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# Modelling of the global JET ILW material migration by WALLDYN: Parameter studies

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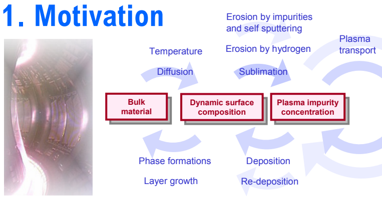
## 1. Motivation




**Prediction of the consequences of long term plasma wall interaction on the first wall material composition**

**System is determined by iterative, closely and non-linearly coupled fluxes driven by hydrogen background plasma and surface temperature**

**Use WALLDYN / DIVIMP to evaluate global material migration considering flux and material conservation.**

## 2. Global material migration model [1,2]

Main differential equation:

$$\frac{d\sigma_{(k,b,t)}}{dt} = \Gamma NET_{(k,b,t)} + \Gamma Bout_{(k,b,t)} + \Gamma Bin_{(k,b,t)}$$

Total flux equation for phase $k$ at bin $b$ at time $t$:

Total eroded flux of phase $k$ from bin $b$ by background erosion (all background species)

Total eroded flux of phase $k$ from bin $b$ by all incoming impurities

Incoming flux of phase ion with charge state $cs$ at bin $b$ (all erosions)

Bulk-Surface-balances $\Gamma Bin$ and $\Gamma Bout$:

$\Gamma TotalNET_{(b,t)} > 0$: NetDeposition

$\Gamma TotalNET_{(b,t)} < 0$: NetErosion

$\Gamma Bin > 0,\ \Gamma Bout = 0$ for NetErosion

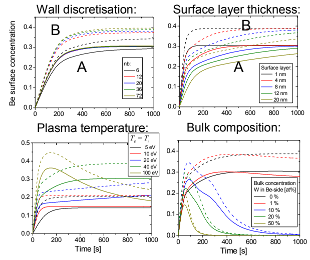
$\Gamma Bin < 0,\ \Gamma Bout = 0$ for NetDeposition

Conventions:

**WALLDYN…**
- formulates spacially resolved coupled flux balance equations for wall material re-distribution by plasma and surface processes with flux and material conservation
- solves the resulting differential-algebraic system numerically (by Mathematica, ~200 ODEs + ~1000 AEs)

## 3. Parameter studies and benchmarking

### 3.1 Test of WALLDYN specific parameters

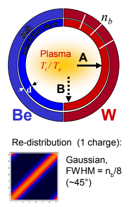



Test the influence of
- wall discretisation
- surface layer thickness
- plasma temperature
- bulk composition

on simplified Be/W system

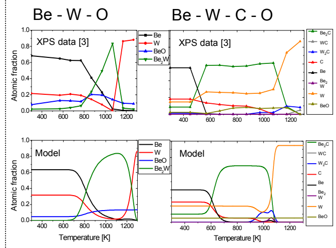
**Follow Be surface concentration at positions**
**A** (far W-side) and
**B** (W-side near Be)

| INFLUENCE OF…ON… | Steady state | Time constants | General behaviour |
|---|---|---|---|
| Wall discretisation | Low | Low | None |
| Surface layer thickness | None | High | None |
| Bulk composition | High | High | High |
| Plasma temperature | High | High | High |




Re-distribution (1 charge):
Gaussian, FWHM = $n_b/8$ (~45°)

### 3.2 Surface chemistry model [3]




**Direct parameterisation of XPS experimental data by coupled 0-dimensional elemental reaction rates**

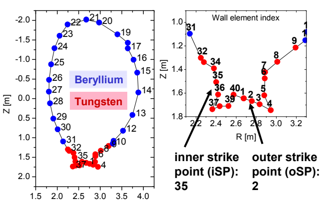
- Qualitative parameterisation of kinetics: $xA + yB \rightarrow C$ → Rate $R(t) = [A]^x \cdot [B]^y \cdot k \cdot Exp(-\Delta E/k \cdot T)$
- Coupling of temperature-driven processes (carbidisation, oxidations, alloy formation, sublimation) to plasma-driven processes (sputtering, material migration)

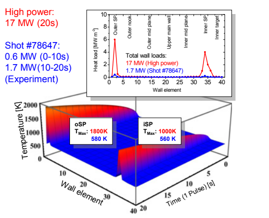
## 4. Parameter studies of the JET Be/W ITER-like wall configuration

### 4.1 Input data

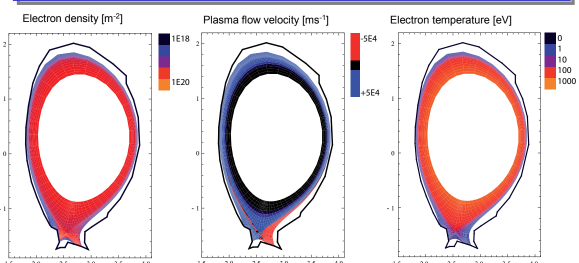
**Wall discretisation:**
- A 2D toroidally symmetric cross section of the vessel wall is discretised to 40 wall elements
- The initial configuration for surface and bulk is Be (main wall) and W (divertor)

**Dynamics of the surface temperature [4]:**
- Surface temperature varies on pulse-to-pulse base
- Heat flux on non-actively cooled surface (assumed to be CFC (fibres ⊥ and ∥ to surface) leads to an increases of T with $t^{0.5}$, restart at 500 K base-T.

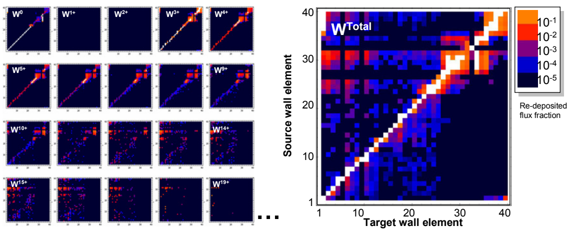


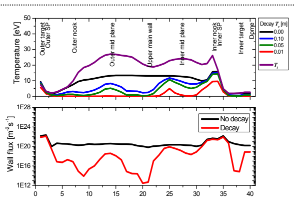




**Constant L-Mode background plasma on standard grid from EDGE2D/EIRENE for JET shot #78647, benchmarked with experiment [5], carbon wall:**




**Impurity transport in the plasma is parameterised by DIVIMP:**
- Assume that the plasma transport is much faster than the processes in the first wall
- Launch an homogeneous flux of impurity test particles (Be, W, N) from each wall element (sources)
- Map the flux fraction of impurities onto all wall elements → Charge-resolved re-distribution matrix




**Projecting the BG flux and plasma temperature to the vessel wall:**

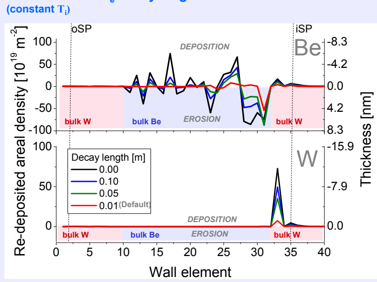
- Raytracing from SOL grid to vessel wall → vector $p$
- Parallel fluxes: $-D\, dn_e/dr\ p$
- Perpendicular fluxes: $n_e c_s R_B p$
- $E_{Kin} \sim 3\, cs\, T_e + 2\, T_i$
- $T_i$ is kept constant
- Scan over decaylength of $T_e$ (0-10 cm)
- Scan over flux decay length (← connection length of field line)

Time evolution by WALLDYN

**Global assumptions / constraints for WALLDYN simulations:**
- Total of **200 s constant background plasma** (#78647, L-Mode, 10 discharges)
- No impurity-plasma interaction between grid and wall (**"Teleportation"**)
- **Surface temperature variation per pulse** (saw-tooth-like temperature evolution)
- Bulk configuration **pure W** (divertor) and **pure Be** (main wall)
- **N seeding simulation uses the same BGP**, no N accumulation in the surface (retention = 0)

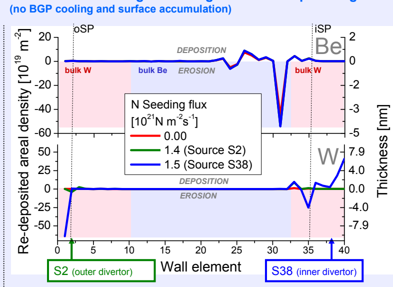
### 4.2 Time-integrated erosion / deposition patterns (after 200 s plasma)

► **Influence of $T_e$ decay length from SOL to wall** (constant $T_i$)



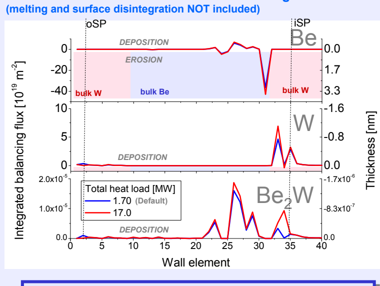

- **Be erosion zone** is upper and lower inner main wall (~0.02 nm/s)
- **Be deposition zone** is inner mid plane (~0.02 nm/s)
- **W deposition zone** is inner strike point (~0.04 nm/s)
- **E/D-pattern is robust against change of $T_e$**
- All fluxes scale (~linearily) with $T_e$

► **Influence of Nitrogen seeding sources on sputtering** (no BGP cooling and surface accumulation)



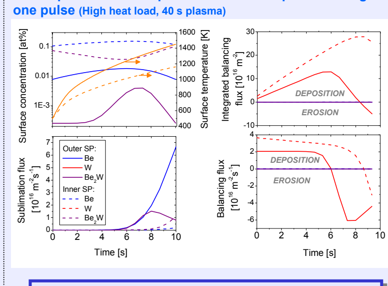

- No influence on main wall Be erosion / deposition pattern
- W divertor re-distribution depends strongly on the source location
- **Outer divertor source: No significant sputtering by N**
- **Inner divertor source: W-erosion at inner SP, W-deposition at dome**
**WARNING: COMPUTED WITHOUT SELF-CONSISTENT COOLING ACTION AND SURFACE ACCUMULATION OF N!**

► **Influence of wall heat load on material migration** (melting and surface disintegration NOT included)




- Virtually **no influence on erosion / deposition pattern**
- Chemical phase formation and sublimation fluxes are much smaller than plasma driven processes
- Simulations show **no wall elements with significant simultaneous Be / W codeposition**

► **Temperature driven processes at strike points during one pulse** (High heat load, 40 s plasma)




- **No significant alloy deposits**: low surface concentration, **formed phase is quickly destroyed by ions and sublimation**
- **Periodic deposition and erosion at outer SP**:
  1) Influx of Be, formation of $Be_2W$ alloy → Flux surface to bulk
  2) Sublimation/decomposition of alloy → Flux bulk to surface

### 4.3 Summary

**Modelling of material migration for JET ILW based on shot #78647 (EDGE2D-BGP):**
- Be erosion at inner mid plane, Be deposition at lower inner main wall, W deposition at inner strike point
- Position of seeding-gas source is important for control of erosion rates
- No indication for significant Be/W-alloy co-deposits, minor contribution of temperature-driven processes


[1] K. Schmid, M. Reinelt, K. Krieger: *"An integrated model of impurity migration and wall composition dynamics for tokamaks"*, PSI-19
[2] M. Reinelt, K. Krieger, S. Lisgo, K. Schmid, S. Brezinsek, JET EFDA Contributors: *„Interpretation of Be migration studies at JET and validation of an integrated numerical model for plasma impurity transport and wall composition dynamics"*, PSI-19
[3] Ch. Linsmeier, M. Reinelt, K. Schmid: *"Surface chemistry of first wall materials - from fundamental data to modeling"*, PSI-19
[4] EDGE2D background plasma solution for JET shot #78647 provided by Mathias Groth and Aaro Järvinen
[5] G. Arnoux et al.: *"Divertor heat load in ITER-like advanced tokamak scenarios on JET"*, J. Nucl. Mat., 390-391 (2009), 263-266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