Summary of Erosion, Deposition and Fuel Retention in TFTR

Charles Skinner
Princeton Plasma Physics Laboratory

Outline:

- Erosion / deposition in DT phase
- NRA and XPS analysis of deposits
- Erosion / deposition in DD phase
- Tritium retention
- Modelling (John Hogan)
- Summary

With credits to:

N Bekris, C A Gentile, Y S Cheng, P Coad, G Federici, J Hogan,
D Hole, M Paffett, W R Wampler, S Willms, K M Young,
and the PPPL tritium group.

PPPL
PRINCETON PLASMA
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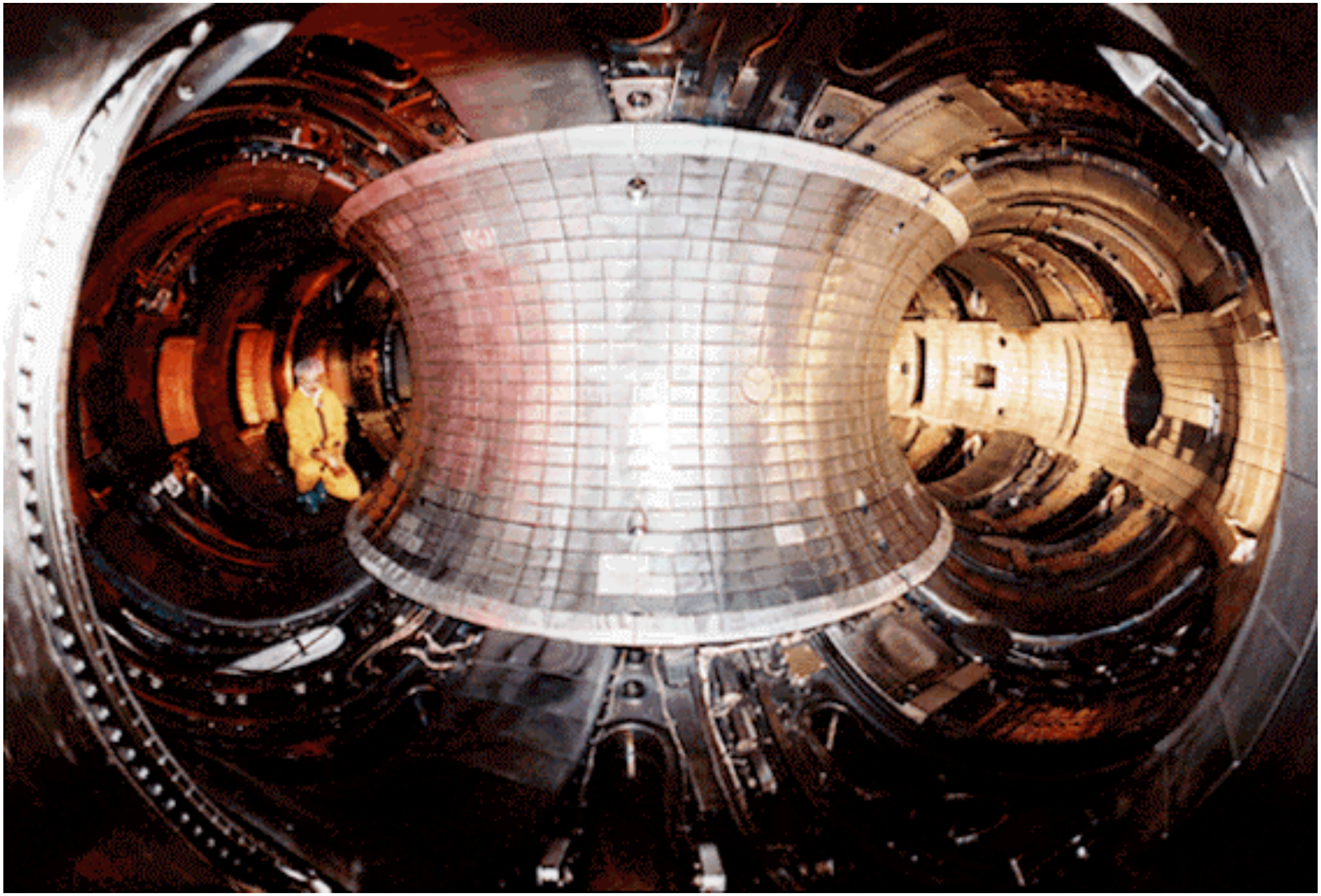
TFTR interior



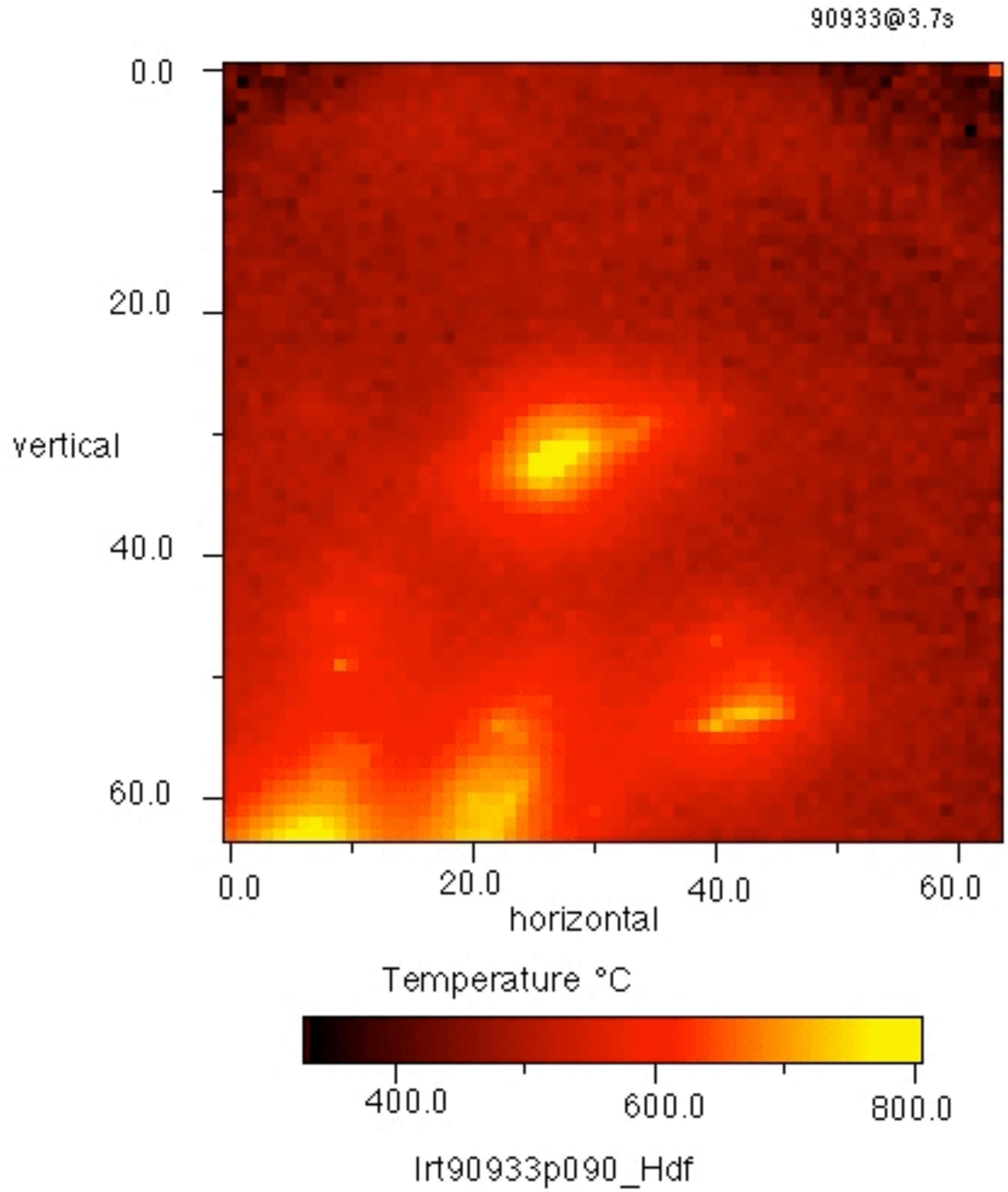
- *Limiter machine - no divertor.*
- *Walls are deposition areas (not erosion)*
- *Walls heated only by plasma (limiter hotspots reached ≈ 800 C).*
- *Different edge conditions to JET*

	TFTR SOL (TRANSP/DEGAS)	JET divertor (EDGE2D)
Ne	0.1 e19 – 1 e19 m-3	≈ 10 e19 m-3
Te	200 - 600eV	<30 eV

IR TV image of limiter

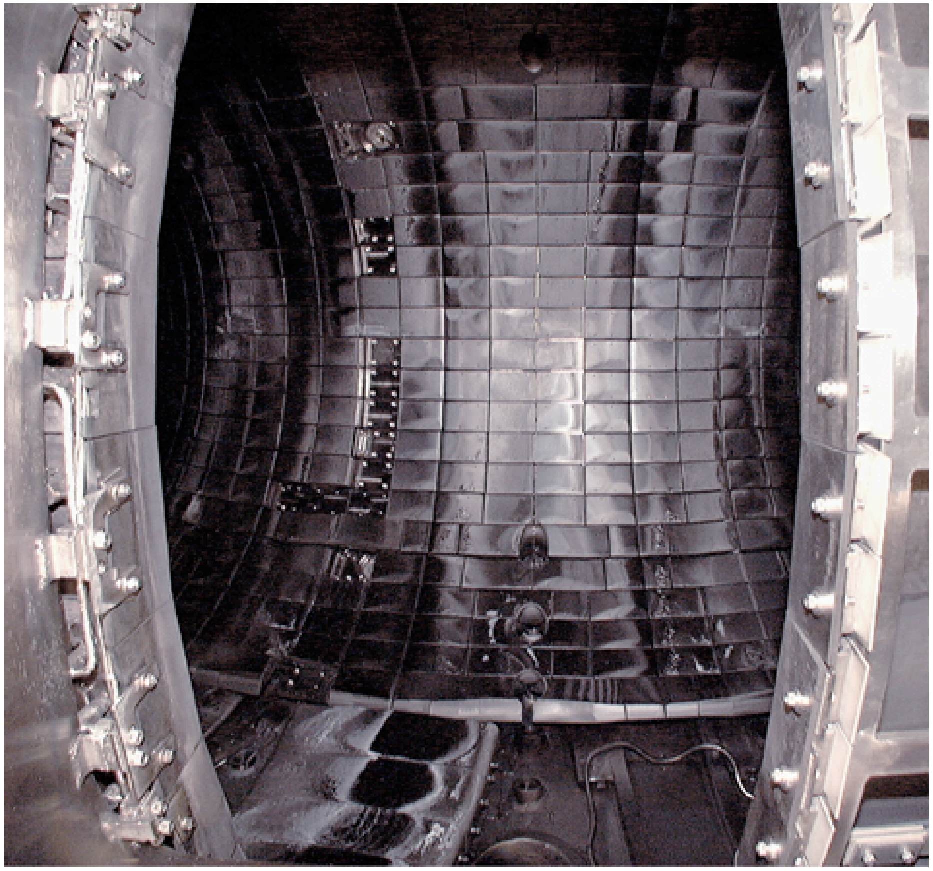
28MW neutral beams

TFTR



Deposition inside TFTR

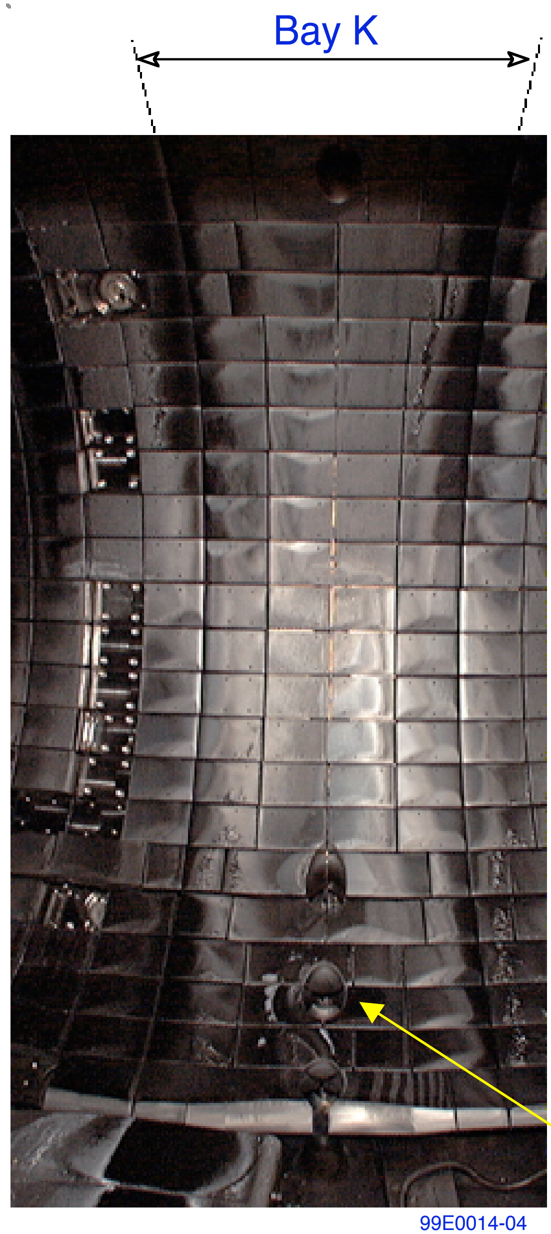
- Codeposition inboard & outboard
- Dust and debris observed
- Tiles, coupons, dust samples retrieved for analysis
- Tritium spatial distribution consistent with modeling...

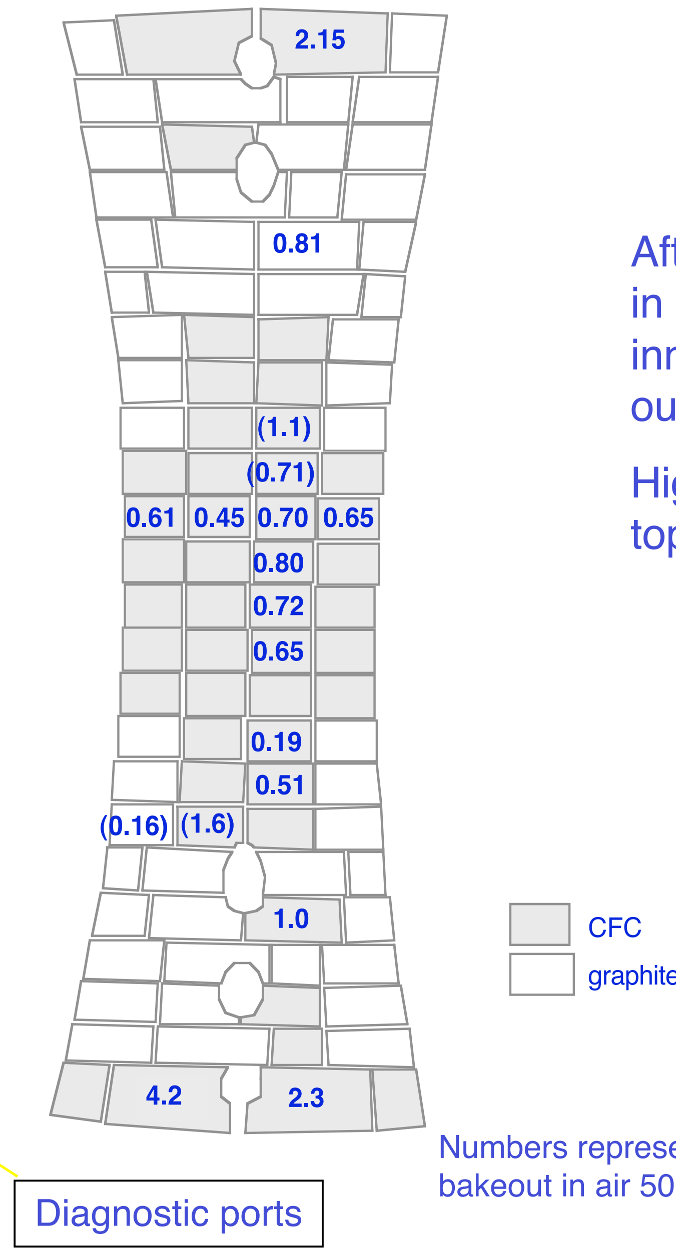


Co-deposition, flaking, deposits inside vessel. Diagonal pattern on inner limiter segments due to geometry of ‘scalloped’ shape and connection length of field lines (Brooks et al.,)

Debris and dust on TFTR vessel floor

Tritium co-deposition, on bumper limiter.



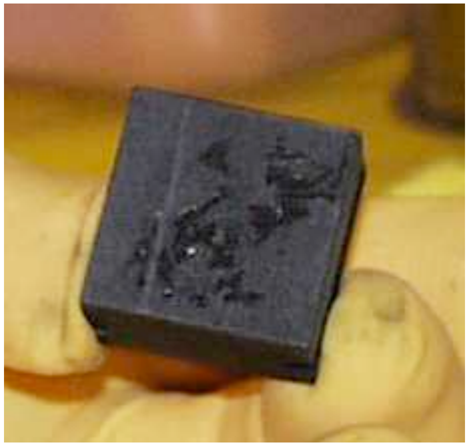


Numbers represent T (Ci) released by bakeout in air 500 C for 1 hour.

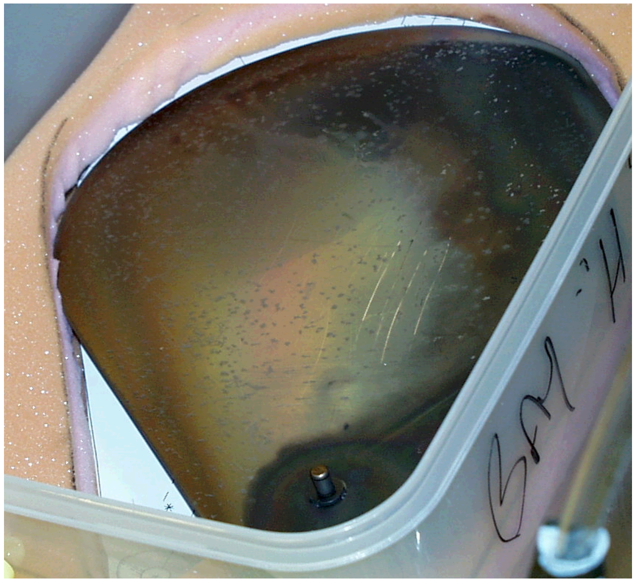
After plasma operations tritium in TFTR was located on inner limiter (0.2 g), and outer wall (0.36 g).

Highest concentrations were at top and bottom of limiter.

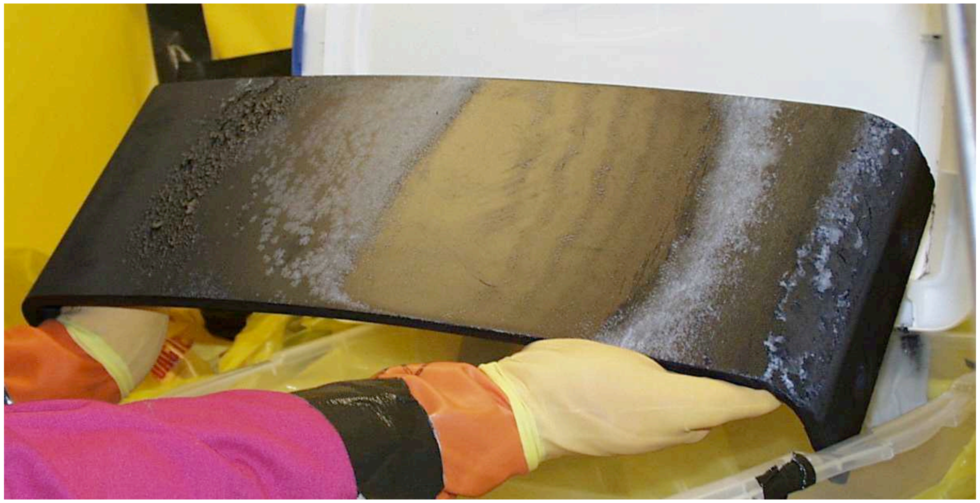
Samples from outboard side of vessel



Bay H midplane graphite coupon: 24 Ci/m^2
Bay N bottom graphite coupon: 65 Ci/m^2
Bay P midplane graphite coupon: 16 Ci/m^2



Bay H shutter (stainless steel) 9 Ci/m2



Bay O/N poloidal limiter tile: 31 Ci/m2

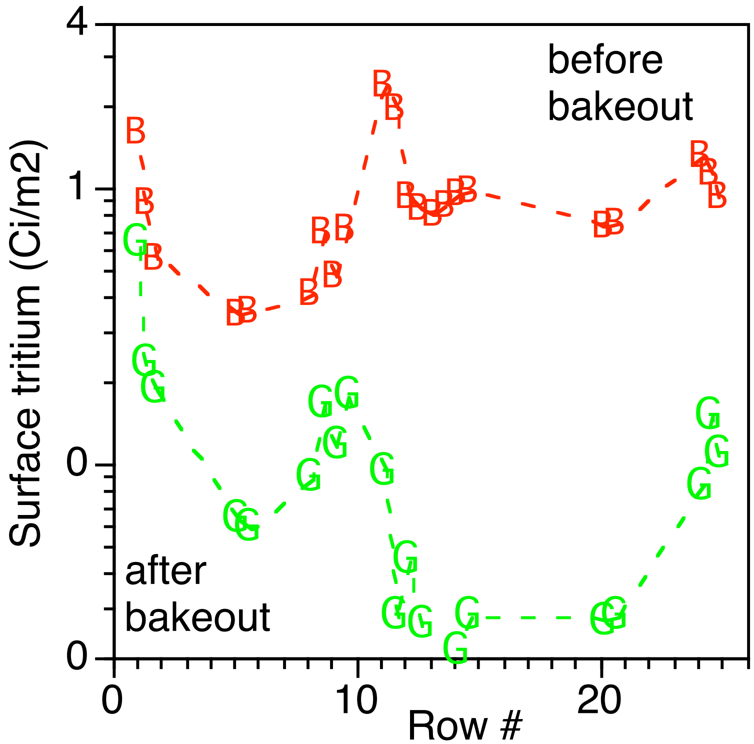
Location of TFTR Tritium inventory:

Location:	Area (m^2)	Average Ci/m^2 from bakeout + 10%	Inventory (Ci)	(g)
Bumper limiter	22	87	1,900	0.2
Outboard	110	32	3,500	0.36
Total			**5,400**	**0.56**
cf. fueling - exhaust			***6,200***	***0.64***

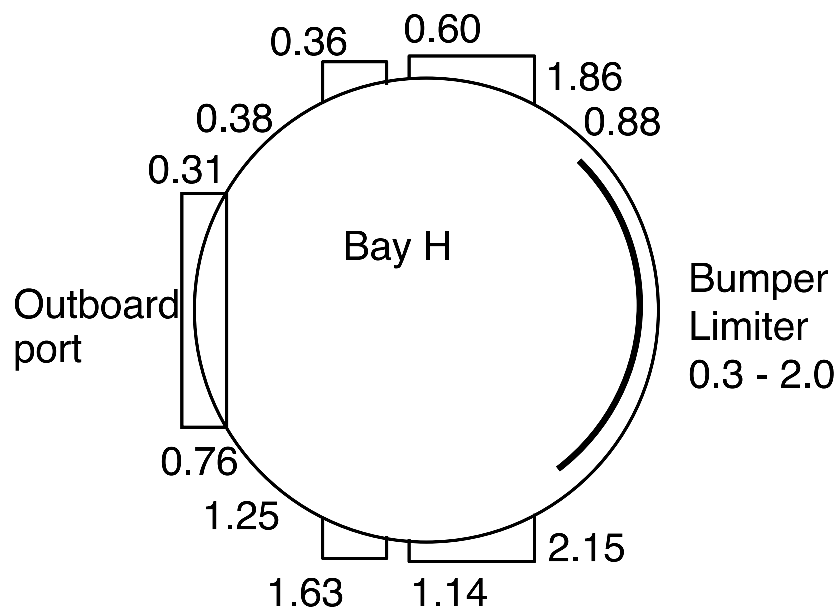
- *1/3 tritium on bumper limiter, 2/3 on outboard wall*
- *Remarkably good agreement between extrapolation from bakeout measurements and difference inventory (fueling less exhaust) and measurements at both PPPL and Savannah River.*

Surface Tritium Measurements

- *Open wall ion chamber provided fast, convenient measurements of surface tritium (within beta range ≈ 1 micron)*
- *Tritium distribution non uniform, some residual after bakeout.*
- *Ratio bulk tritium from bakeout / surface tritium ≈100*

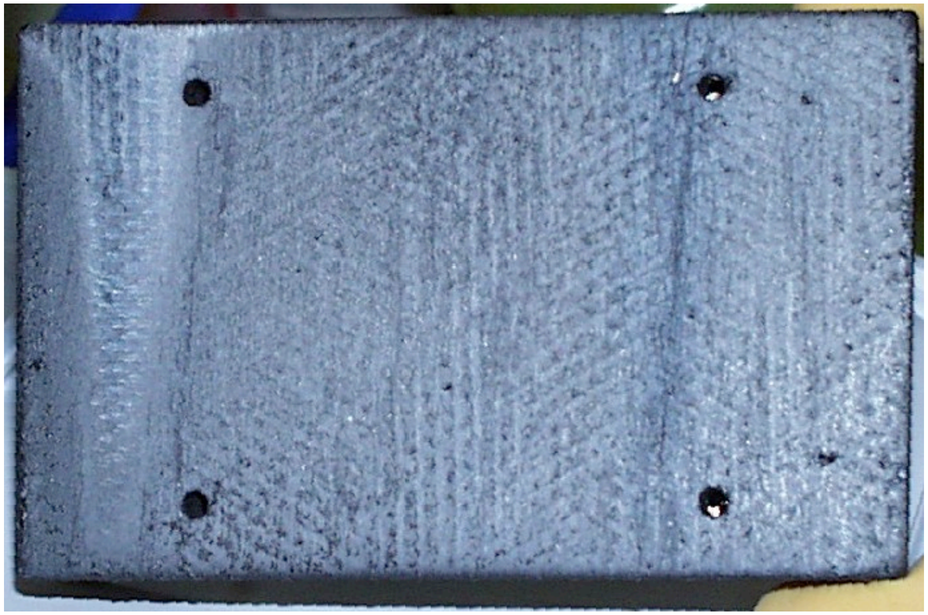


Surface tritium on bumper limiter at Bay K centerline before and after bakeout.

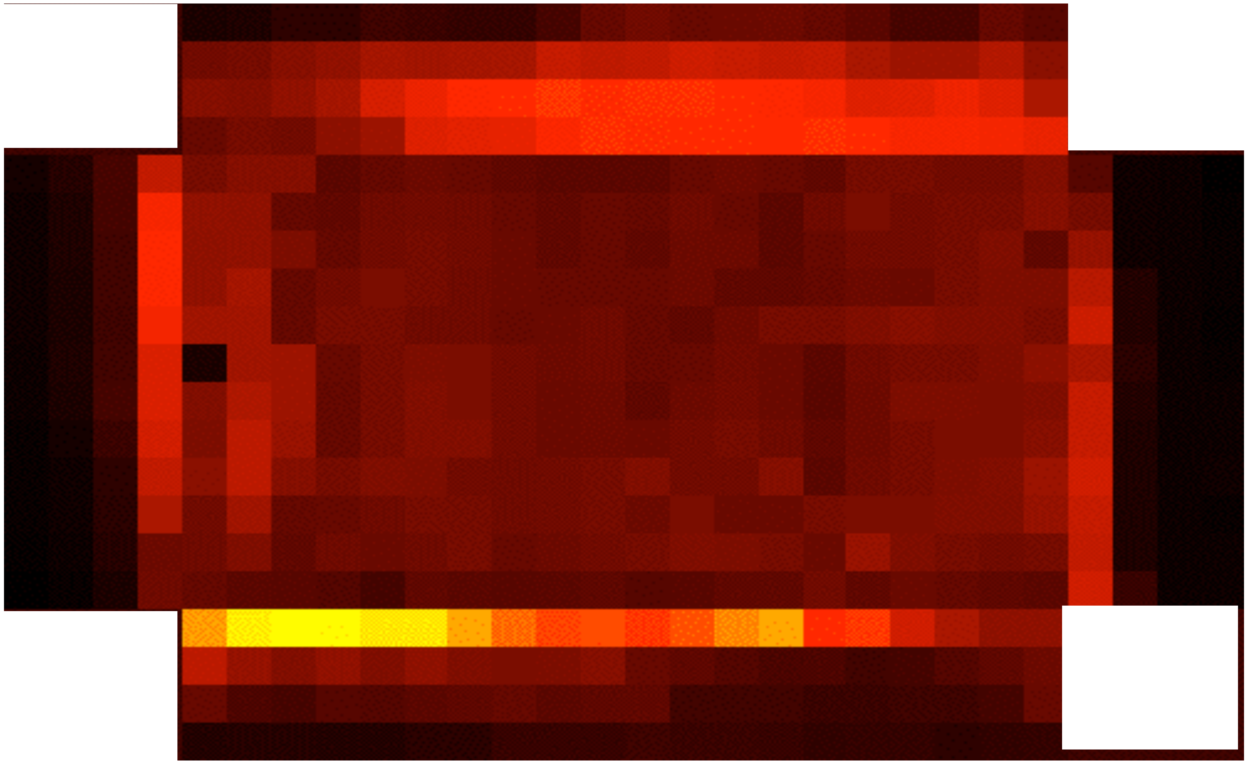


Surface tritium measured on vessel wall at Bay H (Ci/m²)
maximum closest to limiter and on bottom of vessel.

cm-scale variations present on e.g. tile KC17.

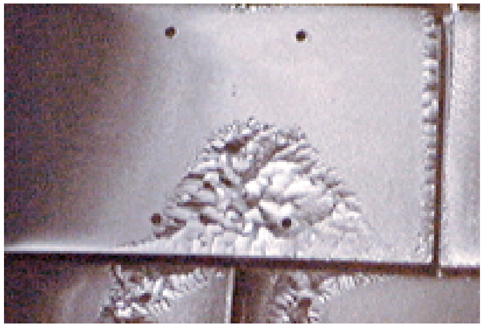


Unfolded map of surface tritium at 1/4” resolution 0.6 - 1.9 Ci/m²

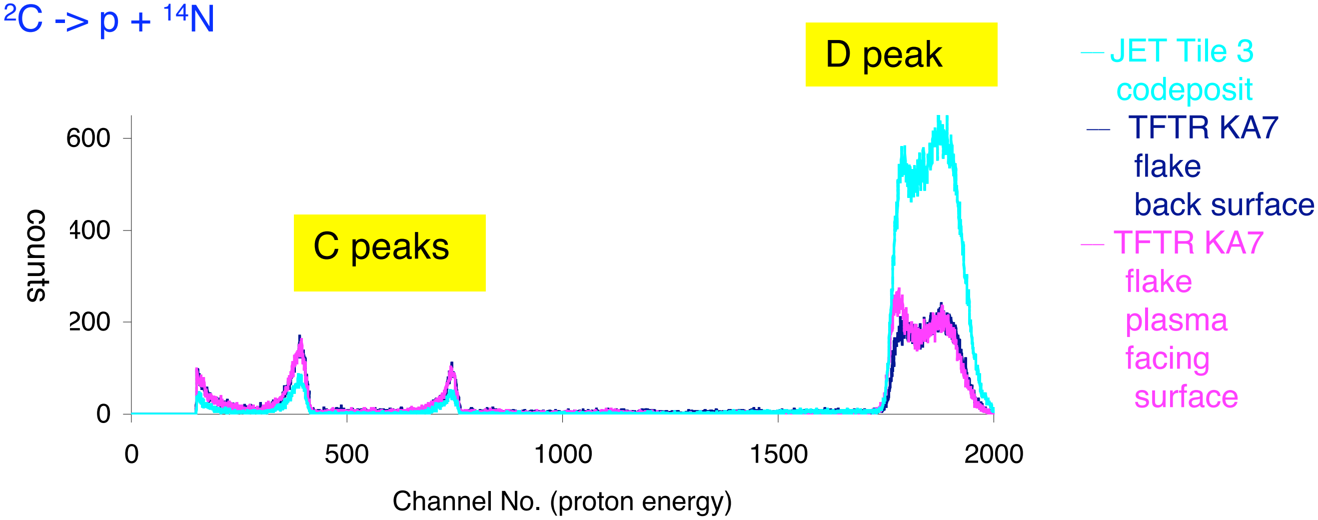


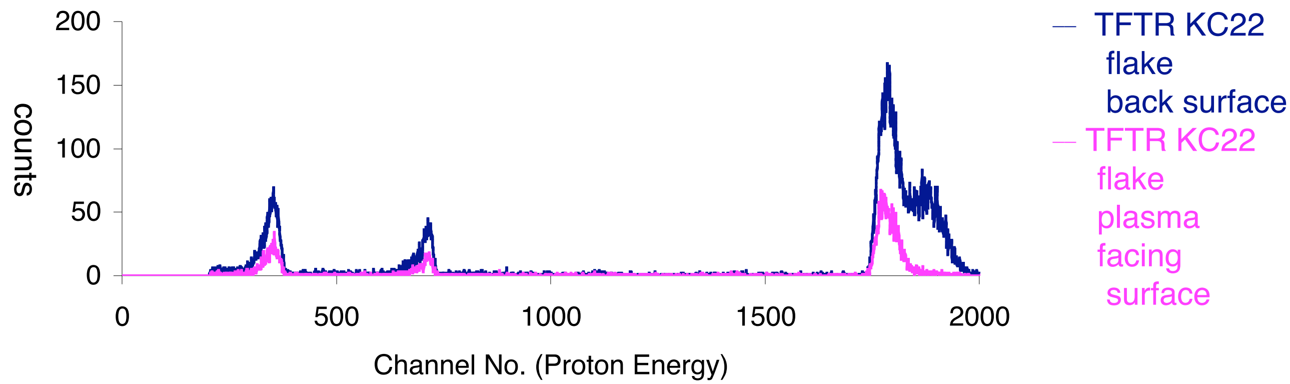
Nuclear Reaction Analysis of TFTR Flakes *(with P. Coad (JET-EFDA) and D Hole (U. Sussex))*

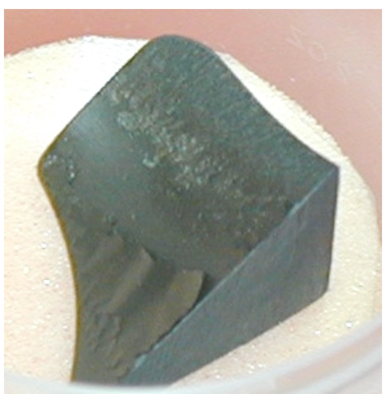
2.5 MeV $^{3}He + D \rightarrow p + {}^{4}He$
2.5 MeV $^{3}He + {}^{12}C \rightarrow p + {}^{14}N$



Flakes from tile KA7.
(plasma facing, inner limiter)







Flakes from diagnostic penetration
on tile KC22 (not plasma facing)

D/C ratio reflects energy of incident ion (D/C ≤ 0.4 at E >50eV, D/C up to 1 at E < 50eV.

- TFTR flake from tile KA7(plasma facing):

  D/C:0.13 on plasma facing, 0.25 back surface, 0.11 bulk (from RBS)

- TFTR KC22 (not plasma facing) D/C ratio approx. 1.7x higher
- JET D/C≈ 0.7

Atomic Concentrations of XPS Detected Elements

Tile KC17

M. T. Paffett et al.,
T2001 conference
Fus. Sci. & Technol.
41 (May, 2002)

Tile KB3

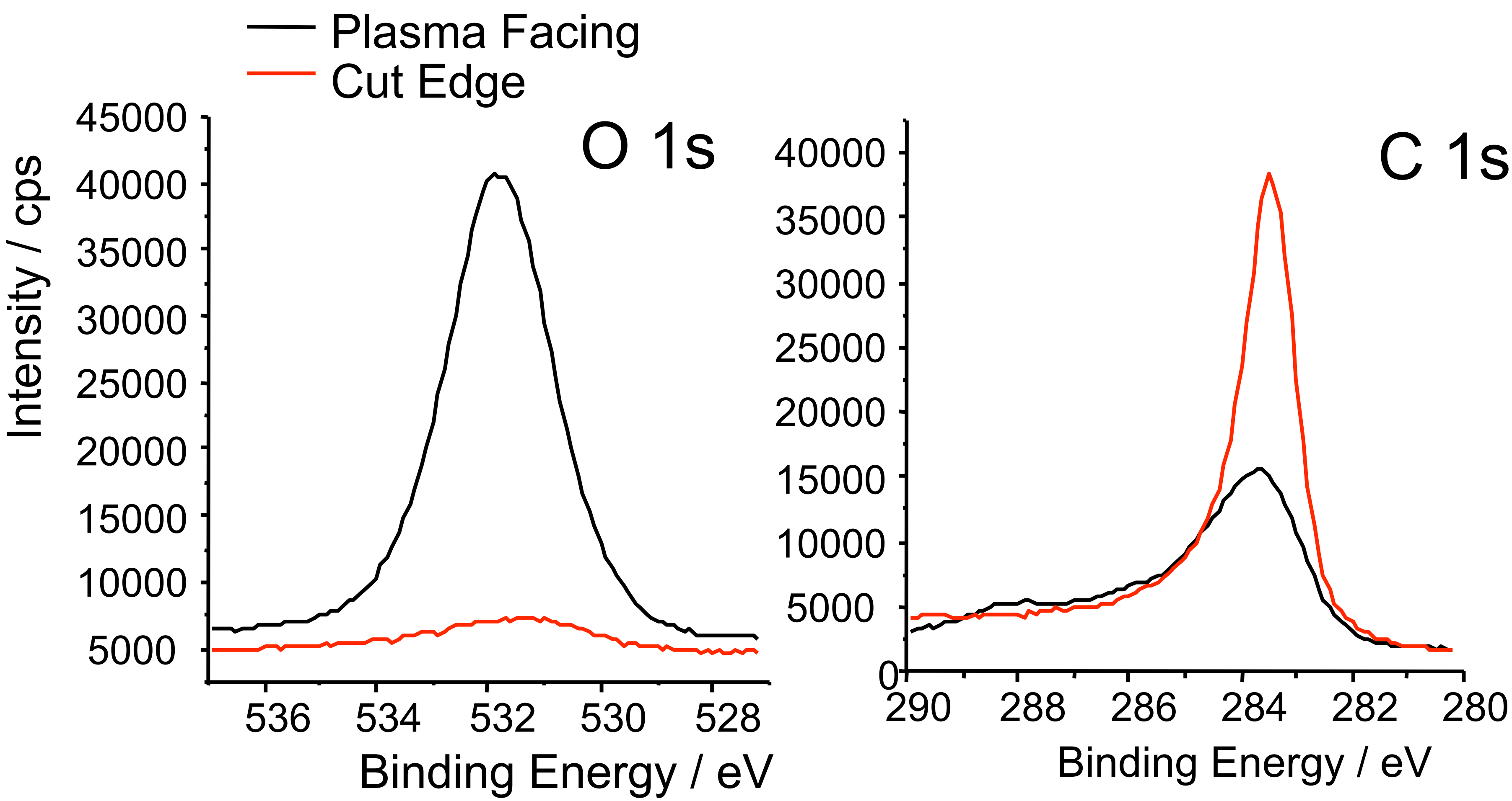
Sample	B	C	O	Si	S
1G	4.1	51.2	39.5	4.5	0.6
4F.1	5.2	49.7	40.4	4.1	0.5
4F.2	4.9	48.5	40.6	5.4	0.6
4B.1	3.7	51.6	38.8	5.9	-
4B.2	2.9	51.6	39.2	5.9	0.6
2C.1	3.1	50.5	39.1	7.2	-
2C.2	3.4	48.4	40.0	8.1	-
4A.1	4.8	31.0	52.6	11.6	-
4A.2	4.4	32.1	50.2	13.3	-
V1.1	-	76.5	21.1	2.4	-
V1.2	4.0	73.4	22.3	0.3	-
V1.3(cut)	-	94.7	3.8	0.2	1.3
V2(rough)	3.4	30.6	50.4	13.9	1.7
V2(smooth)	8.1	48.7	42.1	1.2	-

Crud 1 sample was from poloidal limiter at floor level.

Crud W,X,Y,Z was from flaking deposit on diagnostic penetration in bumper limiter tile KB2 (not plasma facing)

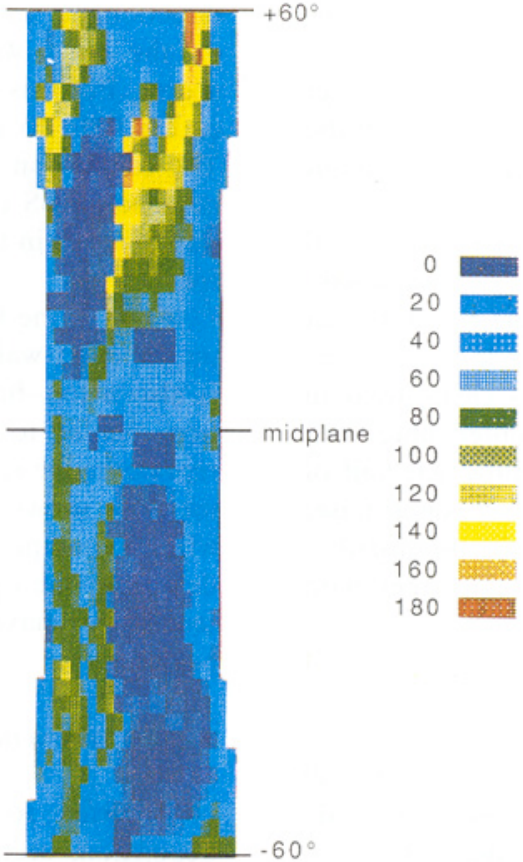
Sample	Li	B	C	O	Si	S
Crud 1	7.3	7.0	45.6	31.3	6.7	2.1
Crud W	-	2.9	70.1	26.4	0.6	-
Crud X	-	0.9	74.3	23.9	0.8	-
Crud Y	-	3.8	66.5	28.7	0.9	-
Crud Z	-	6.1	55.1	35.5	3.3	-

Direct XPS comparison of cut edge versus plasma facing surface: extensive oxidation of carbon surface occurs

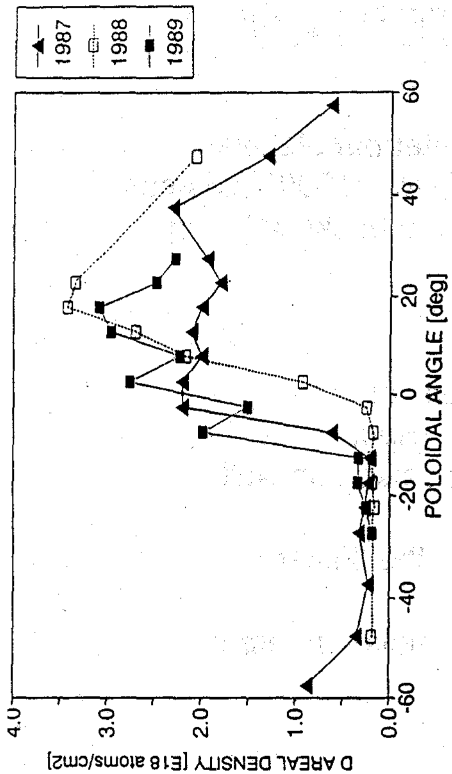


M. T. Paffett et al., T2001 conference
Fus. Sci. & Technol. 41 (May, 2002)

Deposition on bumper limiter in DD phase

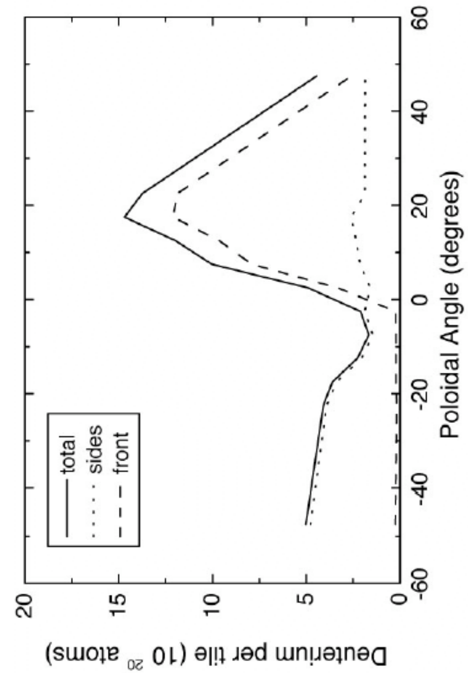


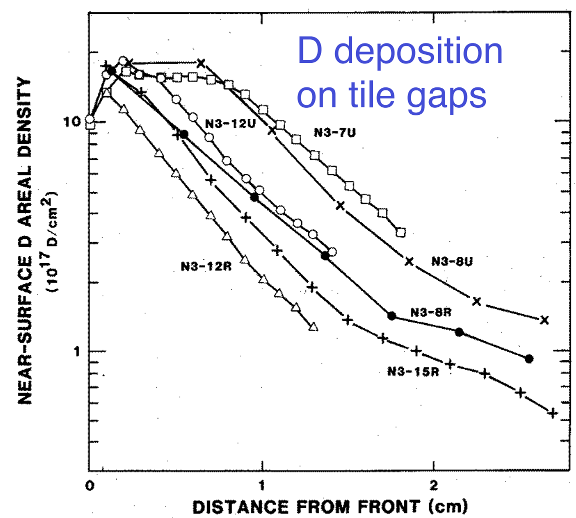
Metals deposition on plasma facing surface of bumper limiter (Beta backscattering)



D deposition plasma facing surface of bumper limiter (NRA)

D on front and sides.



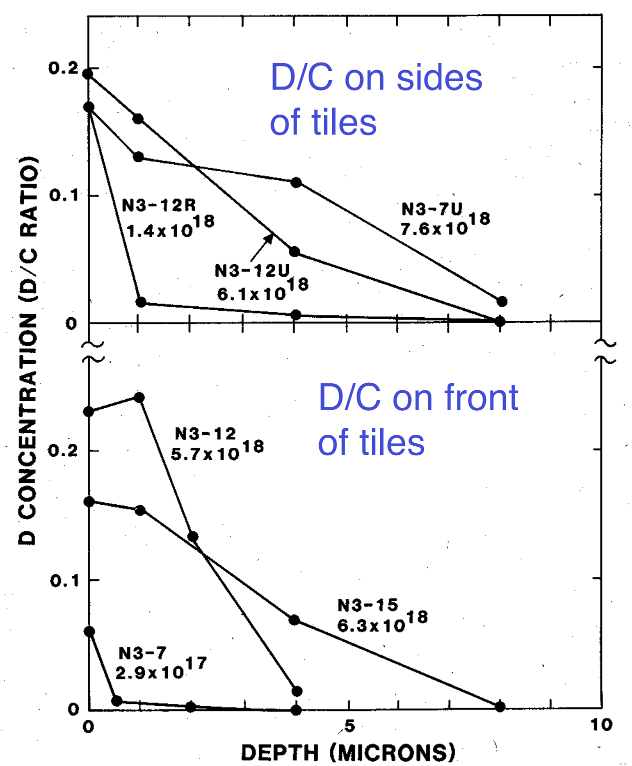


D deposition on tile gaps

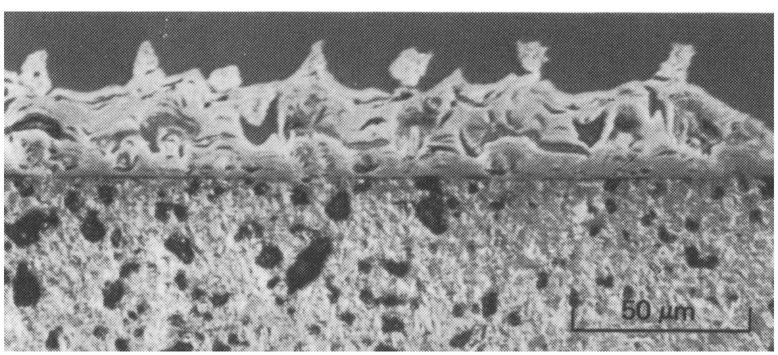
W. Wampler et al., J. Vac. Sci. Technol, A6 (1998) 2111,
B E. Mills et al J. Nucl. Mater, 162-164 (1989) 343.

Deposition on outer wall in DD phase

D/C ratios

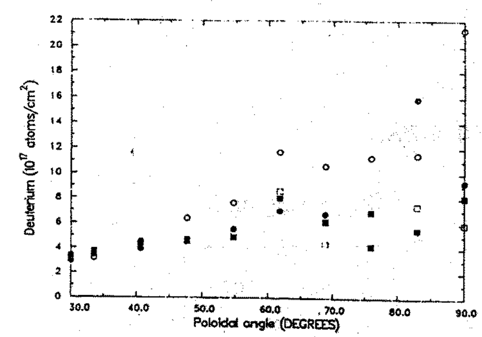


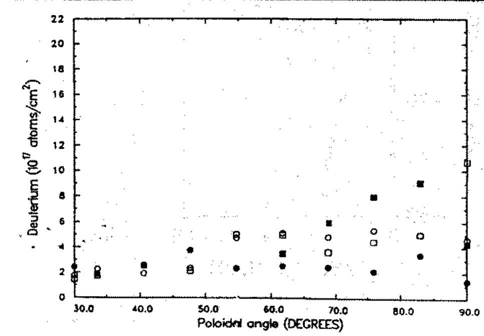
Integrated densities D/cm2 also indicated

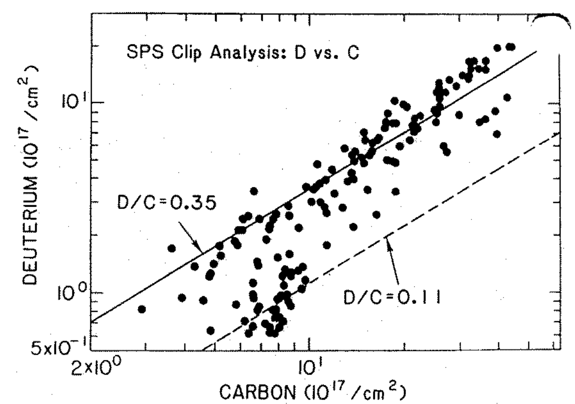


SEM cross section of co-deposit

Deuterium on SPS Clips from the TFTR wall.
Close to the limiter more D is retained.

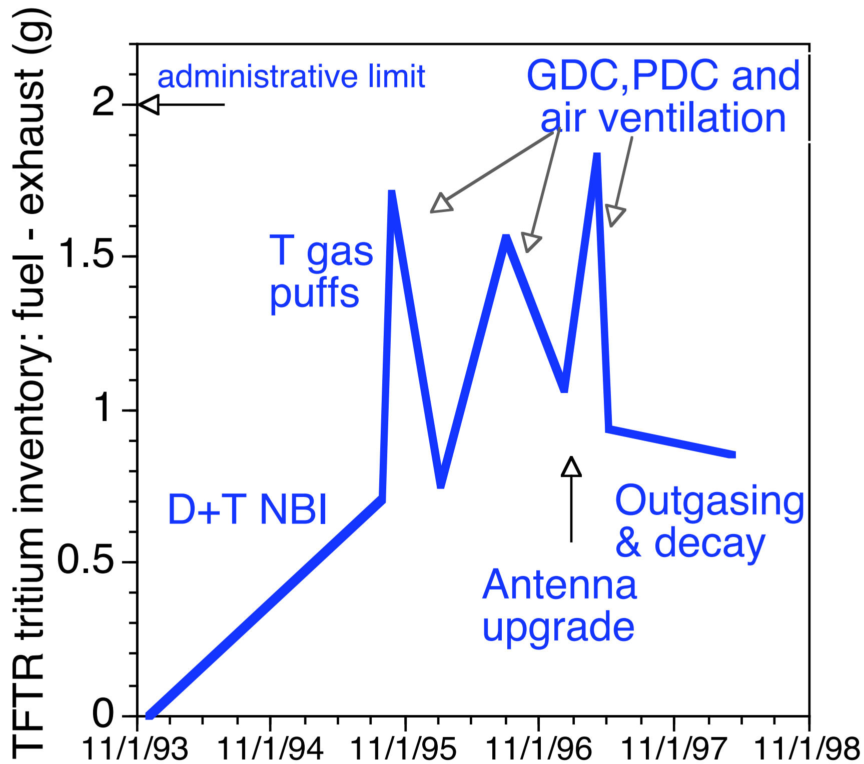


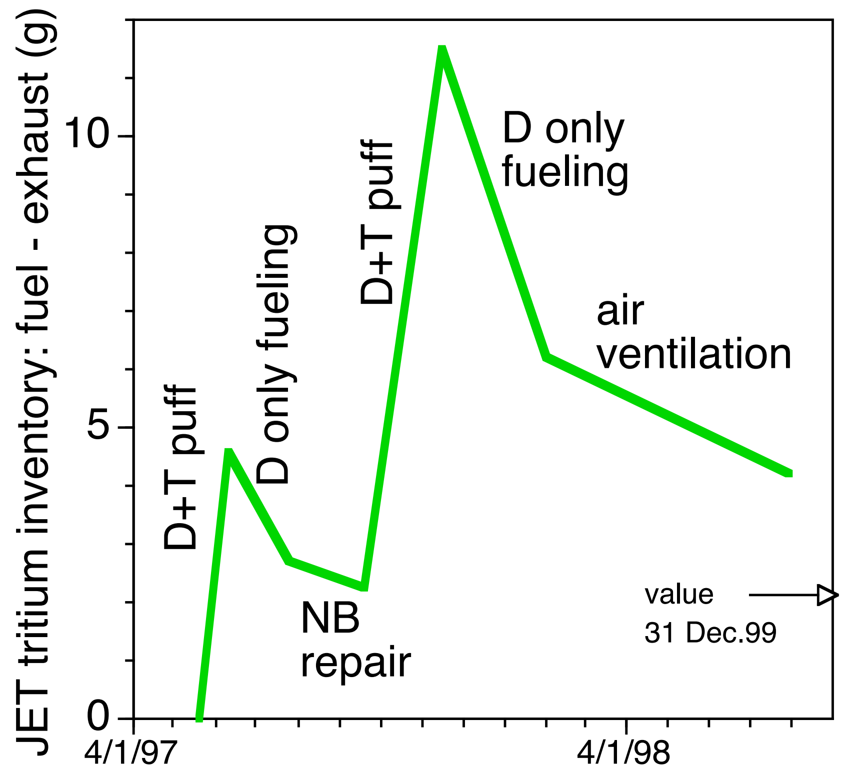




W. Wampler et al., J. Vac. Sci. Technol, A6 (1998) 2111,
B E. Mills et al J. Nucl. Mater, 162-164 (1989) 343.

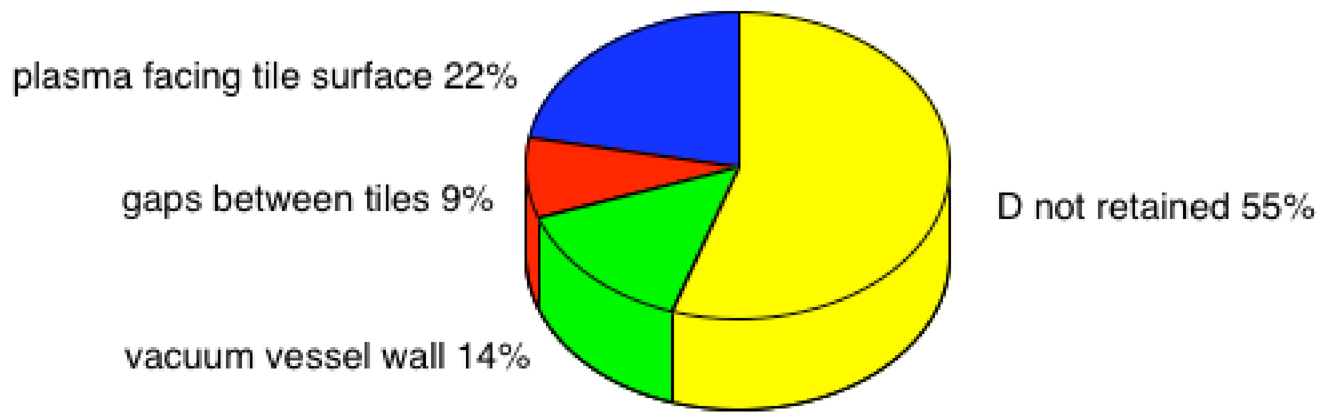
Chronology of tritium retention in TFTR & JET



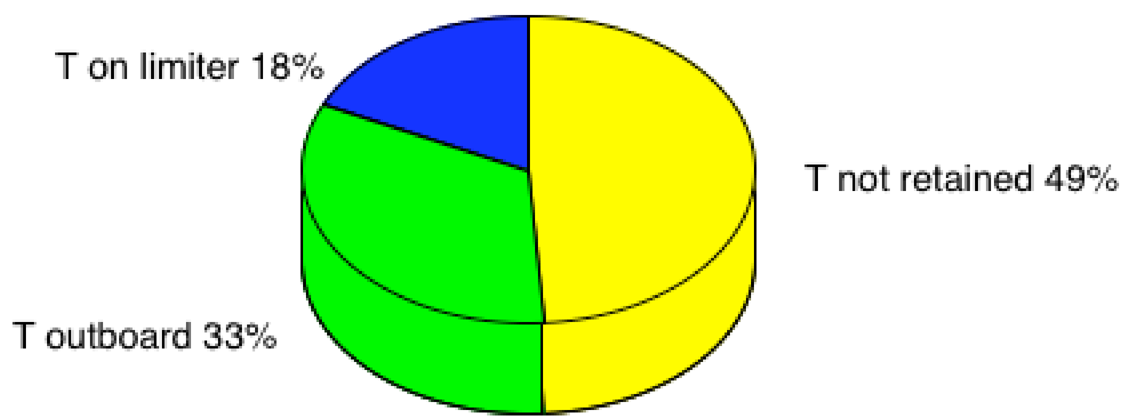


Fuel Retention

D retention from DD phase (Wampler)



T retention from DT phase



Tritium retention

	TFTR: 3 run periods over 3.5 y	JET: DTE1, over 6 m
Total tritium injected, NBI	3.1 g	0.6 g
gas puff	2.1 g	34.4 g
Total tritium retained during DT operations	2.6 g	11.5 g
Initial % retention during T puff fueling (wall saturation + isotope exchange)	≈ 90%	≈40%
Longer term % retention including D only fueling (mostly co-deposition)	51%	17%
Tritium remaining in torus	0.85 g (4/98)	4.2 g (7/98)
Long term retention	16% (4/98)	12% (7/98)
		6% (12/99)

- ***Larger source of carbon (for co-deposition) in TFTR limiter***
    - ***TFTR limiter conditioned to low D/C before T gas puffing.***
- ***D pulsing removed T from JET dynamic inventory leaving ~1/2 in co-deposits***

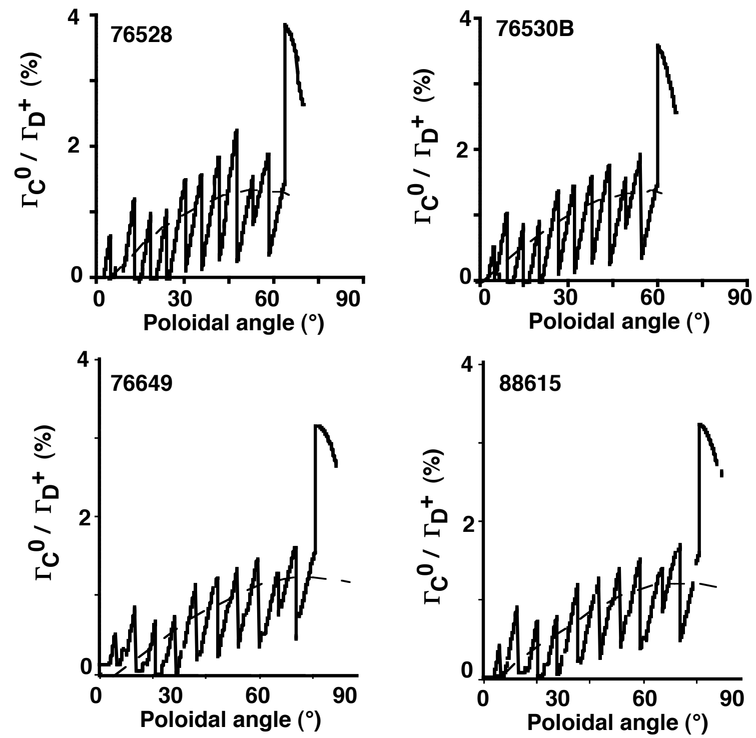
Modeling of C production and Tritium retention in TFTR (John Hogan)

BBQ code describes:

3D space, 3D velocity test particle Monte Carlo code for emitted C impurities from physical, chemical sputtering and radiation-enhanced sublimation (RES)

Parallel, perpendicular diffusion, electrostatic fields, friction with SOL flow, atomic/molecular physics *(includes Erhardt-Langer database for CD4 breakup)*

Combines detailed TFTR Bumper Limiter geometry (CAD) with impurity SOL transport and redeposition



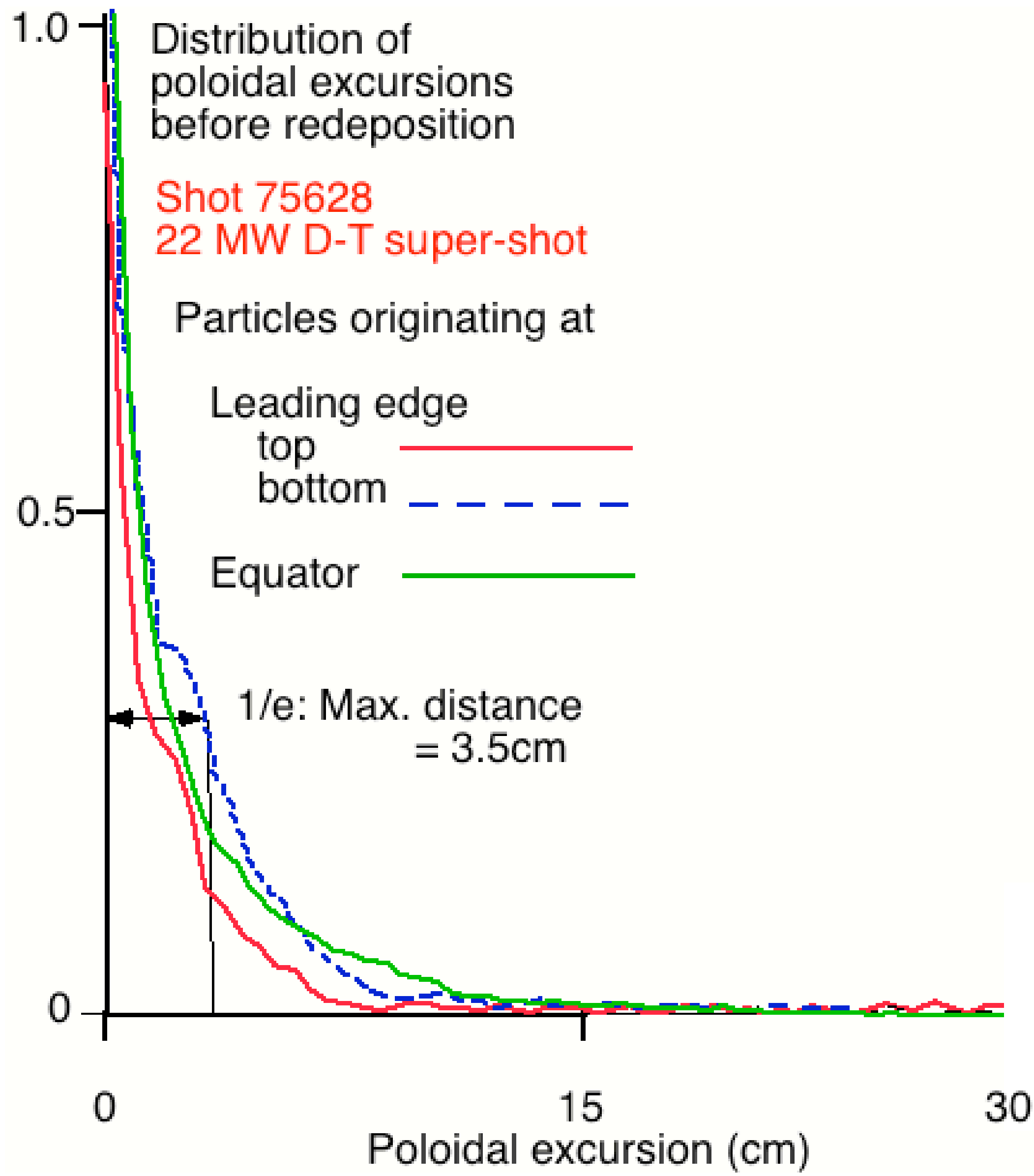
Local effective sputtering yield distribution on bumper limiter (emitted impurity flux / incident D+ flux for 4 representative discharges.

Extrapolate carbon erosion from selected representative discharges
H-isotope/C ratio in co-deposits approximately 0.2 (NRA) – estimate retention….

→ *Modeling can account for order of magnitude of retention (Hogan talk Thursday).*

Carbon + H-isotopes codeposited close to erosion point

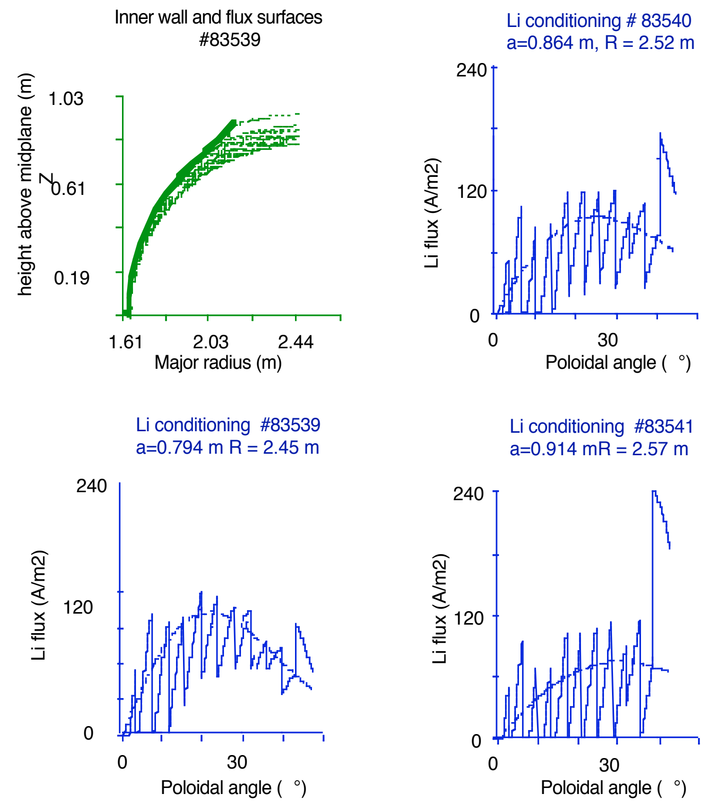
- BBQ shows strong localization of D+ flux at top/bottom leading edges of TFTR limiter.
- Data consistent with considerable number of TFTR discharges with large (≈10cm) radial decay length of the D+ flux due to inner wall recycling and flux amplification.
- Flight of sputtered carbon tracked in radial, poloidal and toroidal dimensions.
- Higher effective sputtering yield at high latitudes and prompt local redeposition leads to high codeposition in these areas.
- Significant concentrations of T predicted on upper and lower leading edges of limiter.



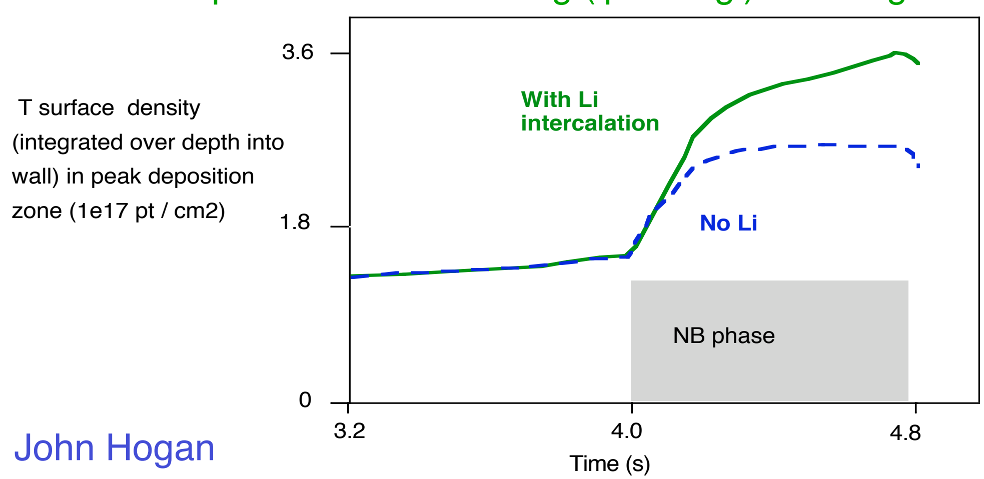
John Hogan

Lithium Conditioning may play role in TFTR tritium retention

- Deposited Li may be absorbed in graphite and form LiT, increasing tritium retention.
- Previous BBQ modeling gave agreement with observed T retention
- BBQ code now used to predict Li deposition in conditioning shots preceding DT shot
- Modeling shows both Li and T localized at high poloidal angle on inner limiter.
- WDIFFUSE code used to calculate Li intercalation (diffusion).
- Li and T implantation can overlap during the high power phase.
- Increase in predicted T retention by x1.3
- Brings modeling even closer to observed T retention (significant uncertainties in diffusion coefficients, SOL parameters and detailed history).



Li deposition pattern on TFTR bumper limiter in a sequence of conditioning ('painting') discharges

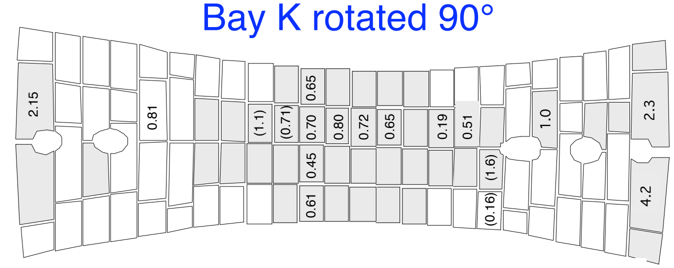


John Hogan

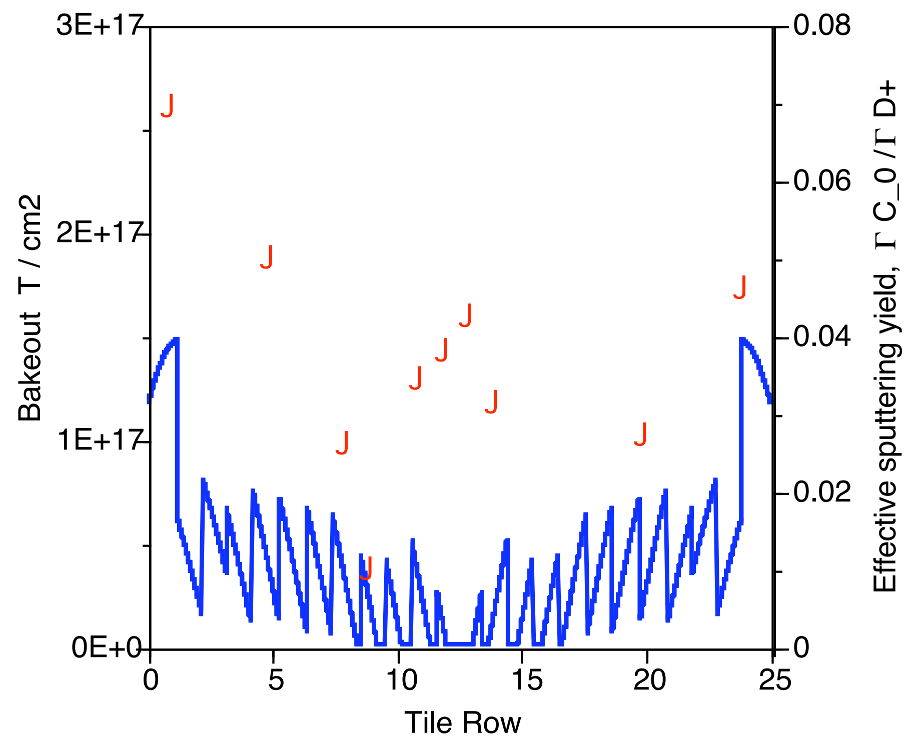
Modelling appears to be on right track

- Higher effective sputtering yield at high latitudes and prompt local redeposition leads to high codeposition in these areas
- Data consistent with considerable number of TFTR discharges with large (≈10cm) radial decay length of the D^+ flux due to inner wall recycling and flux amplification.
- Li deposition at same locations may enhance retention (Li used for wall conditioning).
- Observed tritium concentrations (measured after modeling predictions) suggest model is on right track.

Bay K rotated 90°



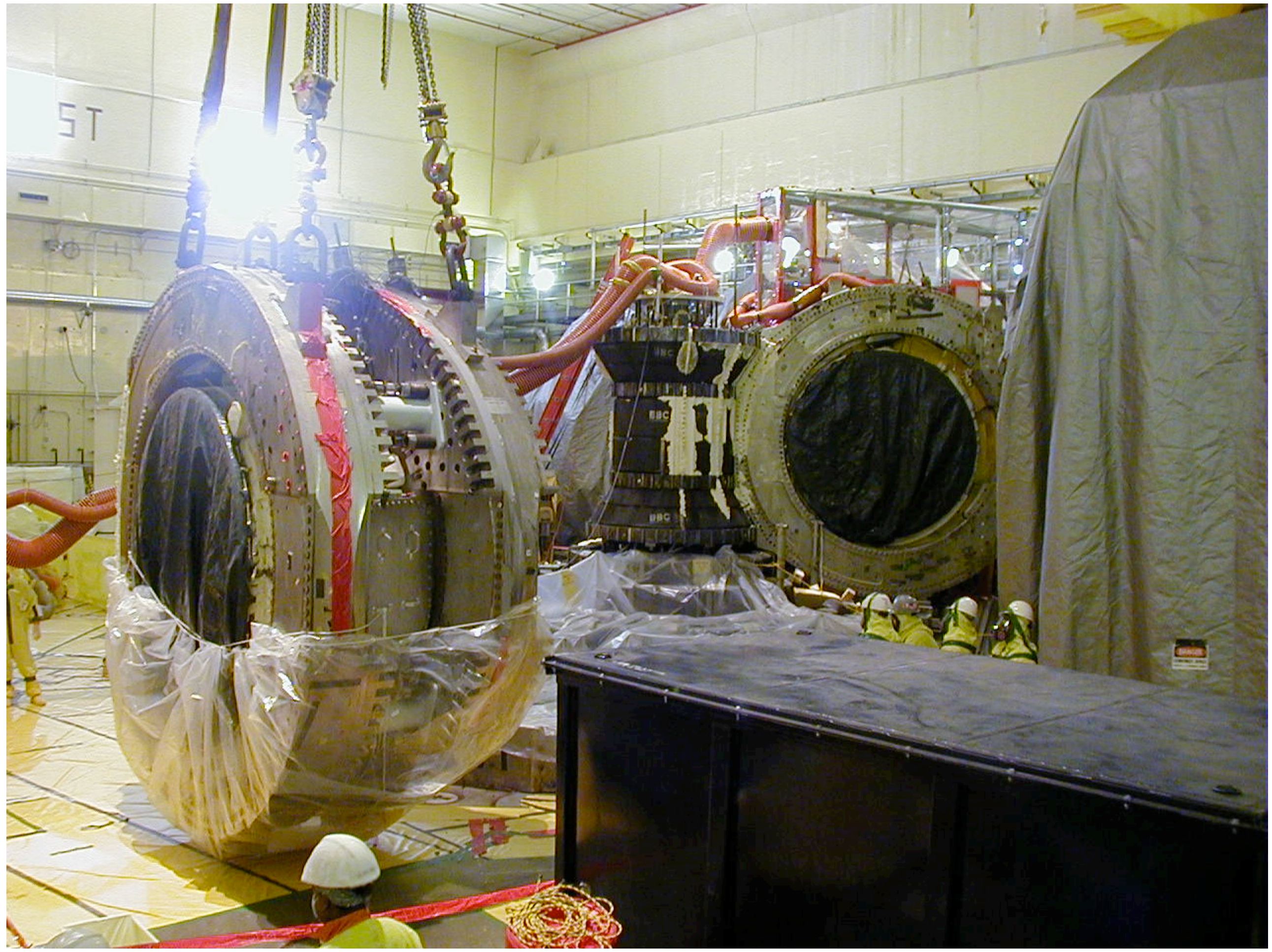
Measure tritium in selected tiles



Row averaged tritium release / plasma facing area (cm^2) compared to effective sputtering yield for # 76528

Postscript: TFTR D&D:

- The TFTR D&D is proceeding according to plan, on schedule, and will conclude by the summer of '02.
- The radiological liabilities and annual costs associated with "mothballing" are being eliminated.
- A modest amount of hardware has been saved and will be available for re-use in future devices.
- The work has been accomplished **SAFELY**.
- Data and lessons learned will be incorporated into a workshop at PPPL scheduled for later this year.



S Raftoupolos & D&D team, SOFE conference Atlantic City, Jan '02

Diamond wire used to section torus

Summary:

- Rich database of erosion/deposition/fueling from both deuterium and tritium phases
- Significant deposition on outboard wall in contrast to JET
- Short scale (1cm) spatial variations in deposition.
- Exposure to air lead to flaking of deposits, and high O content of film.
- Behaviour in DT and DD phase similar, approx 1/2 fuel retained in TFTR
- Broad agreement of observed retention with BBQ modeling.

Note: pdf version of Nuclear Fusion Review on
“Plasma Material Interactions in Current Tokamaks and Their Implications for Next Step Fusion Reactors.”

is available from: “http://epub.iaea.org/fusion/”

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