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NSTX

Dynamic retention and deposition in NSTX measured with quartz microbalances

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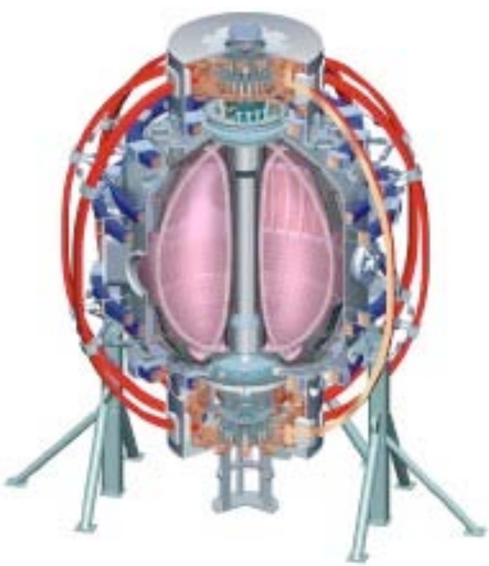

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Motivation:

Tritium retention and removal is a high risk and high consequence issue for ITER.

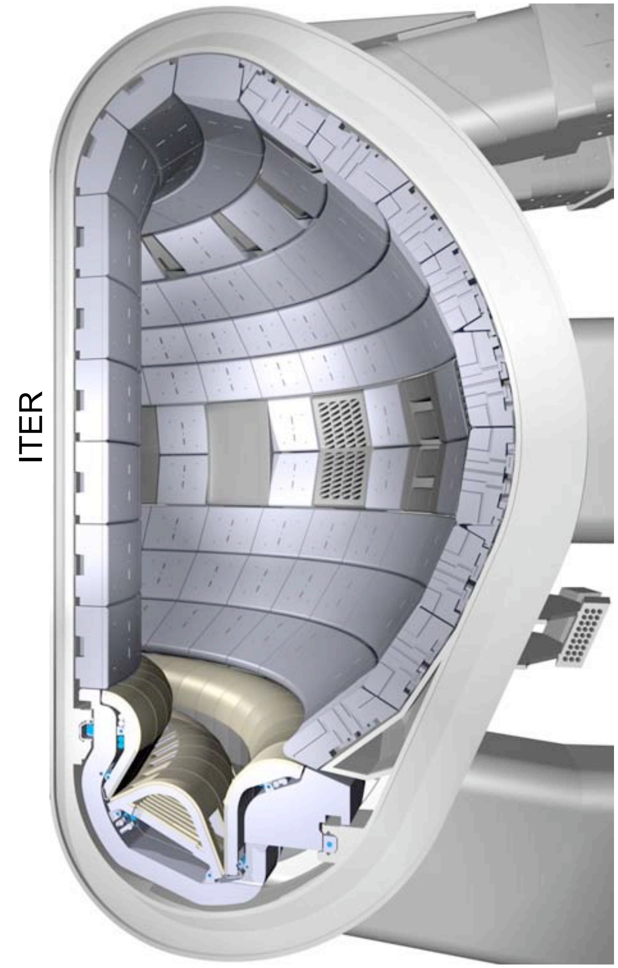
- predictive understanding lacking

Conventional Wall Diagnostics:

1. Tile / coupon samples
   - Well defined spatial location
   - Time integrated 'archeology'
     - no correlation with plasma events
2. Gas balance (fueling & exhaust)
   - Well defined time resolution
   - No spatial information

These typically give widely different values for retention (TFTR a notable exception).

ITER vacuum vessel

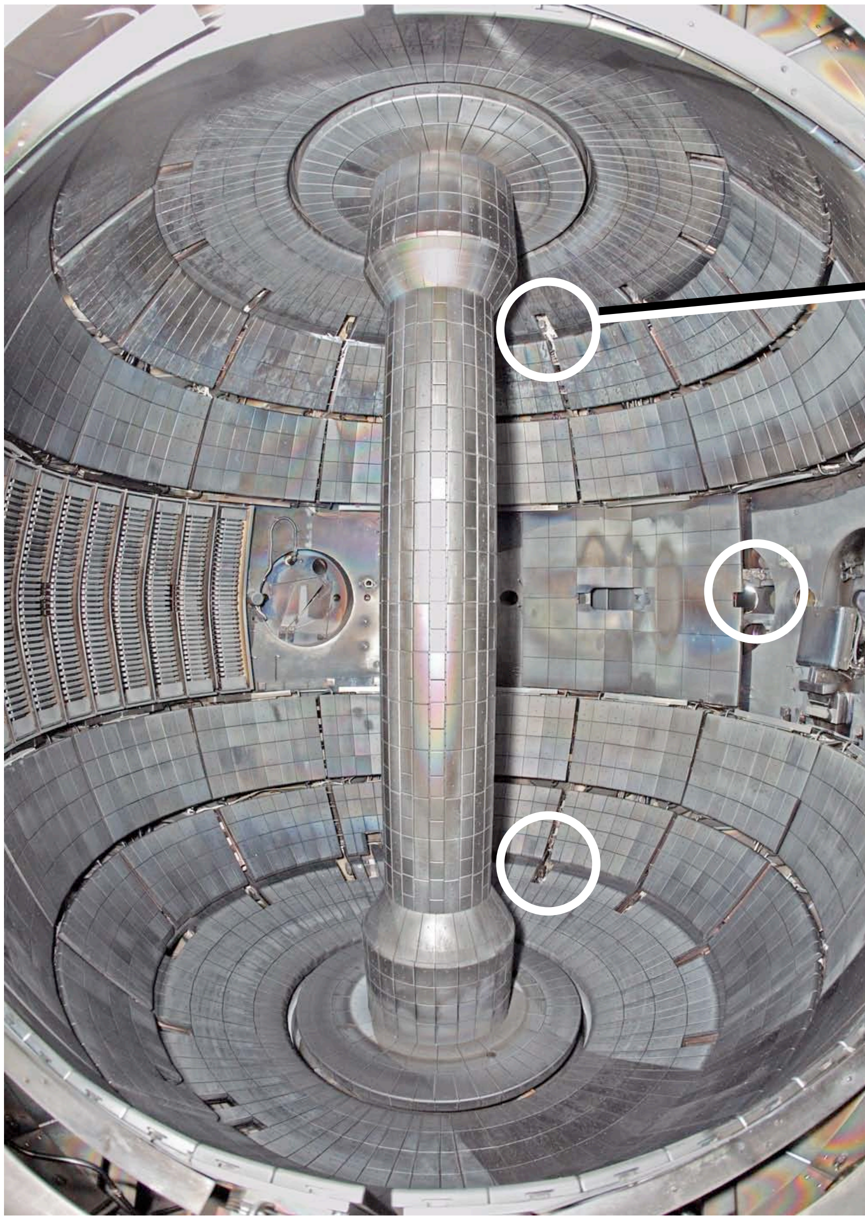


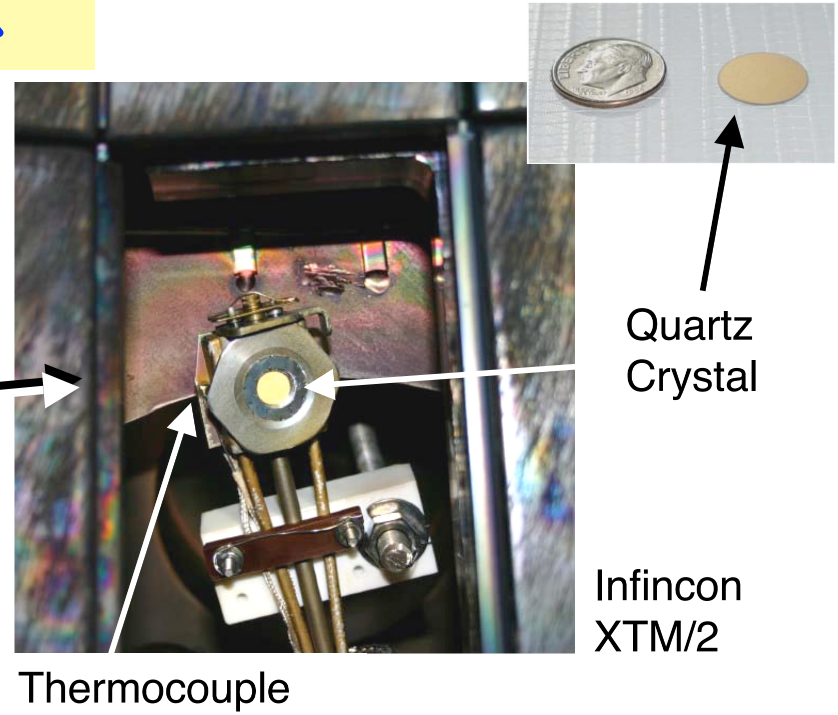
Quartz Microbalances (QMBs) offer both space and time information.

limitations:

- cannot be used in high heat flux area.
- relatively sparse coverage due to cost

Quartz Microbalances in NSTX



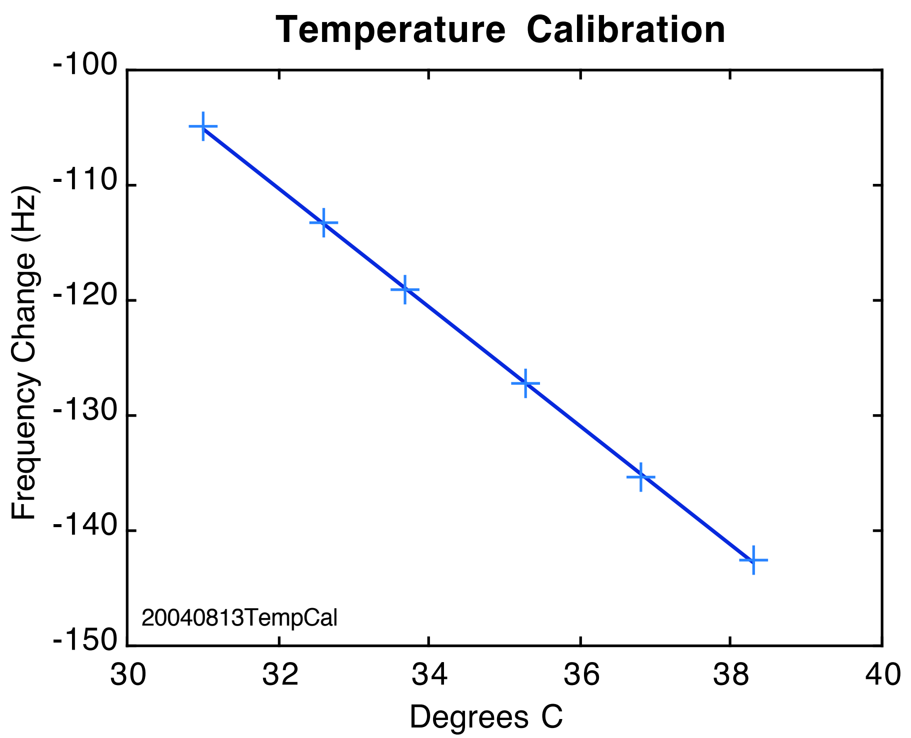


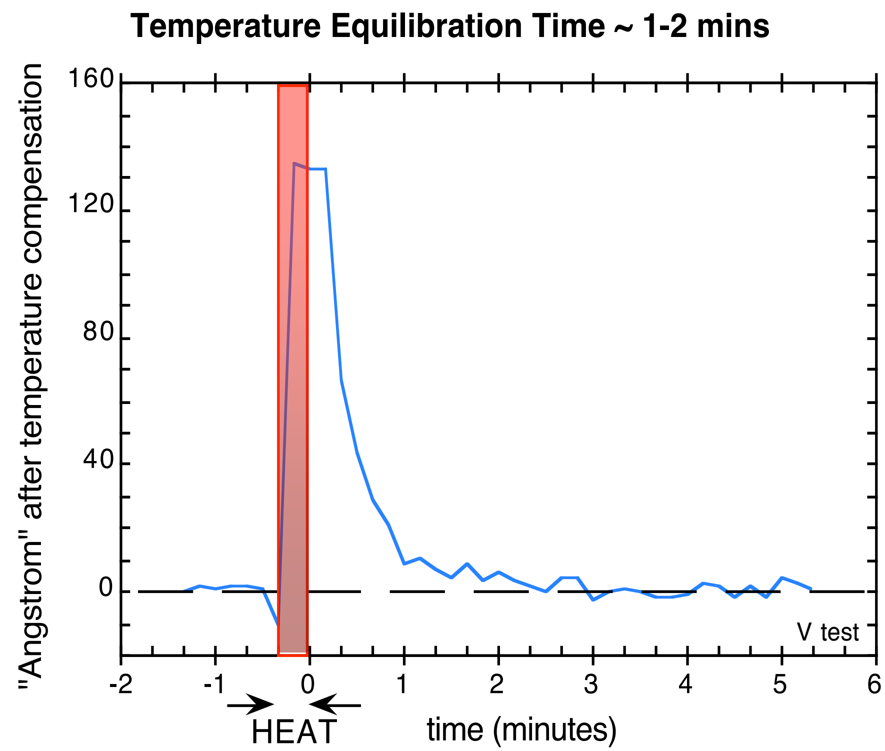
Deposition changes quartz crystal oscillation frequency.

$$\frac{\text{film mass}}{\text{crystal mass}} = \frac{\text{frequency change}}{\text{bare crystal frequency}}$$

- Frequency measured by pulse accumulator controlled by 20 MHz reference oscillator.
- Resolution < one monolayer
- Mass consistent with independent NRA measurements

QMB temperature compensation:



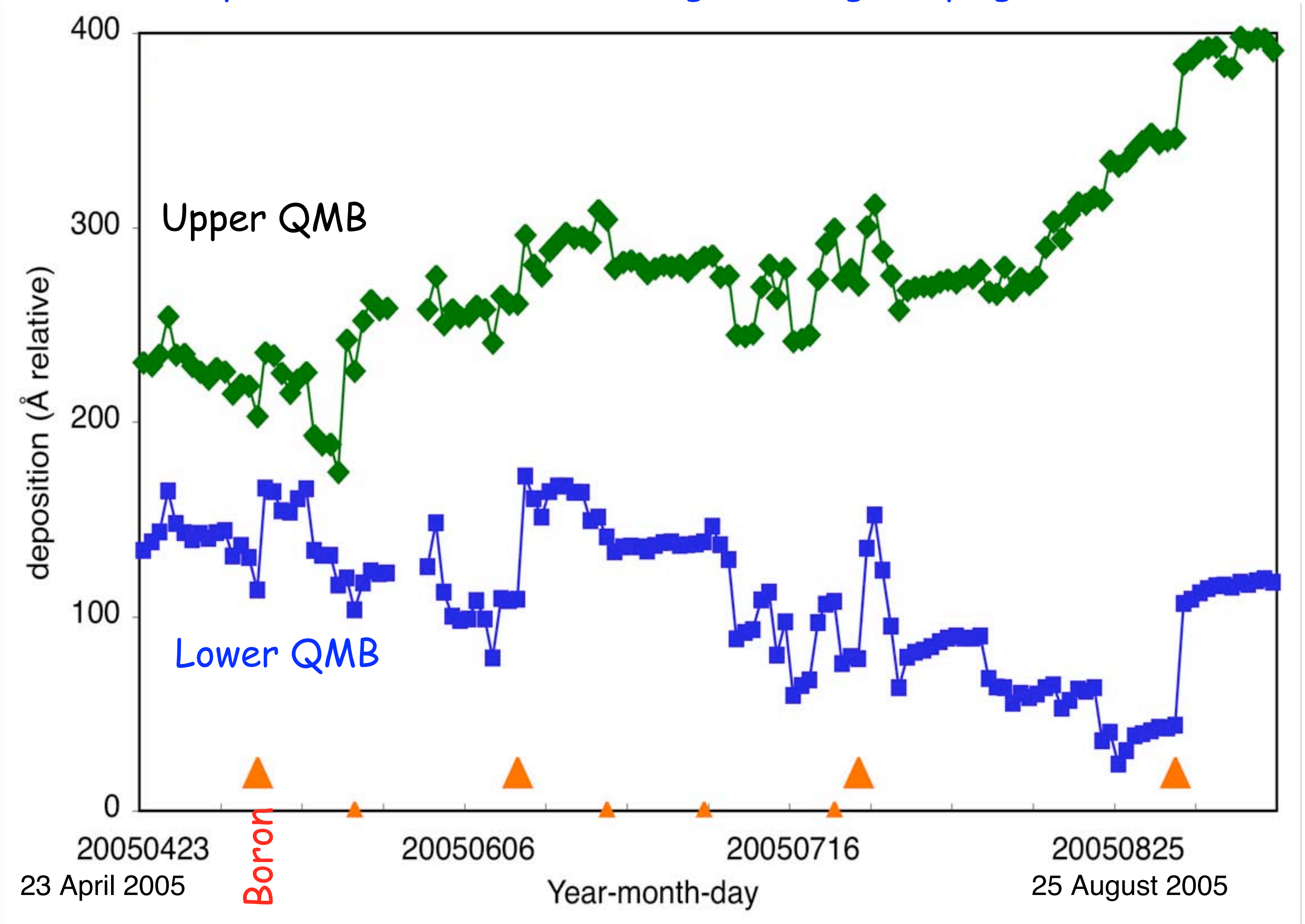


- QMB frequency is temperature dependent
- thermcouple monitors qmb temperature.
- temperature calibration derived from weekend temperature drift:
- 1 degree C increase is equivalent to: 3.7 Å deposition.
- temperature induced frequency changes are subtracted from data

- Transient temperature differences between qmb crystal and thermocouple possible.
- Soldering iron applied to qmb housing for 20 s.
- Frequency changes with temperature.
- Temperature compensated "thickness" recovers after 1-2 mins.

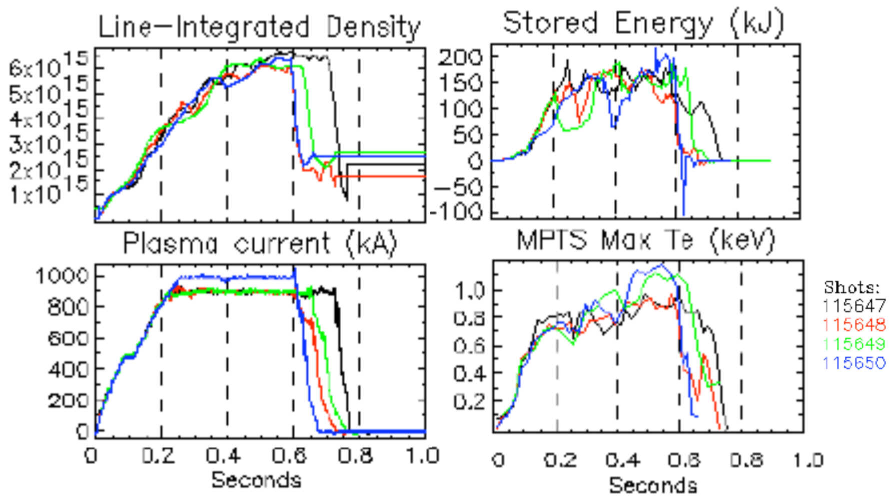
Overview: a complex pattern of material gain and loss

Deposition thickness at midnight during campaign



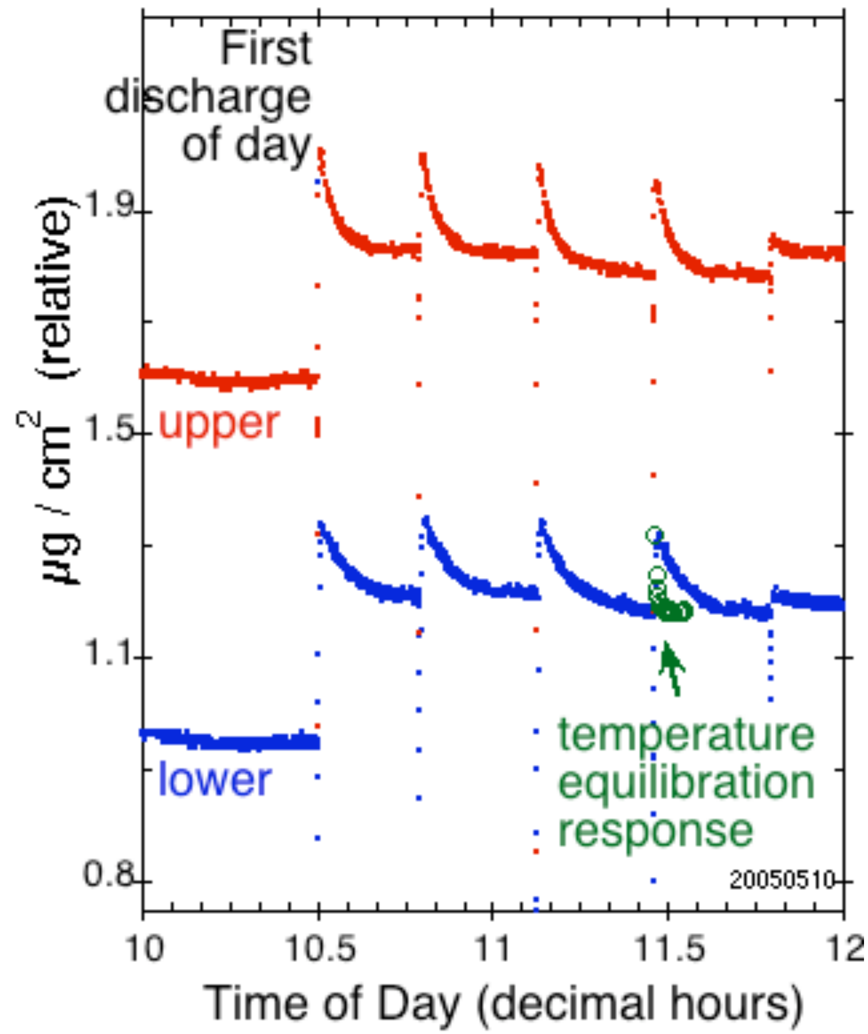
Correlation of thickness with boronization apparent … zoom in to discharges >>

Four similar discharges have very different mass change:



- "Staircase" of discharge-by-discharge erosion or deposition not observed.
- Transient rise seen followed by decay
  - decay longer than thermal relaxation time
- QMB asymptotic level can be higher, lower or the same as before discharge.

QMB mass change



First shot of day always shows a step-up in asymptotic level.

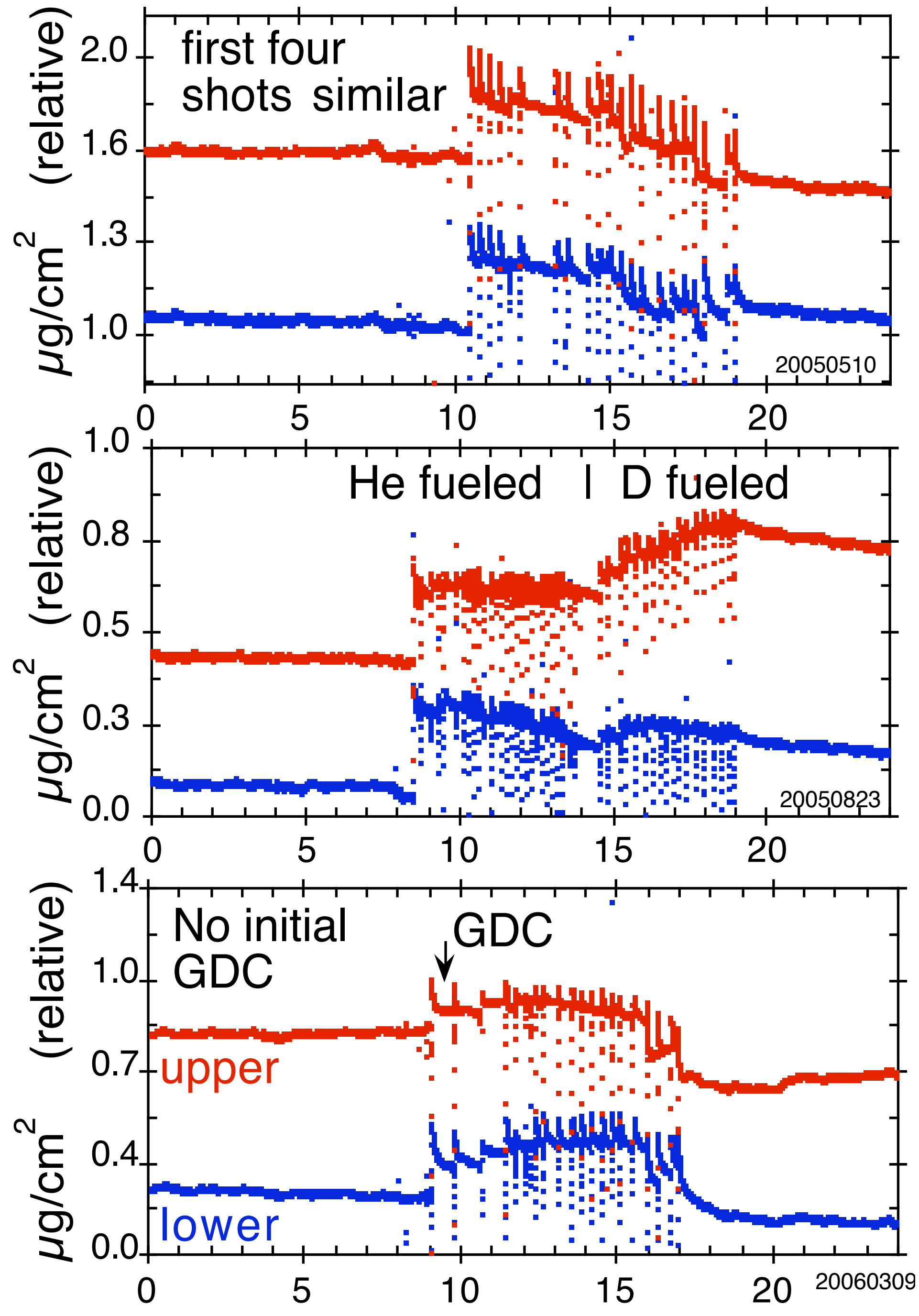
Mass changes over 24 hours:

General Features:

- Discharges show transient rise followed by decay.
- Large step-up in mass on 1st shot of day

  Effect independent of:
  - prior He glow discharge,
  - discharge type: Ohmic (115476) or NBI, He or D
- Some discharges show step-up or step-down in asymptotic level.
- Slow mass loss at end of day.
- Behavior does not fit simple deposition/erosion picture

Y-axis zero point arbitrary



Behavior can be explained by dynamic retention of D

- Overnight outgassing desaturates wall.
- D implanted on 1st shot adds mass, saturates wall.
- Outgassing between shots too slow to desaturate wall.
- Mass gain on subsequent discharges is much less.

Look at numbers:

5e21 D atoms fuel each discharge

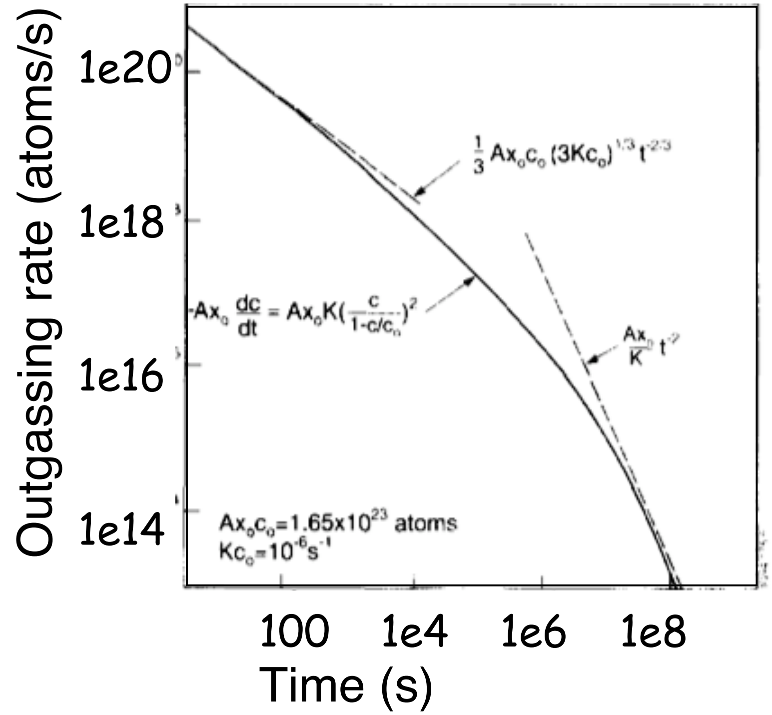
Interior surface area of NSTX

= 40.66 m² = 4e21 Å²

Fueling equivalent to about

one D atom per Å² or 0.04 μg/cm²
if smeared over NSTX interior.

Initial mass gain of QMBs is ≈ 0.35 μg/cm²
i.e. 10 x higher.



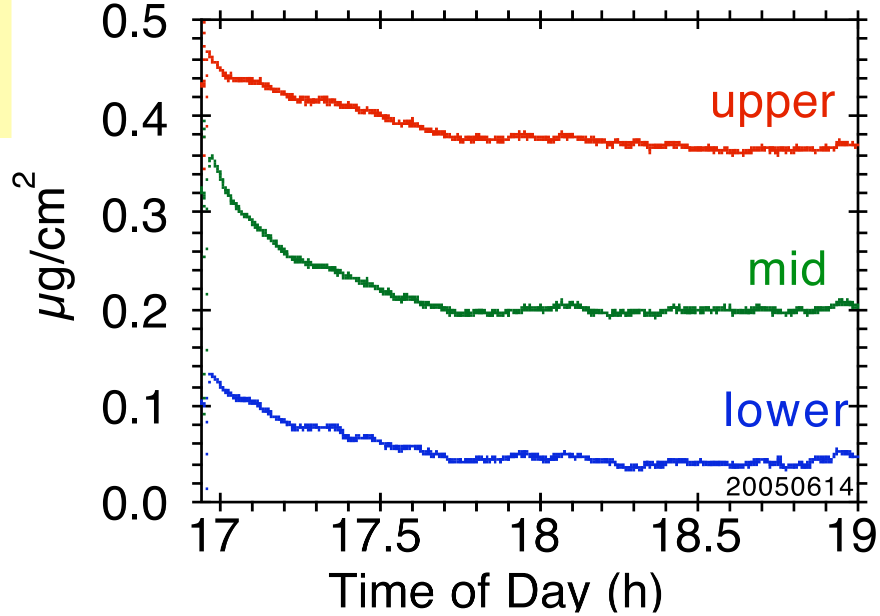
Model of outgassing of H in traps and solution in carbon [Andrew & Pick JNM 220-222 (1995) 601]

Strong dependence of outgassing rate on H concentration

CONCLUDE: Dynamic retention concentrated in plasma shadowed regions.

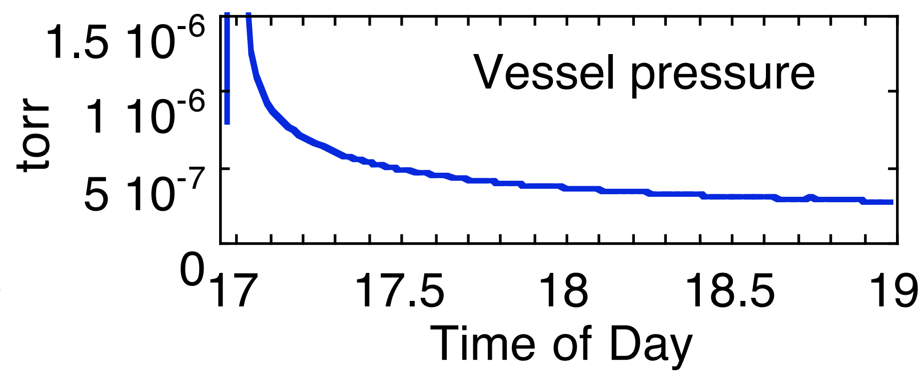
End of day behavior supports dynamic retention:

- Mass loss continues for ~ > 1 h after last discharge
- Outgassing of deuterium evident in ion gauge and rga data.

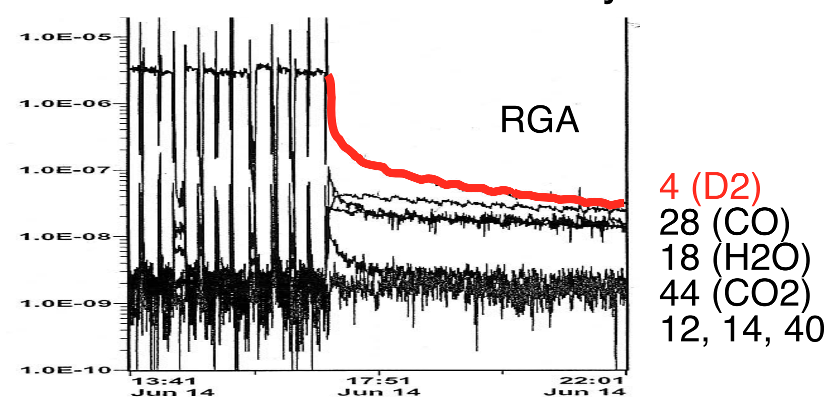


<u>Compare material loss to exhaust pumpout:</u>

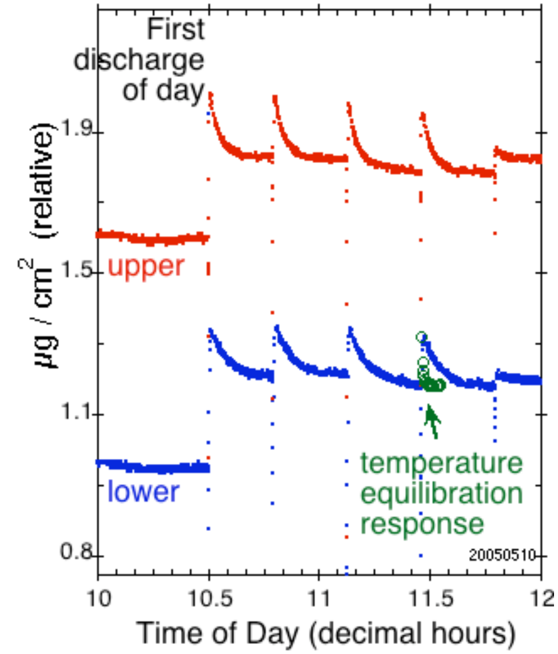
- Average mass loss from 17h - 18 h is 0.11 $\mu g/cm^2$
- RGA shows exhaust mostly D (>70%)
- Mass of deuterium pumped by turbopumps from 17h - 18h is ~ 984 μg
- 1 h exhaust is equivalent to mass loss of 0.1 $\mu g/cm^2$ over 1 m^2



- Suggests dynamic retention occurs over only a small fraction of the NSTX vessel area (consistent with gas uptake on first shot of day)



Conclusions:

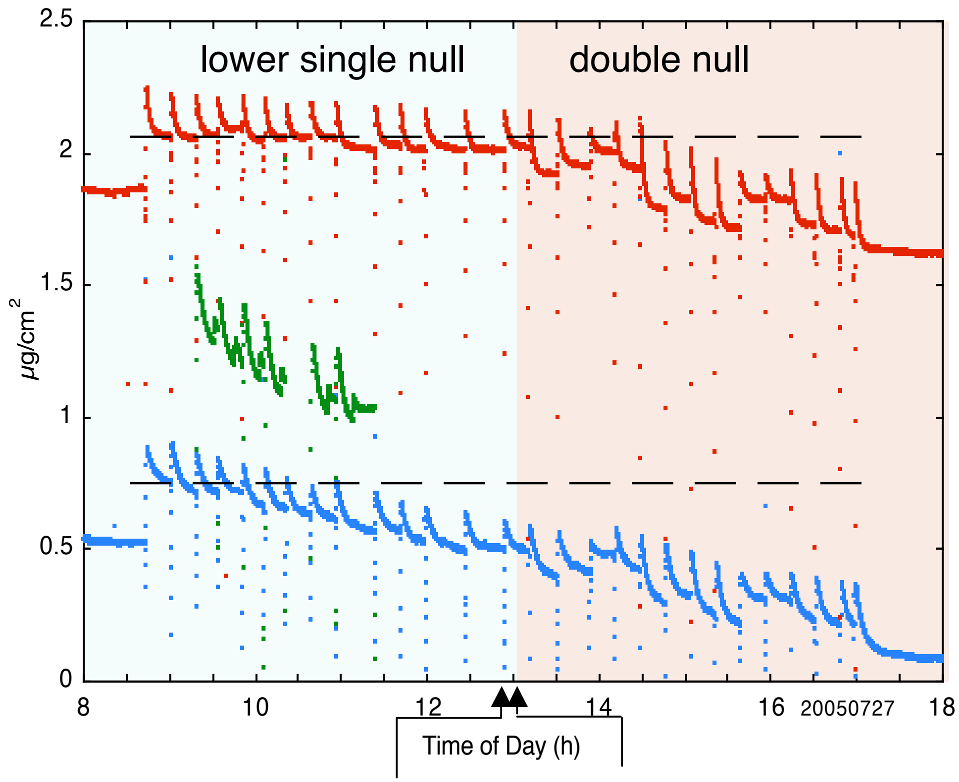


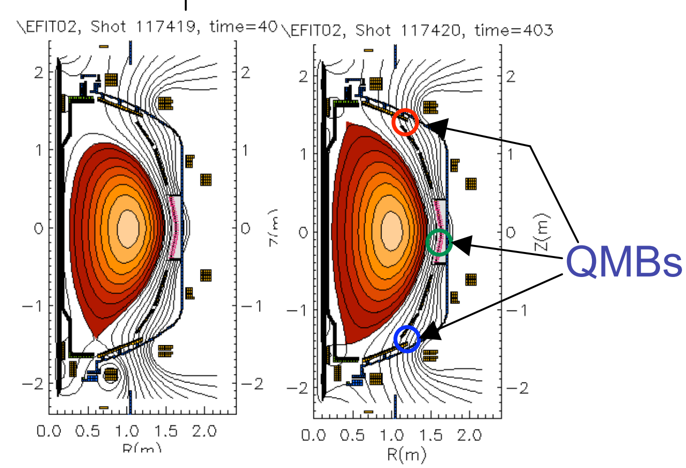
- QMB's offer time <u>and</u> space resolved data on wall coatings.
- Dynamic retention observed in mass gain after 1st shot-of-day and transient material loss after discharges.
  - also seen on Asdex-U
- Step up or step down in asymptotic level observed, depending on plasma shape including shape of prior discharges (memory effect), plasma energy and duration and surface temperature.
- Quantative comparison indicates mass gain / loss at measured rate over ~10% of the vessel area can account for D fueled and pumped.
- Long term erosion / deposition small compared to dynamic retention at these locations.

Extras:

Mass gain/loss depends on plasma shape:

- Transient at discharge time due to dynamic retention (after 1- 2 mins).
- Layer mass asymptotes to level that can be the same or higher/lower than before discharge.
- Interaction at upper divertor increases in double null discharges.
  - change in SOL flows ? - (Fundamenski)
  - Or surface temperature effect ?

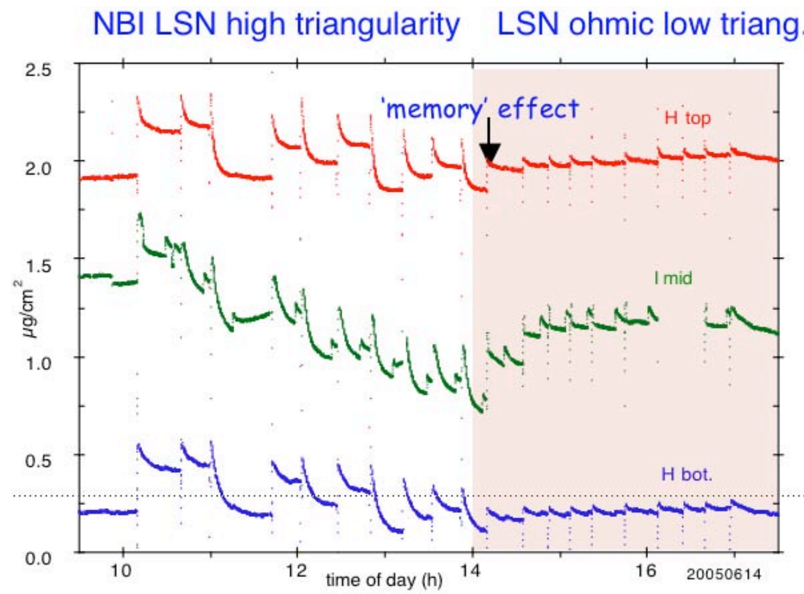




Some correlation of asymptote with stored energy

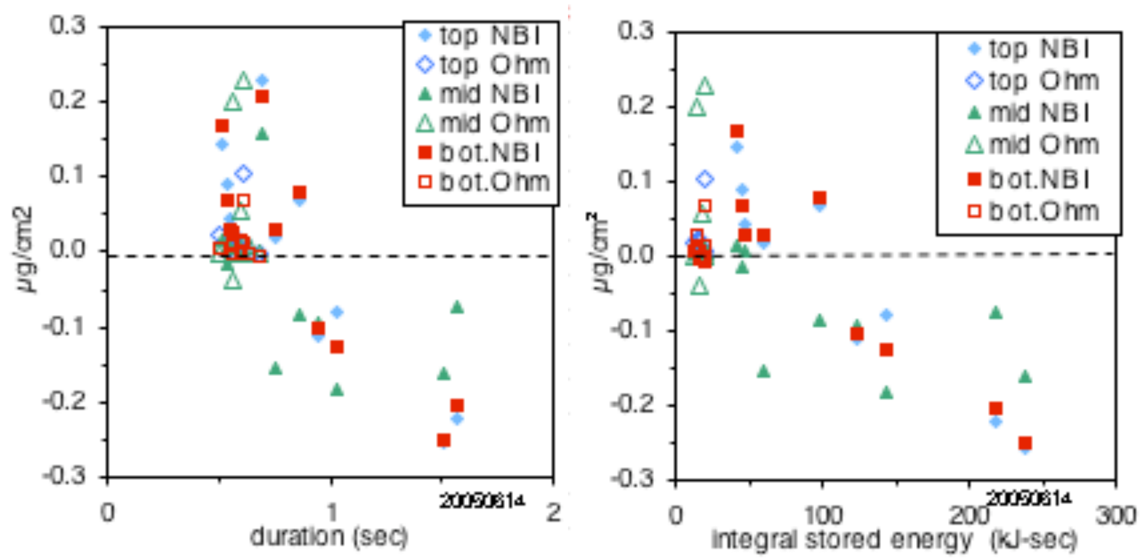
Contrasting plasmas:
Morning: high performance NBI LSN
high triangularity;
Afternoon: LSN ohmic low triangularity

Note change in asymptote with change in triangularity - strike points moved to fresh divertor surface



Also:
Tile surface temperature rises with discharge.
IR camera data shows at Bay H bottom QMB:
Rise = 5°C for short pulse ohmic
Rise = 30°C for long pulse NBI

Change in asymptote with duration and stored energy

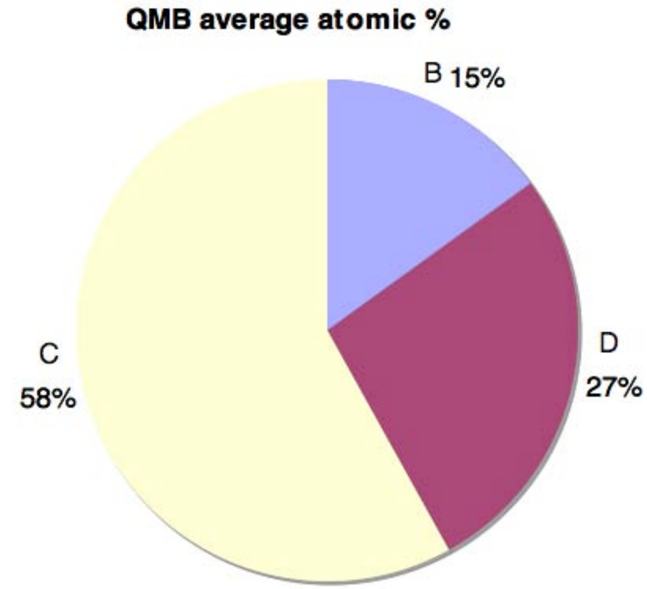


Erosion / deposition apparent over long term

Erosion/deposition is small compared to dynamic retention

	H bottom	H top	
change April 23 - Sept 13 2005	-0.3	2.6	μg/cm2
change due to boronization	4.2	2.1	μg/cm2
plasma only	-4.5	0.5	μg/cm2
average rate	-0.0028	0.0003	μg/cm2/shot
average rate	-0.0051	0.0006	μg/cm2/sec
average rate	-0.32	0.03	Å/s

Ion beam analysis of quartz crystals after 2005 run: (Wampler, SNL)



	10^{17} B/cm^2	10^{17} D/cm^2	10^{17} C/cm^2
QMB Bay H top	0.35	1.13	5.16
QMB Bay I mid	6.81	11.67	22.40
QMB Bay H bot	0.16	0.37	1.13

- Oxygen and protium not measured.
  For 2004 crystals surface oxygen measured by XPS was 13% of carbon density.
- TMB = $B(CD_3)_3$ used for boronization, has different stochiometry to deposits: 9% B, 27% C, 81% D. (D removed by He GDC)

Nuclear reactions used:

$^{12}C(^3He,p)^{14}N$, $^{11}B(^3He,p)^{13}C$, $^{2}H(^3He,p)^{4}He$

Quartz Crystal Microbalance:

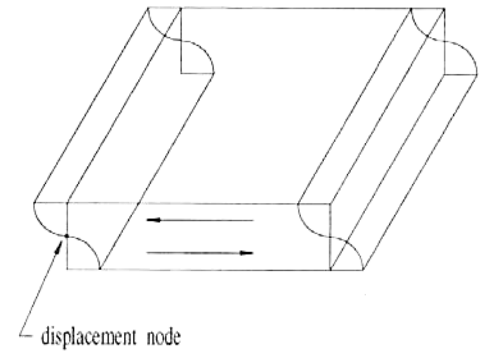
- Deposition changes crystal oscillating frequency.
- Widely used for process control during vacuum deposition.
- Used in TdeV, ASDEX, JET TEXTOR and NSTX tokamaks.
- Frequency measured by pulse accumulator controlled by 20 MHz reference oscillator.
- Commercially available system is relatively fast (1/4 s), precise, able to measure heavily loaded crystals and has immunity from mode hopping.

$$\frac{\text{film mass}}{\text{crystal mass}} = \frac{\text{frequency change}}{\text{bare crystal frequency}}$$

more complex relation available that takes account of acoustic properties of film and is valid up for to 40% frequency shifts.

Calculated sensitivity: -81 Hz / μg /cm^2
or -13 Hz /n.m
(for film density of 1.6 g/cm^3)

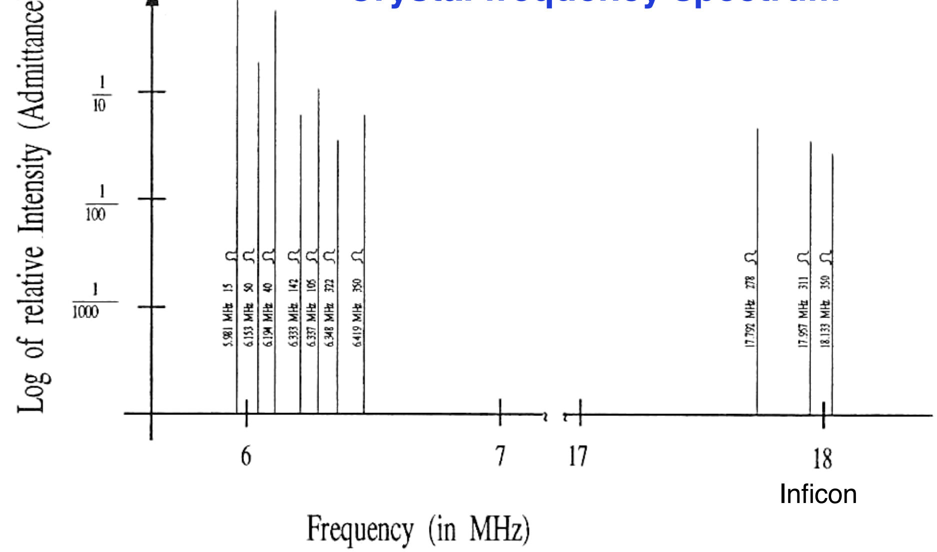
Caveat: frequency also sensitive to temperature, electronics for ITER environment may need development.



Inficon

Crystal 'wobbles' in thickness shear mode

Crystal frequency spectrum



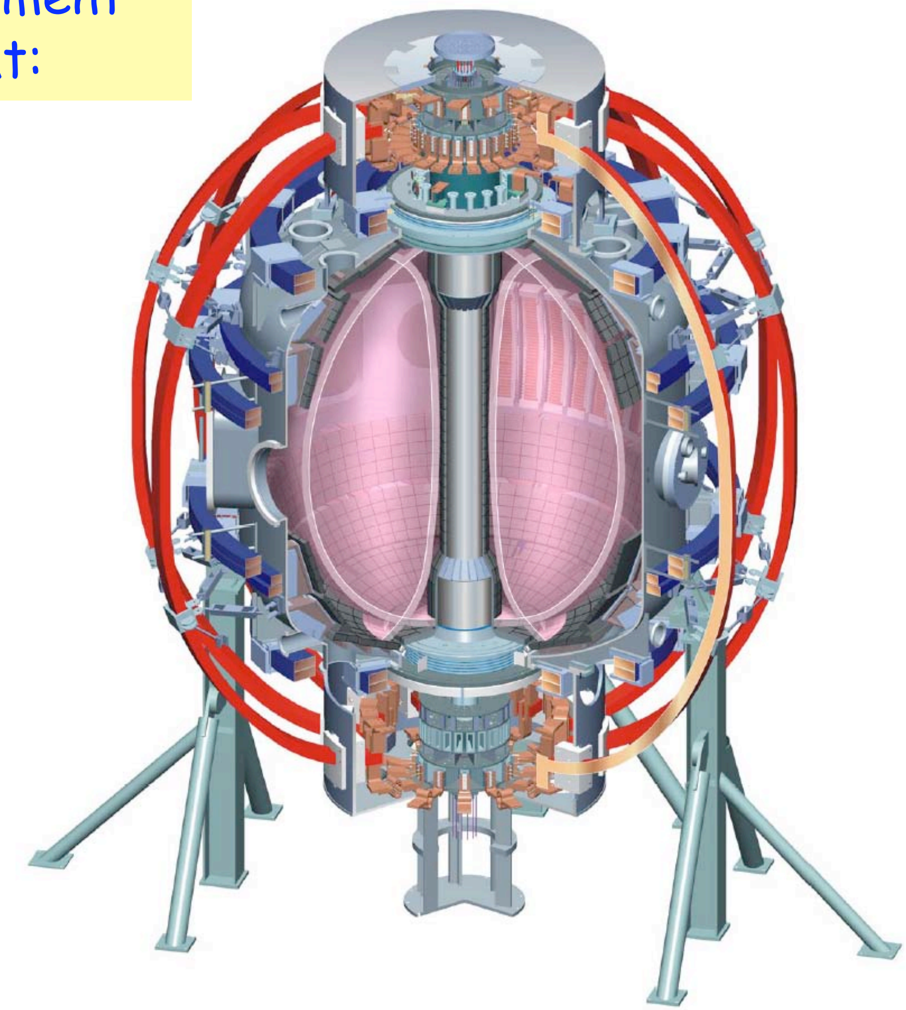
Inficon

5.9 MHz fundamental resonance constantly identified by zero phase difference between applied signal voltage and current passing through crystal.

The National Spherical Torus Experiment (NSTX) research program is aimed at:

- Exploring the physics of high beta and high confinement in a low aspect ratio device
- Demonstrate non-inductive current generation and sustainment.

- plasma major radius: 0.85 m,
- minor radius: 0.68 m,
- toroidal field of up to 0.55 T,
- plasma current up to 1.5 MA
- pulse duration up to 1.5 s.
- 7 MW neutral beam injection
- 6 MW of high harmonic fast wave RF at 30 MHz.



Plasma facing components that are in contact with the plasma are protected by a combination of graphite and CFC tiles.