Beryllium Migration in JET ITER-like Wall Plasmas

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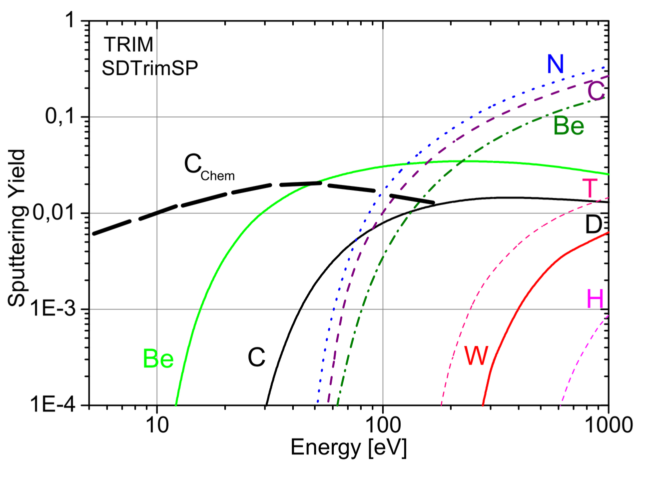
*See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia

INTRODUCTION

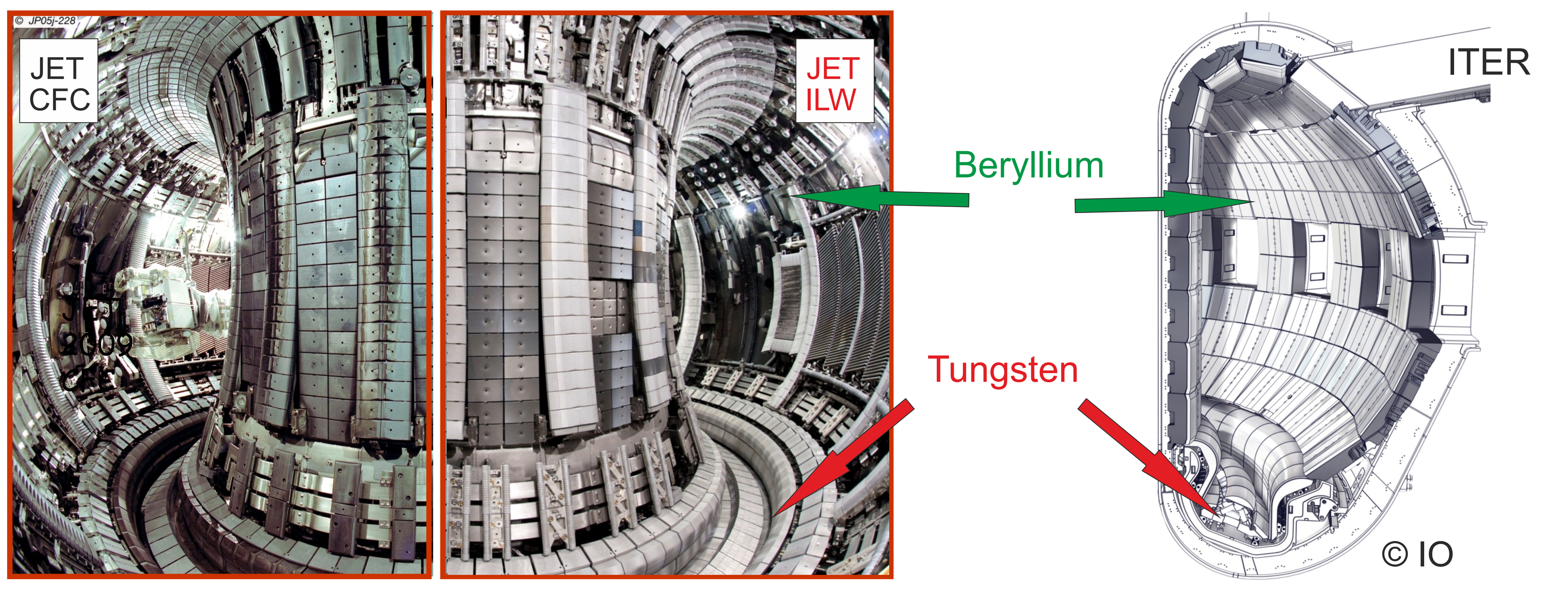
- Beryllium Plasma-Facing Components (PFCs) used in the main chamber of JET and foreseen in ITER owing to low atomic mass, low retention and oxygen gettering.
- Main chamber impurity source in divertor configuration assumed to be driven by charge-exchange neutrals. Exchange of C PFCs by Be PFC shall lead to similiar primary erosion source, thus, similiar global migration.
- Re-erosion of deposited Be in the divertor is expected to be strongly reduced due to absence of ordinary chemical erosion like observed with carbon (JET-C). Transport of Be to remote areas shall be stongly reduced.



[1] S. Brezinsek et al., PSI 2014

JET ITER-LIKE WALL EXPERIMENT

- JET ITER-Like Wall operation [2] with Be in the main chamber and W in the divertor started in 2011

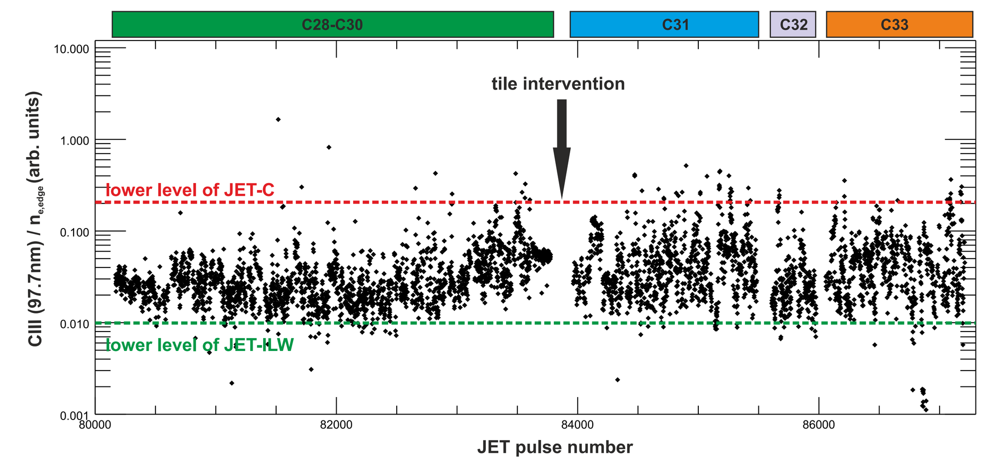


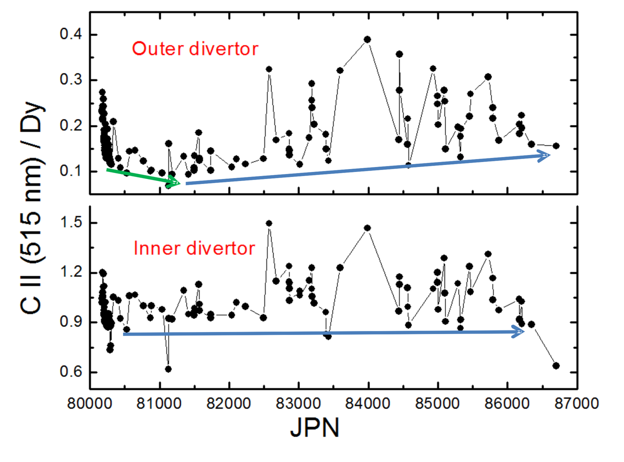
Questions concerning material erosion, transport and depostion which need to be answered:

- What are the Be migration paths? Limiter and divertor configuration?
- Is the Be transport to remote areas reduced? Is the Be accesible in these areas?

RESIDUAL CARBON CONTENT IN THE JET VESSEL

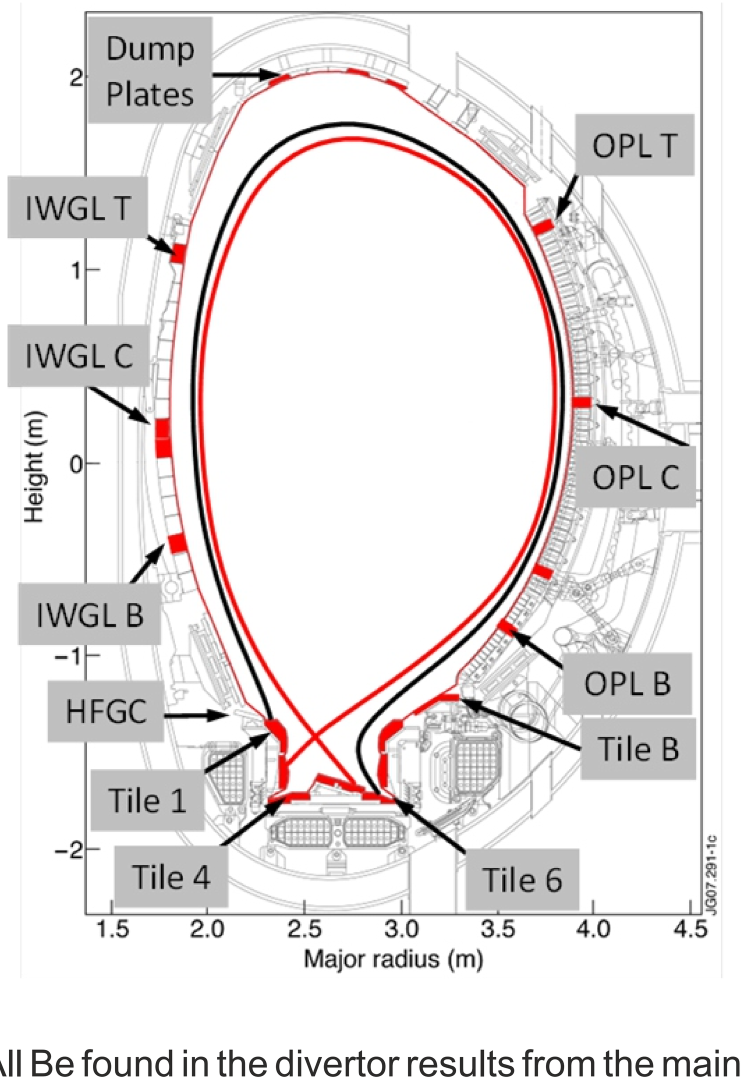
- Long-term evolution of the carbon flux in the plasma edge of the main chamber





- CIII edge flux normalised to density shows drop by a factor 20 (average) with installation of the ILW
- Residual C from back-side of tiles, uncleaned areas, air leaks and from W-coating (intrinsic impurity)
- Post-mortem analysis confirms reduction by a factor ten - residual C predominantly in divertor
- Material Migration in the vessel is determined by Beryllium =>JET-ILW is a good proxy for ITER

CAMPAIGN-INTEGRATED FOOTPRINT OF MATERIAL MIGRATION



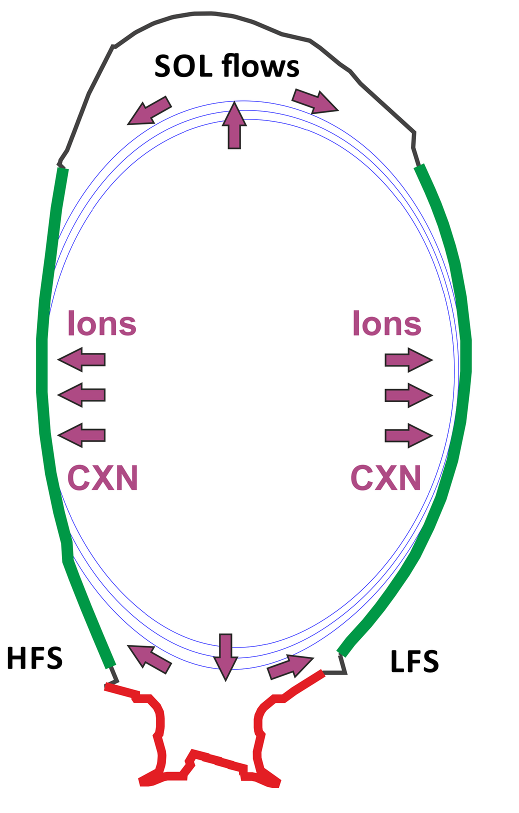
- Strong reduction of overall material migration with the JET-ILW (Be PFCs) in comparison with JET-C (C PFCs) measured.
- Strongest reduction at the bottom of the divertor and in recessed areas.

Intitial analysis:	JET-ILW (2011-2) (6h lim / 13h div)	JET-C (2007-9) (12 lim /21h div)
Main chamber (SUM):	~30g (-)	~273g (-)
Dump Plates	< 2g(±)/melting	130g (-)
IWGL top (1 row)	0	0.8g (+)
IWGL centre (1 row)	8g (-)	11g (-)
IWGL bottom (1 row)	0	No measured
Inner Wall Cladding (all)	15g (-)	129g (-)
OPL top (1 row)	0	No measured
OPL centre (1 row)	5g (-)	3.1g (-)
OPL bottom (1 row)	0	No measured
Divertor (SUM):	~ 37 g (+)	~459g (+)
HFGC	10g (+)	30g (+)
Tile 1	25g (+)	65g (+)
Tile 3,4,6	<6g (+)	428g (+)
Tile 7,8	<4g (-)	64g (-)
Dust :	1 g	233 g

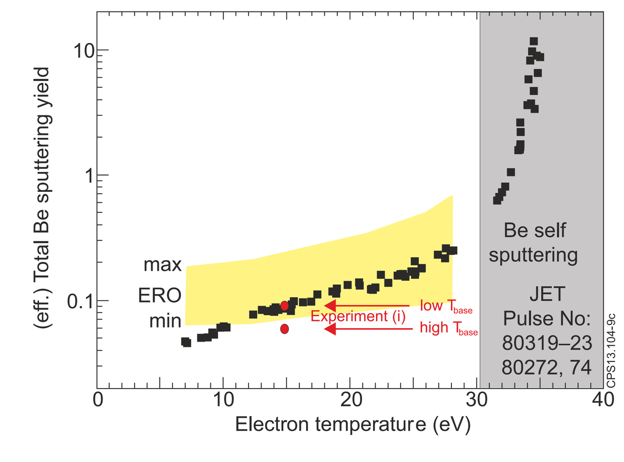
[3] A. Baron-Wiechec et al., PSI 2014
[4] A. Widdowson et al., Phys. Scr. 2014

- All Be found in the divertor results from the main chamber as no primary Be divertor source exists!
- Be migration needs to be devided into transport in the limiter phase and in the divertor phase

MIGRATION IN LIMITER CONFIGURATION



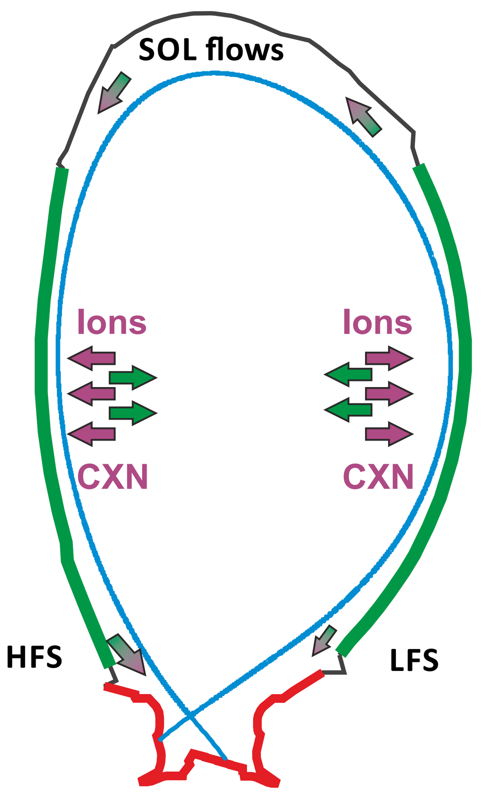
- Be erosion predominantly at contact point on limiters
- Erosion by physical & chemical assisted physical sputtering by deuterium ions and by Be self sputtering [5]
- Effective sputtering yield determined by optical spectroscopy and modelled with the ERO code [6]
- Averaged campaign integrated Be erosion yield amounts to 10%
- Comparison between net and gross erosion reveals a factor 2
- Overall Be source in JET-ILW is 25% higher than in C in JET-C



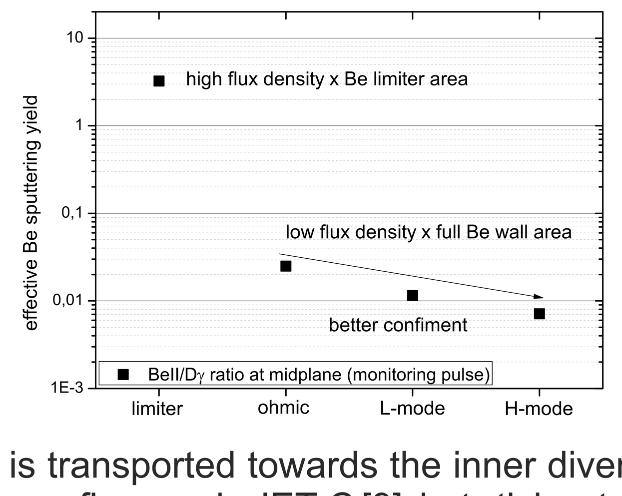
[5] S. Brezinsek et al., Nucl. Fus. 2014
[6] D. Borodin et al., Phys. Scr. 2011

- Eroded Be is re-deposited on the side of the limiters and recessed areas (e.g. W cladding). Transport of Be into the divertor negligible.
- Be eroded in the limiter phase remains predominantly in the main chamber. Only a small neutral fraction reaches divertor geometrically.

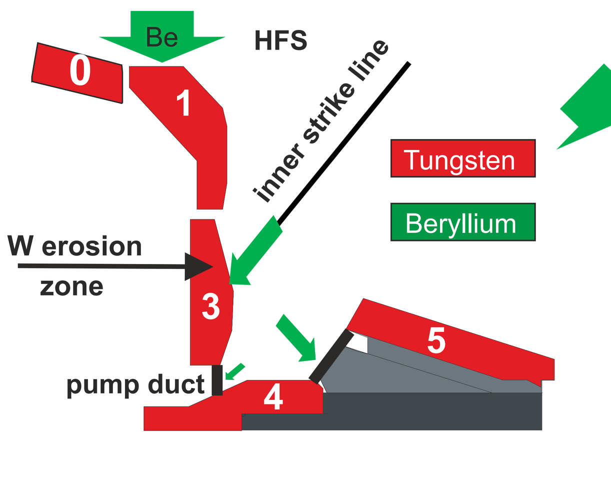
MIGRATION IN DIVERTOR CONFIGURATION

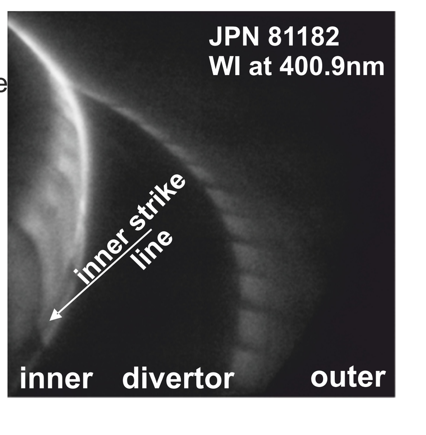


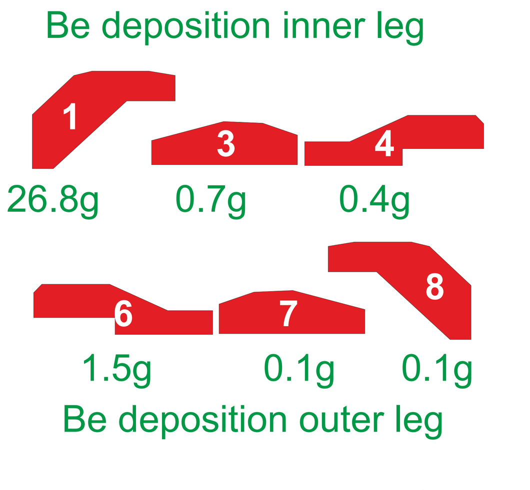
- Be erosion at inboard Be cladding & limiters and outboard limiters assumed to be almost homogenous
- Erosion by physical & chemical assisted physical sputtering by the residual plasma flux and by charge exchange neutrals [5]
- Effective sputtering yield determined by post-mortem analysis using material probes [7]. Spectroscopy confirms qualitatively Be source.
- Be source in JET-ILW is five times smaller than in C in JET-C [8]
- Lower primary source due to absence of chemical erosion in Be



- Eroded Be is transported towards the inner divertor due to poloidal scrape-off layer flows as in JET-C [9], but sticks at contact point [10].
- Main deposition in inner divertor, but factor 7 less than in JET-C [11].
- Outer divertor leg shows no significant Be deposition [13].







- Be entering the inner divertor is hindered to be re-eroded and transported in multiple steps further as C due to absence of low temperature chemical sputtering by thermal species (2 steps vs. 10 steps).
- Transport to remote areas further reduced with respect to C in JET-C by a factor 15 in the reflect step and 30-50 at the pump duct due the absence of re-erosion by thermal neutrals [5,12]
- Total main chamber Be source in divertor configuration (~21g) is close to the amount of Be found in the inner divertor (~28g) confirming general material migration path. Analysis needs to be completed.

Conclusion

- Overall material migration of Be in JET-ILW is lower than expected indicating that the role of chemical erosion of C contributing to the primary source was understimated in the case of JET-C
- Divertor configuration: Be eroded in the main chamber due to charge-exchange neutrals and residual plasma flux is transported towards the inner divertor leg and sticks on the apron of the divertor. Transport of Be to remote areas is low due to absence of chemical erosion.
- Limiter configuration: Be eroded in the main chamber remains in the main chamber and is not contributing significantly to the material deposited in the divertor.
- Validation of the WallDYN code for the global migration into the divertor and the ERO code for the local migration within the divertor and to remote areas is ongoing. Both codes are applied for ITER.

ACKNOWLEDGEMENTS

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