Overview of progress with ITER spectroscopic systems

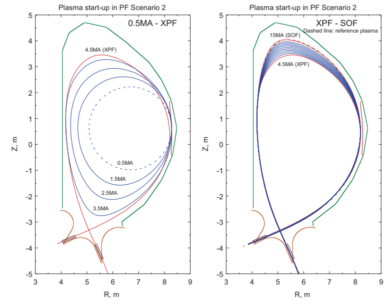
IAEA, Daejeon 15-19 December 2014

Robin Barnsley and ITER team

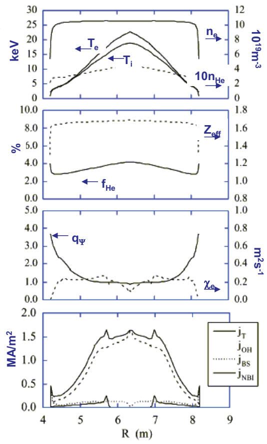
- Status overview
- Generic activities
  - Emission modelling
  - Stray light modelling
  - Neutronics modelling
- Outlook

Project Requirement on Diagnostics is for **Measurements**

A Q=10 scenario with (ELMy H-mode):
I_p=15MA, P_{aux}=40MW, $H_{98(y,2)}$=1



Current Ramp-up Phase



Organization of diagnostics

About 45 different diagnostics for different measurement roles;
- Machine protection, Basic control, Physics, Advanced control

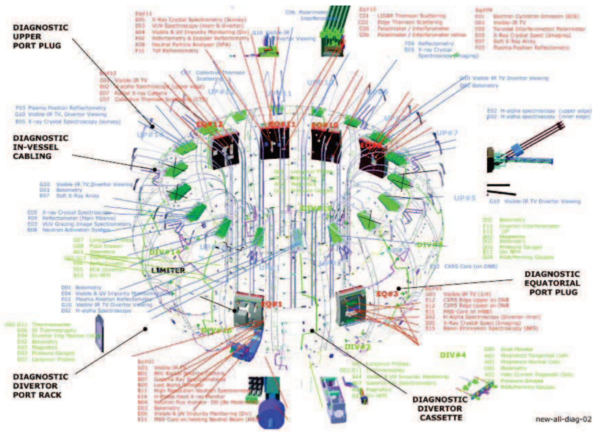
About 100 projects in all, including supporting systems

PBS55 - Diagnostics	PBS55-Engineering of:
A- Magnetics systems	Q- Equatorial Ports
B- Neutrons systems	U- Upper Ports
C- Optical systems	L- Lower ports
D- Bolometry systems	NW- Windows
E- Spectroscopy systems	NE- Electrical Services
F- Microwave systems	PBS57-Engineering of:
G- Operational systems	I - IVVS

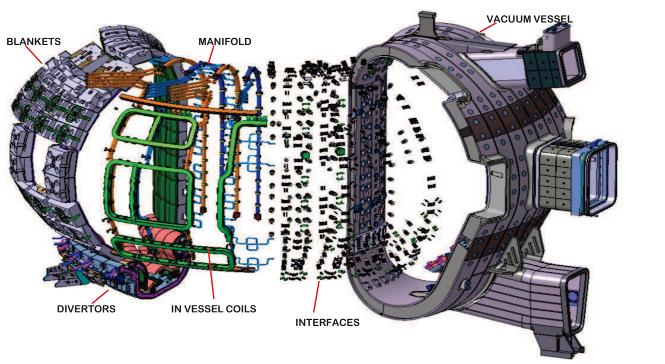
We are in the construction phase

Needs the best scientists, engineers and project expertise etc

Diagnostics are highly integrated



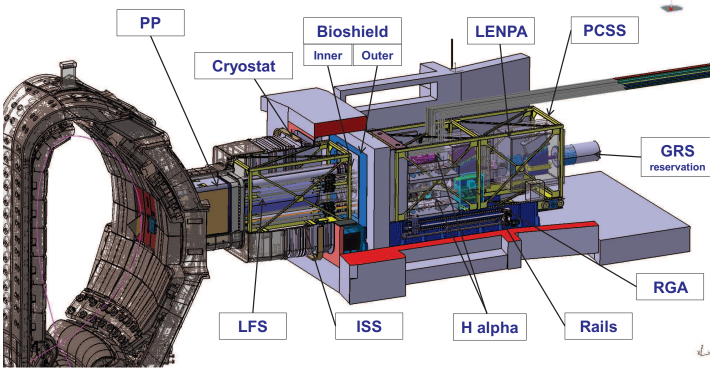
Complex integration – especially in-vessel



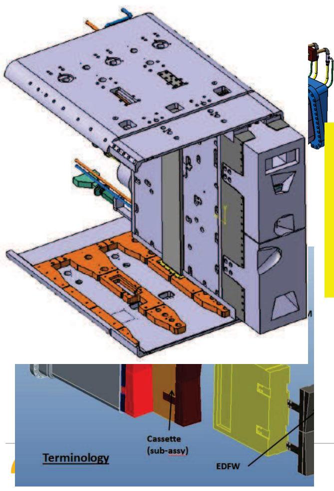
Interfaces are one of the great challenges of ITER, both in design and in assembly. Many components; space tight and harsh environment

Port Integration Activities

- Joint team working closely together to integrate diagnostics and services
- Port Integration very important driver for diagnostics – 2014 big progress
- Driver for all port systems-Interfaces



Port Plugs: Final Design Reviews Completed



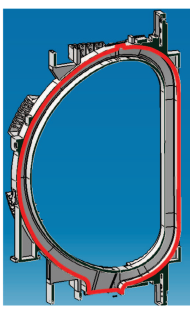
- UPP Assembly: **GUPP**+DFW+DSM
  - FDR completed

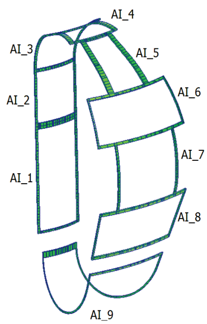
All Diagnostic Port Plugs have
- Common Design and shared Procurement
- This saves costs and time for the project
- Tender started
- Modular structures
- Welded (Electron Beam mainly)
- ESPN

- EPP Assembly: **GEPP**+DFW+DSM
  - FDR completed

Magnetics and In-Vessel Wiring Looms

- Fundamental to the operation of ITER and
- **Needed early** in the assembly phase
- Showing CER (FDR), flux loops (PDR) and prototypes



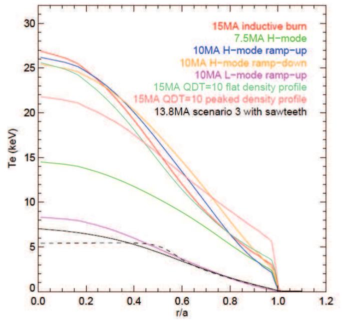


Plasma emission modelling

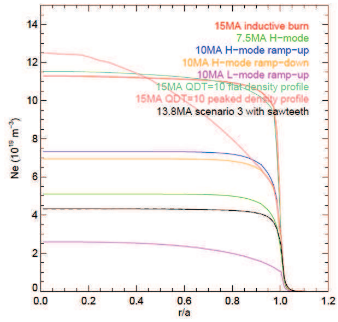
- Impurity emission modelling is essential input to designs – sets requirements for instrument:
  - Sensitivity
  - Spectral range and resolution
  - Field of view and spatial resolution
- Atomic data from ADAS – Atomic Data and Analysis Structure (open.adas.ac.uk).
- Plasma emission modelling with SANCO impurity transport code
- Continuously refined and expanded
  - Wide range of plasma scenarios
  - Wide range of impurities
  - Impurity radiated power – line and continuum
  - Input to all spectroscopy CDRs
  - Input to Bolometry CDR

PBS	System	Range	Function	PA	Status
55E4	Divertor imp monitor	200 – 1000 nm	Impurity species and influx, divertor He density, ionisation front position, T_i.	Yes	PDR prep
55E2	Ha system	Visible region	ELMs, L/H mode indicator, n_T/n_D and n_H/n_D at edge and in divertor.	Yes	PDR prep
55E3	VUV spectr. – main	2.3 – 160 nm	Impurity species identification.	Yes	PDR prep
55EG	VUV spectr. – divertor	15 – 40 nm	Divertor impurity influxes, particularly Tungsten	Yes	PDR prep
55EH	VUV spectr. – edge	15 - 40 nm	Edge impurity profiles	Yes	PDR prep
55ED	X-ray spectr. – survey	0.1 – 10 nm	Impurity species identification	Yes	PDR prep
55EI	X-ray spectr. – edge	0.4 – 0.6 nm	Impurity species identification, plasma rotation, T_i.	Yes	PDR prep
55E5	X-ray spectr.-core	0.1 – 0.5 nm		Yes	Hand-over
55E7	Radial x-ray camera	1 – 200 keV	MHD, Impurity influxes, Te	Yes	PDR prep
55EB	MSE	Visible region	q (r), internal magnetic structure	Yes	Hand-over
55E1	Core CXRS	Visible region	T_i (r), He ash density, impurity density profile, plasma rotation, alphas.	No	CDR prep
55EC	Edge CXRS	Visible region		Yes	PDR prep
55EF	BES	Visible region	Beam-attenuation and fluctuations.	No	CDR Oct 2012
55E8	NPA	0.01- 4 MeV	n_T/n_D and n_H/n_D at edge and core. Fast alphas.	Yes	PDR closed
55EA	LIF	Visible	Divertor neutrals	No	Pre- CDR held
55E	Hard X-ray Monitor	100keV – 20MeV	Runaway electron detection	IO	CDR closed

Range of plasma scenarios for emission modelling



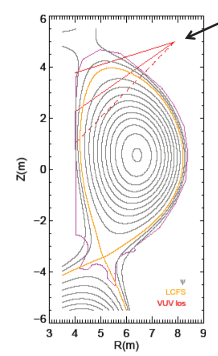
Te profiles



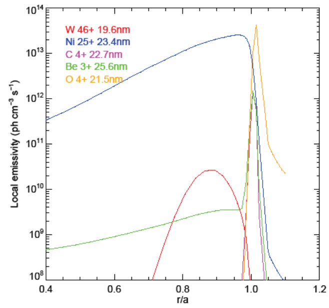
Ne profiles

ADAS/SANCO Modelled spectral emission

Sight-lines and viewing fans can be generated for any location

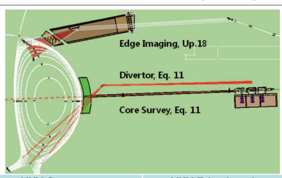


Modelling of emission along lines of sight for imaging VUV spectrometer



VUV lines 10 – 100 nm mostly in the outer plasma

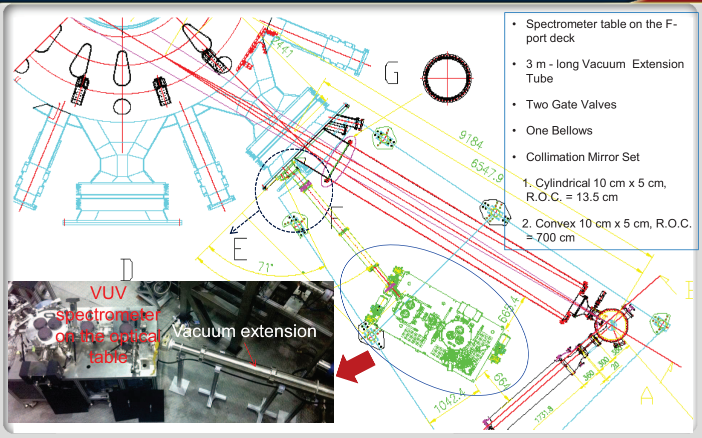
ITER VUV spectroscopy subsystems



Subsystem	VUV Core survey	VUV Edge imaging	VUV Divertor
PBS	55.E3	55.EH	55.EG
Function	Impurity species identification.	Impurity profile	Divertor impurity influxes, particularly Tungsten
Wavelength range (nm)	2.4 – 160	17 – 32	15 - 32
Resolving power (λ/δλ)	~500	~500	~500
Gratings	5	1	1
Implementation	Slot in Eq 11 port-plug 10 x 100 mm^2 Collimating mirrors in port-cell	Slot in Up18 port-plug Field mirror in port-plug Collimating mirror in port-cell	Slot in Eq 11 port-plug Field mirror in port-plug Collimating mirror in port-cell

KSTAR VUV Spectrometer – ITER Prototype

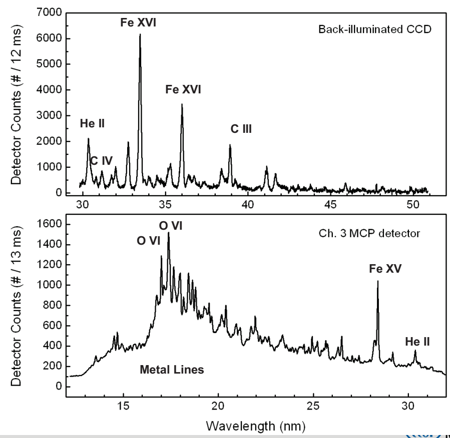
CR Seon, MS Cheon, S Pak & HG Lee



- Spectrometer table on the F-port deck
- 3 m - long Vacuum Extension Tube
- Two Gate Valves
- One Bellows
- Collimation Mirror Set

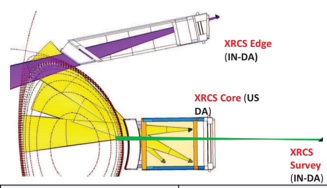
1. Cylindrical 10 cm x 5 cm, R.O.C. = 13.5 cm
2. Convex 10 cm x 5 cm, R.O.C. = 700 cm

First Measurement of KSTAR Plasma Impurity



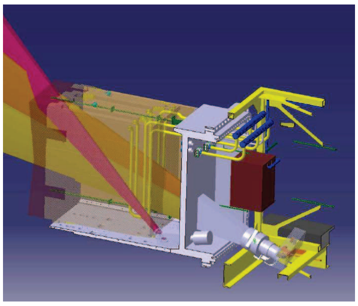
- Impurity lines of initial plasmas at KSTAR 2012 Campaign (2012. 09. 06)

The three ITER x-ray spectrometer subsystems

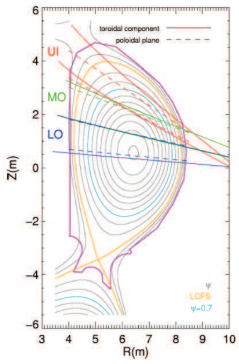


Subsystem	Main plasma x-ray survey	X-ray Core imaging	X-ray Edge imaging
Function	Impurity species identification and monitoring	Core ion temperature, rotation, impurity profile	Edge ion temperature, poloidal rotation, impurity profile
Wavelength range (nm)	0.05 – 10	0.2 – 0.4	0.2 – 0.5
Resolving power (λ/δλ)	Below 2.5 nm ~1000, Above 2.5 nm ~ 100	~8000	~8000
Implementation	Slot in E11 port-plug, Diffracting optic in port-cell	Slot(s) in E09 port-plug, Diffracting optics inside port-plug	Slot in U09 port-plug, Diffracting optic behind the port-plug

Views for Core Imaging X-ray Spectrometer

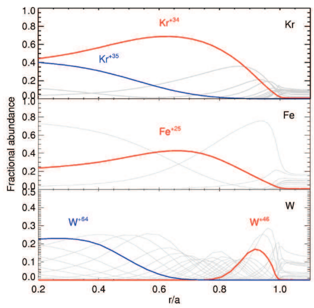


Three sub-views with imaging crystal spectrometers Toroidal component ~25 deg.

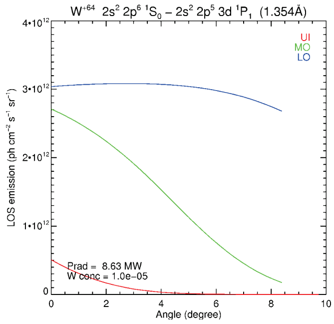


The views projected onto flux surfaces

ADAS/SANCO modelling of impurities relevant for the Core X-ray Spectrometer



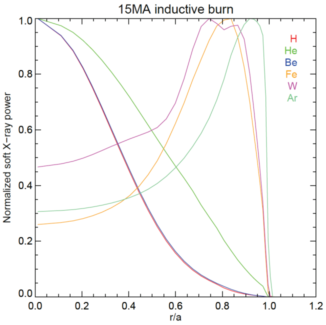
Fractional abundance of relevant ions



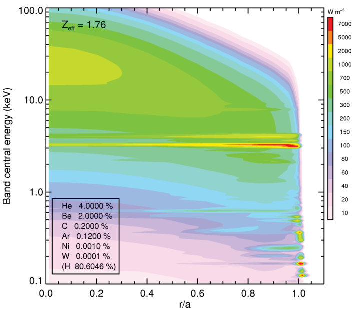
Line-integral intensities of W +64 For the three x-ray views

Total core radiated power is around 50 MW – mostly x-rays

Strong test of atomic data and modelling:
Requires all impurities, ionization stages, excitation processes etc.



Normalized radiated power profiles of individual impurities



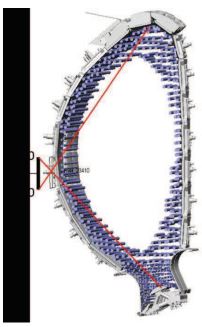
X-ray profile resolved into 5% energy bands

Stray light modelling

- In-vessel reflections are important for all visible systems
- LightTools is now well-established
  - Quantitative results
  - Sources built based on plasma modelling
  - Surface reflectivities can be modelled or measured
  - Directly uses CAD models of in-vessel components
  - Generates image-quality results
  - Benchmarking comparison with JET in progress

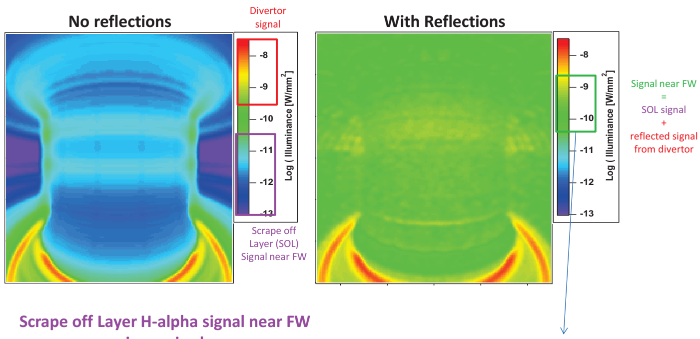
Stray light modelling with LightTools

CAD model of vessel



Model of SOL and divertor sources – ADAS-SOLPS

Use of LightTools for design of H-alpha system

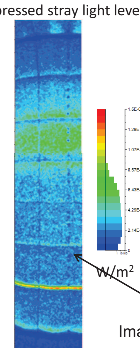


Scrape off Layer H-alpha signal near FW is required

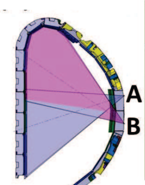
See next slide for detailed image of reflections on FW

Strategies for stray light mitigation led to re-design of H-alpha system

Reflected Light Profile (dark spots are technical holes with suppressed stray light level)



EP#11



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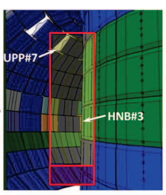

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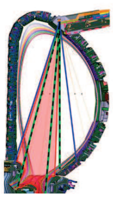


Image features on inner wall

Tangential view most features highest contrast

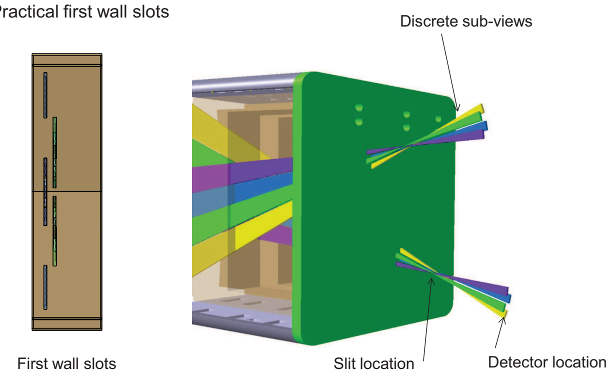
Divertor view to quantify divertor emission

Neutronics modelling

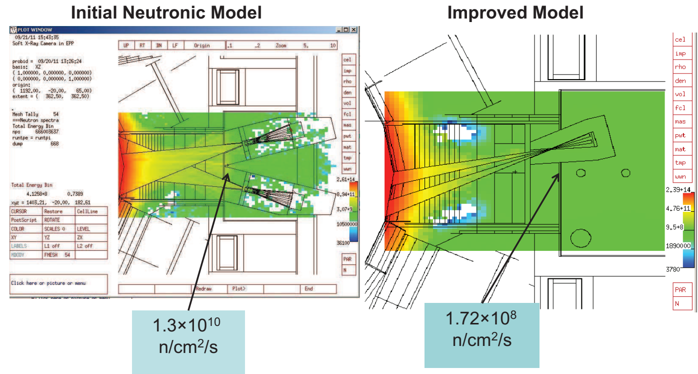
- Major design driver for all systems
- Challenge for direct-viewing diagnostics – X-ray. Neutron, NPA etc
  - Use internal collimation to sub-divide views
    - NPA
    - Core x-ray spectrometer
  - Sub-divide into discrete views
    - Radial x-ray camera
    - Core x-ray spectrometer
    - Radial x-ray camera
  - Tight collimation inside port plug to keep directs neutrons away from sight-tube components as much as possible
    - All systems
    - Miinimize activation of sight-tube for maintenance
    - Use aluminium where possible
    - Stop direct neutrons in beam-dump

Fan array for Radial X-ray Camera divided into sub-views

- Large improvement in neutronics
- No loss of x-ray sensitivity
- Practical first wall slots



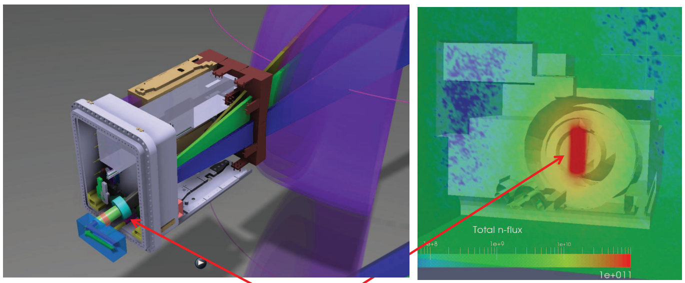
X-ray Camera - Fan view divided into several sub-views
Results in improvement in neutron flux at port flange



Neutronic analysis of shielding is a major design driver

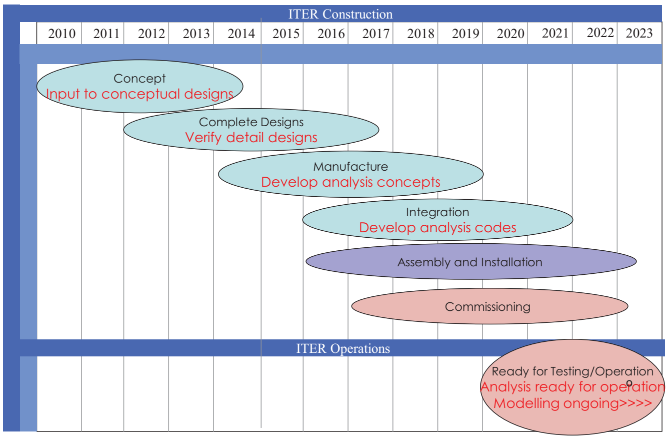
Core imaging x-ray spectrometer

MCNP model



Under study – **Human factors**
- Direct neutrons closely collimated in sight-tube
- Minimize sight-tube activation
- Maximum use of low-activation components – eg Aluminium
- Beam-dump to stop direct neutrons

Present Global planning for ITER Diagnostics
Atomic data and modelling requirements



Long-term outlook

General
- PDR phase through to FDR
- R&D ongoing
- Prototypes already - eg VUV on KSTAR

Stray light
- Goal – operation model of vessel, plasma and diagnostics

Neutronics
- Large effort – almost always on critical path for design progress
- Required throughout operation

Plasma modelling
- Goal – continuously updated data for all impurities, scenarios, diagnostics etc
  - Concept design
  - Detail design
  - Analysis code development
  - Analysis support throughout operations
  - Requires long-term availability and updating of
    - Data
    - Experts