Parameters influencing the D/Be ratio in codeposited material

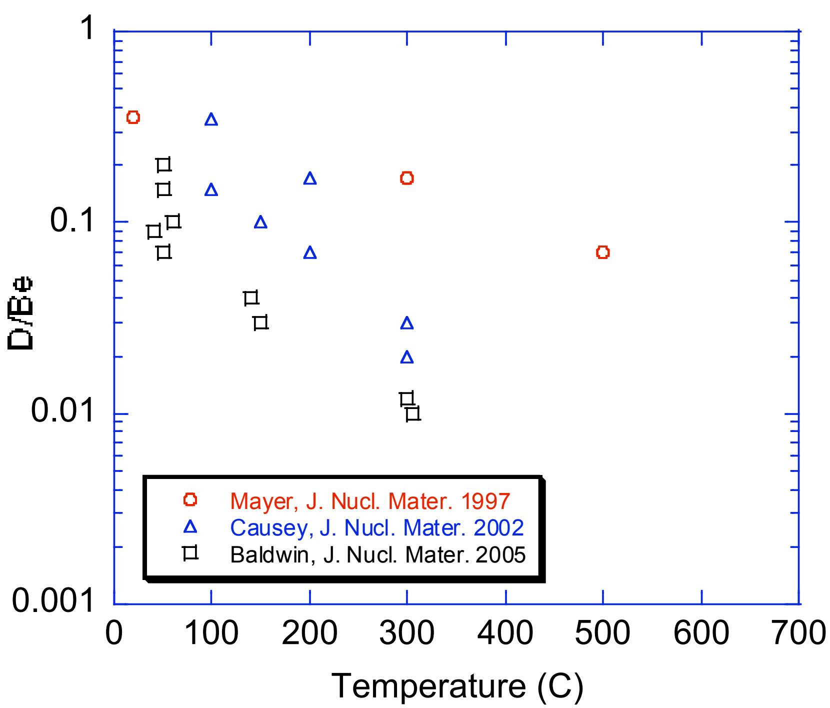
and

Implications for tritium retention in ITER

presented by R. Doerner

- Based on the modeling of:
  - A. Kukushkin, ITER Report [ITER_D_27TKC6]
  - K. Schmid, Report for EFDA Task TUNMOD
  - G. De Temmerman, manuscript submitted to Nucl. Fusion 2007
  - J. Roth, manuscript submitted to PPCF 2008.

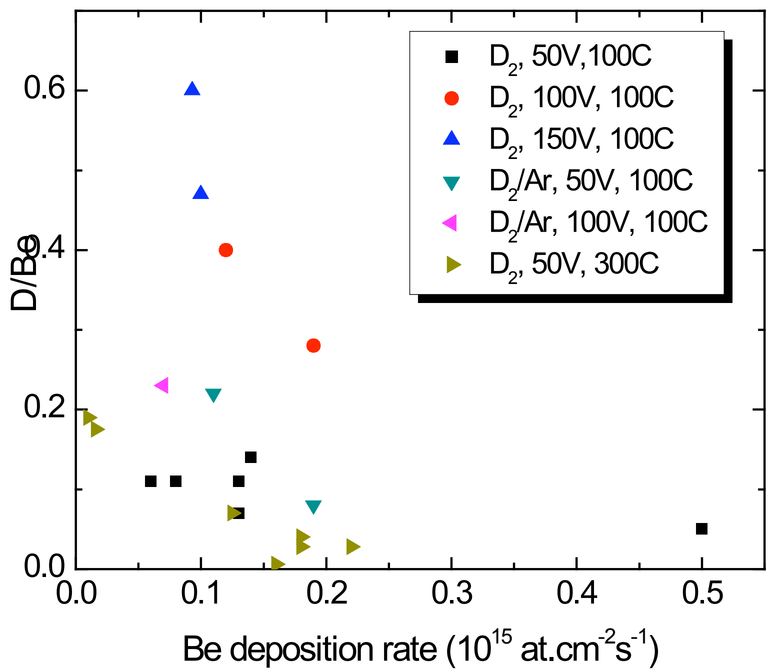
Published database of D/Be levels in codeposits cover a wide range of values



- Almost an order of magnitude variation in measured D/Be levels exists in the published literature for similar conditions
- Be codeposition data by Mayer (from ion beam exp.) was contaminated with oxygen and carbon (~15%).
- Be codeposition data by Causey and Baldwin subsequently showed no systematic dependence with oxygen content, layers also had little carbon content.

Subsequent experiments in PISCES-B revealed even larger variations in D/Be

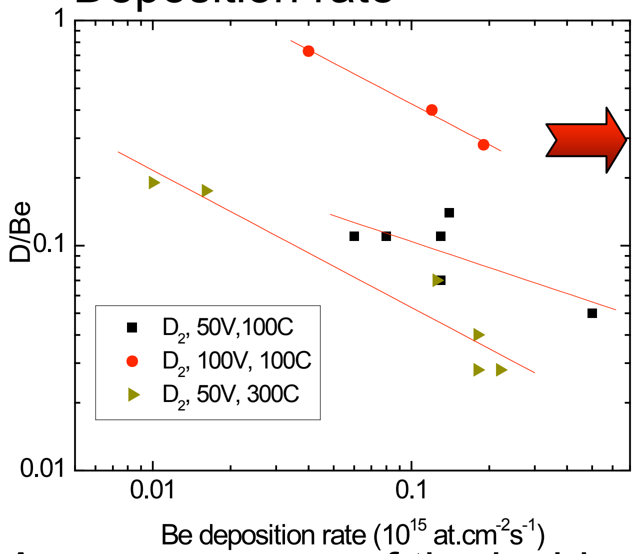
New unpublished data
by G. De Temmerman



- Some trends in the experimental data could be identified
  - D/Be decreases with increasing temperature
  - D/Be decreases with increasing Be deposition rate
  - D/Be increases with increasing reflected deuterium atom energy

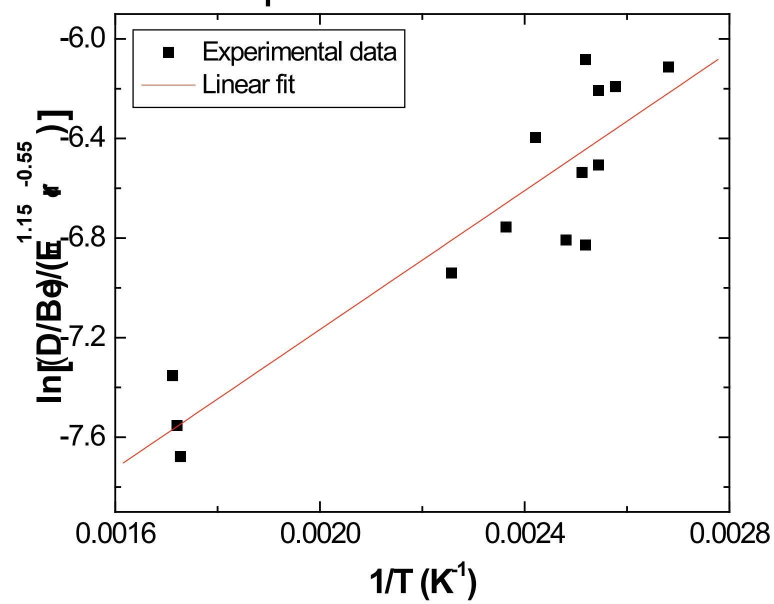
PISCES-B can systematically vary the relevant experimental parameters

Deposition rate

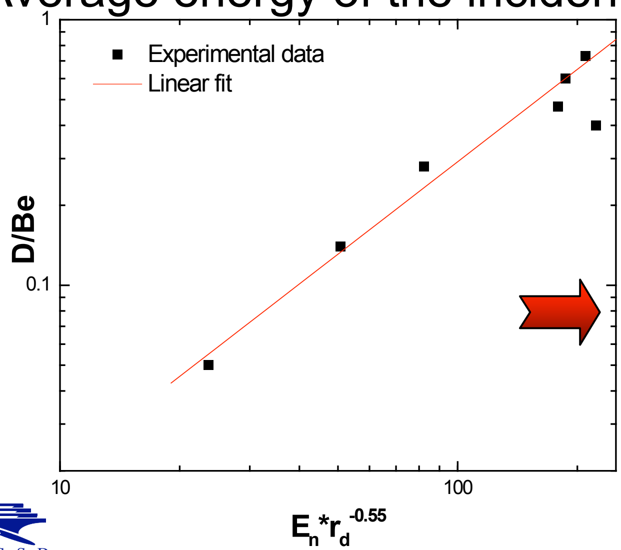


$$\frac{D}{Be} \propto r_d^{-0.55\pm0.1}$$

Temperature



Average energy of the incident particles



$$\frac{D}{Be} \propto E_n^{1.15\pm0.08}$$

$$\frac{D}{Be} \propto \exp\left(\frac{1394 \pm 180}{T}\right)$$

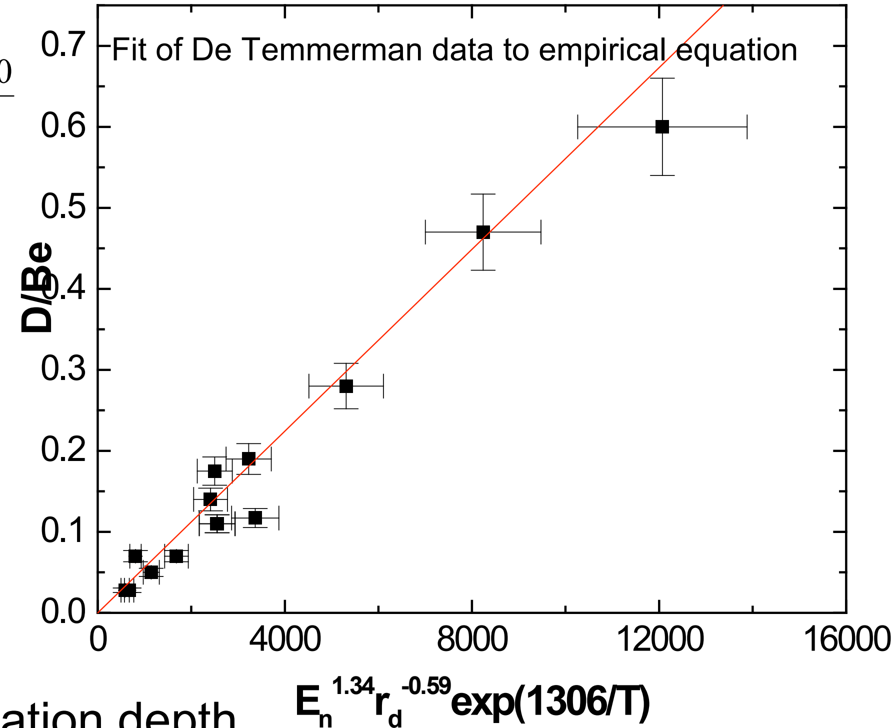
Empirical equation was developed that describes the influence of the independent parameters on the retention

$$\frac{D}{Be} = 2.94*10^{-5} E_i^{1.34\pm0.15} r_d^{-0.59\pm0.1} e^{\frac{1306\pm180}{T}}$$

$$15 \le E_n \le 60 eV$$

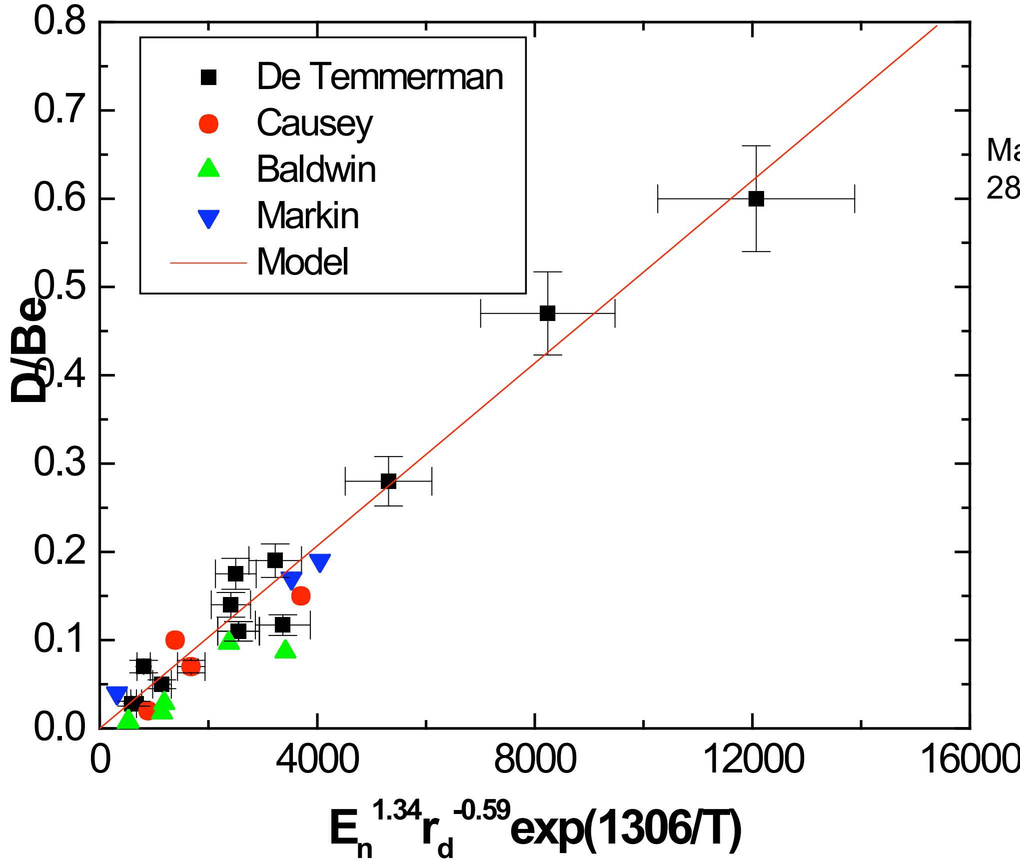
$$293 \le T \le 600 K$$

$$0.01 \le r_d \le 0.5 \cdot 10^{15} \, at.cm^{-2} s^{-1}$$



- Incident particle energy determines implantation depth
- Activation energy for desorption from plasma exposed Be ~1800K (R. Doerner FED 49-50 (2000)183), similar to temperature scaling
- Dependence on deposition rate is yet to be explained (pure deposition scales as r_d^{-1})
- Validity of the equation to entire literature D/Be database ??

Comparison with literature data



Markin, J. Nucl. Mater. 283-287(2000)1094.

- Good agreement between literature data from various plasma based devices (not ion beam data as particle energy is >>60 eV) and parametric equation
- Apparent discrepancies between the different data can be explained by the different experimental conditions, to which the retention is sensitive
- Good basis for prediction of retention in ITER

Applying D/Be model to ITER requires several input variables:

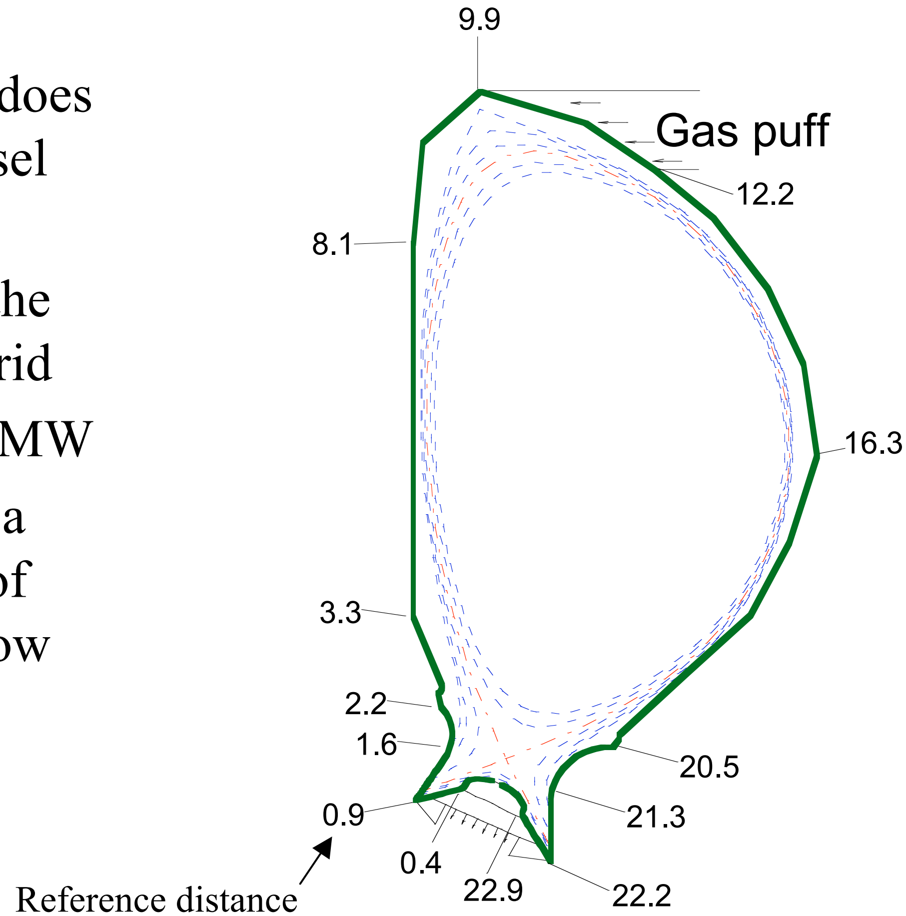
r_d – spatial distribution of Be deposition rate at all PFCs

T – Surface temperature of PFCs

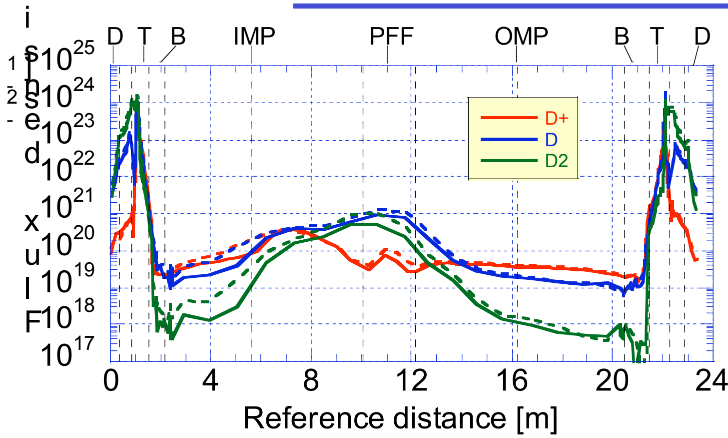
E_n – spatial distribution of incident particle energy

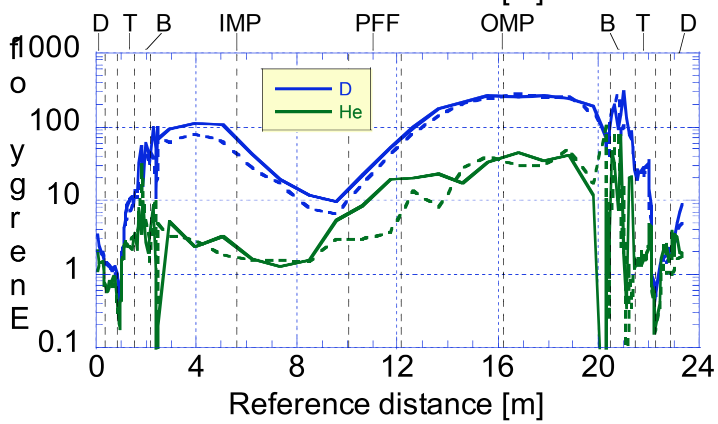
Particle flux and energy calculations come from Kukushkin report [ITER_D_27TKC6, Feb.9, 2008]

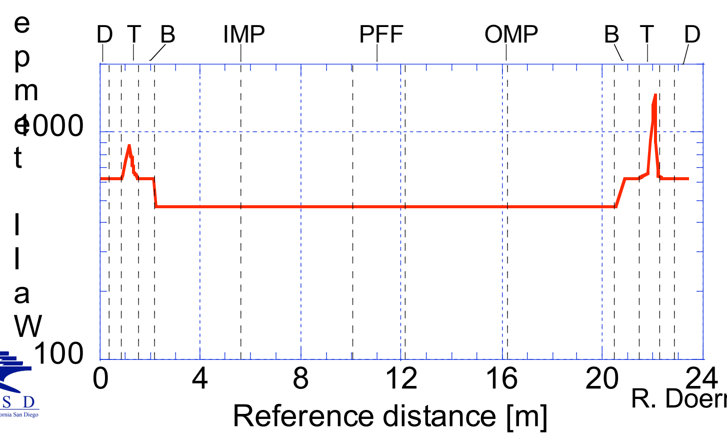
- B2-Eirene calculation grid does not extend to the ITER vessel wall
- Grid fluxes are mapped to the wall from the edge of the grid
- Power into the SOL is 100 MW
- Calculations shown are for a density case in the middle of the ITER operational window
- Calculations are done with carbon targets



Input from B2-Eirene Calculations





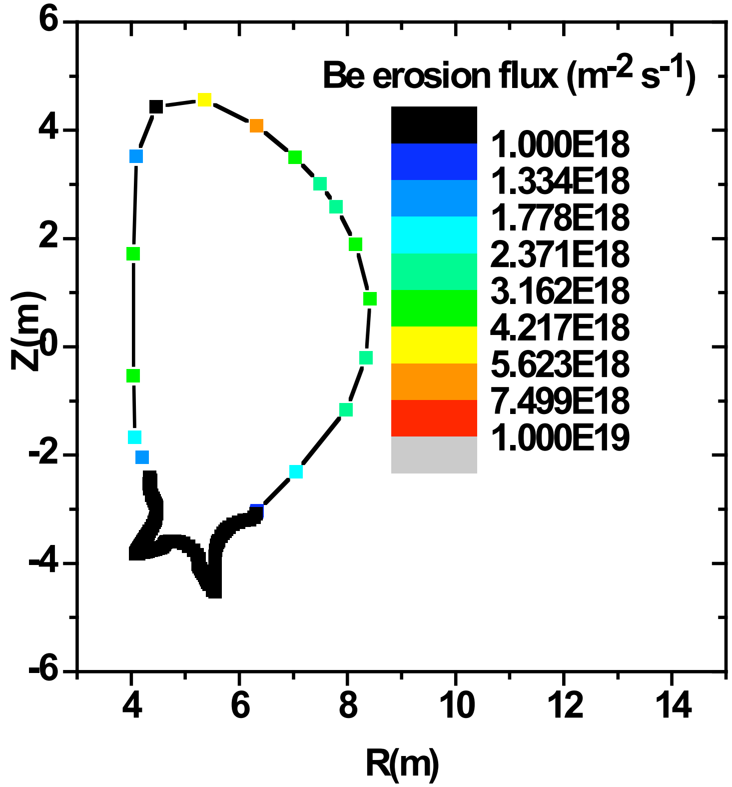


- Two different density cases are available (low & high), high density case (dotted lines) is used here
- D = dome
- T = target
- B = baffle
- IMP = inner mid-plane
- PFF = puff location
- OMP = outer mid-plane
- Design values of surface temperature are used

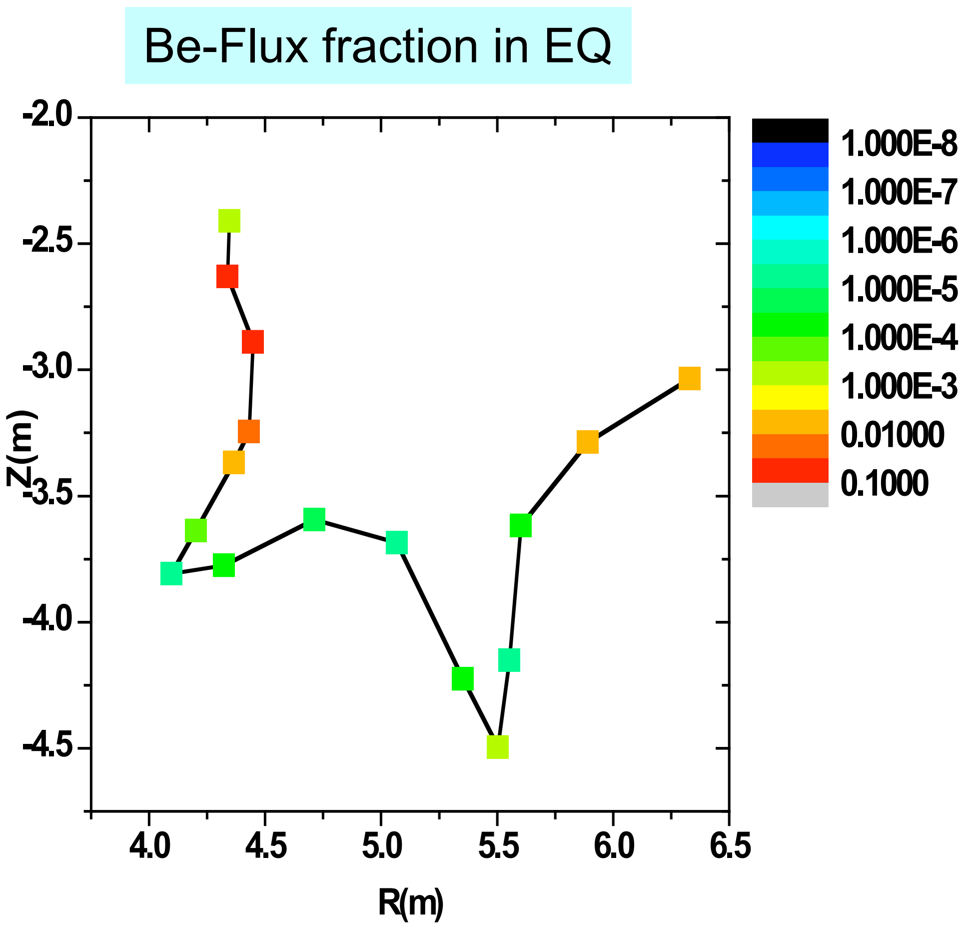
[Note energy at OMP]

DIVIMP calculations are used (from K. Schmid) to obtain impurity deposition rates in divertor

- Beryllium first wall erosion is calculated based on B2-Eirene results (iter491 case)
- DIVIMP calculates impurity distribution in SOL and flux of Be to divertor tile locations
- Beryllium is re-eroded, transported and redeposited in the divertor (and allowed to escape from divertor back to main chamber) until an equilibrium situation is achieved
- Model results in 80% of Be eroded from the first wall is redeposited on the first wall



Equilibrium Be flux obtained in the ITER divertor



- Largest Be fraction found at inner baffle region (~ 5-10%)
- Redeposition has a large impact on Be deposition on dome
- Full W divertor is used
- Ar radiator included

T/Be level in codeposits is calculated from De Temmerman model assuming 50:50 D:T

- Codeposition database includes

  $15 < E_n$ (eV) < 62

  $0.01 < r_d$ (1e15 cm^{-2} s^{-1}) < 0.5

  $373 <$ T (K) < 600

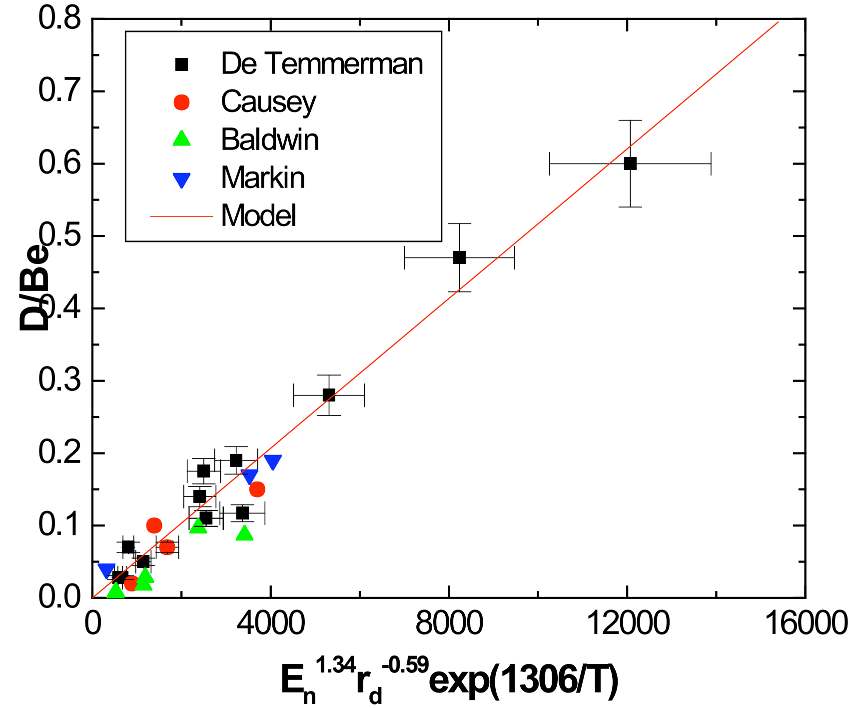
- Limits are applied to some ITER values to ensure applicability of the model

  $2 < E_n$ (eV) < 100

  $3e\text{-}5 < r_d$ (1e15 cm^{-2} s^{-1}) < 10

  $500 <$ T (K) < 1323

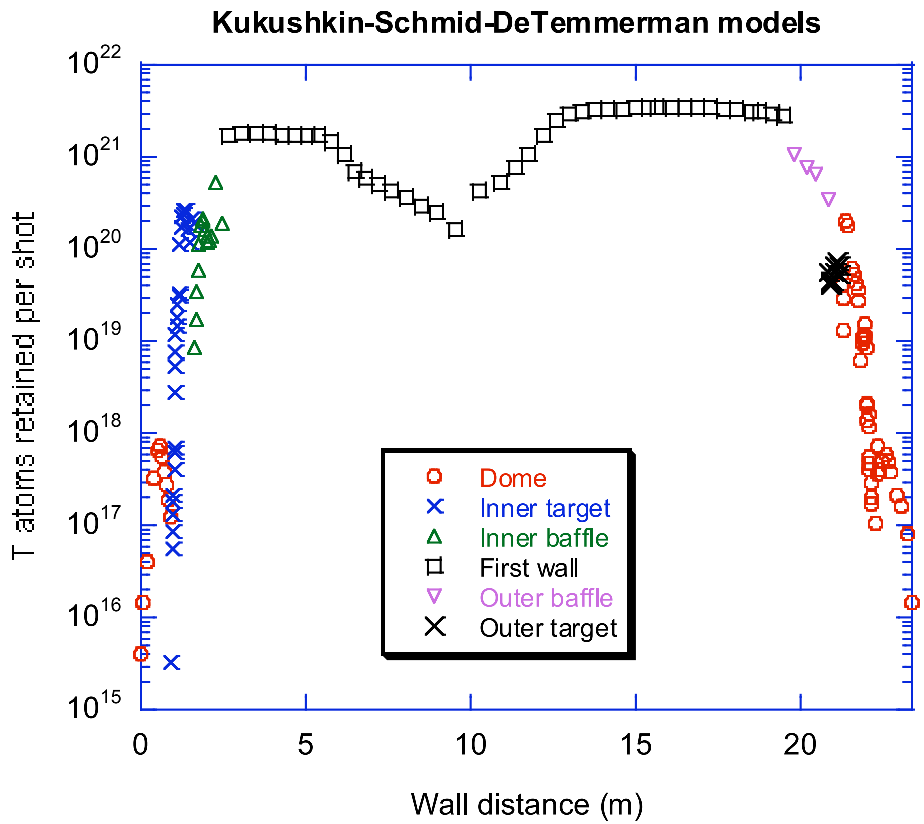
- E_n at outer midplane is above 100 eV (so we are underestimating retention near outer midplane)



Several assumptions are made

- All models are strictly correct (even though they may not all be self-consistent)
- Uniform Be codeposition around first wall (assumption of constant fraction of Be in first wall flux has only a <15% effect, same number of Be atoms incident on wall)
- Toroidal symmetry
- No wall geometry effects included
- No transient phenomenon (i.e. no ELMs or disruptions)
- All steady-state operation (no start-up, ramp down, etc.)

Models indicate codeposition on the first wall cannot be ignored for tritium accumulation in ITER



- Low surface temperature and high particle energy of first wall region push retention up
- Large area first wall
- Imposed energy limit of 100 eV may underestimate first wall retention
- Where are T containing codeposits likely to grow?

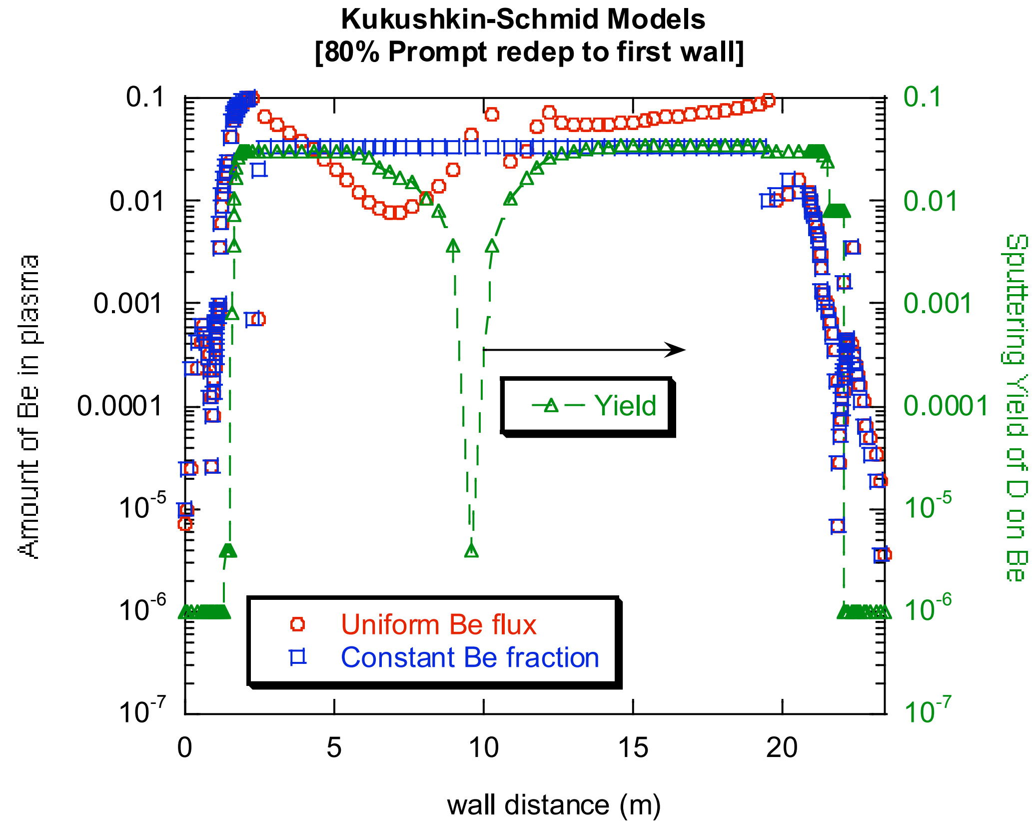
Level of retention in first wall codeposits exceeds the level in divertor codeposits

- First wall global average : (D+T)/Be ~ 0.42
  - High particle energies, low surface temperatures
- Divertor cassette global average : (D+T)/Be ~ 0.008
  - Low particle energies, higher surface temperatures

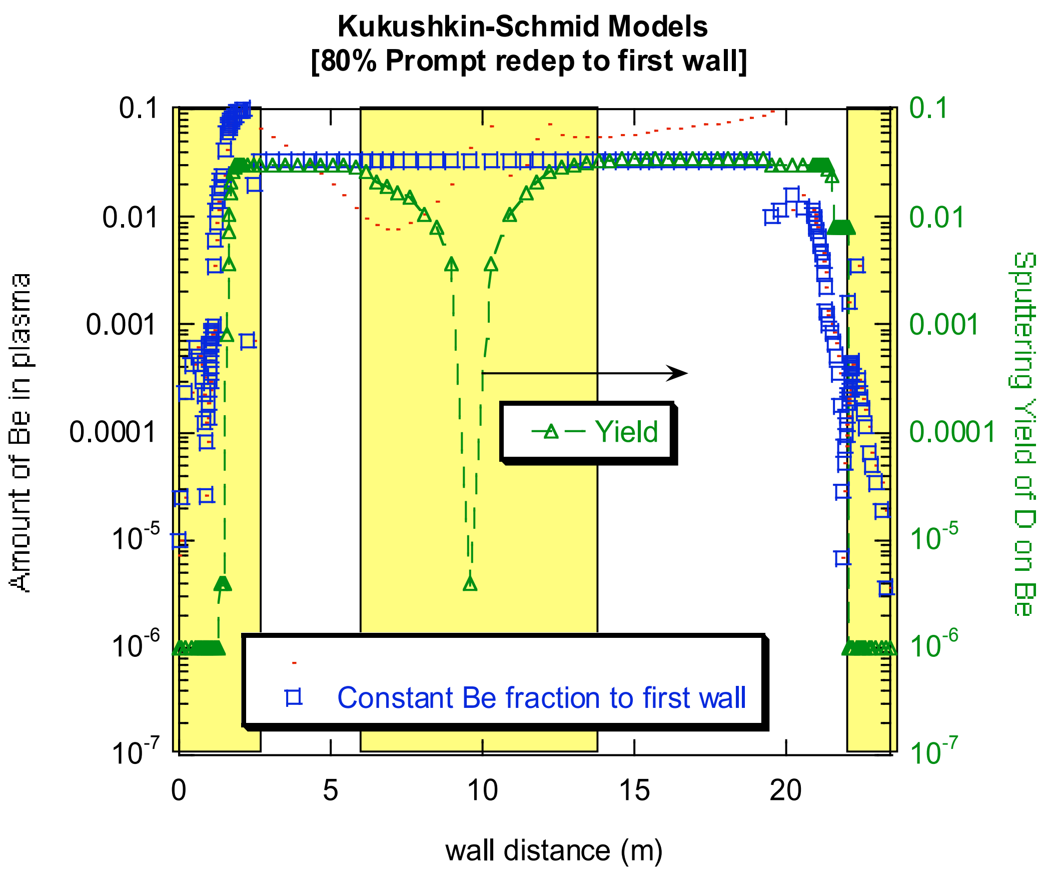
- However, Be codeposits on both first wall or in the divertor may be subsequently eroded and not contribute to retention
- On the other hand, Be codeposited in protected regions of the first wall, such as castellations, may not be re-eroded (the actual first wall geometry would need to be included)

Details of Be prompt redepostion to the first wall will determine where codeposits grow or erode

- Wherever amount of incident Be exceeds the sputtering yield (of D on Be, no He, T, Ar, etc), codeposited layers will grow
- Codeposits may also form in details of surface geometry (castellations, behind poloidal rib limiters, etc.)
- Detailed tracking of eroded Be atoms is necessary



Example assuming a constant Be flux fraction distribution of eroded Be flux back to the first wall



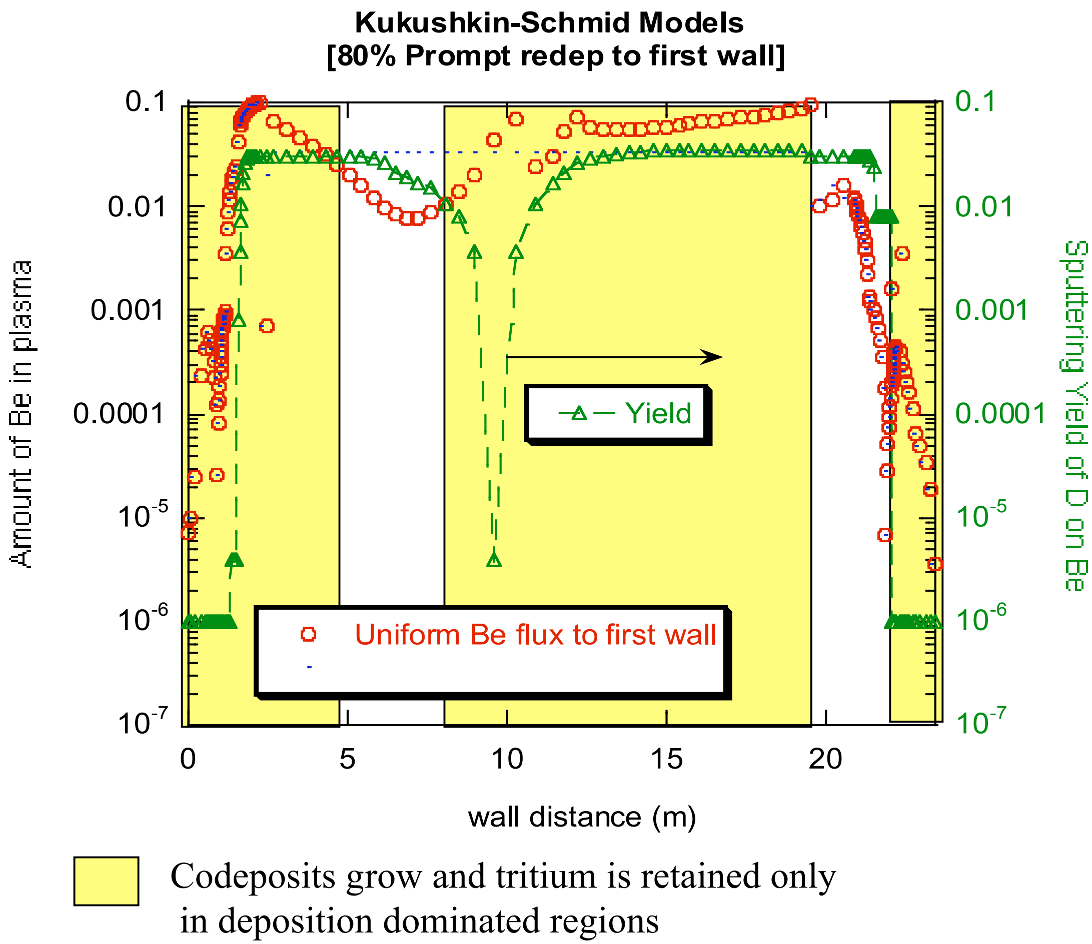
Codeposits grow and tritium is retained only in deposition dominated regions

Tritium retention in first wall codeposits can dominate accumulation in ITER

T in first wall ~ 2e22 T/shot,
T in inner div ~ 2e20 T/shot,
T in outer div ~ 0 T/shot,
T in dome ~ 1e18 T/shot

330 g T limit would be reached in ~3000 shots

Example assuming a uniform distribution of eroded Be flux back to the first wall



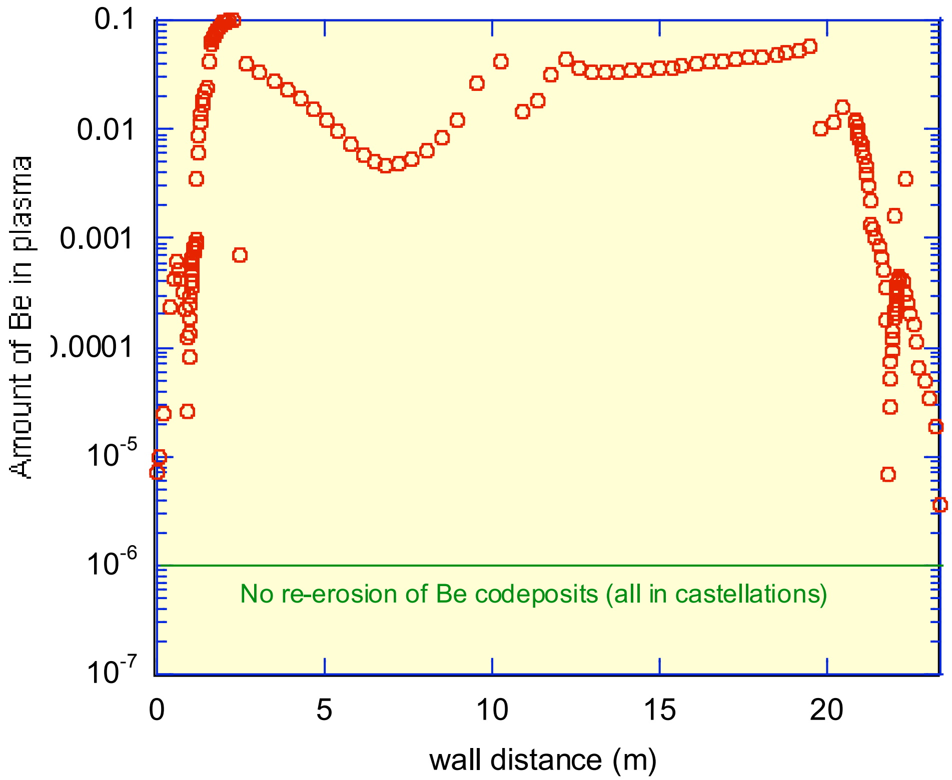
Codeposits grow and tritium is retained only in deposition dominated regions

Tritium retention in first wall codeposits can dominate accumulation in ITER

T in first wall ~ 6e22 T/shot,
T in inner div ~ 2e20 T/shot,
T in outer div ~ 0 T/shot,
T in dome ~ 1e18 T/shot

330 g T limit would be reached in ~1000 shots

Example assuming a uniform distribution of Be flux back to the first wall and no re-erosion



Codeposits grow and tritium is retained throughout first wall region (no re-erosion)

Worst Case Assumption

Tritium retention in hidden first wall codeposits
- 80% of eroded Be back to first wall, all redeposited Be in hidden areas

T in first wall ~ 1.4e23 T/shot,
T in inner div ~ 2e20 T/shot,
T in outer div ~ 2e20 T/shot,
T in dome ~ 1e18 T/shot

330 g T limit would be reached in ~ 500 shots

Some uncertainty in predictions still exist

Retention on the main chamber first wall must be considered during tritium accounting predictions

- T retention in divertor Be codeposits should be less than presently estimated
  - Roth et al., PPCF 2008 : (D+T)/Be ~ 0.1 in divertor
  - De Temmerman scaling (this study) : (D+T)/Be ~ 0.008 in divertor
- T retention in first wall Be codeposits will definitely be more than presently predicted (greater than zero)
- A better understanding of both erosion and prompt redepostion rates at the first wall are needed
- Surface temperature estimates throughout ITER are important
- Re-erosion of Be deposited on the first wall needs better understanding (tile geometry, castellations)
- Transient events need to be considered in any predictions

- First wall retention is not necessarily bad for ITER
  - Can tritium retained in first wall codeposits be easily removed by intentional pulsed heating of large, exposed areas of the first wall?