TFTR experience with tritium accounting and tritiated dust

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ITER / PPPL Conference call
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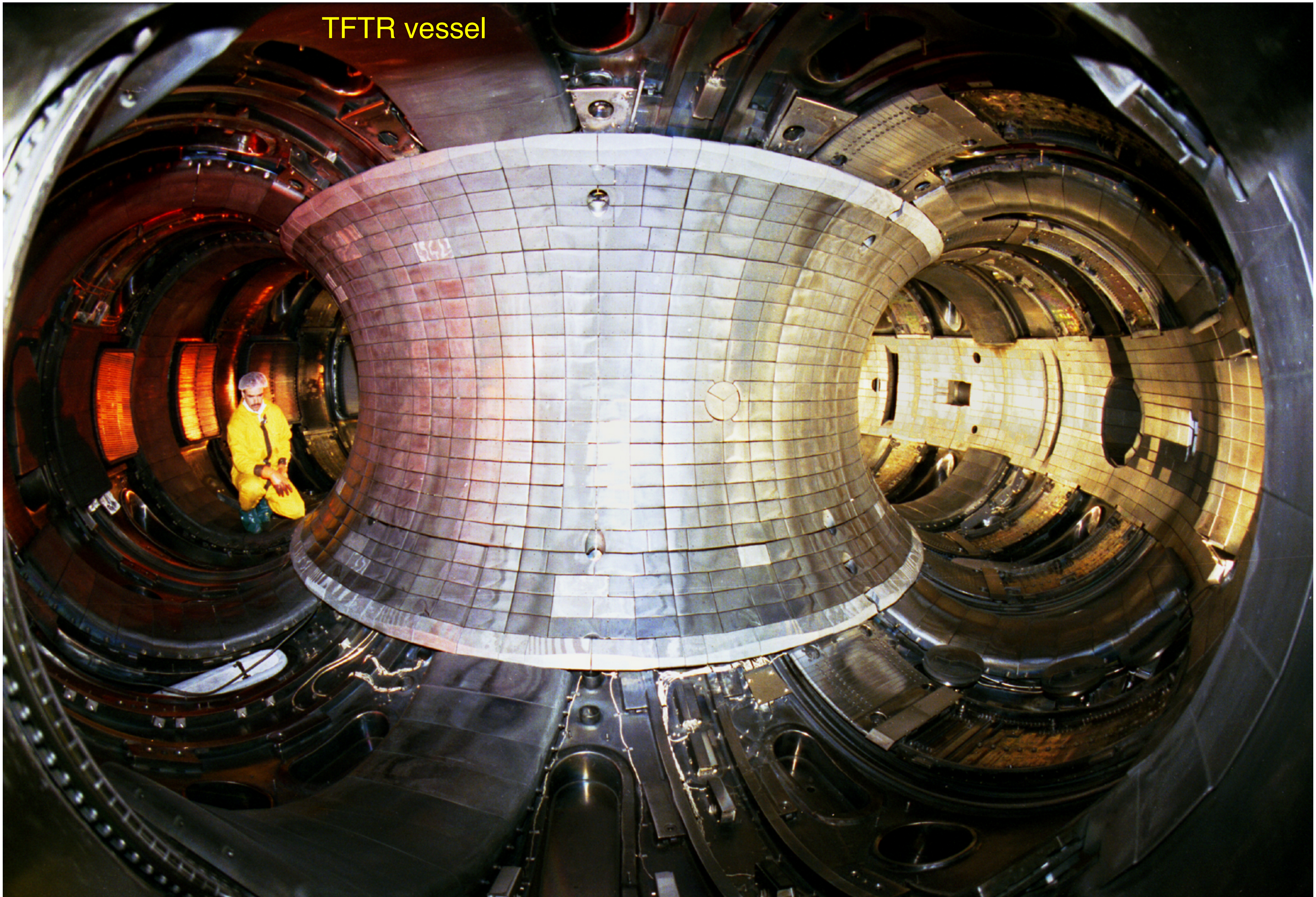
Outline:

- Introduction to TFTR
- Tritium experience
- Dust levitation
- Recommendations for ITER

'*Plasma-material interactions in current tokamaks and their implications for next step fusion reactors*'
G. Federici et al., Nuclear Fusion **41** (2001) 1967.
'*Recent Advances on Hydrogenic Retention in ITER's Plasma-Facing Materials: Be, C, W*'
C.H. Skinner et al., Fusion Science and Technology, **54** (2008) 891.
'*Conf. Report: Tritium experience in Large Tokamaks: Application to ITER*' C.H. Skinner et al., Nuc. Fus. 39 (1999) 271

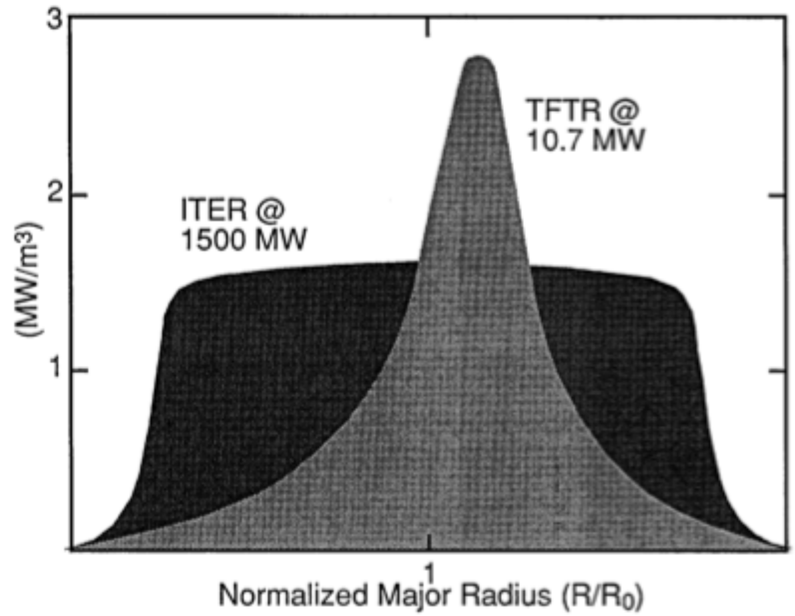


R= 2.6m, a= 0.9m, 6.0 T, 3 MA, 40 MW NB, 11 MW ICRF, ATJ graphite + CFC limiters, no divertor.

'Fusion plasma experiments on TFTR: A 20 year retrospective' R J Hawryluk et al., Phys. Plasmas **5** (1998) 1577.

Reactor level performance

- Reactor level fusion power 2.8 MW m^{-3}
- 10 MW of fusion power
- 6.5 MJ of fusion energy per pulse.
- 841 D-T pulses - 1.4 GJ of fusion energy.
- Total of 99 g-T processed.
- Site limits: 5 g facility, 2 g vessel, 0.05 g stack
  0.0001 g tritium in sanitary system release/year.
- The total annual site boundary dose:
  < 6 μSv, or 6% of the administrative limit of 100 μSv/yr.

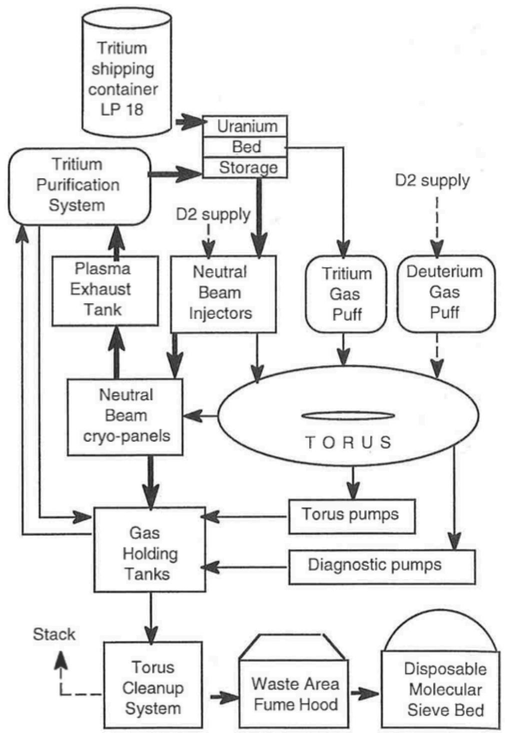


- Repurification of plasma exhaust via low tritium inventory cryogenic distillation system.
  8 g-T recycled back to TFTR for use as fuel during final months of operation.

'*Results from deuterium-tritium tokamak confinement experiments'* R. J. Hawryluk et al., Rev. Mod. Phys. 70 (1998) 537
'*D-T operation on TFTR'* M.D. Williams Fus. Eng. & Des. 36 (1997) 135
'Integration of the Tritium Purification System (TPS) into TFTR Operations' S. R. Raftoupolos et al., 1995, Proc. 16th IEEE/NPSS Symposium on Fusion Engineering, ed. G. Miley, and C. Elliott (IEEE, Piscataway, NJ), Vol. 1, p. 581

Tritium Accounting Lessons

- Pressure-Volume-Temperature (PVT) and Tritium Ion Chamber measurements used.
- All tritium movements required a procedure, pre-authorization and a receipt after the transfer, - these were compiled and tracked by double entry booking (like a bank).
- Hardware lessons learned:
  - Pre-tritium operation bench tests revealed valve throughput leakage due to incompatible seat material, EPDM was successfully substituted
  - During tritium operations piezo-electric pulse valves developed small throughput leaks. These were stopped by reverse biasing the piezos when not in use.
  - Container storage inventory uncertainties caused by the time shift between the "real time" and official databases were resolved by camera monitoring. This was critical when tritium was pressurized in the injector volume.
  - Femtotech U24 ion chamber was calibrated by the manufacturer in hydrogen, but the ion chamber gas function used to calculate the tritium concentration was different in the torus exhaust of N_2, Ar, O_2, He, T_2 leading to error. Re-evaluation resulted in a decrease of -40% in vessel tritium retention values.
  - A stirring fan was used to prevent stratification in the gas holding tank —originally not considered a problem but found in practice to affect GHT tritium measurements.

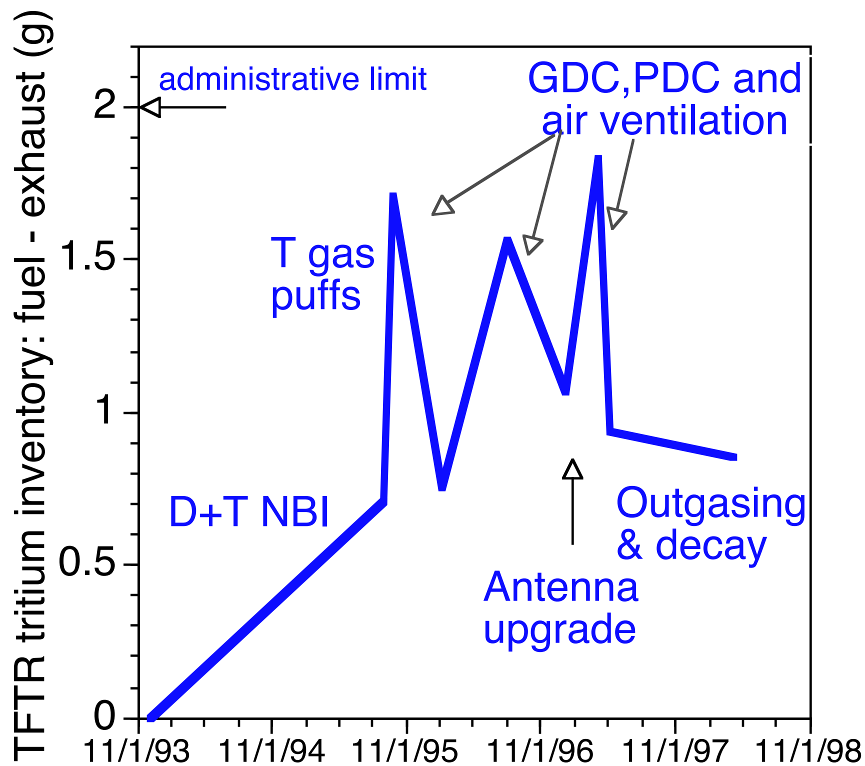


'*TFTR Tritium Accounting System for DT-Operation*' A. Nagy et al., 1995, Proceedings of the 16th IEEE/NPSS Symposium on Fusion Engineering, Champaign, IL, edited by G. Miley, and C. Elliott (IEEE, Piscataway, NJ), Vol. 2, p. 573

High Tritium Retention in TFTR

Total tritium injected, NBI	3.1 g
gas puff	2.1 g
Total tritium retained during DT operations	2.6 g
Initial % retention during tritium gas fueling (wall saturation + isotope exchange)	≈ 90%
Longer term % retention including D only fueling (mostly co-deposition)	51%
Tritium remaining in torus 4/98 (after GDC, PDC air ventilation)	0.85 g (4/98)
Long term retention	16% (4/98)

Three DT campaigns over 3.5 yr



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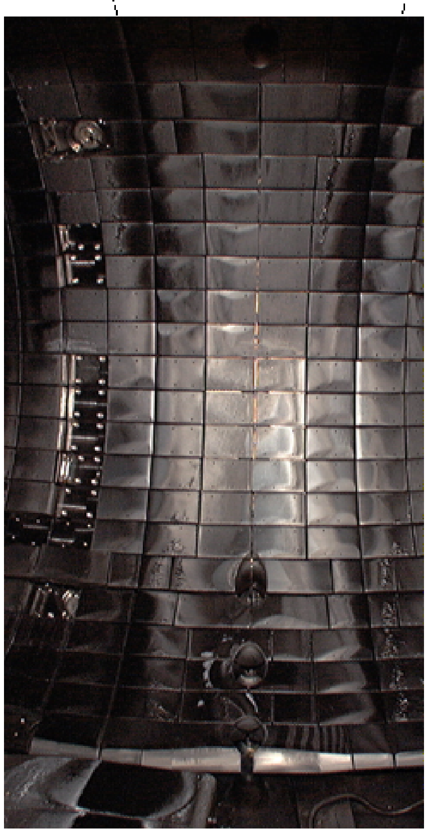
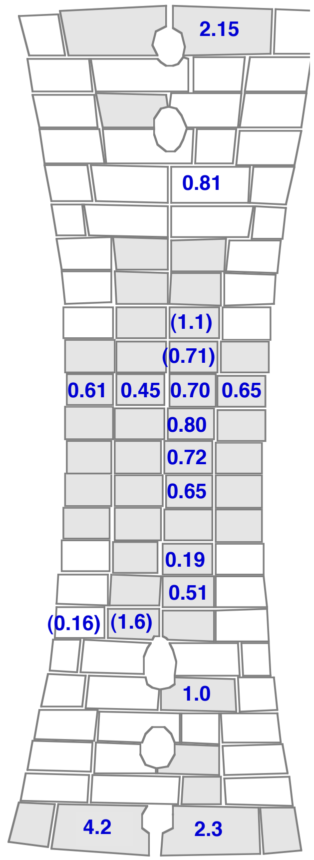
Tritium inventory well established

Bay K



Co-deposition, flaking, on bumper limiter at Bay K.



Tritium released (Ci) by 1-hour 500C bake

Inboard limiter (22 m^2)	0.2 g-T
Outboard (110 m^2)	0.36 g-T
Total from tile/coupon analysis:	0.56 g-T
Gas balance inventory	0.64 g-T

Remarkable agreement between extrapolation from tile measurements and gas balance inventory !

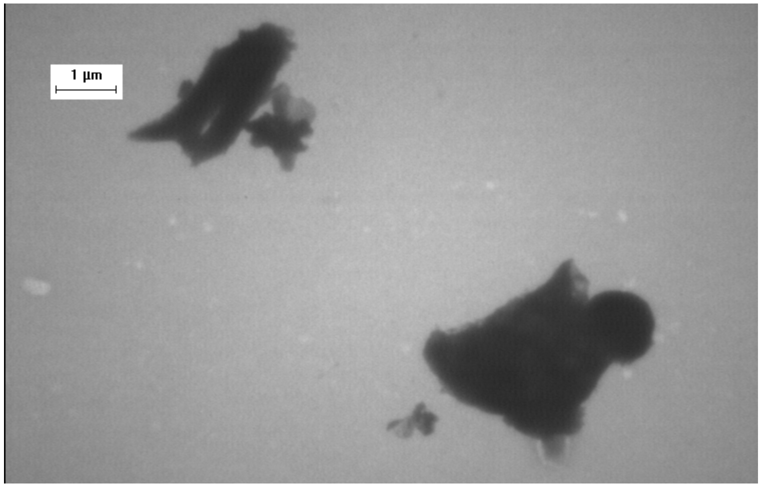
High tritium concentrations found at top and bottom of bumper limiter as predicted by previous BBQ modeling.

'*Studies of tritiated co-deposited layers in TFTR*' C. H. Skinner et al., J. Nucl. Mater. 290-293 (2001) 486

Dust Mobility

- The mobility of tritiated particles is an important factor in:
  - assessing tokamak accident scenarios,
  - occupational safety when handling tritiated components
  - tritium transport in the plasma.
- Dust can become lodged in lung alveoli prolonging exposure
- Radioactive decay of tritium via beta emission leaves a positive charge on a dust particle.
- Such dust is easily attracted to insulating materials such as plastics with a static charge, or may respond to electric fields in tokamaks.
- Tritiated particles appear to be uniquely more mobile than other dust.

Debris and dust on TFTR vessel floor

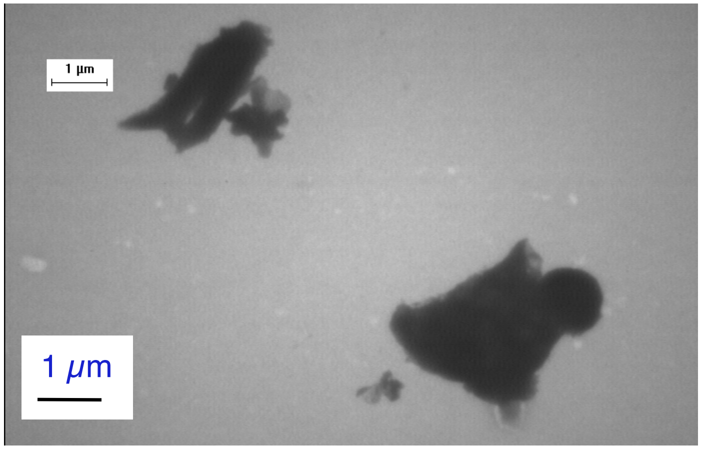


Dust retrieved from TFTR.

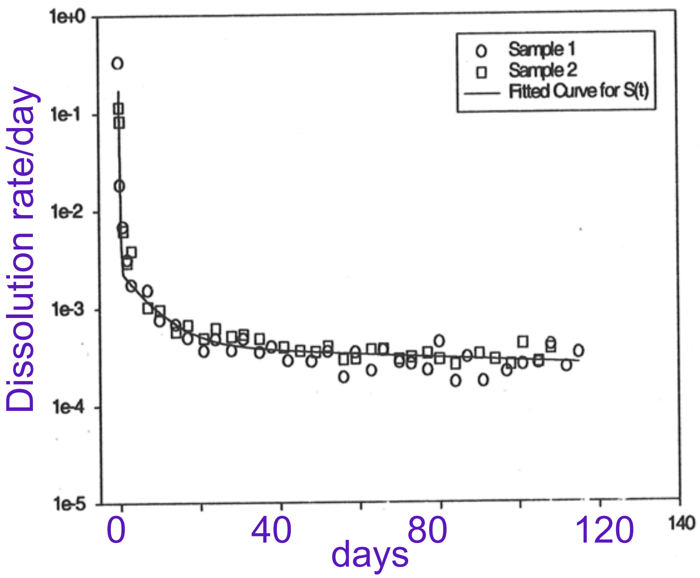
Tritiated dust radiological dose

- Analysis of TFTR tritiated dust showed count median diameter = 1.23 μm
  - can stay suspended in air
  - particles respirable
- Dust can become lodged in lung alveoli prolonging radiation exposure
- > 90% of tritium remained in simulated lung fluid after 110 days (c.f. HTO eliminated from body in 10 days)
  - longer residence time =
    - ➢ less sensitive to biological assay
    - ➢ greater radiological hazard.

What are radiological limits for personnel exposure to BeT dust ???



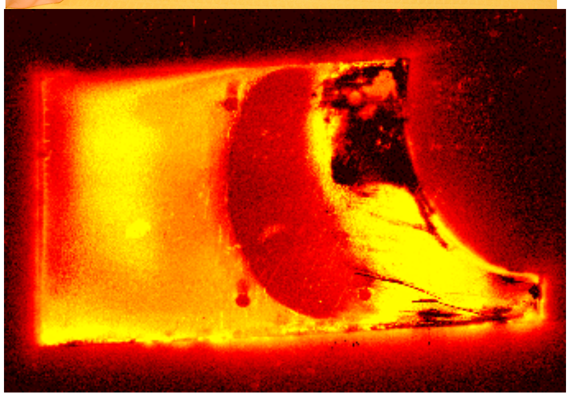
~ 1 μm tritiated dust retrieved from TFTR.



Tritium dissolution out of dust

'*Characterization of Carbon Tritide Particles in a Tokamak Fusion Reactor*.' Y.S. Cheng et al., Fus. Sci. Technol., 41 (2002) 867.
'*Biological hazard issues from potential releases of tritiated dust from ITER*' L Di Pace et al., Fus. Eng & Des. 83 (2008) 1729.
But Pace did not reference Cheng's work and used models that don't appear to consider charged dust dispersal

Tritiated Dust Levitation



Tritiated deposits revealed by Imaging Plate technique

Samples of codeposit were scraped from TFTR tile KB3 for analysis. A small quantity was loaded into a small glass vial with a plastic cap for analysis of beta induced conductivity. In this process the plastic cap was rubbed by neoprene gloves.

'*Tritiated Dust Levitation by Beta-induced Static Charge*.' C.H. Skinner et al., Fus. Sci. Technol., 45 (2004) 11.

CFC tile particles -no tritium

Particles from tritiated TFTR tile KB3

stills from movies

CFC tile particles -no tritium

Particles from tritiated TFTR tile KB3

Tritiated dust is more mobile

- Rubbing plastic cap by neoprene or latex gloves induces a static charge that caused a 'fountain' of dust within the vial.
- Movies document technician experience of mobilizability of tritiated particles
  - dust can levitate, fly across fume hoods and climbs walls !
- Any material exposed inside a fume hood containing tritiated dust can become contaminated.
  - Example: imaging plates were used to map tritium distribution on tritiated TFTR tiles. A 2 micron film was used to prevent contamination of IP. However unwrapping one layer in fume hood still resulted in contamination. A double layer of film with inner layer unwrapped outside fume hood was necessary to avoid IP contamination.
- Stringent precautions (air flow, personnel protective clothing) were successful in keeping dust localized to fume hood.
- Note TFTR overall T/D fueling ratio = 3%, static charge will be much higher with 50/50%.

Recommendations for Dust

Recommendations from TFTR experience include:

- Demonstration of reliable operation of capacitive diaphragm detector for extended periods of time (years) without maintenance while maintaining its calibration in a realistic simulation of the ITER environment including:
  - Large shot-to-shot temperature excursions,
  - Violent mechanical shocks (from ELMs),
  - Radiation,
  - Long signal leads, ITER-scale electromagnetic interference
  - Strategy for emptying the gauge when it is full of dust.
  - Validation of measurements of radioactive dust.
- Validate the extrapolation from spot dust measurements to the total dust inventory in an ITER scale-model.
- Remove at least one ITER divertor cassette and collect dust from the lower vessel after H operations to validate the spot measurements and extrapolation to the total dust inventory.
- Establish personnel/public radiological limits for BeT dust

Recommendations for Tritium handling

Recommendations from TFTR experience* include:

- Central management of tritium transfers
- In situ calibrations
- Effective tritium control valves
- Redundant systems to allow repairs/calibrations on one tritium fuel/exhaust system while the other is supporting operations.
- Tritium processing technology testing in a fusion environment where tokamak exhaust contains exotic and sometimes corrosive impurities.

- Incorporate all DTE workshop issues in the existing ITER risk management process. [*John Tapia / Akko Maas IO-DA Meeting 19 March 2008 ITER_D_2EW3E7]*
- Use Technical Readiness Level (TRLs) to assess status and progress.

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