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Erosion and re-deposition at mirrors for ITER diagnostics: mitigation strategies

A. Litnovsky

with contributions from M. Matveeva, M. Laengner, V Kotov, T. Akiyama, N. Yoshida, D. Thomas, G. Vayakis, D. Johnson, V. Voitsenya, E. Mukhin, members of the First Mirror SWG of the ITPA TG on diagnostics, DAs and ITER Diagnostic Division members and ITER diagnostics teams

Mirrors in ITER diagnostics

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35 mirror-based diagnostics…

…aimed at measuring vital ITER parameters:

T_e, T_i, N_e in the main chamber & divertor,

N_{imp}, $T_{div.\ Plates}$

- **For a machine protection and basic control**
  - **Advanced control**
    - **Performance evaluation and physics**

~ 80 first mirrors **Operating at 2 nm – 114 um**

Mirror lifetime is crucially important for the successful ITER operation

Work plan
of the coordinated R&D on mirrors

❖ **Five main directions (tasks) prioritized**

A. Performance under erosion- and deposition- conditions: material choice

B. Predictive modeling of mirror performance in ITER

C. Mitigation of deposition and erosion
Cleaning of deposited layers on the mirror
+ *in-situ* calibration
→ **Mirror Surface Recovery (MSR)**

D. Tests under neutron, gamma and X-ray environment

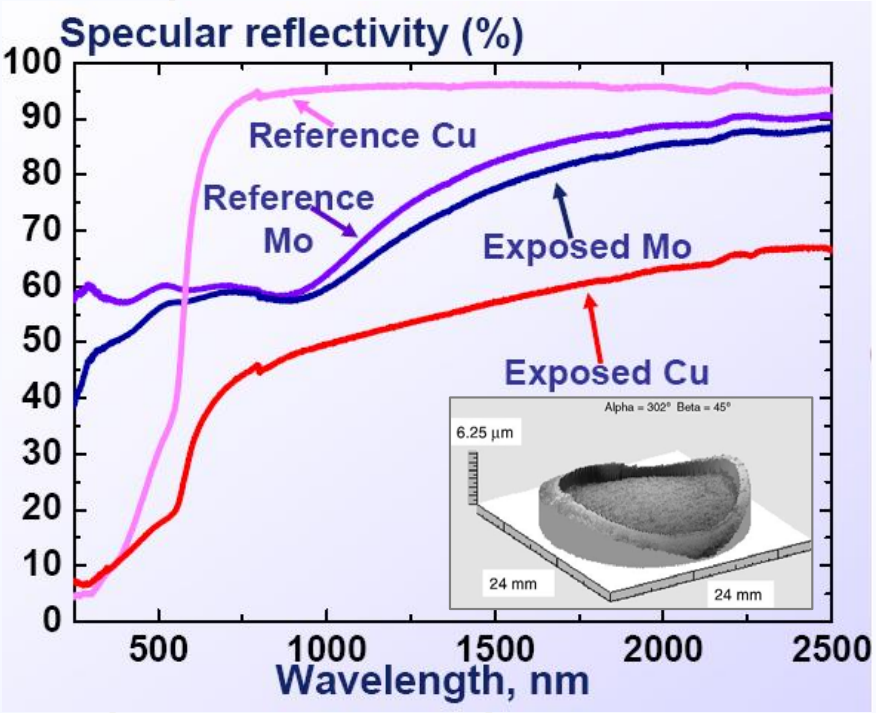
E. Engineering and manufacturing of ITER first mirrors

The work plan is available online at: https://tec.ipp.kfa-juelich.de/mirrorswg/
Access details: a.litnovsky@fz-juelich.de

Implementation to ITER R&D on mirrors: **D. Thomas ITER Doc ID: ITER_D_2MPTR6**

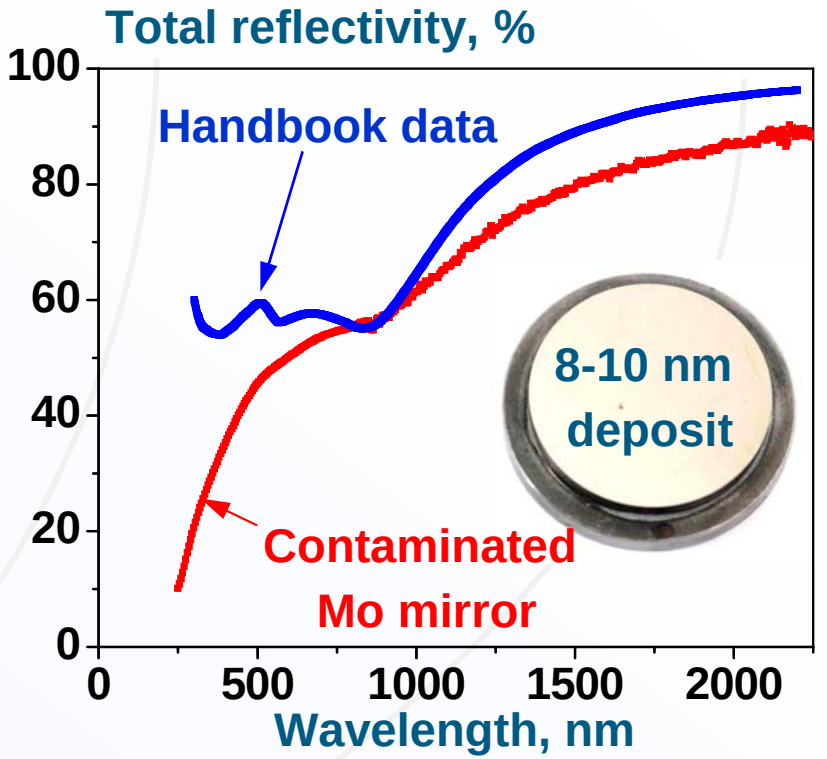
Mirror degradation via erosion & deposition[1]

Erosion



Mo and Cu mirrors after 1 year exposure in Tore Supra[2]

Deposition



Mo mirror after 1 year exposure in DIII-D

Both erosion and deposition may result in mirror failure

Coordinated R&D is necessary

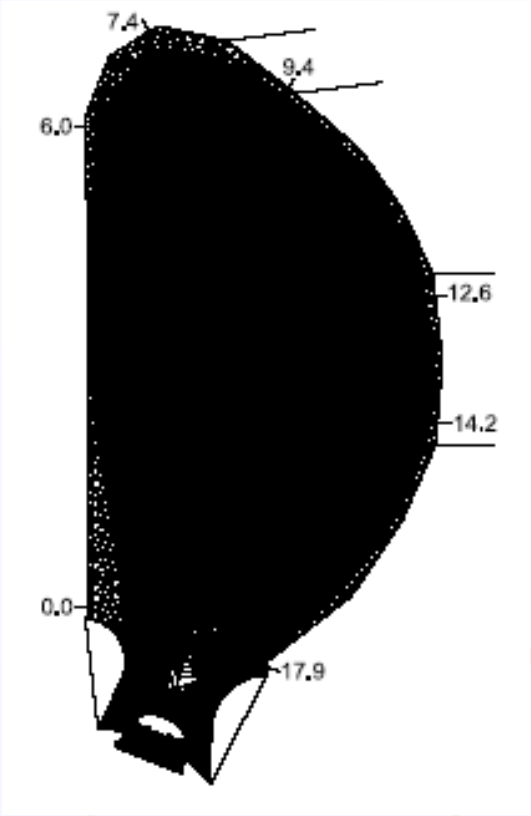
Impact of mirror failure on ITER operation: https://user.iter.org/?uid=3TR4V3&version=v1.0

[1] A. Litnovsky et al., JNM, 363–365 (2007) 1395 [2] M. Lipa et al., FED, 81 (2006) 221

Task B:

Predictive modeling of mirror performance in ITER

Mirrors in ITER environment[1]

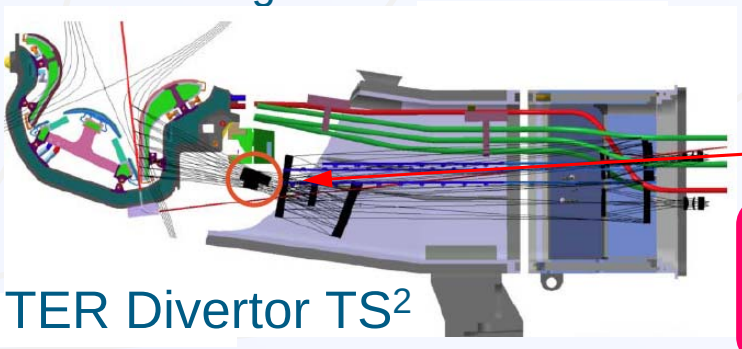


Present B2-EIRENE calculation grid ☺

- *Code: B2-EIRENE*
- *8 ITER cases, new F57 configuration*
- *SOL power 80-120 MW*
- *Gas puffing and/or core fueling*
- *High/low density*
- *Steady-state*
- *Core: ASTRA 1D transport code*

[1] V. Kotov, reports
on ITER contract C4T/09/71/OLT CHD/DIAGNOSTIC

Mirror modeling is the modeling of extremes: gross erosion and gross deposition



ITER Divertor TS[2]

Mirrors in ITER will be located inside the long diagnostic ducts

Mirror degradation in ITER will be primarily due to deposition

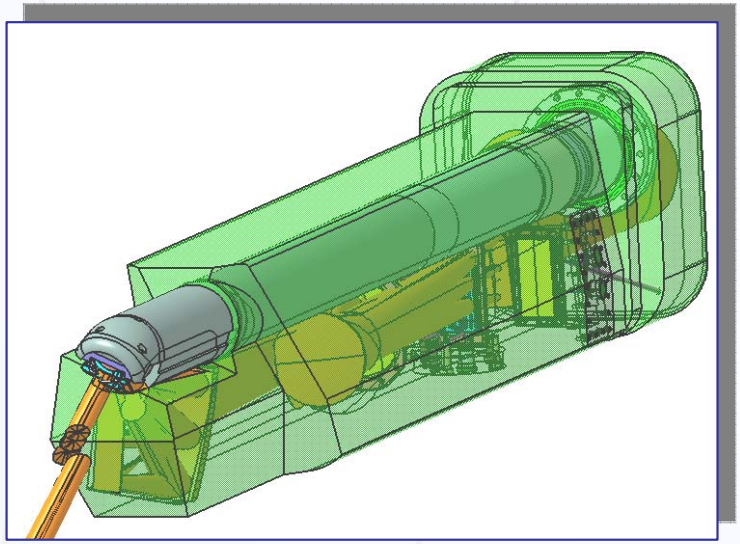
[2] E. Mukhin et a., NF 49 (2009) 085032

Task C:
Mirror Surface Recovery (MSR)

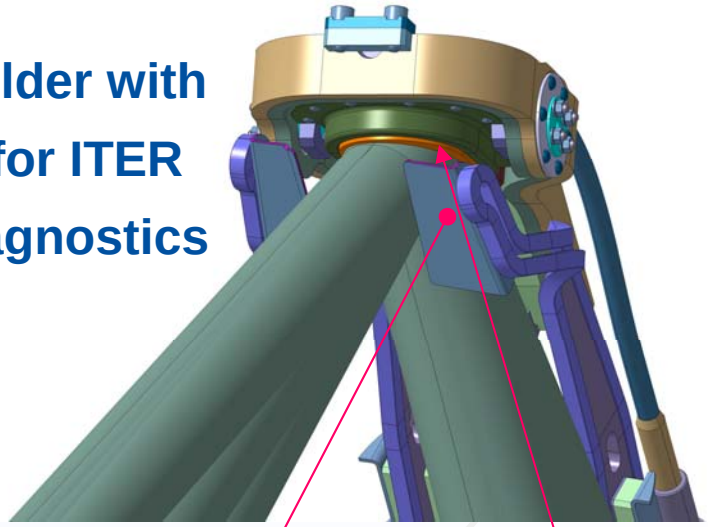
Mitigation of deposition and erosion

Mirror Surface Recovery:

Shutters: protecting from direct particle impact



Mirror holder with shutter for ITER CXRS diagnostics



Shutters: protecting from direct particle impact

Y. Krasikov et al. @SOFT 2010

Effective

during plasma operation and plasma conditioning

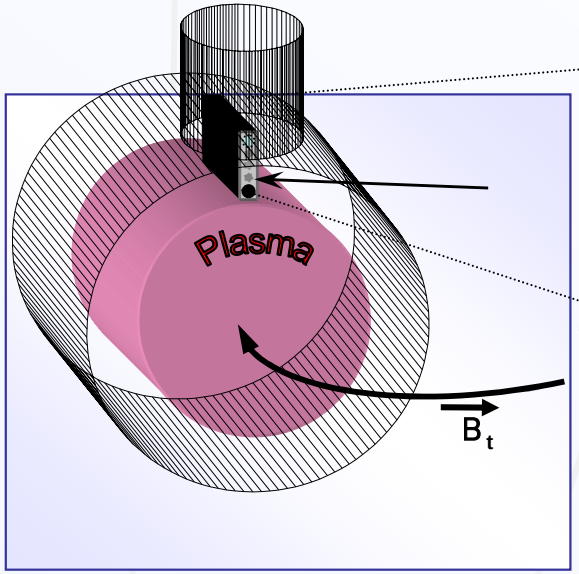
Non-effective

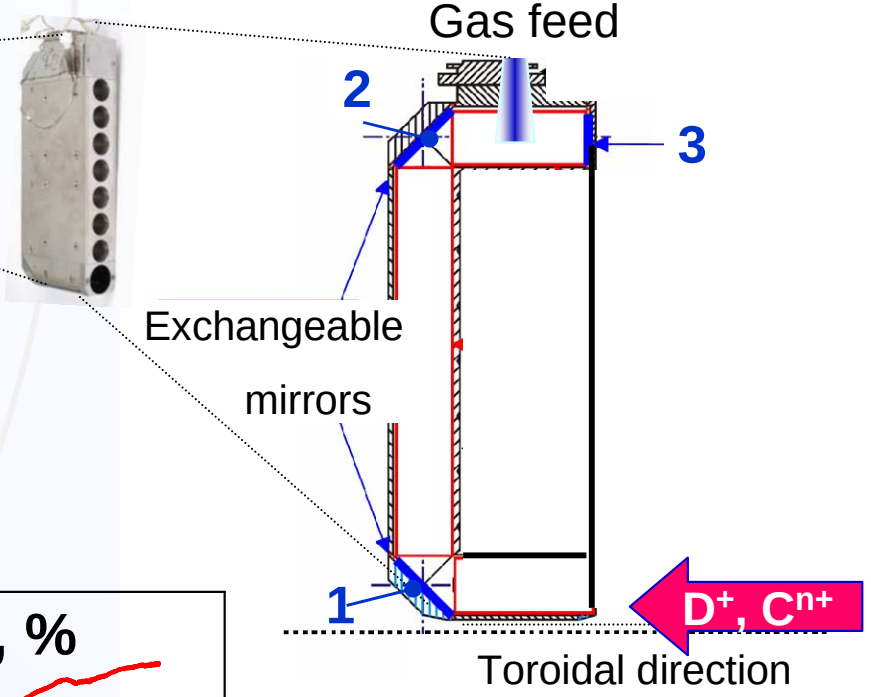
during wall conditioning in the non-plasma environment

H. Ogawa et al., @ IAEA 2008 IT P6-23

Mirror Surface Recovery:

Gas feed to protect the mirrors [1, 2]

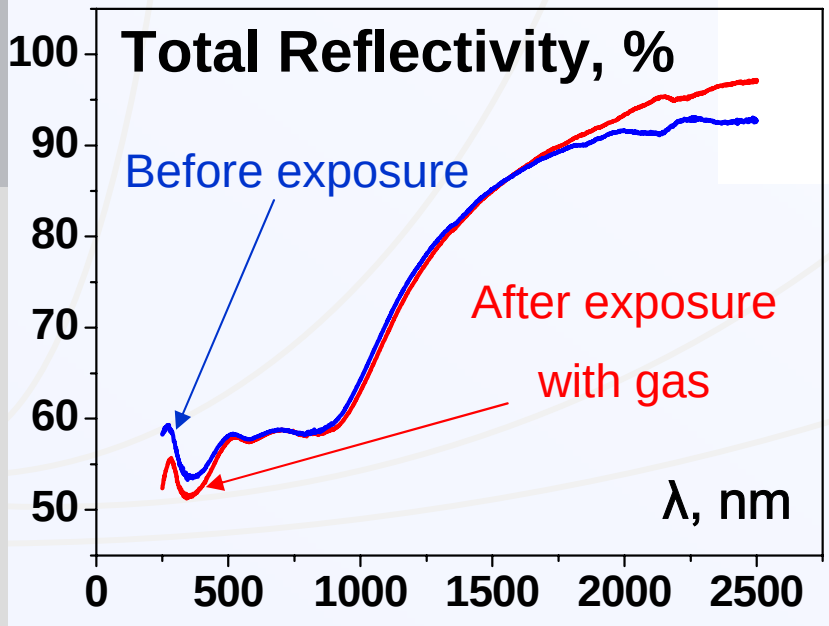




First mirror

Without gas feed

With gas feed



Promising mitigation technique

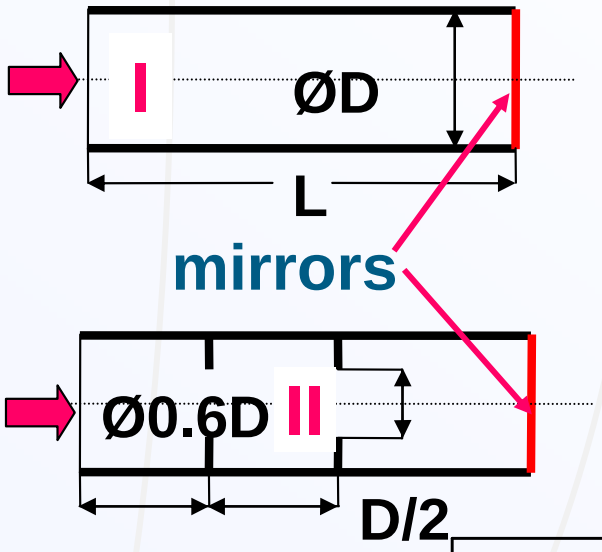
Applicability in ITER is being assessed

[1] A. Litnovsky et al., NF 49 (2009) 075014

[2] A. Litnovsky@ICFRM 14, P. ID 00339 accepted to JNM

Mirror Surface Recovery[1,2]:

Optimized duct geometry to protect mirrors (modeling)



- Sputtering: reflection from the duct wall (TRIM)
- Deposition: reflection, probability R
- Sputtering of the deposit on the duct wall, enhanced by Y_{enh}

Max. deposition ~0.001 nm/sec

[1] V. Kotov@SOFT 2010

Attenuation of particle fluxes

For midplane port

L/D	1	2	5	10	15	20
I Conservative: Reflection=100%, smooth tube						
Erosion	5.8	14	56	160	300	540
Deposition	3.2	4.7	9.0	16	23	29
II Realistic: Reflection=90%, Y_{enh}=10, C_{Be}=10 %, tube with fins						
Erosion	12	78	1100	5700	$1.4*10^4$	$2.6*10^4$
Deposition	2	7.6	240	3700	$1.3*10^4$	$2.7*10^4$

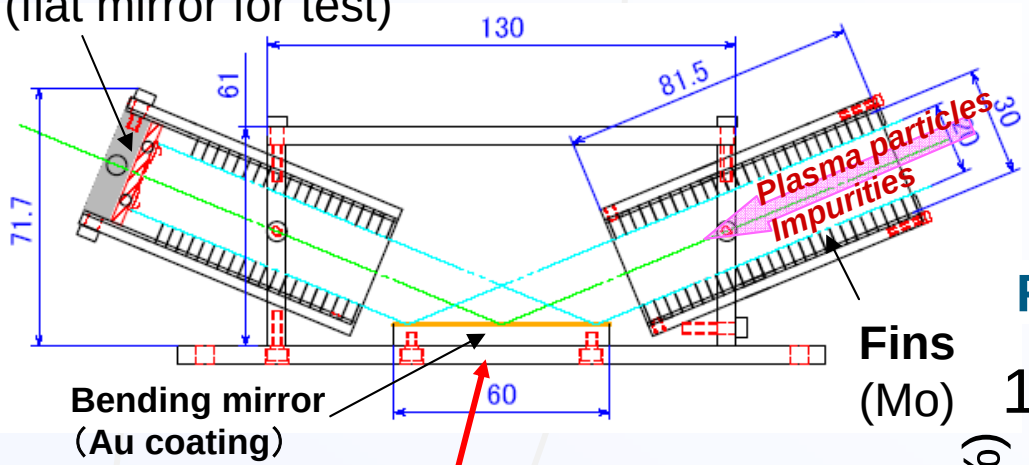
[2] A. Litnovsky ITR P1-05 @IAEA 2010

Drastic decrease of particle flux towards mirrors by ducts with fins

Mirror Surface Recovery:

Duct geometry to protect mirrors (first experiments)

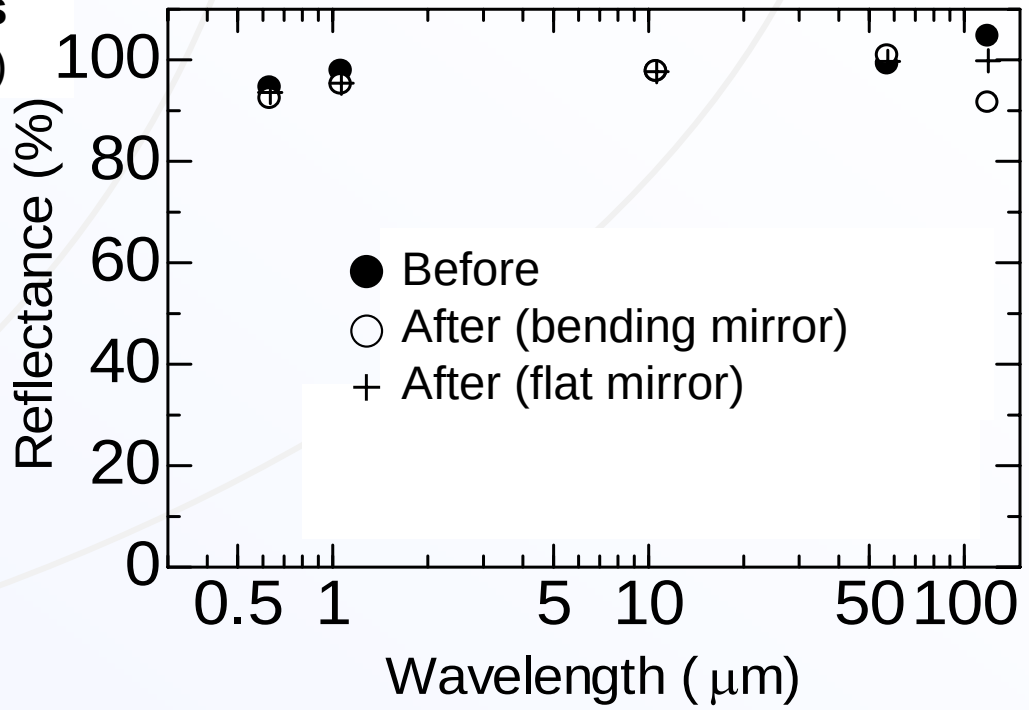
Retroreflector
(flat mirror for test)



Exposure test in LHD for 3 months

- Erosion>deposition at the bending mirror: Moderate erosion cleans the mirror surface.
- Reduction of impurity from the cylinder: Mo (low sputtering yield)+fins

Reflectivity of bending and flat mirrors



- ► No degradation of the reflectivity
- ► Small flux of incoming particles due to a long cylinder and fins

Mirror Surface Recovery:

Duct geometry to protect mirrors

Messages

**Duct geometry plays the major role in decreasing particle fluxes towards the mirrors:
orders of magnitude attenuation is predicted**

**Reduced contamination rates ->
in-situ cleaning w/o magnetic field in ITER becomes feasible**

First experiments back modeling predictions

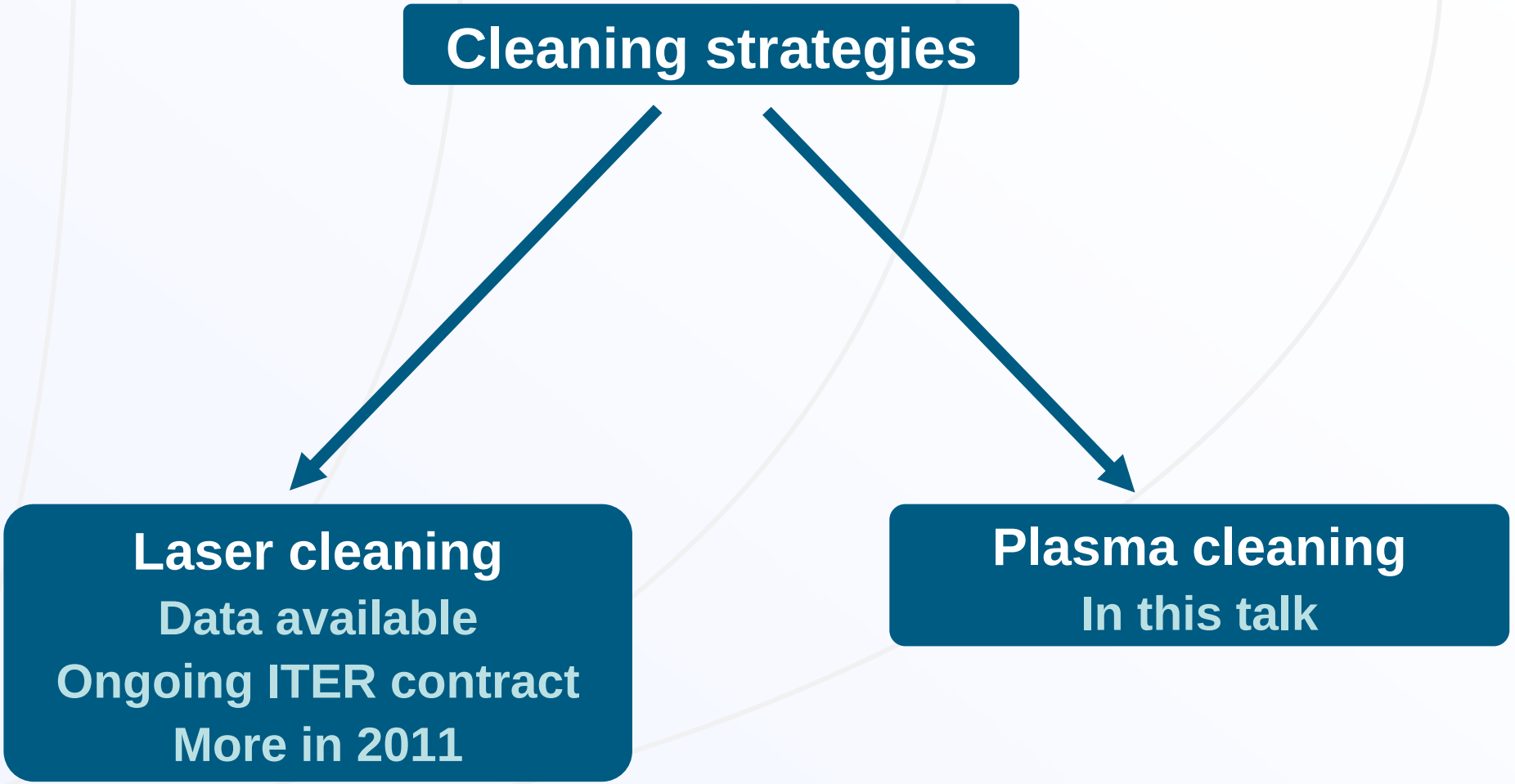
Dedicated experimental benchmarking is crucial

Task C:
Mirror Surface Recovery (MSR)

Mirror cleaning

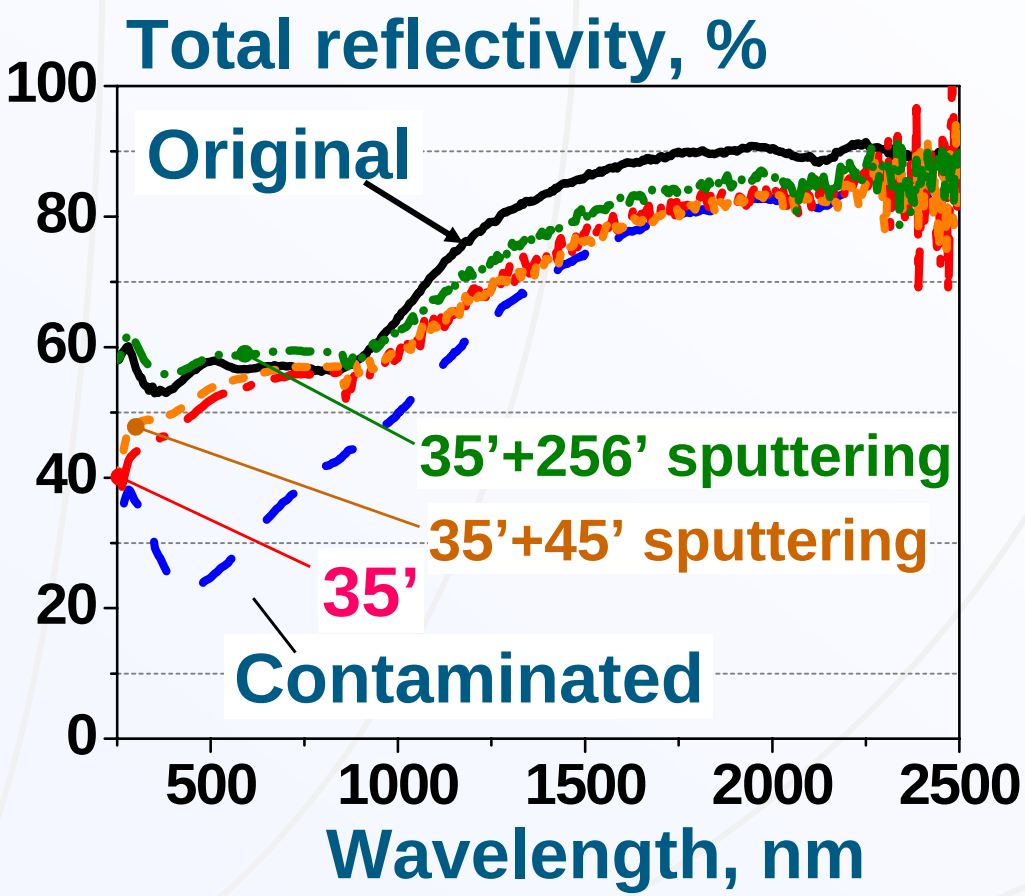
Mirror Surface Recovery:

In-situ mirror cleaning

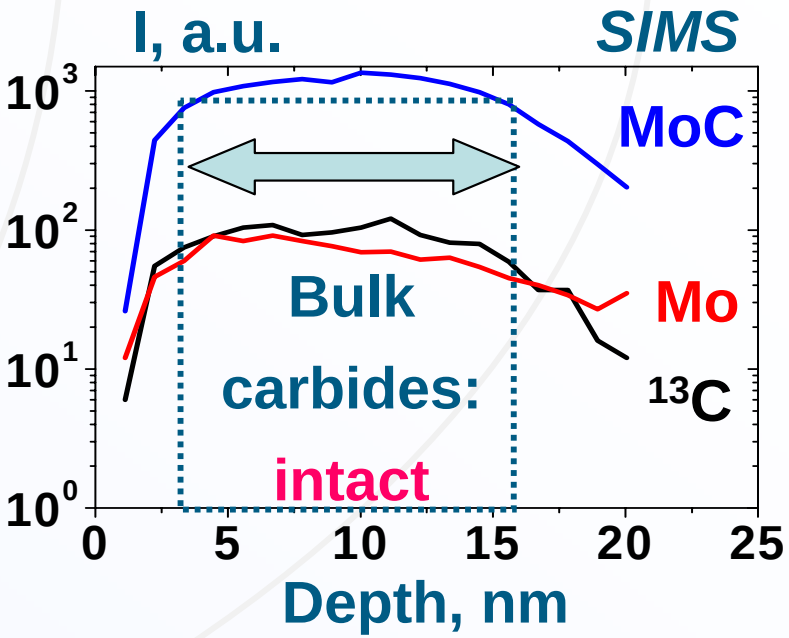


Mirror Surface Recovery:

Cleaning of contaminated mirrors[1]



After cleaning w/o sputtering



Implantation + diffusion into mirror bulk

Min. removal efficiency ~0.001 nm/sec

[1] A. Litnovsky, M. Laengner, M. Matveeva et al., @SOFT 2010, doi: 10.1016/j.fusengdes.2010.11.033

Mirror Surface Recovery:

Duct geometry to protect mirrors

Messages

Reflectivity could only be reliably restored by sputtering of deposit

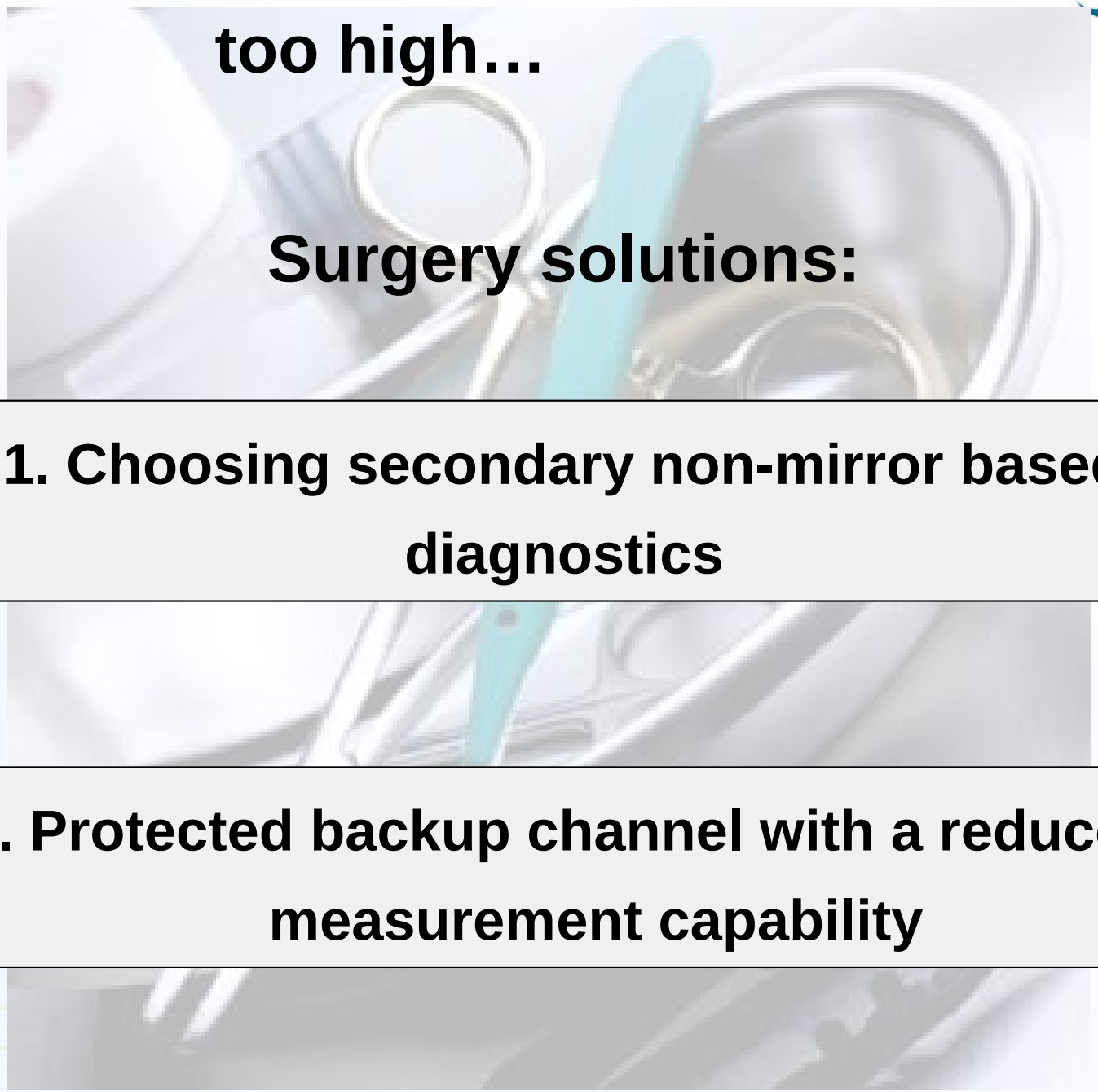
Mirror must be made from erosion-resistant material

Critical issue: cleaning of Be and Be-containing layers

Possible issue: local re-deposition of sputtered material

Possible issue: reproducibility during repetitive cleanings

In case the residual risk is still too high…

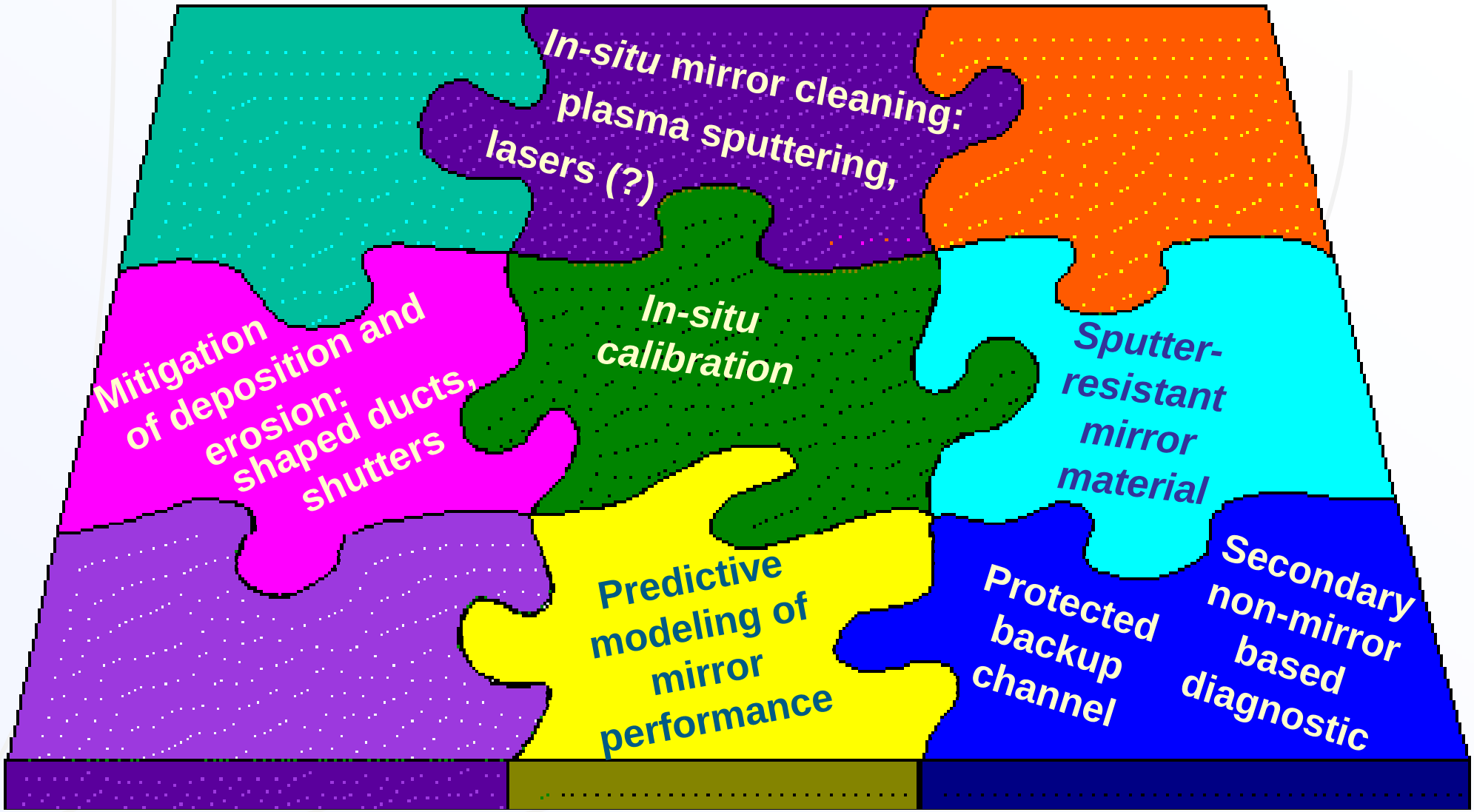


Surgery solutions:

1. Choosing secondary non-mirror based diagnostics

2. Protected backup channel with a reduced measurement capability

Resumé



On a good way to generic mirror solution…

…via joint effort

Thank you