Comprehensive First Mirror Test for ITER at JET
Overview of the Second Stage of the Test

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Outline

- **Project origin**
- **Experimental:** *Mirror materials, Mirror carriers & Location in JET*
- **Results:** *Reflectivity & Surface modification*
- **Remarks:** *Protection & Cleaning of mirrors*

Origin of the Project

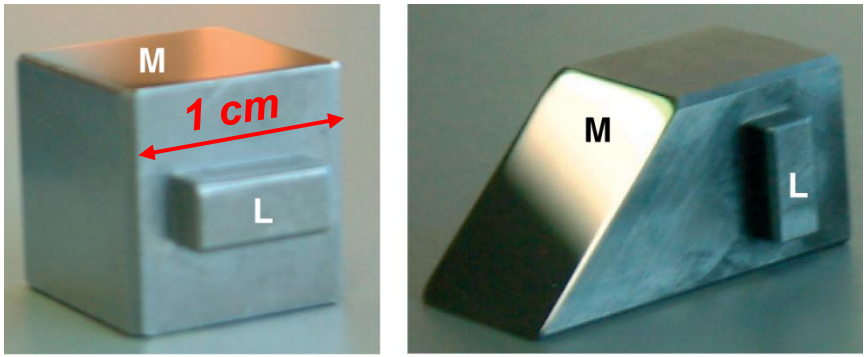
- **All optical systems in ITER will rely on metallic first mirrors.**
- **A comprehensive test in JET is done on the request of the ITER Design Team (2002).**
- **Mirrors were exposed during 2005-2007 and 2008-2009 campaigns.**
- **The first set of mirrors was retrieved in 2007 shut-down and the second in 2010.**

Mirrors, Carriers and Exposure in JET

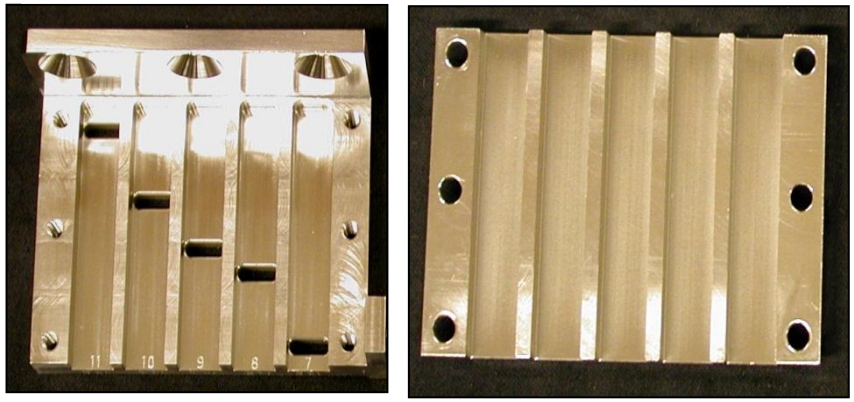
Tested mirrors: 32 polycrystalline Mo including 4 with Rh-coating (2008-2009)

Mirror carriers: 8 cassettes with channels to place mirrors at different distance from plasma, *i.e. to simulate different aspect ratio and resulting solid angle*

Flat front and 45° angled mirrors (M) with "legs" (L) for positioning in cassettes



5-channel cassette: base and cover



Exposure time

2005 – 2007: 126 600 s (35 h) including 96 900 s (27 h) of X-point operation

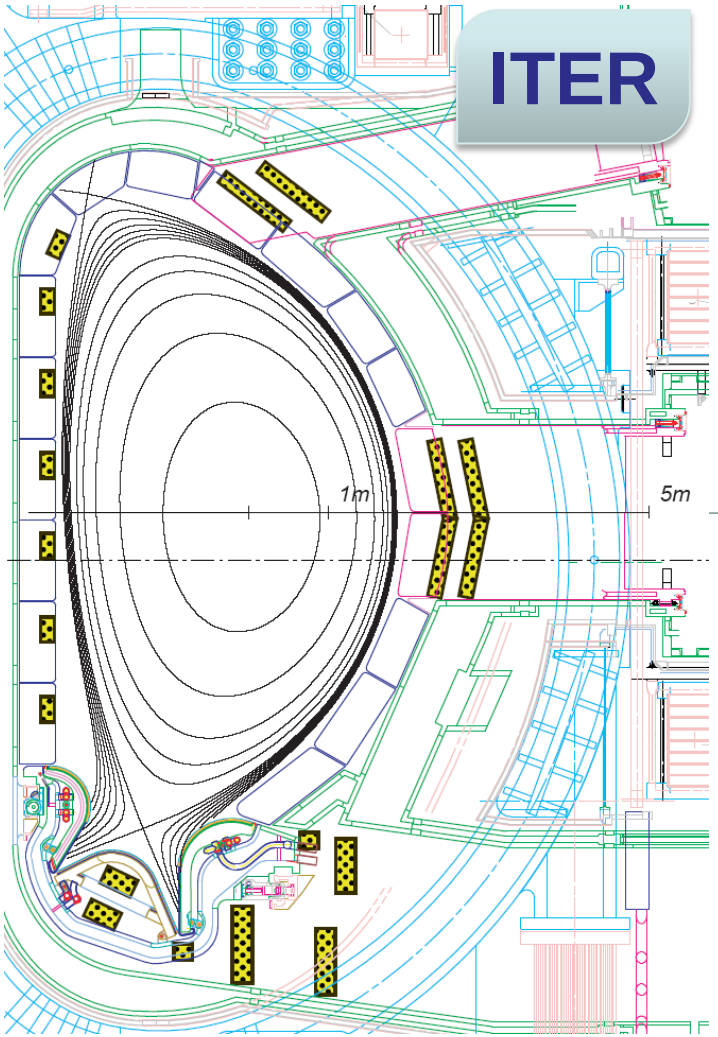
2008 – 2009: 161 680 s (45 h) including 117680 s (32,7 h) of X-point operation

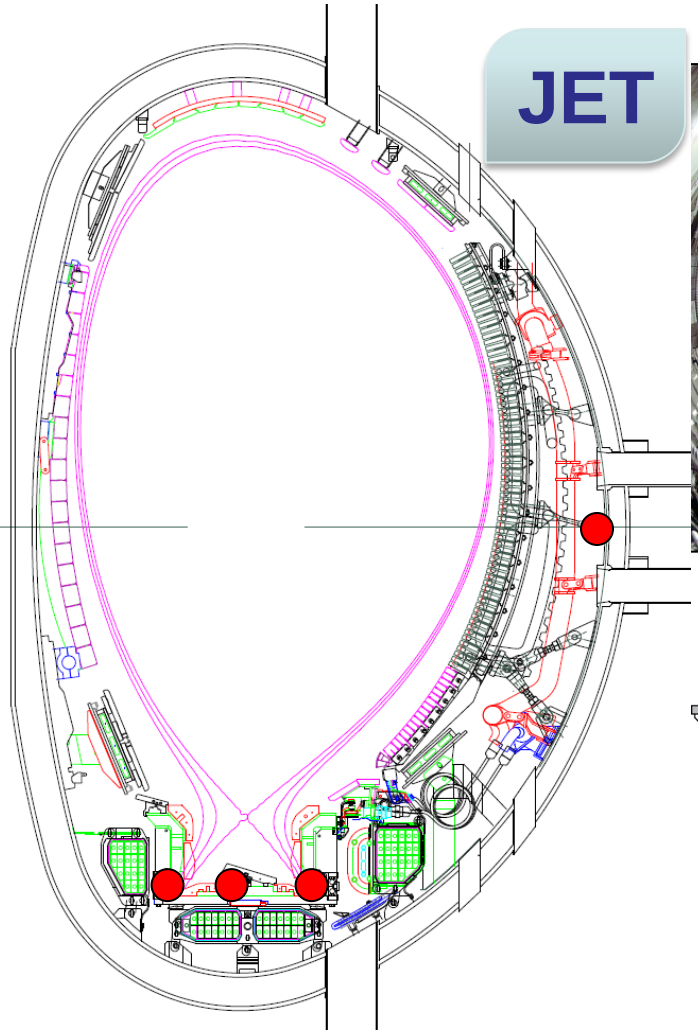
One set of mirrors was exposed during both campaigns: 80 h.

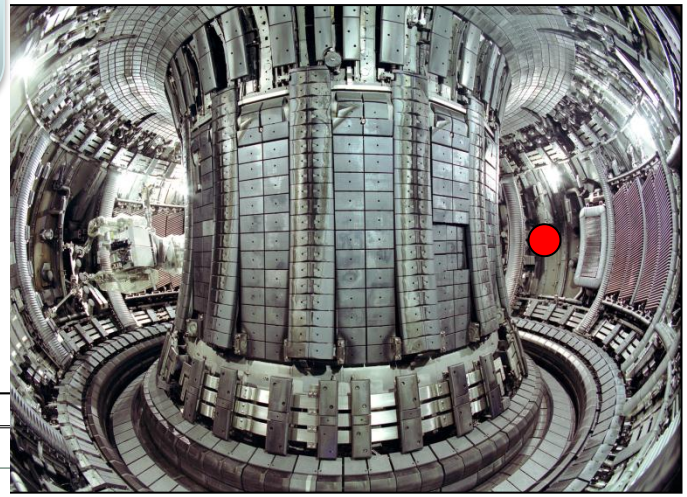
Conditions: Large variety of discharge scenarios, conditioning shots, disruptions.

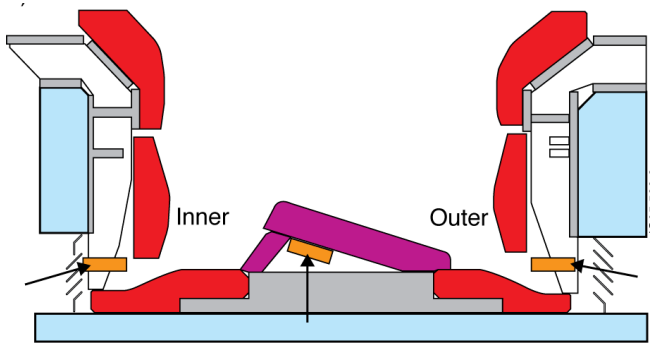
Correspondence to ITER pulses: ~ 20 ITER pulses scaled by energy input,
~ 2-3 pulse scaled by expected divertor fluxes *(R. Pitts, PPCF, 47, 2005)*

Location of Mirrors in ITER and JET









Minimum 80 First Mirrors

Solid angle for particle bombardment:

$\Omega_{PB} = 5 \cdot 10^{-5} – 1.4$ sr

$\Omega_{PB} = 10^{-3} – 0.2$ sr

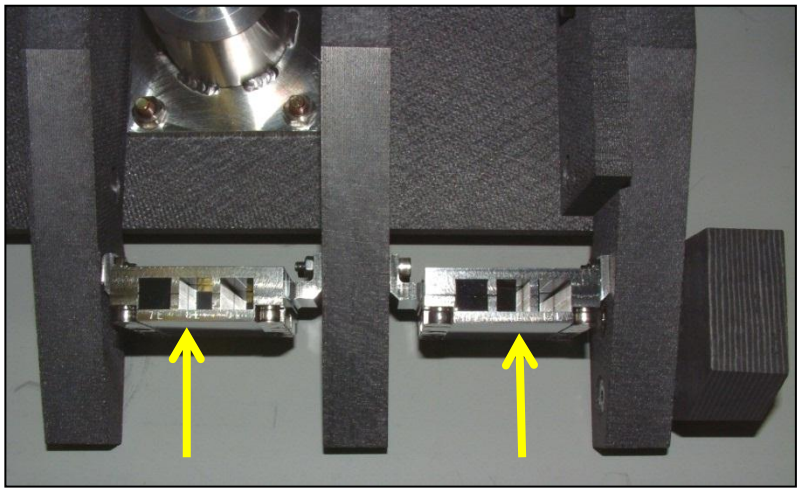
Aspect ratio (depth in channel / mirror width): 0 – 4.5

Assembly in JET

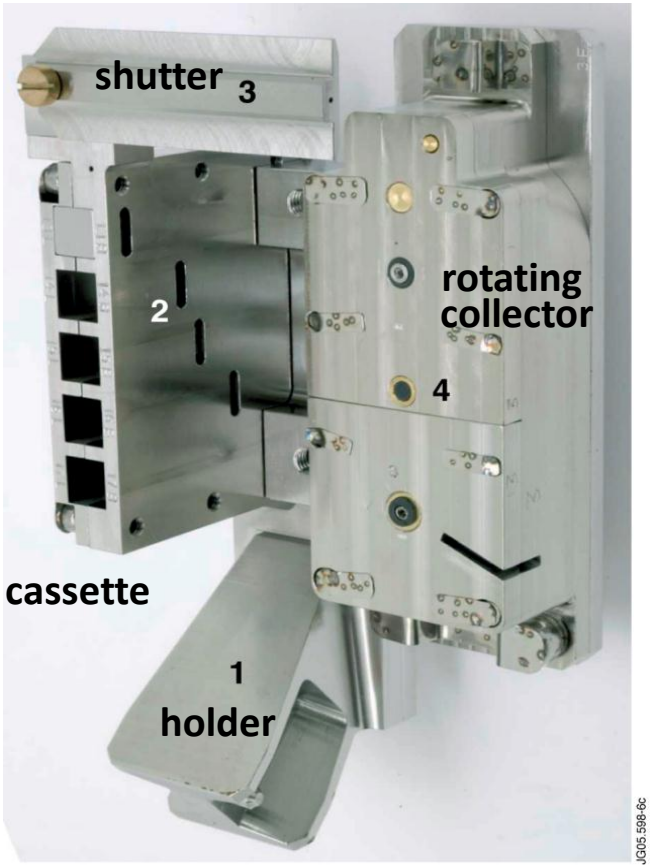
Mirror test at JET is a part of a broad programme on erosion-deposition studies.

Other diagnostics are installed next to the cassettes with mirrors.

Mirrors in cassettes under the load bearing plate (divertor base)



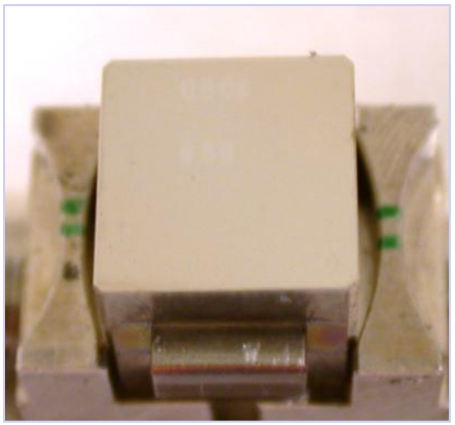
Mirrors installed on the outer divertor carrier



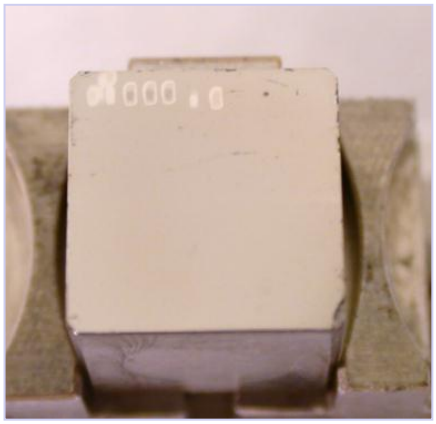
Bracket assembly for installation of mirrors and deposition monitors on the main chamber wall.

Exposed Mirrors

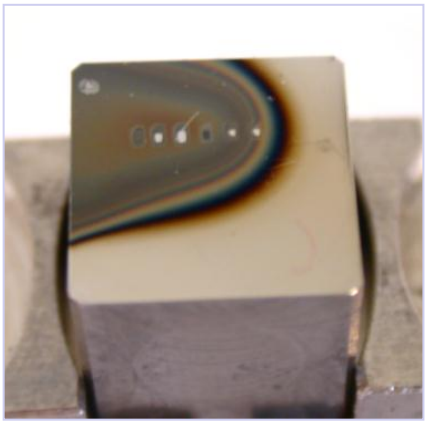
Outer Wall



0 cm

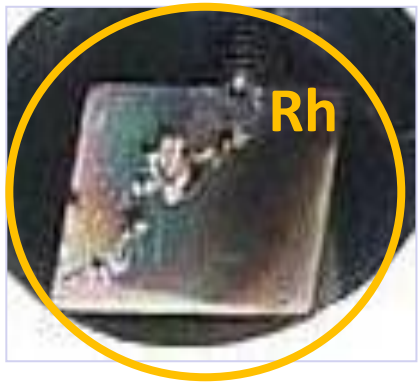


1.5 cm



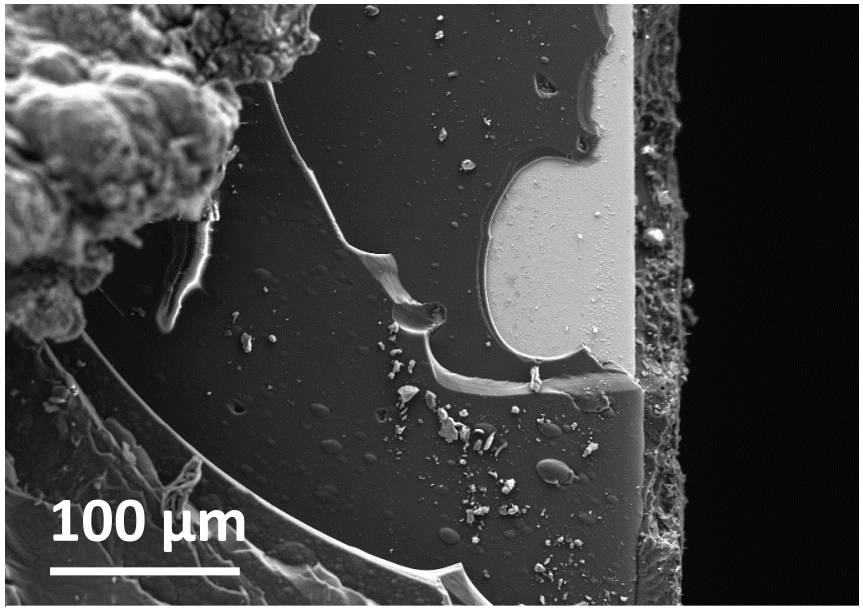
4.5 cm

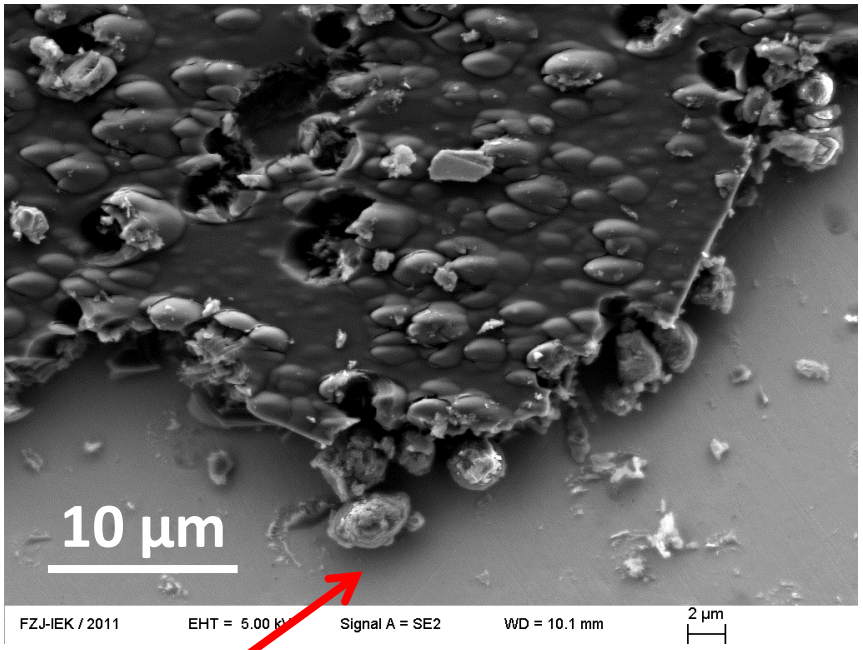
Divertor



No visual difference between Mo and Rh-coated mirrors

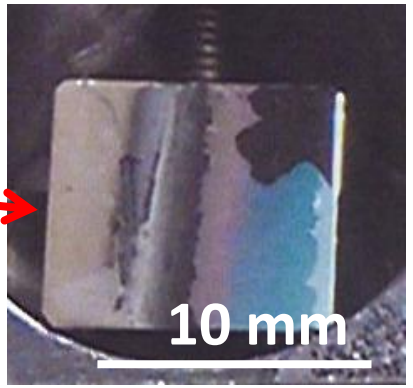
Exposed Mirrors: SEM





Growth of the consecutive co-deposited layers is observed.

It indicates that the first layer peeled-off in JET.

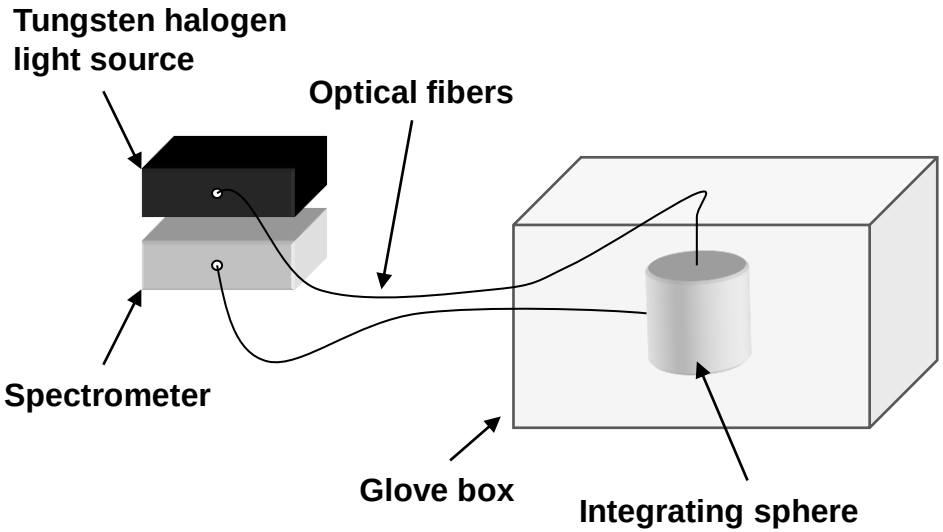


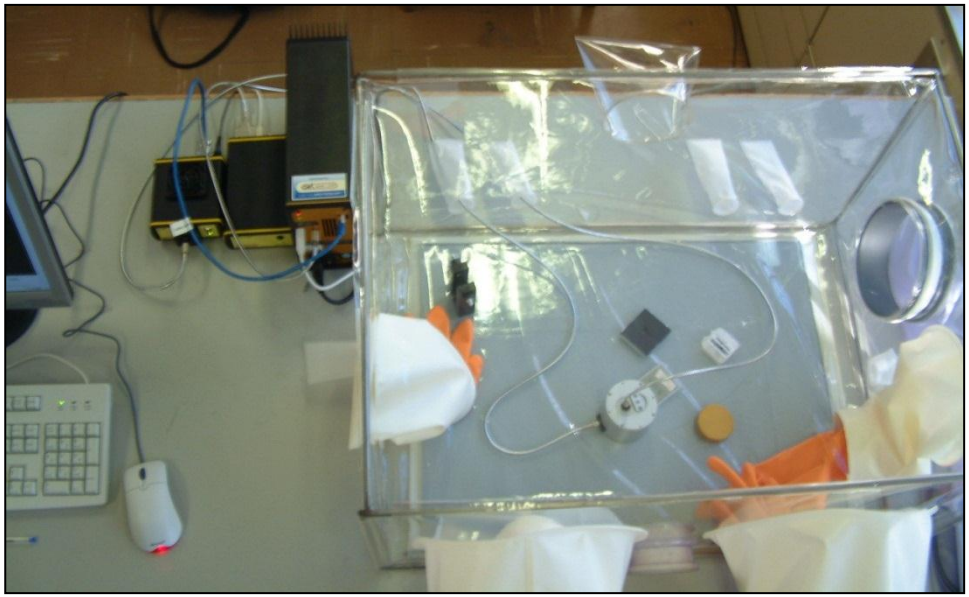
This complex surface structure influences the analyses.

Reflectivity Measurements

Cost-optimised solution for studies of Be and T contaminated mirrors:

- Integrating sphere in the glove box.
- Spectrometers outside the glove box.



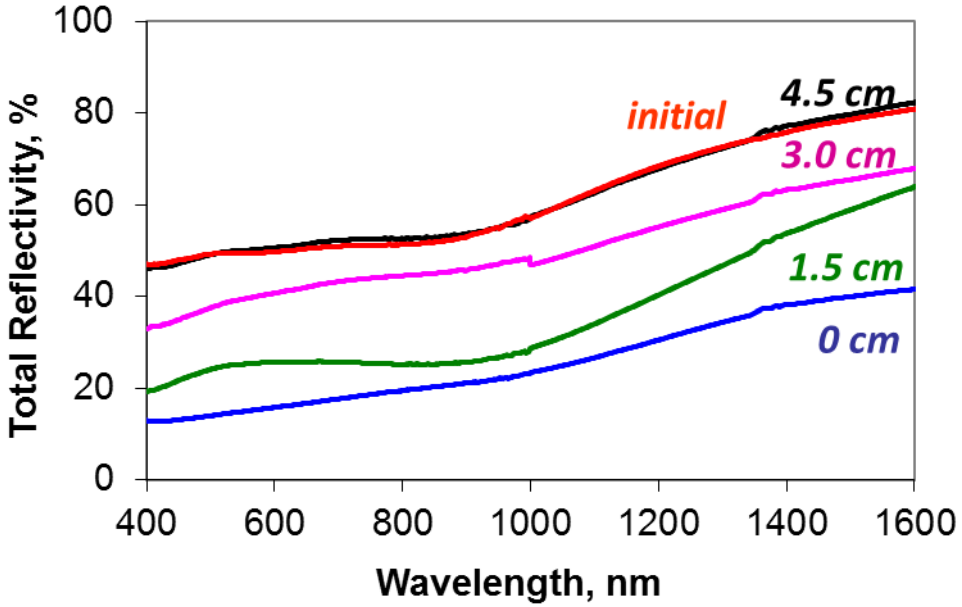


Another integrating sphere is installed outside the glove box for characterisation of new mirrors.

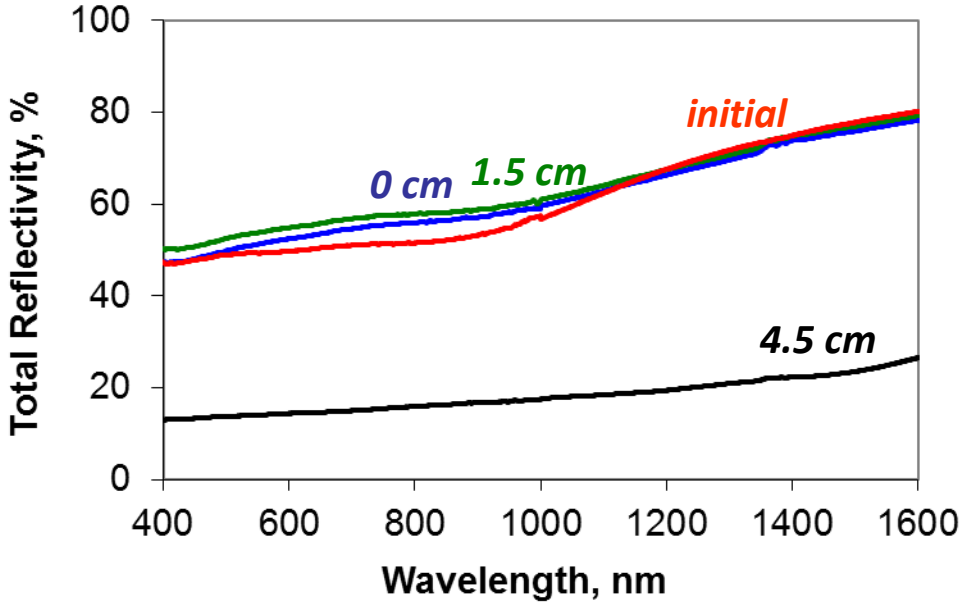
Reflectivity of Mirrors: Divertor and Wall Samples

Reflectivity change with depth in the channel

Divertor Base



Outer Wall, *unit without shutter*



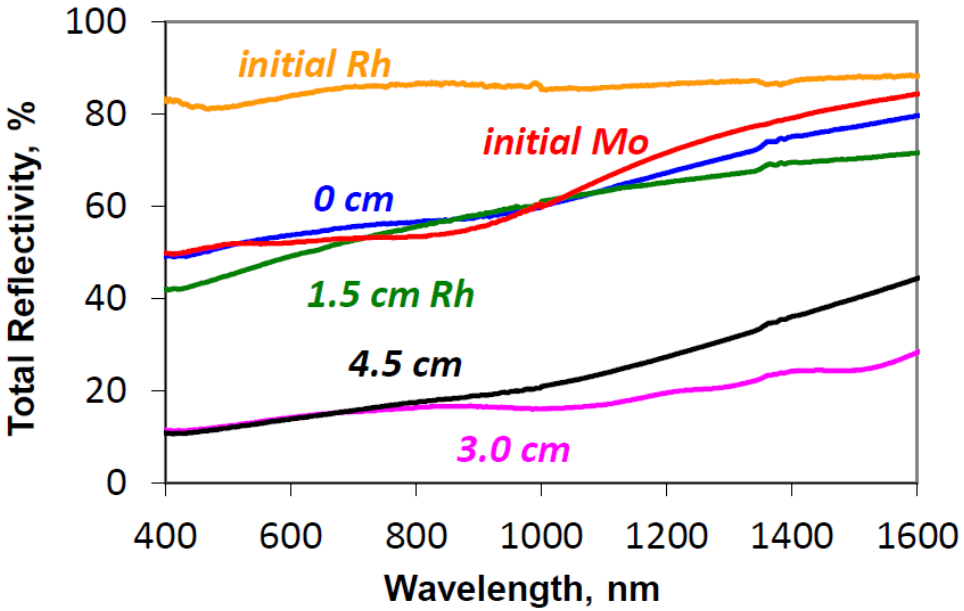
Divertor: ***Reflectivity loss for mirrors close to plasma is larger than deep in the channel.***

Wall: ***Reflectivity loss for mirrors close to plasma is smaller than deep in the channel.***

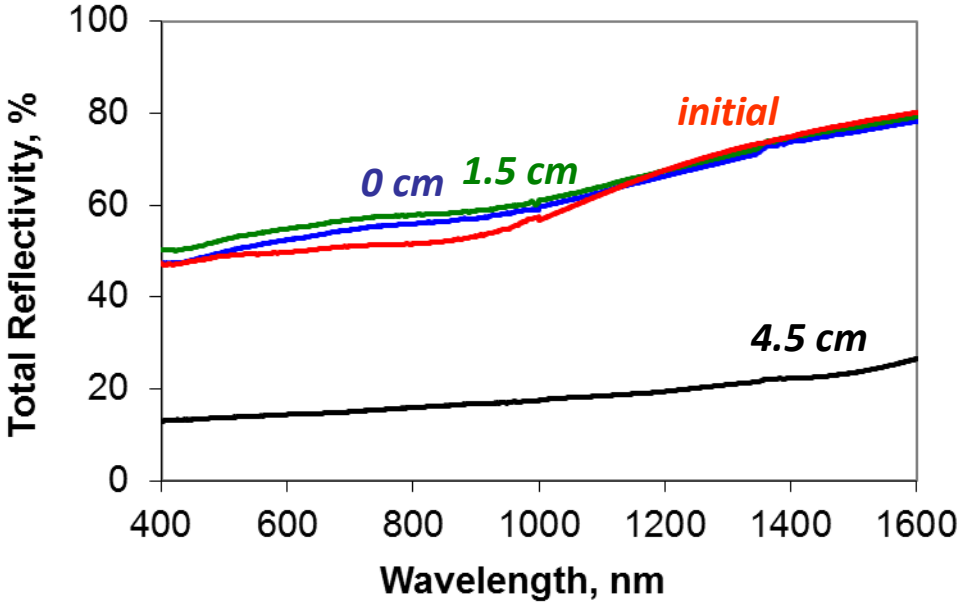
Reflectivity of Mirrors: Outer Wall Samples

Reflectivity change with depth in the channel

Outer Wall, *unit with shutter*



Outer Wall, *unit without shutter*



No significant difference between mirrors protected and not protected by shutter.

No difference between Mo and Rh-coated mirrors after exposure.

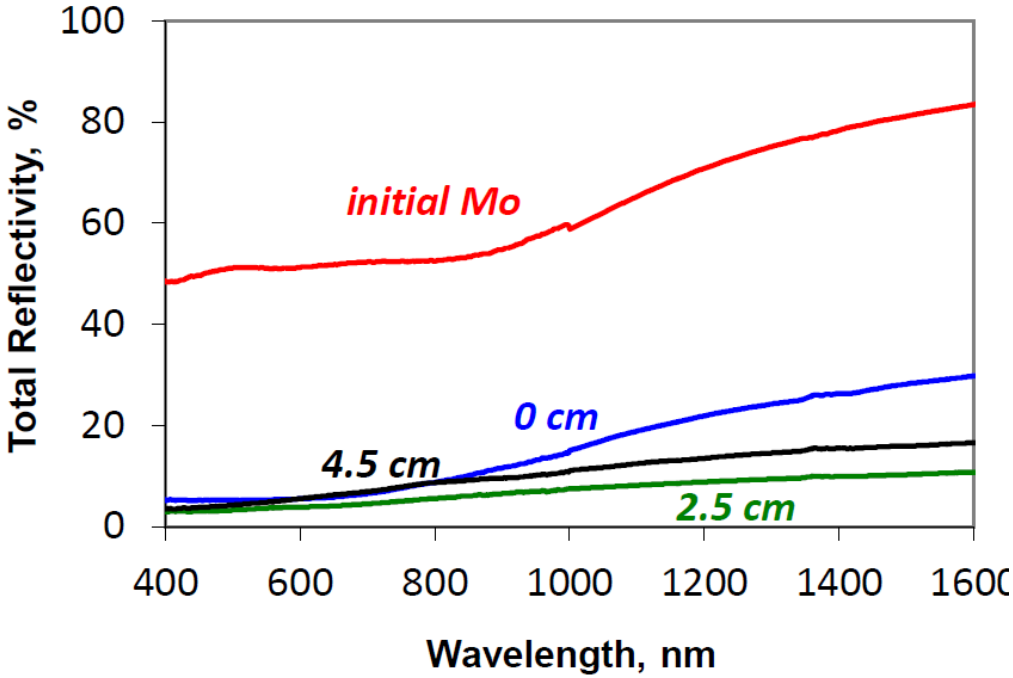
This result points to the surface modification by deposition and erosion by CX flux.

High specular reflectivity is maintained by mirrors near the channel mouth.

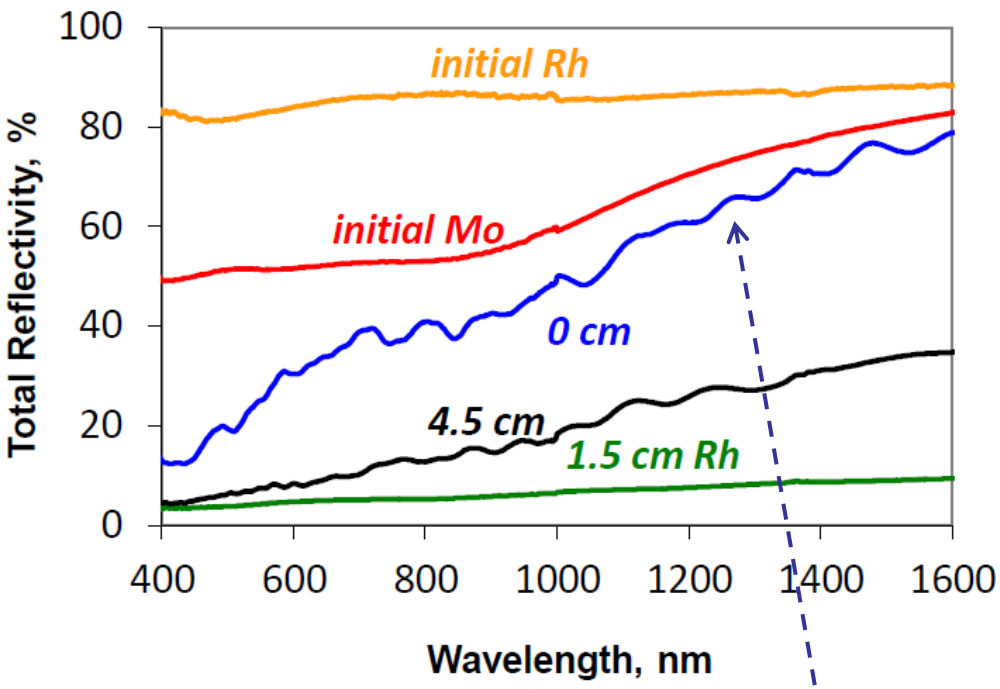
Reflectivity of Mirrors: Inner Divertor Samples

Reflectivity change with depth in the channel

Inner Divertor, *2005 - 2009*



Inner Divertor, *2008 - 2009*



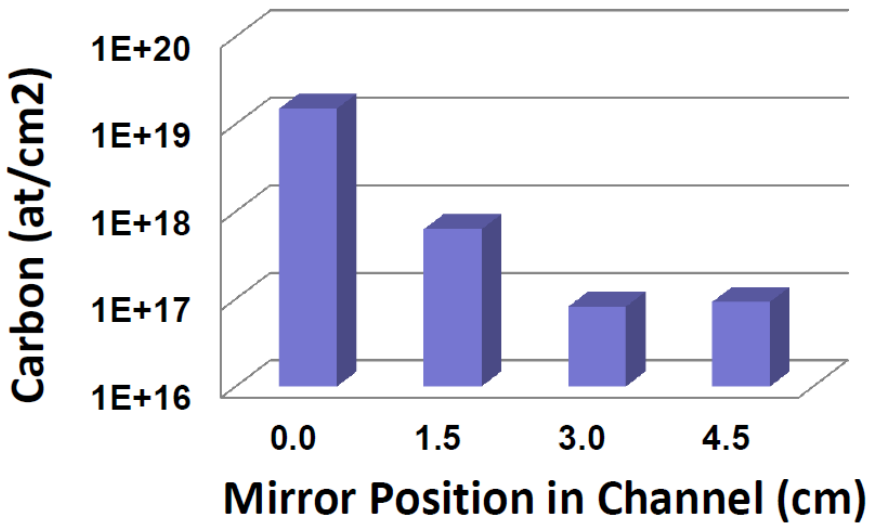
Reflectivity is related to a thin layer after peeling-off the thick deposit.

All mirrors covered by thick and flaking co-deposits.

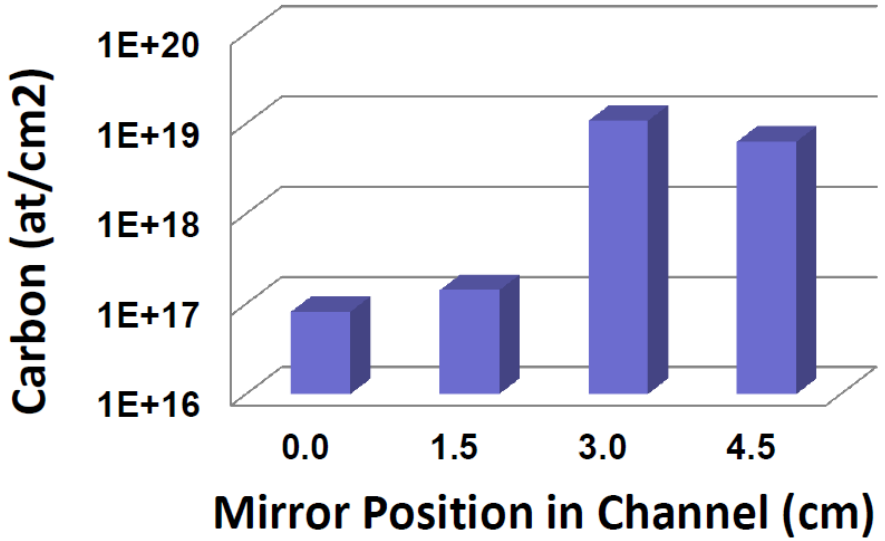
No difference between Mo and Rh-coated mirrors after exposure.

Deposition on Mirrors: Ion Beam Analysis

Divertor Base



Outer Wall



General tendency:

On the divertor mirrors deposition decreases with the depth in channel.

On the wall mirrors deposition increases with the depth in channel.

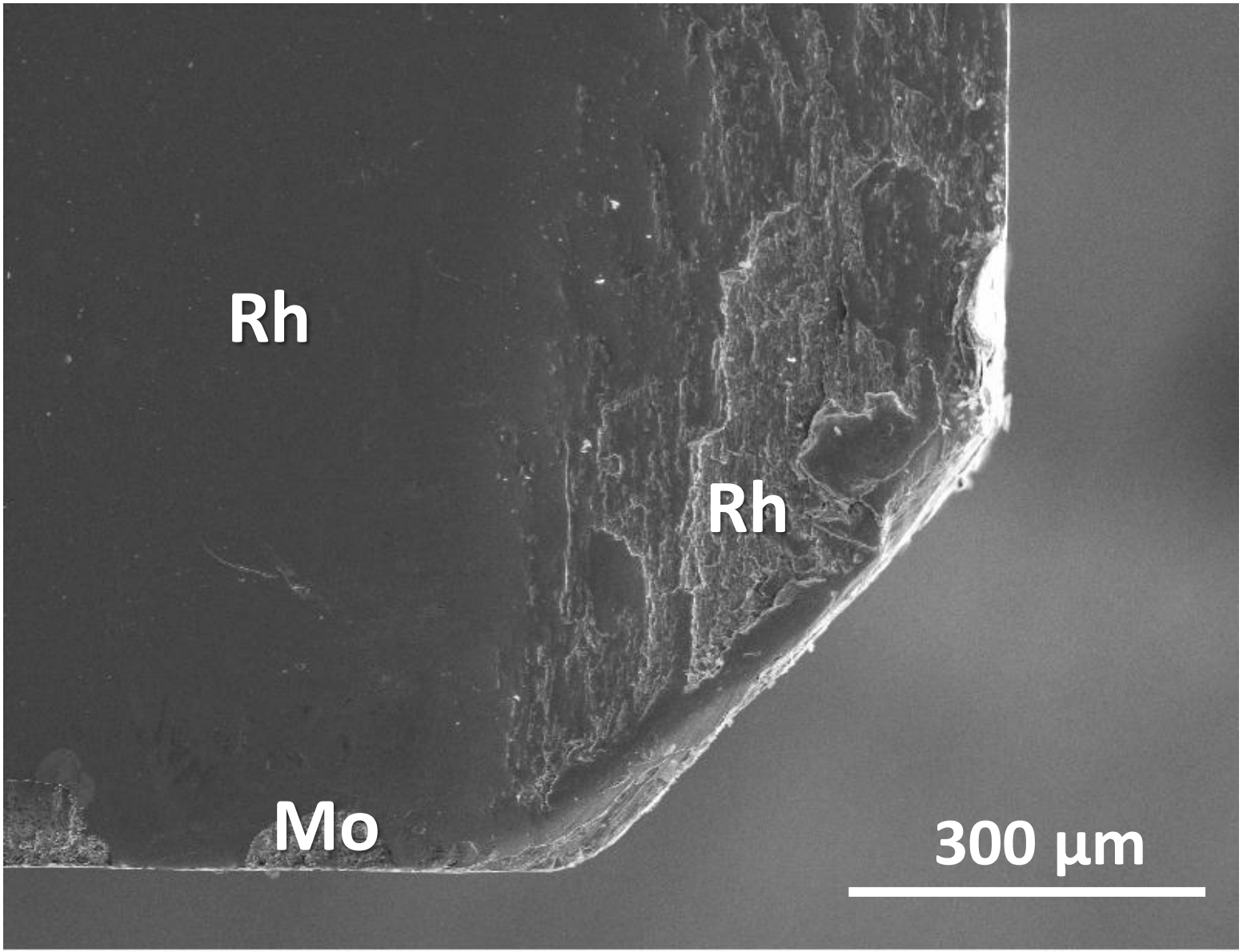
Other results:

Co-deposits contain ^{12}C, D and small quantities of Be and ^{13}C.

In some cases layers are thicker than the information depth with ion beam methods.

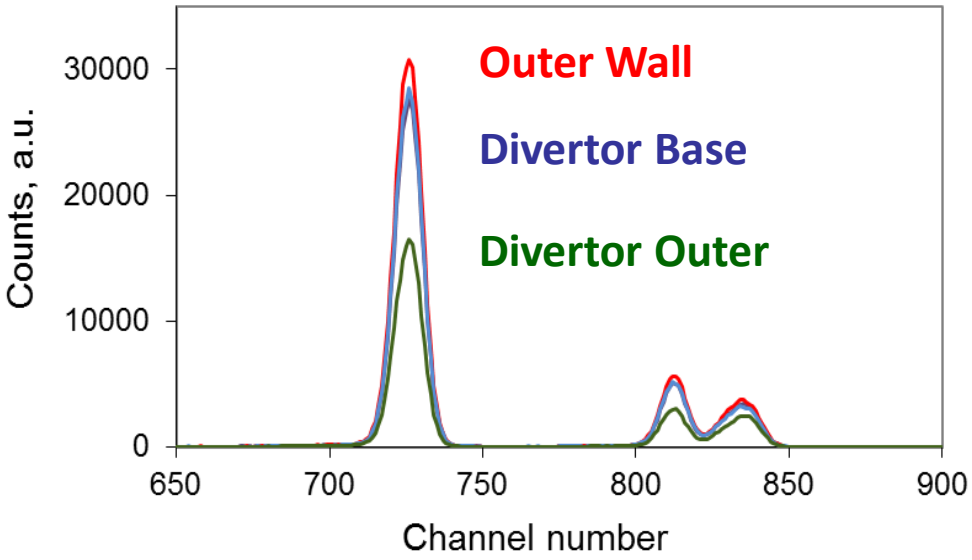
Fate of Rh coating

SEM-EDX: Rhodium Coating

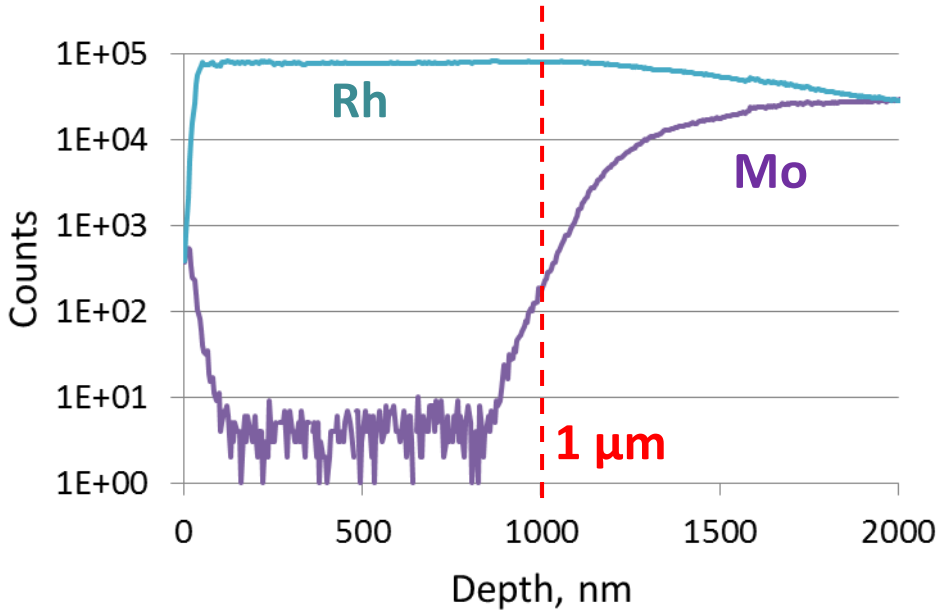


The Fate of Rhodium Coating

PIXE of Rh-Coated Mirrors



SIMS of Rh-Coated Mirror (Outer Wall)



Messages:

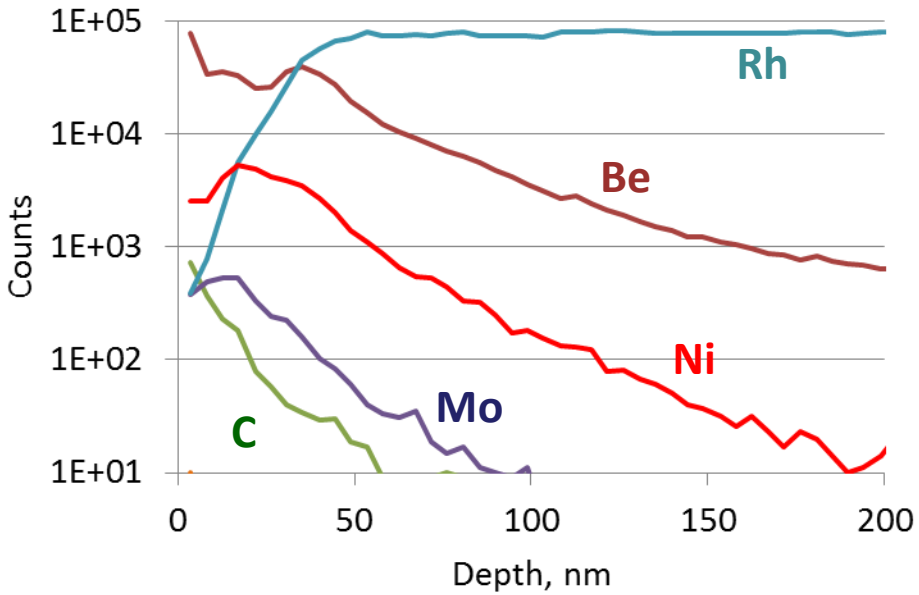
- **Rh presence is detected on all originally coated mirrors.**
- **Rh line intensity on divertor mirrors decreases for thicker co-deposits.**
- **The highest Rh intensity is on the mirror from the main chamber wall.**

Question:

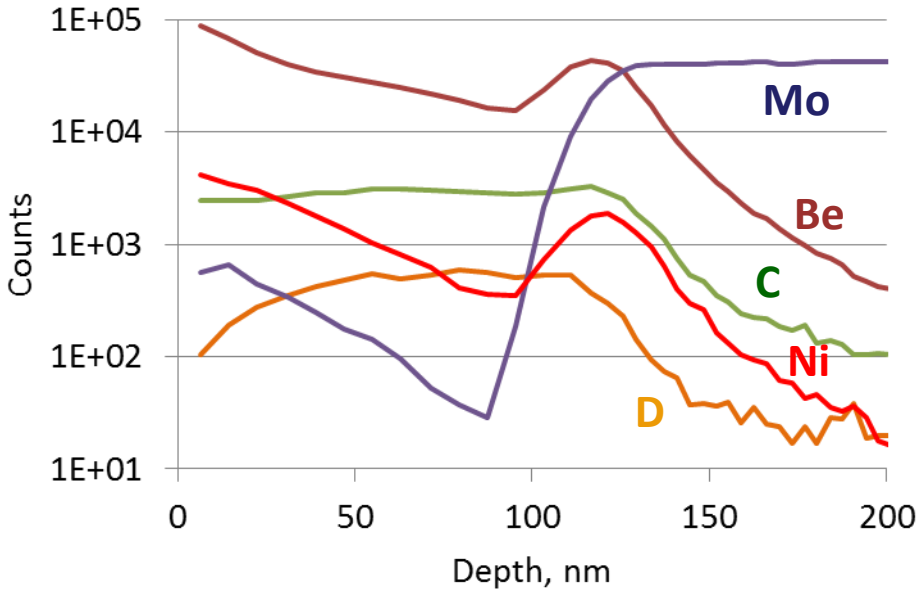
- **What is the surface modification?**

SIMS and XPS: Outer Wall Samples

Rh-Coated



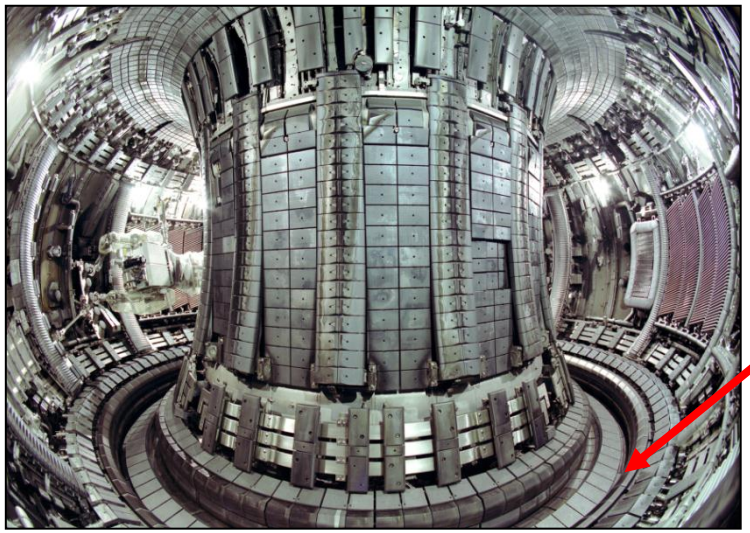
Molybdenum



Messages:

- **Both surfaces are modified by co-implanted/co-deposited C, Be, D.**
- **The quantities are small as determined by IBA: 1-10 x 10^{16} at cm^{-2} range.**
- **There is also small deposition of Mo and Ni from the Inconel wall.**
- **The very surface *(region deciding reflectivity)* contains mixed material.**
- **XPS: Metals in the modified layer are oxidised.**

Mirrors as Erosion – Deposition Diagnostic Tools



7 g of ^{13}C injected in 30 shots.

Injection: base outer divertor ring.

^{13}C content determined with NRA: $^{3}He(^{13}C,p)^{15}N$

Location in channel (cm)	^{13}C (10^{17} cm^{-2})
0	5.2 – 6.5
1.5 *(Rh-coated)*	1.0 – 2.3
3.0	0 – 1.4

^{13}C detected only on mirrors from the outer divertor

→ **No direct cross-divertor transport.**

Summary

- **Two sets of mirrors exposed in JET were studied by optical and surface analysis.**
  The geometry of test units in JET partly imitated the situation planned in ITER.

- **Results show consistently:**
  - ***Decrease of deposition with the depth in the channel for all divertor samples,***
  - ***Increase of deposition with the depth in the channel on the main chamber samples.***

- **The formation of flaking, dust generating layers occurred on several divertor samples.**
  Deposits contain a mix of elements: C, D, Be, some metals.

- **No differences in the behaviour of pure Mo-poly and Rh-coated mirrors is observed →**
  No clear advantage of using coated mirrors for long-term operation.

Concluding Remarks

First Mirror Test in JET with carbon walls has been completed.

- **THE PERFORMANCE OF EXPOSED MIRRORS HAS BEEN DEGRADED.**

  The same effects may be expected in ITER after a few shots in carbon surrounding.

- **The most urgent issue is to develop methods for cleaning and/or mitigation of the plasma impact on mirror performance.**

- **The formation and detachment of layers is to be taken into account when laser-induced cleaning or local plasma discharge in the vicinity of mirrors is considered:**
  risk of dust generation and mobilisation in diagnostic channels.

- **Shutters proposed by ITER may prolong the lifetime of mirrors, but will cause problems for continuous dignostics.**

- **Replacement of mirrors using a mechanical exchange cassette seems to be the most effective method, though very challenging from the engineering point of view.**

Mirror test in JET will be continued during the ITER-Like Wall operation in full metal surrounding.

ITER-Like Wall in JET

A new set of mirrors has been installed.