2003 US-Japan Workshop on
High Heat Flux Components and Plasma Surface Interactions for Next Fusion Devices & High Power Density Devices and Designs
Manresa Hotel, Port Townsend, Washington, USA, July 28-31, 2003 7th inter.

Tritium retention in large tokamak

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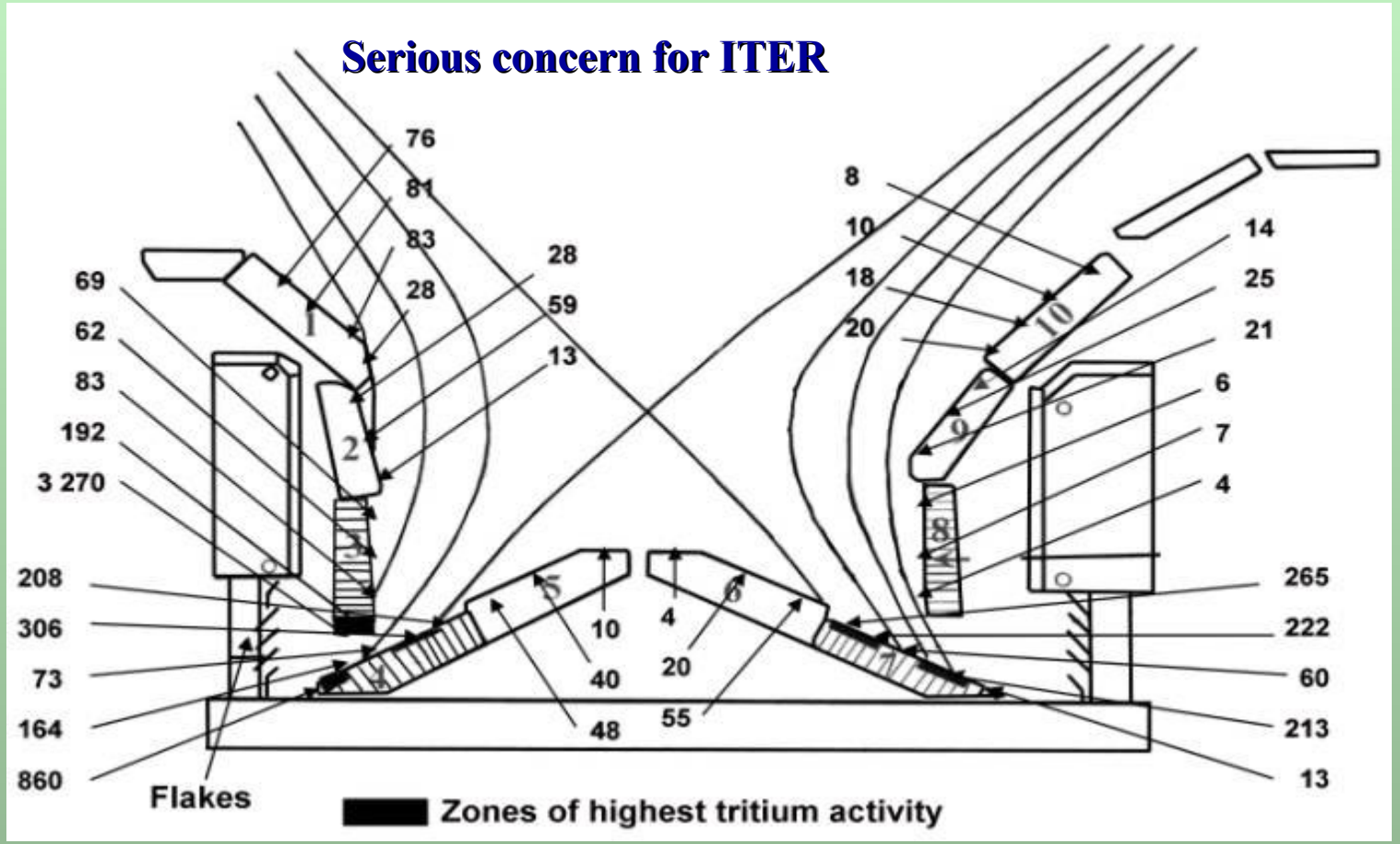
J. P. Coad; UKAEA Fusion, Culham, JET Joint Undertaking
N. Miya, JAERI, Naka

Contents

1. Introduction (Tritium inventory)

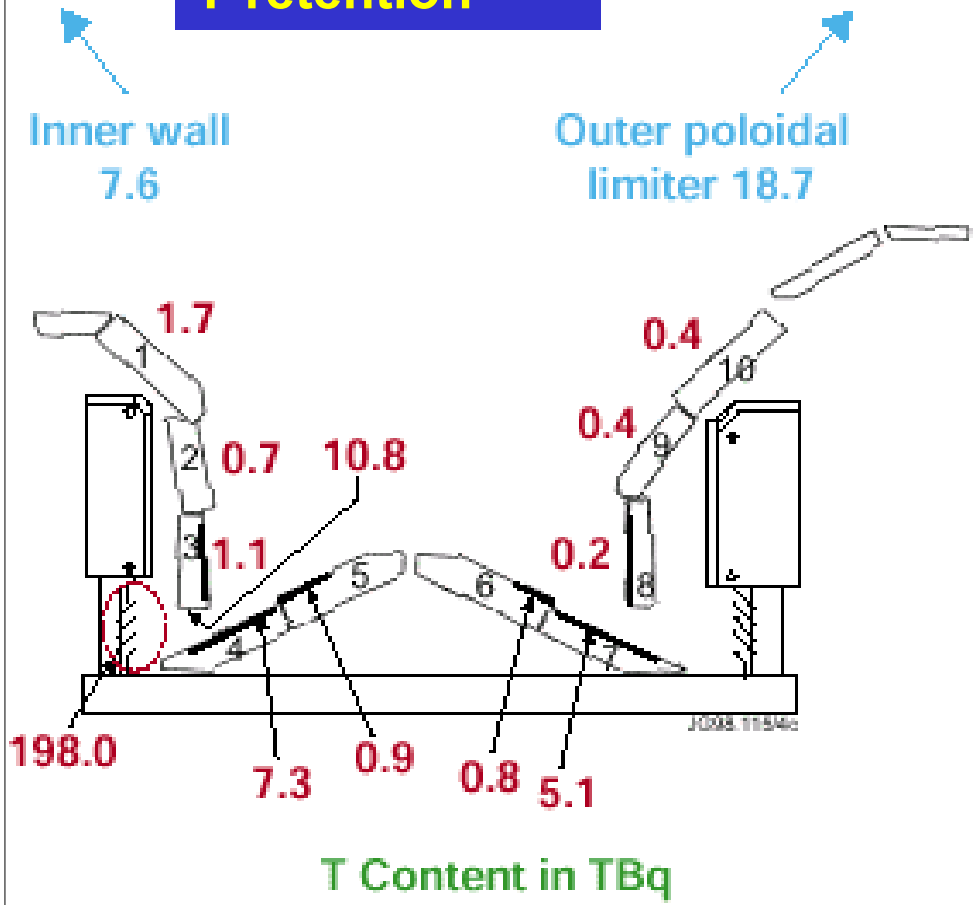
- **Tritium (β decay （～Max18kev）) $\tau_{1/2}$=12.3year）**



- Tritium codeposits with carbon and other impurities at low temperature region
- No detailed profile
- Necessity to develop removal technique

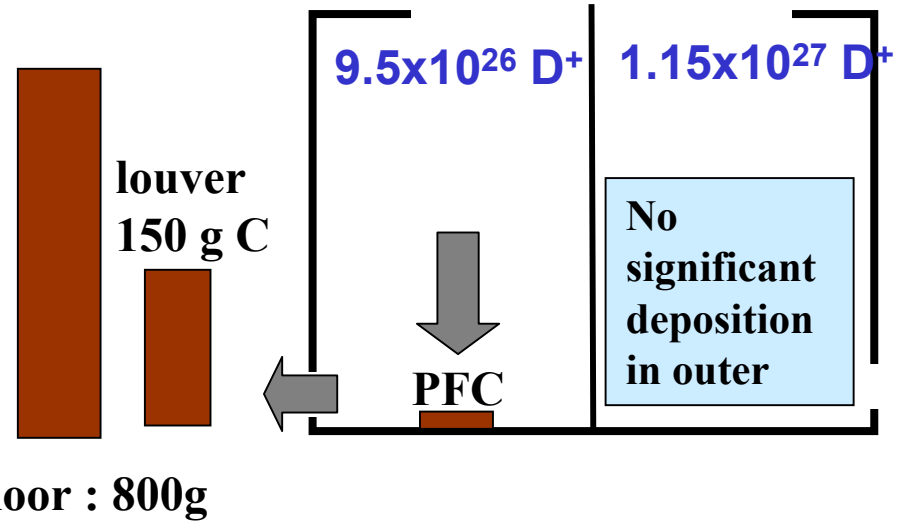
T-retention

Example:JET MKIIA



Carbon redeposition

≈ 18 h , 170 ITER shots



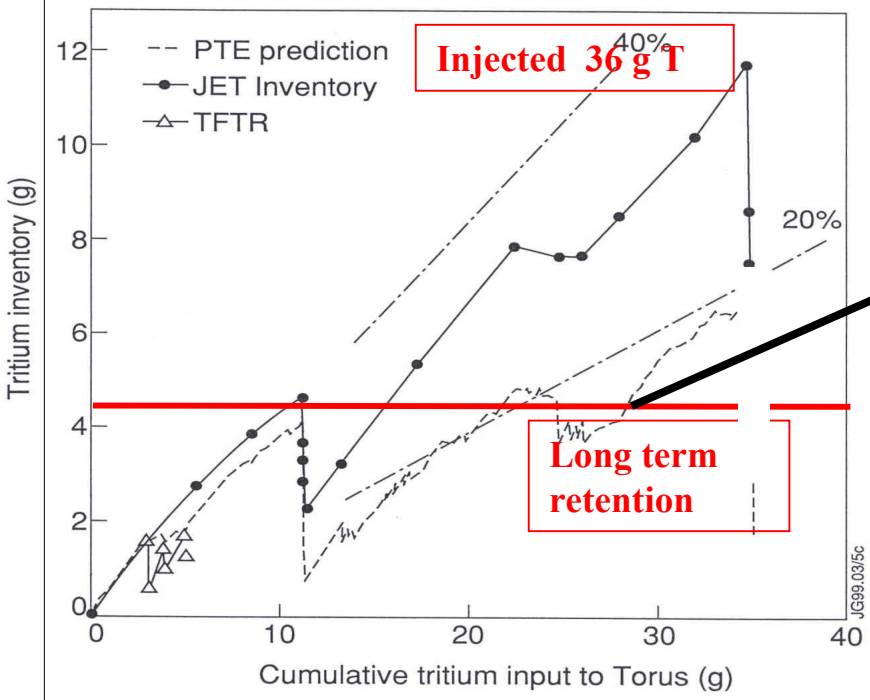
on floor : 800g

55 g C/ h ⇒ ≈ 4.8gT/h (T/C= 0.35)

JET MKIIA:C- deposition	55g C/h	≈ 4.8 gT/h
D-fueling	48g/h	8% of fuel

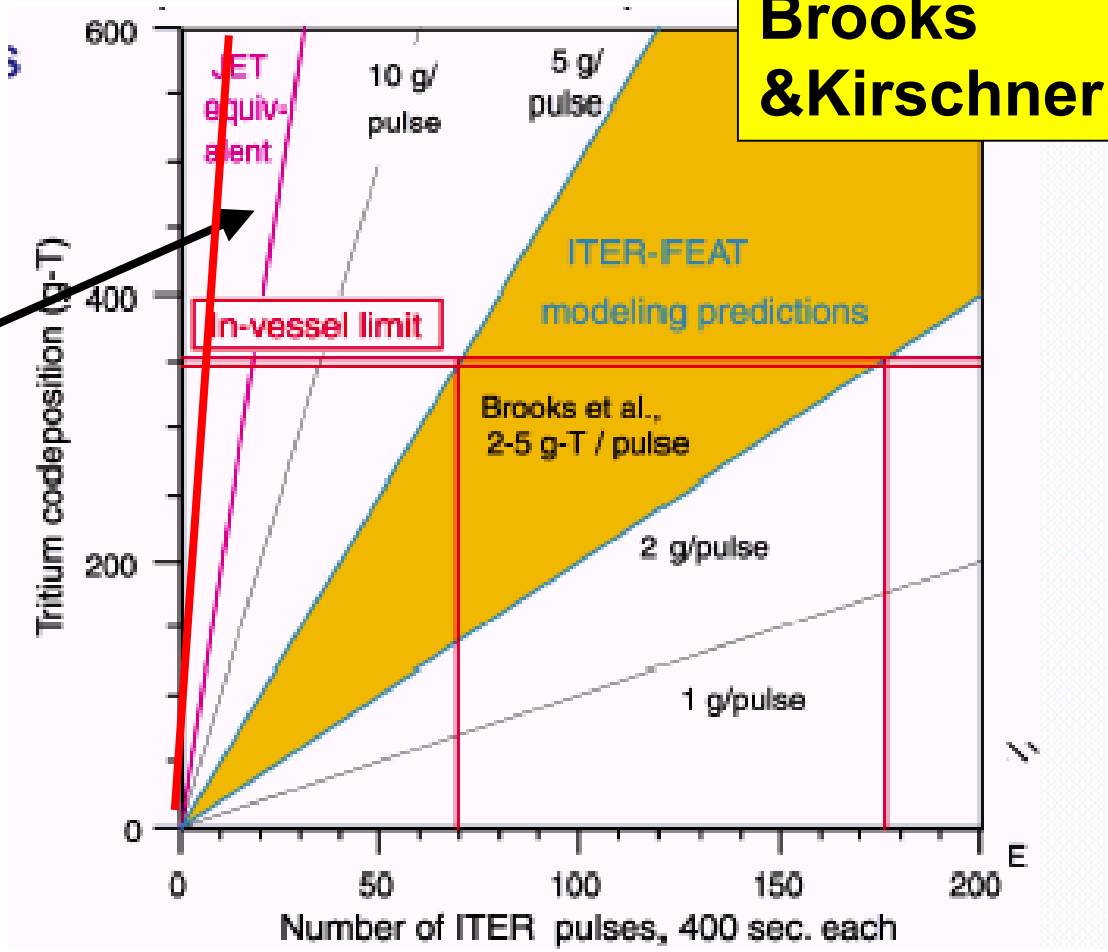
Long term tritium retention

JET



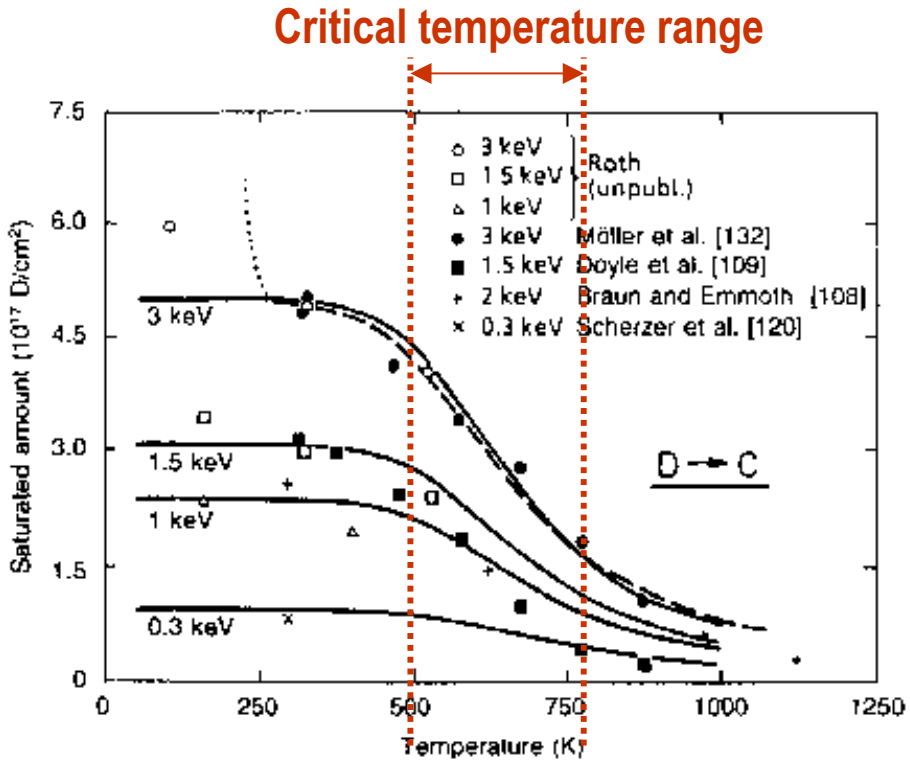
ITER

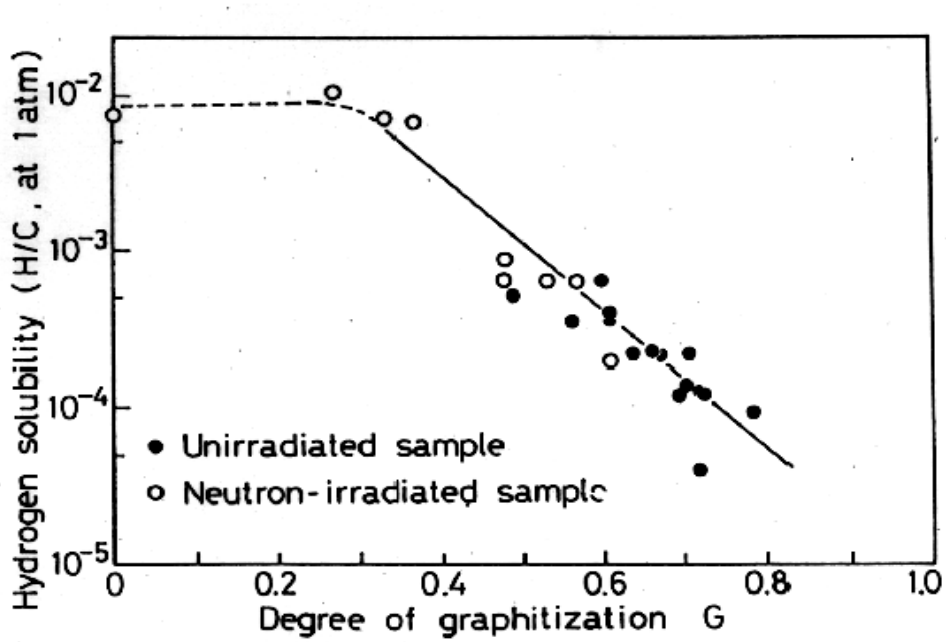
Modelling Brooks &Kirschner



Predictions are pessimistic but based on full carbon devices.
Predictions and modelling need significant improvements

Carbon-Hydrogen Chemistry





Temperature dependence of hydrogen saturation level in graphite

Hydrogen gas absorption depends Defects in graphite

◆ Four different kinds of tritium sources

1. High energy triton

Produced by D-T reaction in plasma (~1/300 of He)

2. Tritium fueled by gas, NBI and Pellet

Can be simulated by H and D

3. Residual gas (Thermalized at wall)

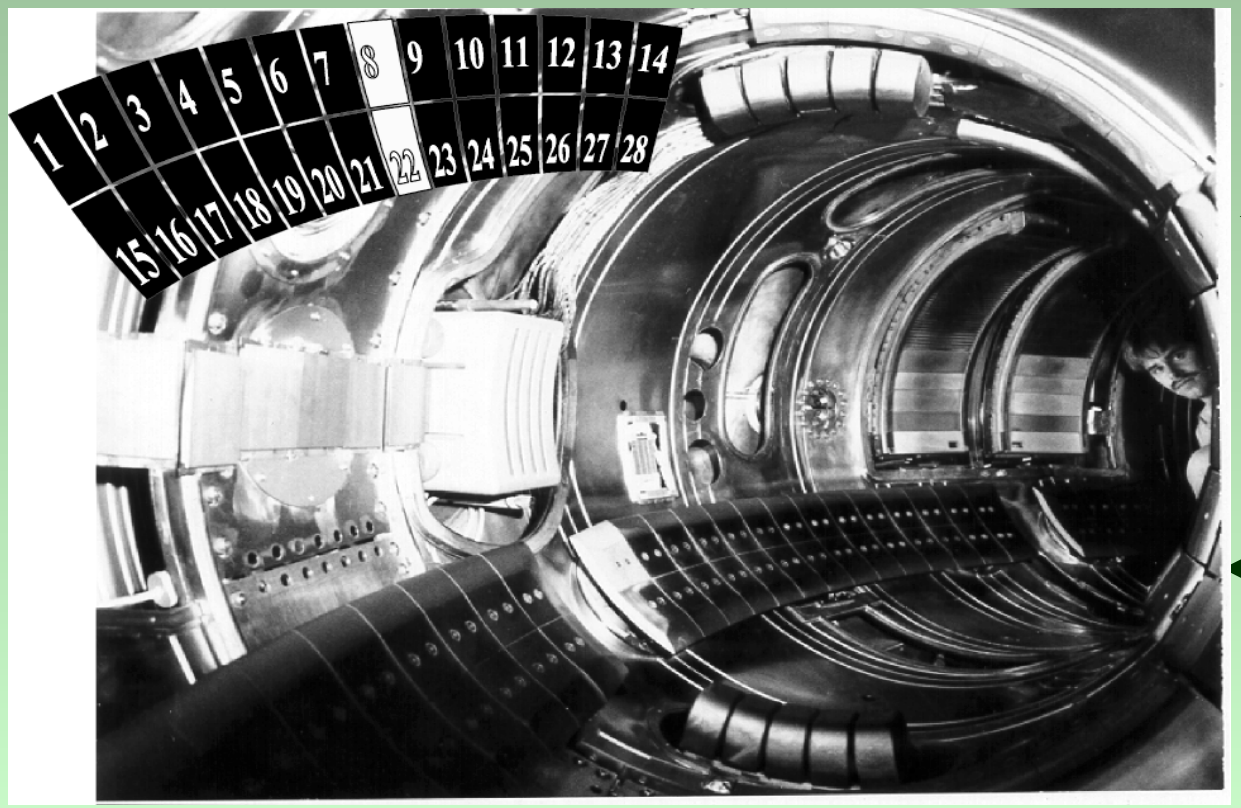
4. Triton produced by nuclear transmutation in materials

2-1. High energy triton in TEXTOR

Limiter (Graphite IG-110U Exposed to 10000 discharges)

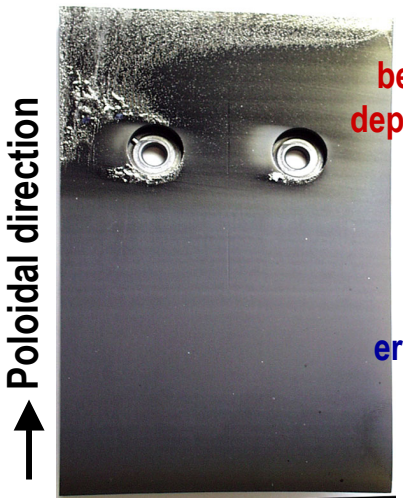
ALT-II toroidal belt limiter

TEXTOR

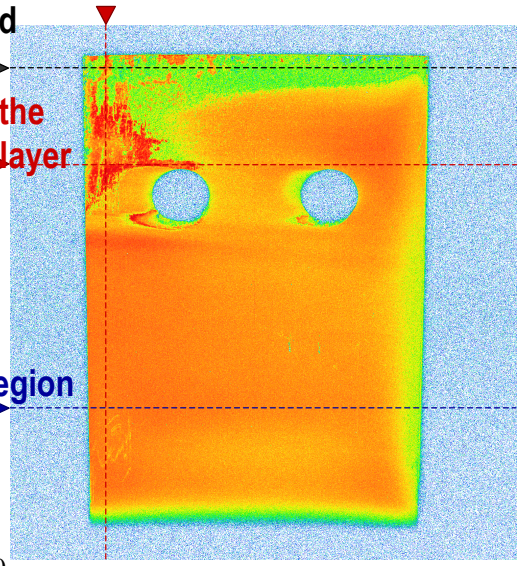


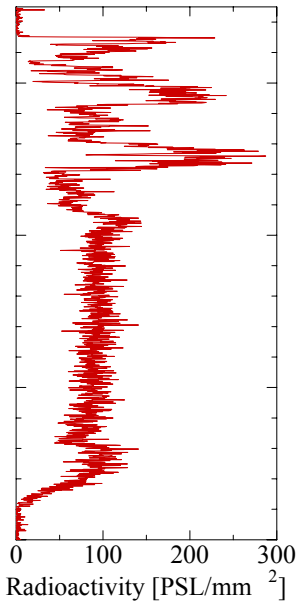
Bumper limiter

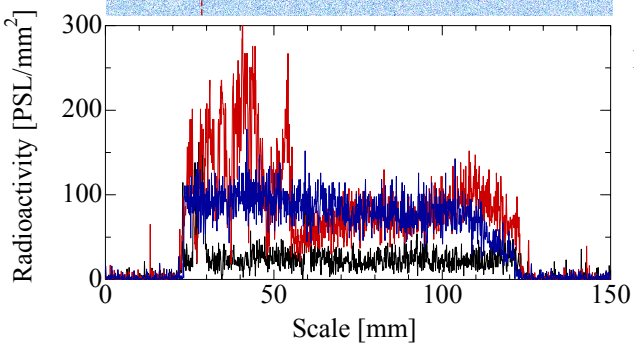
TEXTOR ALT-II belt limiter tile

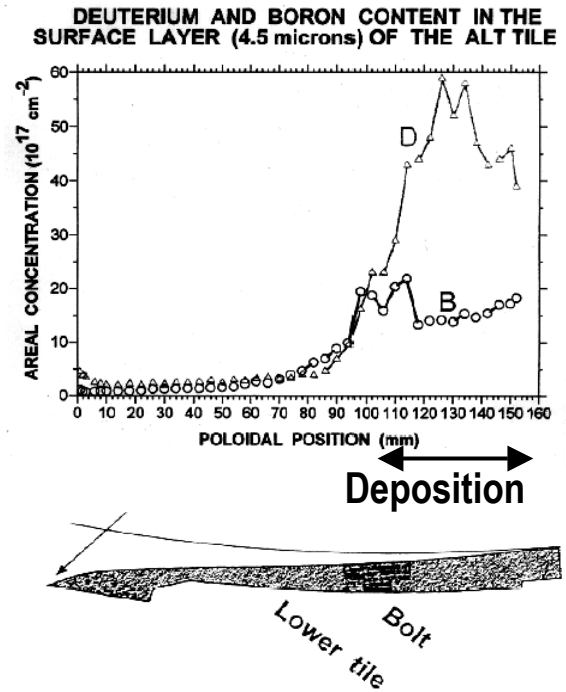


Photograph (No. 22)



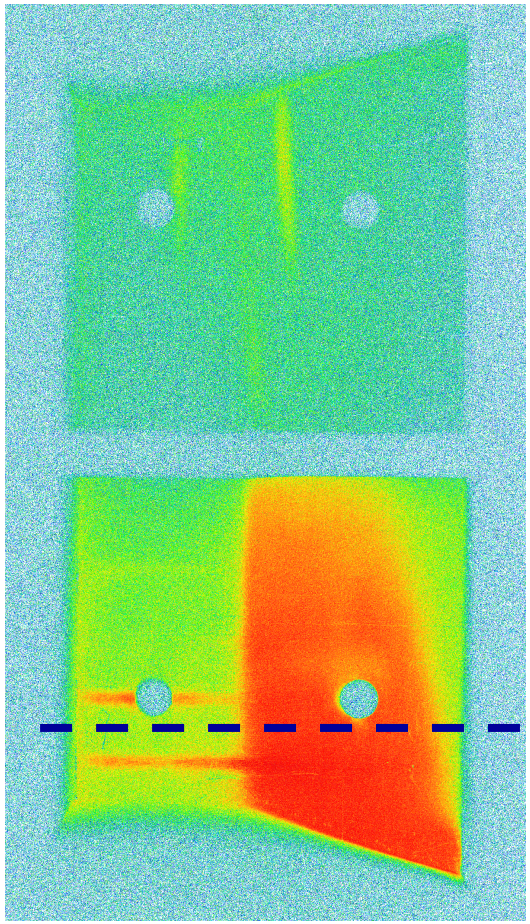


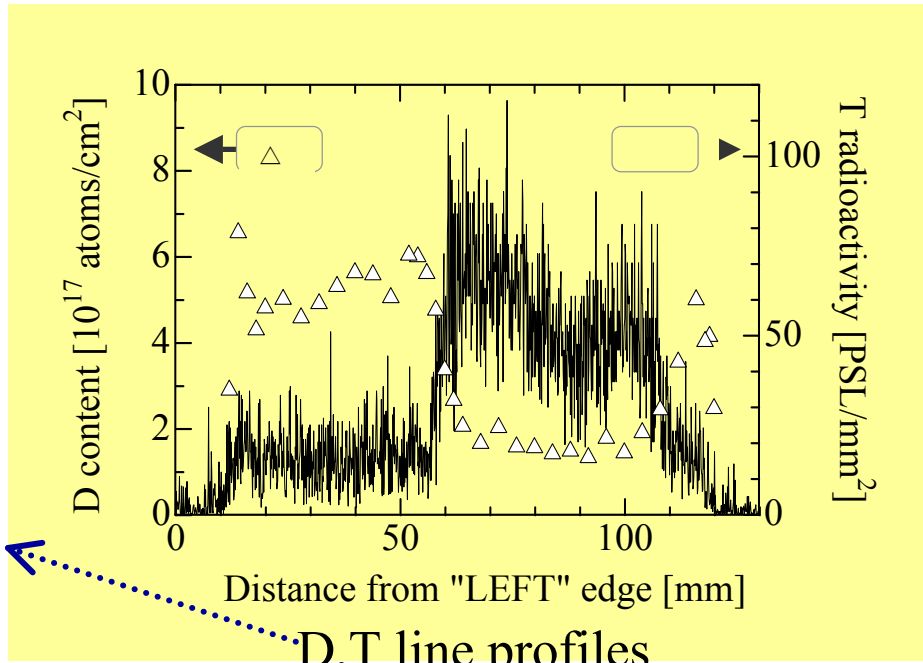




Two (top and bottom) bumper limiters out of 5 tiles

Top tile





D,T line profiles

Bottom tile

△ Deuterium : mostly in redeposited layer

— Tritium : mainly on ion-drift side

Asymmetries : Poloidally (top and bottom) and toroidally

2-2. High energy triton in ASDEX

Sample tile: ASDEX-U divertor IIb tiles

exposed in campaign 2001/2002.

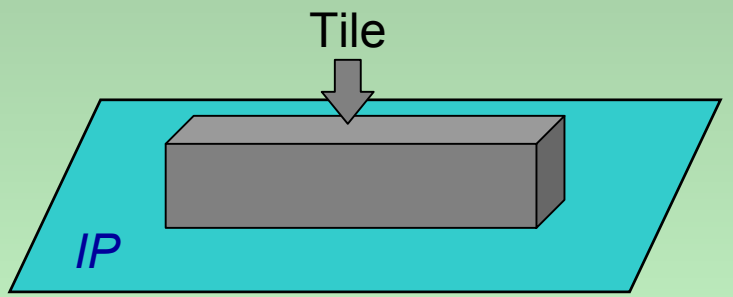
Total discharges ~ 6450s.

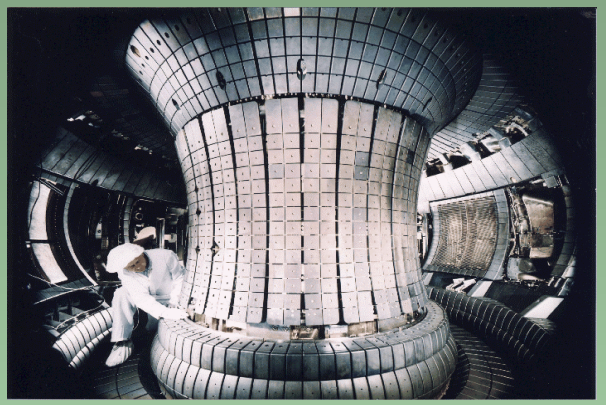
Imaging plate : BAS-TR2025 (Fuji Film Co. Ltd.)

Exposure time: about 50 hours (at IPP Garching)

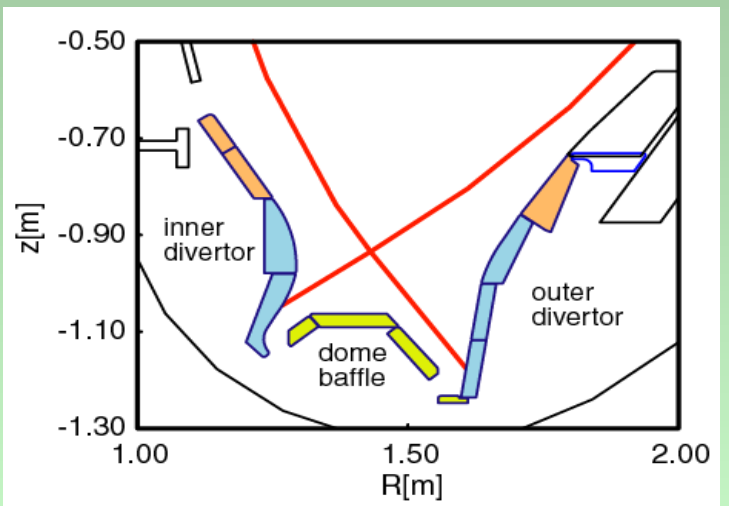
Image plate reader : FLA-3000/3000G (at FZK)

(image resolution 100μm*100μm/pixel)



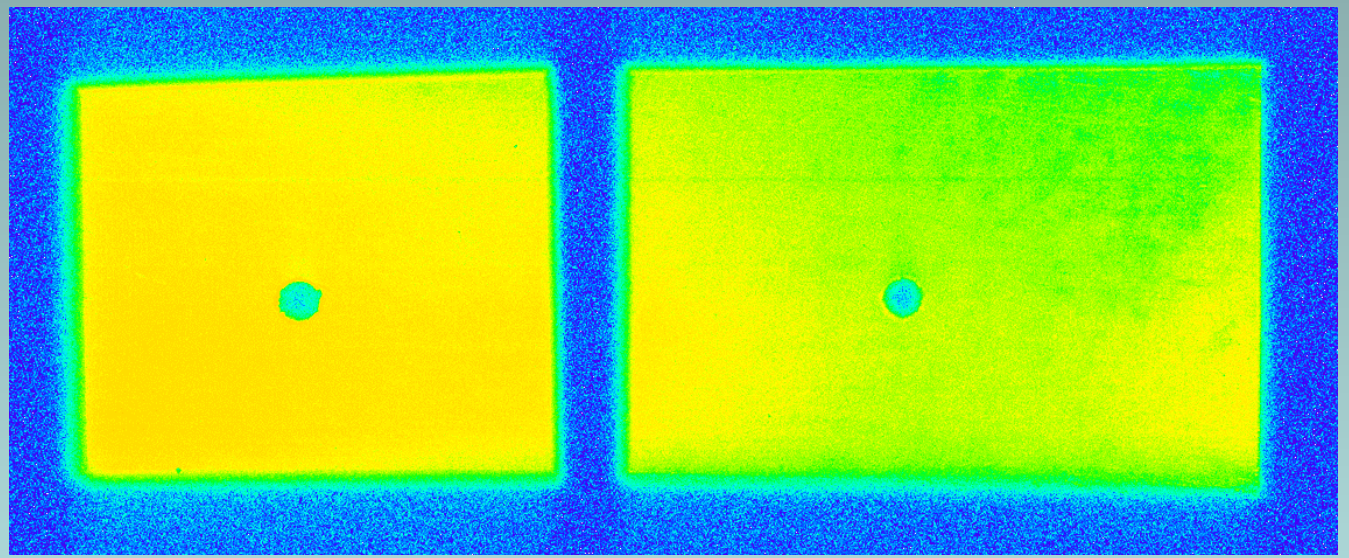


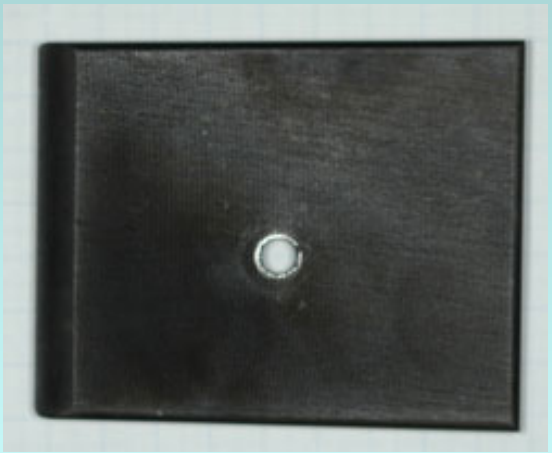
Axially Symmetric Divertor EXperiment -Upgrade

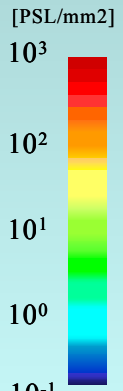


Divertor IIb

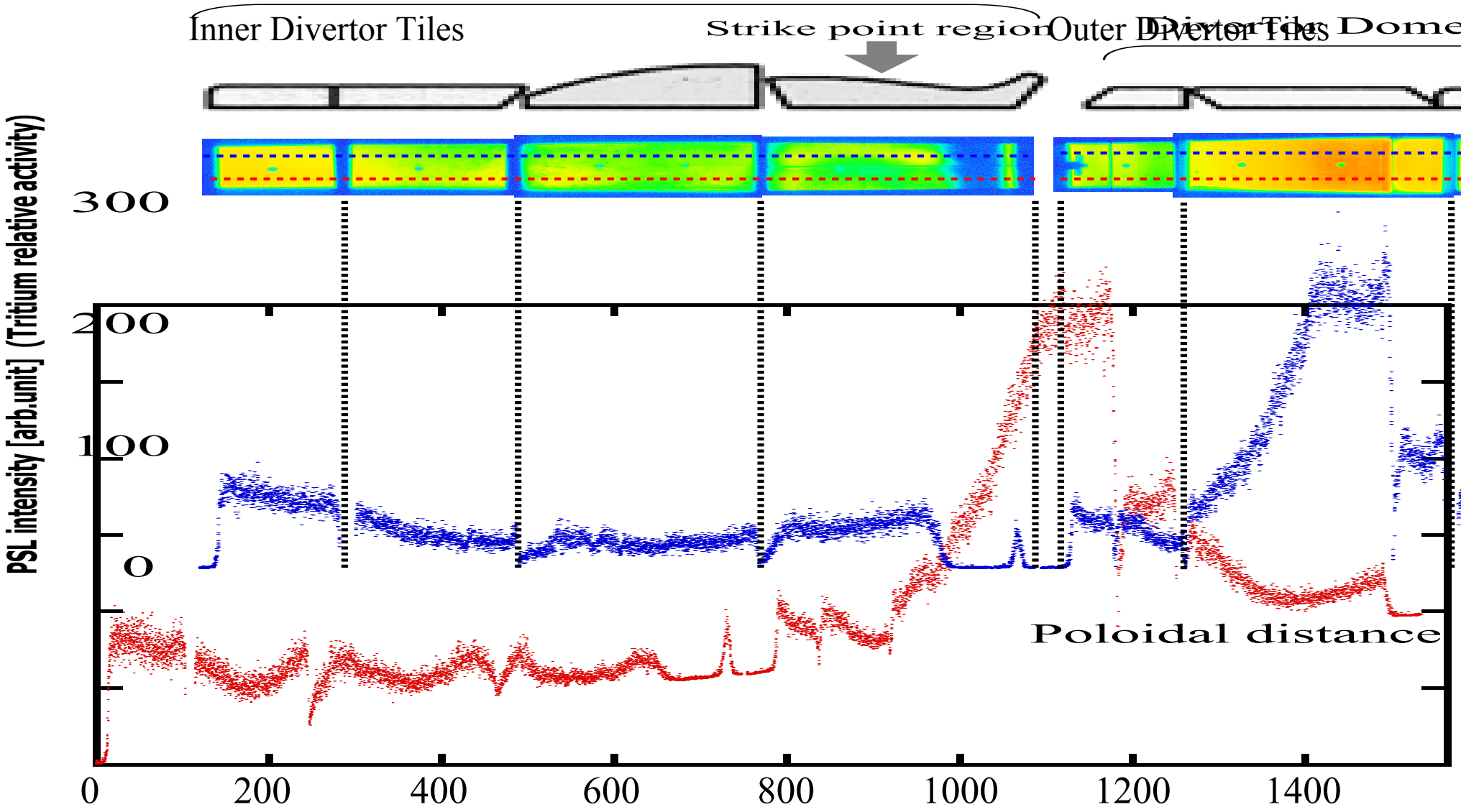
Inner Divertor tiles





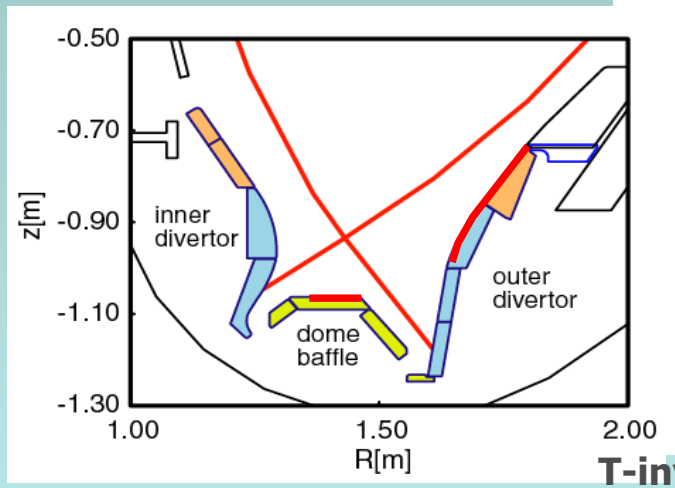


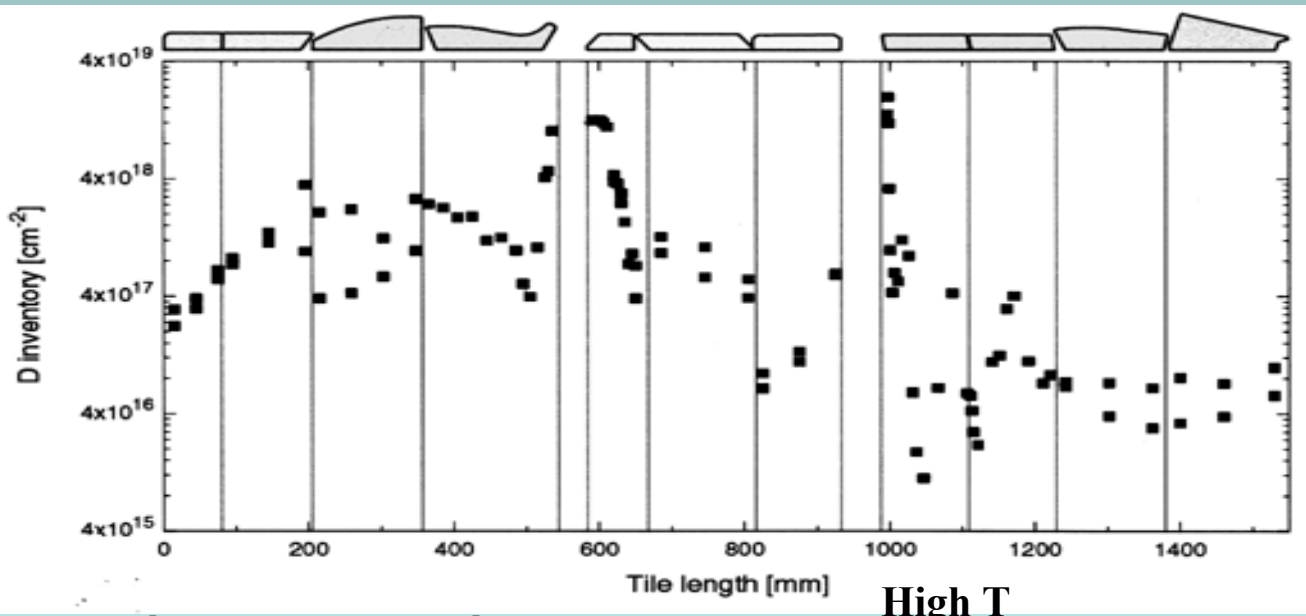
T - Distribution in Divertor Region



Comparison between T and D Distribution

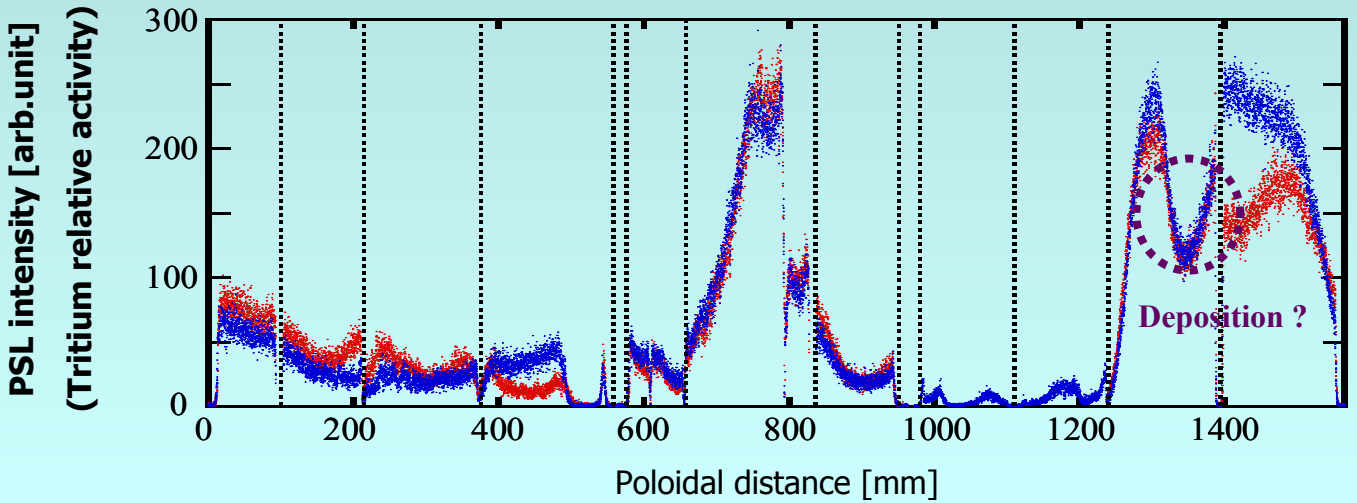
D-inventory (K.Krieger)





High T

T-inventory (IP measurement)



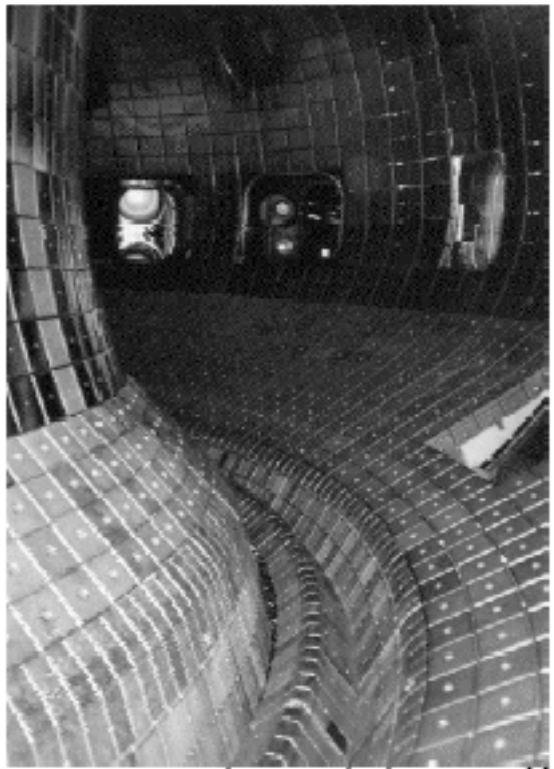
2-3. High energy triton in JT-60U

◆ Divertor tiles and first wall tiles used in JT-60U

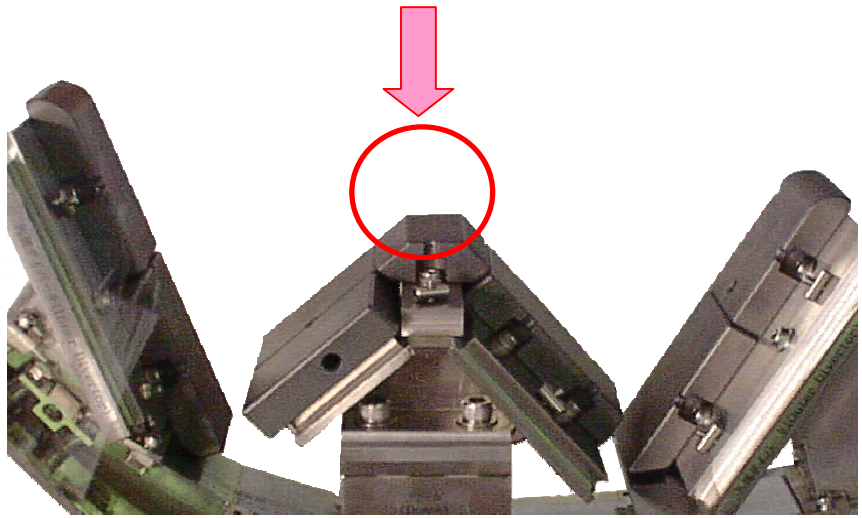
 # ^{3}T within the depth of ～3 μ can be detected

Exposed 1 year discharge （～3000shots/year)

CFC（CX-2002U）



Dome top tile



Poloidal direction

Pumping : inner side only

both sides

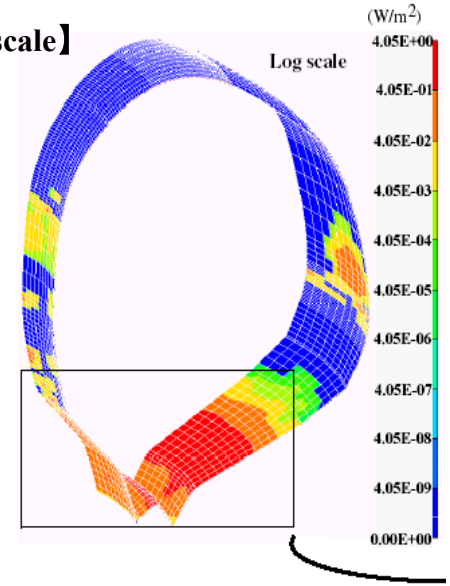
◆ Comparison with OFMC codes

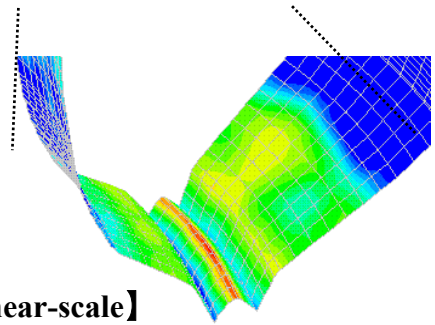
Higher tritium on bottom tiles

Higher tritium on outer wall

Very high tritium on midplane of outer wall

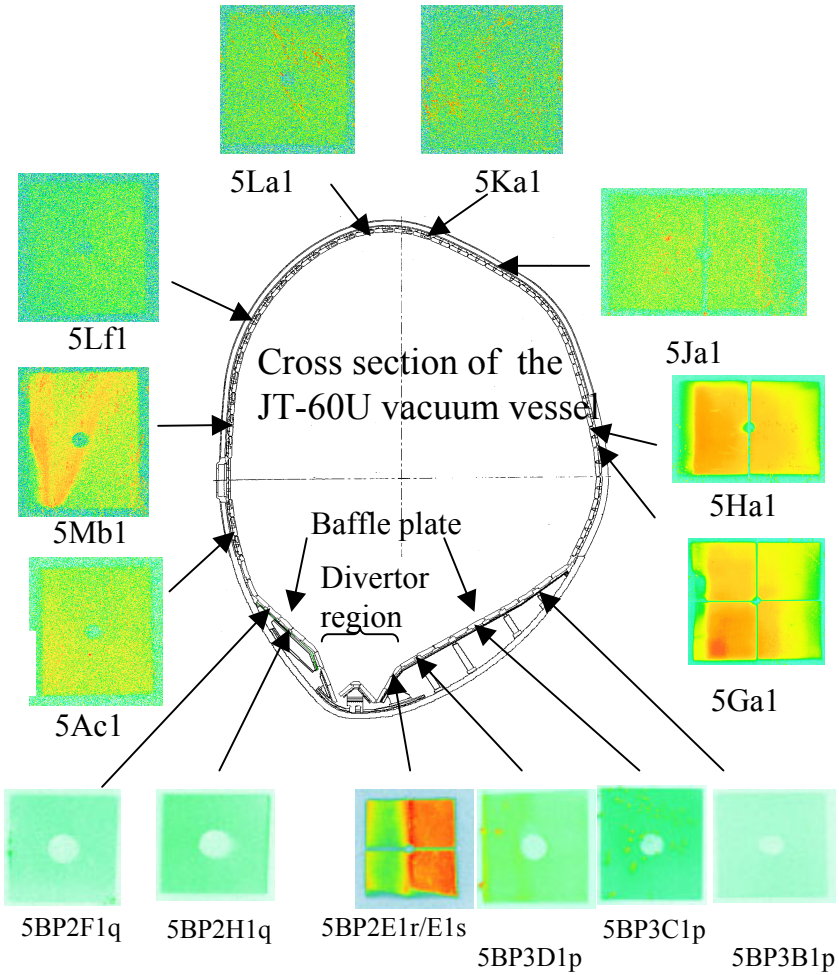
【Log-scale】

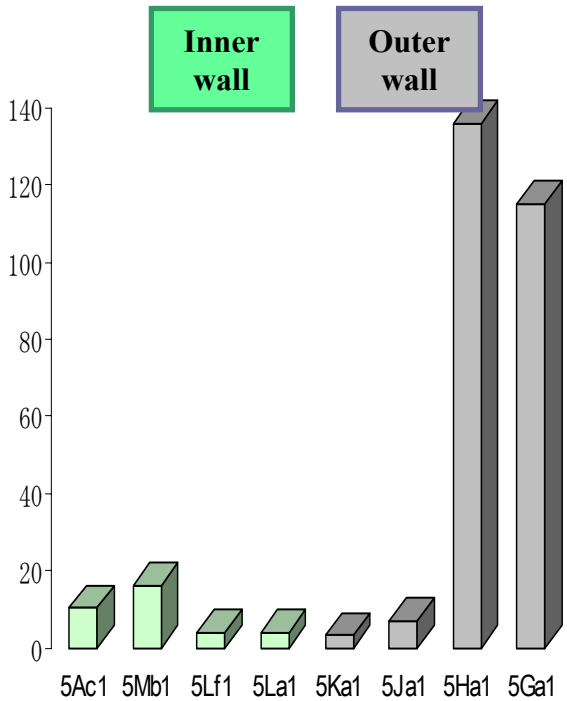


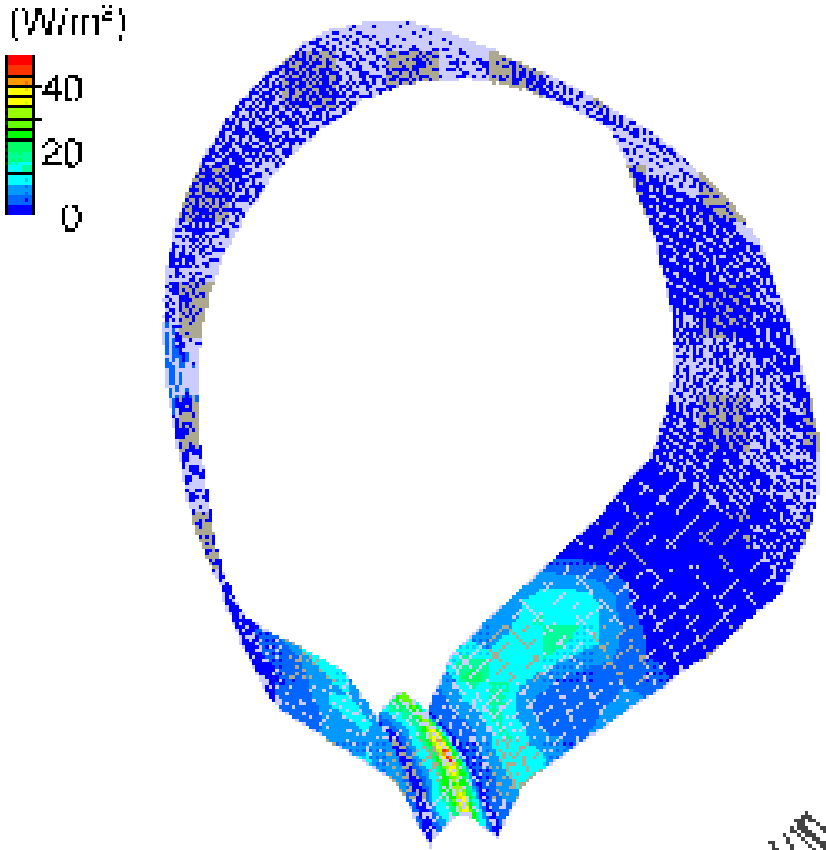


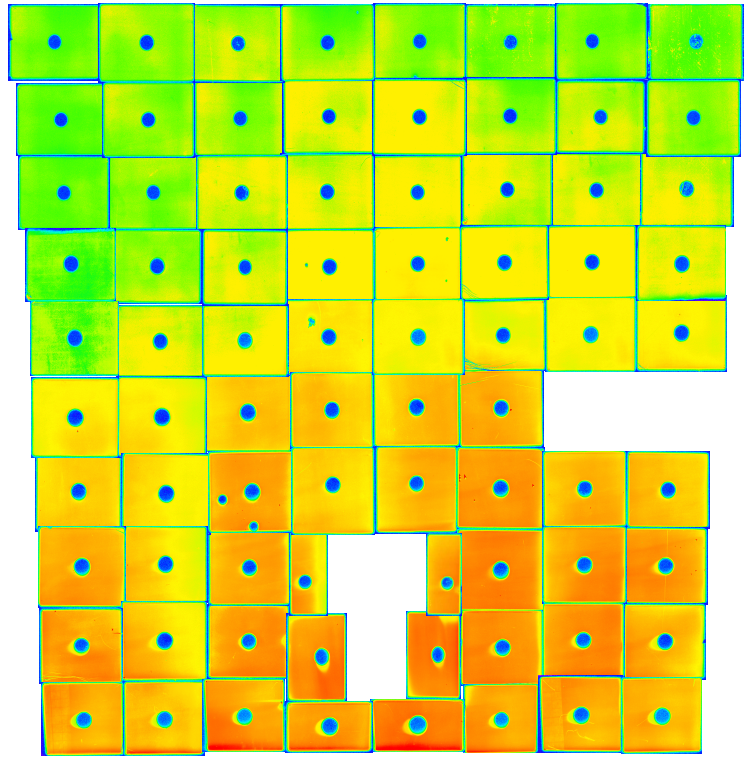
【Linear-scale】

Particle flux by OFMC

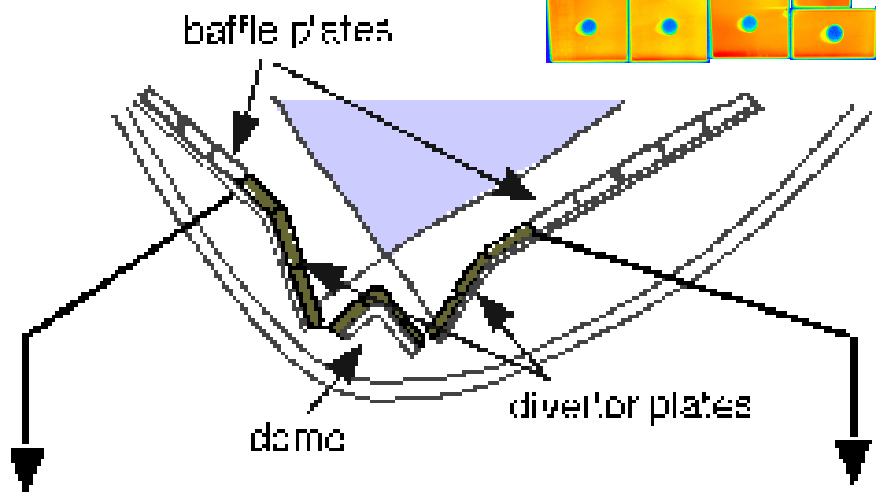


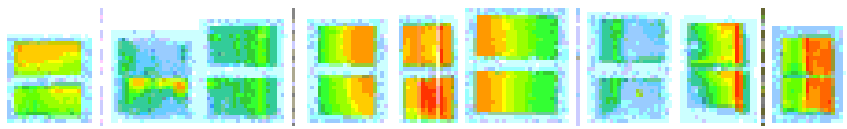






OFMC calculation

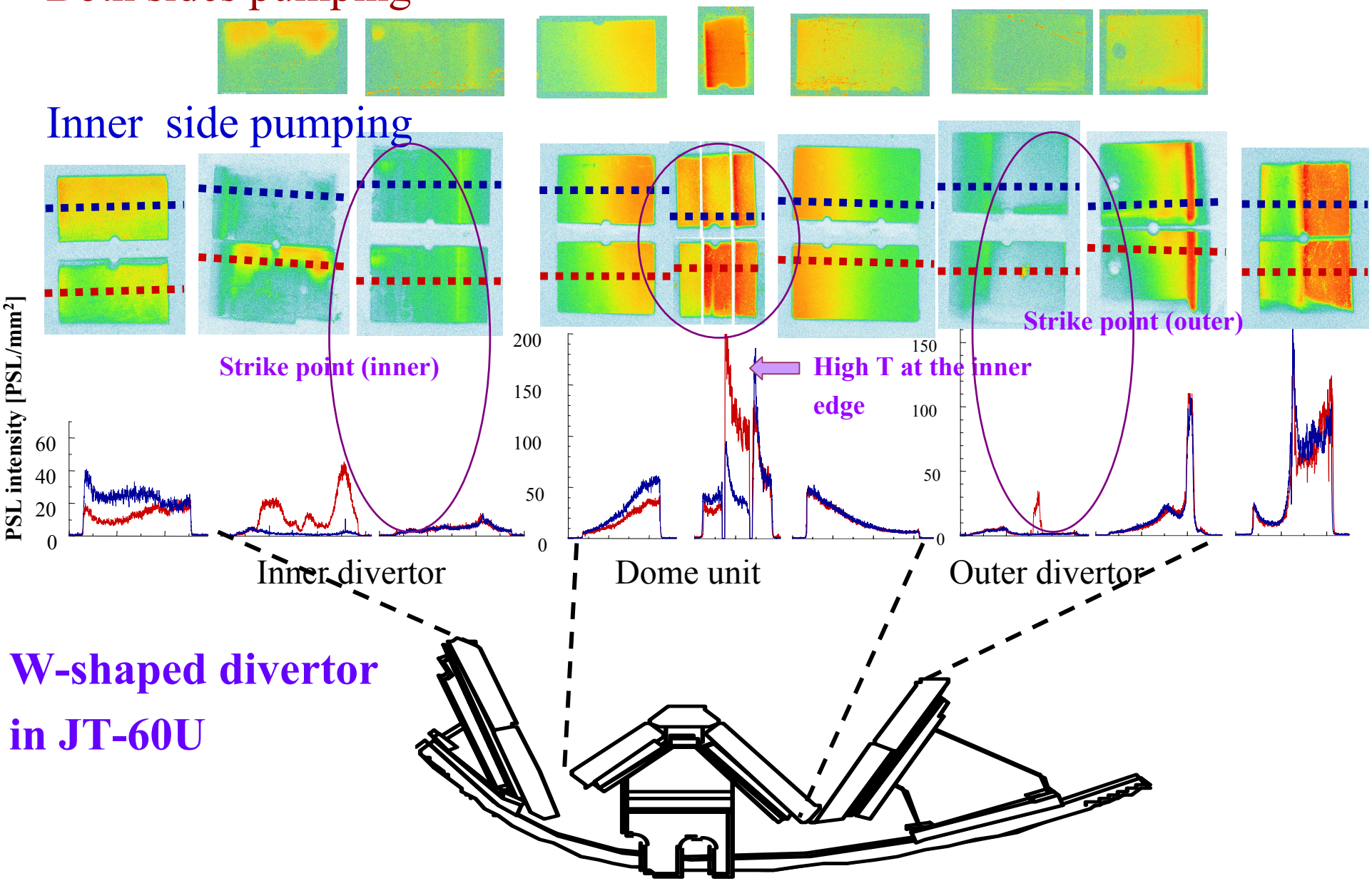




Both sides pumping

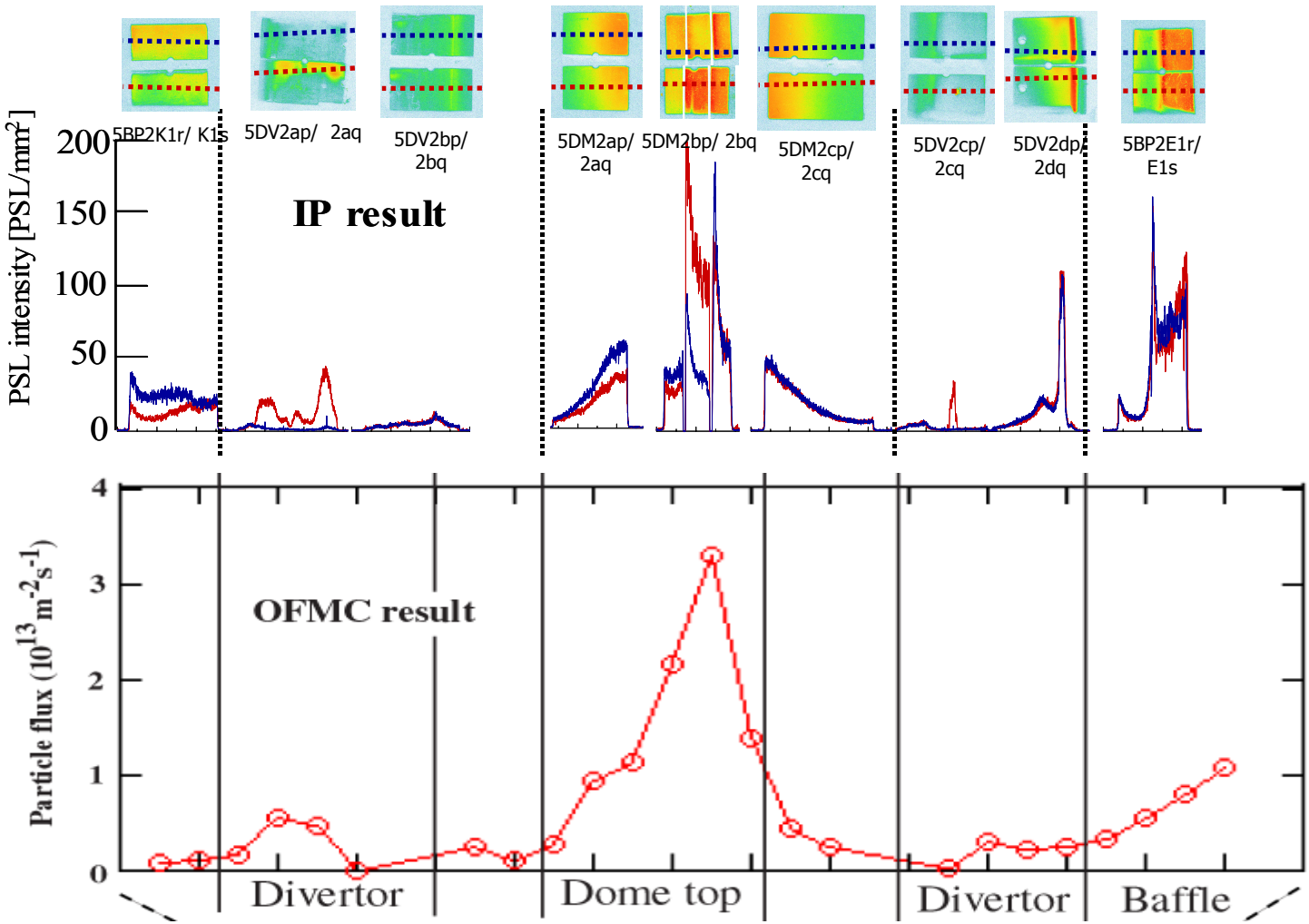
Poloidal direction

Inner side pumping



W-shaped divertor in JT-60U

Comparison of IP results and OFMC calculation

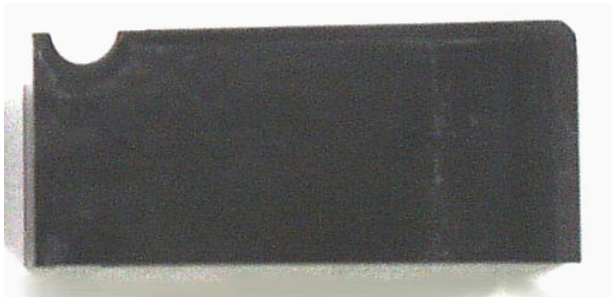


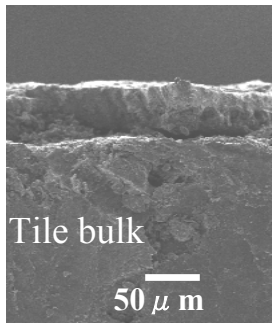
Tritium depth profile

Tritium beneath the deposited layer (Inner divertor tile)

 # Exfoliate some redeposited area on inner diverot tile 5DV2ap

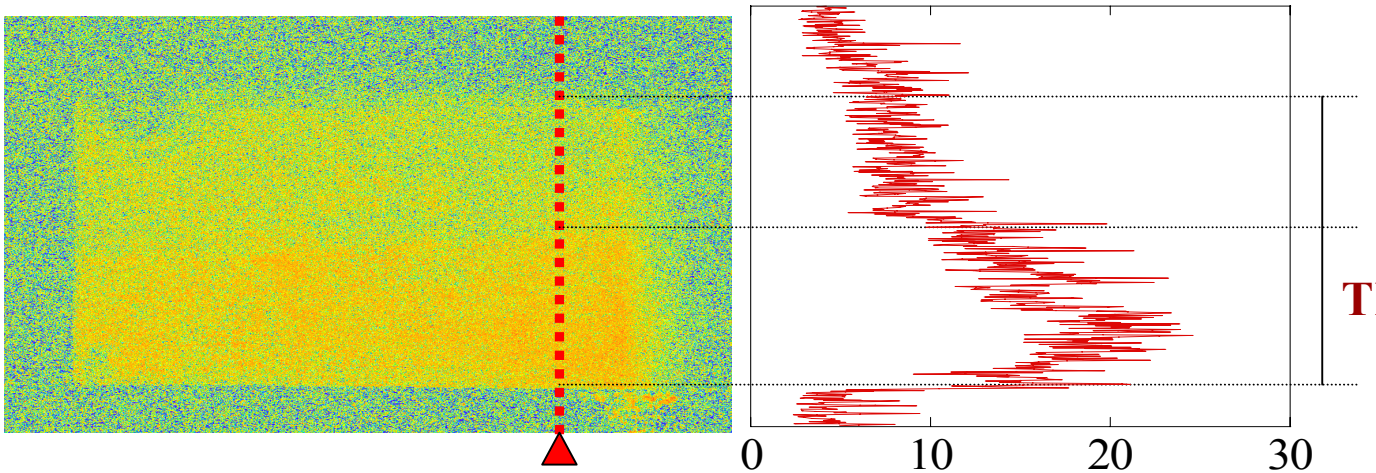
- Redeposited layer with thickness of ～20 μ m (Max 60 μ m)





Redeposited layer

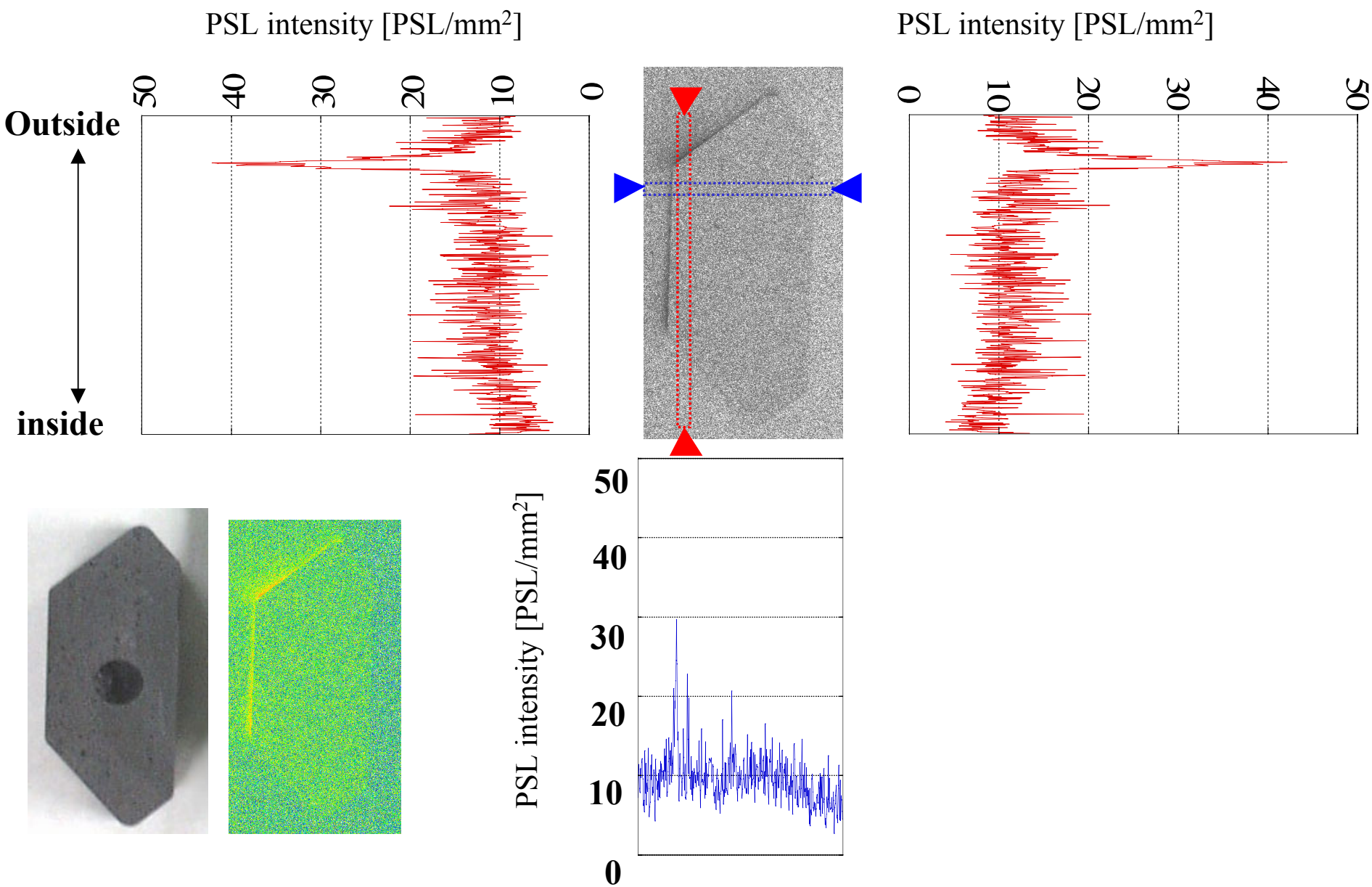
[SEM photograph]
Near the top surface
of the inner divertor tile



Surface of the redeposited layer

The exfoliated region

Tritium depth profile :
observed by cross-sectional view of dome top tile

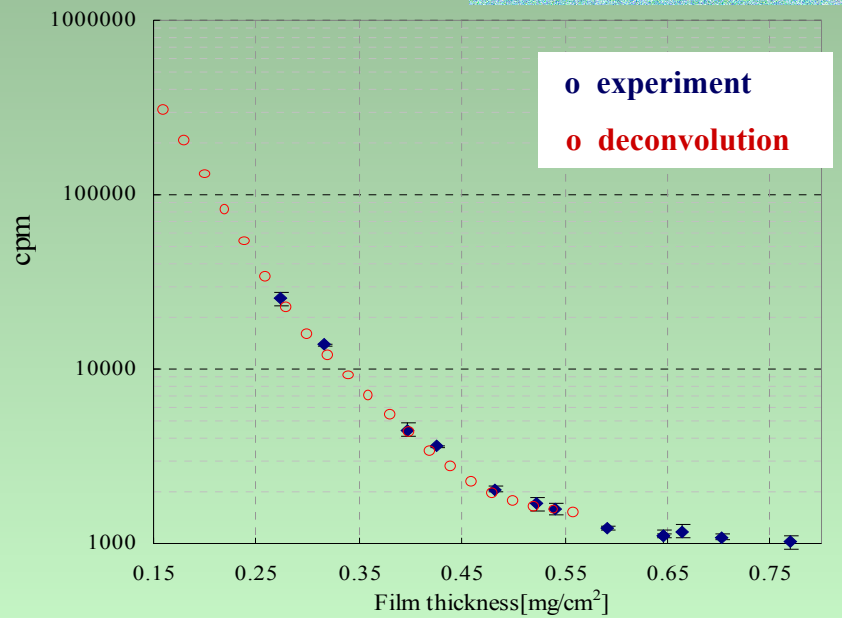


CIRSE
Nagoya University

Depth profile of tritium (Implanted more than 1μm in depth)

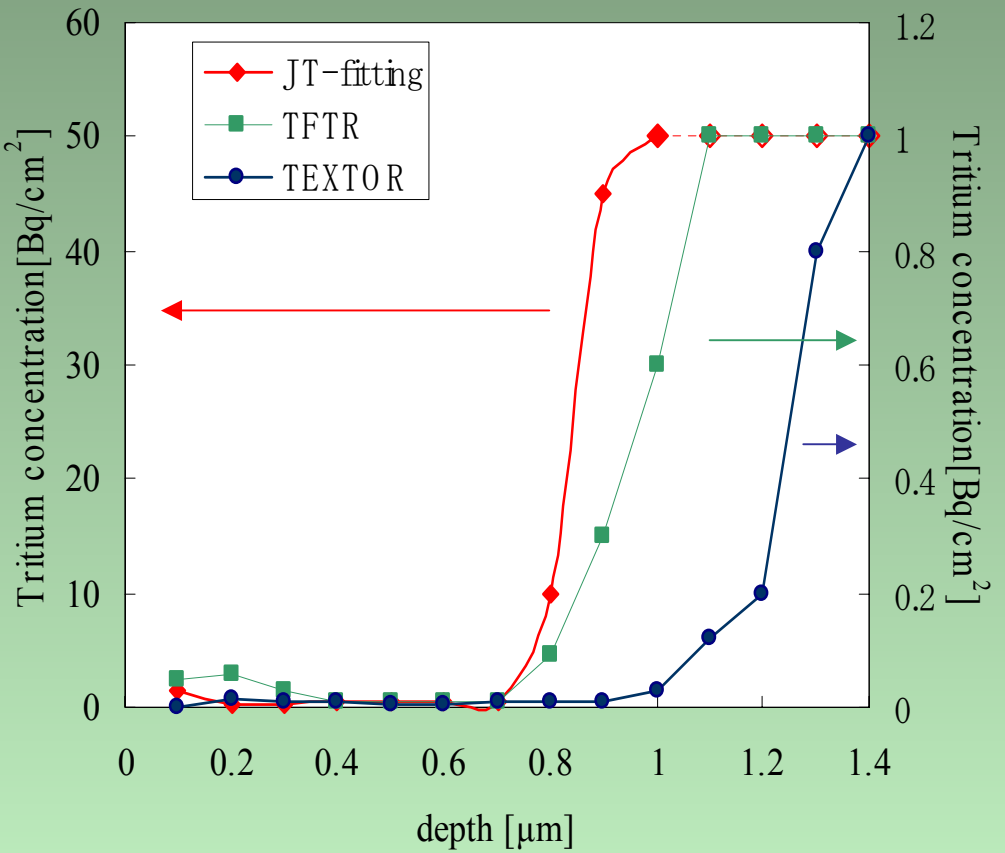
Inserted film thickness / micrometers

1.2	3.6	6.0	5.2
2.0	4.0	6.0	5.6
2.4	4.4	6.0	8.0
3.2	4.8	6.0	10



Deconvolution of depth profile

convolution



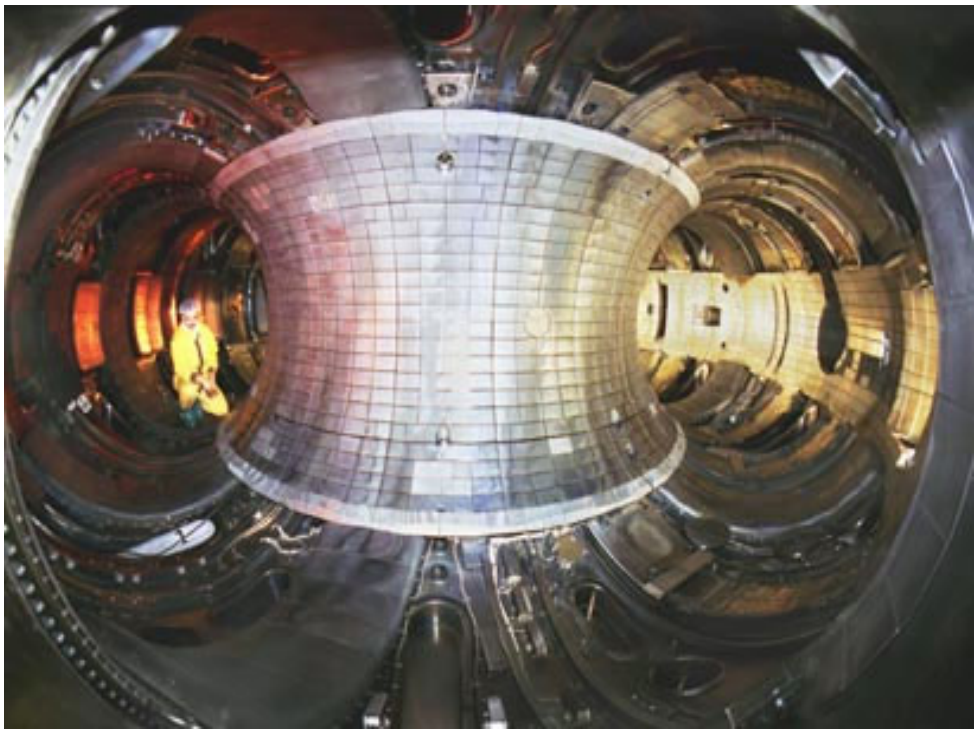
Comparison of tritium depth profile of D-D tiles

3-1. D-T operation in TFTR

. Bumper limiter machine – no divertor.

. Walls are deposition areas (not erosion)

. Walls heated only by plasma (limiter hotspots reached ≈ 800 C).



- 1993-1997: Tritium introduced ~5.2g
- To remove tritium: GDC, Air ventilation etc.
- Long-term tritium retention

  ··16% of totally introduced

Different edge conditions to JET	
TFTR SOL	JET divertor
(TRANSP/DEGAS)	(EDGE2D)
Ne 10^{18} ~ 10^{19} m^{-3}	~10^{20} m^{-3}
Te 200 - 600eV	<30 eV

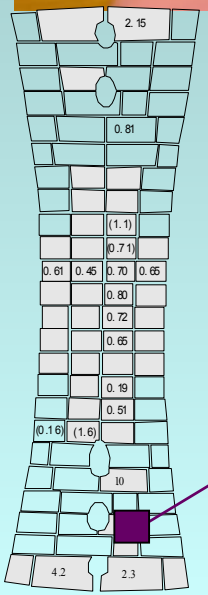
KC3 CFC tile in erosion area

Characteristic Pattern of 3D C-C tile

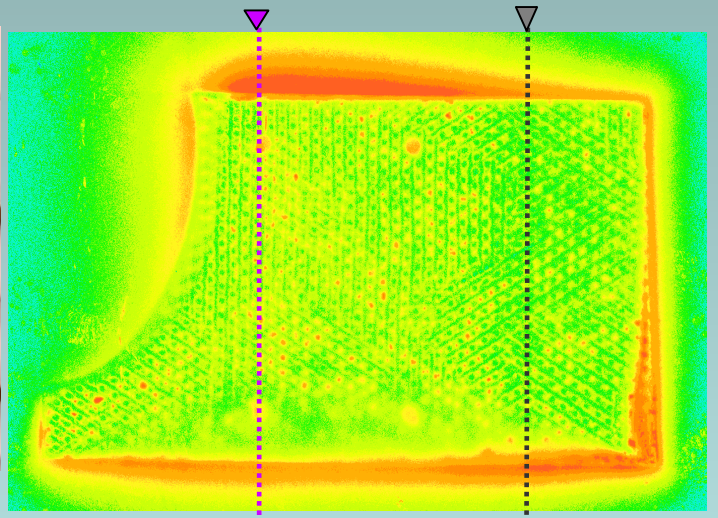
Very high tritium retention in codeposits in all sides

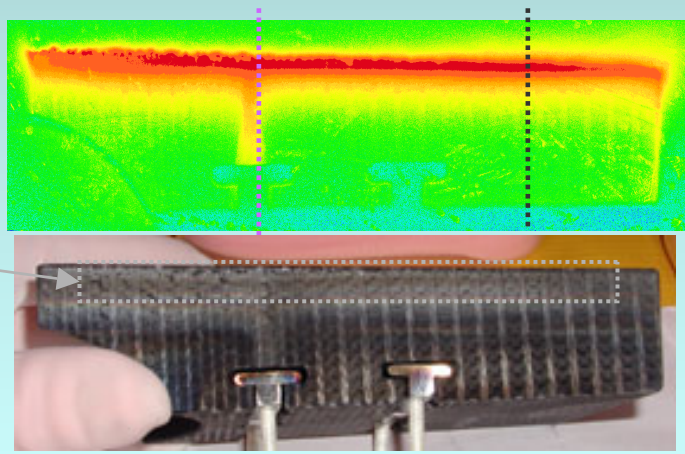
Poroidal direction

Toroidal direction

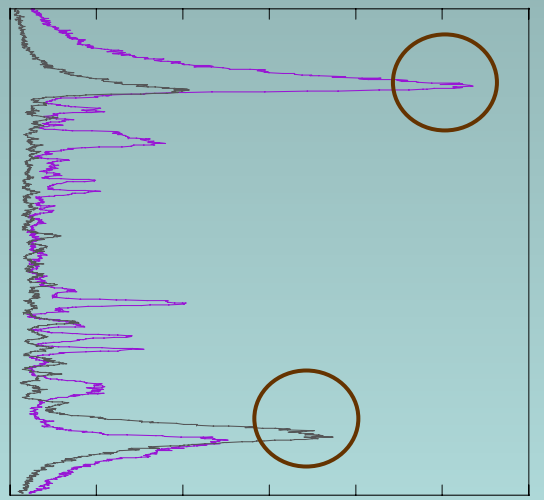


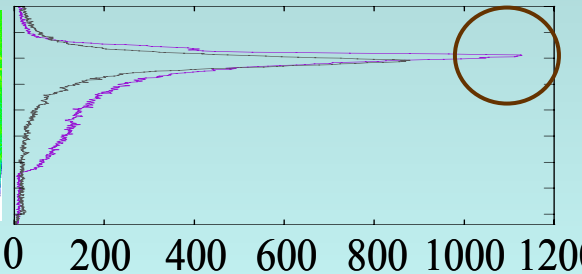
KC3





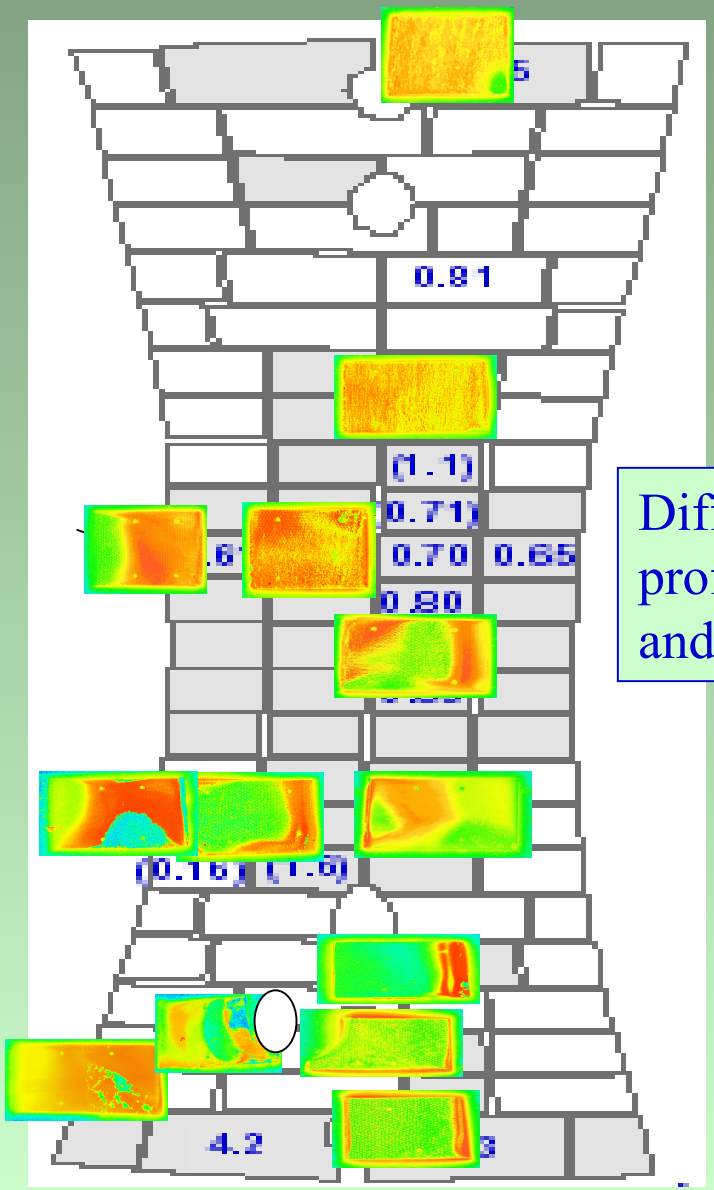
flake





Tritium relative activity
[PSL/mm^2 (a.u.)]

Tile selection



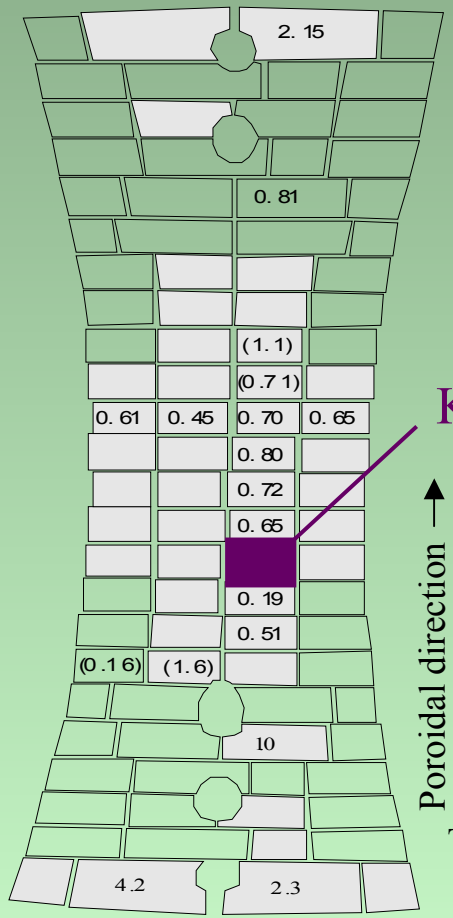
Different deposition profiles between upper and lower area

Grey : CFC

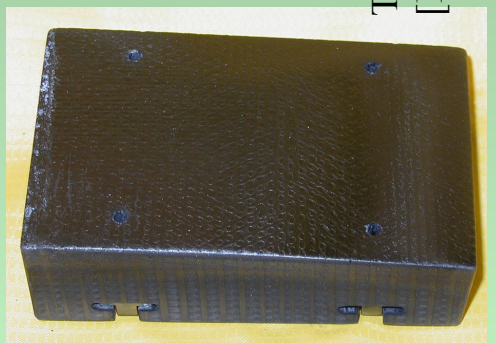
White : Graphite

KC10 CFC in erosion and deposition area

- Erosion & deposition : due to difference of plasma flux
- High tritium concentration at the deposition area

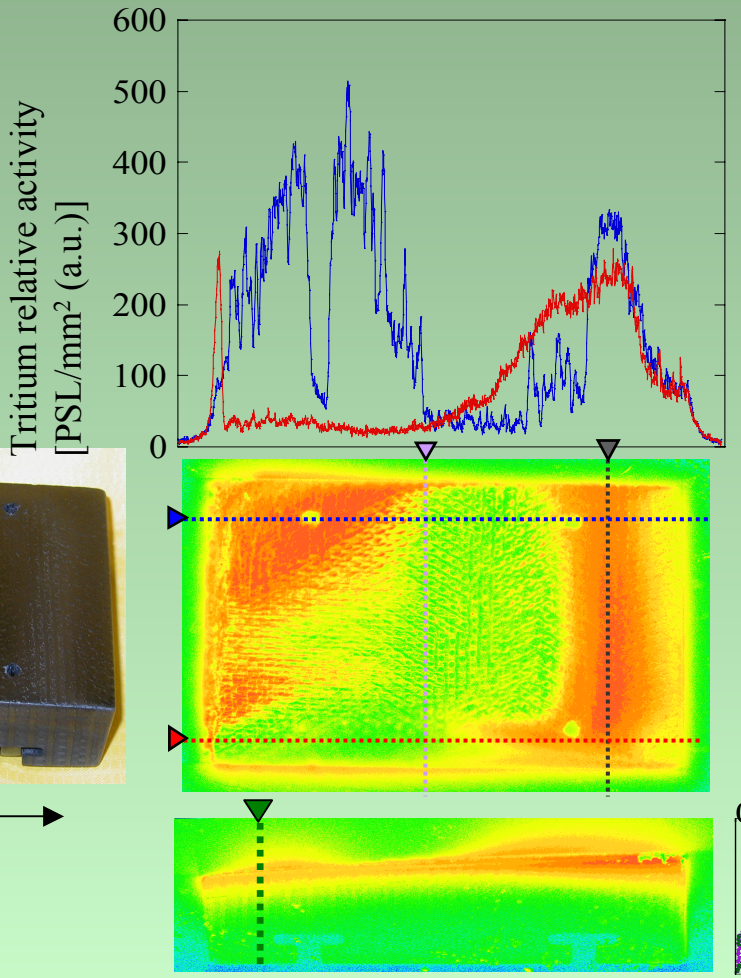


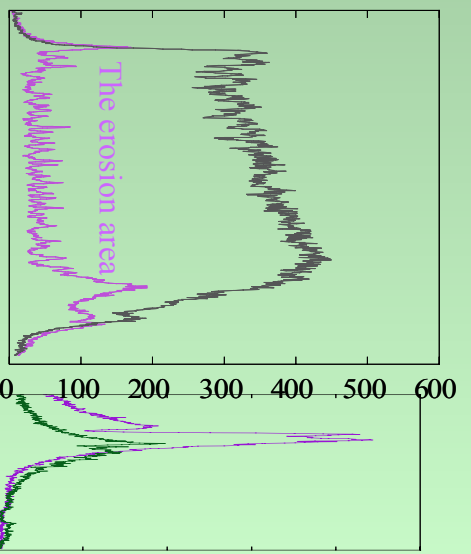
KC10



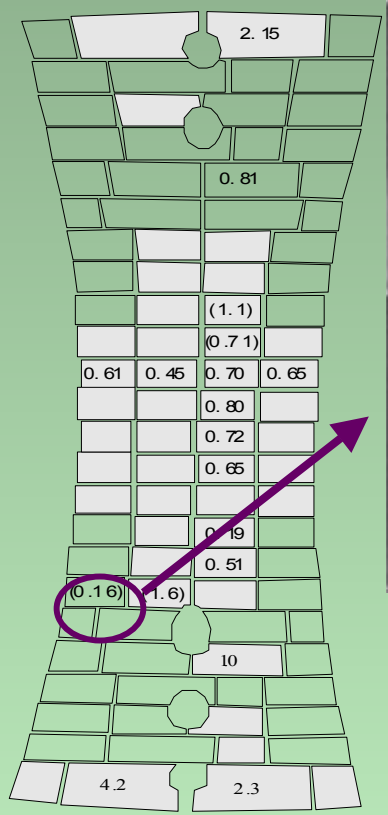
Poroidal direction

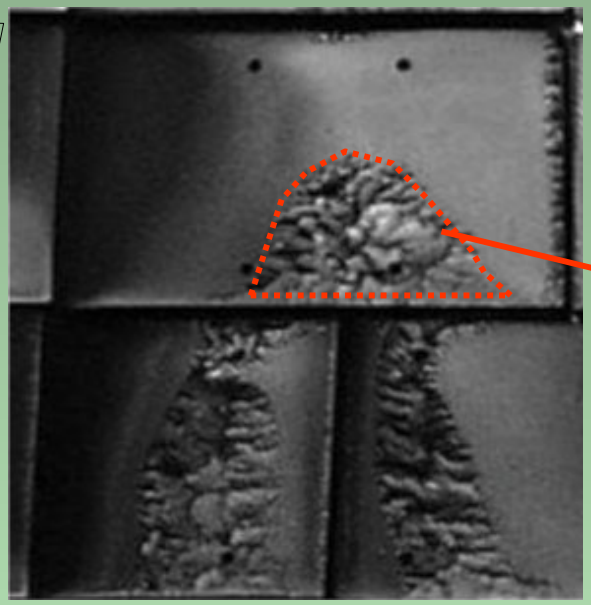
Toroidal direction

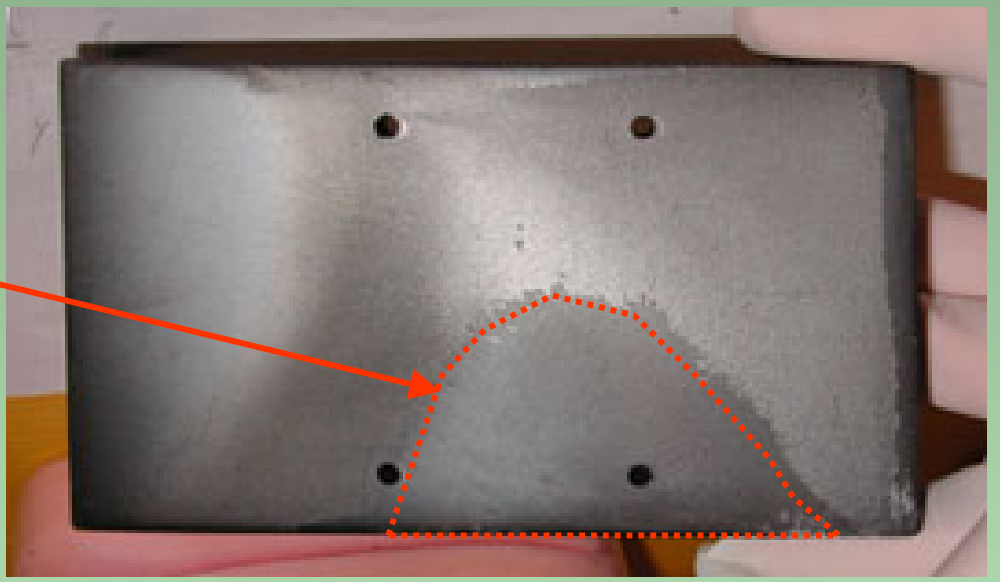


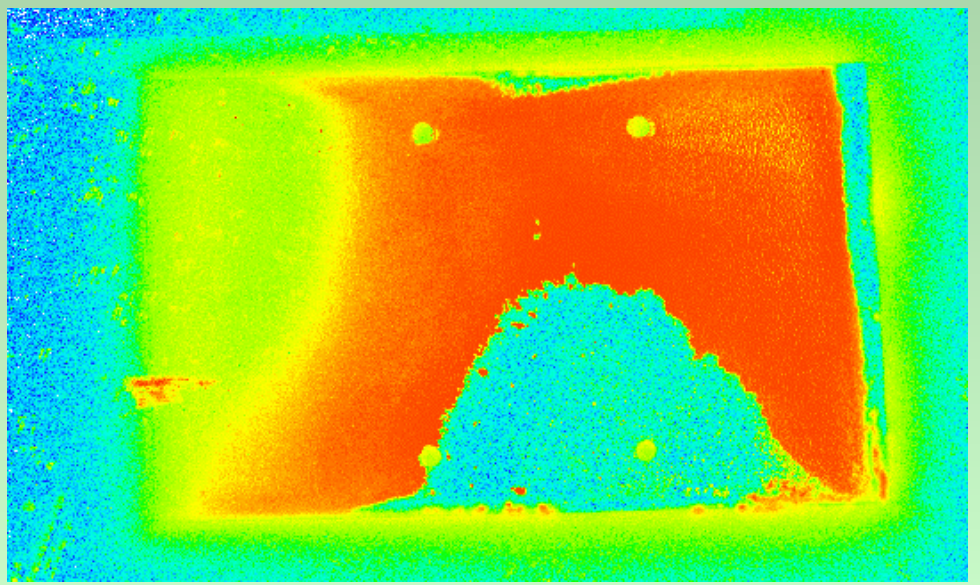


KA7 graphite tile very small retention beneath the deposits









In-situ observation

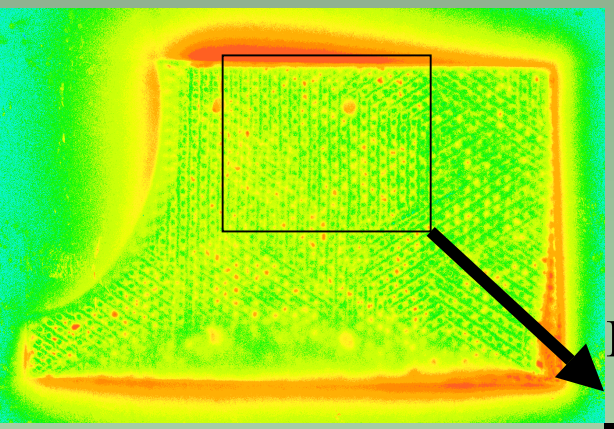
"The thin flakes (~10- 50μm thick) range in size from several mm to 1.5cm in length and are ultra fragile."

C.A.Gentile et al. 5th Int. Symp. Fus. Nucl. Tech. Rome (1999)

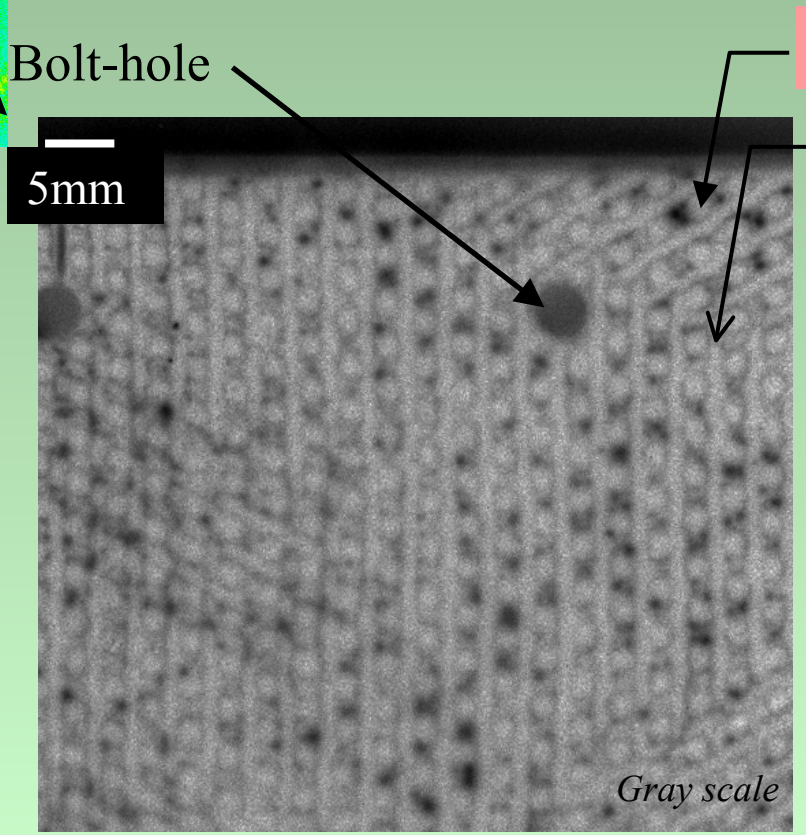
Tritium retention on eroded surface

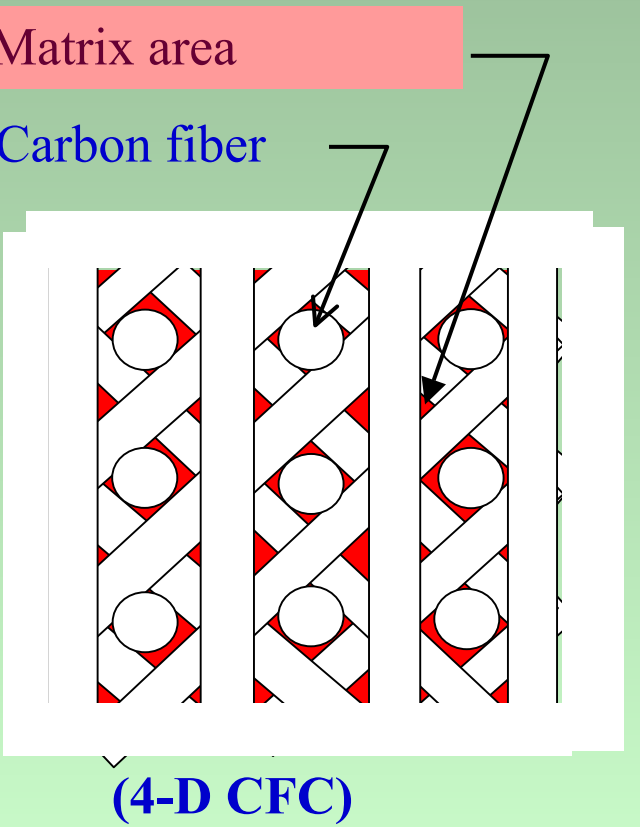
Matrix has higher retention than fivers

Different erosion yield between matrix and fibers produced non flat surface and codeposition with T on shadowed area



Tritium image
(KC3 CFC tile)

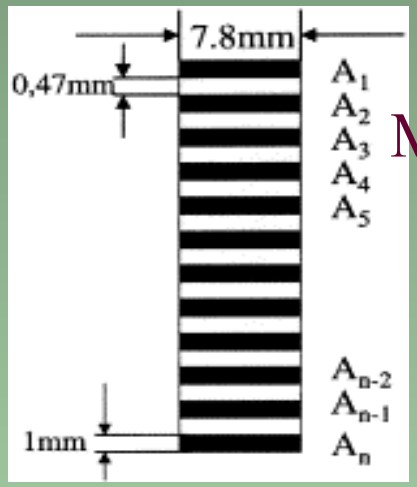


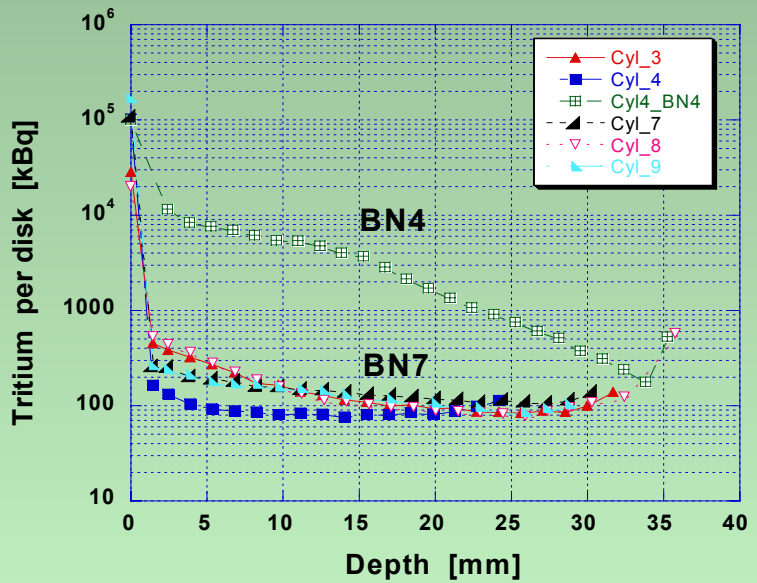


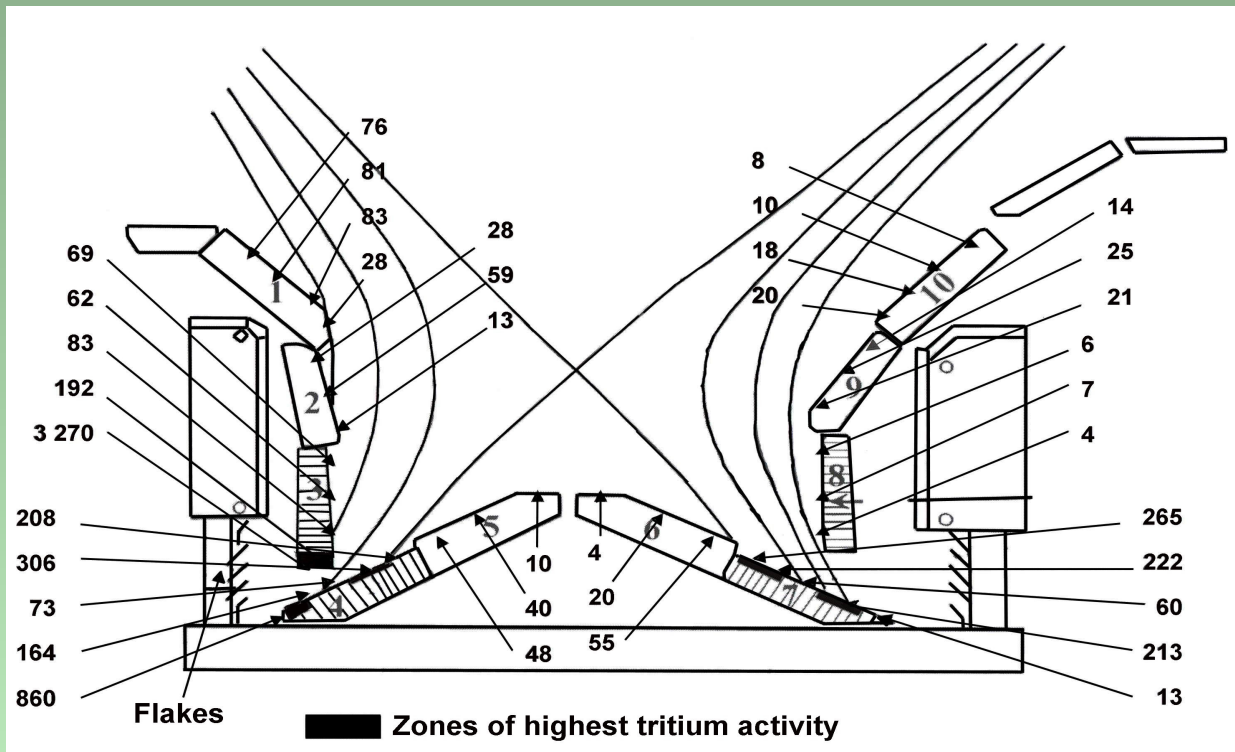
Poster P10 : by K. Sugiyama

3.2 D-T operation in JET

Most of tritium codeposits at plasma shadowed area



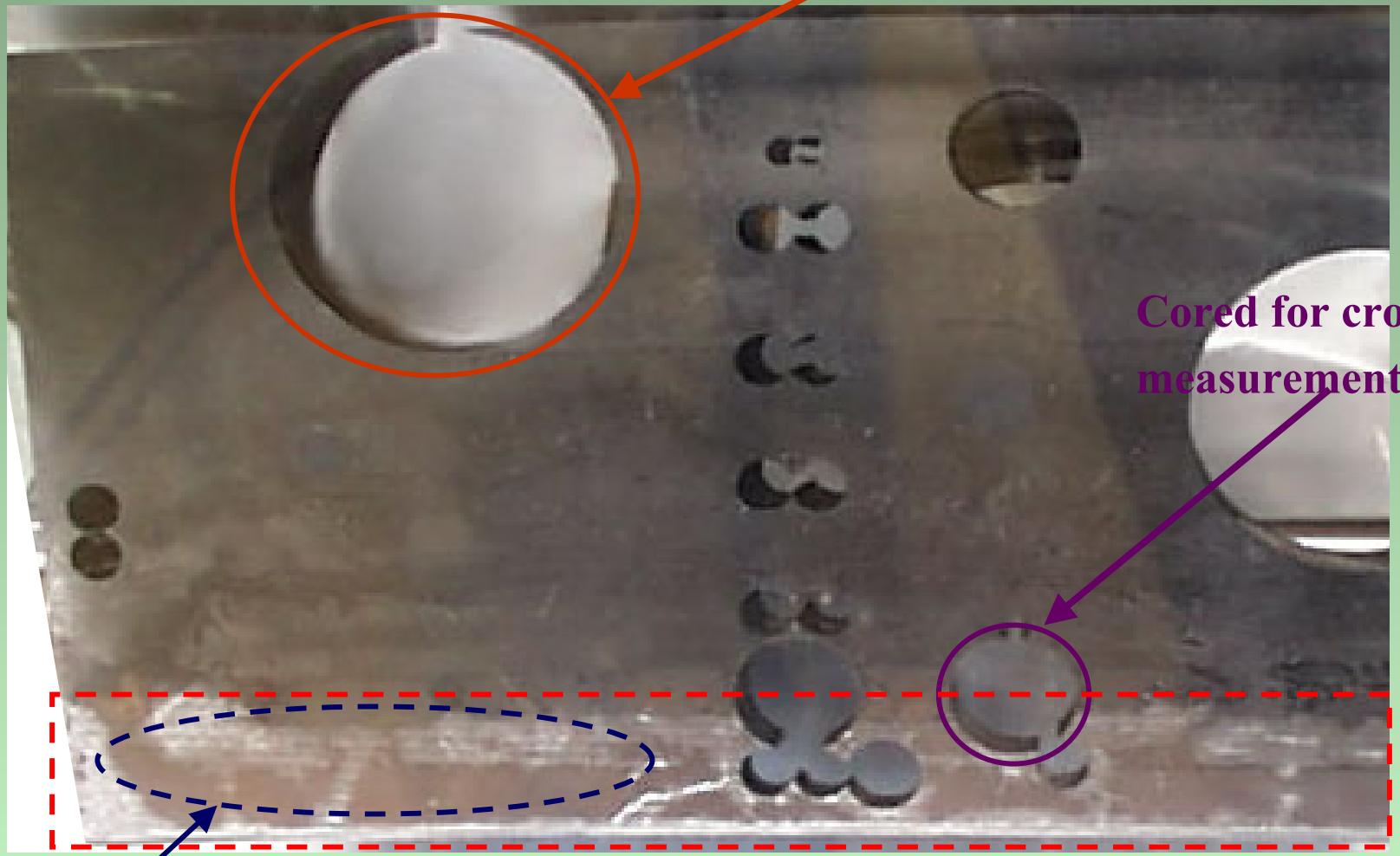




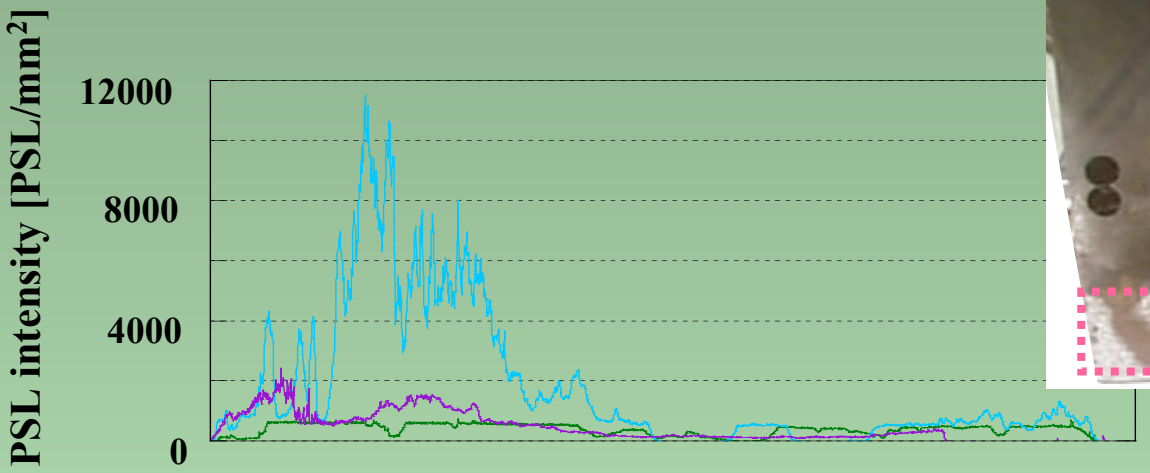
R. -D. Penzhorn, et al., Fusion Eng.&Design 56-57(2001)105-106

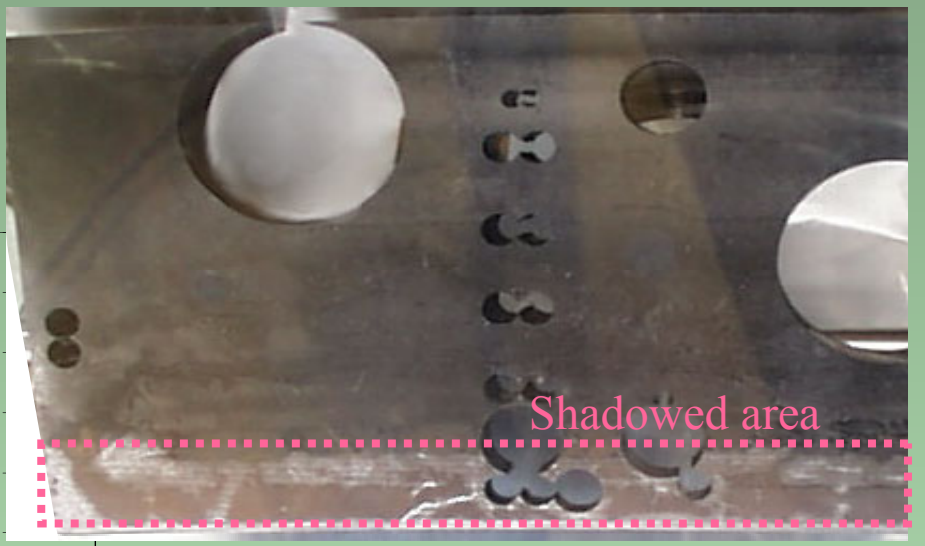
Tritium in plasma facing components

Divertor base tile : 1BN4



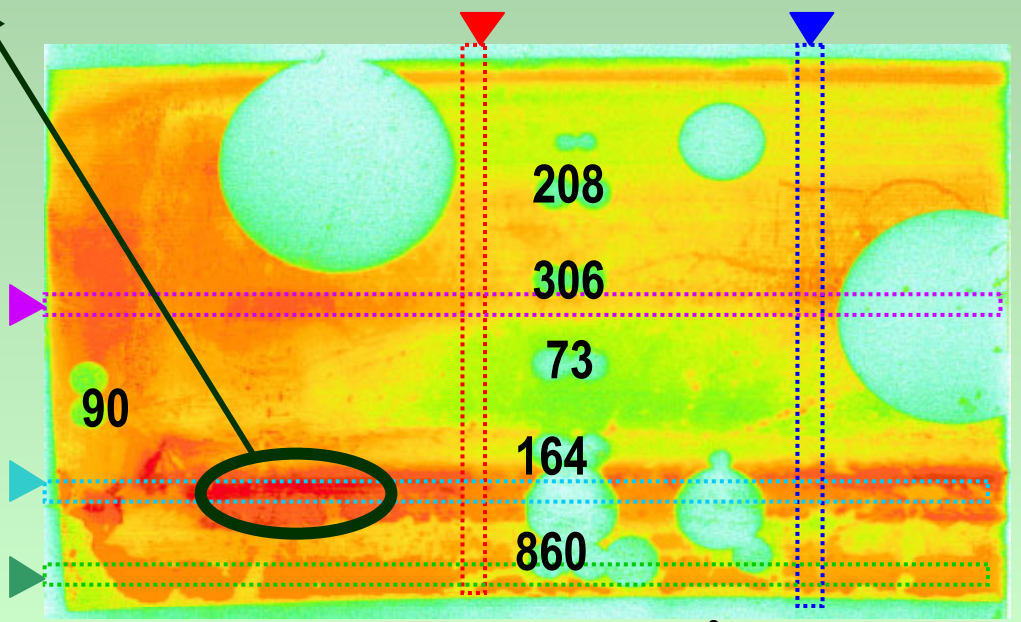
Divertor base tile : 1BN4



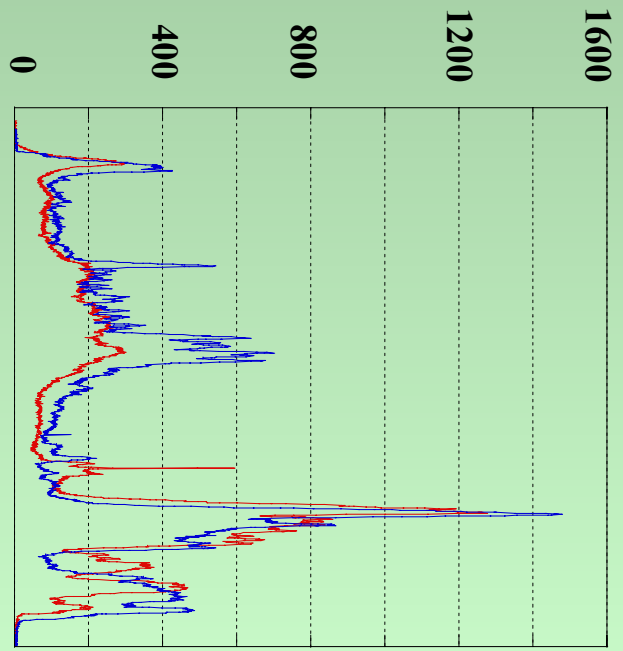


PSL intensity [PSL/mm²]

Highest tritium level ≒ 3GBq/cm²

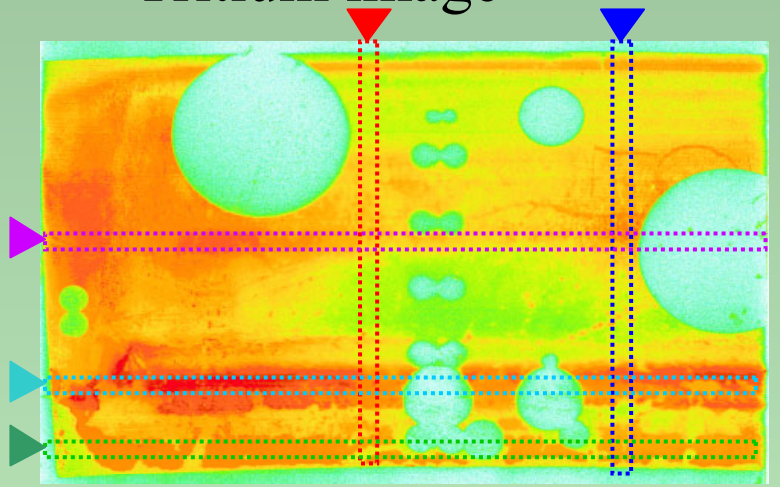


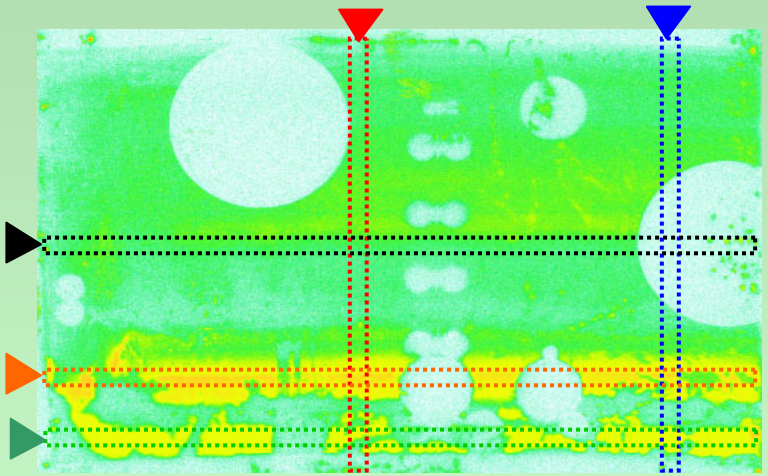
Numbers in MBq/cm²



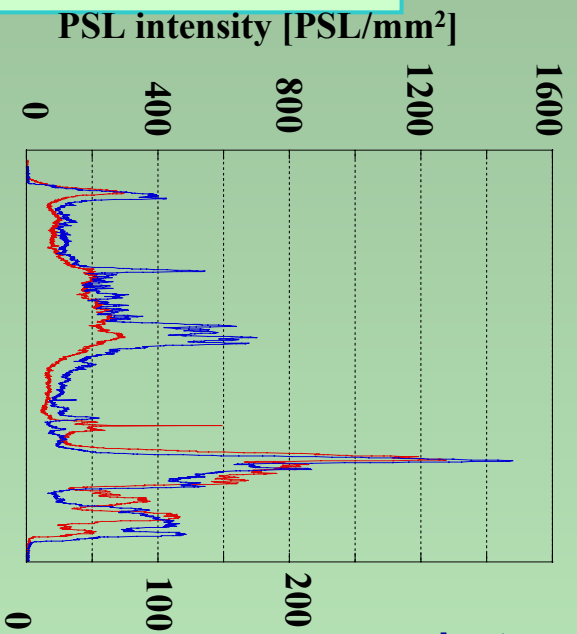
Inner divertor base tile : 1BN4

Tritium image





Radiative metal impurities



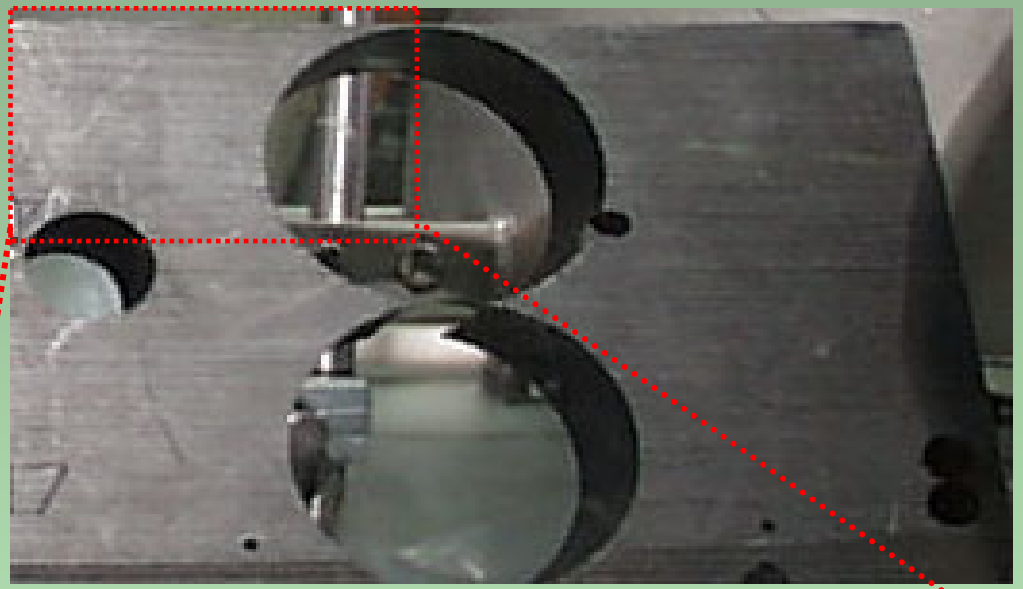
Isotope	Activity	Half life
Be	750Bq/g	53.3d
51Cr	1Bq/g	27.7d
54Mn	1Bq/g	312.2d
56Co	7Bq/g	77.3d
57Co	16Bq/g	272.0d
58Co	65Bq/g	70.9d
60Co	16Bq/g	5.3y

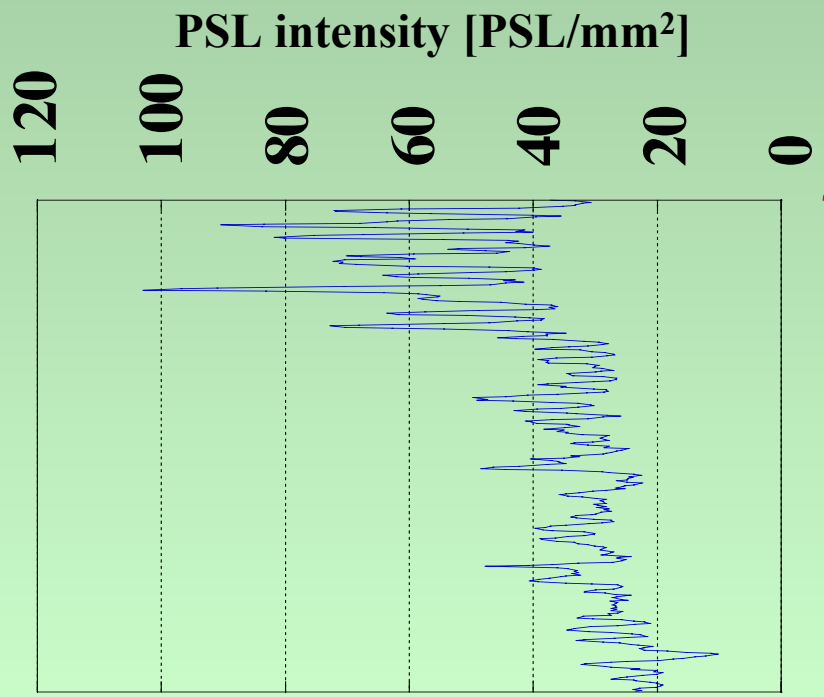
Radioactivity less than 1/10 of T ; mainly on redeposited layers

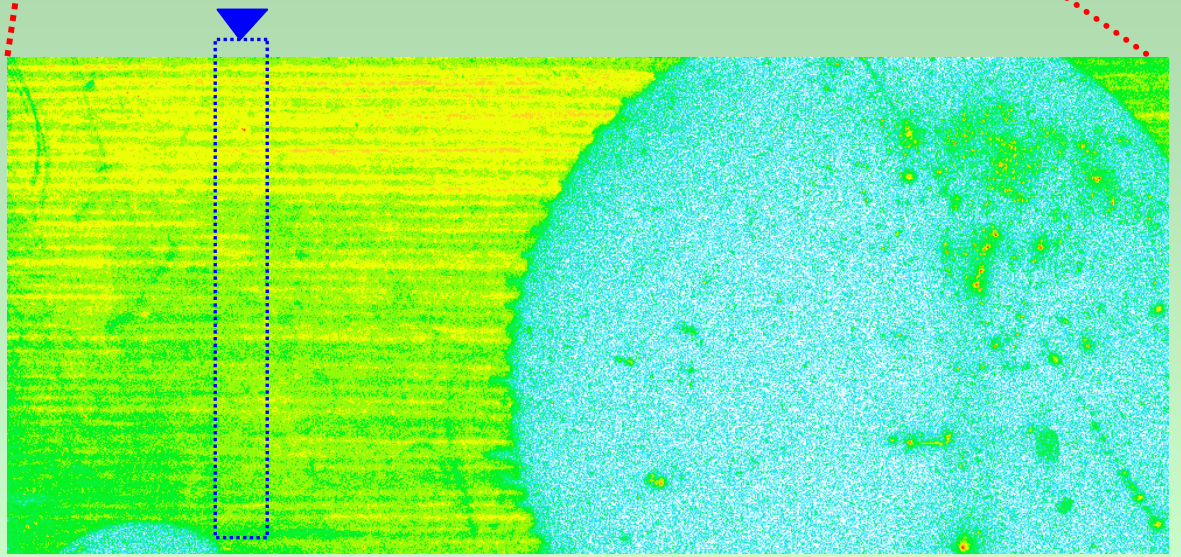
4.Tritium absorption at non-plasma facing surface in JET

Backs side of BN7

Stripes corresponding the woven structure of 2-D CFC







(Inner)

(Outer)

(1)

(2)

(3)

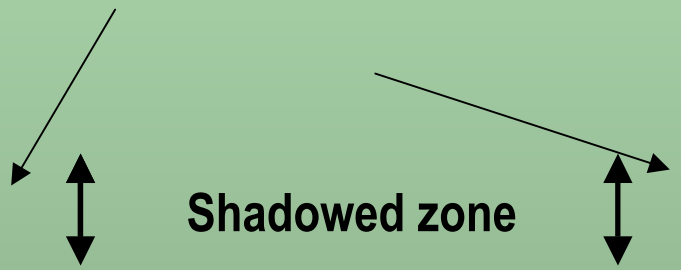
(4)

(10)

(9)

(8)

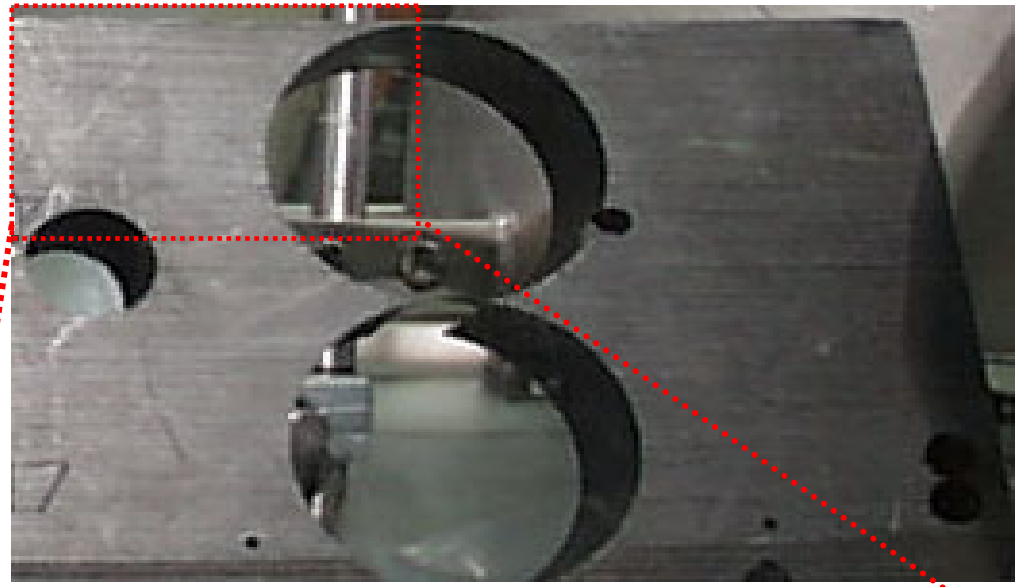
(7)

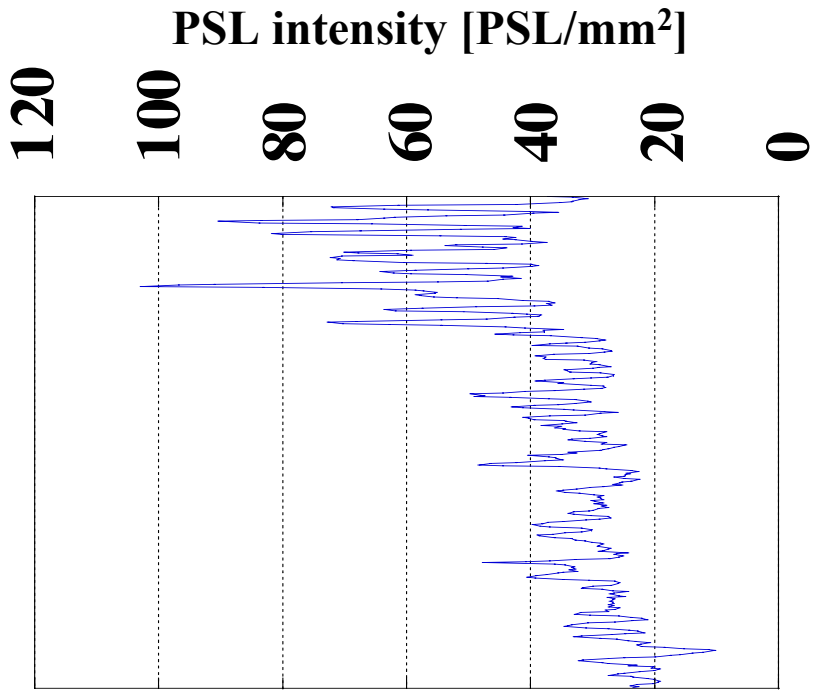


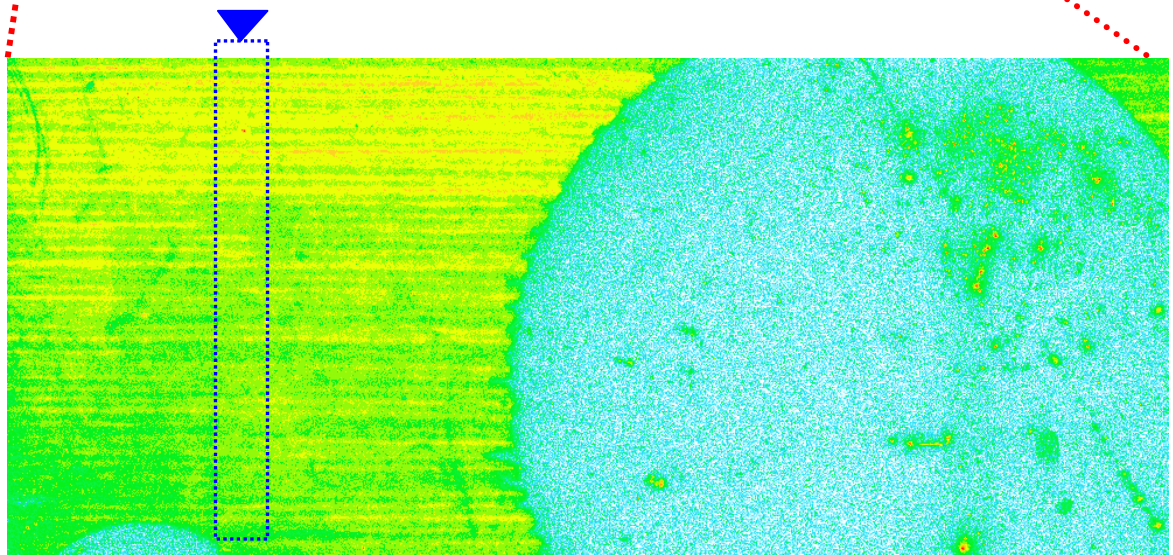
4. Tritium absorption at non-plasma facing surface in JET

Backs side of BN7

Stripes corresponding the woven structure of 2-D CFC







◆ Four different kinds of tritium sources

Nagoya University

1. High energy triton (1/300 of He in D-T reactor)

- Implanted into tiles in μm range uniformly in present tokamaks
- Toloidal and poloidal asymmetry due to magnetic filed and heat load

2. Tritium fueled by gas, pellet and NBI (Similar behavior as H and D)

- Codeposits with carbon at plasma shadowed low temperature area
- Non-uniformity due to plasma flux and tile geometry
- Main contribution on low temperature machine
- Small retention at eroded area

3. Gaseous T

- Retention (absorption) in nonplasma exposed area

could be large tritium retention source

4. Triton produced by nuclear transmutation in materials

On the selection of PFM materials

Be? No, I do not like

W? Yes, I did try to promote, but operational temperature window is too narrow to use. W still needs examination

Carbon based PFM kept above 800K is promising

☆Main tritium source : Implanted high energy trition

☆ Tritium in deposited layer : Very small

☆ Tritium on shadowed area : Totally temperature depend

☆ Recycling : Metal like at higher temperature

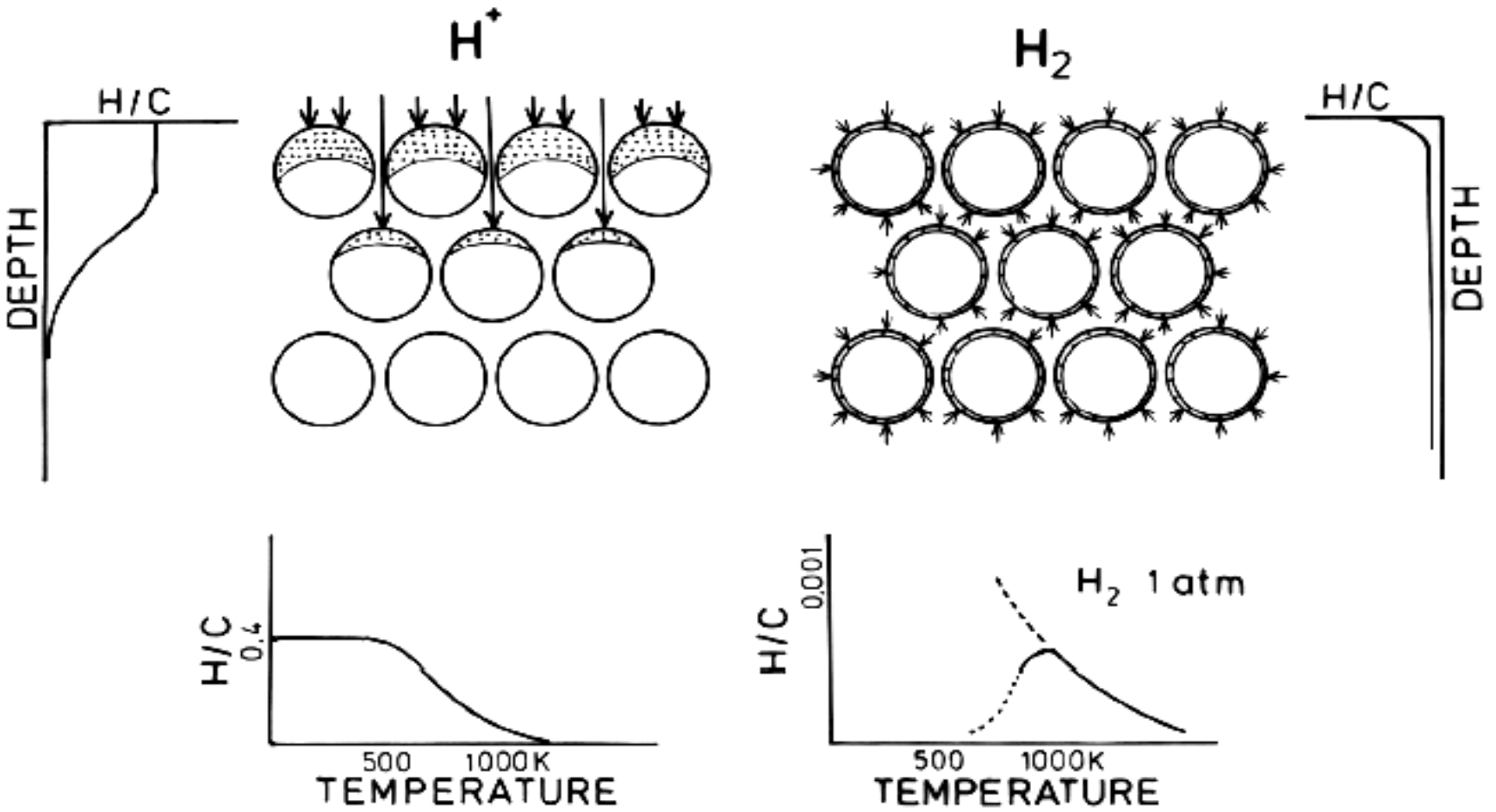
☆ Erosion ? : That is a question! (Maybe overestimated)

Remaining issues ;

Tritium codeposition at low temperature area

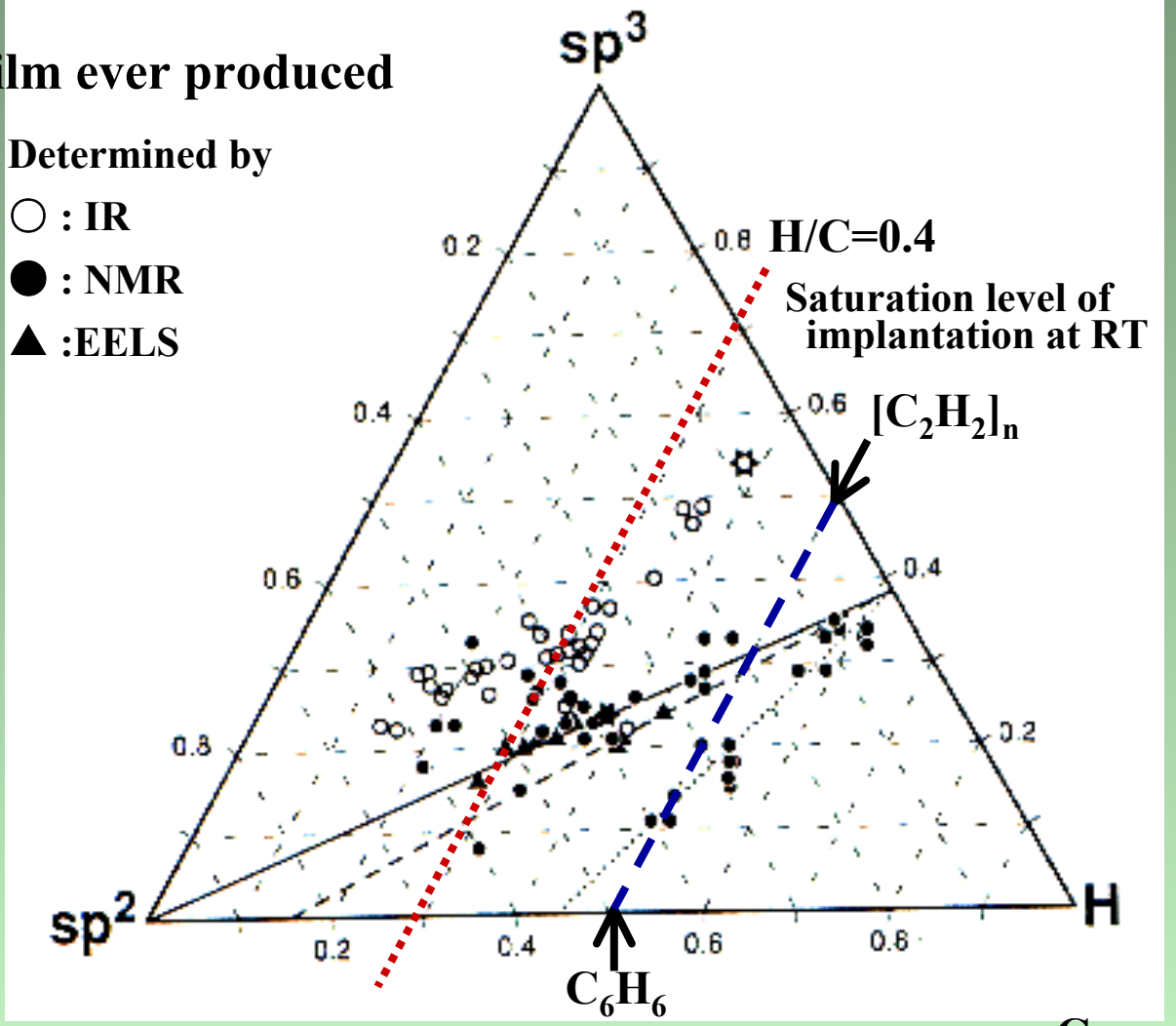
Detritiation of implanted T

Carbon-hydrogen Chemistry



Carbon-Hydrogen Chemistry

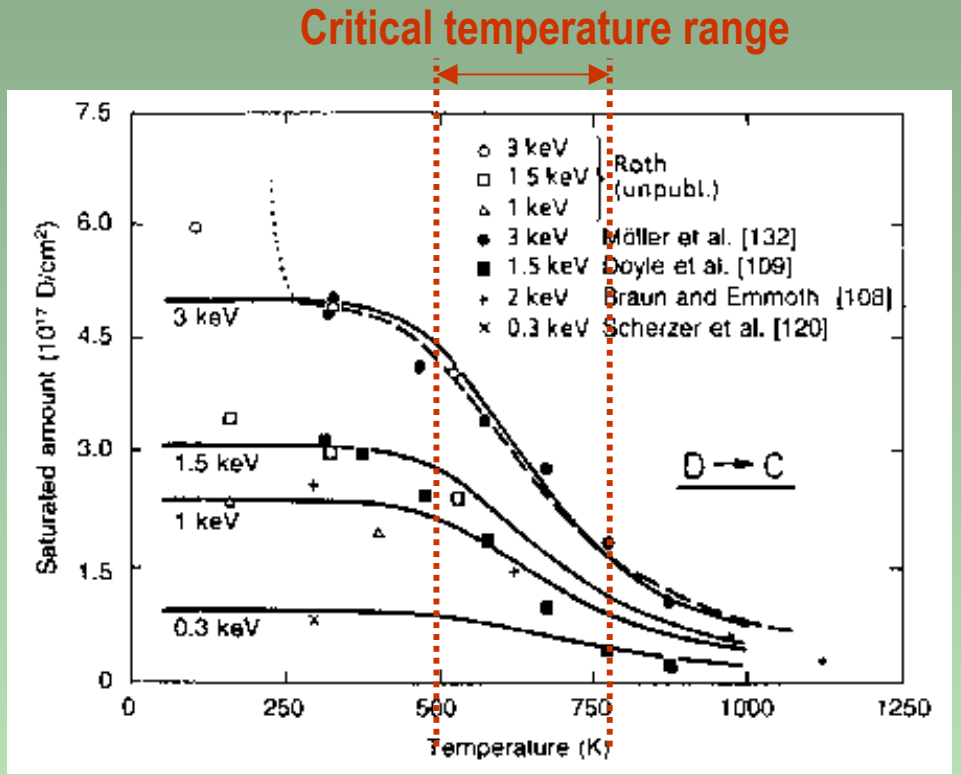
a:C-H film ever produced

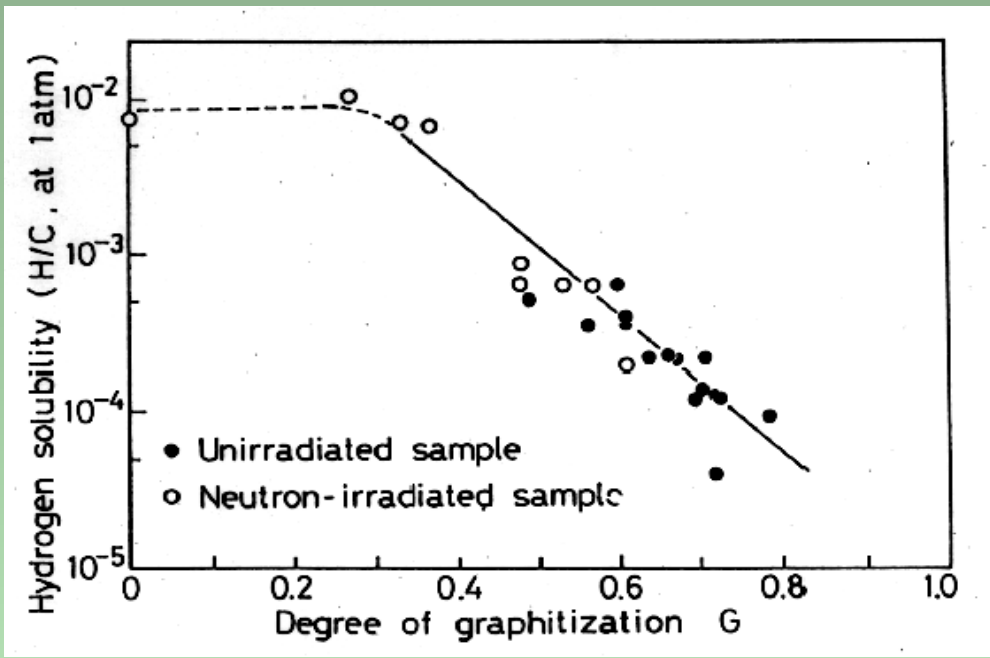


Graphite(Solid) ← Liquid → Gas

W. Jacob and W. Moeller, Appl. Phys. Lett, 63 (1993)1771

Carbon-Hydrogen Chemistry





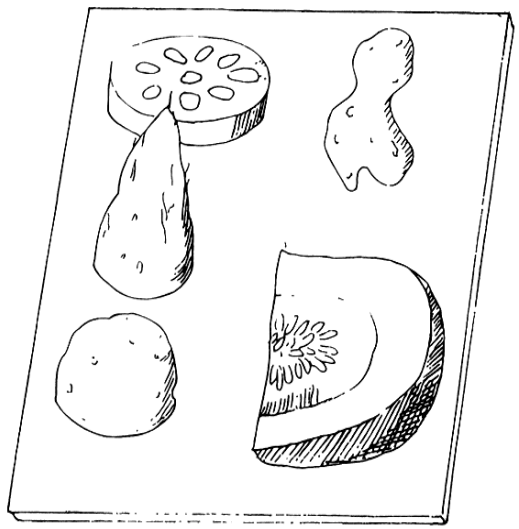
Temperature dependence of hydrogen saturation level in graphite

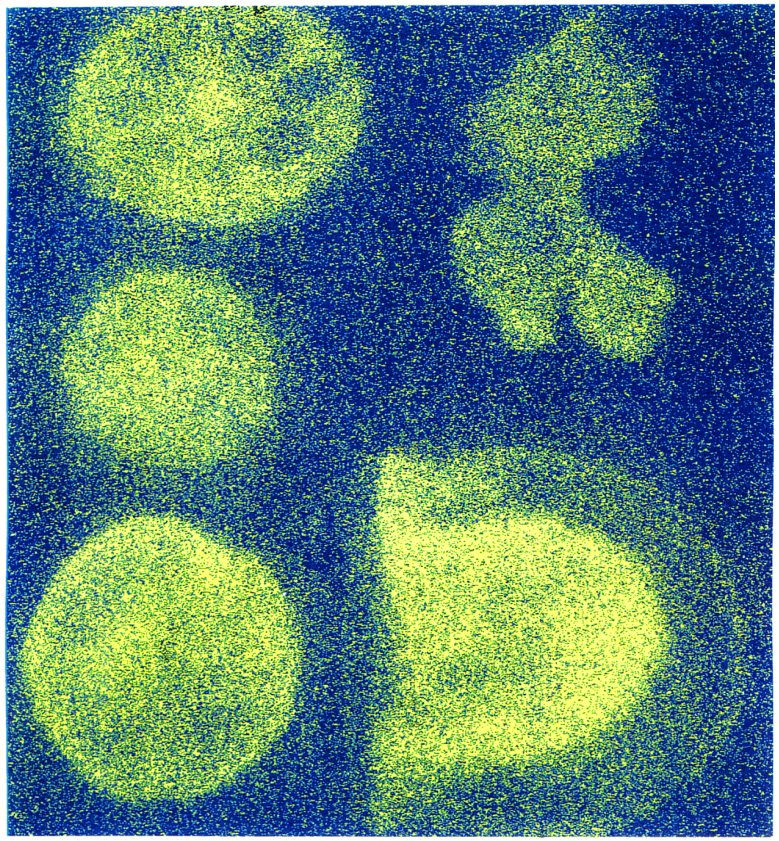
Hydrogen gas absorption depends Defects in graphite

2. Technique mainly used : Tritium imaging plate

Imaging plate technique to make a profile of radioactive source

Ultrahigh sensitivity of the IP enables detection of beta-rays from ^{40}K in natural foods →





Tritium codeposits with carbon

Estimation of Tritium retention in ITER

Extrapolation from experiments	T-retention rate T/ion	ITER retention gT/s Extrapolation flux 1.8 10^{24}/sc	Shots /T limit (400 sec)
TEXTOR	6.4 10 $^{-4}$	0.0064	136
JET T experience	1.75 10^{-2} (only louver)	0.10	9
JET GB on tile	2.7 10^{-3}	0.024	36
JET C5 on louver from GB	2.9 10^{-4}	0.0026	340
Modeling			
ERO code 2% (CxHy er.)		0.006	145
WBC code		0.007	125

Only ~100 full D-T shots will give trtium retntion more than site limitation!

After Volker Phlipps(EFDA)

Workshop Agenda