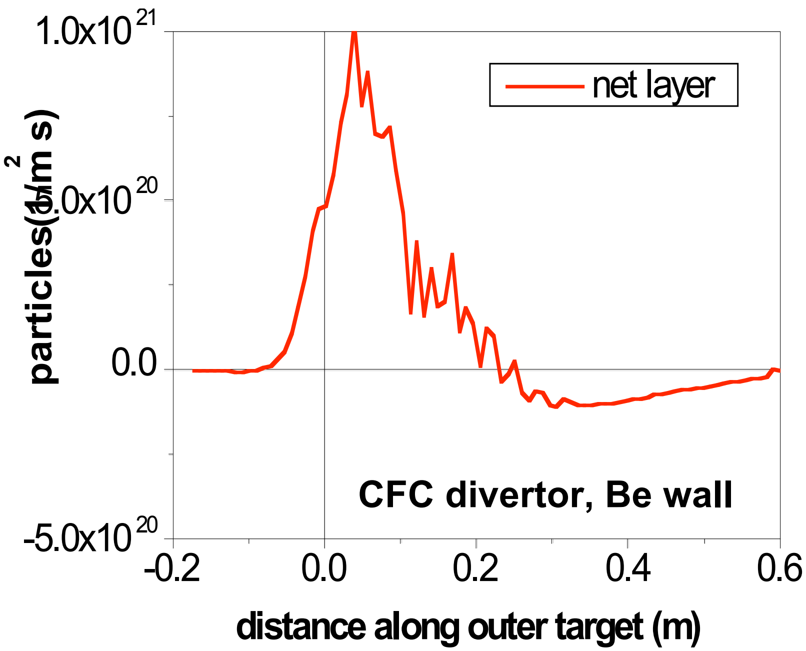
Erosion of Be first wall may become a lifetime problem for inhomogeneous loading

Lifetime of PFCs

Divertor erosion in steady state:

CFC divertor erosion is calculated using ERO based on B2-Eirene results (including 0.1% Be^{2+}, but reduction of chemical erosion due to Be not included)

W erosion mainly due to Ar impurities (0.1 %) (DIVIMP)



see A. Kirschner P2-20

Divertor mat.	nm/s	atoms/s	g/shot
CFC gross	**100**	$4x10^{22}$	330
net	**1**	$4x10^{20}$	3
W gross	**2**	$4x10^{20}$	48
net	**0.3**	$6x10^{19}$	7

Lifetime of PFCs

ELM induced erosion: CFC

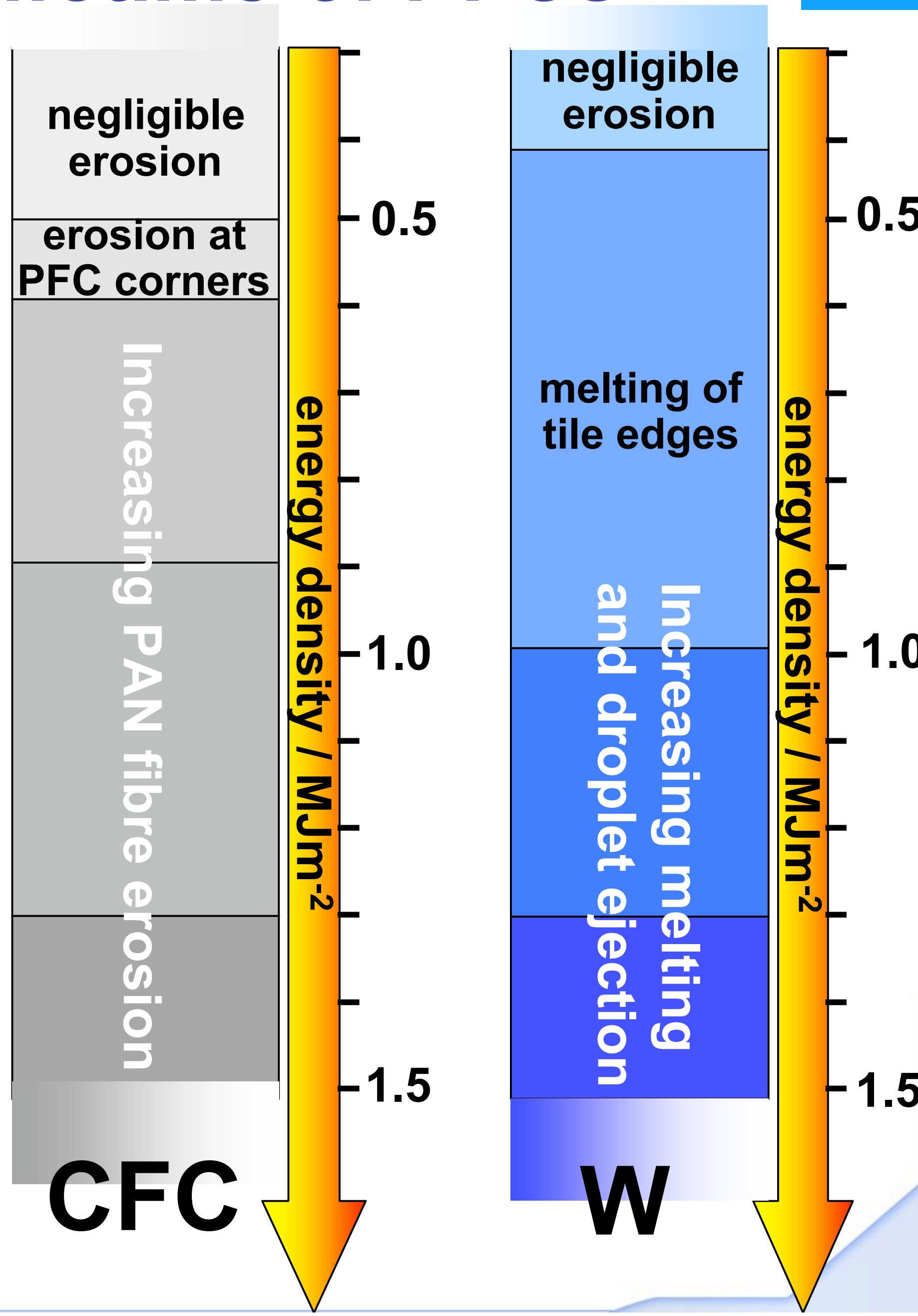
Results from Russian plasma simulators:

- ❑ Erosion limit for CFC reached due to PAN fibre erosion
- ❑ Erosion limit for W reached due to melting of tile edges

Crack formation was observed at energy densities ≥ 0.7 MJ/m^2. Repetitive sub-threshold ELM investigations ongoing in JUDITH2

Recommended threshold for damage 0.5 MJm^{-2} ⇨ adopted by ITER

Efficient mitigation methods needed



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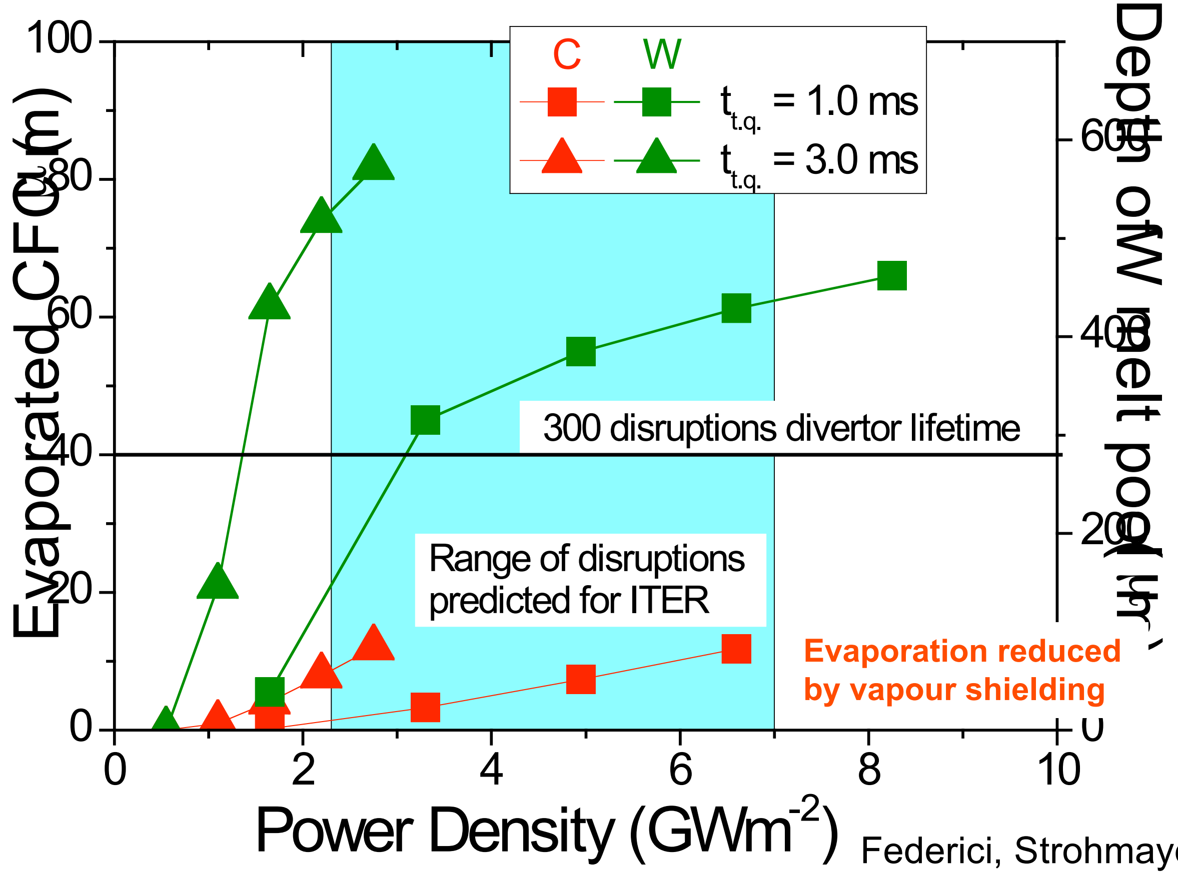
Lifetime of PFCs

Disruption induced erosion:

- Vapour shielding reduces CFC evaporation by factor 10
  see S. Pestchanyi P1-97
- Predicted ITER disruptions exceed the 300 disruptions lifetime limit for W
- **Efficient mitigation methods needed**



Federici, Strohmayer
RACLETTE
Riccardo, Federici
Nuclear Fusion 2005

ITER assumptions:

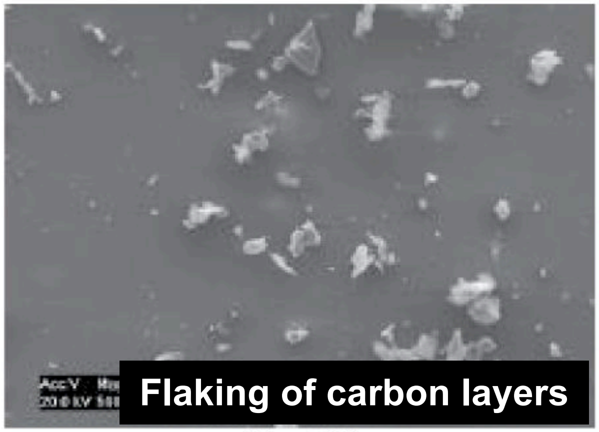
30 disruptions in about 2000 discharges

10 % of melt layer lost in the case of W divertor plates

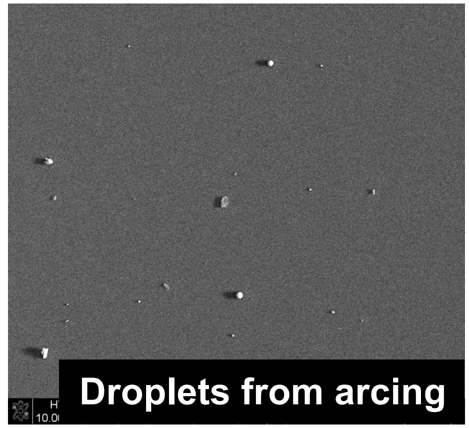
5 kg erosion per disruption

Dust generation

Collection July 2000



Collector probes 2007



AUG

full-C and full-W phase

J. Sharpe, V. Rohde et al., JNM 2003

M. Balden et al, post-deadline poster 2008

Potential safety concerns:

Potential release in environment ⇨ **1000 kg limit**

W is the major radioactive source

Dust contains trapped Tritium

Hydrogen production when hot dust reacts with steam

Be major contributor

with carbon: ⇨ **6 kg C, 6 Be, 6 kg W limit**

without carbon: ⇨ **11 kg Be, 230 kg W limit**

Possible pure Dust or Hydrogen/Dust explosion

Be, C, W involved

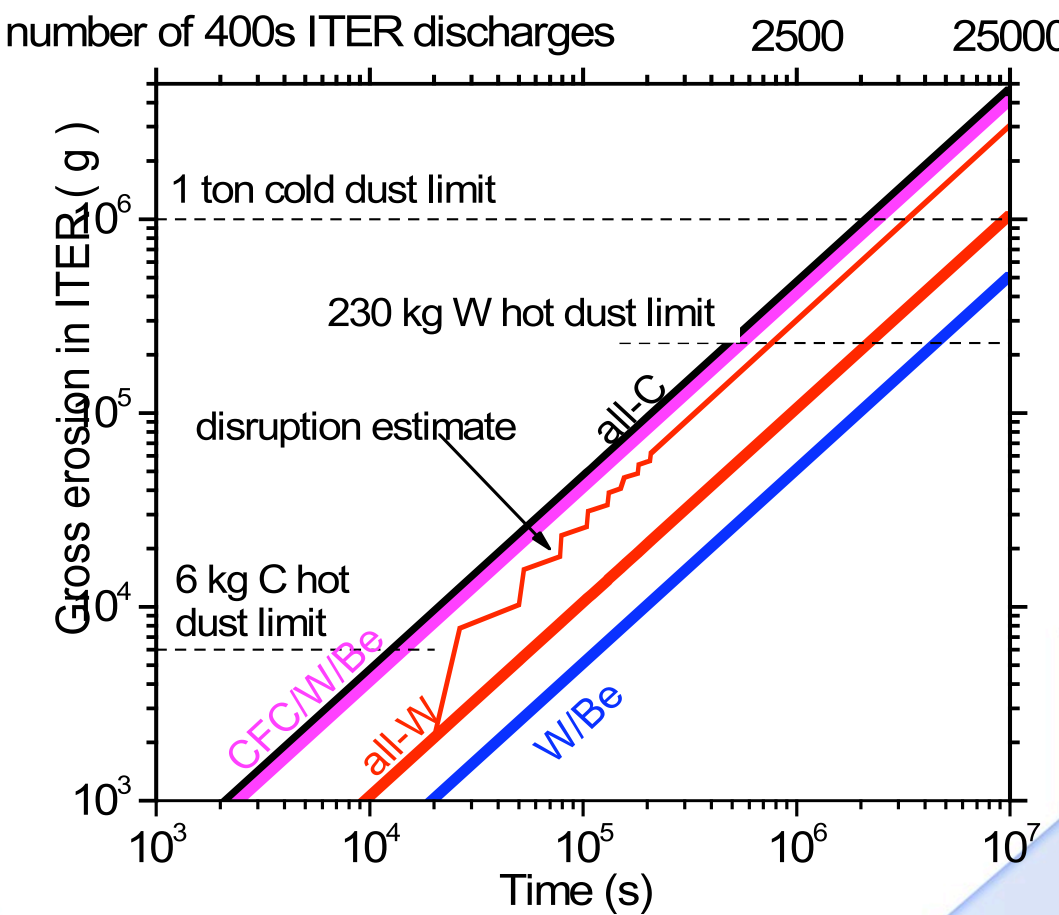
Dust generation

Total dust generation:

Assumption:

- ❑ Dust generation dominated by erosion, deposition, layer disintegration
- ❑ Conversion from erosion to dust for safety reasons: 100 %

  (about 10 % in Tore Supra and JT-60U)



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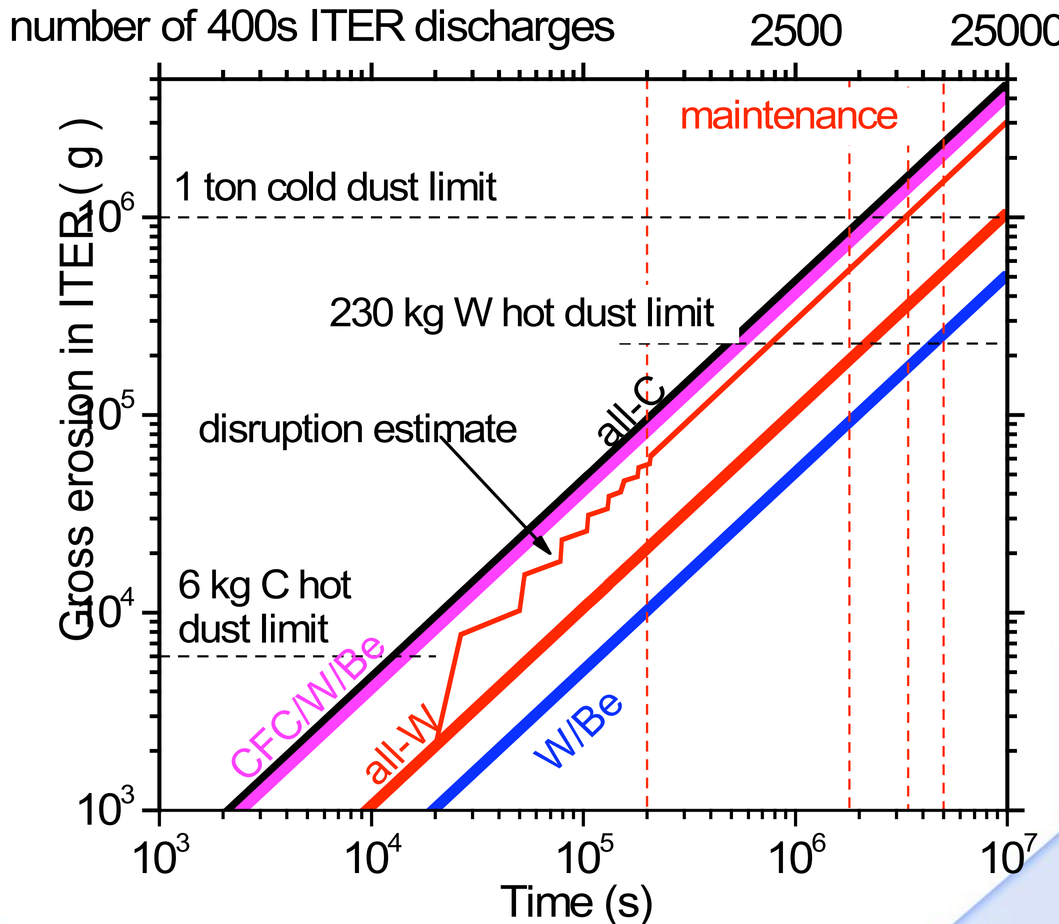

Total dust limit not reached before scheduled maintenance and exchange of divertor cassettes

What fraction of dust resides in hot (>600°C) areas?

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Dust generation

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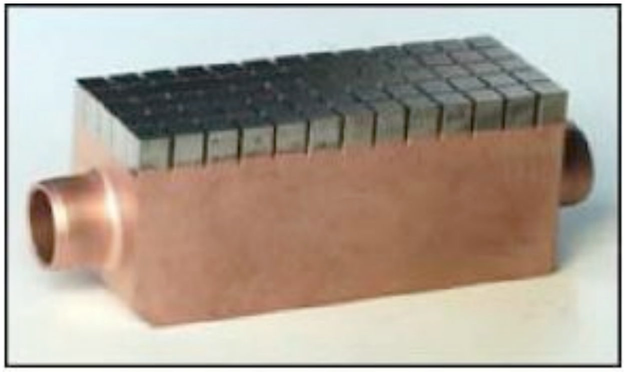
Dust on hot areas:

Assumption:

- ❑ On hot plasma (>600°C) wetted areas deposits and dust will only survive in castellation
- ❑ Need to estimate the fraction of impurity deposition in gaps from experimental data base **see A. Litnowski O-7**



Assume dust at hot area collects only in gaps:

Flux of Be to outer target hot zone (DIVIMP): $2\times10^{19}/m^2s$

Area of hot zone: $8m^2$

⇨Total Be flux: $1.6\times10^{20}/s \approx$ 1g/discharge

Gap area 2%

⇨Hot Be dust rate: 0.02g/discharge

⇨ 11kg Be dust for W/Be wall in 60000 disch.

Hot dust estimate requires better understanding of dust transport and gap deposition

Tritium inventory

Potential safety concerns:

Potential release in environment

In order to avoid evacuation of population ⇨ **1000 g limit**

Administration limit lower

previously large uncertainties in accounting
reduced uncertainties to 180 g ⇨ 820 g
inventory in cryo-pumps ⇨ 120 g

present administration limit ⇨ **700 g limit**

Tritium inventory

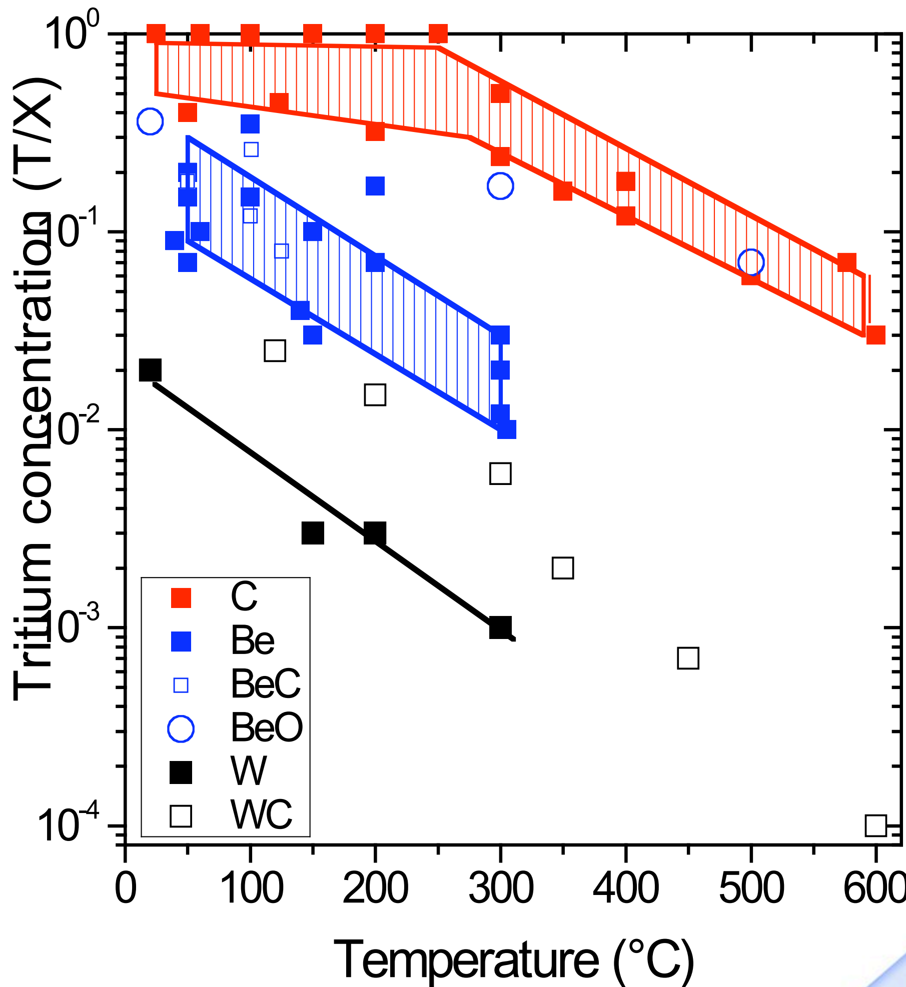
Erosion determines co-deposition:

- ❑ Rough estimate: total net erosion rate x co-deposition concentration
- ❑ Detailed evaluation: impurity transport including re-erosion, co-deposition concentration depending on final deposition conditions

Co-deposition with C and Be depends on deposition conditions: energy, deposition rate, temperature

see G. De Temmerman O-20

	atoms/s	g/shot
Be wall	$3x10^{20}$	1.8
CFC divertor	$2x10^{21}$	3.2
W divertor	$4x10^{17}$	$8x10^{-4}$



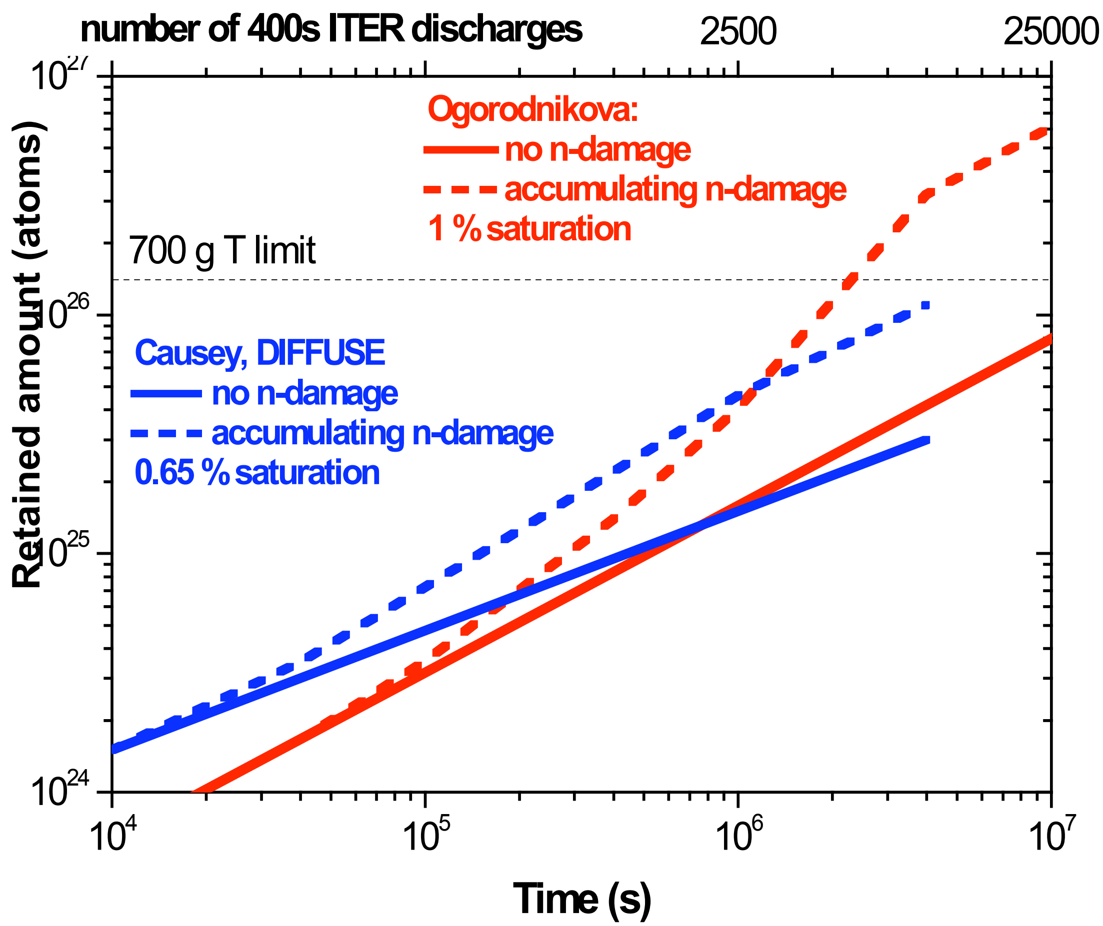
Tritium inventory

Implantation: D in W divertor tiles

Code calculations (Ogorodnikova) based on experiments.

n-irradiation assumes saturation at 1% additional trap sites.

DIFFUSE code (Causey) predicts square root fluence dependence with and without n-induced traps



see talks: **M. Mayer I-13: ASDEX U**
B. Lipschultz I-14: Cmod

n effects **D. Whyte O-19**
J. Sharpe P3-65
R. Causey P3-69

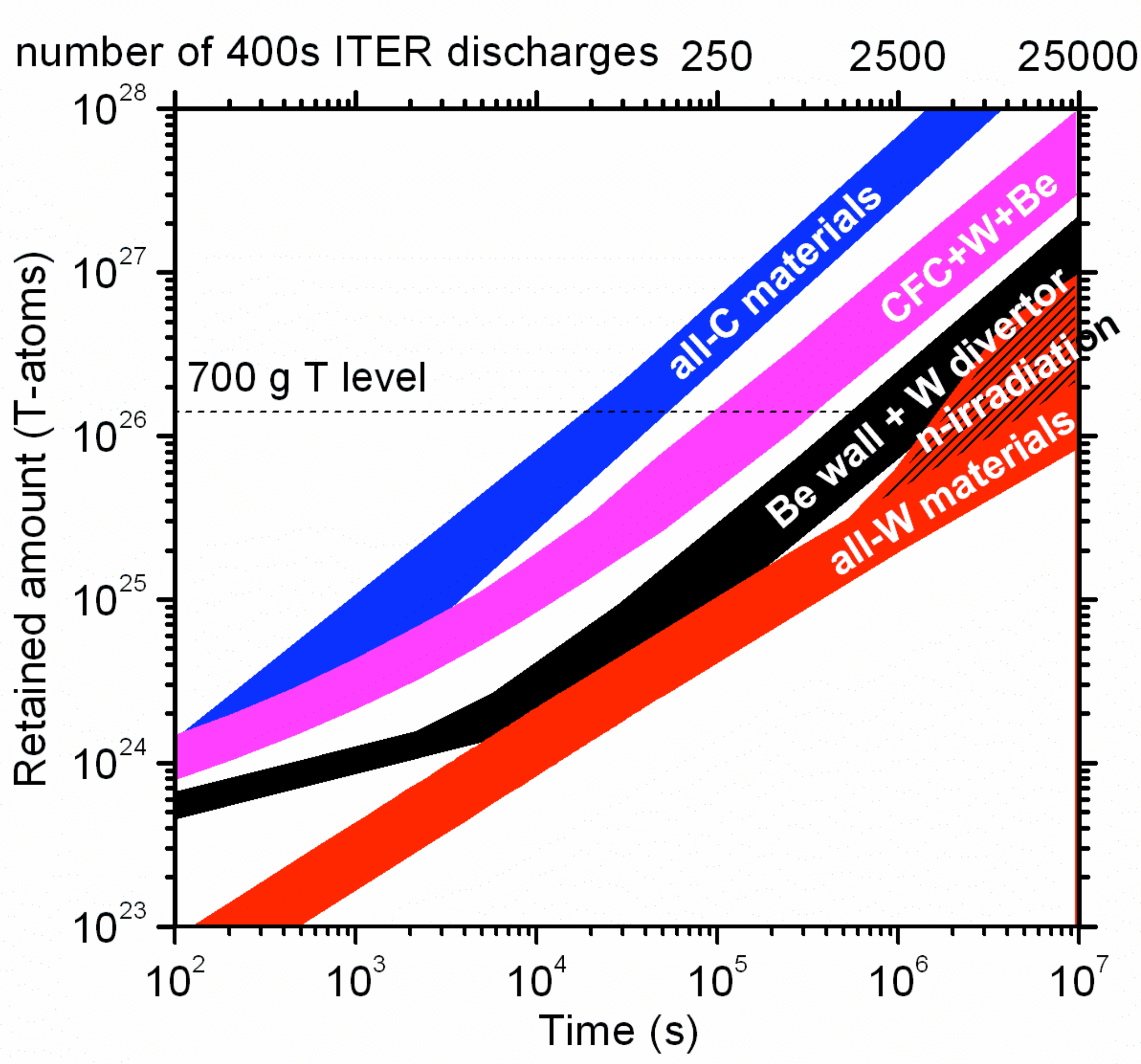
Good agreement without n,
main uncertainties in estimate of n dpa,
damage structure and hydrogen trapping

Tritium inventory

Sum of both processes:
comparison of materials options

EU assessment

Review for PPCF, submitted March 2008

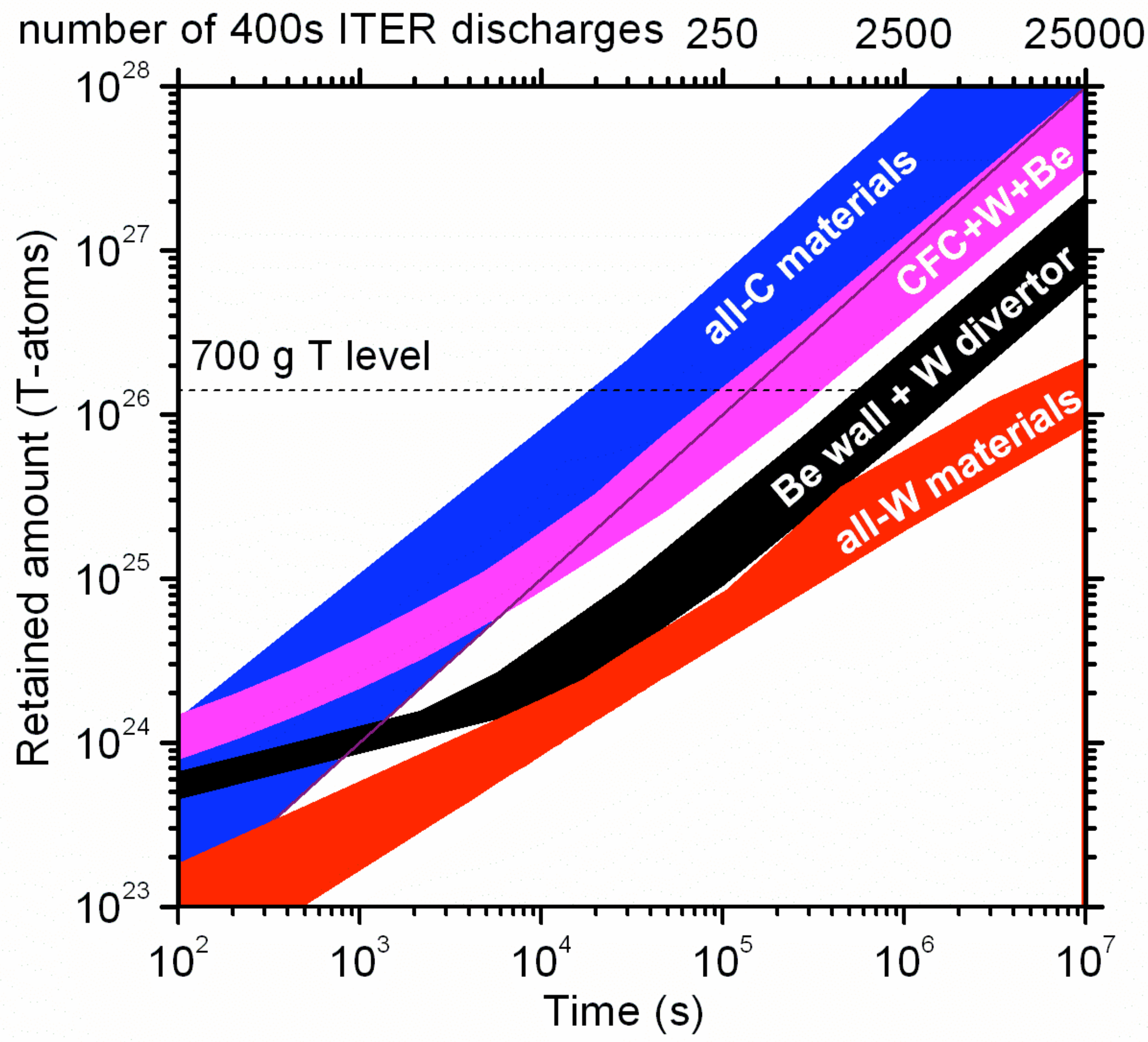


Tritium inventory

Sum of both processes:
comparison of materials options

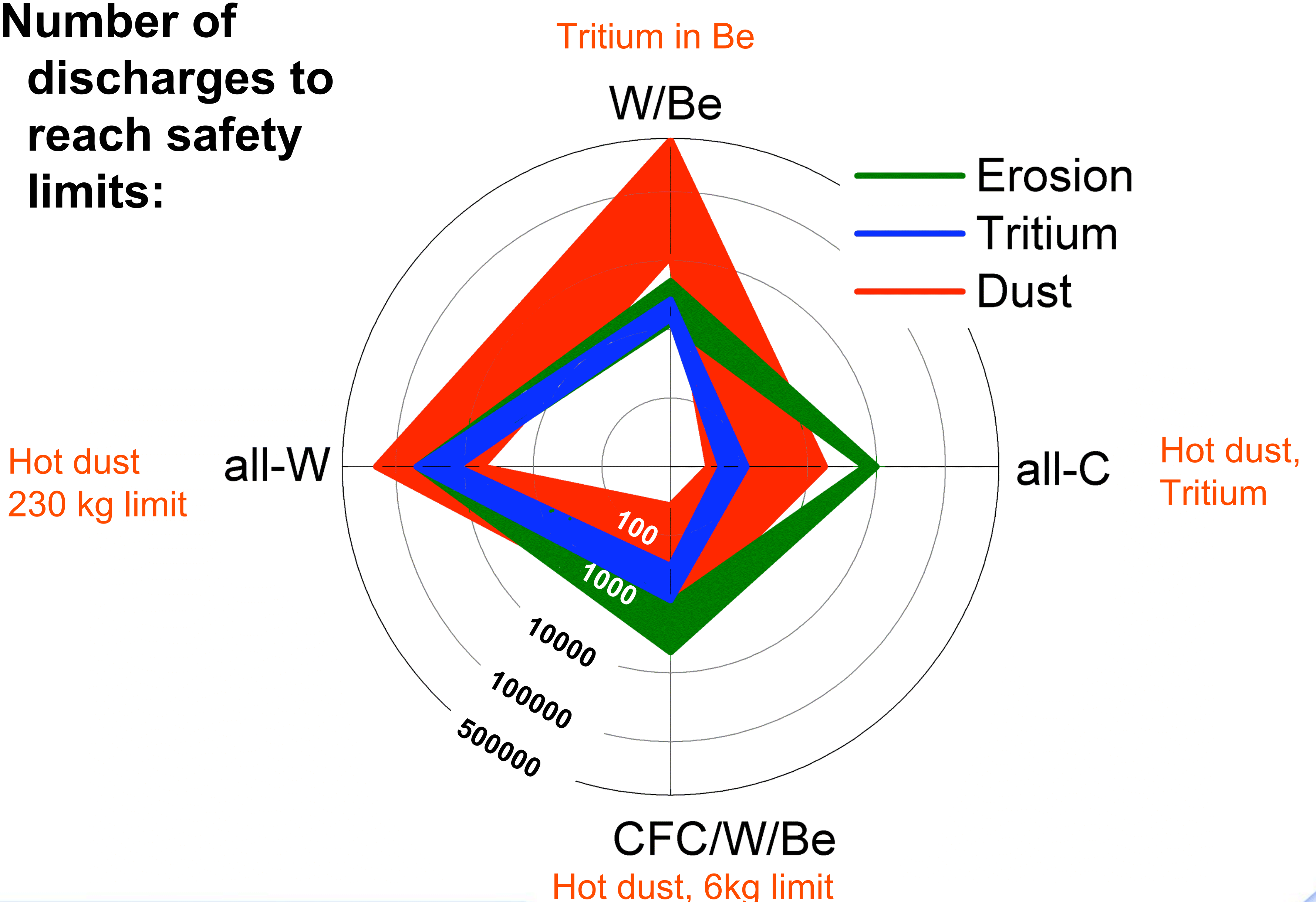
ITPA SOL/DIV assessment

Contribution to the IAEA, Geneva 2008



Conclusions

Number of discharges to reach safety limits:



High priority PWI issues

Lifetime of PFCs:

- Material properties require plasma scenarios with
  - mitigated ELMs <0.5 MJ/m^2 and
  - without (or very few) disruptions ⇨Review by W. Fundamenski R-2
  - for the use of W PFCs ⇨Invited talk by R. Dux I-6
- Damage studies for a high number (10^6) of sub-threshold ELMs
- Damage studies for mitigated disruptions

Dust generation:

- More data needed on dust in tokamaks
- Dust transport to evaluate hot dust accumulation

Tritium inventory:

- Influence of n-irradiation on tritium inventories in W
- Improve experience from all-metal machines (JET ILW)

Removal methods:

- no single method sufficient
- 'good housekeeping' method for inventory mitigation
- Oxidation of carbon deposits ⇨ Invited talk by J. Davis I-10