Material Erosion and Redeposition during the JET MkIIIGB-SRP Divertor Campaign


8 October 2006
- Motivation
- Deposition on a quartz-microbalance
- Erosion/deposition of a tungsten-stripe
- $^{13}$CH$_4$ injection experiment
- Conclusions
Wall erosion – Material migration – Re-deposition

\[\downarrow\]

Critical issues for ITER:
- Lifetime of wall elements
- Long-term tritium retention
- Availability of ITER

\[\downarrow\]

Existing experiments necessary for extrapolations to ITER
JET is currently the most ITER-relevant experiment with respect to:

- size
- magnetic field
- high plasma current

Before upgrade to ITER-like wall:
Understanding of material migration in full-carbon surrounding
The Quartz Micro Balance (QMB)

Principle:
Resonance frequency of quartz changes with mass
Thickness resolution: ~0.2 nm

Shot-resolved measurement of deposition (erosion) at one specific location.
C deposition [atoms/cm²s]

-6E+16
-4E+16
-2E+16
0E+00
2E+16
4E+16
6E+16

Strike point position z [m]

-1.75 -1.65 -1.55 -1.45 -1.35

base I vertical tiles

- H-mode - L-mode

z=-1.32m
z=-1.52m
z=-1.69m
z=-1.74m

QMB

Largest deposition if strike point is on base plate

H.G. Esser et al., PSI 04
Schematic horizontal cut of QMB-system across crystal

(1) Quartz
(2) Electronic board (Al₂O₃)
(3) Lid of copper box
(4) Inner heat shield (stainless steel)
(5) Outer heat shield (stainless steel)
(6) Stainless steel ring with metal mesh
Deposition on quartz

Layer Thickness (SIMS)

Average layer thickness on quartz: 1.85 µm
⇒ in accordance with total frequency shift:
9 · 10^{18} C atoms, layer density: ~1 g/cm³
Deposition on inner heat shield

**Significant deposition on inner heat shield:**

\[6.2 \times 10^{18} \text{ atoms}\]

*(compared to \(9 \times 10^{18}\) on crystal)*

H.G. Esser et al., PSI 06
Tungsten stripe on one poloidal row in the divertor

W-stripe
(on one poloidal row)

W-stripe:
- 3 μm thickness
- 2 cm width

- Study of erosion and deposition behaviour in the divertor
- ITER-like wall project: assessment of required W-layer thickness for outer divertor

A. Kirschner 10 (18) 21st IAEA, Chengdu, China 16 – 21 Oct 2006
Inner divertor:
metallographic cross sections of W-stripe

- Inner divertor is deposition-dominated
- Largest deposition on inclined part of tile 4
- In total: 540 g (3.2 \times 10^{20} \text{ atoms})
Outer divertor:
ion beam analysis of W-stripe

M. Mayer et al., PSI 06

- Vertical tiles 7, 8 are erosion-dominated
- Largest erosion at position with highest fluence (tile 7)
- Large erosion at apron of tile 8
Outer divertor: microscopic analysis of W-stripe

SEM picture of tile 7

- Non-uniform erosion on a scale-length of 10 – 30 µm
- Possible explanation: surface roughness

↓

Preferential erosion of hills, less erosion (or even deposition) in valleys

A. Kirschner  13 (18)  21st IAEA, Chengdu, China  16 – 21 Oct 2006
Modelled net erosion along tile 7

- **Red**: erosion due to background carbon
- **Blue**: erosion due to recycled physically sputtered carbon
- **Green**: erosion due to recycled chemically eroded carbon

**Key Points**
- Using campaign-averaged plasma parameters
- C\(^{3+}\) - influx: 0.5%
- Symmetry in toroidal direction
- ~50% W-redeposition on stripe
- Erosion-dominated by background carbon
- Max. erosion ~ 7 \(\mu\)m
Overall deposition in the divertor

- **Inner divertor tiles 1, 3, 4:** 540 g  
  (from metallographic cross-sections)
- **Outer divertor tile 6:** 380 g  
  (from metallographic cross-sections)
- **Inner louver region:** 60 g  
  (from QMB)
- **In total:** 980 g

or \(5.9 \times 10^{20}\) atoms/s

Not included: SRP, gaps and main chamber!

Average deposition rate during MkIIgB-SRP is similar to previous campaigns (\(6.6 \times 10^{20}\) in MkIIa and \(3.5 \times 10^{20}\) in MkIIgB)
\[ ^{13}\text{C} \text{ marked methane injection} \]

- Carried out at last shot day of the campaigns
- \[^{13}\text{CH}_4\] injection into outer divertor during 32 identical discharges (ELMy H-mode, strike points on vertical tiles)
- In total: \(4.3 \times 10^{23}\) \(^{13}\text{C}\) atoms
- No further plasma operation

- About 20\% of injected \(^{13}\text{C}\) deposited at outer divertor tiles
- About 7\% of injected \(^{13}\text{C}\) at inner divertor tiles
- \(^{13}\text{C}\) also detected on fast reciprocating probe at top of low field side \(\Rightarrow\) transport around main plasma
- Only small amount of \(^{13}\text{C}\) at shadowed areas
- NIMBUS code for neutrals, EDGE2D for ions
- SOL flow adjusted to measured data
- No re-erosion of $^{13}$C

$^{13}$C deposition along inner targets

- **Long-range $^{13}$C transport mainly in between ELMs**
- Most of $^{13}$C deposited on outer target (~90%)
- $^{13}$C deposition on inner target in SOL in good agreement with exp.

A. Kirschner 17 (18) 21st IAEA, Chengdu, China 16 – 21 Oct 2006
Conclusions

- **Inner divertor**: everywhere deposition-dominated
- **Outer divertor**: vertical tiles erosion-dominated, base plate: deposition
- **Tungsten stripe**: at outer vertical tile heavy erosion
  ⇒ ITER-like wall: 200 μm suggested
- **Material transport to remote areas** mainly in specific magnetic configurations (strike point on base plate)
  ⇔ QMB, $^{13}$CH$_4$ tracer injection
- **Estimated fuel retention rate**: 2.7%
  (w/o gaps, SRP and main chamber ⇒ plus 50%)