Application of the ERO code for simulation of linear devices: benchmark of ITER-relevant assumptions

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Background Plasma

\[ E \]
\[ \rho \]
\[ B \]

Input:
\[ n_e, T_{e,i}, \text{geometry} \]

Local transport:
- ionisation, dissociation
- friction (Fokker-Planck), thermal force
- Lorentz force
- cross-field diffusion

Plasma-surface interaction:
- physical sputtering/reflection
- chemical erosion (CD\(_4\))
- (re-)erosion and (re-)deposition
- HMM and SDTrimSP surface models

\[ \text{PFC (substrate Be, C, W, Mo, ...)} \]

\[ \text{C}^{x+}, \text{Be}^{x+}, \ldots \]
\[ \text{CD}^z_{0,+} \]
\[ \text{C}, \text{Be}, \ldots \]
\[ \text{CD}_4 \]

\[ \text{re-eroded/} \]
\[ \text{reflected particles} \]
**Code development:**
- PSI & transport
- material mixing
- castellated surfaces
- atomic data, ADAS

**Benchmarking:**
- PISCES-B (with beryllium)
- Pilot-PSI
- TEXTOR
- JET,
- AUG,
- ...

**Estimations for ITER:**
- tritium retention
- target & limiter lifetime
- impurities into plasma

**Coupling with other codes:**
- plasma parameters from: e.g. B2-Eirene, Edge-2D
- surface mixing: TriDyn, MolDyn
ITER Be wall – BM erosion

- Blanket module (BM) shapes optimized for heat loads (P.C. Stangeby)

- FLFS close to 2nd separatrix => First PFC *life time* estimates assuming limiter-like contact on outboard BM11

- BM11

- BM 15

- BM 18

- banana-shaped far SOL region

- Be + low Z - high erosion
Aim – predictive modelling of ITER first wall life time

LIM predicted life time due to transient events is not a limiting factor – we concentrate on steady state

Complications:
- Complex geometry e.g. leading to shadowing
- Uncertainty in atomic and surface data for Be
- Other uncertainties: enhanced re-erosion, carbide and alloy formation, Be-D molecules, etc.
The net erosion in LIM and ERO is in a very good agreement.
BM11, ‘HDC’: profiles at y=-187mm

Life time limiting erosion: \(1\text{[cm]}/0.05\text{[mm/h]} = 200h\)

ERO uses in this case angle averaged W.Eckstein 2002 data for sputtering yields from LIM and ADAS ‘93’ Be ionization . . .
Be sputtering yields – extreme assumptions

Only the ‘calculated’ data are included!
1) “maximum” – static TRIM + MD
2) “minimum” – SDTrimSP with 50% of D (reasonable limit)

Experimental data too much scattered!
1) Large deviations: no sense to analyse shape of curves
2) Various effects are difficult to separate

Normal incidence! Angle dependence should be taken into the account!
Be sputtering yields – self sputtering

Normal incidence

Be → Be, normal incidence

Angular dependence

1000eV Be → Be

Estimation based on calculated data as for Be by D\(^+\) sputtering

Angular part is essential!

For following BM simulations ERO uses Eckstein 2007 fit.
Sputter yields assumptions and net erosion

BM11, ‘HDC’: net erosion (deposition) profile at y=-187mm

In most pessimistic case life time about 30% less than in earlier LIM predictions
Intrinsic Be impurity and sputter yields effect

BM11, ‘HDC’: net erosion (deposition) profile at y=-187mm

Deposition (ERO-min +3%Be)

Sputtering yield and intrinsic Be assumptions determine the outcome to a large extent!

Influence of enhanced Be re-erosion (typical ERO assumption) of is not yet studied!
Improvement in sputtering yield uncertainty
→ model testing in PISCES-B

Perfect for Be sputtering yields benchmark
1. Spectroscopy
2. Target weight loss
3. Witness plate

The ERO was earlier applied for modelling of PISCES-B
Witnness plate

ERO: elastic collisions decrease transfer by about 20%

5000s exposure Experiment

Target weight loss
Exp.: 20.4mg ERO: 38.4mg

Transfer rate TARGET→WP
Exp.: 7.5*10^{-3} ERO: 3.9*10^{-3}
Estimation (solid angle): 1.0*10^{-2}

Very preliminary results!
Spectroscopy as benchmark

Axial BeI light intensity profiles in case of Be target erosion

Many discrepancies, starting with 10 times difference in absolute values

Line ratios (metastables), redeposition, dependence on biasing, … are reasonable

Vast material for benchmark!

(3 plasma conditions) x (4 biasing) x (BeI singlet and triplet + BeII profiles)
Initial MS population influences intensity near the target.

Population of MS during sputtering (or effusion) is an open issue . . . Seems to be always close to MS/GS=1 . . .
ERO particularities for linear devices

- Elastic collisions with residual gas ($D_2$)
- Different impact energies for molecular ions ($D^+, D_2^+, D_3^+$)
- Be carbide formation (suppressing chemical erosion of C)
- Tracking of metastable state (MS) in Be
- Bohm diffusion
- Be-D molecules – missing in ERO!

Physical effects implemented for linear devices can be relevant for tokamaks as well!

Technical issues:

- Geometry, target, Be oven, …
- Plasma parameters (3D) - fitting formulas for radial and axial profiles
- Electric field (3D), target biasing, …
B2.5 [1] modeling results of Pilot-PSI plasma will be used

- 2D multifluid code describing the quasineutral plasma beam.
- Neutral particles are treated as fluid species.

\[
V_{\text{target}} = -5V \quad \text{and} \quad V_{\text{target}} = -22V
\]

B2.5 output for two different target potentials, showing Ohmic heating and detachment, particularly in the -5V case

Presentation by PSI-2010 by R. Wieggers (FOM)

Radial electric field is connected with plasma potential

Axial electric field is determined by sheath, pre-sheath and biasing
Summary

- ERO predictions for ITER are a subject for underlying data and assumptions.

- PISCES-B is a perfect test stand for ERO Be erosion model – the benchmark is underway . . .

  ➔ Independent measurements (weight loss/gain, spectroscopy)

- ERO was applied earlier for several experiment at PISCES-B and Pilot-PSI and improved in a process.

- Though many relevant physical effects were introduced (elastic collisions, metastables, molecular ions) there are indications that several other effects are of importance.
  - BeD molecules
  - 3D plasma parameters and E-field
The End
Be MS tracking in ERO: effect for PISCES-B

a) Plasma source
b) Be seeding
  - Be oven (z=150mm)
  - Radial profile
  - Axial profile
  - Emiss. int. [Ph/(sr*s*cm²)] of Be

c) Be sputtering
  - Axial profile
  - Target

Plasma column
Simulation volume
Target
Be oven
Radial profile
Axial profile
Emiss. int. [Ph/(sr*s*cm²)] of Be

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Be metastable state (MS) tracking in ERO

The system of 2 balance equations can be solved analytically . . .

ADAS, $T_e=1\text{eV}$, $n_e=2\times10^{12}\text{cm}^{-3}$

Effective rates:

1,2) transitions between "GS" and "MS"

3,4) ionization from "GS" and "MS"

5,6) line intensity (PEC – photon emission coefficient), contributions from "GS" and "MS"

MS resolved approach allows to treat in ERO effectively the slow relaxation between triplet and singlet levels – important if MS population affected by extra processes and at high plasma parameter gradients.