FIP/1-4

ITPA

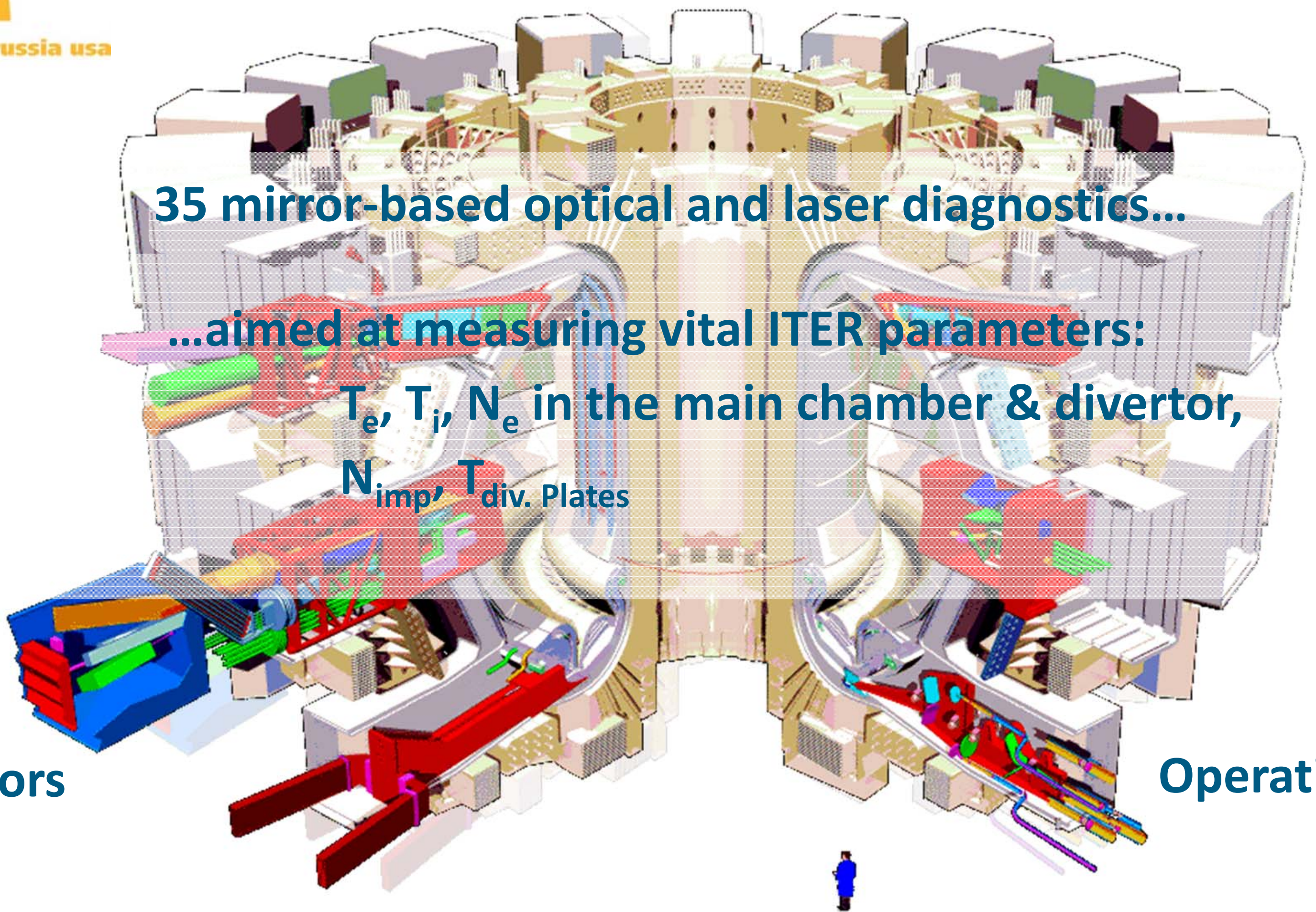
Diagnostic mirrors for ITER: research in the framework of the International Tokamak Physics Activity

A. Litnovsky

V.S. Voitsenya, R. Reichle, M. Walsh, A. Razdobarin, A. Dmitriev,
N. Babinov, L. Marot, L. Moser, R. Yan, M. Rubel, S. Moon, S. G. Oh, P. Shigin,
I. Orlovskiy, K.Yu. Vukolov, A. Krimmer, V. Kotov and Ph. Mertens
for the Specialists Working Group on First Mirrors of the ITPA Topical Group on Diagnostics

Mirrors in ITER diagnostics

ITPA



35 mirror-based optical and laser diagnostics…

…aimed at measuring vital ITER parameters:

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

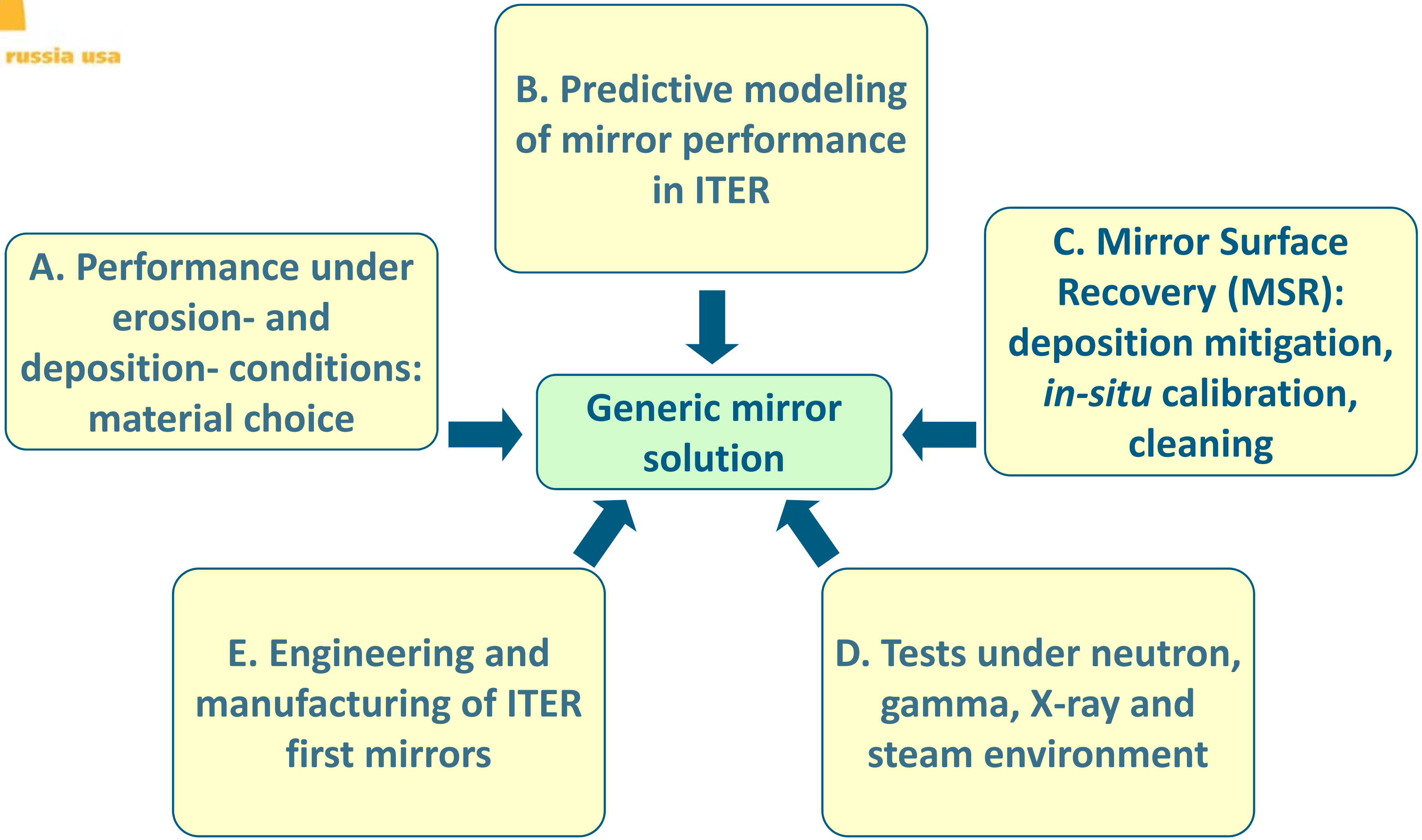
N_{imp}, $T_{div. Plates}$

~ 80 first mirrors

Operating at 2 nm – 114 μm

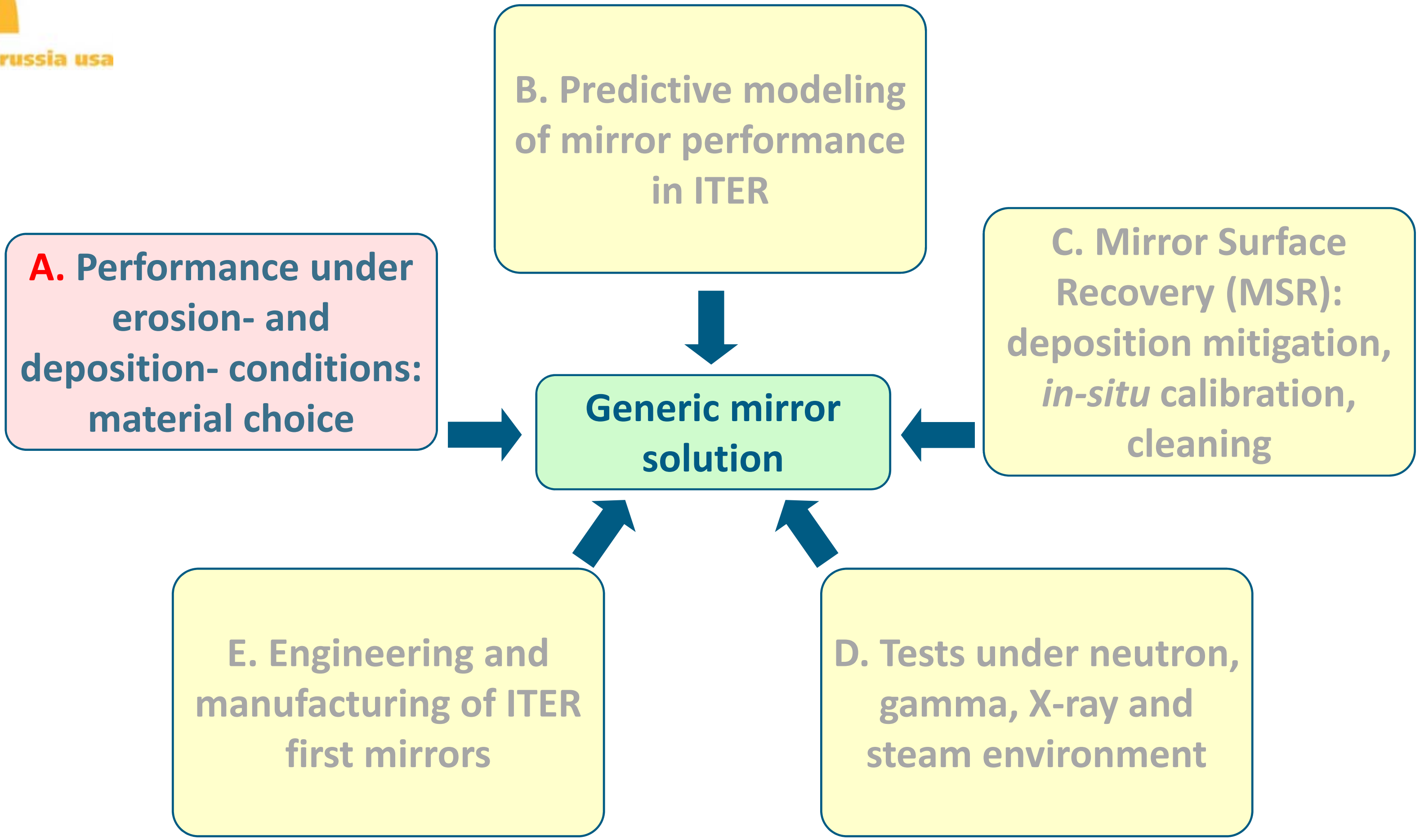
Mirror lifetime is crucially important for the successful ITER operation

Work plan of the coordinated R&D on mirrors



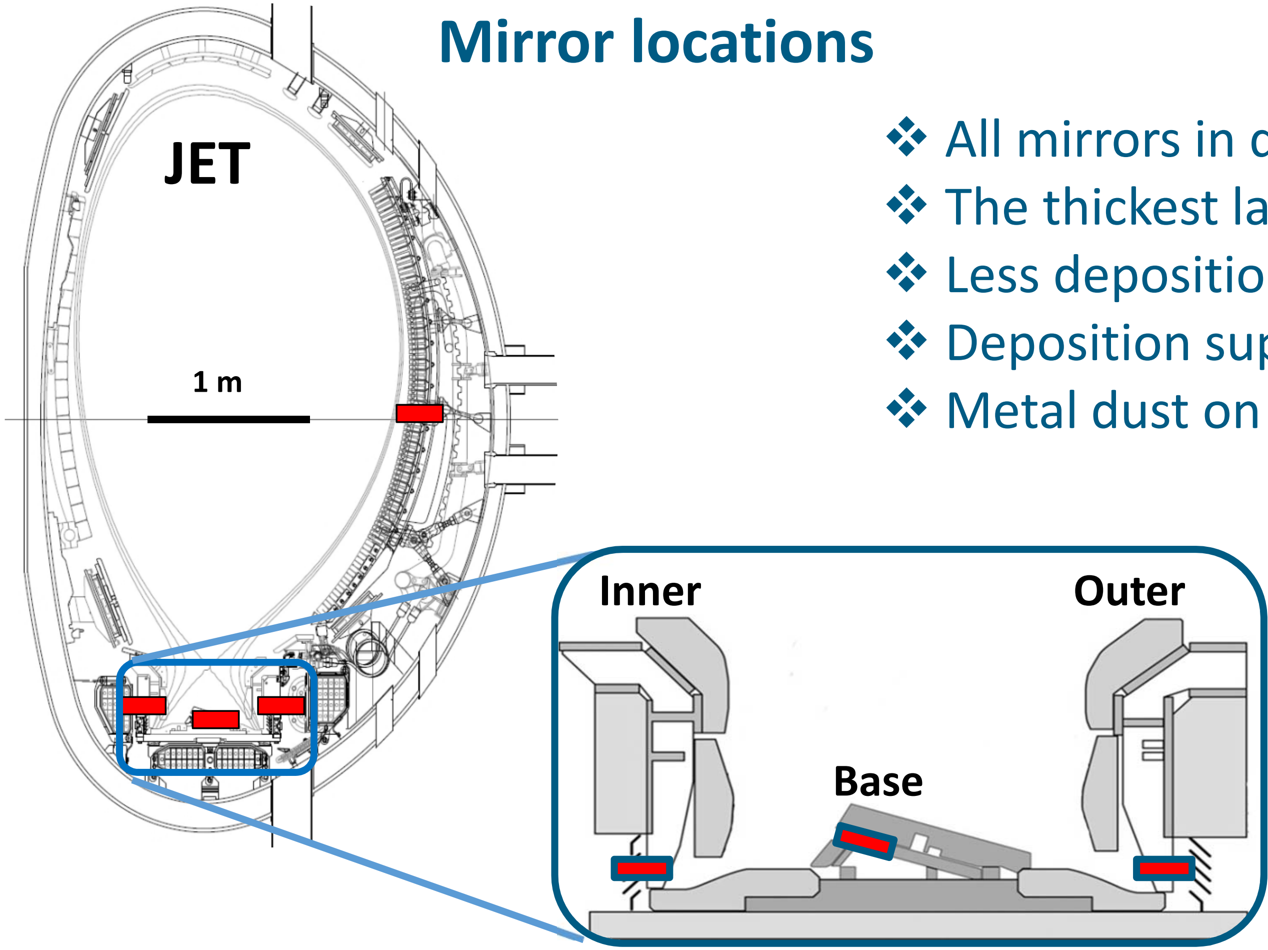
Implementation to ITER R&D on mirrors: ITER_D_2MPTR6

Task A: Performance under erosion- and deposition conditions. Material choice



First mirror test at JET

Mirror locations



Main findings

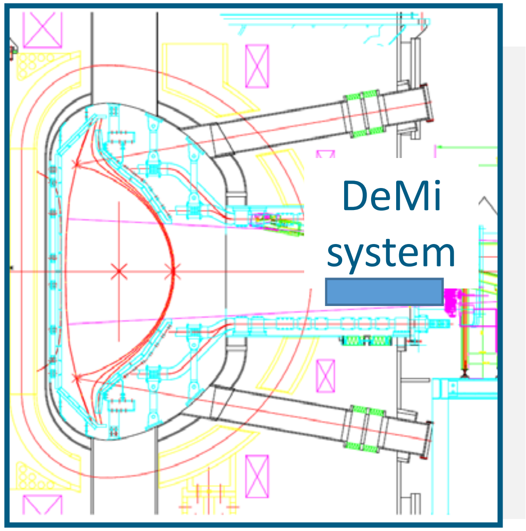
- All mirrors in divertor lost reflectivity by 20-80%
- The thickest layers the outer divertor
- Less deposition on mirrors in main vessel
- Deposition suppressed in diagnostic ducts
- Metal dust on mirrors: Be, Inconel, W

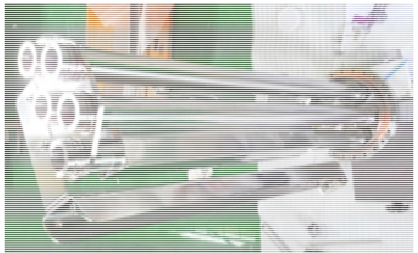
Results from ILW 1-3 campaigns

Regular plasma operation vs. wall conditioning

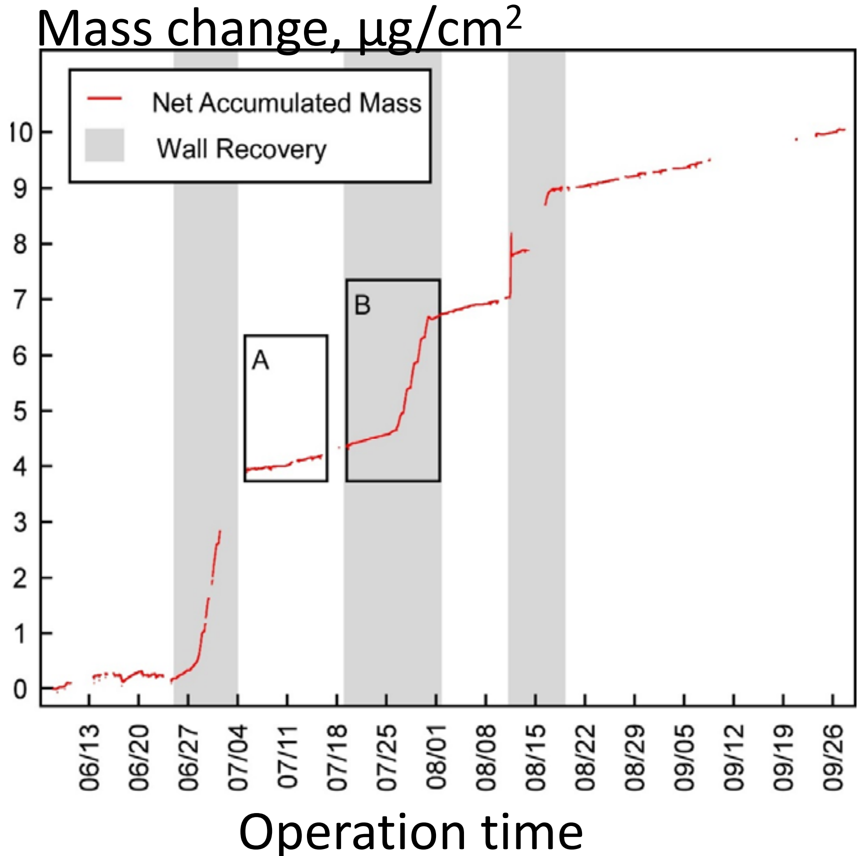
Deposition Mitigation (DeMi) diagnostic tube system

KSTAR





DeMi system



- Quartz crystal microbalances (QCMs) as mirrors
- Installed in diagnostic ducts
- Real-time monitoring of contamination

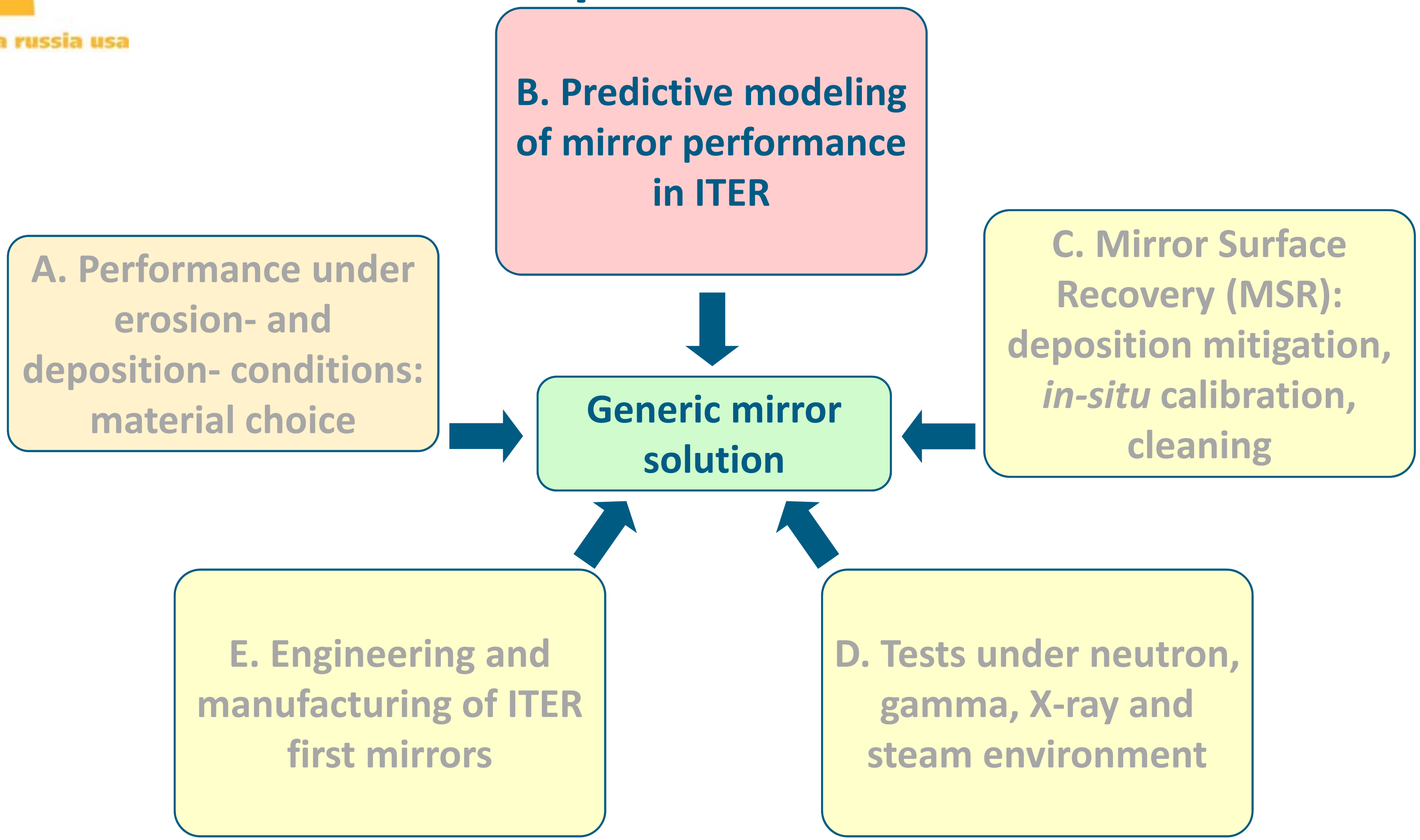
Contamination mostly caused by wall conditioning

Mirrors must be protected with shutters

iter
china eu india japan korea russia usa

Task B: Predictive modeling of mirror performance in ITER.

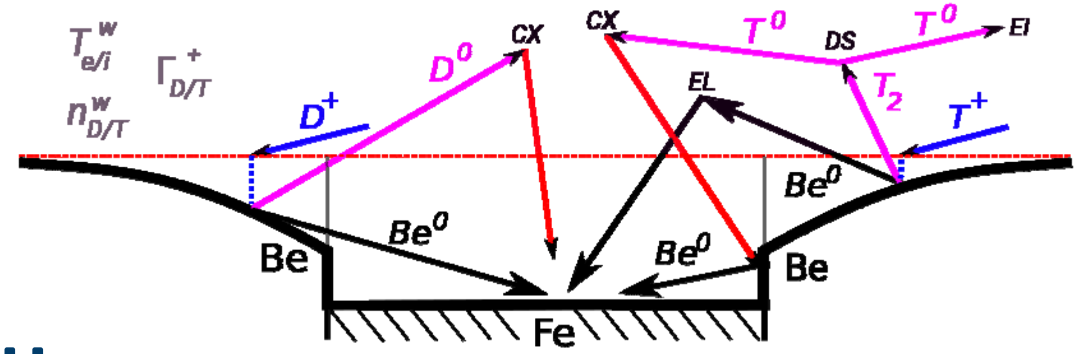
ITPA

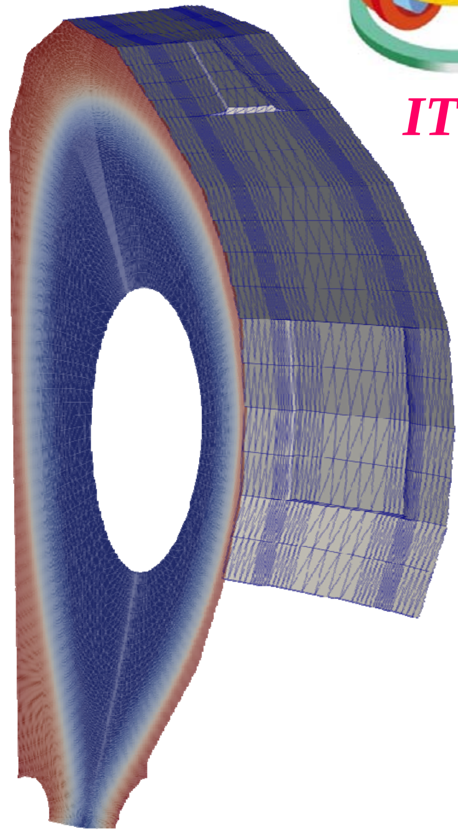


Numerical estimates of the erosion/deposition rates in ITER

ITPA

- 2.5D model* (3D first wall, 2D plasma)
- Only steady-state, no ELMs and abnormal effects
- Fluxes of Fe and Be are comparable
- "Erosion / Deposition" ratio of Be on the port-plug faces >3
- "Erosion / Deposition" ~ 1 for cylindrical ducts **





* V. Kotov, Nucl. Fusion 56 (2016) 106027
V. Kotov, 43rd EPS (2016) P5.051
**V. Kotov, Fus. Eng. Des. 123 (2017) 834

Task C: Mirror Surface Recovery (MSR): deposition mitigation, *in-situ* calibration, cleaning

ITPA

B. Predictive modeling of mirror performance in ITER

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

Generic mirror solution

C. Mirror Surface Recovery (MSR): deposition mitigation, *in-situ* calibration, cleaning

E. Engineering and manufacturing of ITER first mirrors

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

Single crystal mirrors: resistance to sputtering*

- ❖ Direct comparative test of single crystal Mo and Rh mirrors
- ❖ Finding a limit for material
- ❖ Identical plasma-sputtering conditions
- ❖ Equivalent to ~ 200 cleaning cycles
  - ✓ Steady-state He plasma
  - ✓ Ion energy: ~ 105 eV
  - ✓ Fluence: 4.0×10^{25} He/m^2
  - ✓ Mirror temperature 245°C

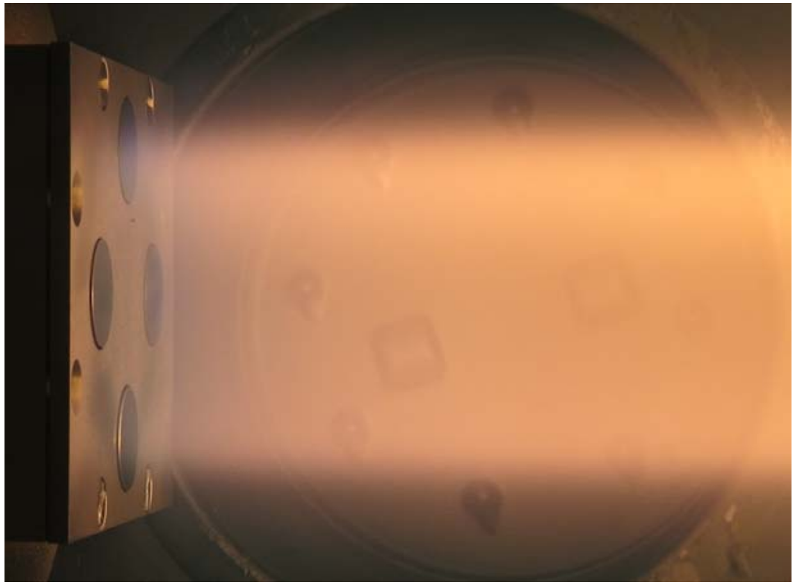


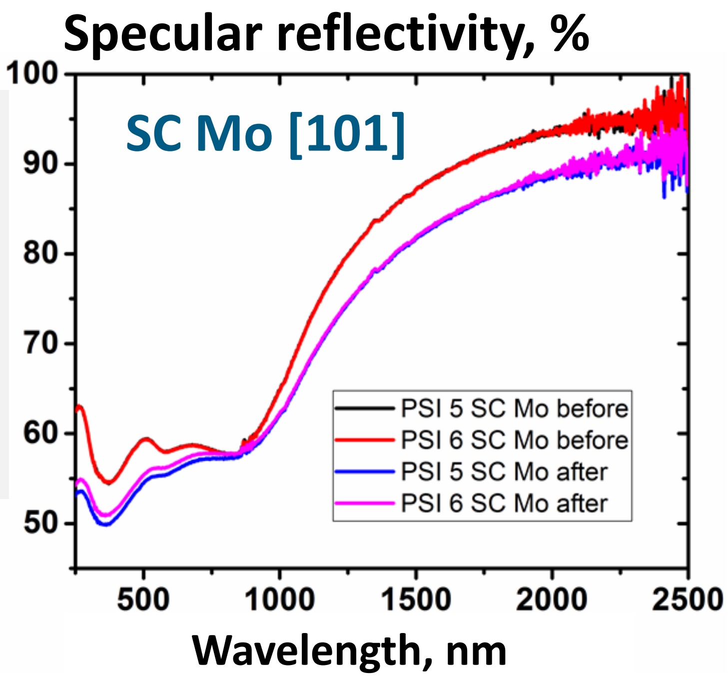
Photo: Mirrors in PSI 2 linear plasma device

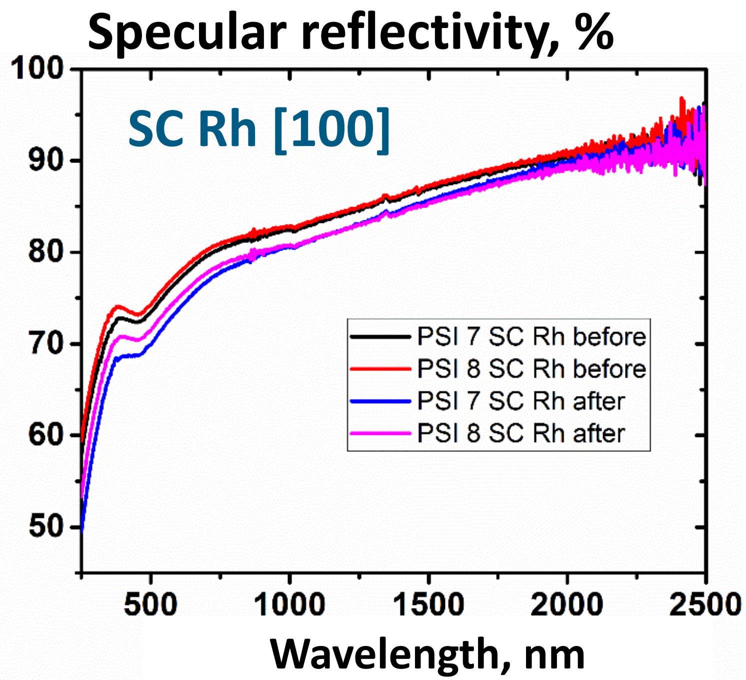
Sputtered:

- ❖ 850 nm of SC Mo
- ❖ 1800 nm of SC Rh

*J. Peng et al., JNM 128 (2018) 107

Impact of sputtering on mirror reflectivity





ITPA

- Very small degradation, less than 9%
- Similar drop of reflectivity for all mirrors

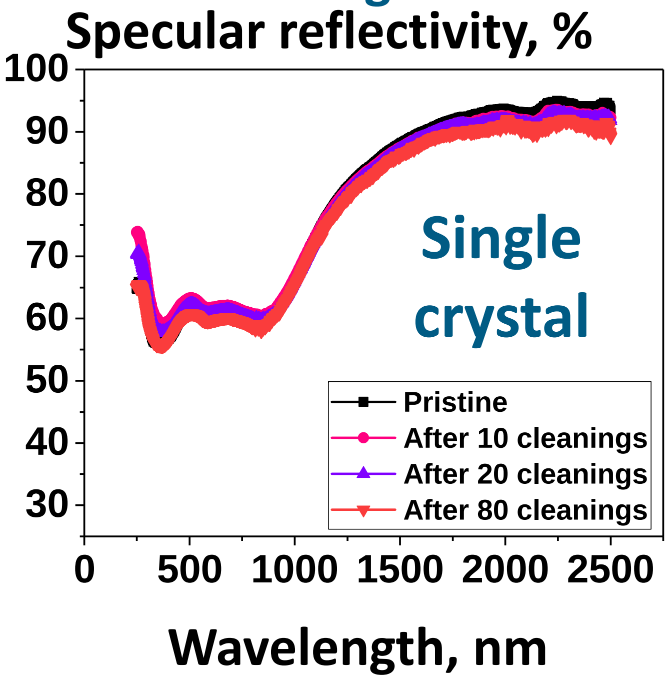
Single crystal Mo and Rh mirrors are extremely robust to sputtering

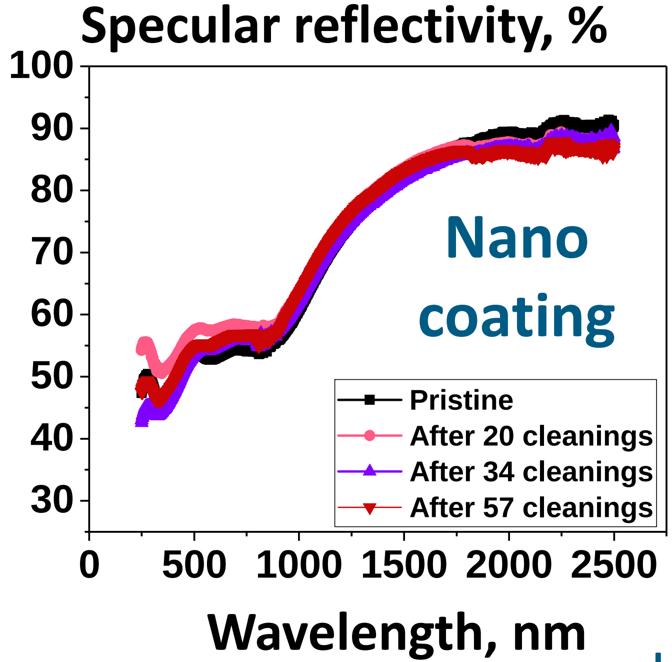
Repetitive cleaning

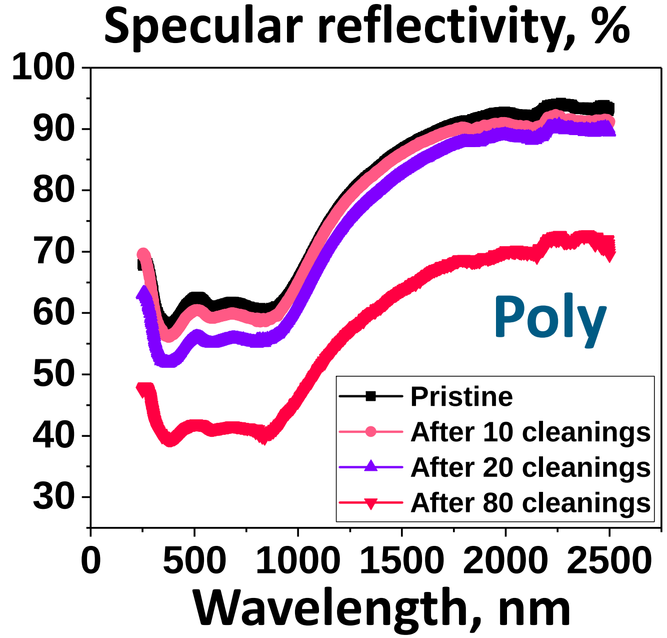
Mirror material: molybdenum

RF-cleaning — **Contaminant Al/W/O, thickness 25 nm** — **Up to 80 cycles**

ITPA







L. Moser et al., Phys. Scr. T170 (2018) 014047

University of Basel

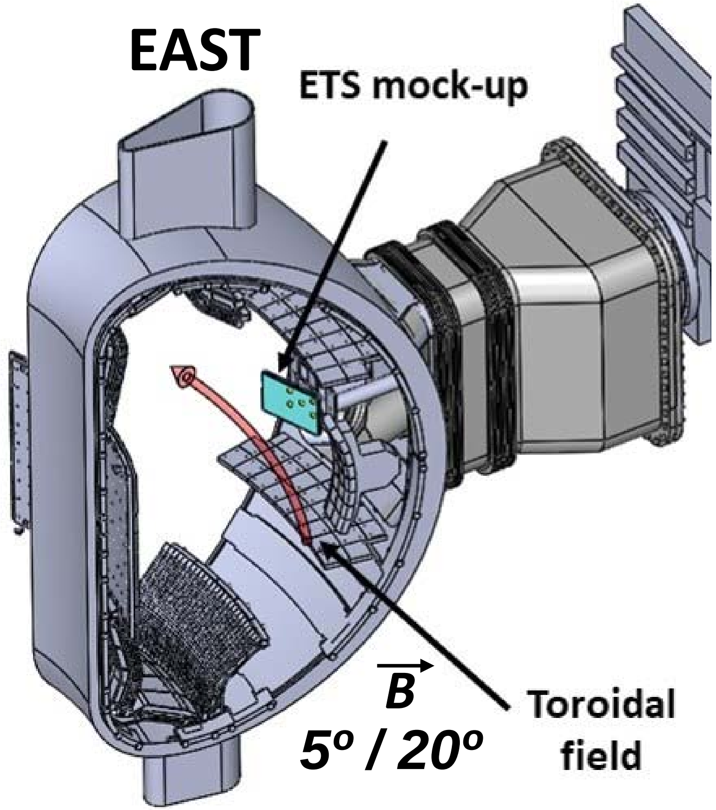
Single crystal mirrors hold repetitive cleaning

Single crystals are favorite candidate materials

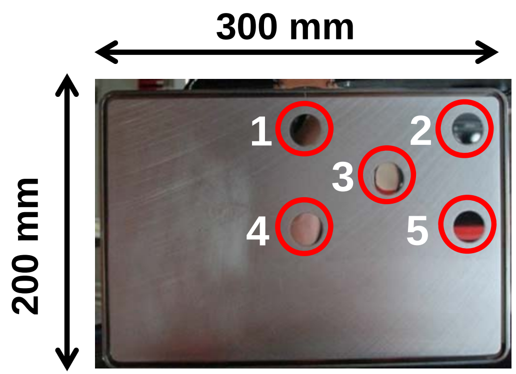
UWAVS (U.S.A.)
Successful RF cleaning of mirrors

First in-situ mirror cleaning*

ITER Edge Thomson Scattering (ETS) mock-up plate in EAST



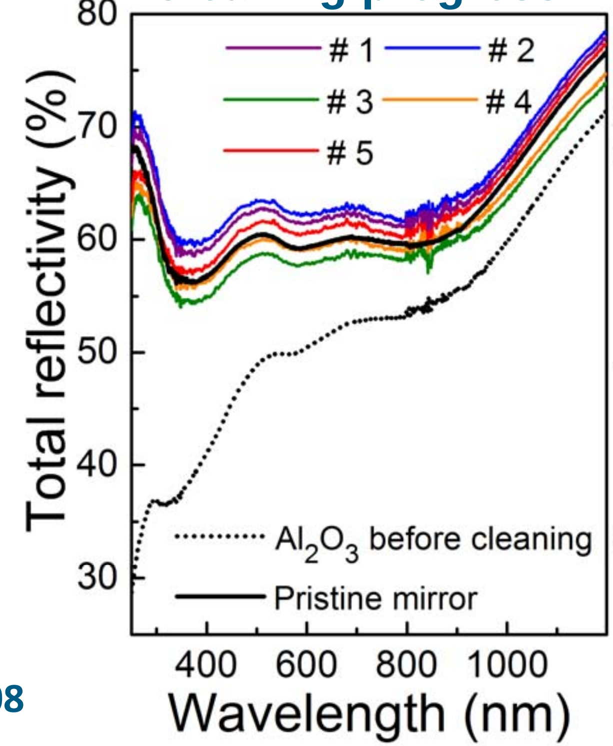
R=1.7 m (6.2 m for ITER)
B=1.77 T (3.5 T for ITER)



Mo mirrors coated with 10 nm Al_2O_3

*R. Yan et al., NF 58 (2018) 026008

Cleaning progress



Recovery of total reflectivity, removal of contaminants

Experimental and numerical study of impurity transport and re-deposition in RF discharge

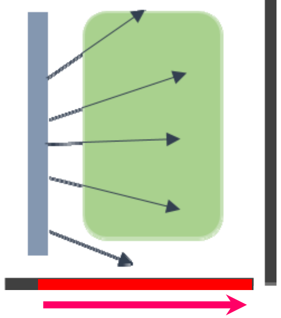
china eu india japan korea russia usa

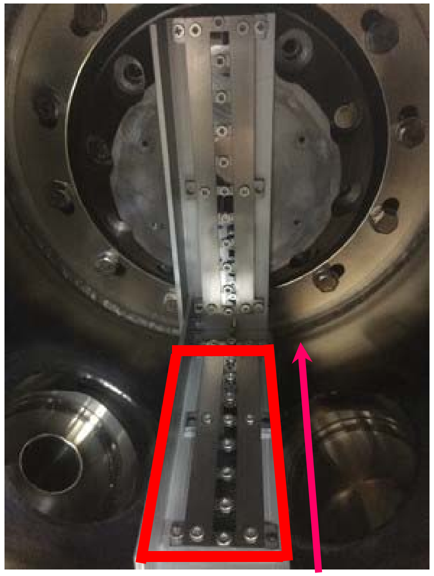
ITPA

Ioffe Institute

Monte Carlo transport code for neutral particles developed at Ioffe Institute

RF-mirror

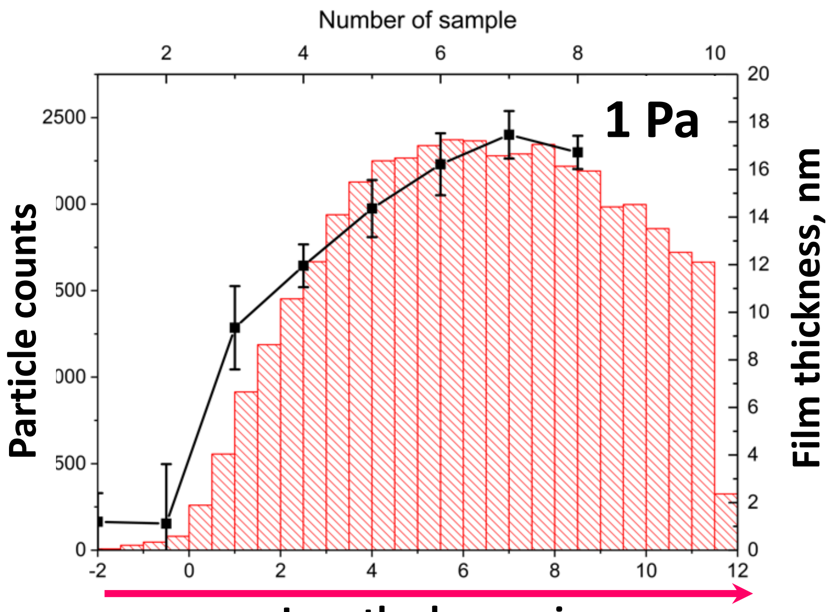




- Sputtering, re-deposition, re-erosion processes
- Thermal velocities of gas particles
- 3D-space with geometry import from CAD-models

Comparison of modeling and experiment

Validating experiment: gold film sputtered in neon RF plasma at 1 and 10 Pa



E. Mukhin FIP/1-5

Excellent agreement of the experiment and modeling

Task E: Engineering and manufacturing of ITER first mirrors

ITPA

B. Predictive modeling of mirror performance in ITER

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

Generic mirror solution

C. Mirror Surface Recovery (MSR): deposition mitigation, *in-situ* calibration, cleaning

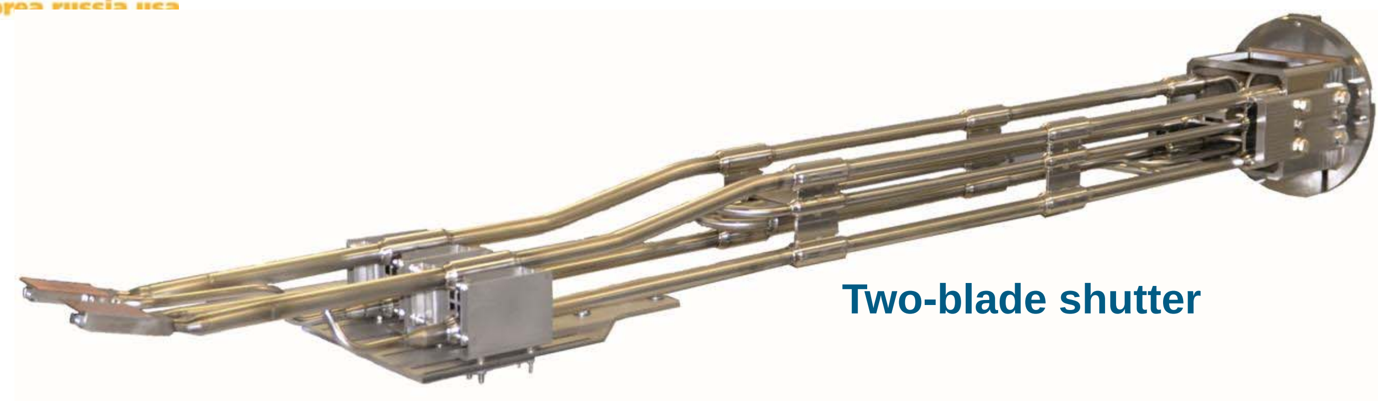
E. Engineering and manufacturing of ITER first mirrors

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

Prototypes and mockups: development and testing

ITPA

Shutter of ITER core Charge-eXchange Diagnostic (cCXRS)



Two-blade shutter

- cCXRS shutter prototype
- Pneumatic He-driven actuator
- Long-term testing
- Water at 250ºC
- **> 1 000 000 cycles**
- 600.000 required
- No cracks and no leaks

Shutter
for Edge Thompson Scattering (ETS) system
(Japan)

- Tested for 10.000 cycles
- 8.000 is required

Development of mock-ups is booming

Impressive performance results

Summary

- ❖ Sound progress in studies of diagnostic mirrors for ITER
- ❖ Single crystals: rhodium and molybdenum are favorite mirror materials
- ❖ Mirror to be cleaned *in situ*
- ❖ Successful repetitive RF cleaning, up to 80 cycles for single crystal Mo mirror
- ❖ Cleaning in strong magnetic field succeeded in EAST
- ❖ Intensive mock-up manufacturing and prototyping in progress
- ❖ First components tested already

Outlook: Critical topics for future research

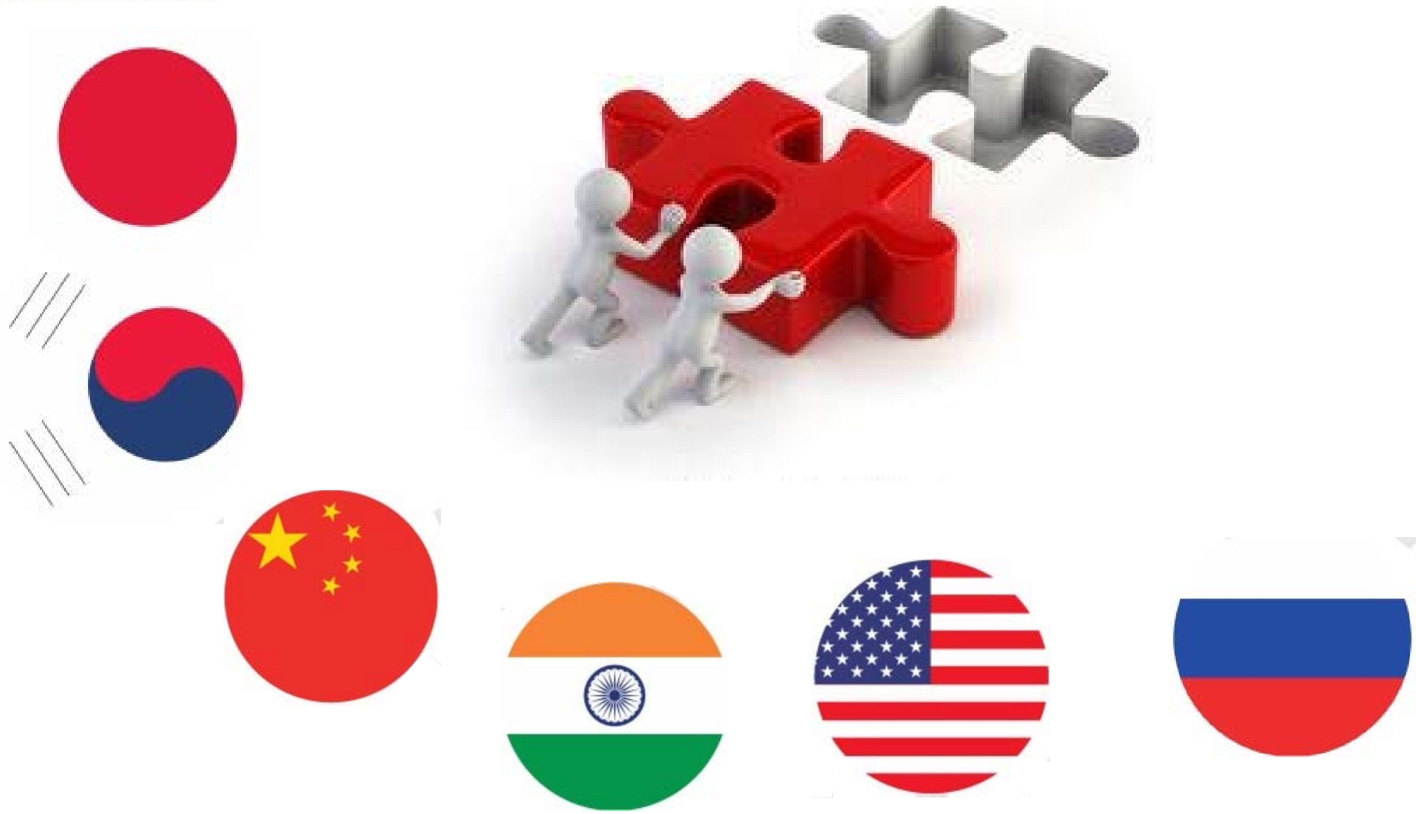
ITPA

- ❖ **Tests in accidental conditions, recovery of affected mirrors**
- ❖ **Predictive modeling**
- ❖ **Fine tuning of mirror concept: crystal orientation etc.**
- ❖ **Full-scale prototyping and tests of first mirror units**

iter
china eu india japan korea russia usa

Sound progress

ITPA



via joint effort

Acknowledgments

ITPA

Experimental activity is partially supported via ITER purchase order Nr. 4100006576, IDM UID: U9F2VW and a contract: IO/17/CT/4300001626.

This work has been also partly carried out within the framework of the EUROfusion Consortium and has also received partial funding from the Euratom research and training programme 2014–2018 under grant agreement no. 633053.

A part of the work reported was supported via National Natural Science Foundation of China under Contracts 11505231 and 11475218.

This activity was performed in part under the contract 2007-2006997 of the Ministry of Science and ICT of the Republic of Korea

Disclaimer

The views and opinions expressed herein do not necessarily reflect those of ITER Organization, the European Commission or the National Natural Science Foundation of China.

Thank you