THE DESIGN AND IMPLEMENTATION OF DIAGNOSTIC SYSTEMS ON ITER*

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PLAN

Requirements for Plasma and First Wall Measurements

ITER Environment and Potential Impact on Diagnostic Components

The Implementation of Diagnostic Systems on ITER

- in the vacuum vessel
- in ports (upper and equatorial)
- in the divertor

Assessment of Performance Relative to Target Requirements

Summary

REQUIREMENTS FOR MEASUREMENTS

In order to prevent the plasma and auxiliary heating systems from damaging the internal components, especially the divertor and first wall, measurements of key parameters will be needed in real time at very high reliability, for example: separatrix/wall gap, first wall temperature, fusion power, etc

Machine Protection

Many other measurements are needed to control the plasma in real time so that the required operating regime and plasma performance is achieved, for example: plasma shape and position, plasma current, electron density, impurities, etc

Plasma Control

Additional measurements are needed for specific physics studies, for example: confined and escaping alpha particles, turbulence, n_e and T_e fluctuations, etc

Physics Studies

Required Measurements According to Operational Role

GROUP 1a Measurements For Machine Protection and Basic Control	GROUP 1b Additional Measurements for Control in Specific Scenarios	GROUP 2 Additional Measurements for Performance Eval. and Physics
Plasma shape and position, separatrix-wall gaps, gap between separatrixes Plasma current, q(a), q(95%) Loop voltage Fusion power $\beta_N = \beta_{tor}(aB/I)$ Line-averaged electron density Impurity and D,T influx (divertor, & main plasma) Surface temp. (div. & upper plates) Surface temperature (first wall) Runaway electrons 'Halo' currents Radiated power (main pla, X-pt & div). Divertor detachment indicator (J_{sat}, n_e, T_e at divertor plate) Disruption precursors (locked modes,m=2) H/L mode indicator Z_{eff} (line-averaged) n_T/n_D in plasma core ELMs Gas pressure (divertor & duct) Gas composition (divertor & duct) Dust	Neutron and α-source profile Helium density profile (core) Plasma rot. (tor and pol) Current density profile (q-profile) Electron temperature profile (core) Electron den profile (core and edge) Ion temperature profile (core) Radiation power profile (core, X-point & divertor) Z_{eff} profile Helium density (divertor) Heat deposition profile (divertor) Ionization front position in divertor Impurity density profiles Neutral density between plasma and first wall n_e of divertor plasma T_e of divertor plasma Alpha-particle loss Low m/n MHD activity Sawteeth Net erosion (divertor plate) Neutron fluence	Confined α-particles TAE Modes, fishbones T_e profile (edge) n_e, T_e profiles (X-point) T_i in divertor Plasma flow (divertor) $n_T/n_D/n_H$ (edge) $n_T/n_D/n_H$ (divertor) T_e fluctuations n_e fluctuations Radial electric field and field fluctuations Edge turbulence MHD activity in plasma core

In total about 45 parameters have to be measured and there are detailed specifications: parameter ranges, resolutions, accuracies for each one.

ITER ENVIRONMENT

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) (essentially zero)**
- **High fluxes of energetic neutral particles from charge exchange processes (up to x5)**
- **Long pulse lengths (up to x 100)**
- **High neutron fluence (> 10^5 !)**

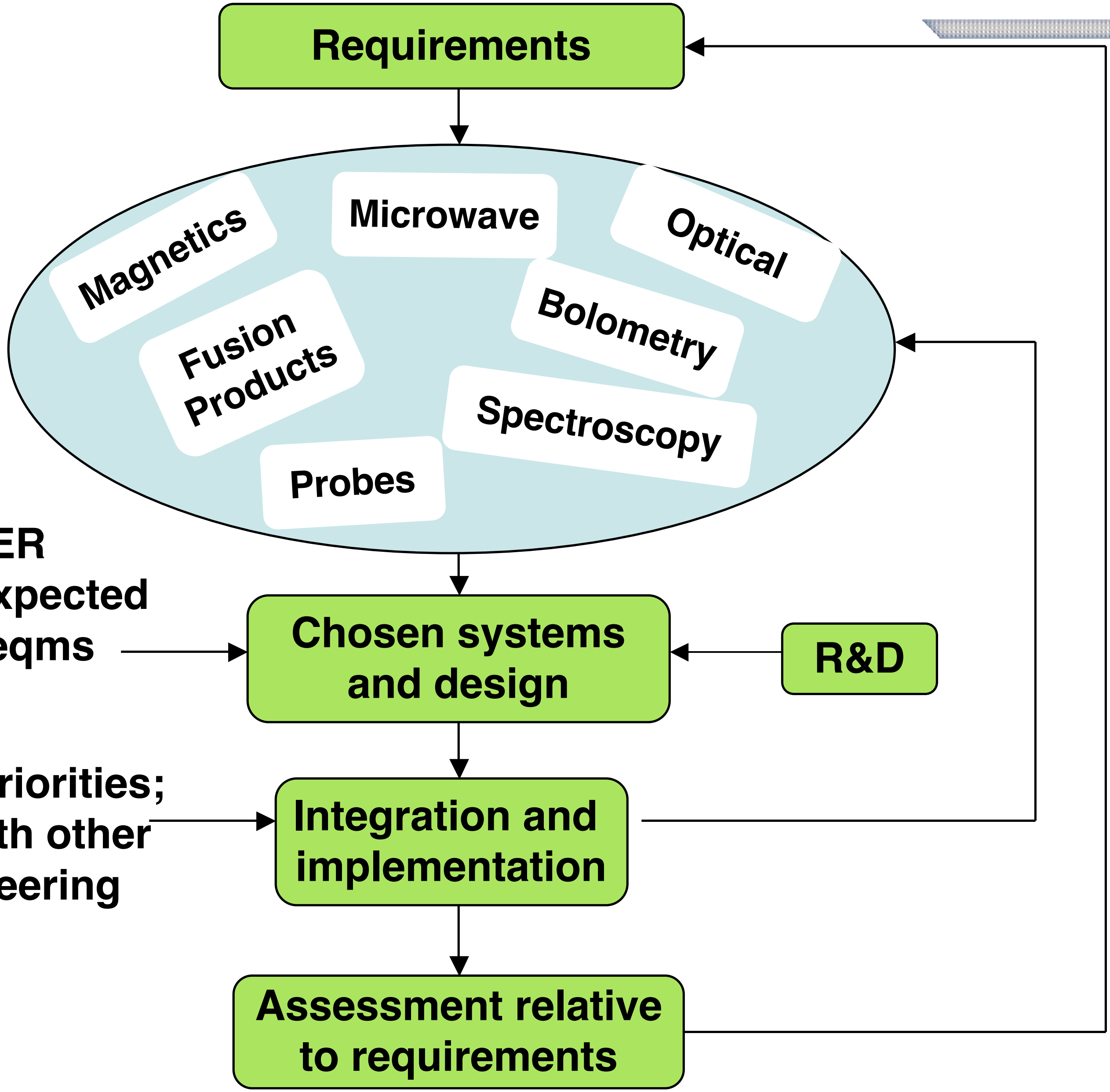
New territory for diagnostics

Consequentially a range of phenomena have to be considered that are new to diagnostic design including:

- **Radiation-induced conductivity (RIC)**
- **Radiation induced electrical degradation (RIED)**
- **Radiation-induced electromotive force (RIEMF)**
- **Erosion and deposition on mirrors**
- **Radiation induced absorption**
- **Radioluminescence**
- **Heating**
- **Change in other properties such as activation, transmutation and swelling**

Moreover, the nuclear environment sets stringent demands on the engineering of the diagnostic systems – for example on neutron shielding, Tritium containment, vacuum integrity, RH compatibility.

~100 - 150 techniques



Suitability in ITER environment; expected performance; reqms for space, etc,

Measurement priorities; combination with other systems; engineering constraints, etc

SELECTED DIAGNOSTICS FOR ITER

Magnetic Diagnostics	Spectroscopic and NPA Systems
Vessel Magnetics	CXRS Active Spectr. (based on DNB)
In-Vessel Magnetics	H Alpha Spectroscopy
Divertor Coils	VUV Impurity Monitoring (Main Plasma)
Continuous Rogowski Coils	Visible & UV Impurity Monitoring (Div)
Diamagnetic Loop	X-Ray Crystal Spectrometers
Halo Current Sensors	Visible Continuum Array
Neutron Diagnostics	Soft X-Ray Array
Radial Neutron Camera	Neutral Particle Analysers
Vertical Neutron Camera	Laser Induced Fluorescence (N/C)
Microfission Chambers (In-Vessel) (N/C)	MSE based on heating beam
Neutron Flux Monitors (Ex-Vessel)	**Microwave Diagnostics**
Gamma-Ray Spectrometers	ECE Diagnostics for Main Plasma
Neutron Activation System	Reflectometers for Main Plasma
Lost Alpha Detectors (N/C)	Reflectometers for Plasma Position
Knock-on Tail Neutron Spectrom. (N/C)	Reflectometers for Divertor Plasma
Optical Systems	Fast Wave Reflectometry (N/C)
Thomson Scattering (Core)	**Plasma-Facing Comps and Operational Diag**
Thomson Scattering (Edge)	IR Cameras, visible/IR TV
Thomson Scattering (Divertor region)	Thermocouples
Toroidal Interferom./Polarimetric System	Pressure Gauges
Polarimetric System (Pol. Field Meas)	Residual Gas Analyzers
Collective Scattering System	IR Thermography Divertor
Bolometric System	Langmuir Probes
Bolometric Array For Main Plasma	**Diagnostic Neutral Beam**
Bolometric Array For Divertor	

About 40 distinct measurement systems in total.

HANDLING THE ENVIRONMENTAL EFFECTS

Environmental Aspect	Phenomena	Diagnostic Components Potentially Affected	Principal Effects	Adopted Remedy
High neutron and gamma fluxes	RIC, RIEMF, RIED, RITES, Thermally Induced EMF (TIEMF)	In-vessel wiring, magnetic coils and loops, microfission chambers, pressure gauges, bolometers, soft x-ray detectors, Langmuir probes	Changes in conductivity, degradation in insulator properties, induced currents and voltages leading to spurious signals	Shielding, careful choice of materials to minimize effects, compensation using dummy detectors, in-situ calibrations, generic redundancy and cross-checks
	Bulk heating	All in-vessel components	Temperature rise, possibly melting	Active cooling
	Radioluminescence Radiation induced absorption	Windows, fibre optics	Spurious optical signals, enhanced absorption	Shielding, careful choice of materials, in-situ calibrations
High neutron fluence	Material structural damage, activation, transmutation, swelling	All in-vessel components	Change in physical properties of material	Careful choice of materials, in-situ calibrations, remote handling design
Energetic neutral particle bombardment	Erosion, deposition	Plasma facing mirrors	Degradation in reflectivity	Careful choice of materials, shutters, baffles, in-situ cleaning and calibrations
High levels of EM radiation	Surface heating	All plasma facing components	Change in surface physical properties	Design for minimum exposure, in-situ calibration

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High neutron fluence	Material structural damage, activation, transmutation, swelling	All in-vessel components	Change in physical properties of material	Careful choice of materials, in-situ calibrations, remote handling design
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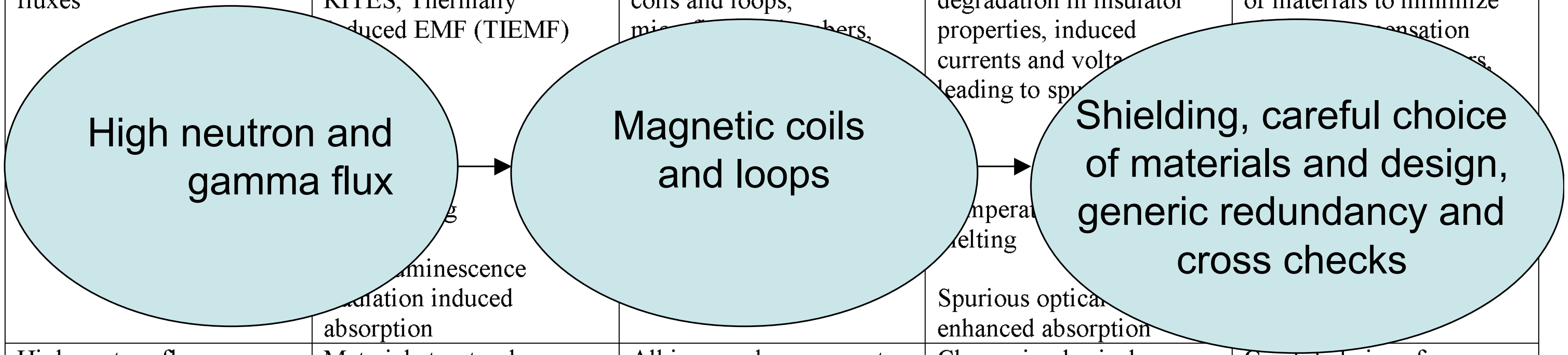
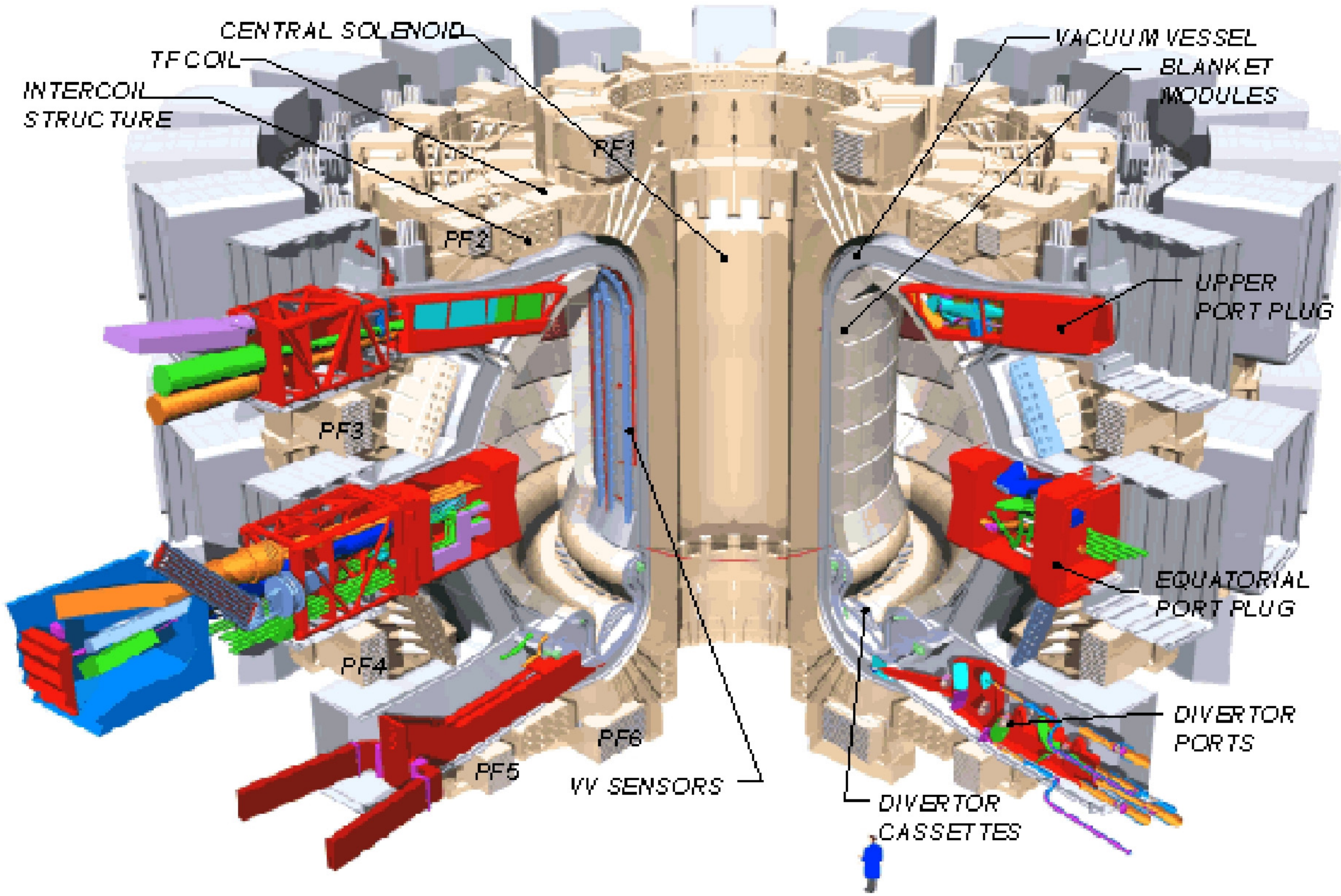


More details in the paper and poster

INTEGRATION AND IMPLEMENTATION

Diagnostic components and systems are installed in multiple locations: the vacuum vessel; upper, equatorial and divertor ports; divertor; port cells, galleries, and diagnostic building.

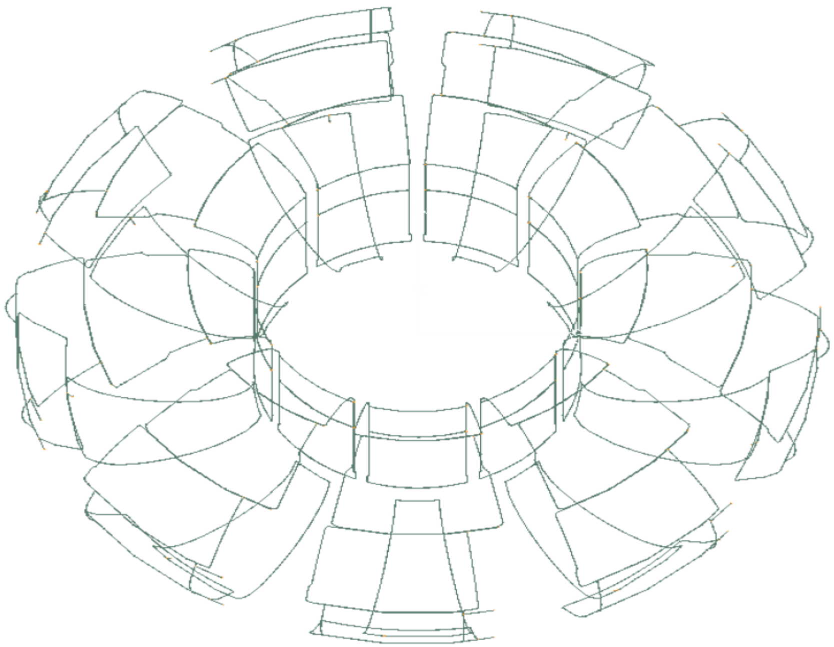


In-Vessel Systems

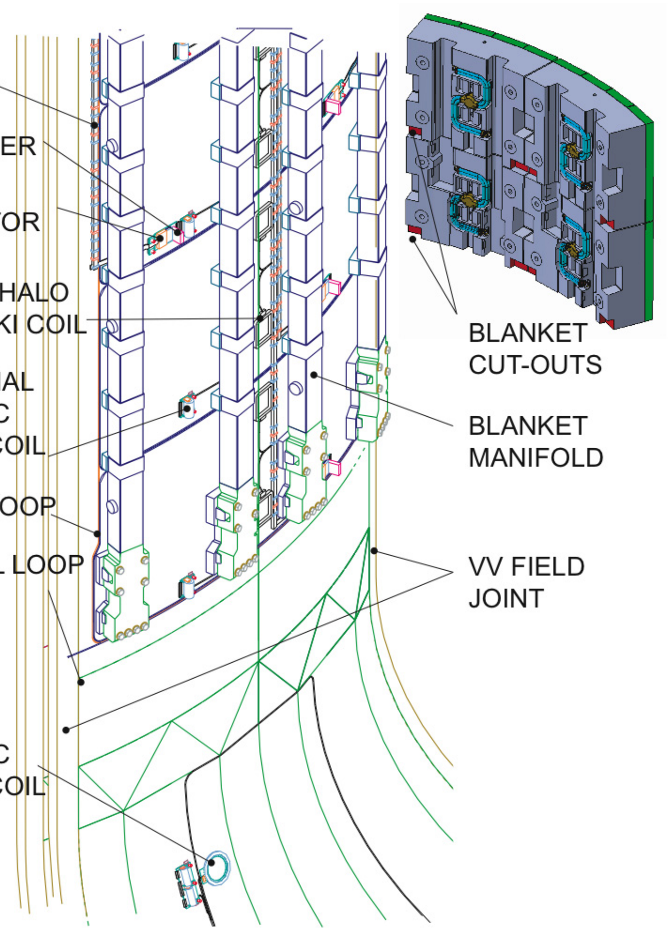
The principal diagnostic components mounted in the vacuum vessel are sensors for the magnetic diagnostics, bolometers, microfission chambers, soft X-ray and UV detectors, and waveguides for reflectometry.

Sensors are mounted at sites where the maximum protection possible is sought from the blanket modules, with standard cut-outs provided if extra space is required. Where necessary the plasma is viewed through the gaps between blanket modules, which may have to be locally widened. Sensors and cabling are cooled by conduction to the vacuum vessel and thermal radiation to the blanket, and typically operate in the range 150-300°C.

In-Vessel Systems



MHD saddle flux loops



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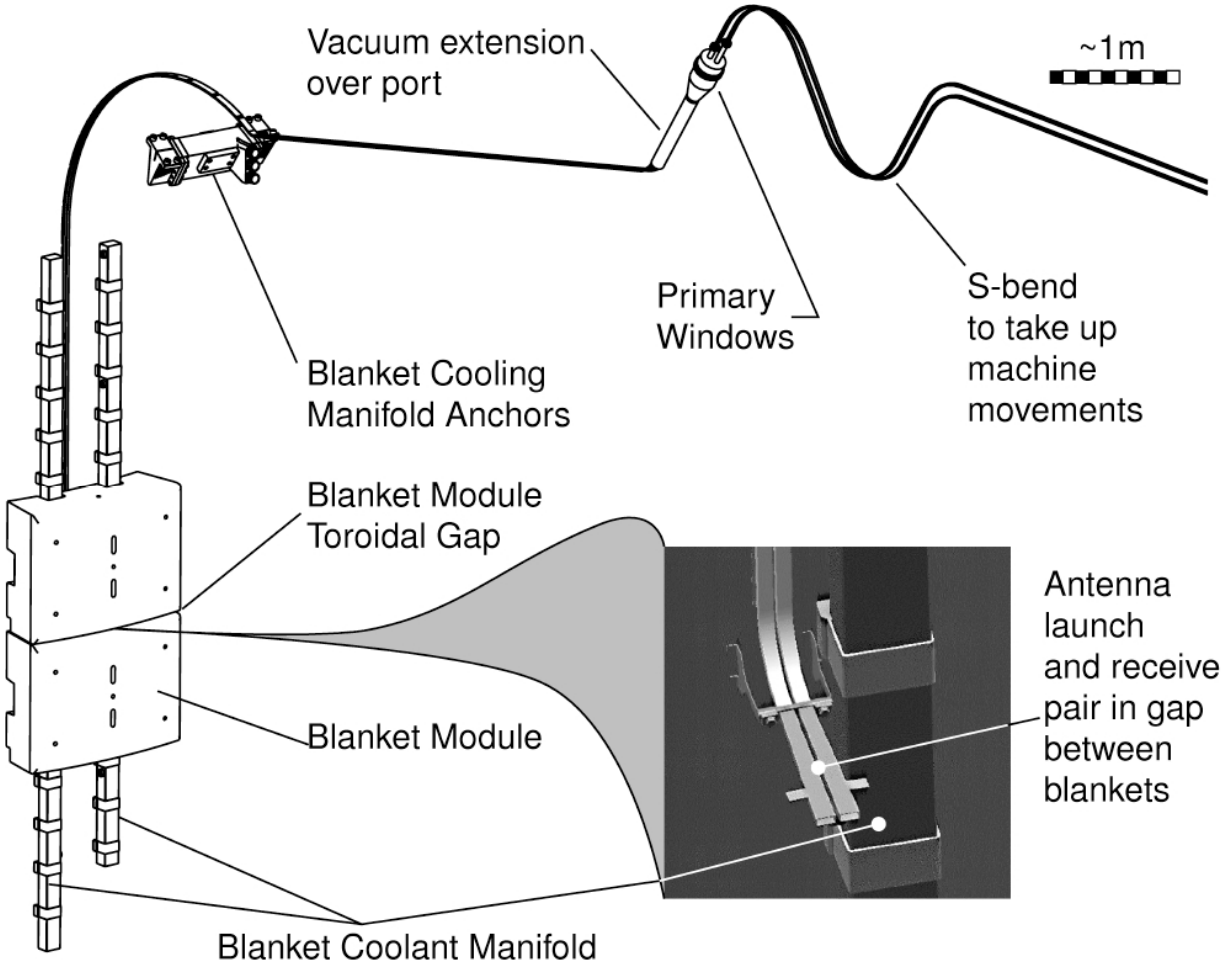
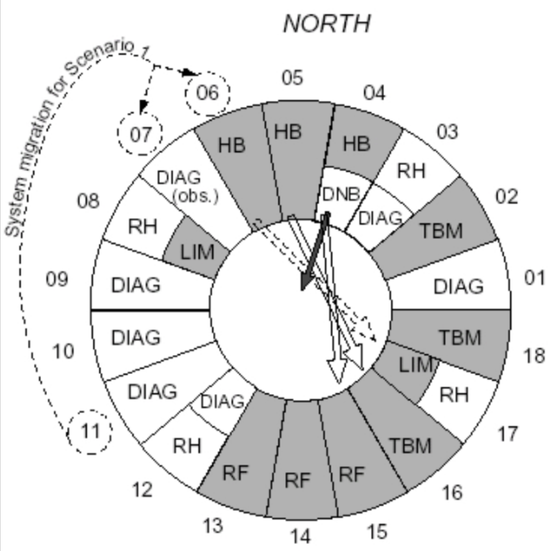
In-Vessel Waveguide
for Reflectometry from the High Field Side



Upper, Equatorial and Divertor Ports

Several systems in each port. Allocation to ports is done according to guidelines which take into account many factors such as the role of the measurements, the need to work in conjunction with other systems and, where possible, the simplification of transmission lines, eg equatorial level:



EQUATORIAL PORT

01 Vis. / IR TV (1 of 4)
Radial Neutron Camera
Bolometry, MSE (core, HB4)
Divertor Impurity Monitor
Gamma Ray Spectroscopy
High Resolution Neutron Spectrometer

03 Vis. / IR TV (2 of 4)
CXRS (on the DNB)
MSE (edge, HB5)
Ha Spectroscopy (divertor inner)

07 Activation System (16N, 1 of 2)
Activation System (foil, 1 of 2)
Neutron Flux Monitor (DD)

08 Neutron Flux Monitor (DT)

09 Vis. / IR TV (3 of 4)
Toroidal Interferometer/Polarimeter
ECE, X-ray Crystal Spectrometry (imaging)
Fast Wave Reflectometry
Soft X-ray Array

10 Thomson Scattering (main plasma)
Polarimeter
Thomson Scattering (inner divertor)

11 X-ray Crystal Spectrometry (survey)
VUV (main and divertor)
Reflectometry for the main plasma
NPA

12 Vis. / IR TV (4 of 4)
Ha Spectroscopy (upper edge)
Visible Continuum Array
CTS

17 Neutron Flux Monitor (DT)
Activation System (16N, 1 of 2)
Activation System (foil, 2 of 2)

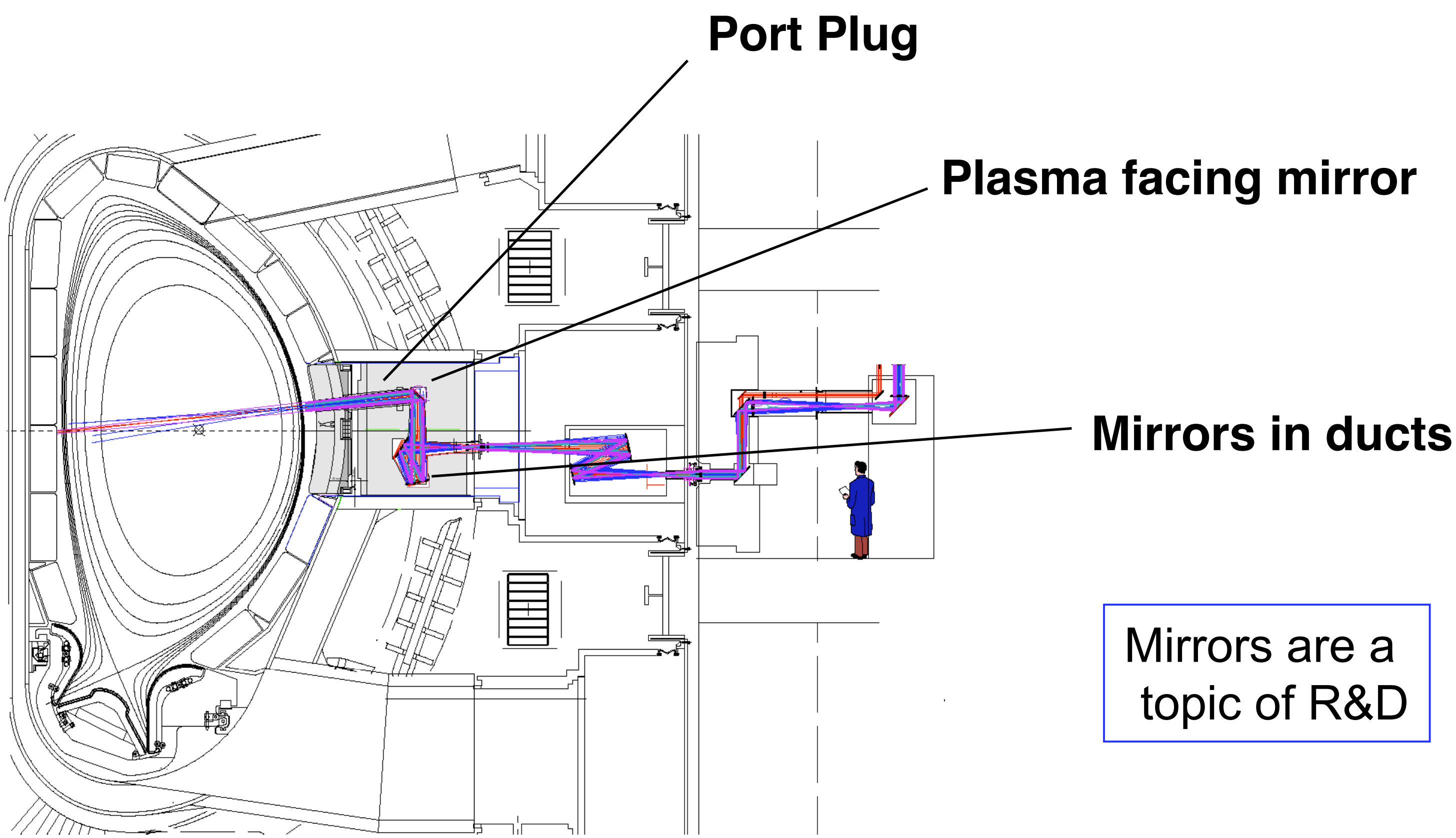
Similarly at the upper and divertor levels (12 and 5 ports respectively)

Port Plugs in Upper and Equatorial Ports

A novel approach has been adopted for installing diagnostic components in the ports. Diagnostic components will be installed in port-plugs and these will contain modules, customized to the specific diagnostics in the port, to ease the construction and maintenance. It also provides flexibility for upgrades should these be necessary or desirable.

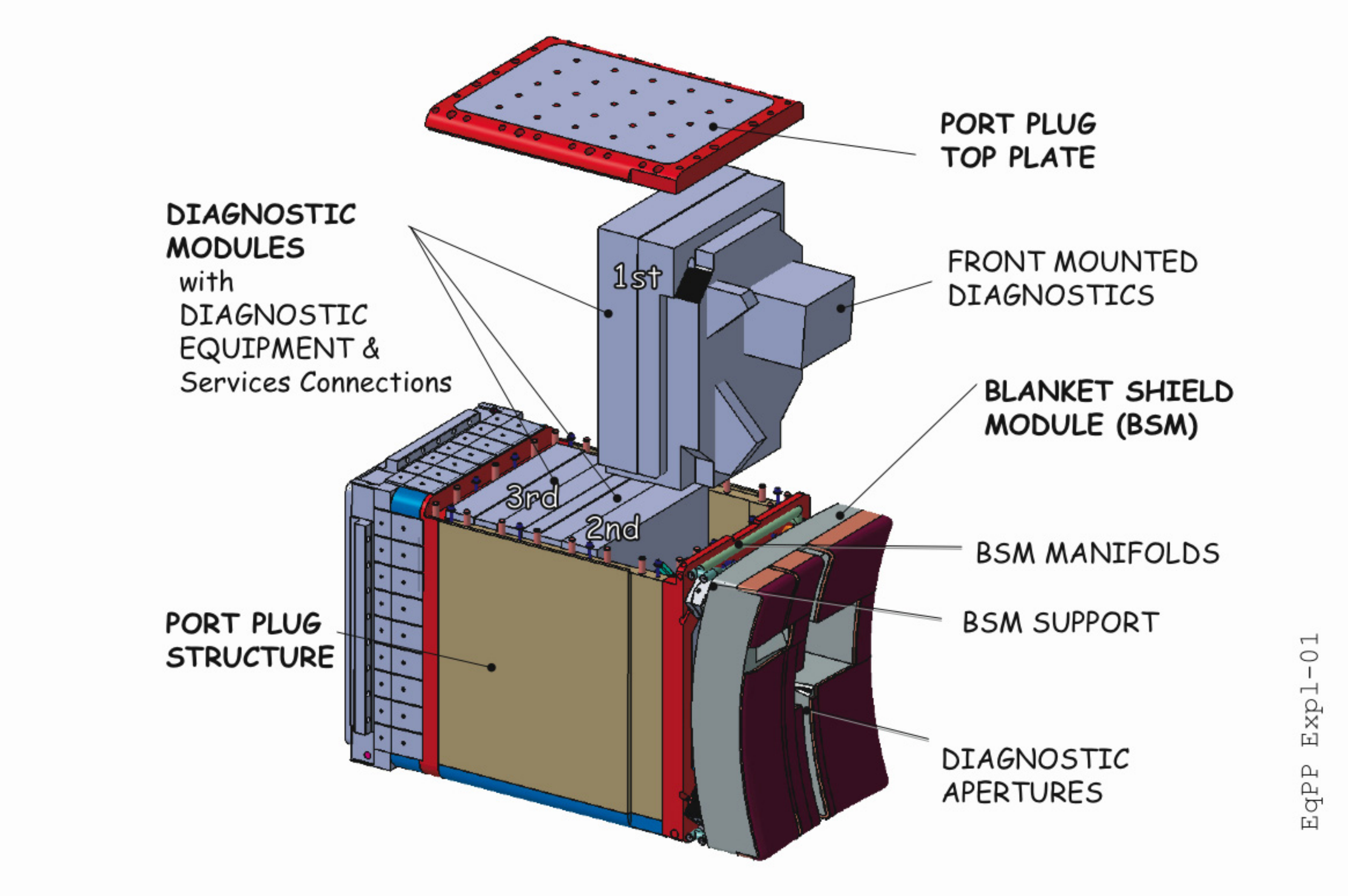
The port-plug provides the primary vacuum boundary at the port, as well as the feed-out for diagnostic transmission lines, feed-throughs for electrical systems, and feed-in for control signals. It provides access for the diagnostics and at the same time effective neutron shielding.

For example, Core (LIDAR) Thomson scattering in Equatorial Port #10. Folded optical labryinth in shielded modules

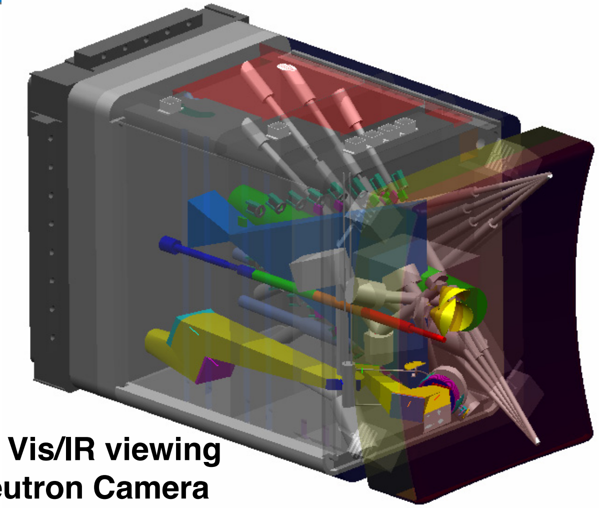


Mirrors are a topic of R&D

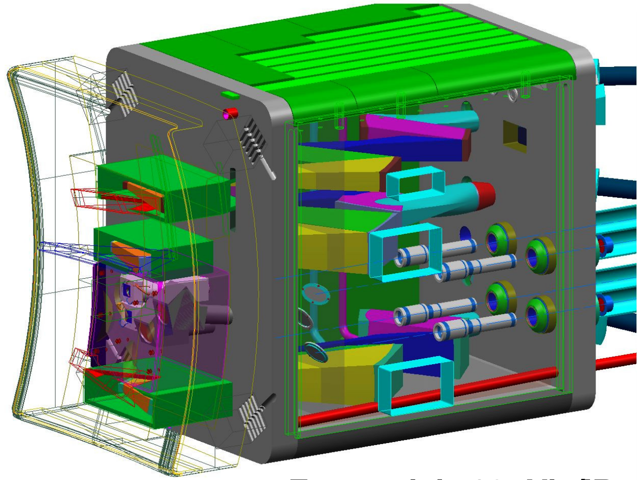
Equatorial Port Plugs



Equatorial Ports



Eq#01: Vis/IR viewing
Rad Neutron Camera
MSE, Div Imp Mon

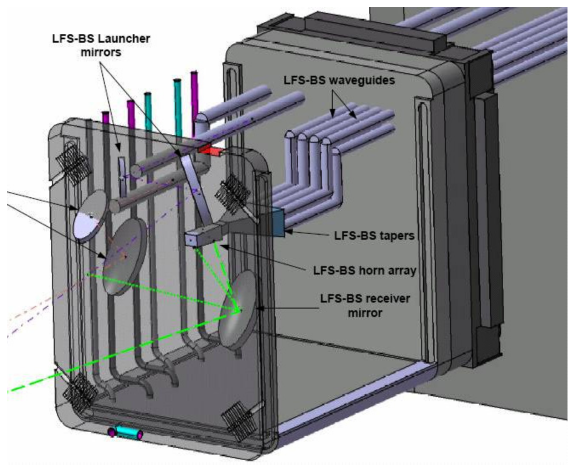


Equatorial #03: Vis/IR viewing
CXRS (x2), MSE, H alpha

PERFORMANCE ANALYSES

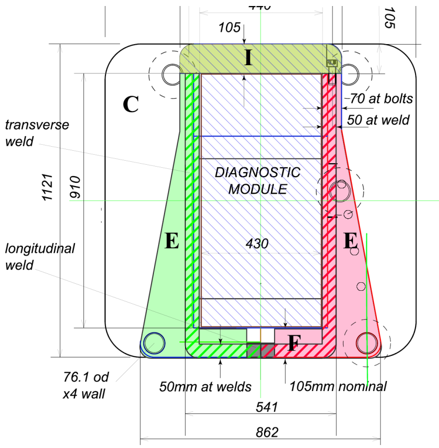
Full engineering treatment includes:

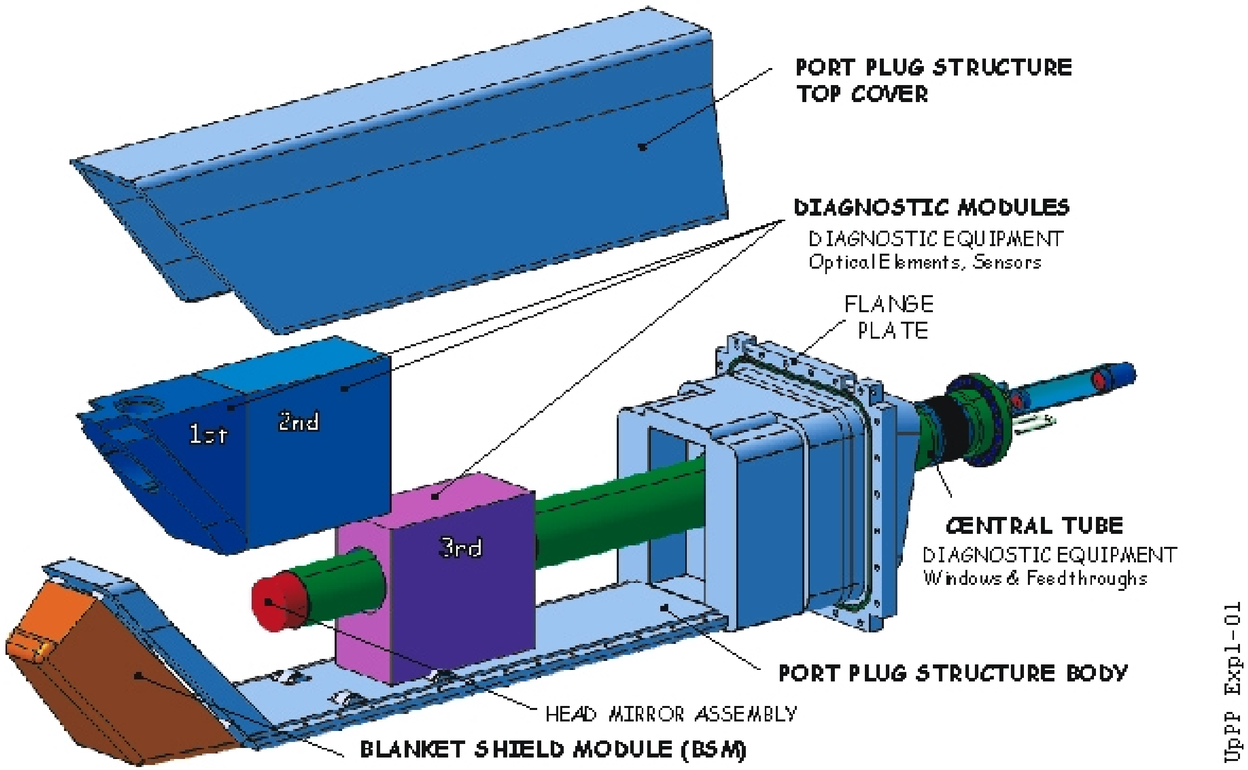
1. Structural Analysis
2. E-M Analysis
3. Static Stress Analysis
4. Dynamic Mechanical Analysis of E-M loads
5. Natural Frequency of Port Plug Structure, with BSM
6. Seismic Analysis
7. Port Plug Nuclear Analysis
8. Port Plug Cooling System Analysis
9. Cantilevered Handling
10. Neutronics analysis



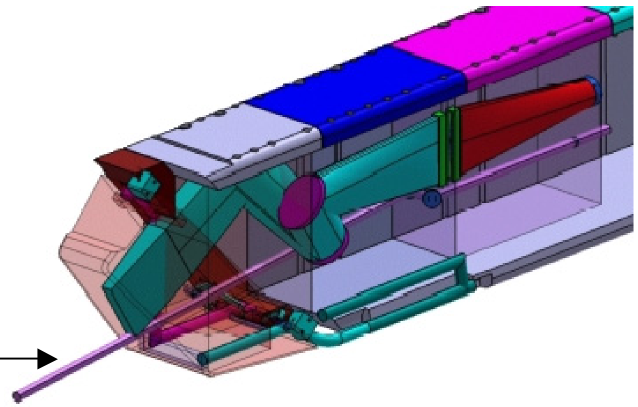
Equatorial #12: Vis/IR viewing
Vis. cont, H alpha, CTS

Upper Ports



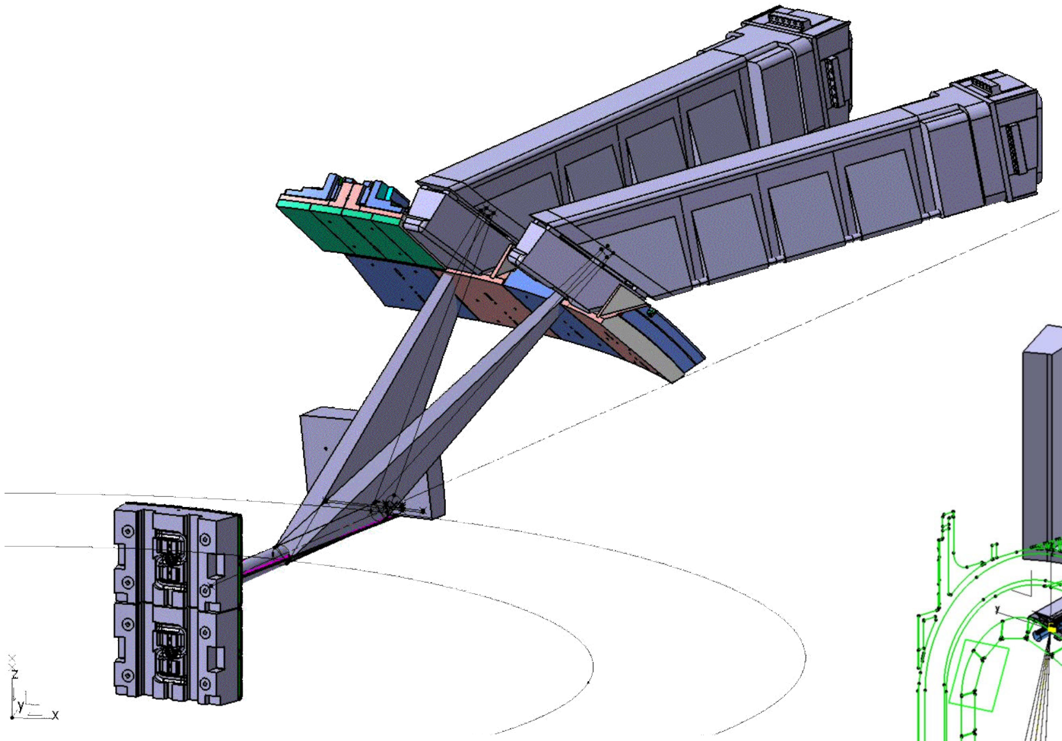


Optics for Edge Thomson Scattering system

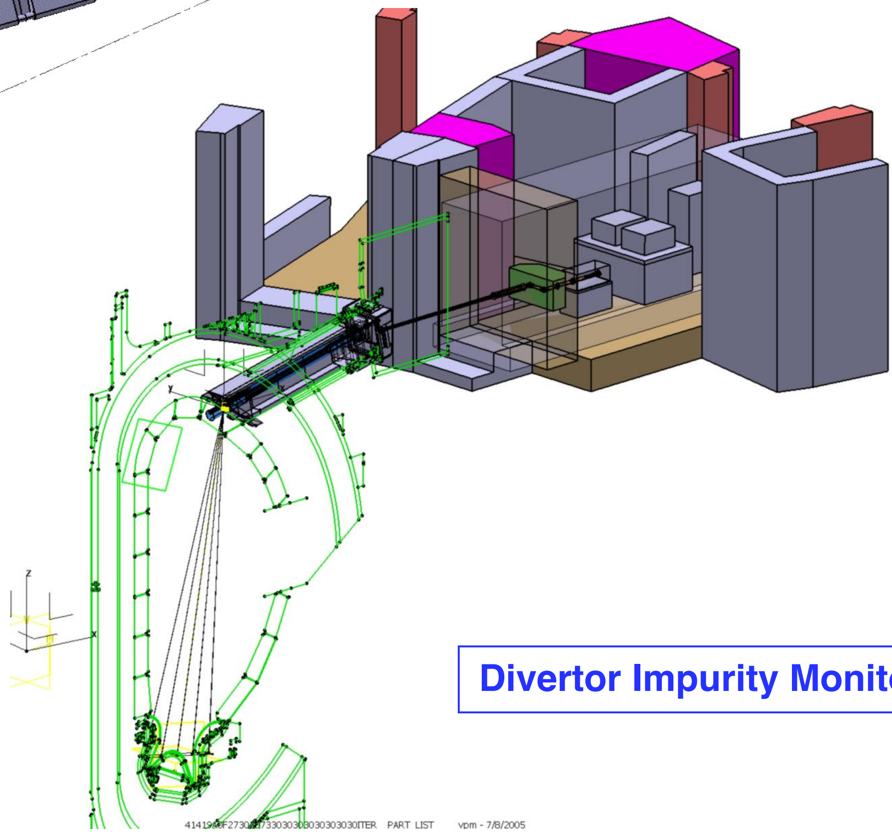


Input laser beam

Upper Ports



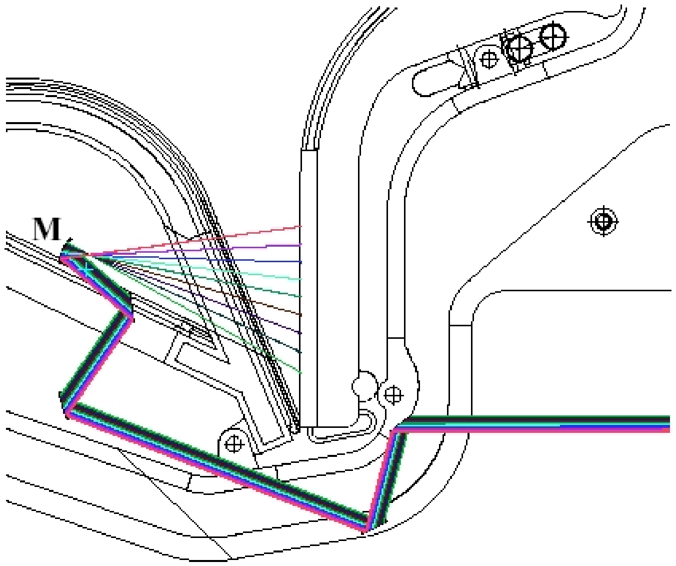
CXRS Upper #03 (or #02)
Two views of the Diagnostic
Neutral Beam



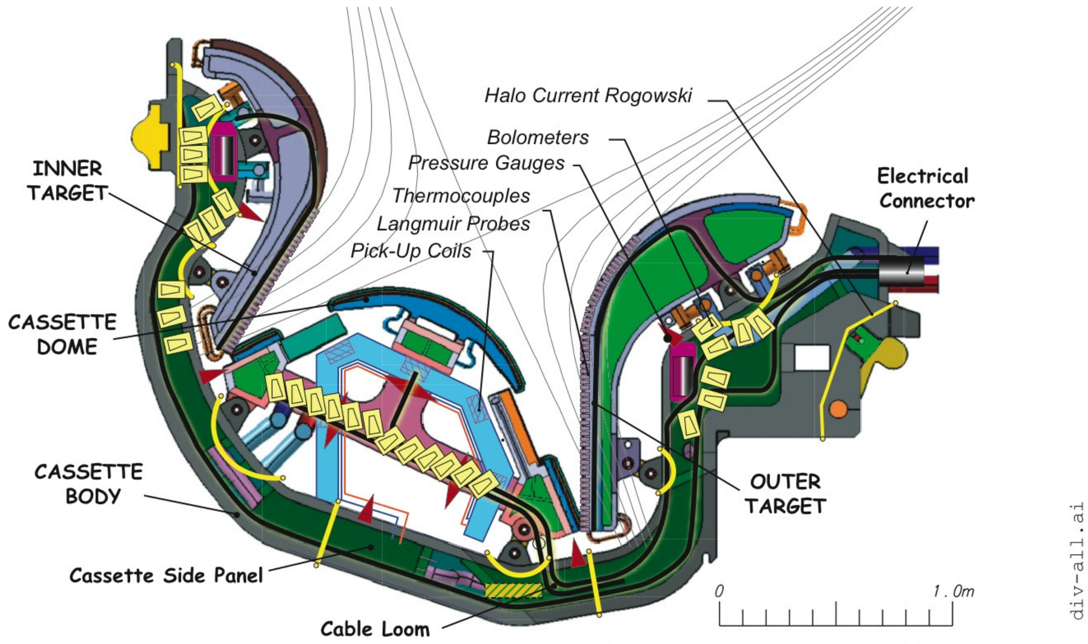
Divertor Impurity Monitor

Diagnostics in the Divertor

Diagnostic components are concentrated in five locations. Optical diagnostics make use of the central aperture of the cassette and the gaps between the cassettes. Systems requiring electrical connections are incorporated into special instrumented divertor cassettes.

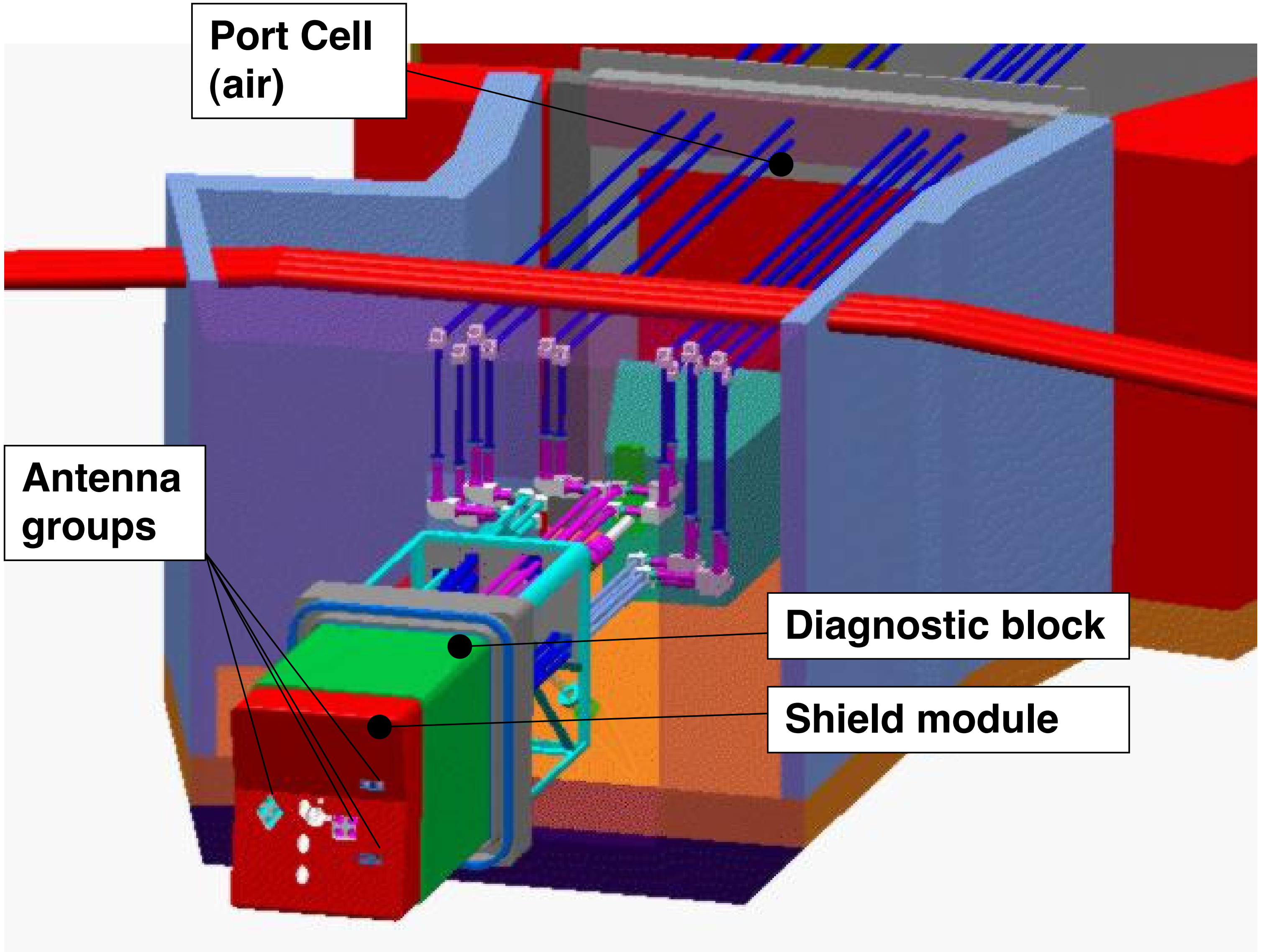


Optical access



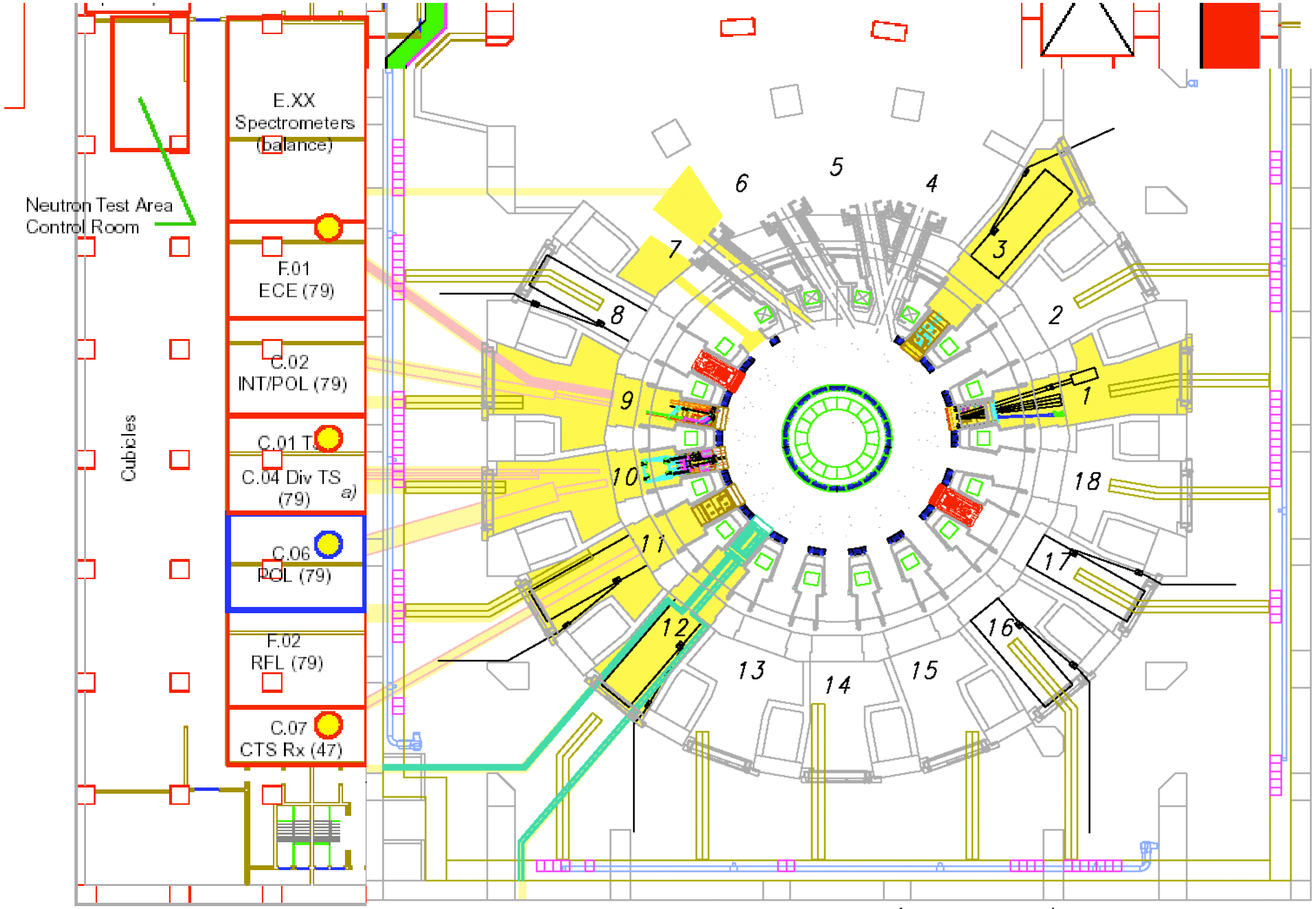
Electrical access

Port Cells and Galleries



Diagnostic Building

Transmission lines pass through the galleries to lasers, detectors, spectrometers etc in the diagnostic building



DIAGNOSTICS PLAN (EQ. LEVEL)

Assessment Relative to Target Measurement Requirements

GROUP 1a Measurements For Machine Protection and Basic Control	GROUP 1b Additional Measurements for Control in Specific Scenarios	GROUP 2 Additional Measurements for Performance Eval. and Physics
Plasma shape and position, separatrix- wall gaps, gap between separatrixes Plasma current, q(a), q(95%) Loop voltage Fusion power $\beta_N = \beta_{tor}(aB/I)$ Line-averaged electron density Impurity and D,T influx (divertor, & main plasma) Surface temp. (div. & upper plates) Surface temperature (first wall) Runaway electrons 'Halo' currents Radiated power (main pla, X-pt & div). Divertor detachment indicator (J_{sat}, n_e, T_e at divertor plate) Disruption precursors (locked modes,m=2) H/L mode indicator Z_{eff} (line-averaged) n_T/n_D in plasma core ELMs Gas pressure (divertor & duct) Gas composition (divertor & duct) Dust	Neutron and α-source profile Helium density profile (core) Plasma rot. (tor and pol) Current density profile (q-profile) Electron temperature profile (core) Electron den profile (core and edge) Ion temperature profile (core) Radiation power profile (core, X-point & divertor) Z_{eff} profile Helium density (divertor) Heat deposition profile (divertor) Ionization front position in divertor Impurity density profiles Neutral density between plasma and first wall n_e of divertor plasma T_e of divertor plasma Alpha-particle loss Low m/n MHD activity Sawteeth Net erosion (divertor plate) Neutron fluence	Confined α-particles TAE Modes, fishbones T_e profile (edge) n_e, T_e profiles (X-point) T_i in divertor Plasma flow (divertor) $n_T/n_D/n_H$ (edge) $n_T/n_D/n_H$ (divertor) T_e fluctuations n_e fluctuations Radial electric field and field fluctuations Edge turbulence MHD activity in plasma core

Expect to meet measurement requirements; performance not yet known; expect not to meet requirements

SUMMARY

- ITER will require an extensive diagnostic system in order to meet the requirements for machine protection, plasma control and physics studies.

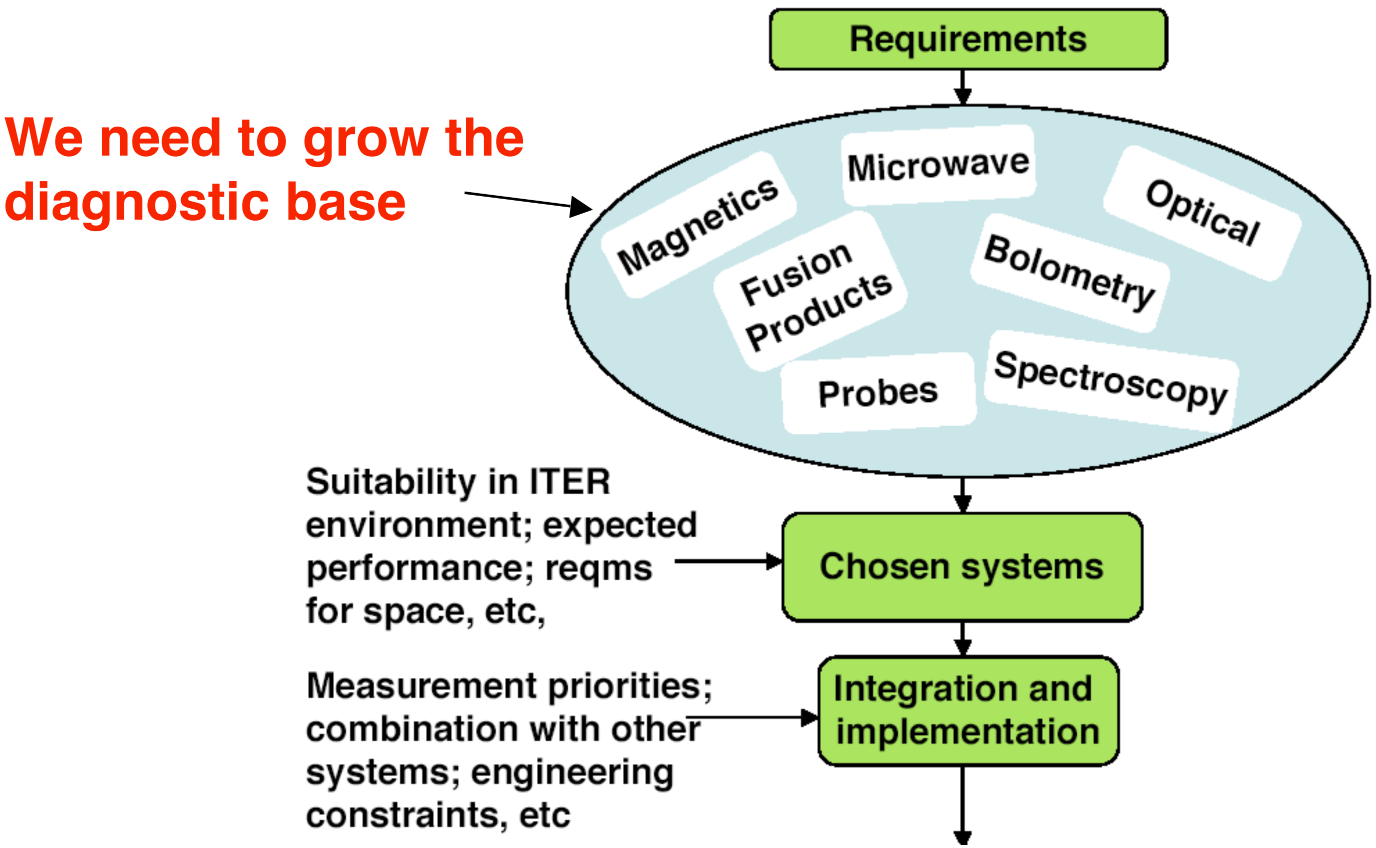
- The realisation of the diagnostic system is a major challenge because of the harsh environment and the nuclear requirements.

- Components will be installed in multiple locations. Novel approaches have been adopted especially for the components in the ports where port-plugs with customised diagnostic modules will be used.

- It is expected that the measurements necessary for machine protection and basic plasma control can be made at the required level but more development and design work are needed before the full performance of the system can be established.

SUMMARY

- **The development of new diagnostic techniques specifically for the reactor environment is needed especially for the later phases of ITER and for the devices that will follow ITER (DEMO etc).**



Related papers at this conference:

High Priority R&D Topics in Support of ITER Diagnostic Development
A.J.H. Donné et al paper IT/P1-24

First Mirrors for Diagnostic Systems of ITER
A Litnovsky et al paper IT/P1-22

Progress in Diagnostic ITER relevant Technologies at JET
A Murari, paper IT/P1-23

Progress in Development of Thomson Scattering Systems for ITER
G T Razdobarin, paper IT/P1-25

Review of Beam Aided Diagnostics for ITER
M G von Hellermann, paper IT/P1-26

Requirements for Fast Particle Measurements on ITER and Candidate Measurement Techniques
F P Orsitto et al paper IT/P1-27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