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Passive protection of the ITER first mirrors

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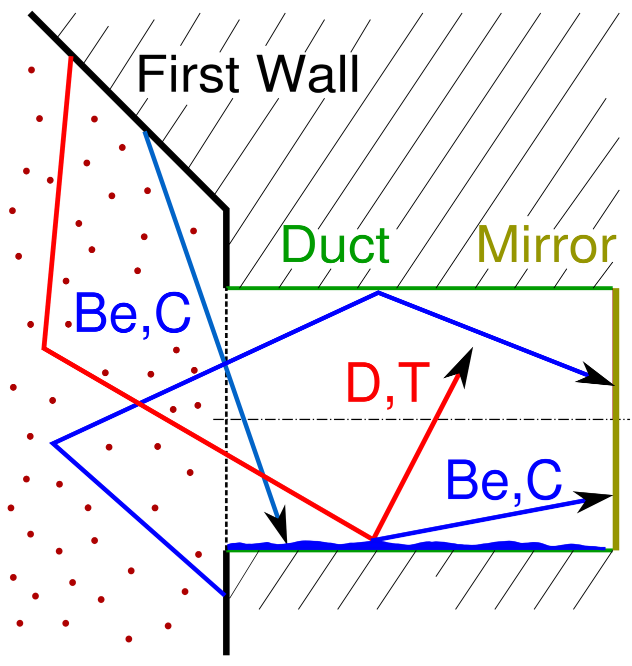
The issue: protection of first mirrors from deposition

- Degradation of mirrors limits the life-time and performance of ITER optical diagnostics
- Preliminary analysis [A. Litnovsky et al. NF2009], [V. Kotov et al FED2011]: deposition of impurities is more dangerous than sputtering

Physical processes leading to deposition



- Recessed first wall elements: no ion fluxes
- Fluxes of neutral impurities due to:
  - Line-of-sight transport
  - Elastic collisions with ions
- Transport to the mirror:
  - Prompt deposition
  - Reflection from the duct wall
  - *Re-erosion of deposits from the duct wall*

Engineering model: a conservative (upper) estimate

Uncertainties:

- Impurity reflection coefficients = ?
  - Low energies: TRIM is not valid
- Erosion yield of deposits = ?
  - Known to be higher than for bulk

Basic assumptions:

- TRIM is used only for reflection of fast DT atoms
- Prescribed reflection coefficient R_N for impurities
- The whole duct wall is already covered by deposit
- The deposit is sputtered by DT atoms
- "Handbook" sputtering yield is multiplied by f_{enh}
- Full sticking on the mirror

$$\Gamma_{imp} = \min\left[C_{imp}A^1_{imp},\ \overbrace{C_{imp}A_{imp} + f_{enh}I_{imp}}^{gross\ deposition}\right]\Gamma - f^M_{enh}E\Gamma$$

Γ_{imp} is the impurity flux density on the mirror

Γ is the flux density of DT atoms incident to the duct entrance aperture

$C_{imp}\Gamma$ is the impurity flux density incident to the aperture

$C_{imp}A_{imp}\Gamma$ is the impurity flux calculated for given R_N w/o re-erosion from the duct wall

$C_{imp}A^1_{imp}\Gamma$ is the impurity flux calculated for $R_N = 1$ w/o re-erosion from the duct wall

$f_{enh}I_{imp}\Gamma$ is the impurity flux to the mirror due to re-erosion of deposit from the duct wall

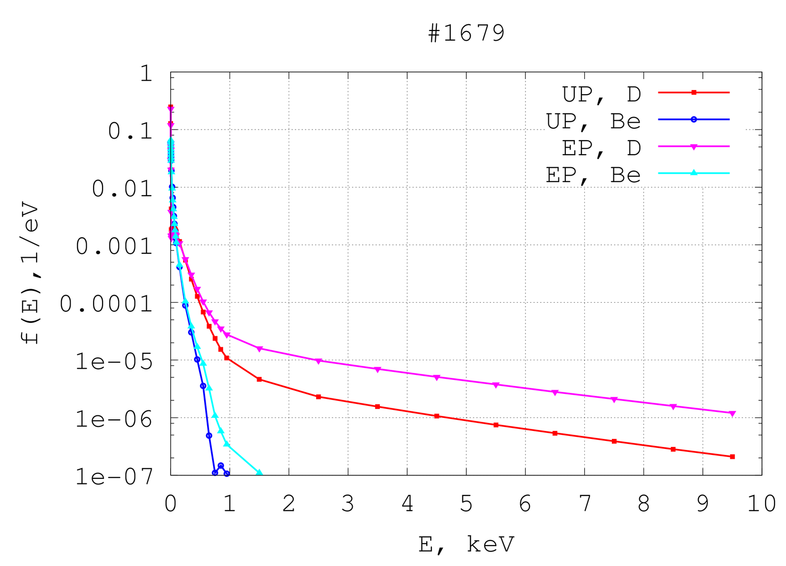
$f^M_{enh}E\Gamma$ is the sputtering rate of the deposit from the mirror itself

- The model is implemented in EIRENE: the Monte-Carlo particle transport code

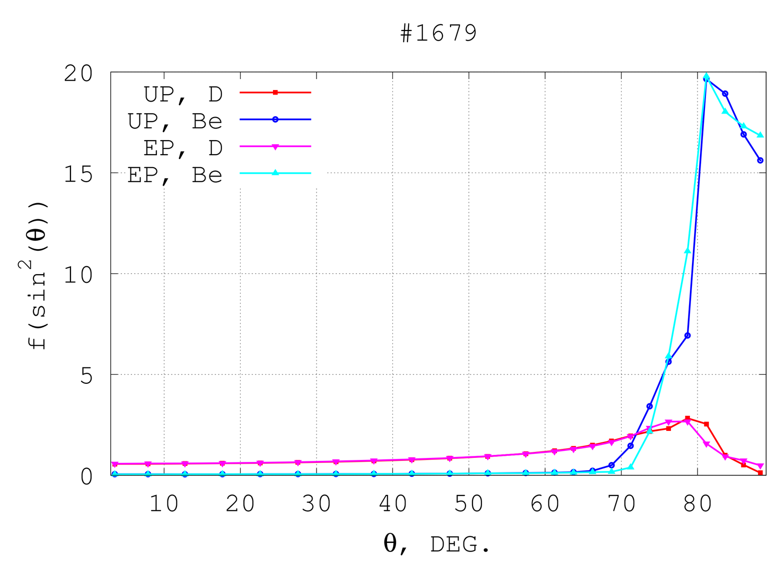
Atoms incident to the entrance aperture

- Monte-Carlo neutral transport (EIRENE) in the main chamber with fixed plasma
- Plasma background from B2-EIRENE (scrape-off-layer) and ASTRA (core and pedestal)

Example of Energy Distribution



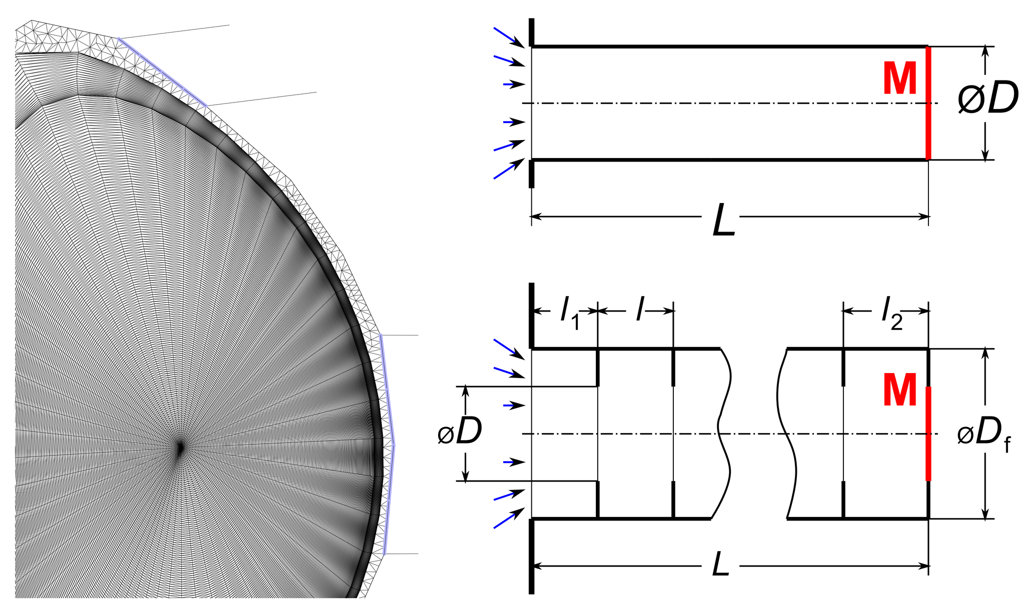
Example of Angular Distribution



High Energy Tail ⇒
⇒ effective re-erosion is expected

Grazing Incidence ⇒
⇒ small prompt deposition is expected

Reduction of *gross* deposition in the ducts with and without baffles



Fe duct wall
Mo mirror
Be impurity

#1639, #1679

$D_f = 2D,\ l = D$
$l_1 = 0,\ l_2 = 2D$

Attenuation factor $C_{imp}\Gamma/\Gamma_{imp}$ in the Equatorial Port, assumed C_{imp}=10 %

L/D	2	5	10	20	30	duct
R_N=1.0	4.7..5.0	8.9..9.5	16..17	29..31	43..46	w/o bfl.
	8.5..8.7	20..21	41..43	49..52	118..128	**with bfl.**
R_N=0.9	4.7..5.0	9.0..9.5	20	150..164	550..620	w/o bfl.
f_{enh}=10	8.5..8.7	60..63	730..780	3600..4300	13000...16000	**with bfl.**
R_N=0.5	5.6..5.9	32..34	170..180	910..1000	3000..3400	w/o bfl
f_{enh}=5	10..11	420...520	2600..3500	11000...16000	27000..41000	**with bfl.**
R_N=0.1	39..42	230..250	1100..1200	5300..6000	16000..18000	w/o bfl
f_{enh}=1	55..62	800..1400	3800..6300	15000..26000	32000..59000	**with bfl.**
R_N=0.1	10	56..58	280..290	1400..1500	4500..5000	w/o bfl
f_{enh}=5	17..18	570..800	3000..4500	13000..20000	29000..48000	**with bfl.**

Significant extra reduction of depositions with baffles if $L/D \geq$10 and R_N <1

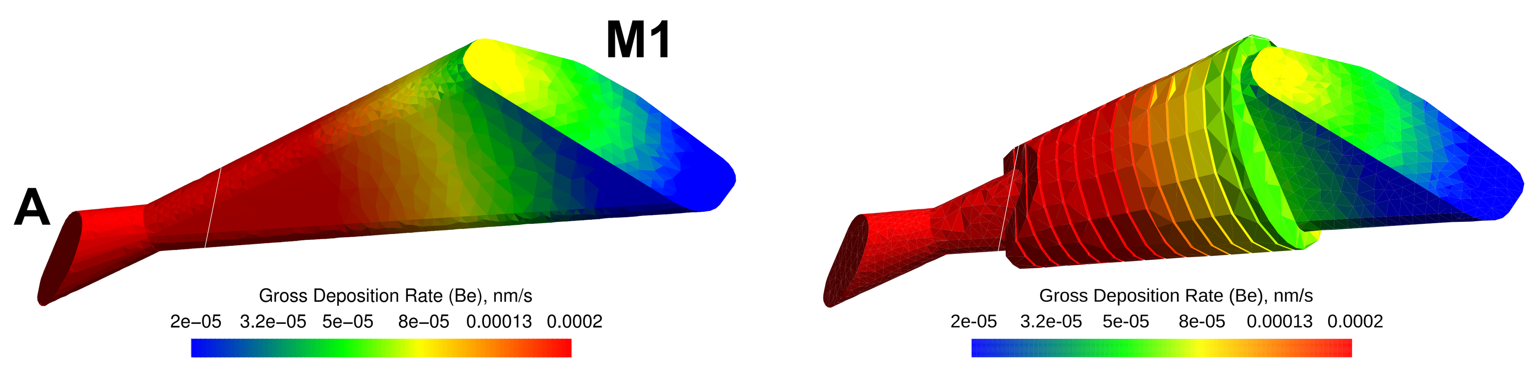
Main action of baffles - reduction of the re-erosion of deposit

E.g. a *hypothetic* extreme case Γ=1e21 m^{-3}/s, C_{imp}=10 % (1.6 nm/s).

⟶⟶ Attenuation factor=13000 ⇒ 20 nm is deposited after 400 shots.

A case study: core CXRS diagnostic

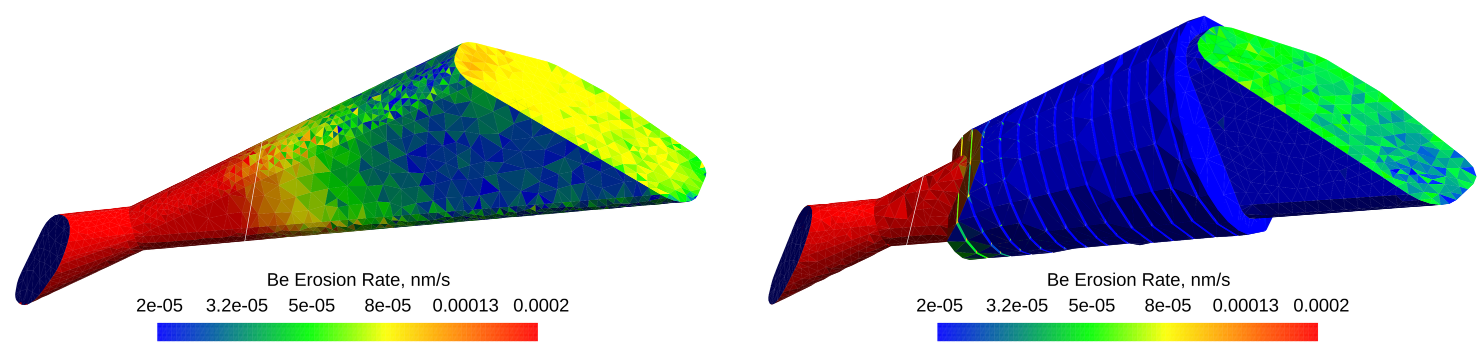
Example for R_N=0.9, f_{enh}=10 (attenuation factor ≈ 50)



Estimated life-time (in 400 sec shots) in respect to Be deposition, Γ=0.8e19 m^{-3}/s, C_{Be}=0.3 % (0.004 nm/s), incident spectra of #1679, max tolerable thickness of deposit is 20 nm

R_N	0.9			0.5			0.1		
f_{enh}	1	5	10	1	5	10	1	5	10
W/o baffles	586	586	586	587	587	587	696	586	586
(σ, %)	(2.9)	(2.9)	(2.9)	(2.9)	(2.9)	(2.9)	(23)	(2.9)	(2.9)
With baffles	618	618	618	1100	630	630	1900	630	630
(σ, %)	(4.9)	(4.9)	(4.9)	(7.2)	(1.0)	(1.0)	(11)	(1.0)	(1.0)

Marginal effect of baffles in this case. The reason: no reduction of re-erosion from the front part



- Net-erosion conditions on the mirror are not excluded
- BUT the sign of the net deposition is sensitive in respect to R_N, f_{enh}, C_{imp}
- The life-time estimate in respect to Mo erosion is >70000 shots (1 μm is eroded)

Summary

- A conservative (engineering) model of impurity deposition on the mirrors is proposed
- Attenuation of the gross deposition in the cylindric ducts with and without baffles is analyzed
- Baffles can bring extra reduction of gross deposition by an order of magnitude *in sufficiently long ducts*
- A case study for a real geometry: core CXRS, is made
- The estimated life-time is >500 full (400 sec) discharges
- Net erosion of deposit from the mirror is not excluded but no confident prediction can be made

To be done

- Experimental data are required to validate the incident impurity fluxes at the aperture
- Real 3D structure of the first wall has to be taken into account in the model