ITER Diagnostics Challenges

ITER Diagnostics Team

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29/06/2011

Ack: Special thanks to all colleagues who provided support and information for this presentation

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

Outline

- ITER overview
- Differences in ITER
- Design progress
- System examples
- Status
- Summary

Diagnostic systems

About 45 different diagnostic systems installed around ITER tokamak

1) for machine protection or basic control,
2) for advanced performance control, and
3) evaluating the plasma performance and understanding important physical phenomena

To Observe:

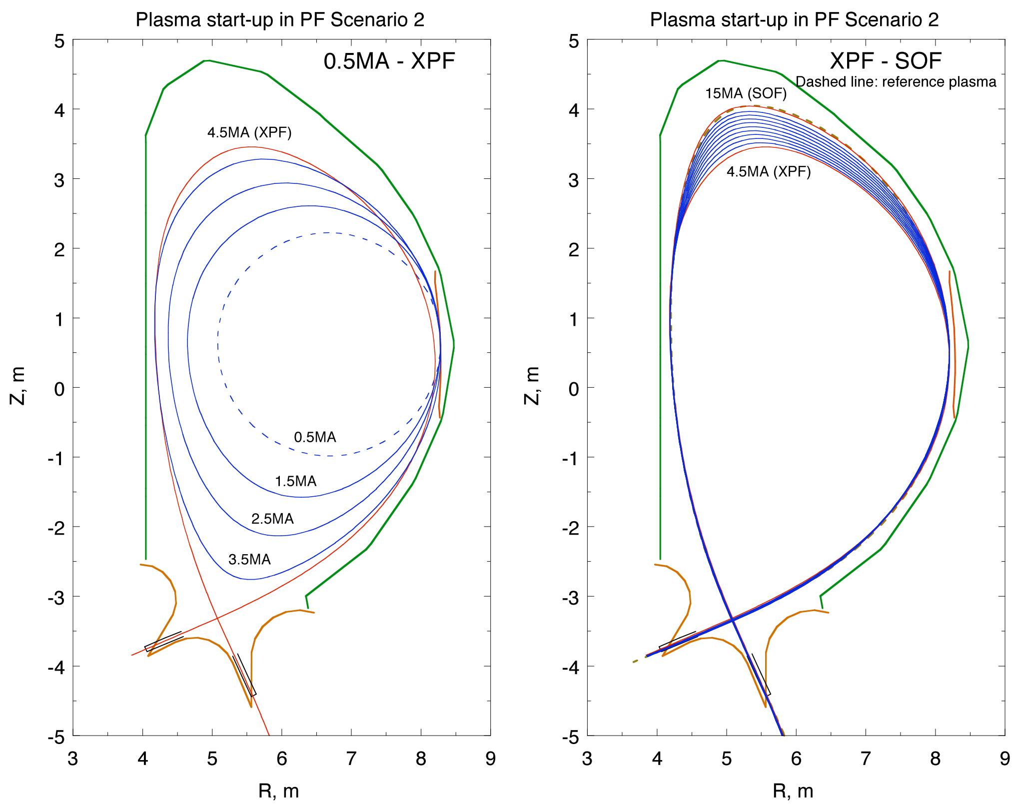
Neutrons
Magnetics
Passive Spectroscopy
Active Spectroscopy
Infrared Thermography
Particle monitoring
Alphas
Tritium & Dust
Density/Temperature

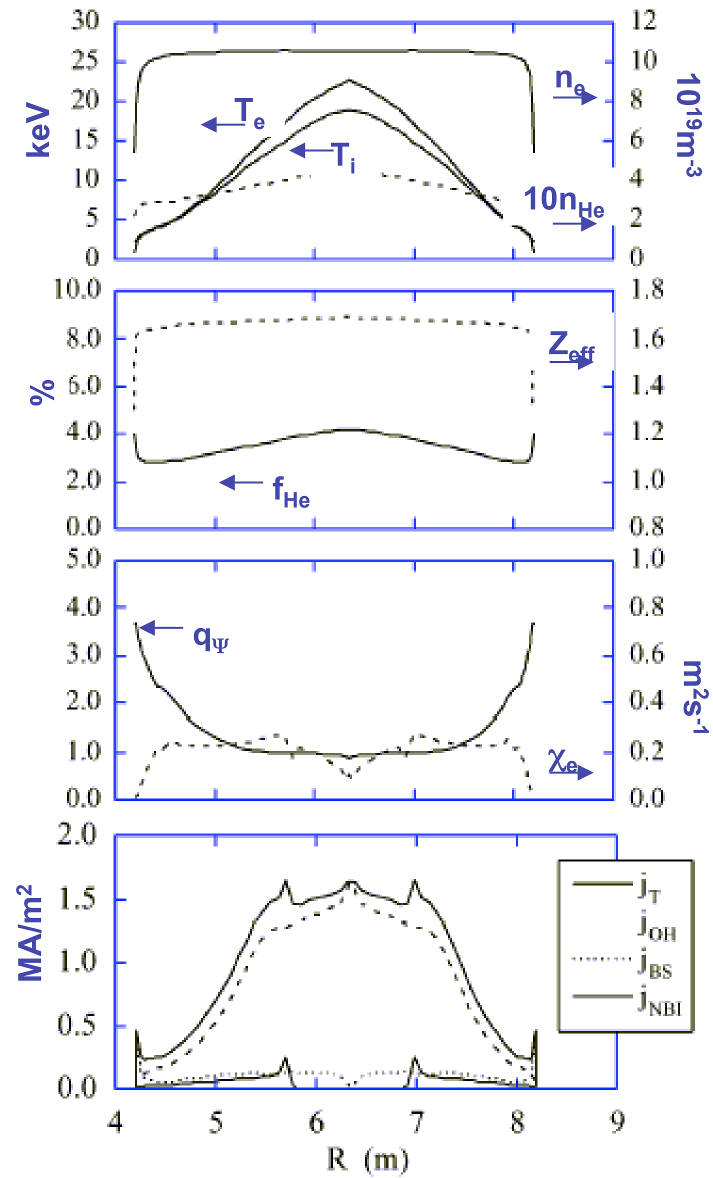
All integrated directly in to machine or port plugs

ITER Plasma Scenario - ELMy H-mode

A Q=10 scenario with:

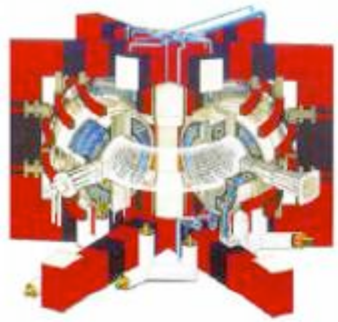
I_p=15MA, P_{aux}=40MW, $H_{98(y,2)}$=1

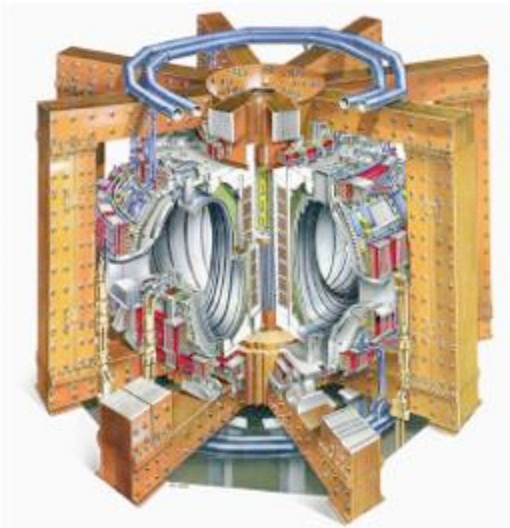


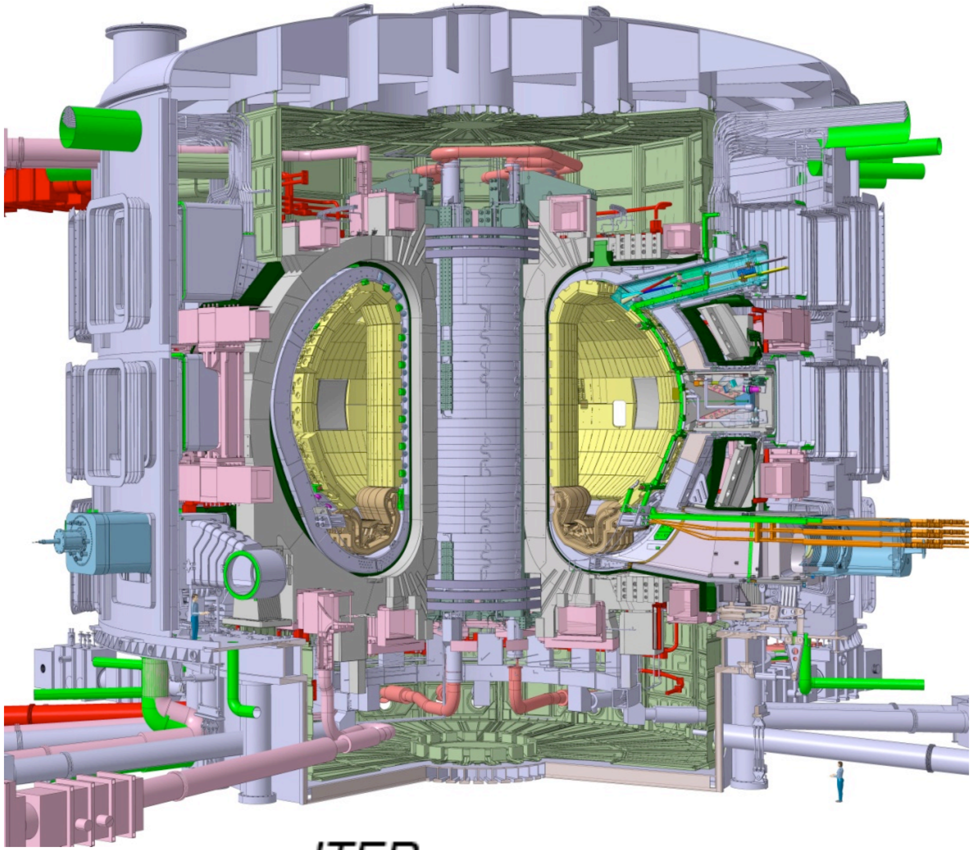


Current Ramp-up Phase

ITER is twice as large as our largest existing experiments







Tore Supra
V_{plasma} 25 m^3
P_{fusion} ~0
t_{plasma} ~400 s

JET
V_{plasma} 80 m^3
P_{fusion} ~16 MW 2s
t_{plasma} ~30 s

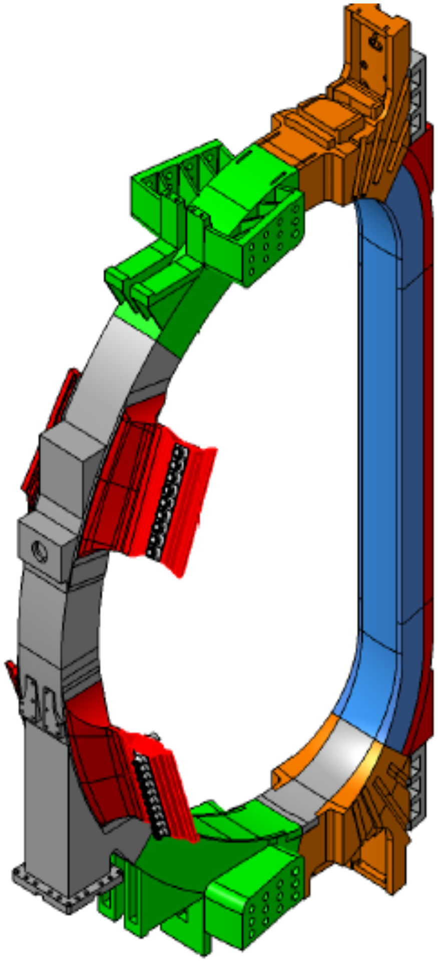
ITER
V_{plasma} 830 m^3
P_{fusion} ~500 MW 500s
t_{plasma} ~400 s

Environment for ITER Diagnostics

Relative to existing machines, on ITER some of the diagnostic components will be subject to (relative to JET)

- **High neutron and gamma fluxes (up to x 10)**
- **Neutron heating (1 MW/m^3) (very high)**
- **High fluxes of energetic neutral particles from charge exchange processes (up to x5)**
- **High electron temperatures (up to x 3 to 5)**
- **Plasma Current (up to x 3 to 5)**
- **Long pulse lengths (up to x 100)**
- **High neutron fluence (> 10^5 !)**
- **For Instrumentation and Controls relevant are:**
  - ➢ **High magnetic field and radiation levels in port cell**
  - ➢ **Long cables to diagnostic building**

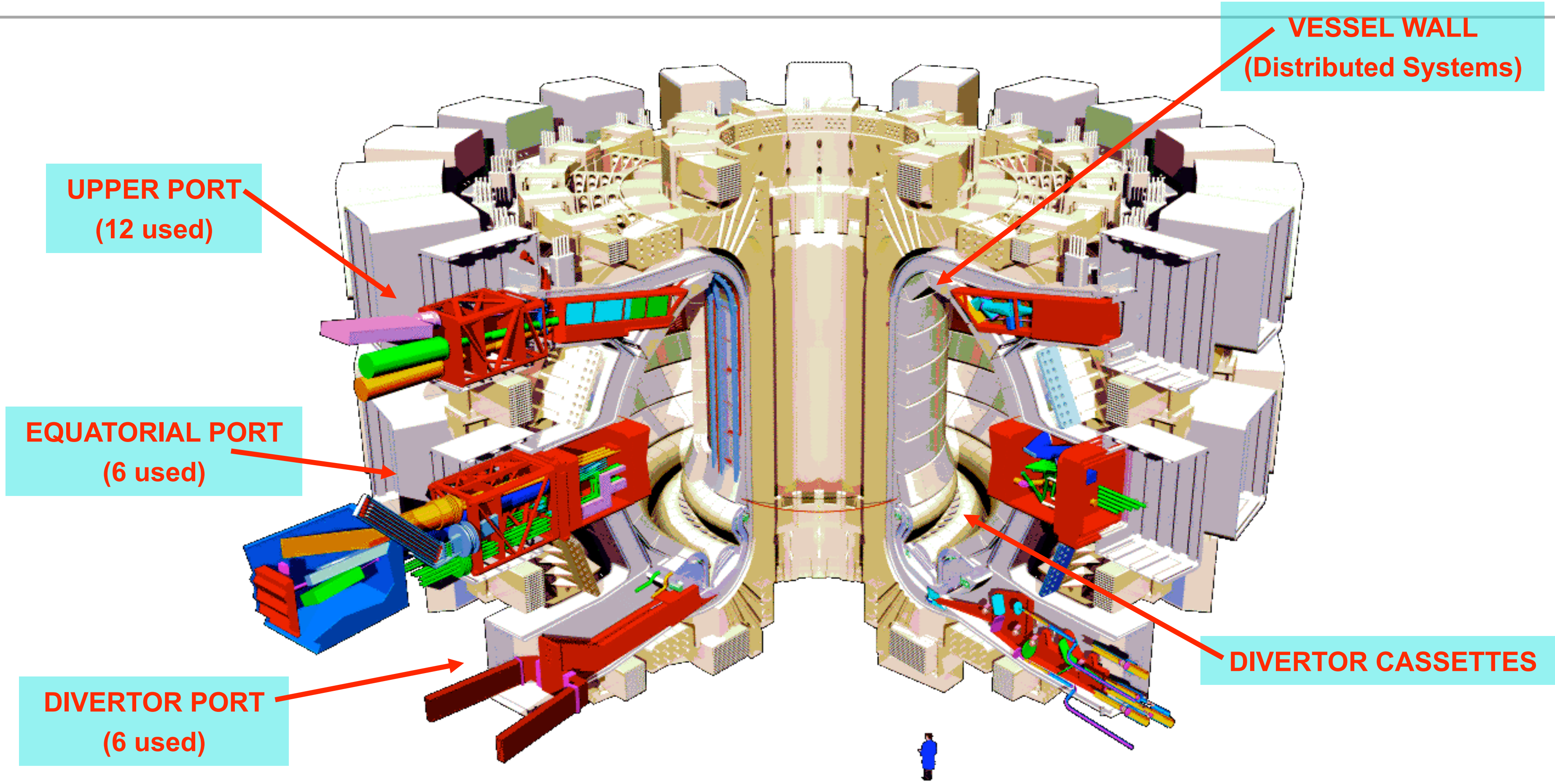
TF Coil – To contextualise



Mass of (1) TF Coil:
16 m Tall x 9 m Wide, ~360 t

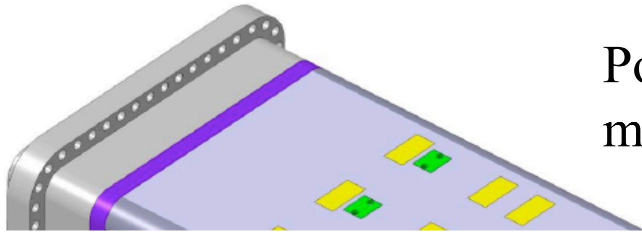
Boeing 747-300
(Maximum Takeoff Weight) ~377 t

Diagnostic Locations

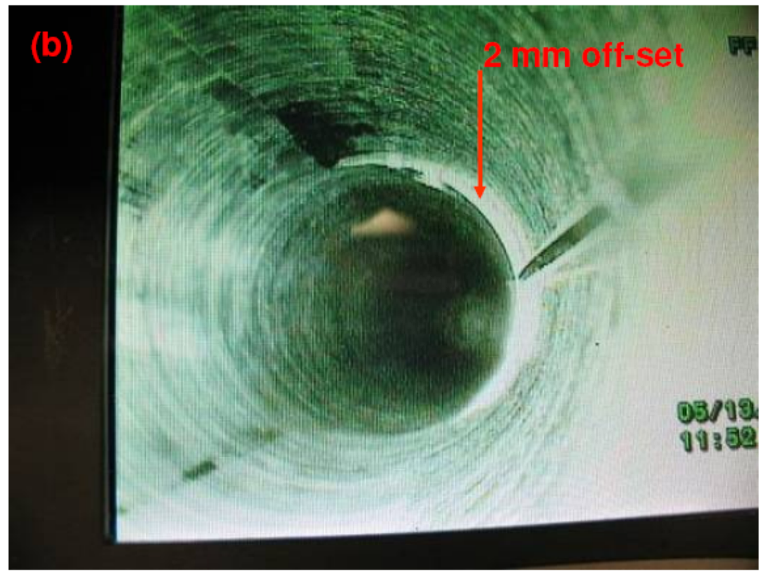


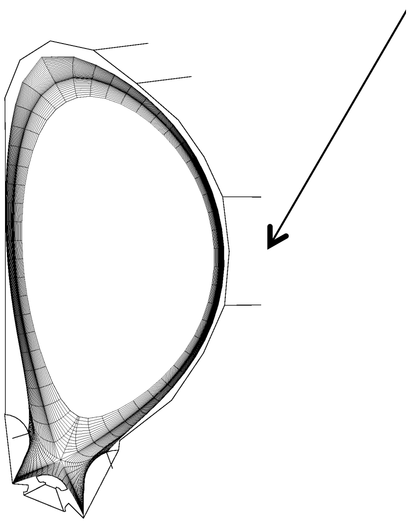
- Measurements from DC to γ-rays, neutrons, α-particles, plasma species
- Neutral Beams (DNB) for active spectroscopy (CXRS, MSE ….)

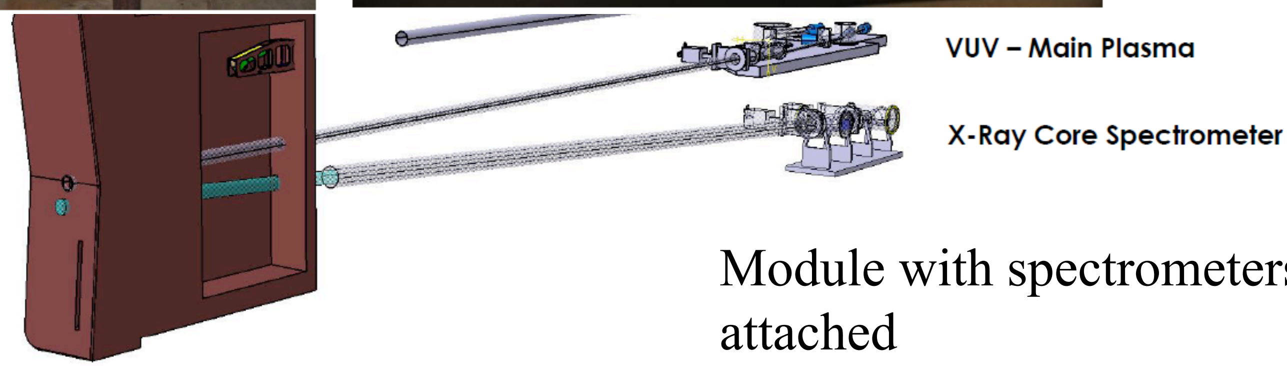
Equatorial Port plug design



Port plug structure with modular arrangement



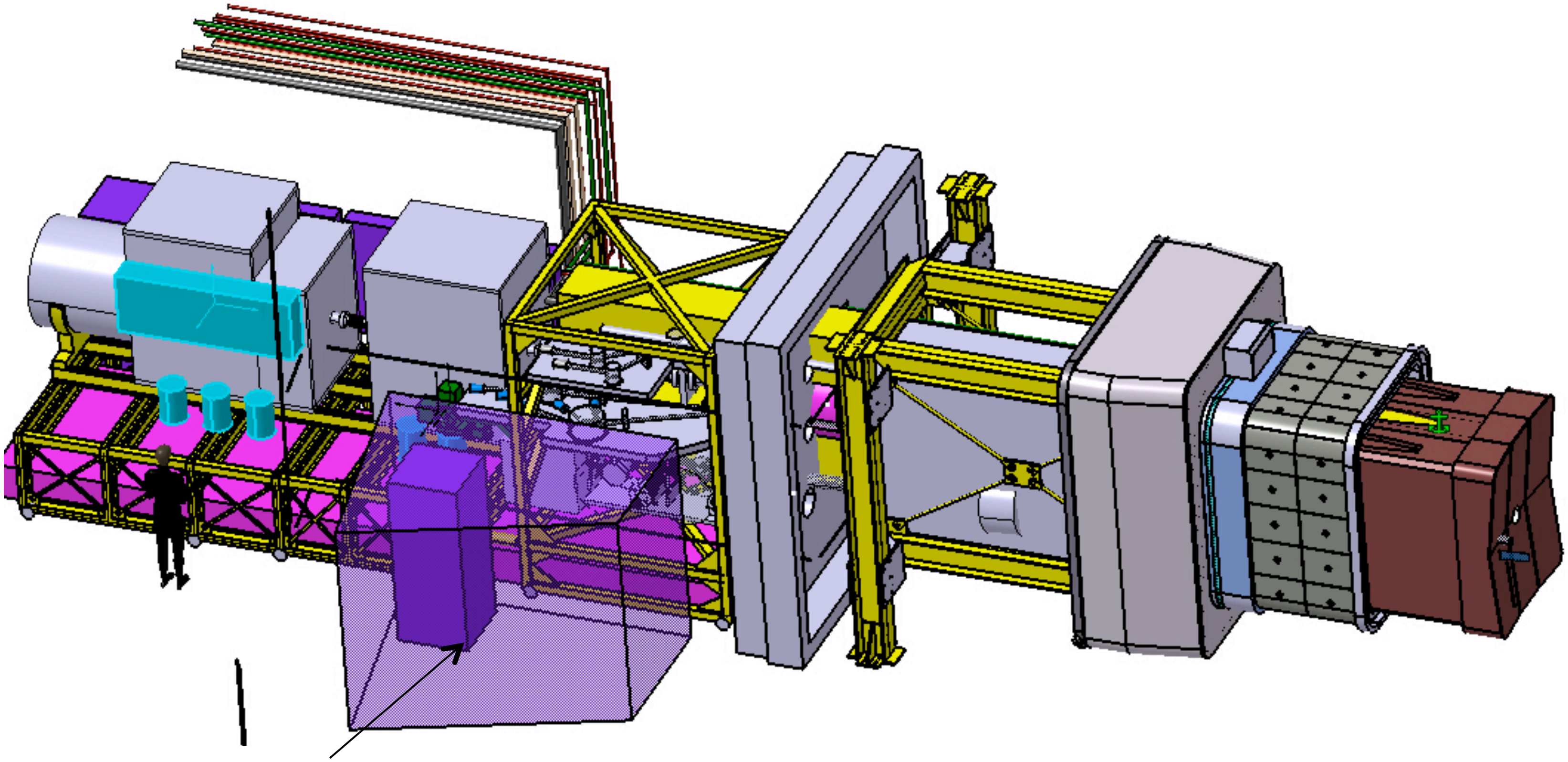


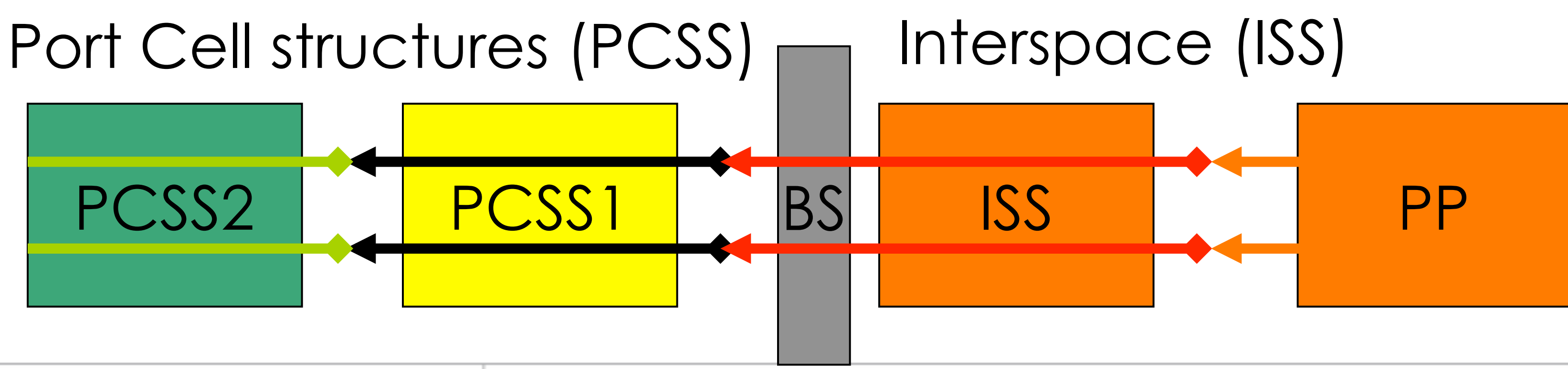


Module with spectrometers attached

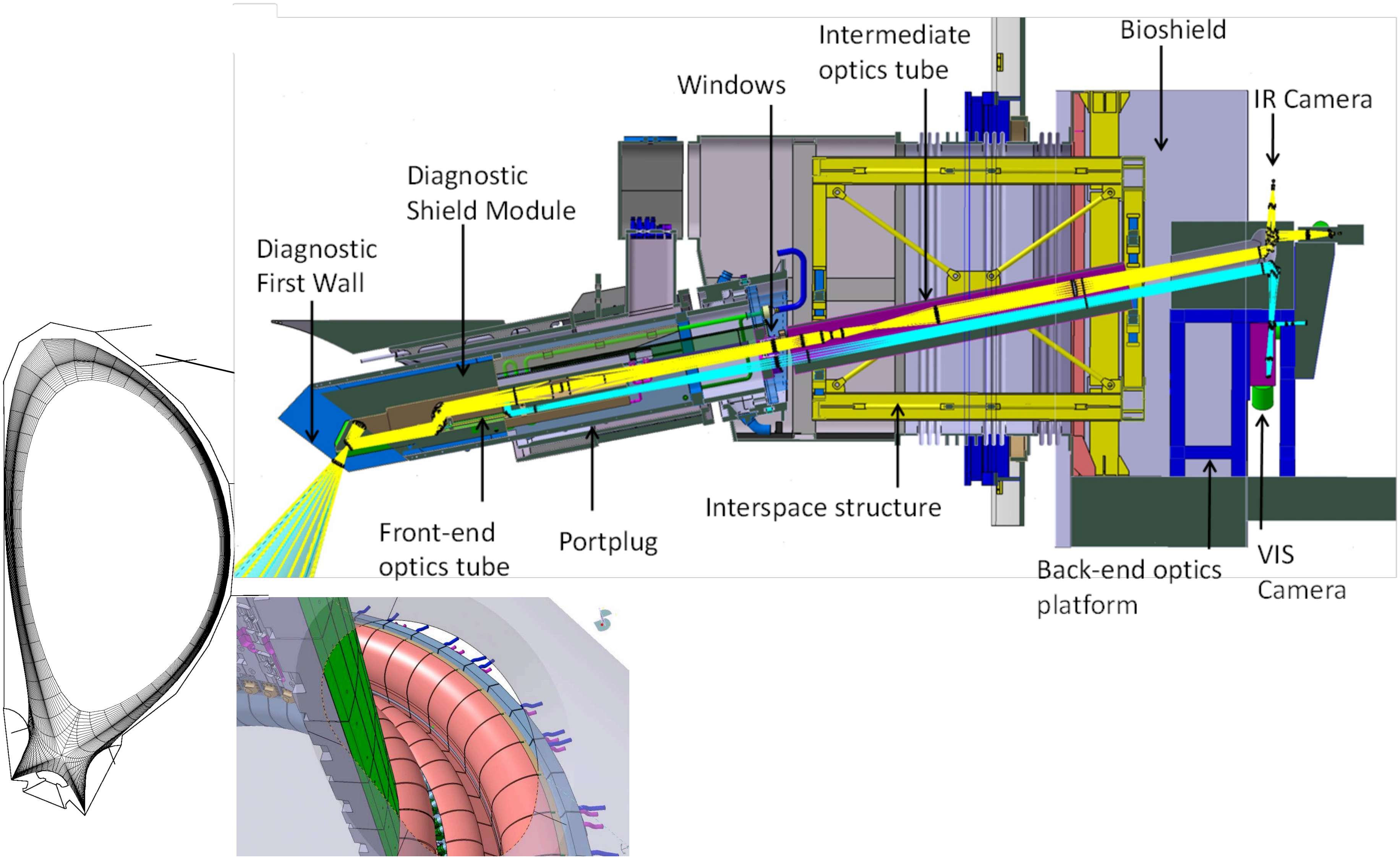
Integrating the diagnostics?

Port Integration on Eq 11 through SIR

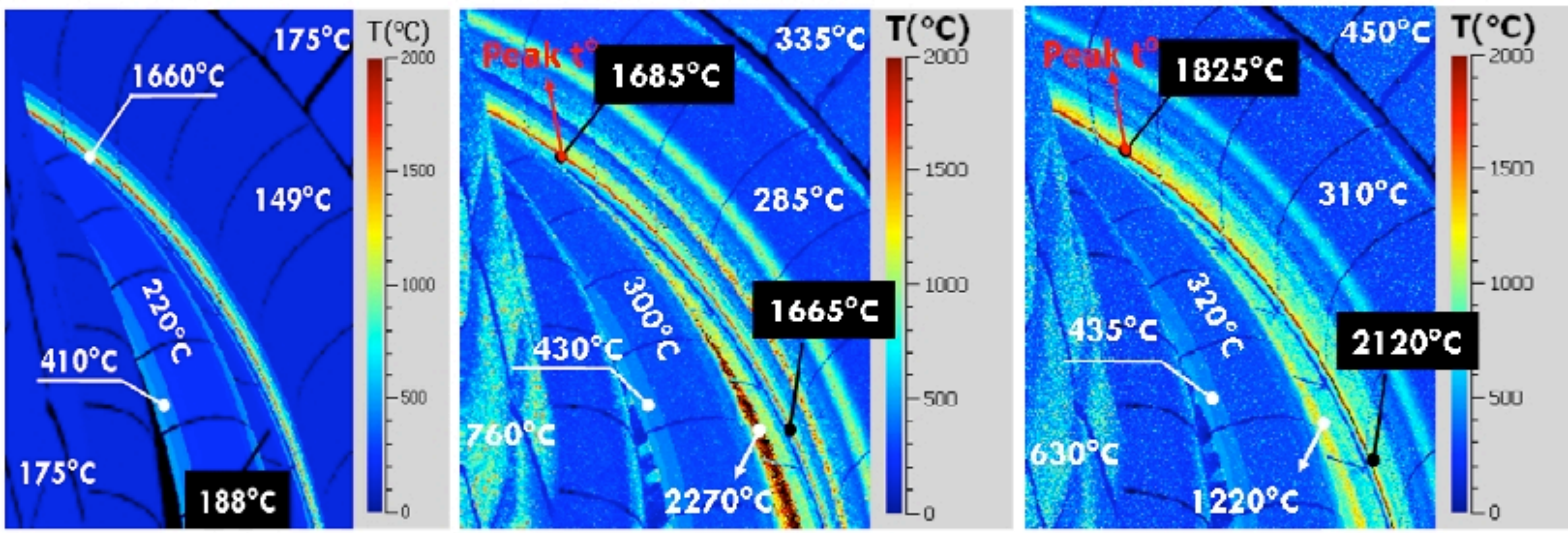




Look at Upper Vis/IR System



Reflection simulation examples for ITER Infrared diagnostics



[M.H. Aumeunier et al., SOFE 2011 CEA-See Paper]

No reflections

Realistic reflections with Be, W and CFC divertor

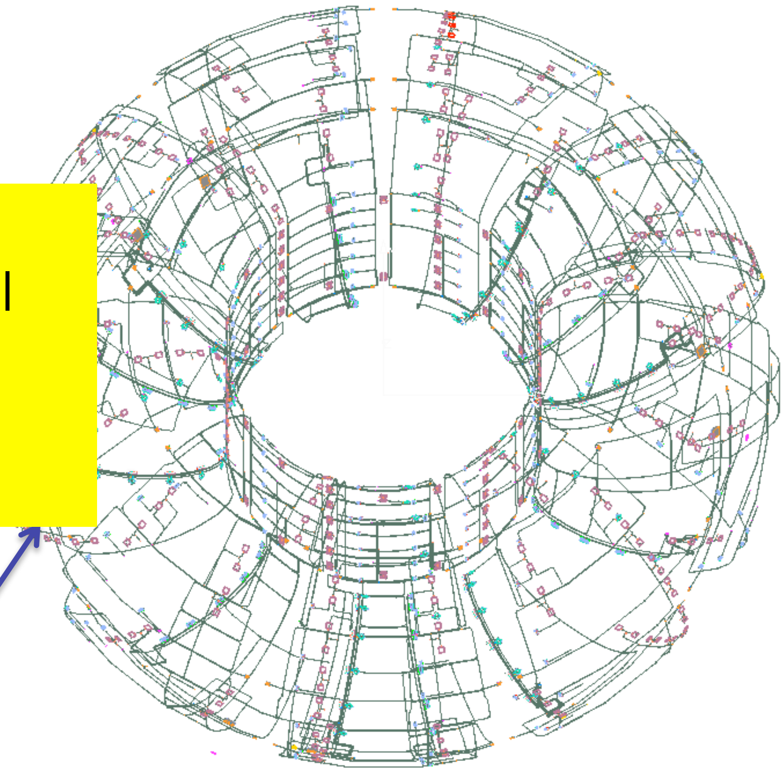
Realistic reflections with Be and W divertor – note significant influence of angular dependence of W emissivity, which is not corrected here

The maximum temperature is estimated relatively correctly, especially if angular dependence of emissivity is accounted for, but in cooler areas large deviations are observed due to reflections.

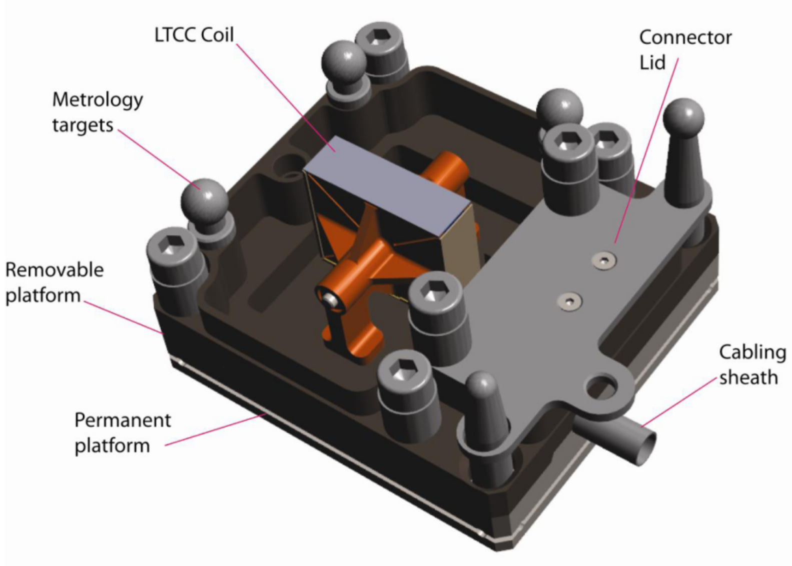
Knowledge of optical properties of observed target is important and requires more work.

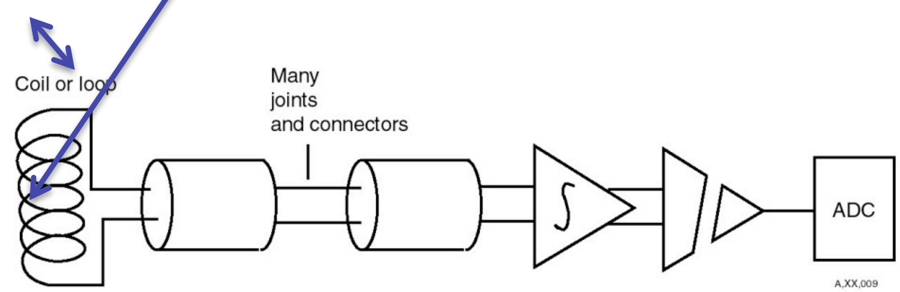
Magnetics

- ITER has a conventional magnetics system: measures dB/dt
  - locally using pickup coils or
  - averaged over a large area using

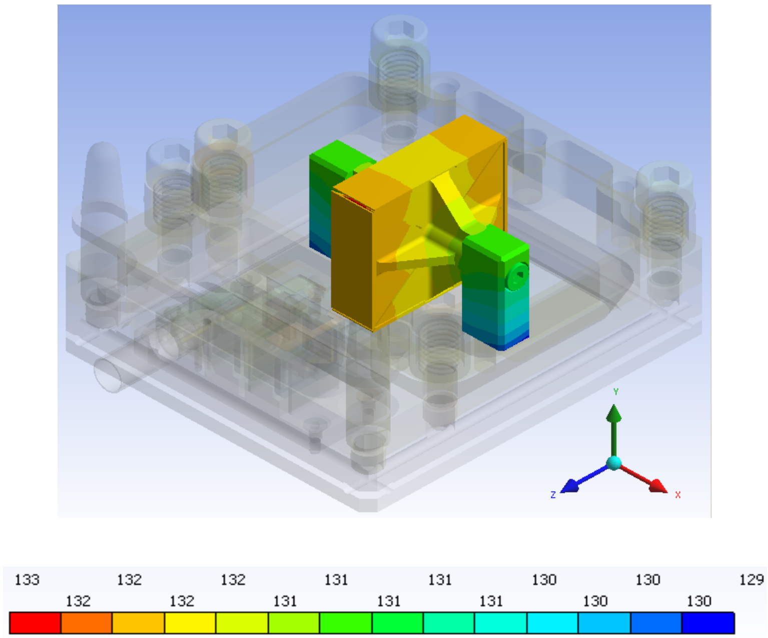


Main approach for discrete coils:
- Mechanical attachment to vacuum vessel
- Electrical connection to invessel wiring
- Heat transfer to vacuum vessel
- Remote handling compatibility

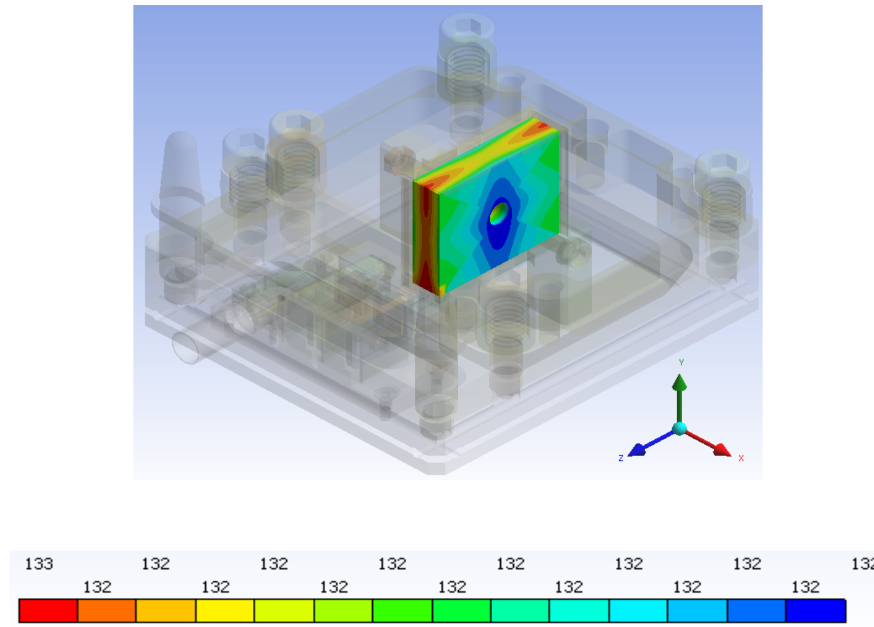




Magnetics- Thermal view



View of the temperature for the entire pickup coil assembly.

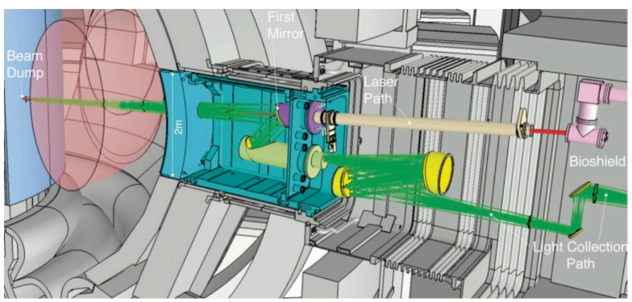


View of the temperature in the coil.

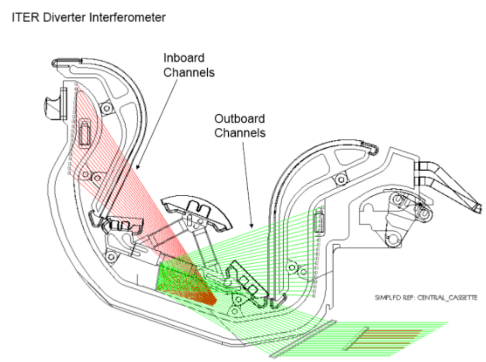
ITER FM systems

There are ~30 diagnostic systems on ITER involving first mirrors.

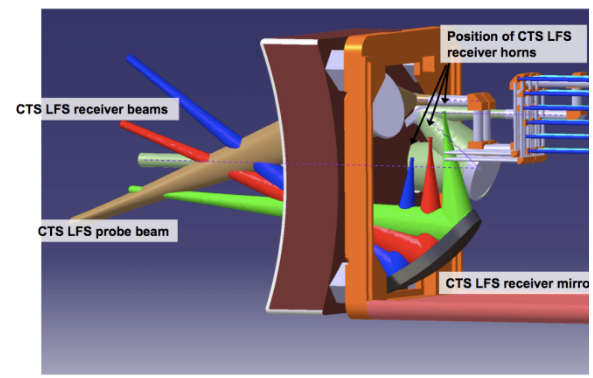
- **They provide information on close to 100 plasma parameters**
- **They span the wavelength range from nanometer to millimeter and involve a wide range of solid angles and presumed fluxes.**



Core LIDAR (300-1000nm)



Divertor interferometer (10μ)



Low-field side CTS (1 mm)

Major Areas to be Tackled

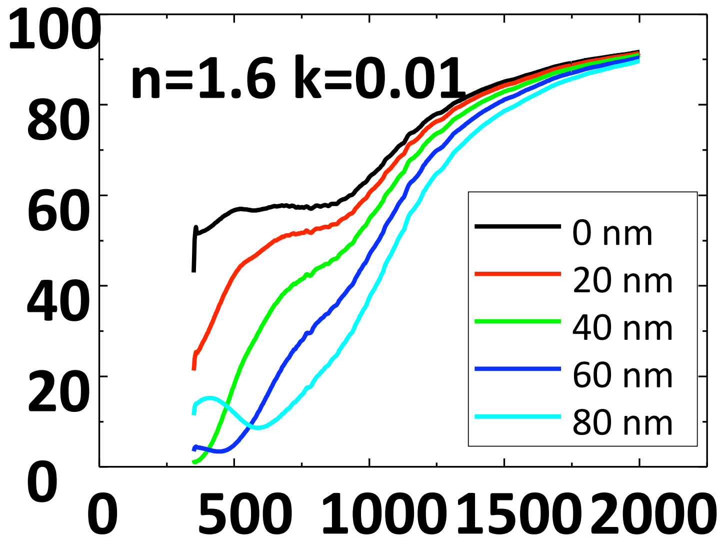
From ITPA SWG:

6 main areas:

- **<u>Material choice</u> for erosion and deposition dominated conditions**
- **<u>Predictive modeling</u> of plasma/neutral environment and irradiation effects on mirror optical properties**
- **<u>Mitigation of deposition</u> - Carbon and Beryllium**
- **<u>Cleaning of deposited</u> layers Carbon and/or Beryllium**
- **<u>Mirror tests</u> under neutron, gamma, and x-ray environment**
- **<u>Engineering and Manufacturing</u> of ITER first mirrors and supporting mirror surface recovery systems**

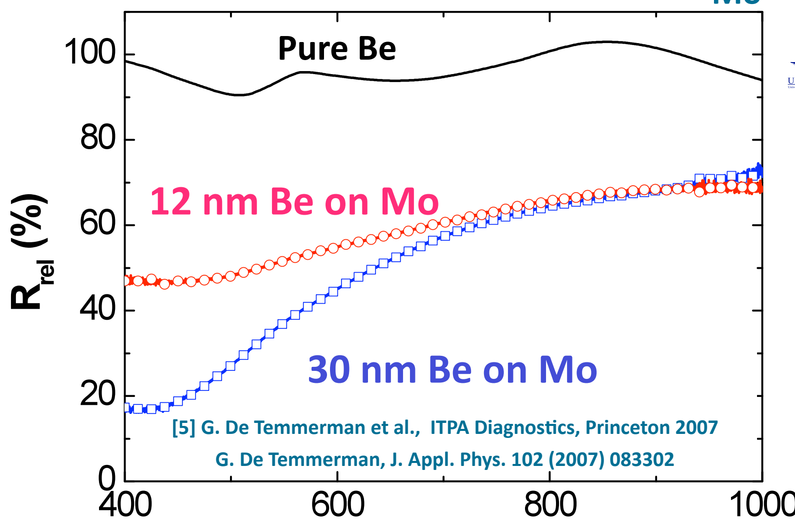
Impact of deposition on the mirror performance

C on Mo
Total reflectivity, %



Wavelength, nm

Be on Mo [5]
Normalized reflectivity (R/R_{Mo}), %



Wavelength, nm

Deposition of ~ 20 nm affects VIS

Mirror lifetime for UP VISIR: converting nm/s to ITER discharges

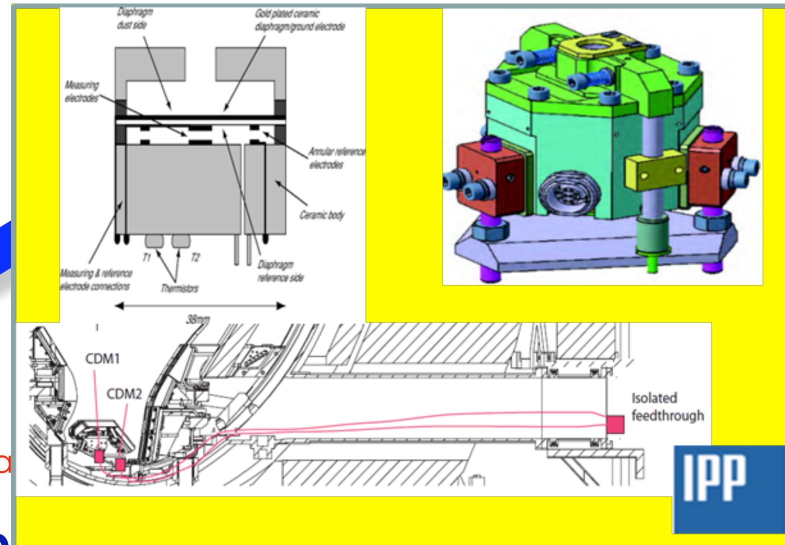
- **Minimum lifetime limited by deposition: ~ 5000 ITER discharges;**
- **Minimum lifetime limited by erosion: ~ 12500 ITER discharges*.**

*using ~ 1 um of removed Mo as a merit. Negligible effect of such a removal was proved in a tokamak

A. Litnovsky , UP VISIR CDR, ITER 27/7/2010

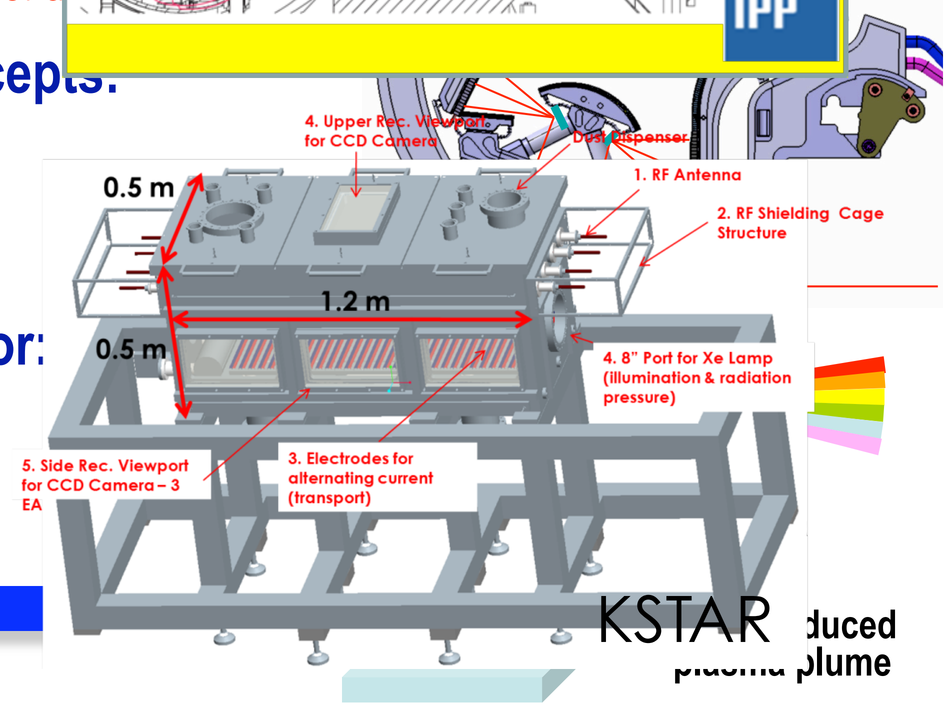
Dust/Erosion/Tritium Diagnostics

- **ITER dust/tritium inventory strategy comprises measurement of**
  - **Local dust concentration**
  - **Divertor target erosion**
  - **Tritium retention**
  - **Hot dust**



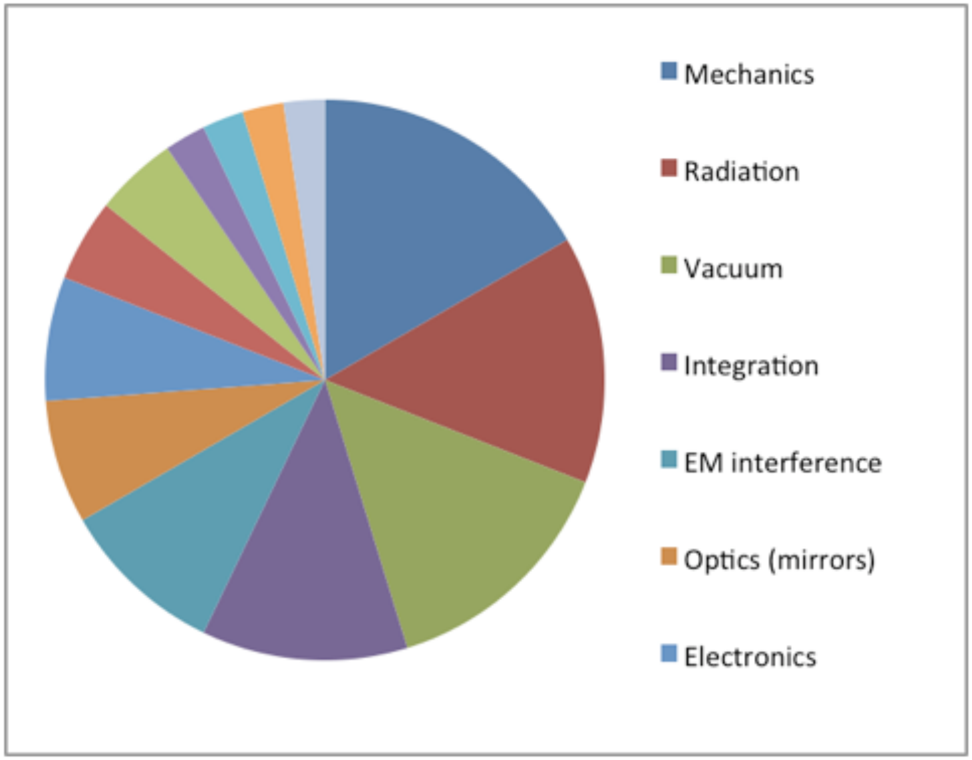
[F. Le Guern et a
Work in EU]

- **For local dust concentration, 2 concepts:**
  - **Capacitive diaphragm microbalance**
  - **Electrostatic grid**
- **For divertor erosion, laser-based concepts implemented at the divertor:**
  - **FM LADAR, Speckle interferometry, Digital holography**
- **For tritium retention, laser-induced spectroscopy is considered.**
  - **LIDS, LIAS, LIBS**



A risk based approach to design?

Analysis of top risks (design reviews) assessed so far (total 45) categorised according to type of risk.



These risks are being and will be dealt with by engineering analysis, design and prototyping.

RAMI: Measurements Provided by the Vis/IR Thermography and Thermocouple Systems.

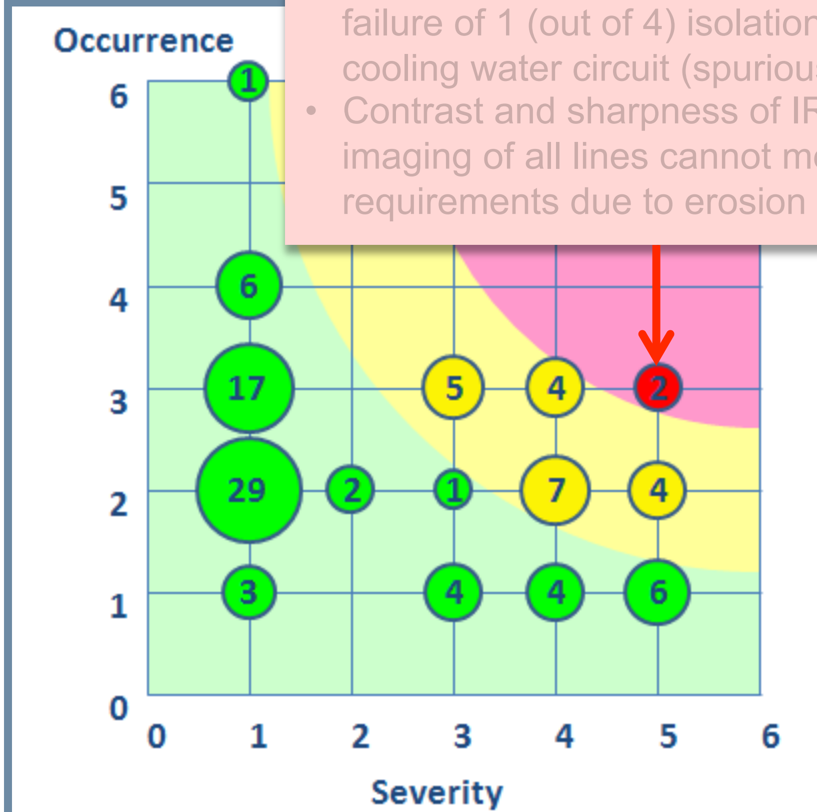
REQUIRED ACTION 1

•Coolant flow sensor shall be

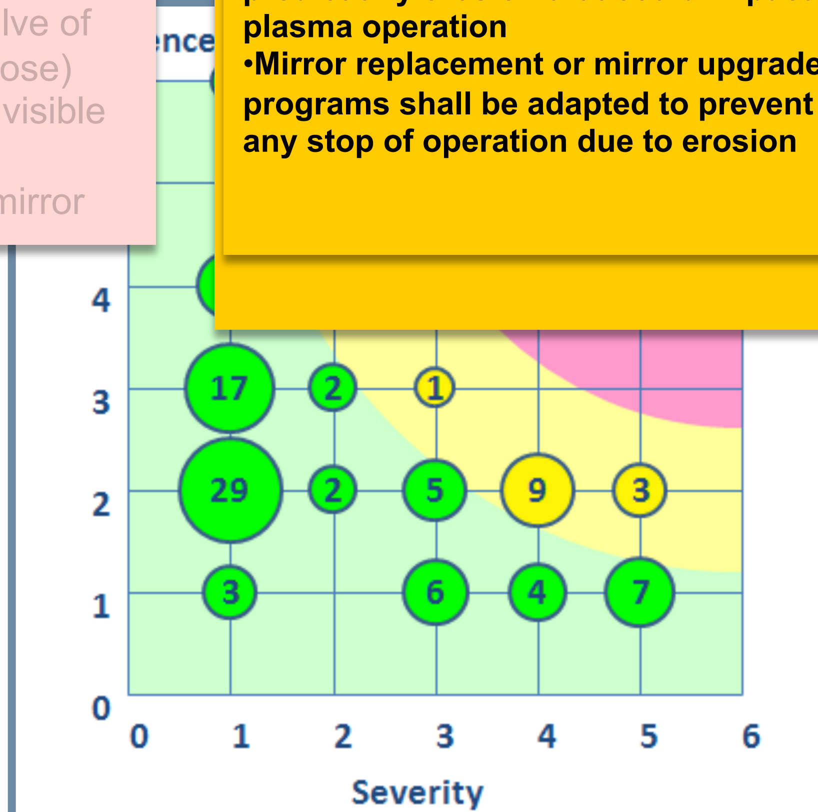
REQUIRED ACTION 2

- Erosion of mirrors shall be monitored in order to anticipate and predict any erosion that could impact plasma operation
- Mirror replacement or mirror upgrade programs shall be adapted to prevent any stop of operation due to erosion

- Fail to cool optical component due to failure of 1 (out of 4) isolation valve of cooling water circuit (spurious close)
- Contrast and sharpness of IR & visible imaging of all lines cannot meet requirements due to erosion of mirror



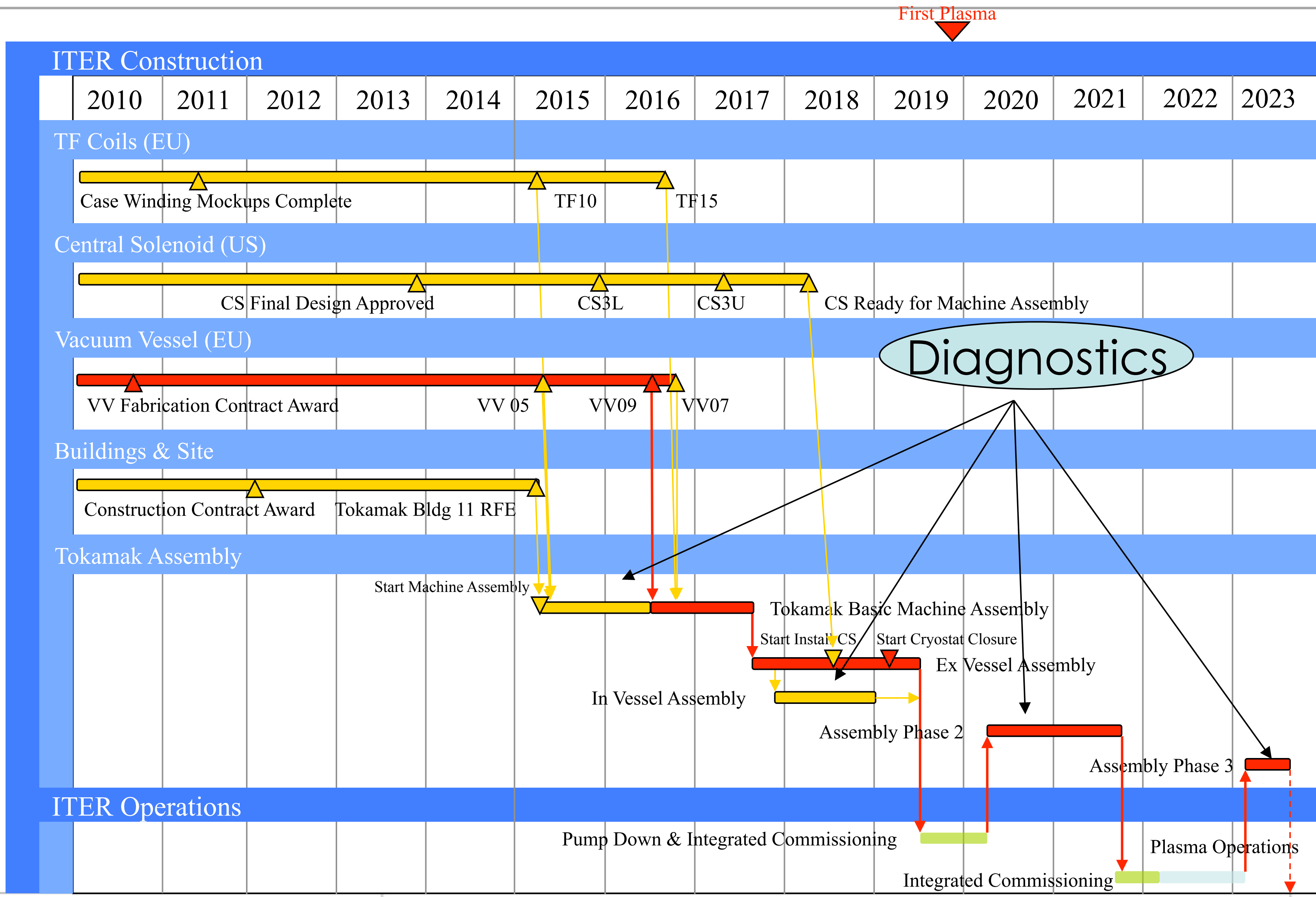
Initial state without considering risk mitigation action



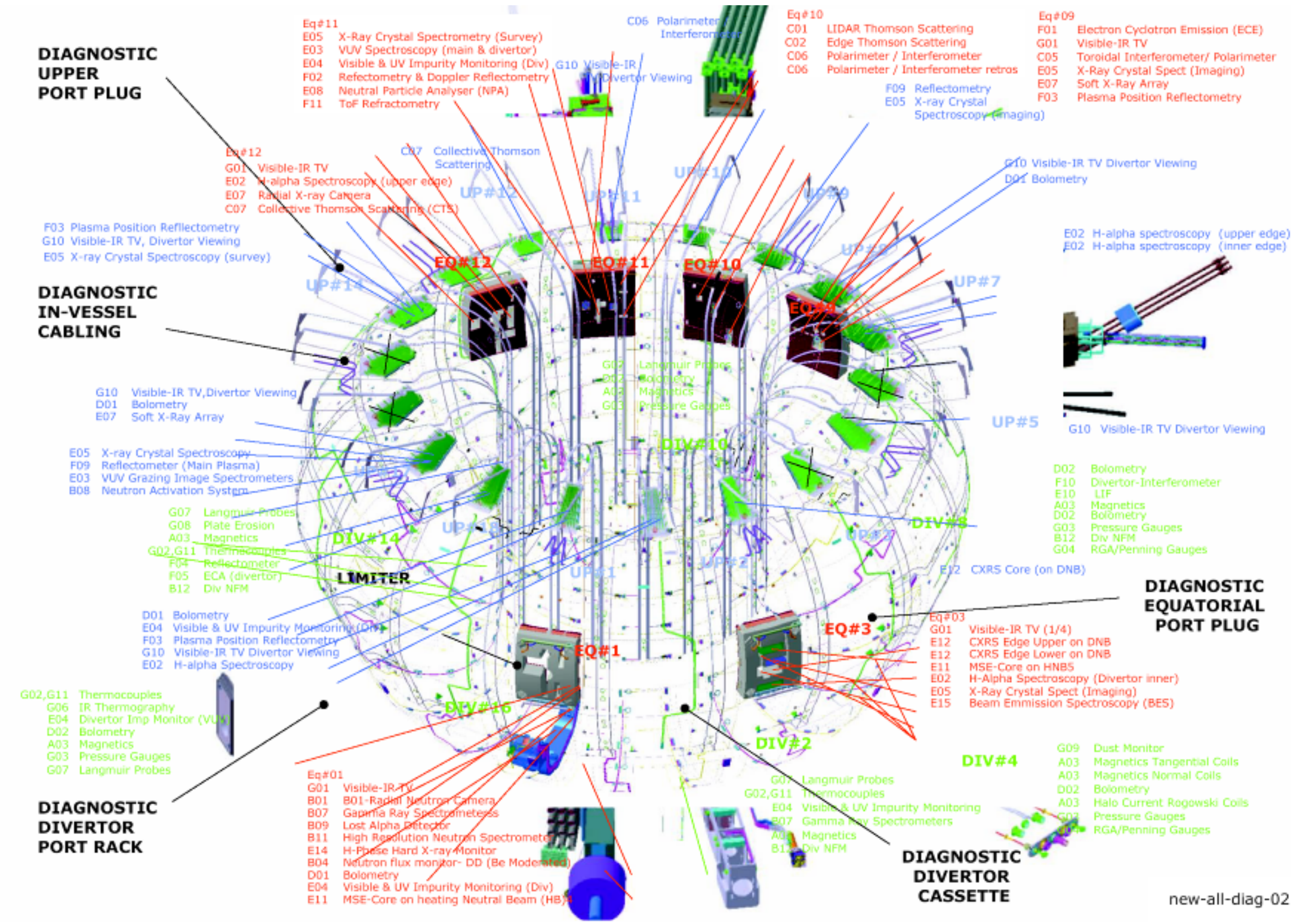
After taking into account all the necessary risk mitigation means

Where are we?

Overview of Construction



A more integrated system



Diagnostic Design Review Progress 2010/11

System
*Generic Upper Port Structure
Residual Gas Analyser
Neutron flux Monitors Eq 7
Neutral Particle Analyser
Upper Visible/IR
VUV Upper port
TF Magnetics

System
Micro-fission chambers
Activation system
UPP X-ray
HFS Reflect
Magnetics Part 2
Generic EQ Port Structure

System
Pressure Gauges
Windows and Window Assemblies
Equatorial VUV Spectroscopy
Equatorial X-ray Spectroscopy
Divertor VUV Spectroscopy
EQ 11 System Integration Review

Concept design except * which is PDR
Each ITER Partner involved in Diagnostics

Summary

- ITER is now in the construction phase
- The unique requirements of ITER present many technical challenges for the design and manufacturing of diagnostics
- ITER system designs, R&D, and plans aimed at addressing diagnostic challenges
- Key design activities ongoing and more about to begin
- Procurement contracts for many major systems are officially being put in place through Domestic Agencies