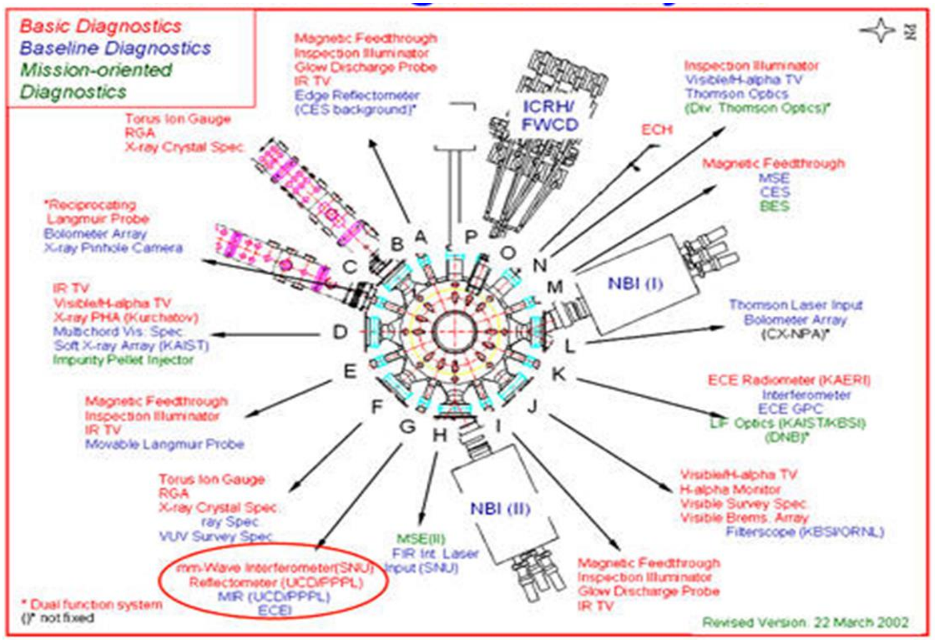
Strategy for Plasma Diagnostics in Fusion Reactors

- Design state-of-the-art diagnostics for present day devices with
  - ➢ high accuracy,
  - ➢ high spatial and temporal resolution.

  → Establish appropriate plasma models

ITER diagnostics



- Consider how to diagnose and control DEMO
  - ➢ Harsh environment with radiation, heat and particles
  - ➢ Small number of crude (but robust and reliable) diagnostics are available

  → Utilize models heavily

Reference: A.J.H. Donné | ESI | Garching, DE | 16th June 2015 |

Challenges and Requirements for ITER Diagnostics

Many Challenges:

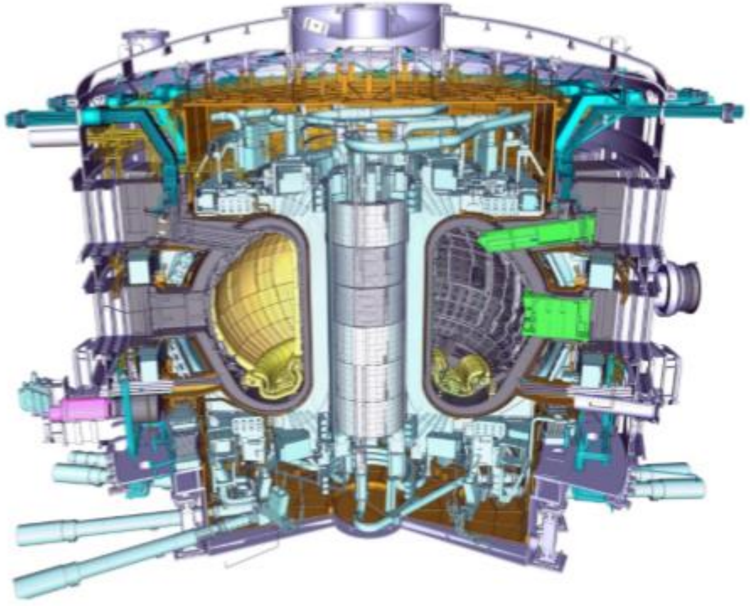
Advanced diagnostics for physics study and control with Hostile environment (neutrons, gammas, ions, tritium)

Nuclear environment
- Stringent demands on the engineering including remote handling
- Requires robustness

Long plasma pulse length
- Requires high stability

Control role of the measurements
- Requires high accuracy and reliability

Integration of multiple diagnostics in single ports
- Requires well organized engineering



Roles of ITER Diagnostics

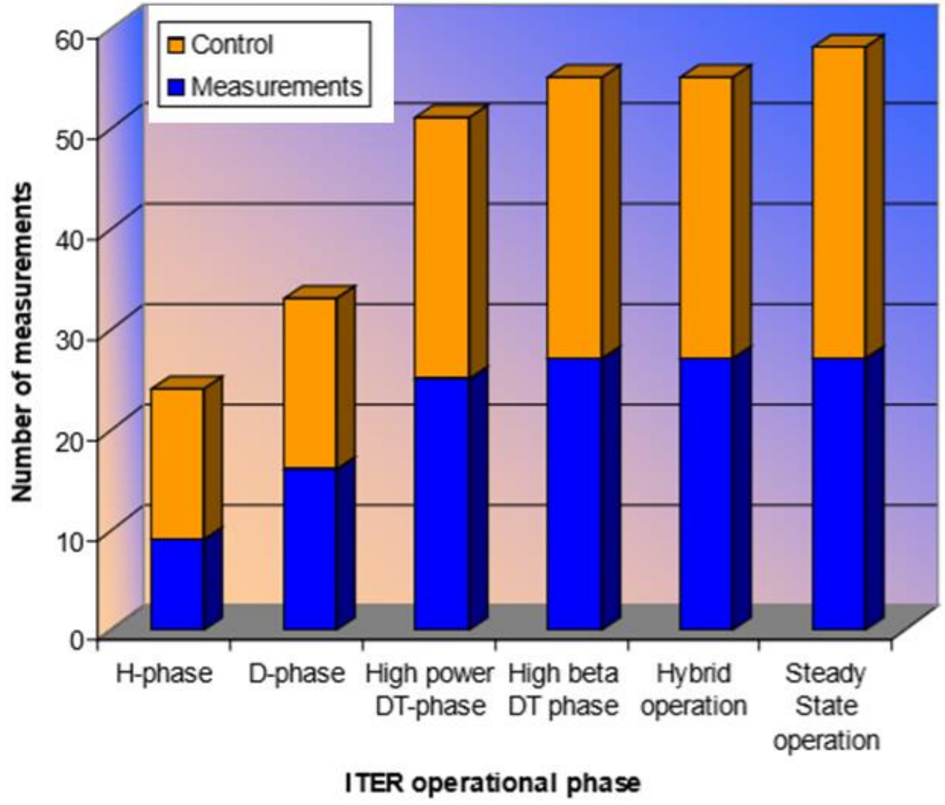
An extensive set of diagnostics to provide measurements for

Machine protection
- **Separatrix/wall gap, first wall temperature, etc.**

Plasma control
- **Plasma shape and position, plasma current, divertor diagnostics, etc.**

Physics studies
- **Confined alpha particles, alpha-driven modes, etc.**

> 50 individual measurements



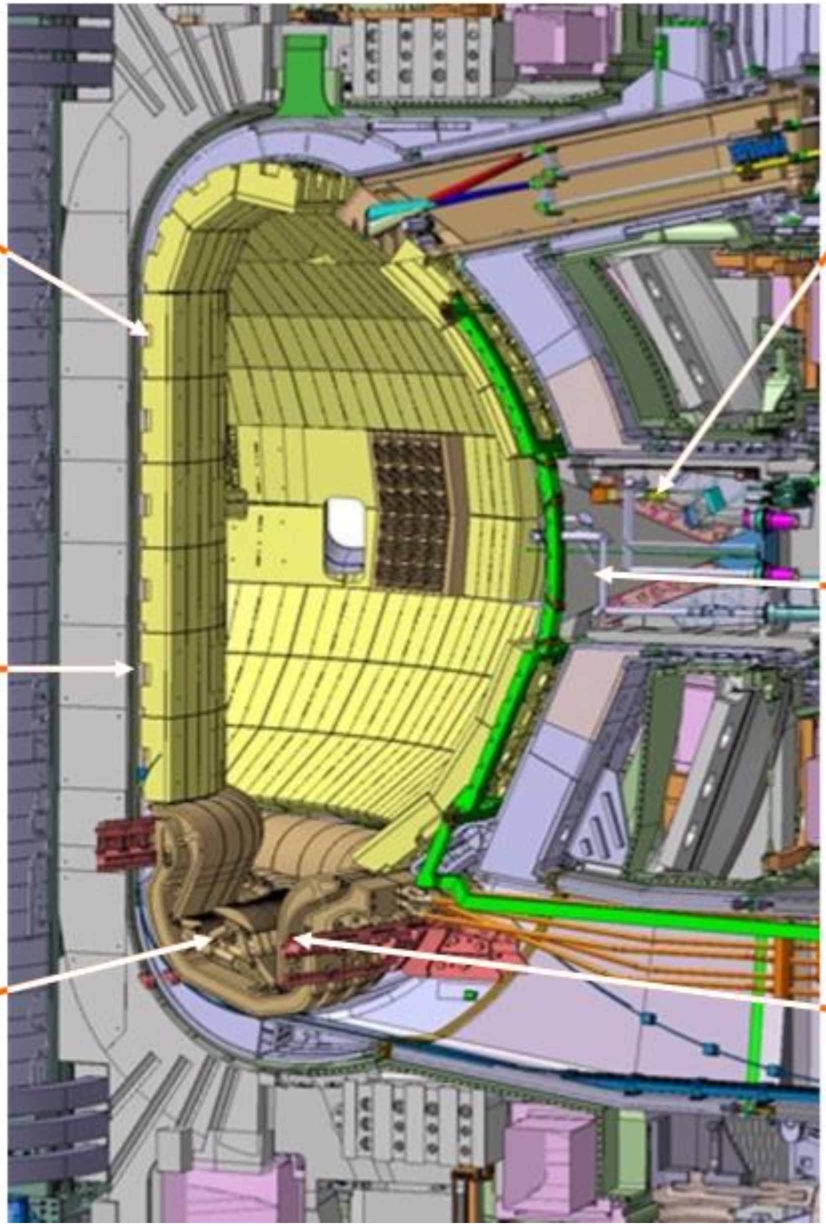
ITER Diagnostics Issues

Radiation

Magnetic coils
- Radiation Induced Conductivity (RIC)
- Radiation Induced Electric Degradation (RIED)
- Radiation Induced Electromotive Force (RIEMF)

Bolometers
- RIC
- Nuclear Heating
- Sputtering
- Contact degradation
- Differential swelling and distortion

Pressure gauges
- RIC
- RIED
- Filament aging



Neutron cameras
- Noise due to γ-ray, proton, α
- Radiation damage on solid state detectors

Optical diagnostics
Mirror
- Deposition, erosion
- Swelling, distortion

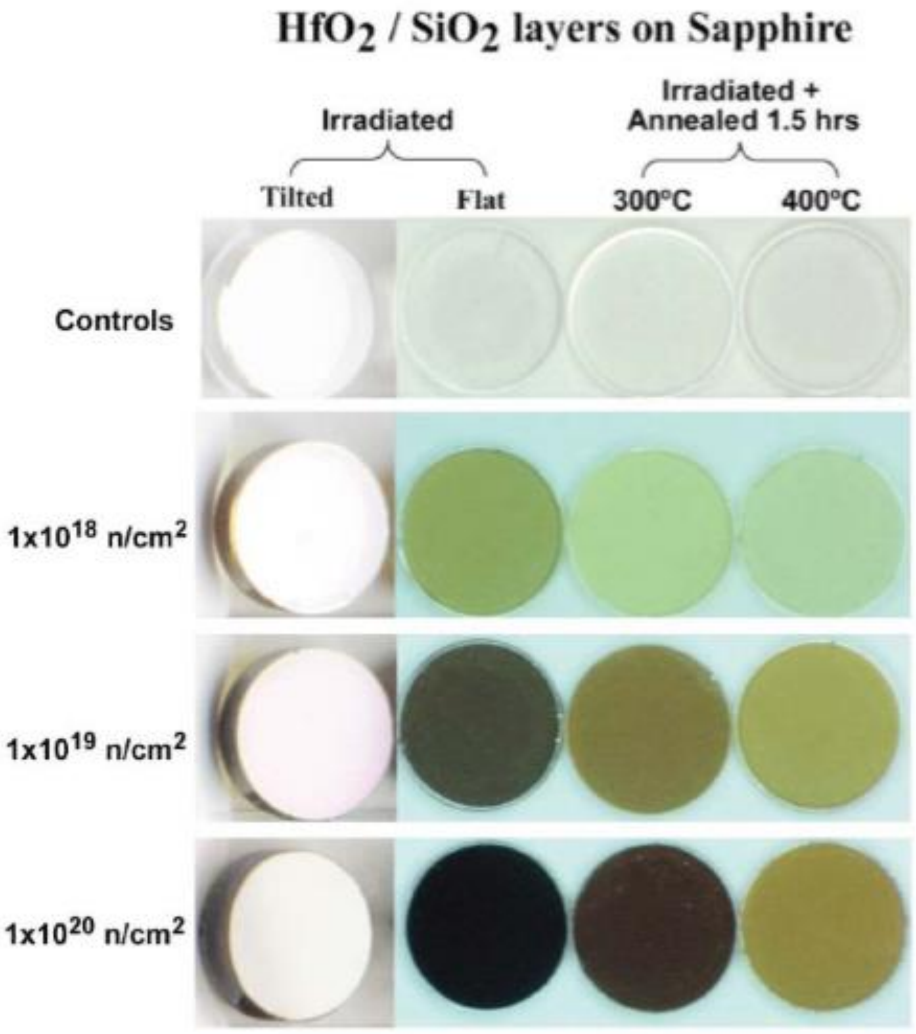
Window
- Permanent transient absorption
- Radioluminescence
- Swelling, distortion

Deposition & erosion

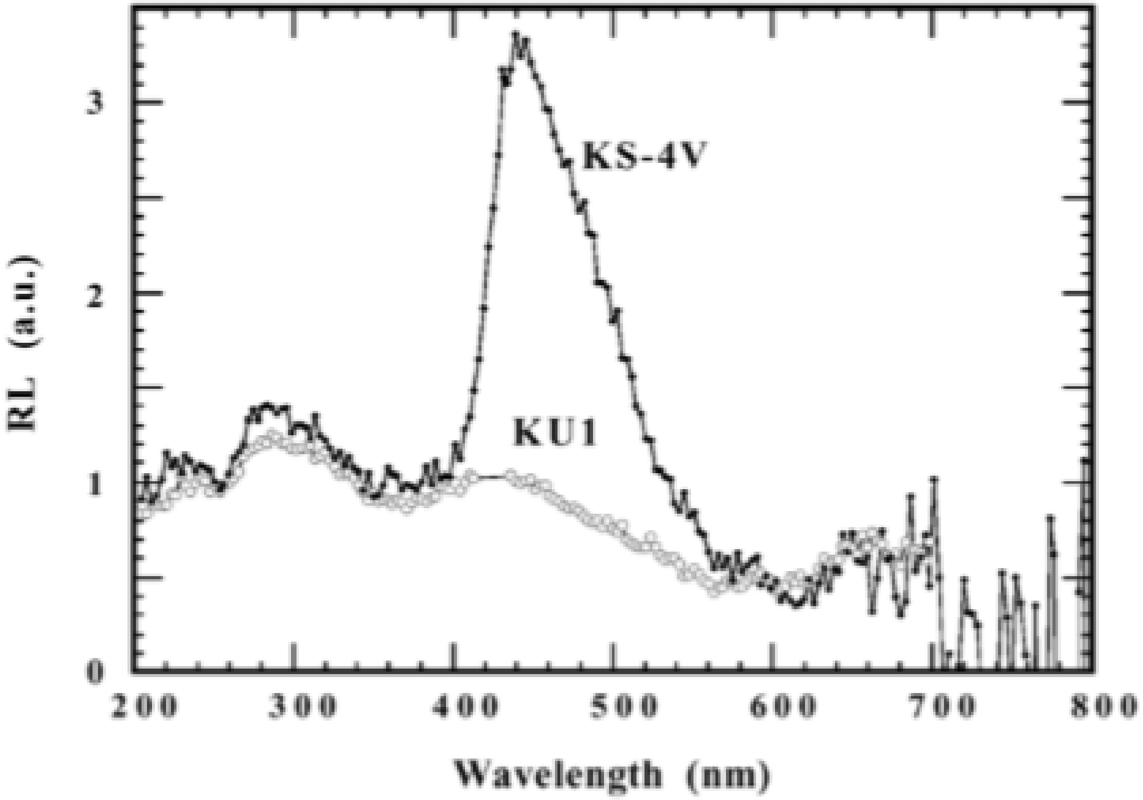
Impurity monitoring
Mirror and windows
- same as above

Fibers
- Permanent transient absorption
- Radioluminescence

Radiation induced absorption and emission



Radiation Induced Absorption (RIA) due to neutron irradiation

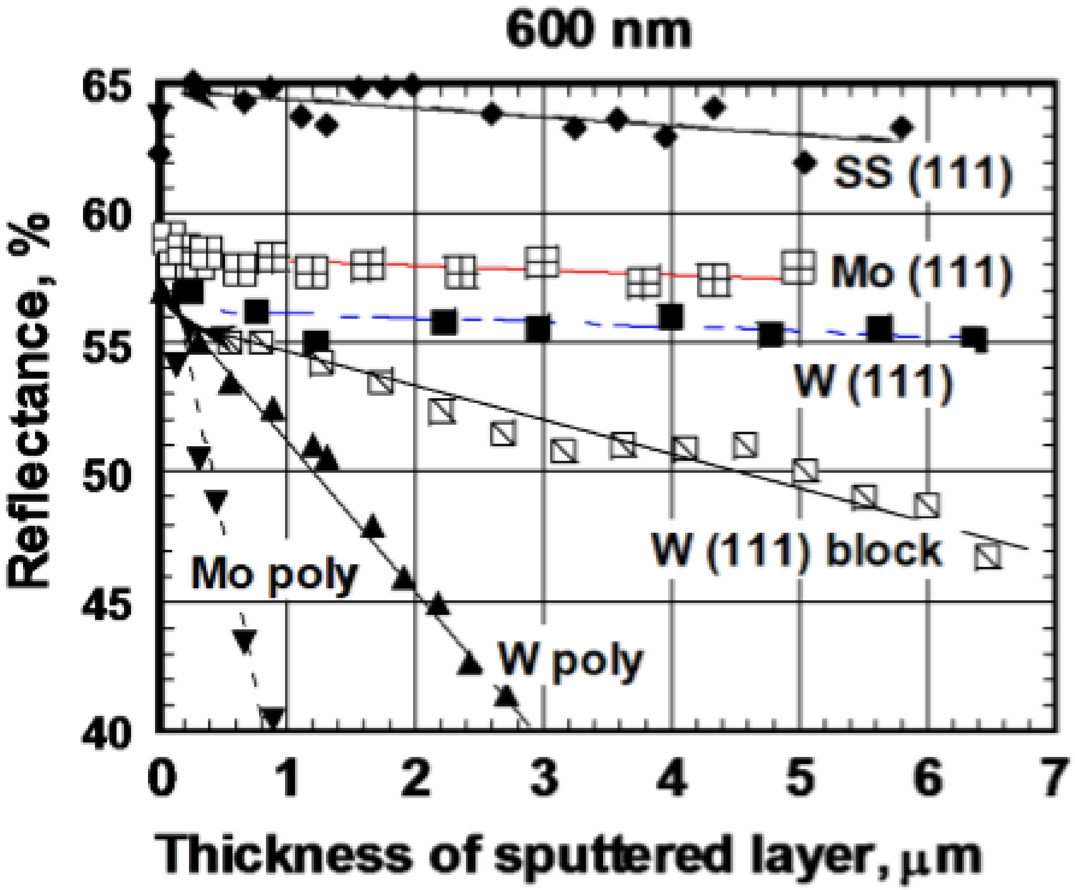


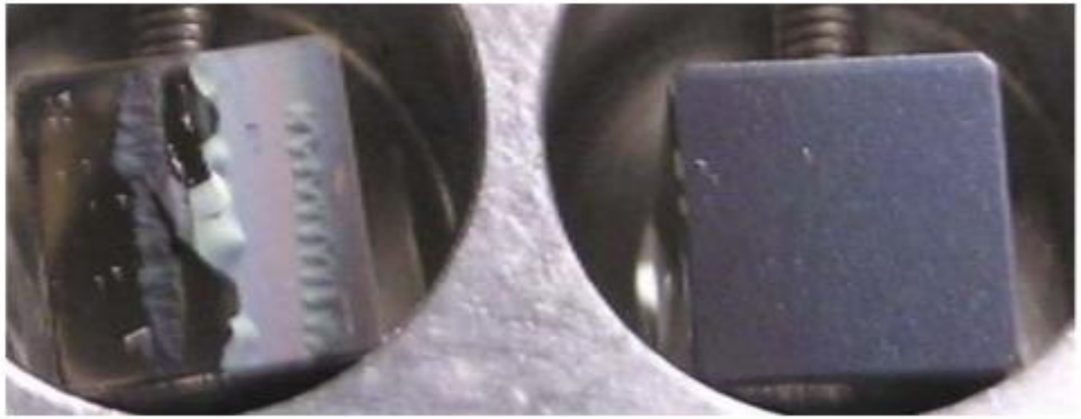
Radiation Induced Emission (RL or RIE) of two types of quartz fibers exposed to gamma irradiation of 700 Gy/s

Erosion/re-deposition

Reflectivity for eroded mirrors

V. Voitsenya, Rev. Sci. Instrum. 76 (2005) 083502.





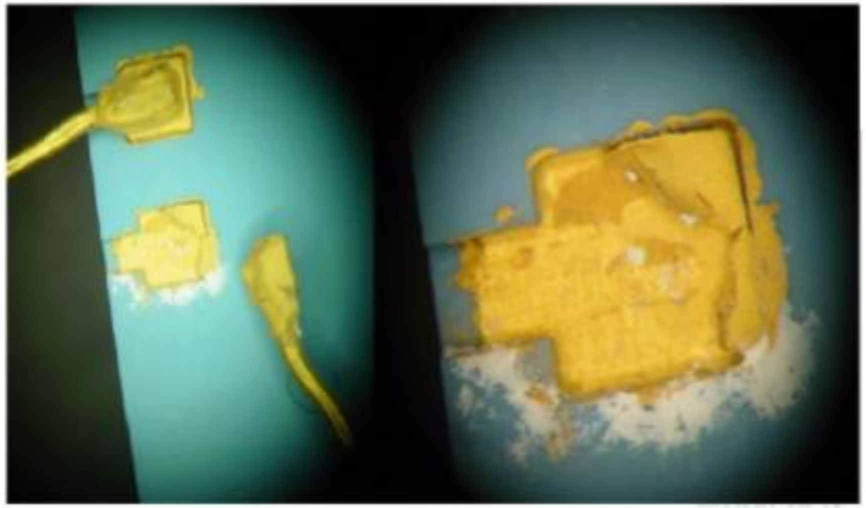
Material eroded away elsewhere can be redeposited on mirrors

M. Rubel, 18th ITPA Diagnostics meeting

Courtesy: A. Litnovsky

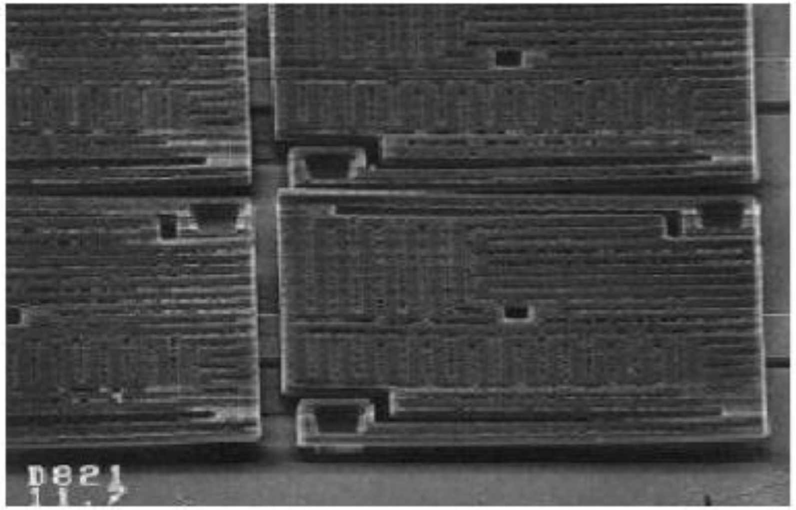
Transmutation / contact degradation

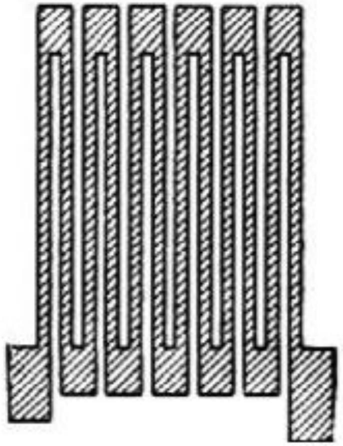
Transmutation was an issue for bolometers with Au resistors (transmuting in to Hg)



Courtesy Ludo Vermeeren (SCK/CEN)

Good results have been achieved with Pt resistors





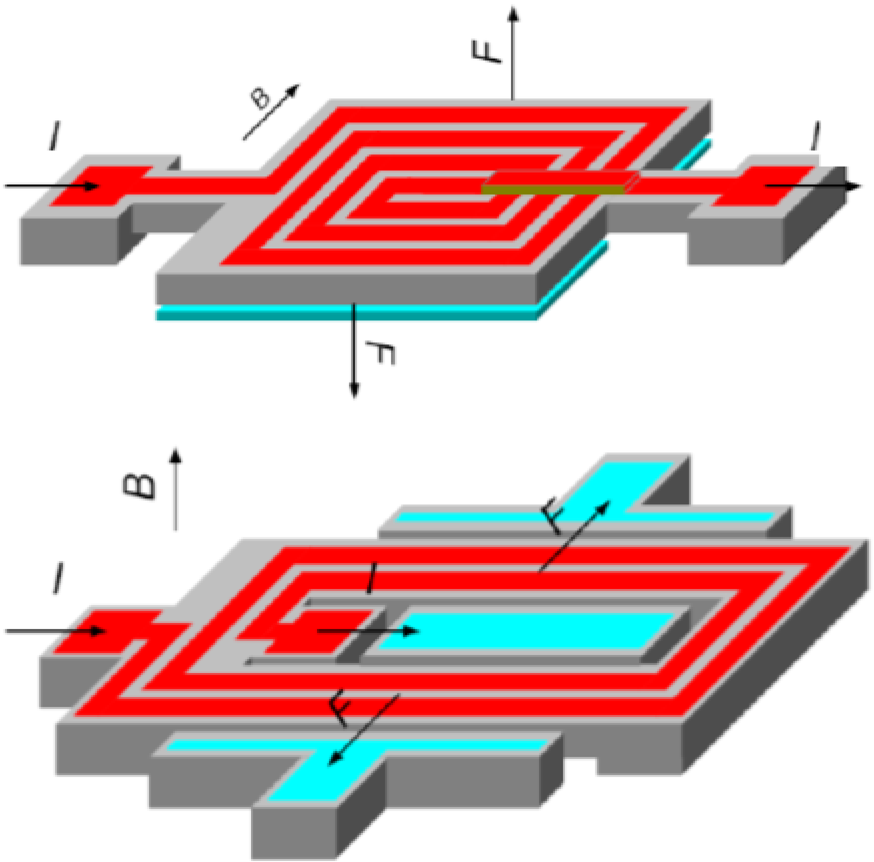
Long plasma pulse operation

Traditional methods to measure steady-state magnetic fields have problems with drifts in the integrator, etc. (apart from radiation-induced effects)

Challenge to find alternative solutions

- Better integrators
- Alternative magnetic field probes (e.g. Hall probes, micromechanical sensors)
- Alternative measurements (position reflectometer)

Micromechanical sensors (force-balance)

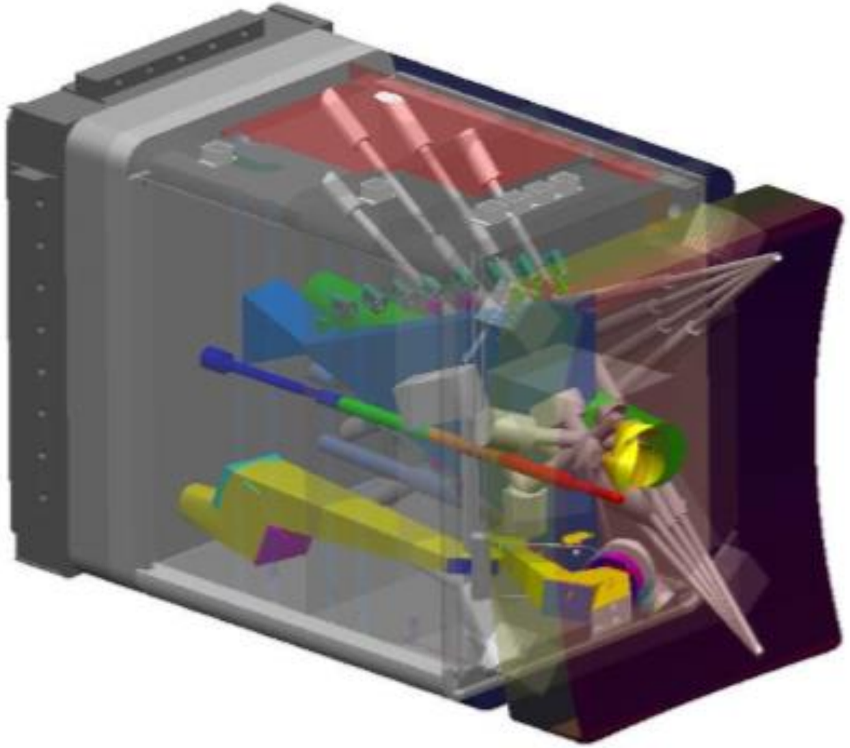


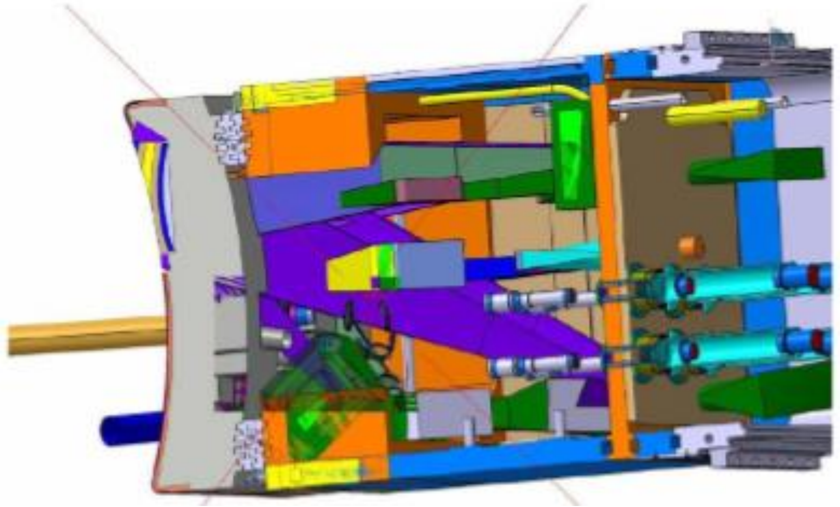
Two layout types: torsional (top) and double-ended turning fork (bottom)
Blue: electrodes.
Red: Multi-turn excitation coils

A. Kärkkäinen *et al.*, VTT, TEKES

Integration and engineering

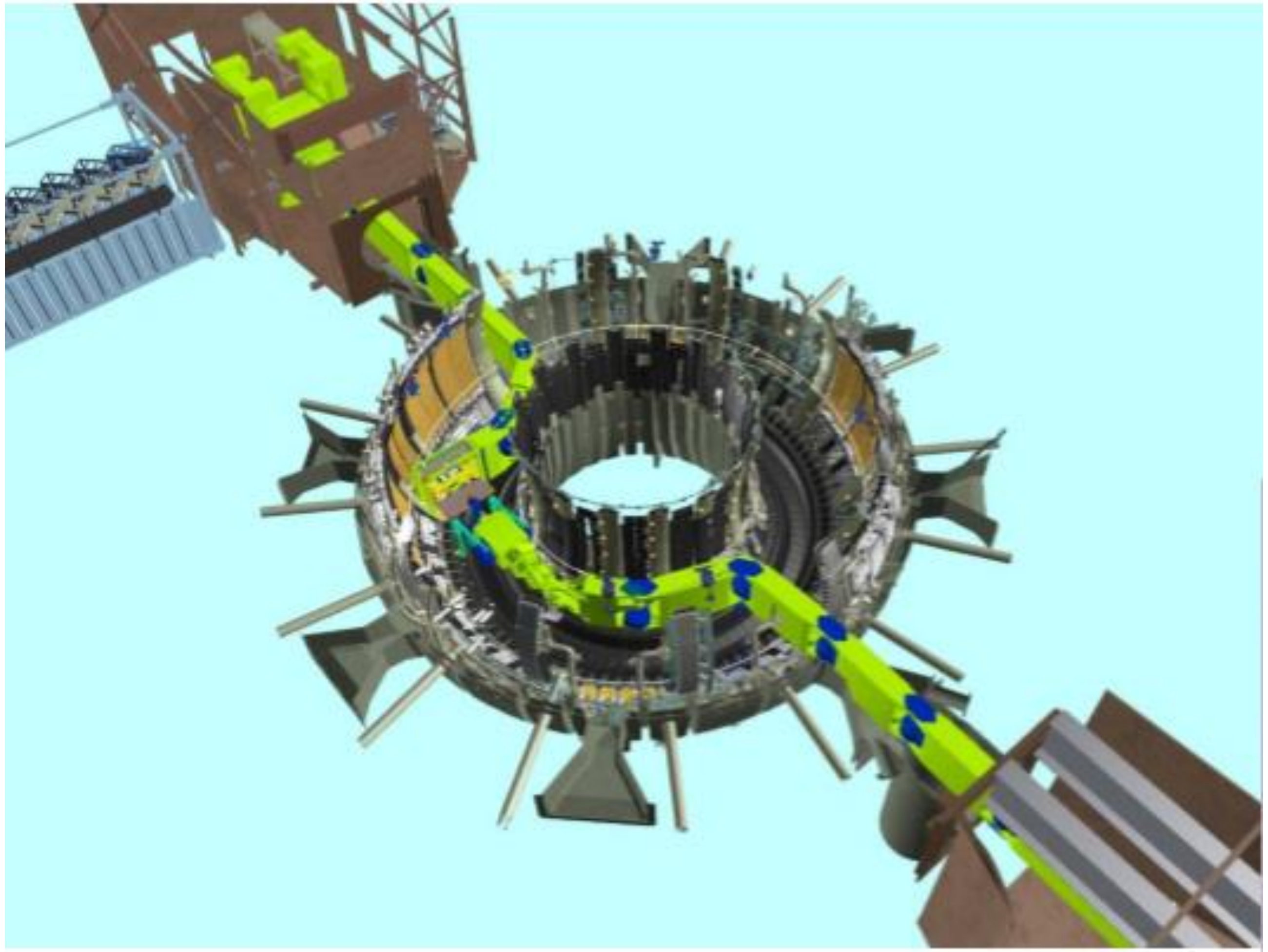
Eq#01	DIAGNOSTICS	package
E01	Port Cell	P11
G01	G01-Visible-IR TV	P11
B01	**B01-Radial Neutron Camera**	P11
B07	B07-Gamma Ray Spectrometers	P11
B10	B10-Bubble Chambers	P11
B10	B10-High Resolution Neutron Specttrometer	P11
D01	D01-Bolometry	P21
E04	E04-Divertor Impurity Monitor	P17
E11	E11-MSE-Core on heating Neutral Beam (HB)4	P12
N01	N01 -In-Vessel Diagnostic Services	P10
N02	Equatorial BSM	B1-xxx
N04	N04-Interspace Blocks and Second Enclosures	P10
N06	N06-Ex-Bioshield _ Electrical Equipment	P10
N07	N07-Window assemblies	P31

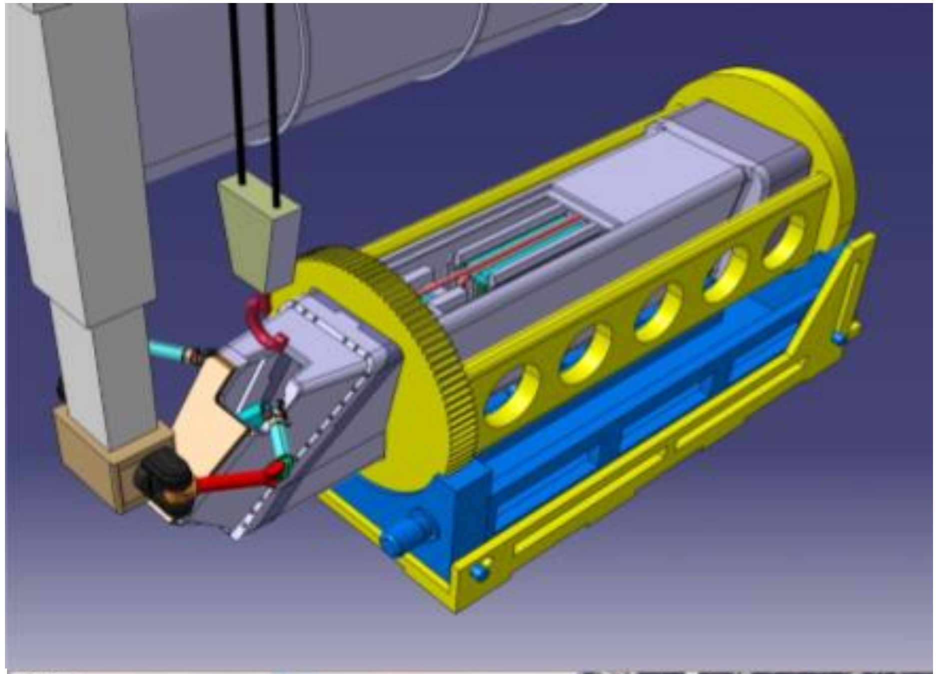




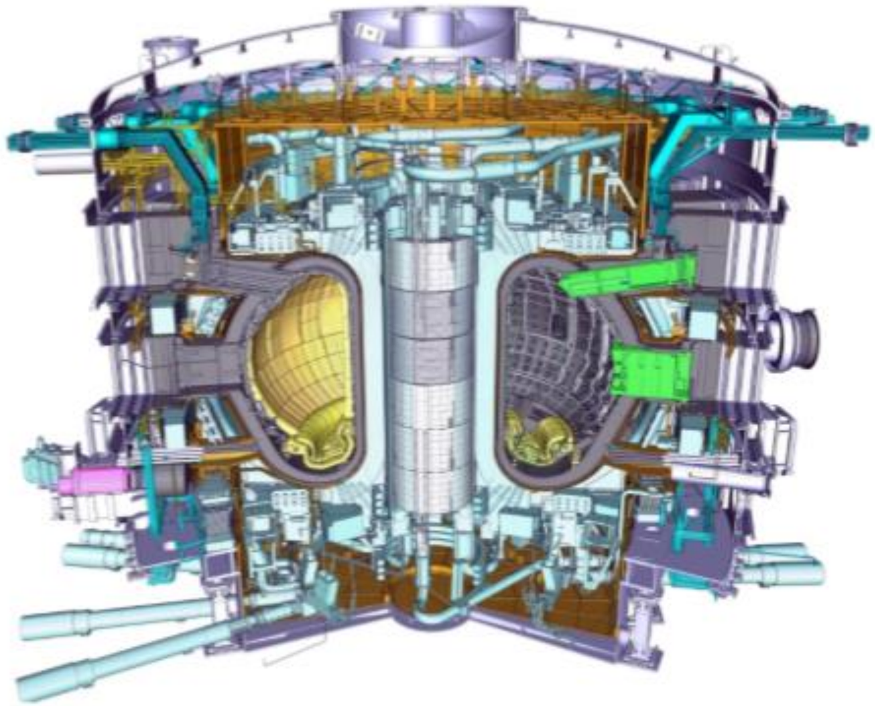
Many diagnostics in a single port plug

Remote handling





Implications of ITER Diagnostics



- Many challenges are somewhat under control

→ Expected problems are identified: radiation and deposition are most critical

→ Many of the present diagnostic techniques still work (but some marginally)

- How about DEMO?

Diagnostics for DEMO

	ITER	DEMO	Reactor
Fusion Power	0.5 GW	2.5 – 5 GW	2.5 - 5 GW
Heat flux (first wall) (divertor)	0.1-0.3 MW/m^2 ~ 10 MW/m^2	0.5 MW/m^2 ~15-20 MW/m^2	0.5 MW/m^2 ~20 MW/m^2
Neutron Load (FirstWall)	0.78 MW/m^2	< 2 MW/m^2	~ 2 MW/m^2
Integrated Neutron Load (First Wall)	0.07MW.year/m^2 (3 years operation)	5 - 8 MW.year/m^2	10 - 15 MW.year/m^2
Displacement per atom (dpa)	< 3 dpa	50 - 80 dpa	100 - 150 dpa

Radiation

Very limited access possibilities

Large emphasis on Reliability, Maintainability, Robustness

Environmental conditions more extreme than in ITER
(>100 times higher neutron fluence):

- ✓ No electrical and refractive components close to the plasma
- ✓ Limited application for first mirrors

Needs:
Development program for new materials testing under DEMO conditions

DEMO: Fewer robust diagnostics are needed !

DEMO is not a flexible research machine
but will have only 1 or 2 operating scenarios

- Smaller number of measurements/diagnostics
- Advanced predictive/analysis codes to combine data from various diagnostics in an intelligent way are needed with limited diagnostics.

Experience on ITER may guide the selection of diagnostics
that can operate with the harsh environment

Selection of diagnostics for DEMO

Set of ITER diagnostics can be only validated to a limited extend on present day devices.

- So the ultimate test of the techniques will be on ITER
- The same will be true for DEMO

Going from ITER to DEMO is a smaller step for plasma physicists than that from JET to ITER, but it is a much larger step for plasma diagnosticians.

- Experience on ITER will be beneficial for DEMO

Note: fluence in DEMO is still ~50 times higher than that in ITER.

→ Issues marginally acceptable in ITER might be impossible/unacceptable in DEMO