DEPOSITION OF ^{13}C TRACER IN THE JET MKII-HD DIVERTOR

J. Likonen, M. Airila, M. Groth, A. Hakola, S. Koivuranta, T. Makkonen

VTT and Aalto University, Association Euratom-Tekes, Finland

S. Brezinsek, J. P. Coad, S. Devaux, S. Grünhagen, S. Jachmich, G. Matthews, M. Stamp, J. Strachan, A. Widdowson

CCFE, Culham Science Centre, United Kingdom

E. Alves, N. Barradas

Instituto Tecnológico e Nuclear, Portugal

M. Rubel

Royal Institute of Technology, Association EURATOM-VR, Sweden

D. Hole

University of Sussex, United Kingdom

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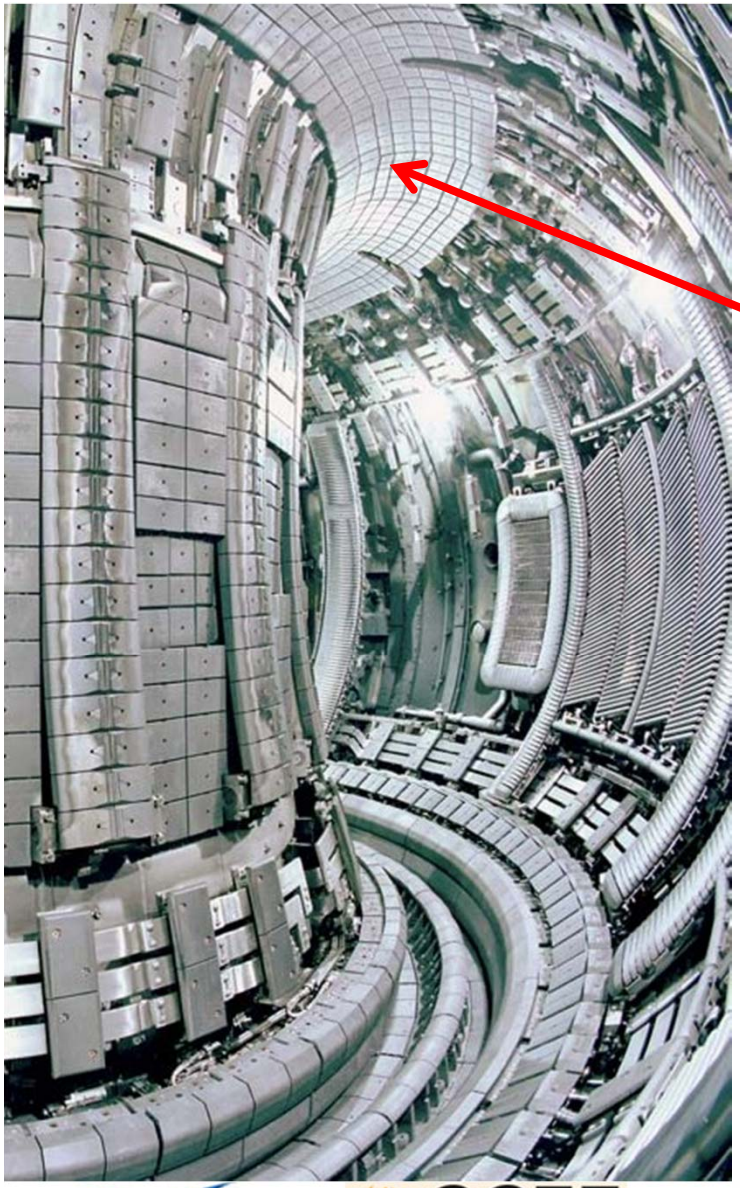
Outline

- Introduction
- ^{13}C experiments (2001, 2004, 2007, 2009)
- Experimental results: ^{13}C deposition on divertor tiles
- Migration pathways
- Experimental results: ^{13}C deposition on C/W surfaces
- (Preliminary) modelling results for global ^{13}C migration (DIVIMP, EDGE2D)
- (Preliminary) modelling results for local ^{13}C migration (ERO)
- Conclusions

Introduction

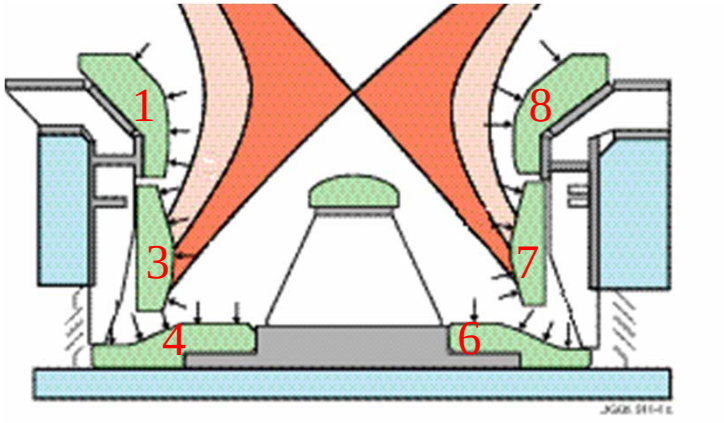
- To study material erosion, transport and deposition under constant plasma conditions
- To understand the conditions for heavy deposition and tritium retention in the shadowed region of the divertor floor at JET
- To provide data for modelling (EDGE2D, DIVIMP, ERO) of material migration
- To have a reference for the ITER-like wall (Be vs. C) and to document changes in migration to remote areas
- Prediction of carbon migration and tritium retention in ITER

Gas injection locations

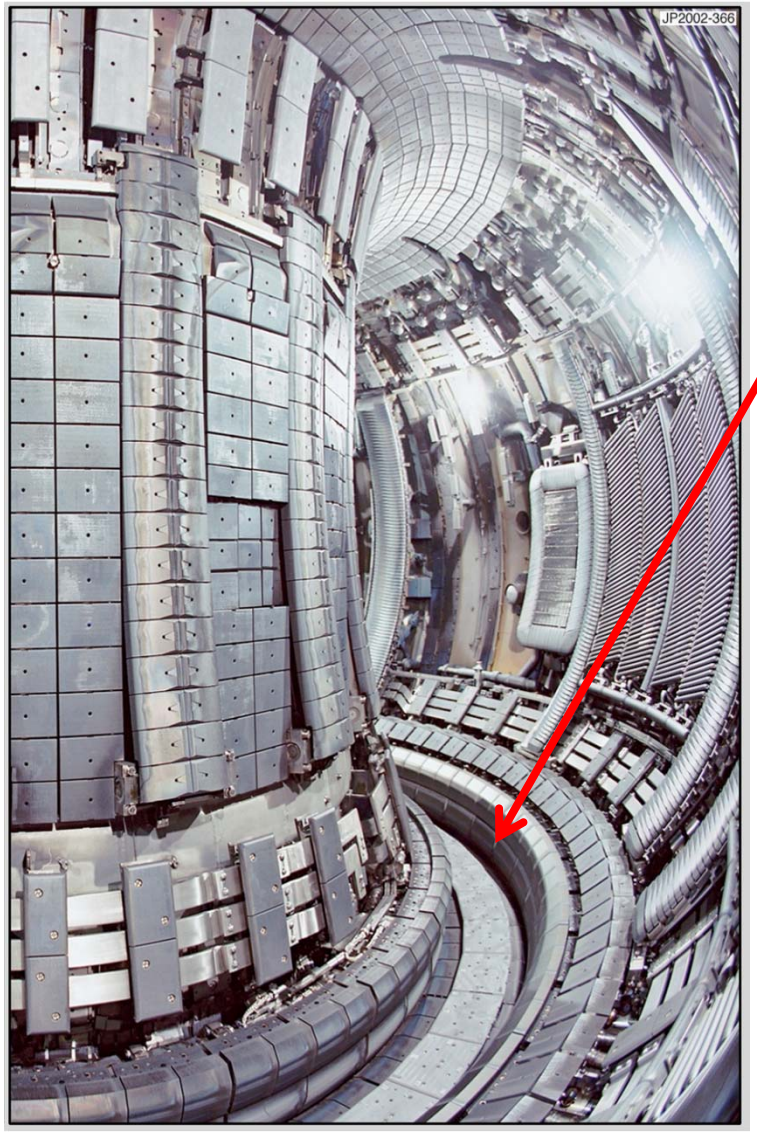


Main plasma in 2001:

- I_p= 2.4 MA
- B_t= 2.5 T
- P_{aux} = 0 MW
- n_e= 7.5x10^{19} m^{-2}
- Ohmic discharges
- 16 good shots (54330-54345)
- Puffed ^{13}C amount: 2.8g (1.3x10^{23} atoms)

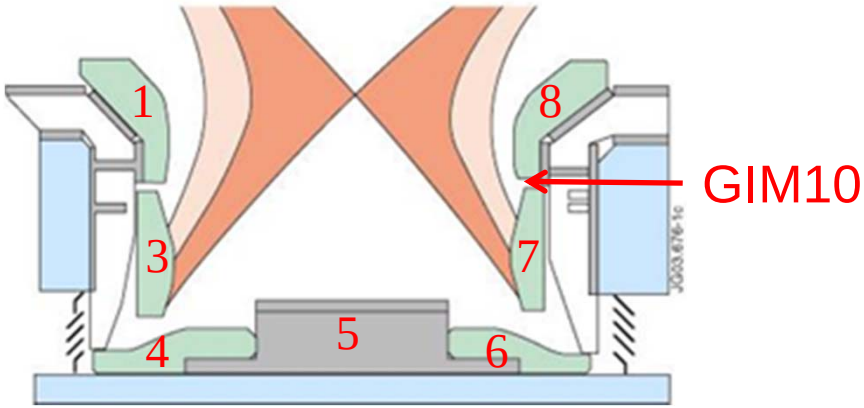


Gas injection locations

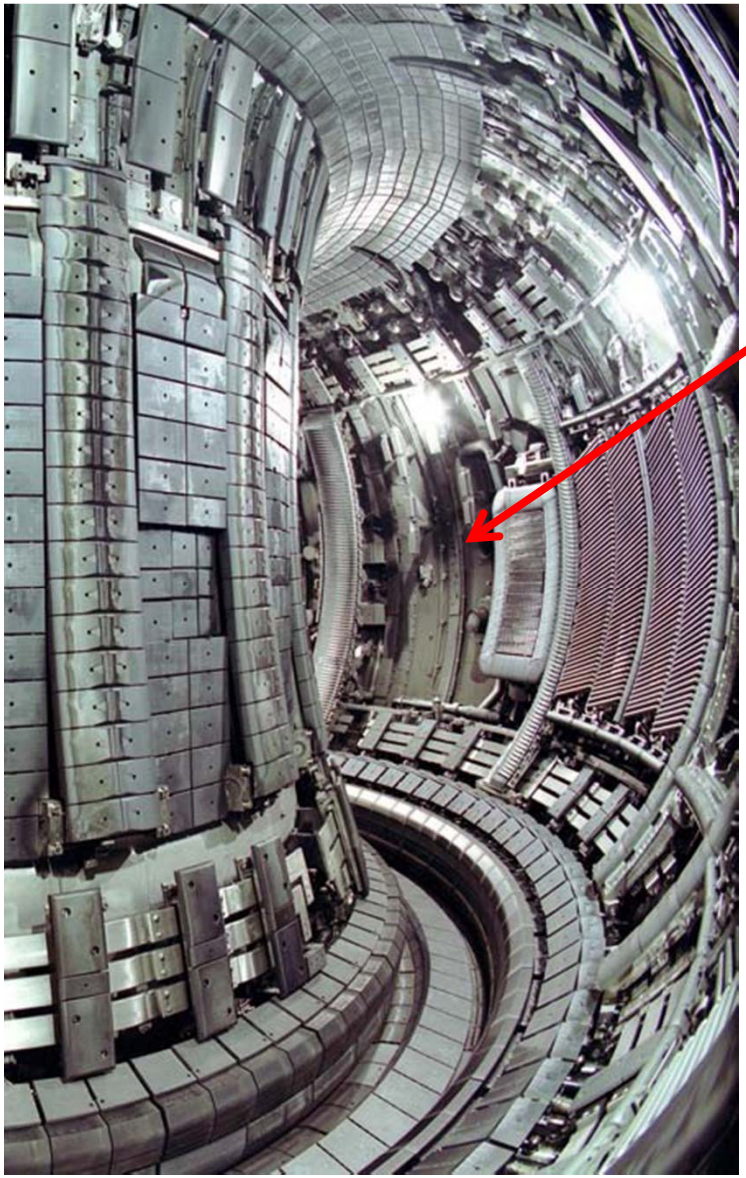


Main plasma in 2004:

- I_p= 1.2 MA
- B_t= 2.4 T
- P_{aux} = 4.7 MW
- n_e= 7.8x10^{19} m^{-2}
- H-mode discharges (ΔW = 30kJ)
- 32 good shots (63405-63445)
- Puffed ^{13}C amount: 9.3g (4.3x10^{23} atoms)

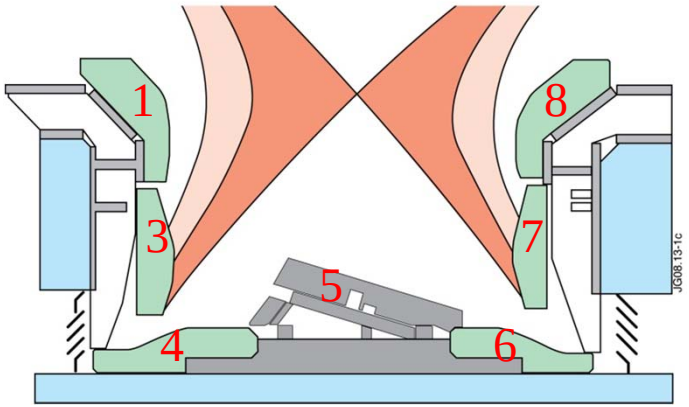


Gas injection locations

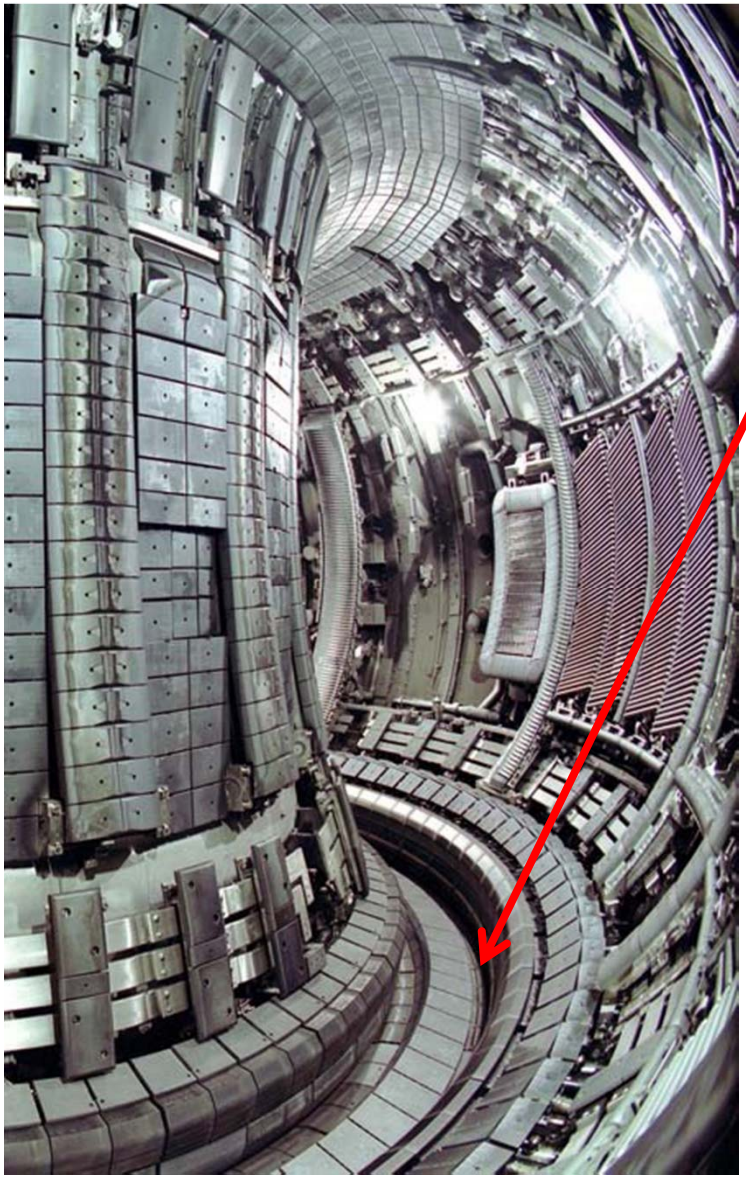


Main plasma in 2007:

- I_p= 1.6 MA
- B_t= 1.6 T
- P_{aux} = 9MW
- n_e= 10.8x10^{19} m^{-2}
- H-mode discharges (ΔW = 150kJ)
- 18 good shots (70729-70749)
- Puffed ^{13}C amount: 2.0g (9.3x10^{22} atoms)

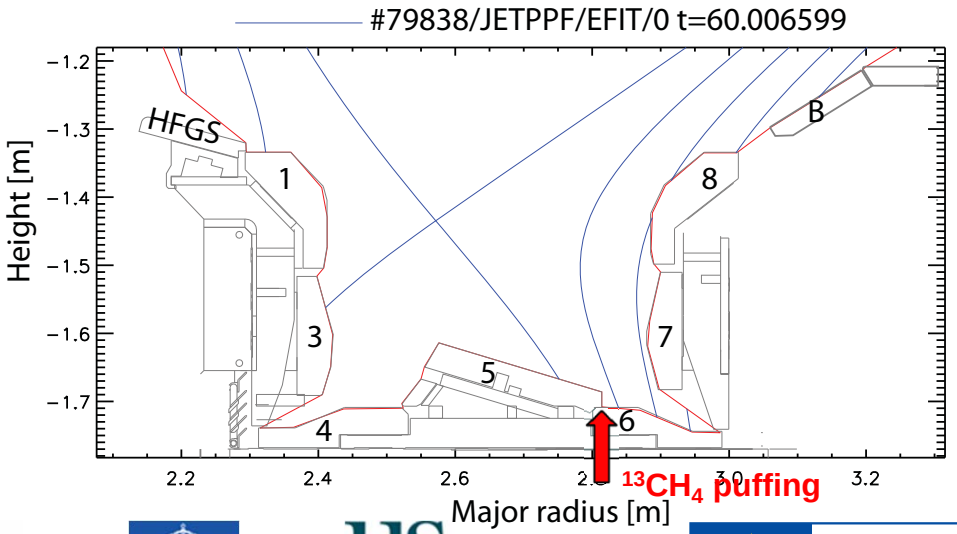


Gas injection locations



Main plasma in 2009:

- Operation scenario representative for 2008-2009 operations
- I_p= 2.5 MA
- B_t= 2.5 T
- P_{aux} = 15MW
- n_e= 14.8x10^{19} m^{-2}
- H-mode discharges (ΔW = 400kJ)
- 30 good shots (79816-79853)
- Puffed ^{13}C amount: 7.1g (3.3x10^{23} atoms)



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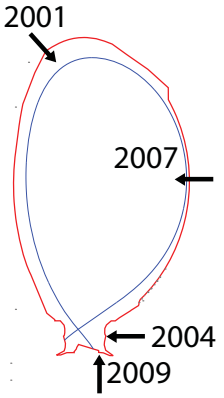
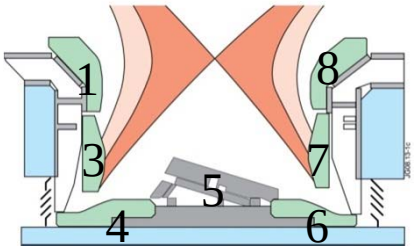
^{13}C inventory

^{13}C amount (% of puffed amount):

	2001	2004		2007	2009
Inner div.	45	3.2	2.9	7.7	1.6
Floor	0.9	6.3	7.5	5.6	8.8
Outer div.	0.4	17	16.4	5.5	4
Main wall			2.7	4.1	0.4
Pumped amount	n/a	n/a	n/a	n/a	33
Total	46.2	26.5	29.4	22.9	14.8





- More balanced pattern in 2004, 2007 and 2009 experiments than in 2001
- This is most likely due to longer migration path in SOL
- "Missing" ^{13}C possibly in gaps and shadowed regions
- In 2009 ~ 33 % of puffed ^{13}C pumped instantly by cryopump
- This 33% for pumped ^{13}C amount is perhaps upper limit

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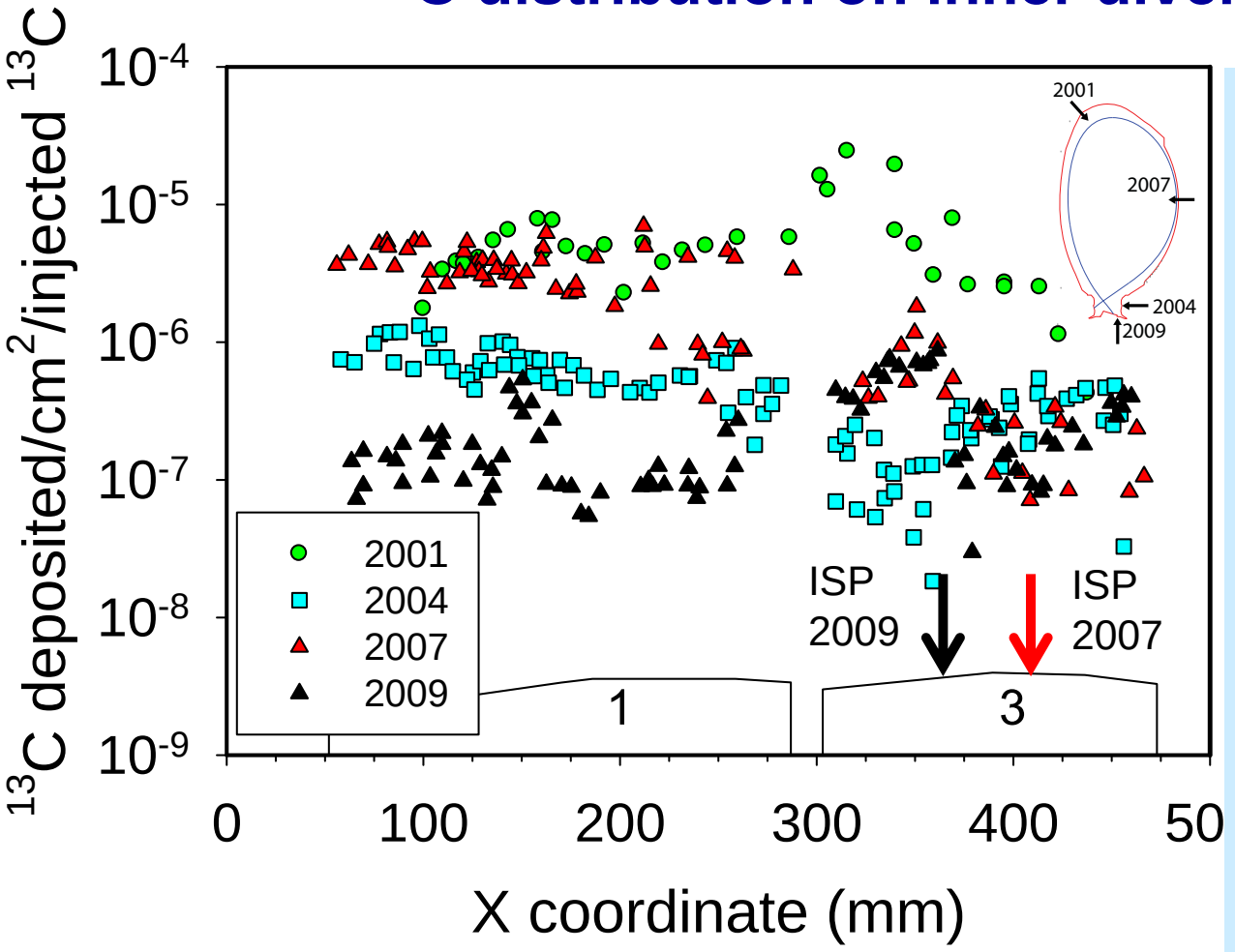
^{13}C distribution on inner divertor tiles



^{13}C distribution measured with SIMS and RBS

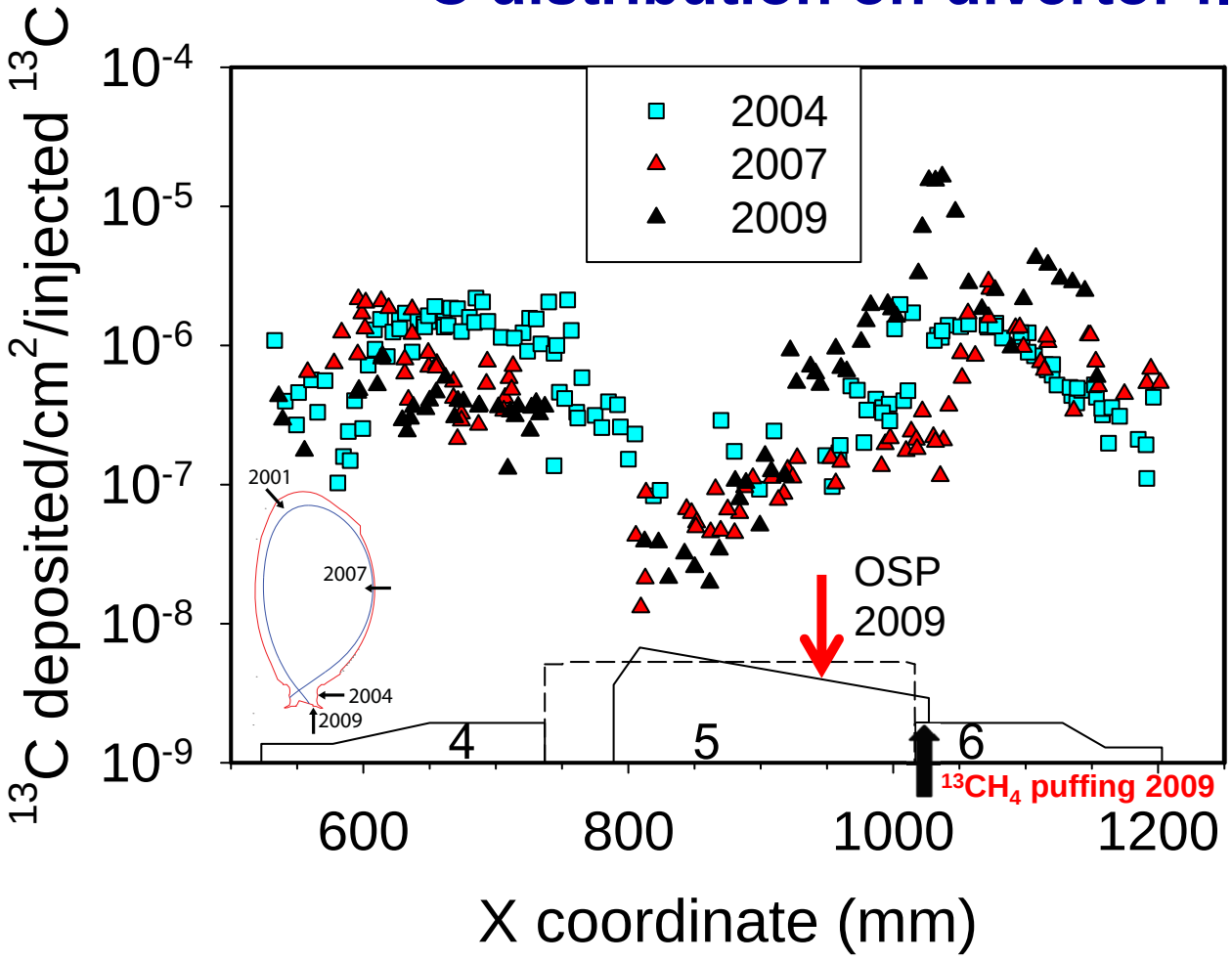
Tile 1:

- ^{13}C amount 1-2 orders of magnitude higher in 2001 and 2007 than in 2004 and 2009
- Could be due to shorter migration path in SOL
- Higher ^{13}C amount in 2001 and 2007 indicates that main wall is important source for long-term deposition on inner divertor tiles

Tile 3:

- Peak in ^{13}C distribution above ISP
- Minimum below ISP

^{13}C distribution on divertor floor tiles

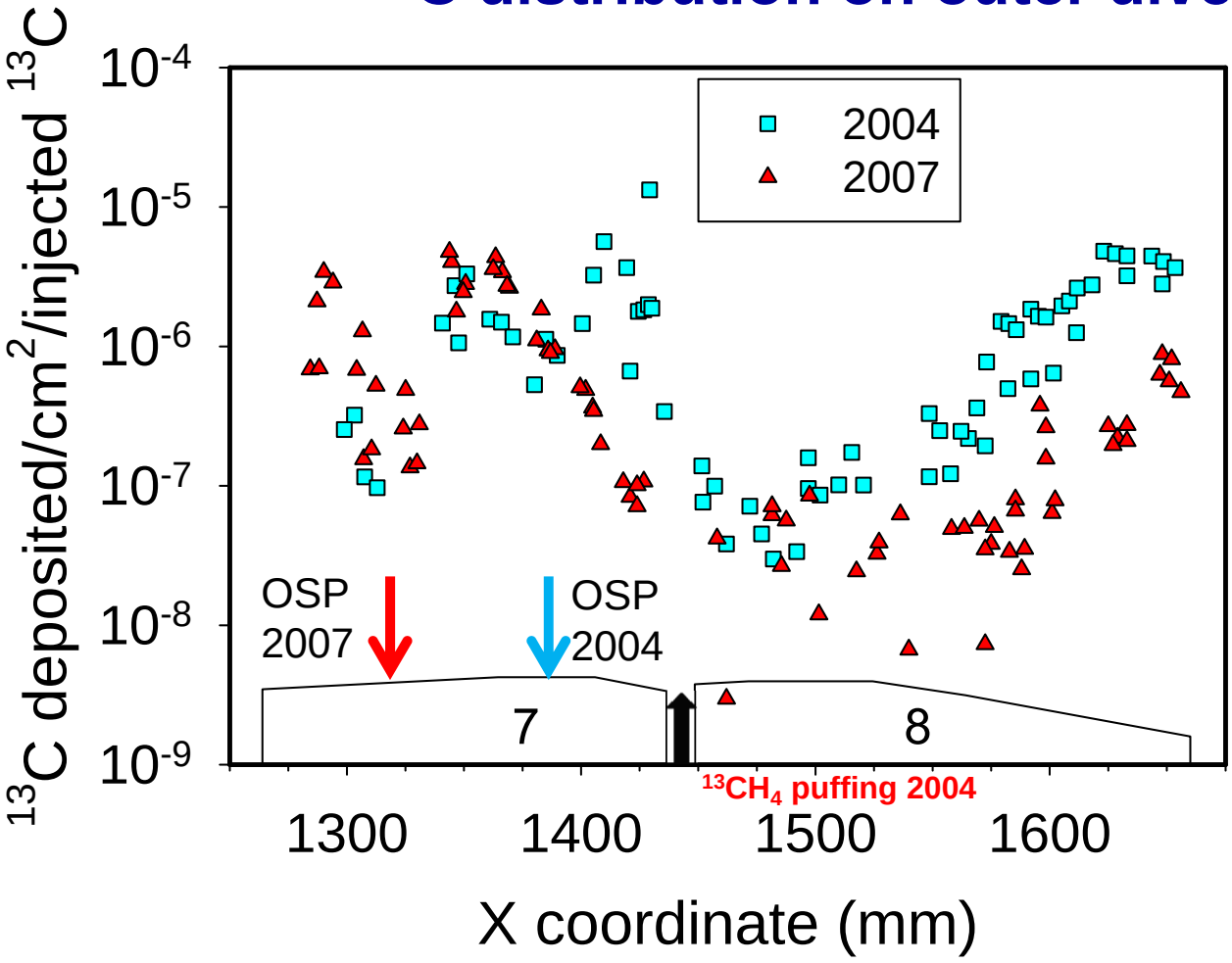


Tile 4:
- On horizontal part ^{13}C amount in 2004 highest, in 2007 and 2009 similar
- On sloping part ^{13}C peak more pronounced in 2007 than in 2009

Tile 5:
- In 2004 a hollow profile
- In 2007 and 2009 ^{13}C amount increases as function of major radius

Tile 6:
- In 2009 strong toroidal ^{13}C deposition band

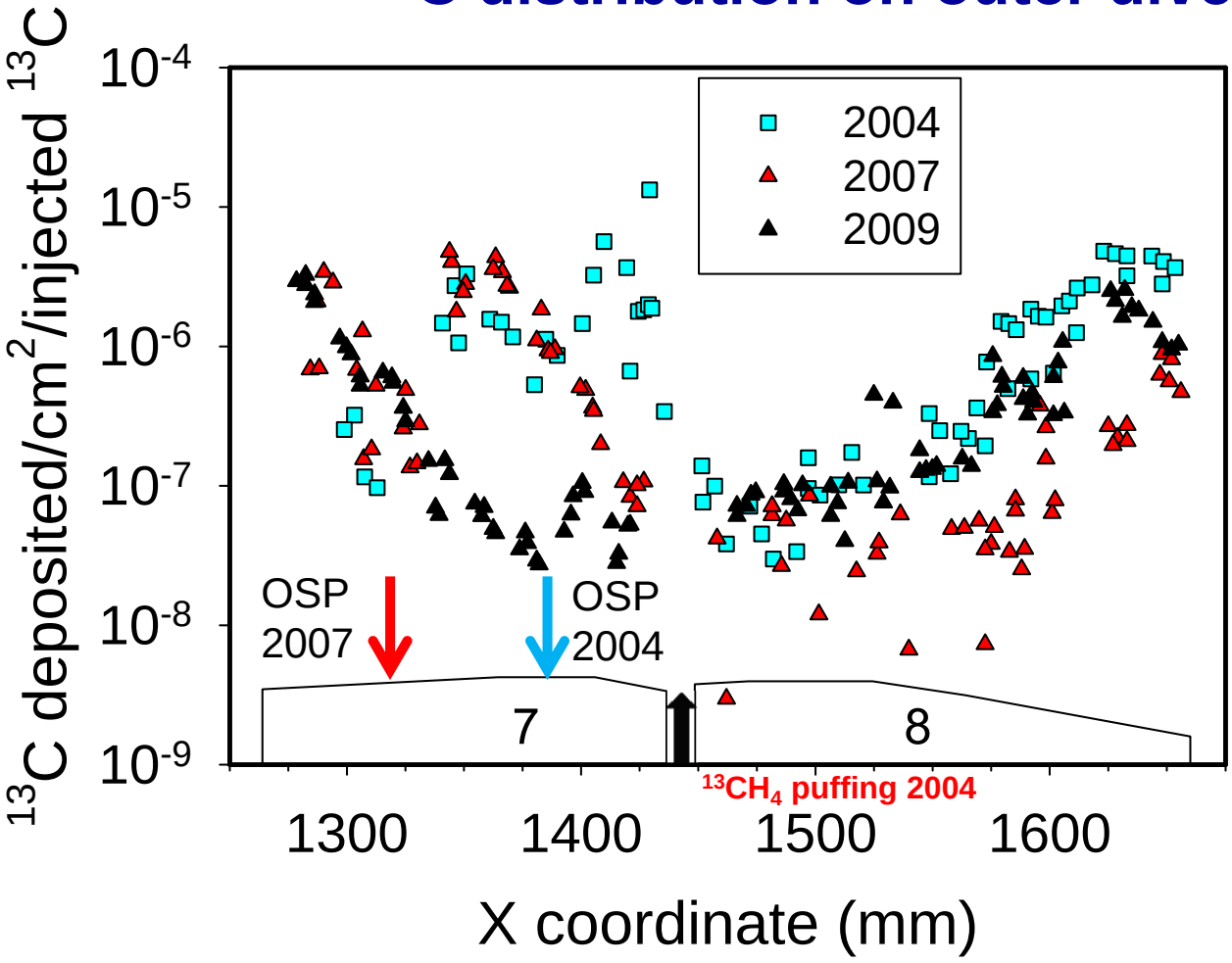
^{13}C distribution on outer divertor tiles



In 2004, 2007:

- ^{13}C distributions qualitatively quite similar (except the peak at ~ 1420mm in 2004)

^{13}C distribution on outer divertor tiles

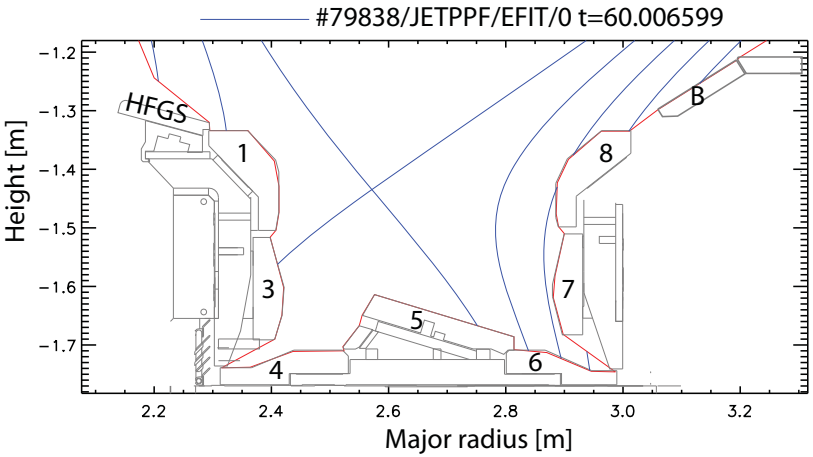


In 2009:

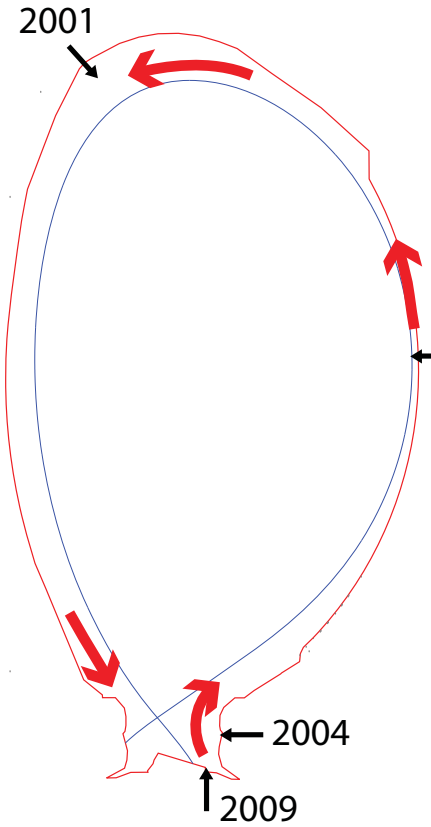
- ^{13}C distribution in 2009 qualitatively different from 2004 and 2007 ones.
- Highest ^{13}C amount at bottom of tile 7 and top of tile 8
- No peak at centre of tile 7

Summary of migration pathways

Tile 1



Migration pathways identified with EDGE2D and ERO simulations

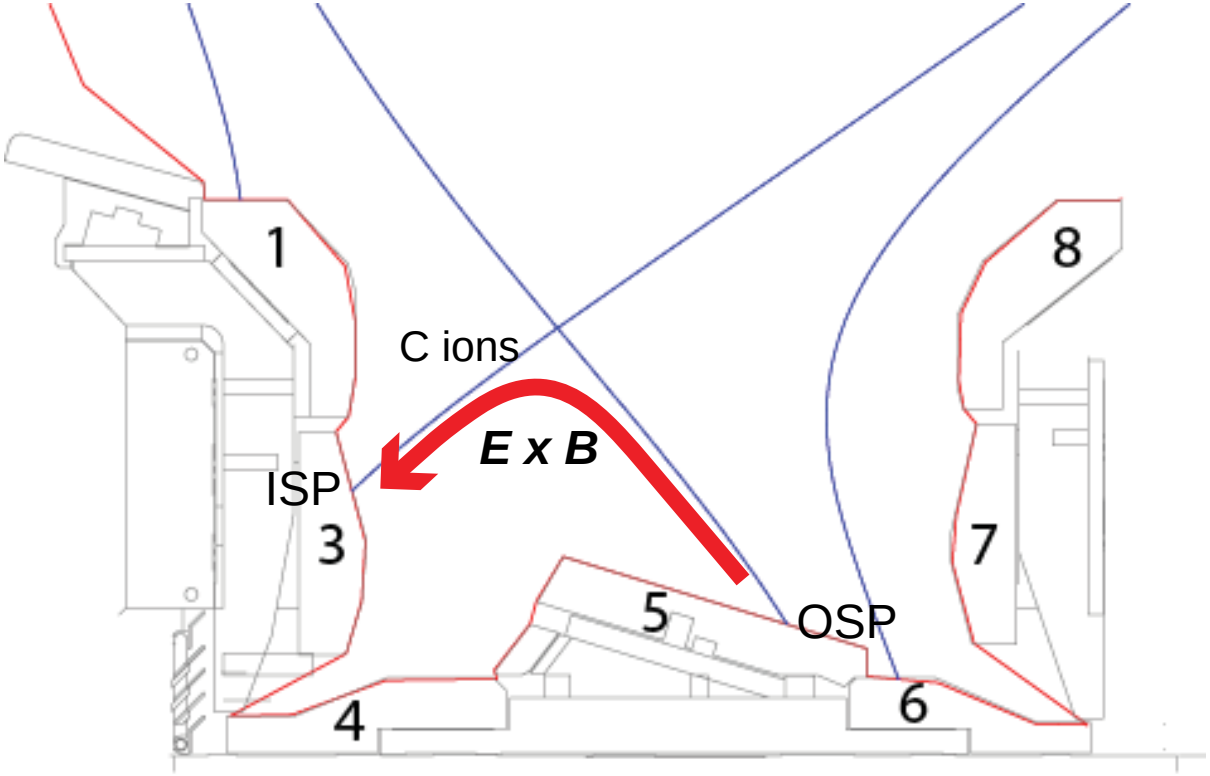


Tile 1 (above ISP):

- Migration through main SOL due to SOL flows

Summary of migration pathways

Tile 3

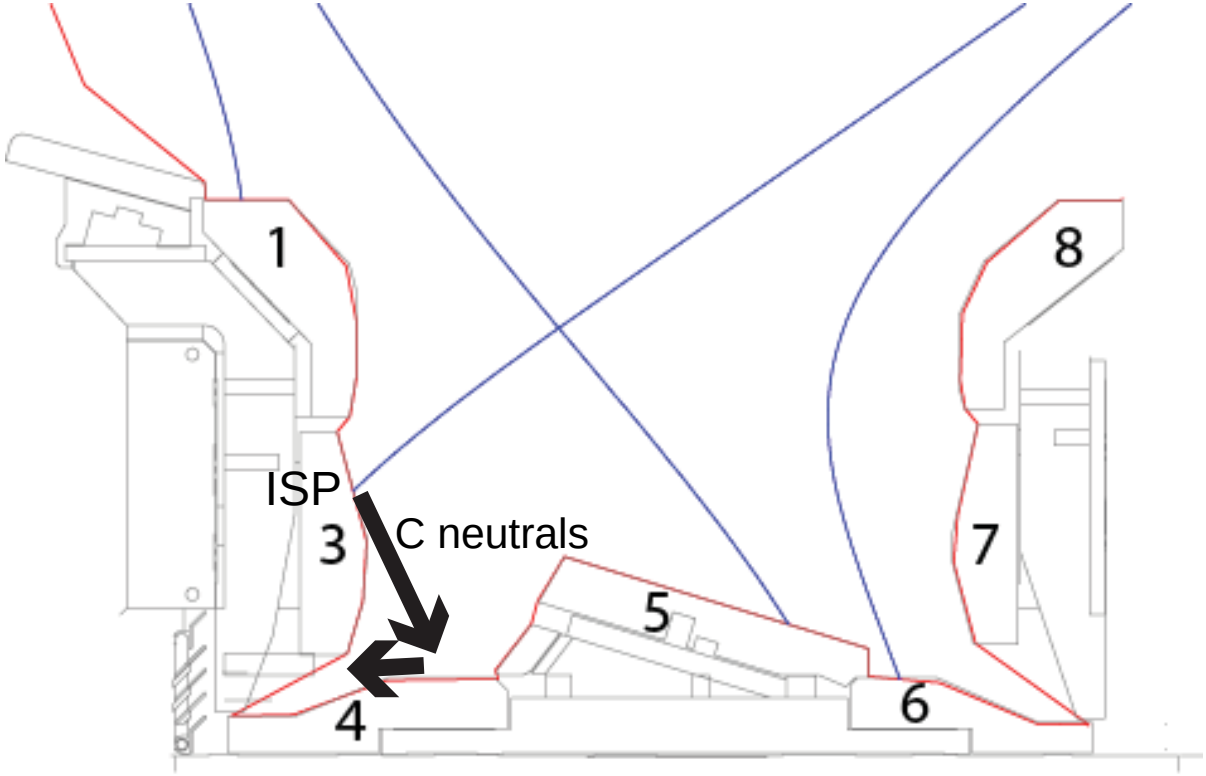


Tile 3 (below ISP):

- ***E x B*** drift from OSP through PRF to ISP

Summary of migration pathways

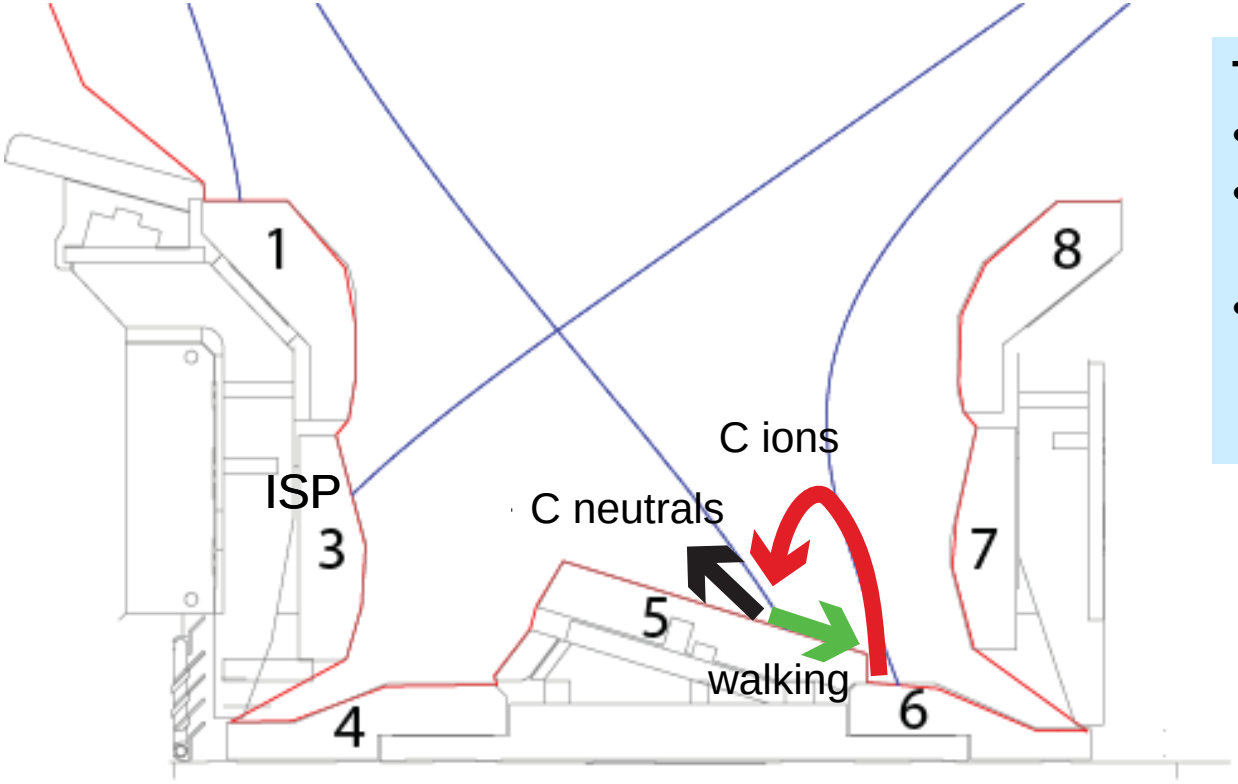
Tile 4



Tile 4:
- Neutral emission from ISP
- Further re-erosion from horizontal part and migration towards shadowed region

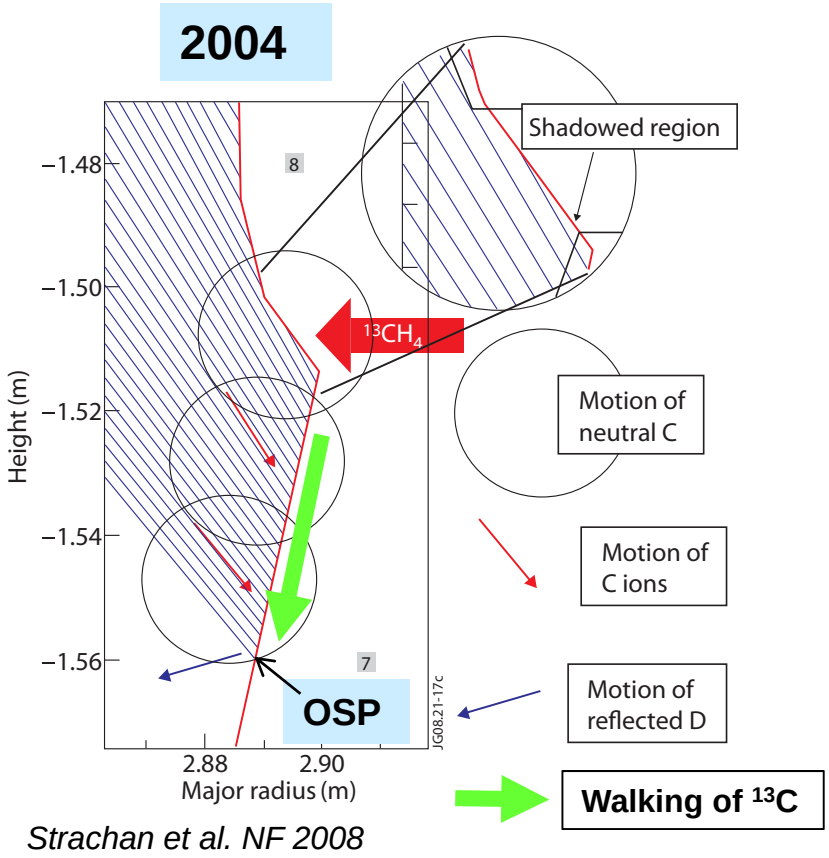
Summary of migration pathways

Tile 5

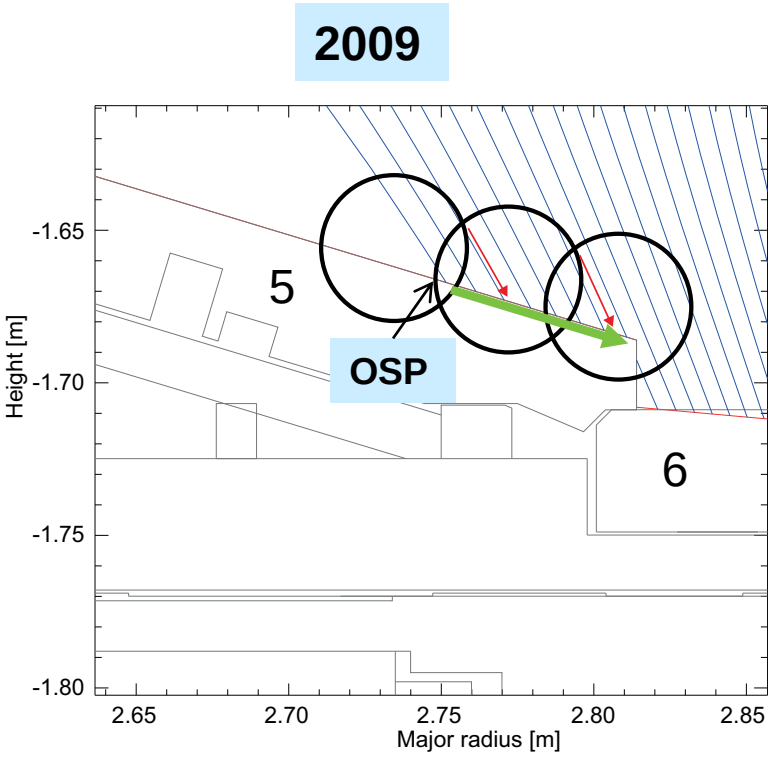


Tile 5:
- Migration from Tile 6
- Walking away from OSP towards tile 6
- Migration of neutrals from OSP due to re-erosion caused by ELMs

Walking of ^{13}C towards OSP in 2004 and away from OSP in 2009



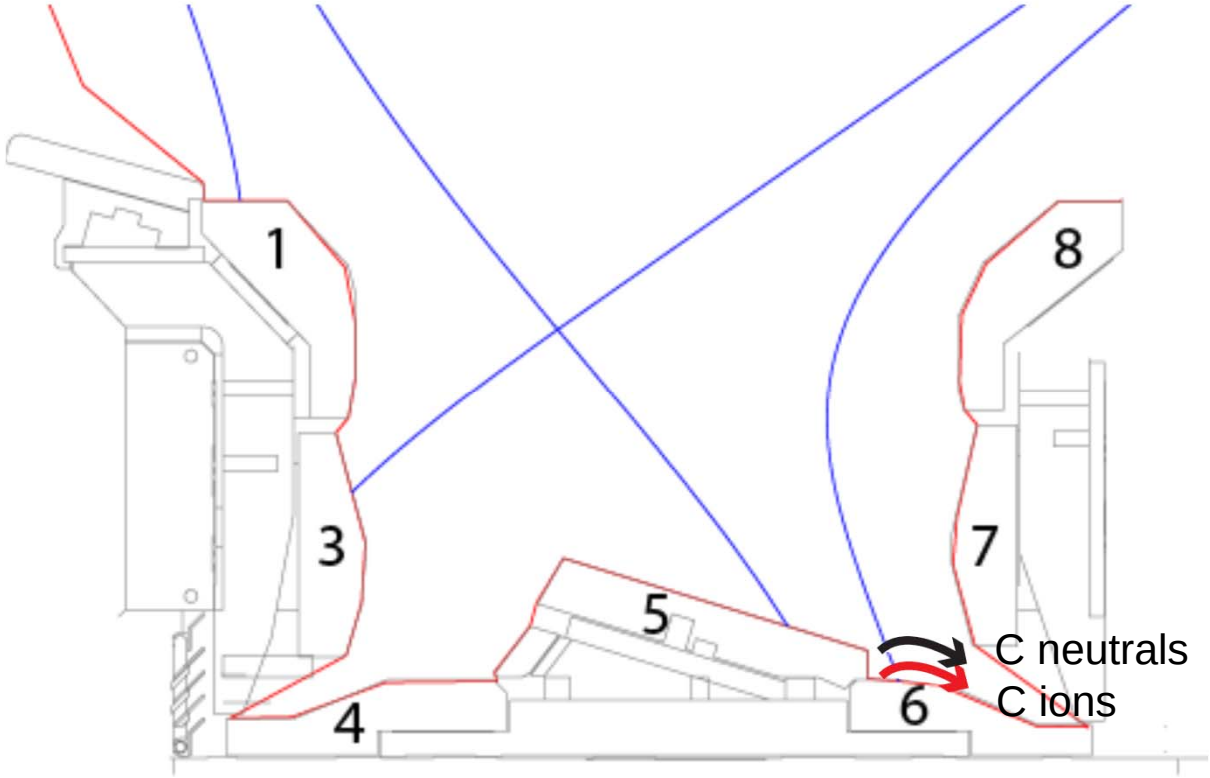
Strachan et al. NF 2008



Multistep erosion/re-deposition process

Summary of migration pathways

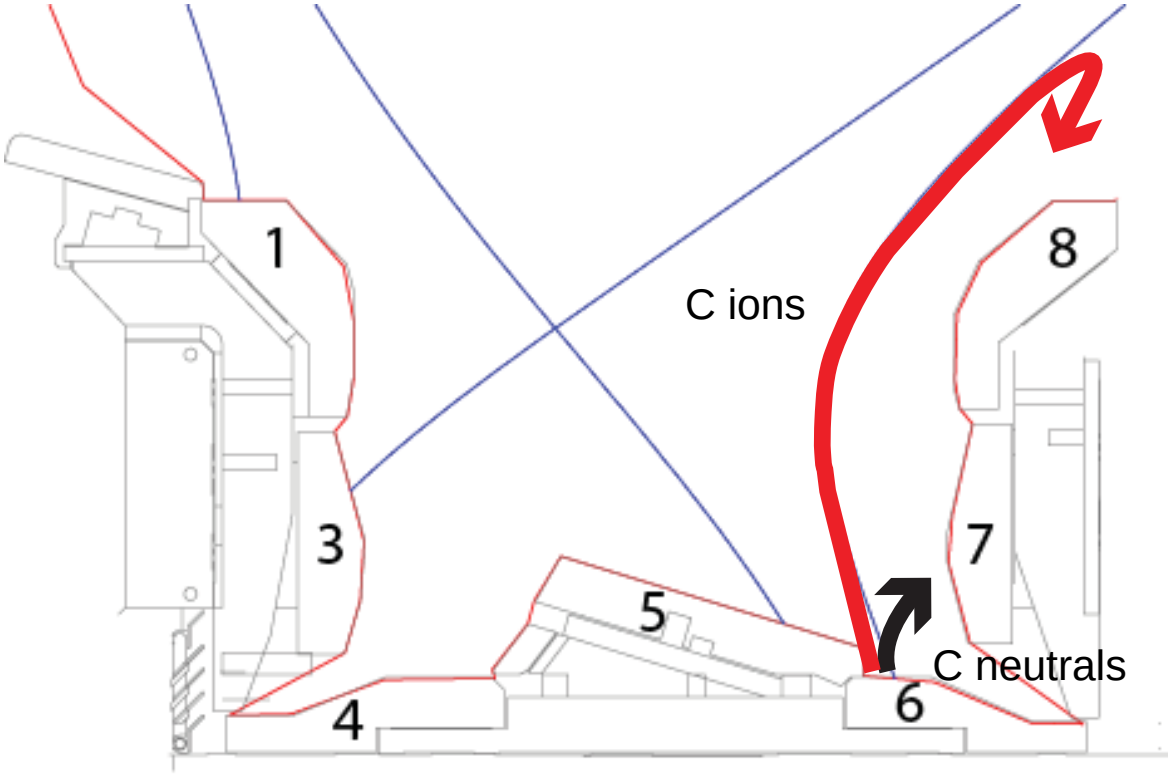
Tile 6



Tile 6:
- Local ^{13}C deposition
- Migration towards shadowed area (under Tile 7)

Summary of migration pathways

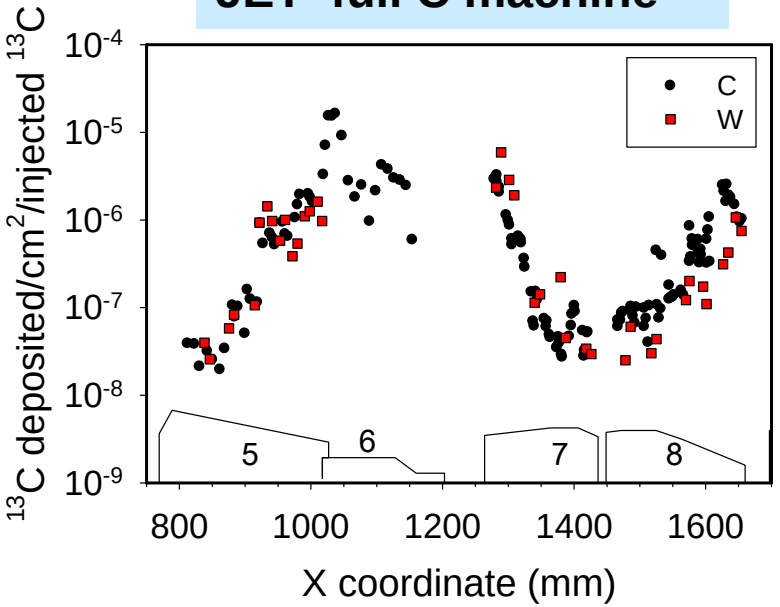
Tiles 7,8



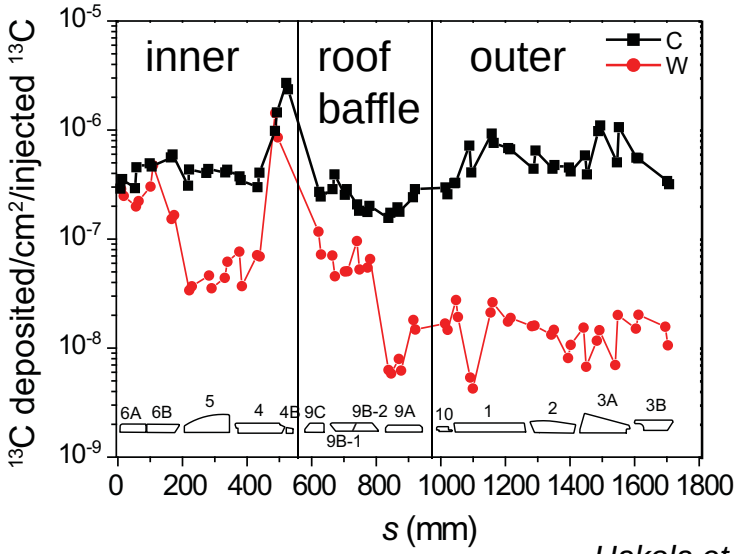
Tiles 7 and 8:
- migration of neutrals to bottom of Tile 7 (ERO)
- migration of ions to Tile 8 (due to ∇T_i ?)

^{13}C deposition on C and W surfaces

JET- full C machine



AUG- full W machine



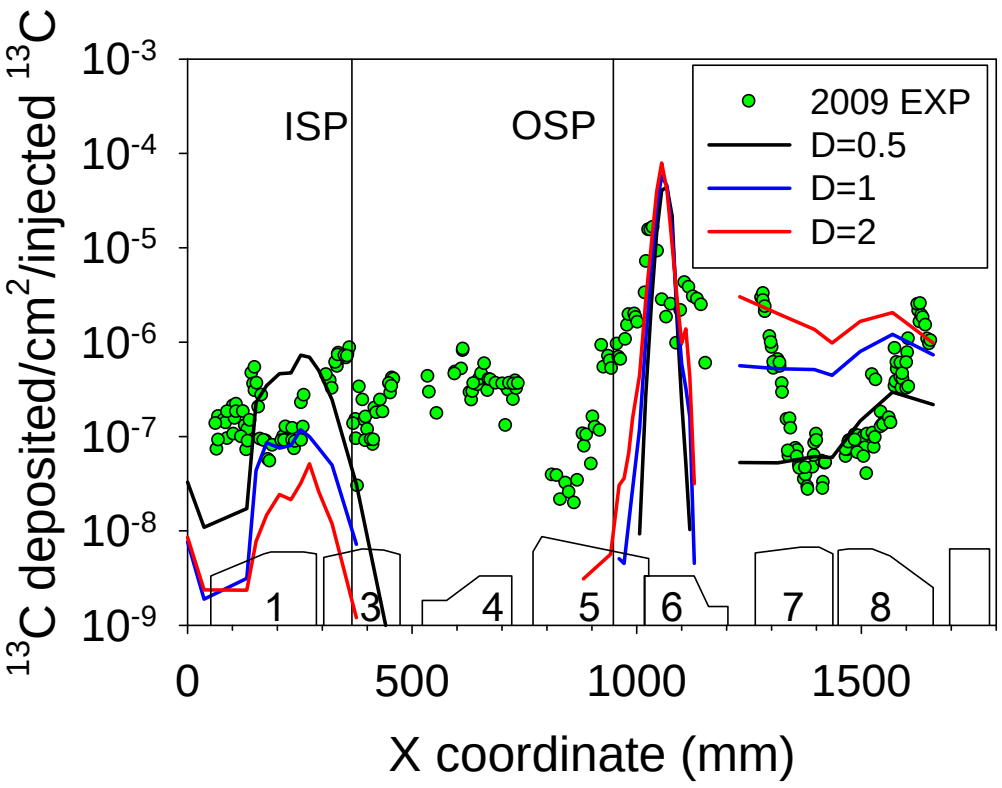
Hakola et al. PPCF 2010

^{13}C deposition similar on to C and W surfaces

Pronounced difference between ^{13}C deposition on C and W surfaces

- Enhanced erosion of a thin ^{13}C film from W surface attributed to a larger recoil of plasma particles from W⇨ higher physical sputtering ⇨ less ^{13}C deposition on W
- AUG: roughness <600 nm (C), <700 nm (W)
- JET: roughness ~10 µm (CFC, W)

DIVIMP simulation of global ^{13}C migration



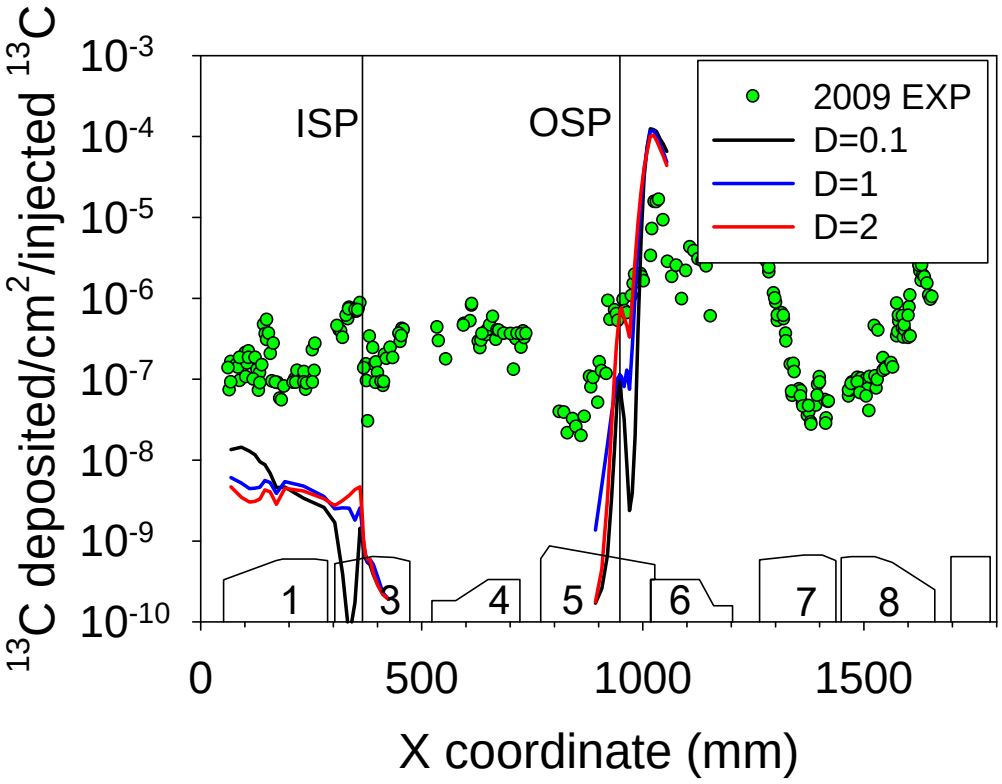
Parameters:

- Onion-skin modelled plasma background
- Prompt deposition included; re-erosion and subsequent re-deposition of ^{13}C not included
- Cross-field diffusion D = 0.5-2 m^2/s

Results:

- D=0.5 m^2/s gives best match with experimental results
- Strong prompt deposition of ^{13}C directly near injection point
- Strong deposition in far SOL along both inner and outer divertor
- Qualitatively reproduce measured ^{13}C deposition along Tile 8
- No deposition along divertor surfaces facing PFR

EDGE2D/EIRENE simulation of global ^{13}C migration



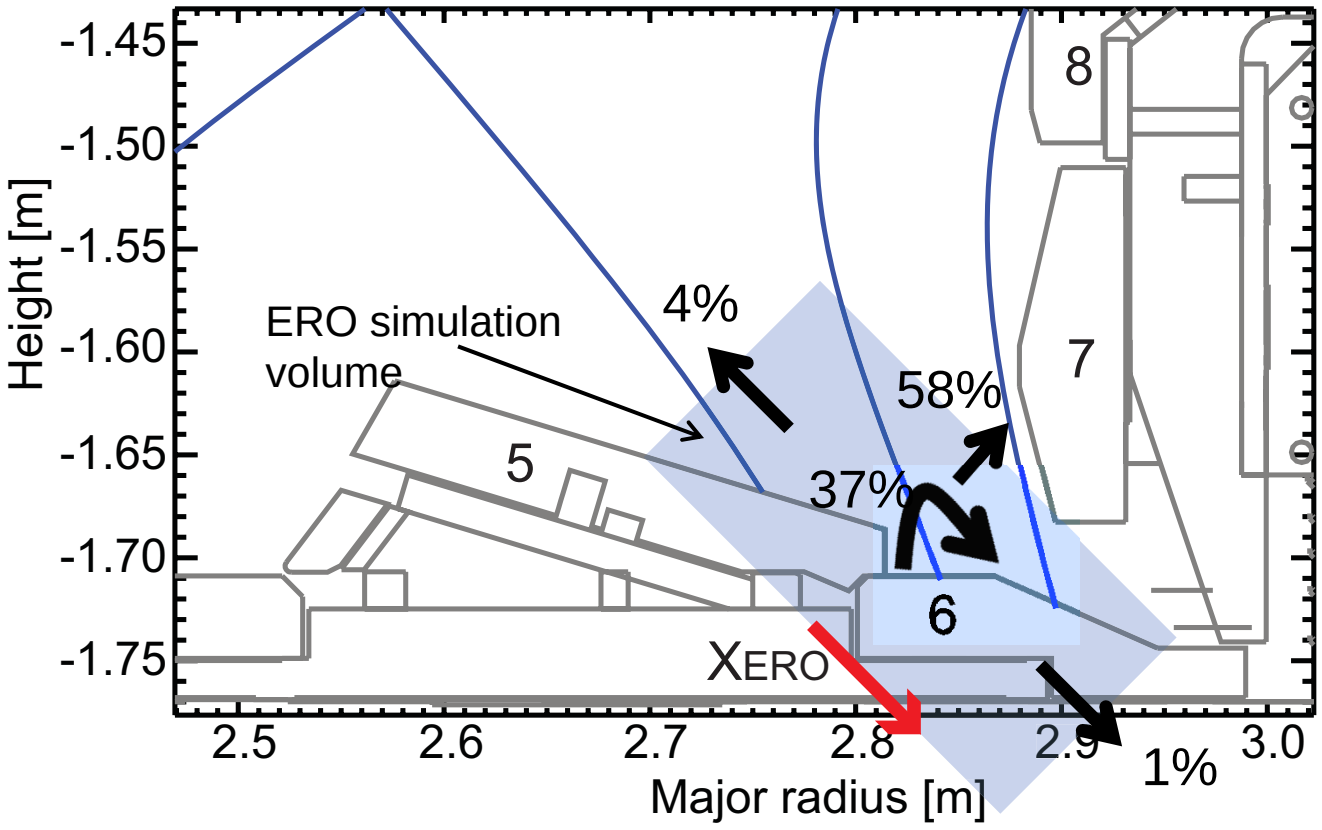
Parameters:

- EFIT based grid used (extended grid available)
- C neutrals modelled by EIRENE
- Cross-field diffusion D = 0.1-2 m^2/s

Results:

- Strong prompt deposition of ^{13}C directly near injection point (overestimation)
- Deposition on Tile 1 underestimated
- Effect of D not very strong

ERO simulation of local ^{13}C deposition

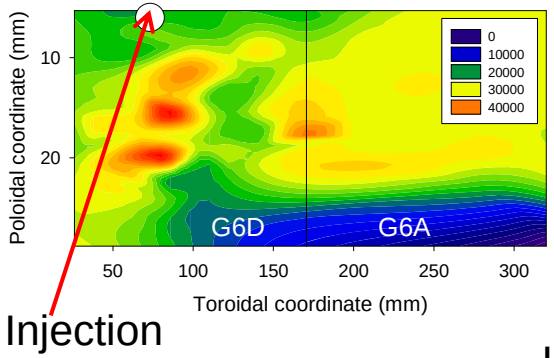


Parameters:

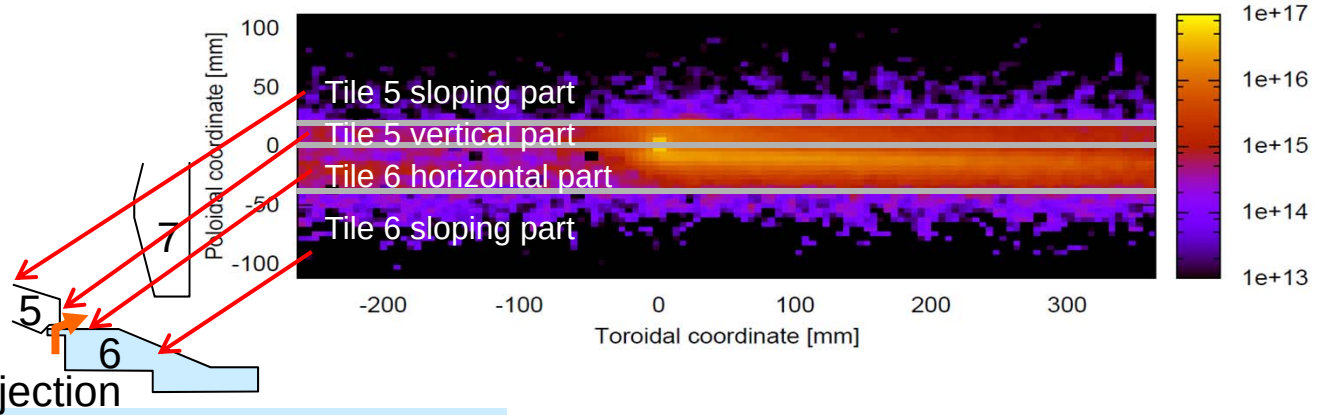
- $T_i = T_e = 5eV$ (constant)
- $n_e = 5 \times 10^{18}$ cm^{-3}
- Chemical erosion yield 1-2%
- Sticking S = 0.1
- Enhanced re-erosion of deposits 5x
- ELMs neglected

ERO results for local ^{13}C deposition

Experimental

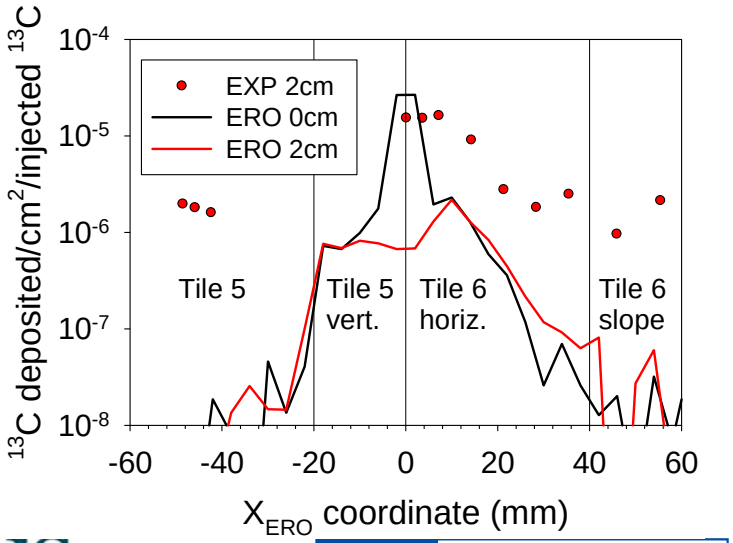


ERO



Results:

- Simulated deposition band more uniform toroidally than experimental one
- Simulated poloidal distributions narrower than experimental one
- Simulated ^{13}C amount at X_{ERO} = 0 one order of magnitude smaller
- ELMs not included



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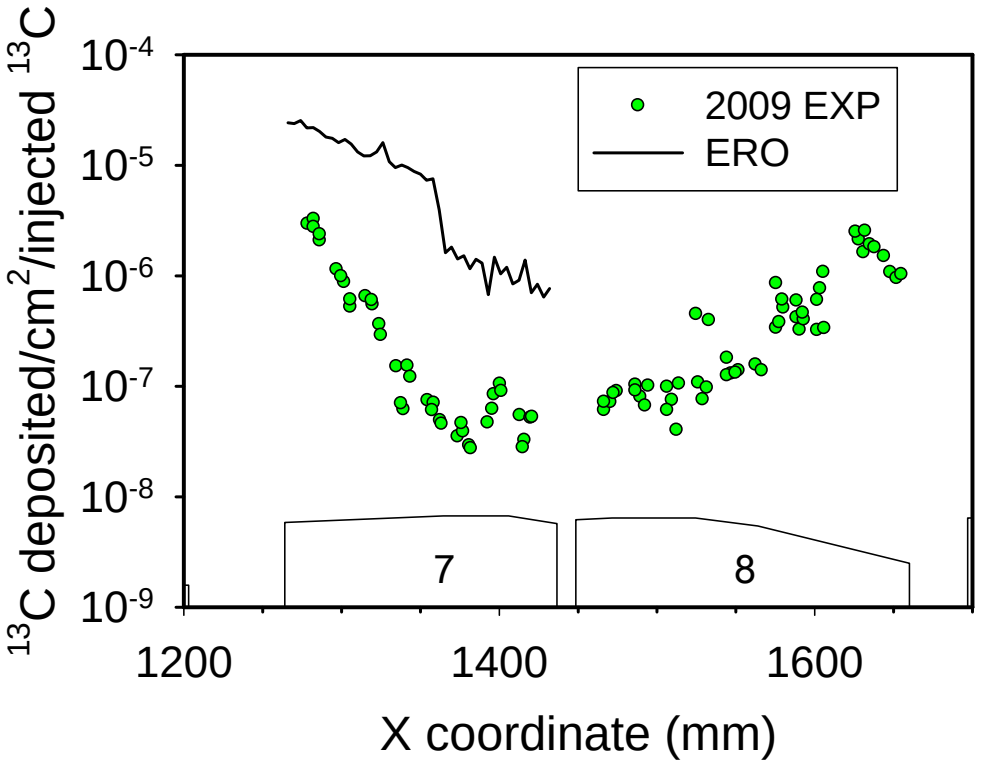
ERO: ^{13}C deposition on Tile 7



Results:

- Loss through simulation volume ~ 58% towards Tile 7
- Qualitative agreement between experimental results and ERO is good
- ERO reproduces peak at bottom of Tile 7 and decrease of ^{13}C along Tile 7

Summary

- Full poloidal set of divertor tiles analysed with RBS and SIMS
- ^{13}C deposited mainly near puffing location on Tile 6, and at outer divertor (bottom of Tile 7 and top of Tile 8)
- Main wall is important source for long-term deposition on inner divertor
- ~1/3 of puffed ^{13}C pumped instantly by cryopump in 2009
- ^{13}C deposition on C/W surfaces similar
- Completion of tile analysis (Tile 5, Tiles 6, main wall…)

- Simulation results (EDGE2D, DIVIMP, ERO) are preliminary
- Migration pathways identified with EDGE2D and ERO calculations
- Qualitative features of global and local ^{13}C migration reproduced by EDGE2D, DIVIMP and ERO codes but quantitative not
- More realistic grid and plasma background required, re-erosion/re-deposition phenomena have to be included, scanning of parameters (plasma parameters, diffusion coefficient…)

Thank you for your attention!

To be continued at next PSI in 2012…