Diagnostic Opportunities on ITER

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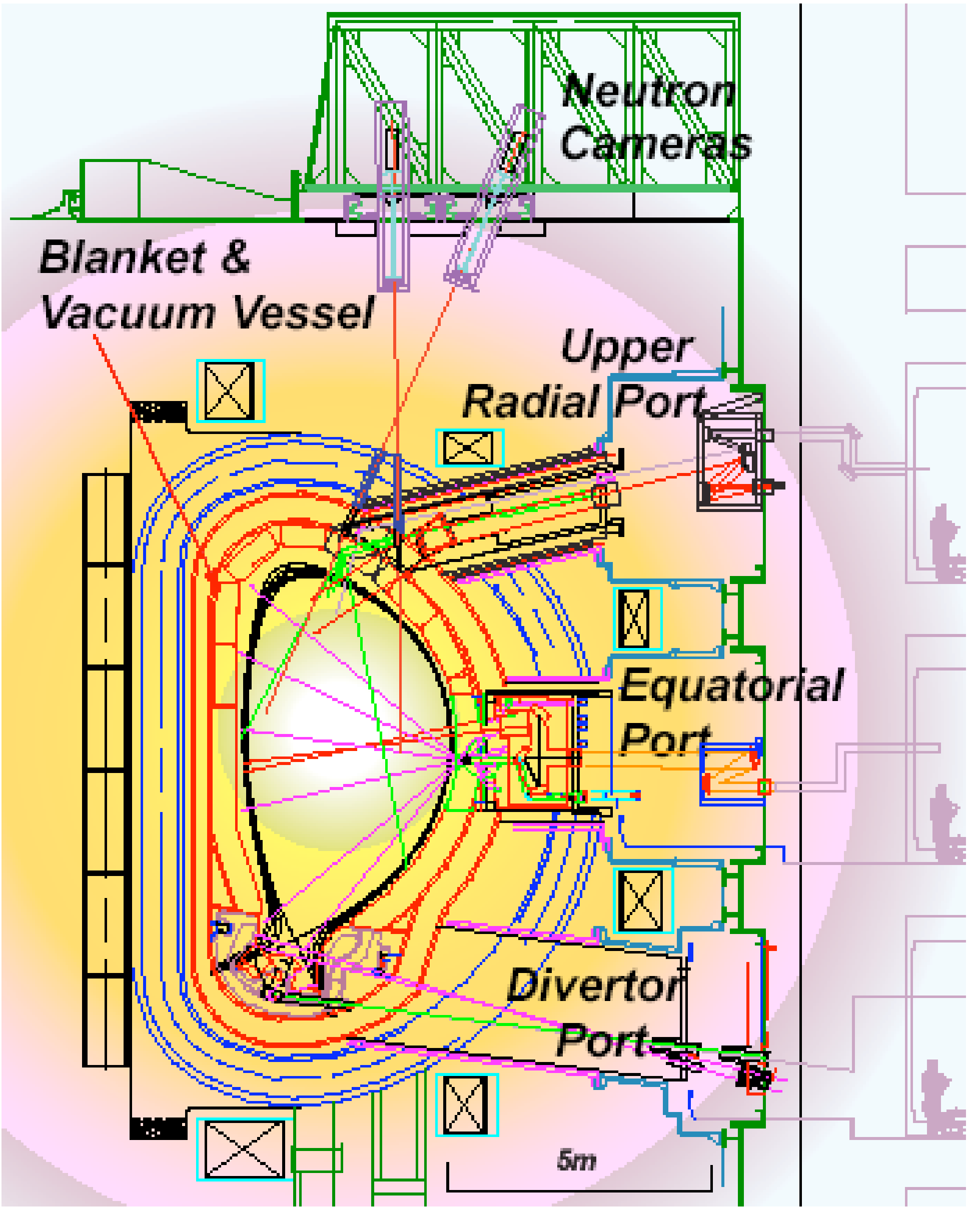
- Motivation for US interest in ITER diagnostics
- Attributes of ITER diagnostics
- Examples of diagnostics and required R&D
- Scale of the ITER diagnostic effort
- Near-term US involvement

Motivation for US interest in ITER diagnostics

- The US has a strong diagnostic program which has pioneered many measurement innovations.
  - Applying US diagnostic expertise will increase the chances for ITER success.
- From ITER PDD: "The responsibility for design and procurement of these specific systems should be shared by the Laboratories of the Parties which aim at participating in ITER operations through their physicists." ⇒ diagnostics close-coupled to physics research
- ITER measurement development will have spin-offs which will benefit diagnostics for the base program.
- Diagnostic development for ITER will create opportunities to train young people, who are 1) needed for the US program, 2) will be important in ITER operation and 3) will be essential to insure a return on US investment in ITER.

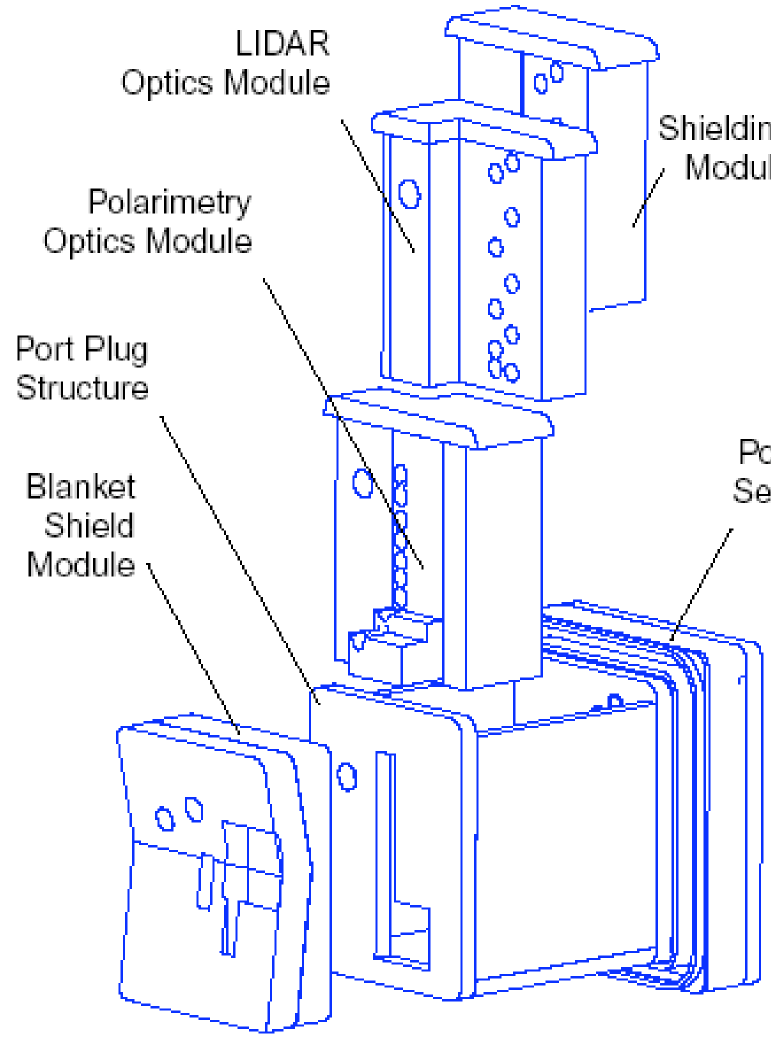
ITER diagnostic attributes

- Diagnostic front-ends exist in a very harsh environment
- High reliability is needed for
  - plasma control
  - minimize maintenance in radiation environment
- Limited access for diagnostics space constraints, high level of integration necessary
  - 6 of 18 equatorial ports
  - 11 of 18 upper ports
  - 6 divertor cassettes
  - small penetrations to prevent streaming



Diagnostic plugs accommodate harsh environment

- Neutron & gamma fluxes ($10^{16}/m^2s$)
  - ➢ labyrinthine shields
- Nuclear heating (~ .1-1W/cc)
- Thermal-induced motion
  - ➢ in-situ alignment & calibration
- Optics degrade due to deposition & CX neutral bombardment
  - ➢ real time monitoring, calibration
- Design, integration and assembly of diagnostic plugs and divertor cassettes is 20-25% of ITER budgeted diagnostics effort
  - ➢ blanket & shielding require heavy engineering - shown ~ 60 tons



High reliability required for many measurements

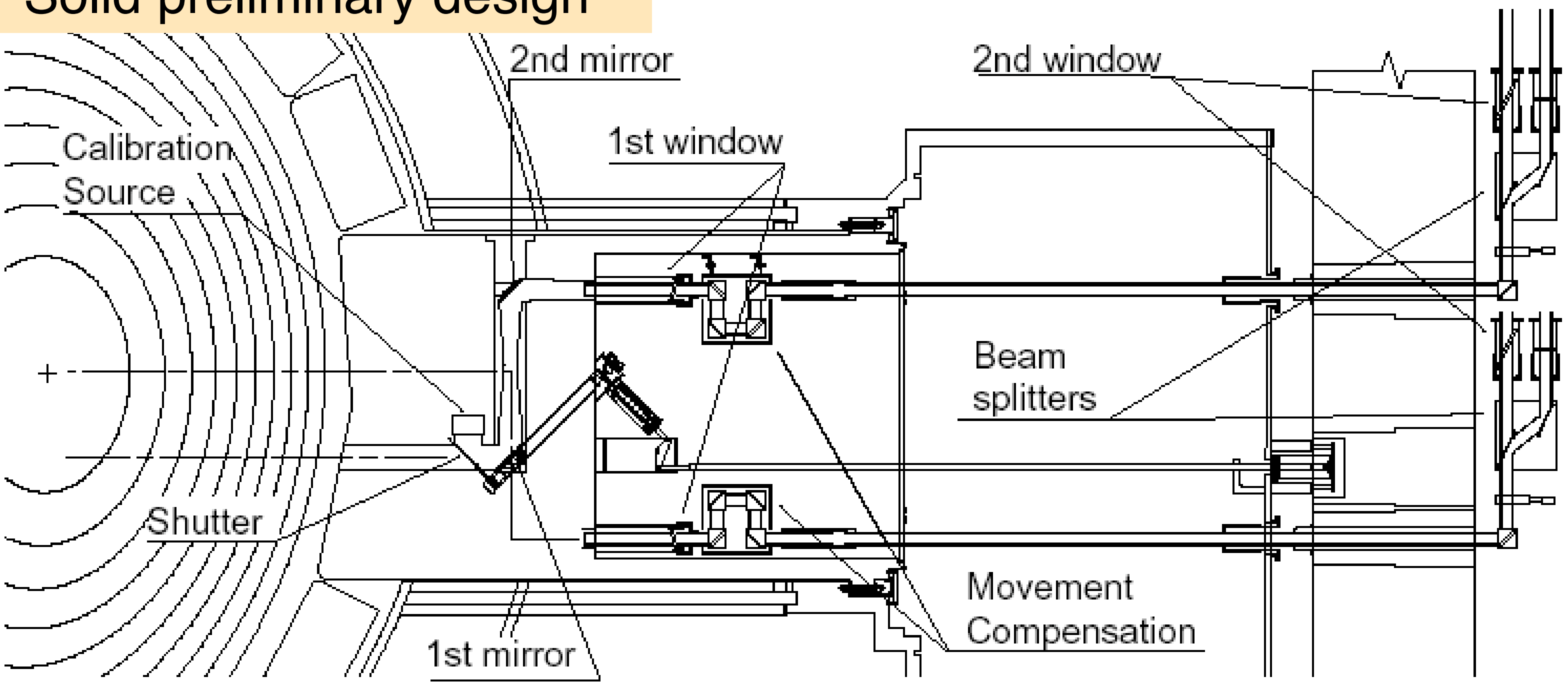
GROUP 1a Measurements For Machine Protection and Basic Control	GROUP 1b Measurements for Advanced Control	GROUP 2 Additional Measurements for Performance Eval. and Physics
Plasma shape and position, separatrix- wall gaps, gap between separatrixes Plasma current, q(a), q(95%) Loop voltage Fusion power $\beta_N = \beta_{tor}(aB/I)$ 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)	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 meas. reqs maybe/maybe not expect not to meet meas reqs.

Electron cyclotron emission

Design

- Solid preliminary design



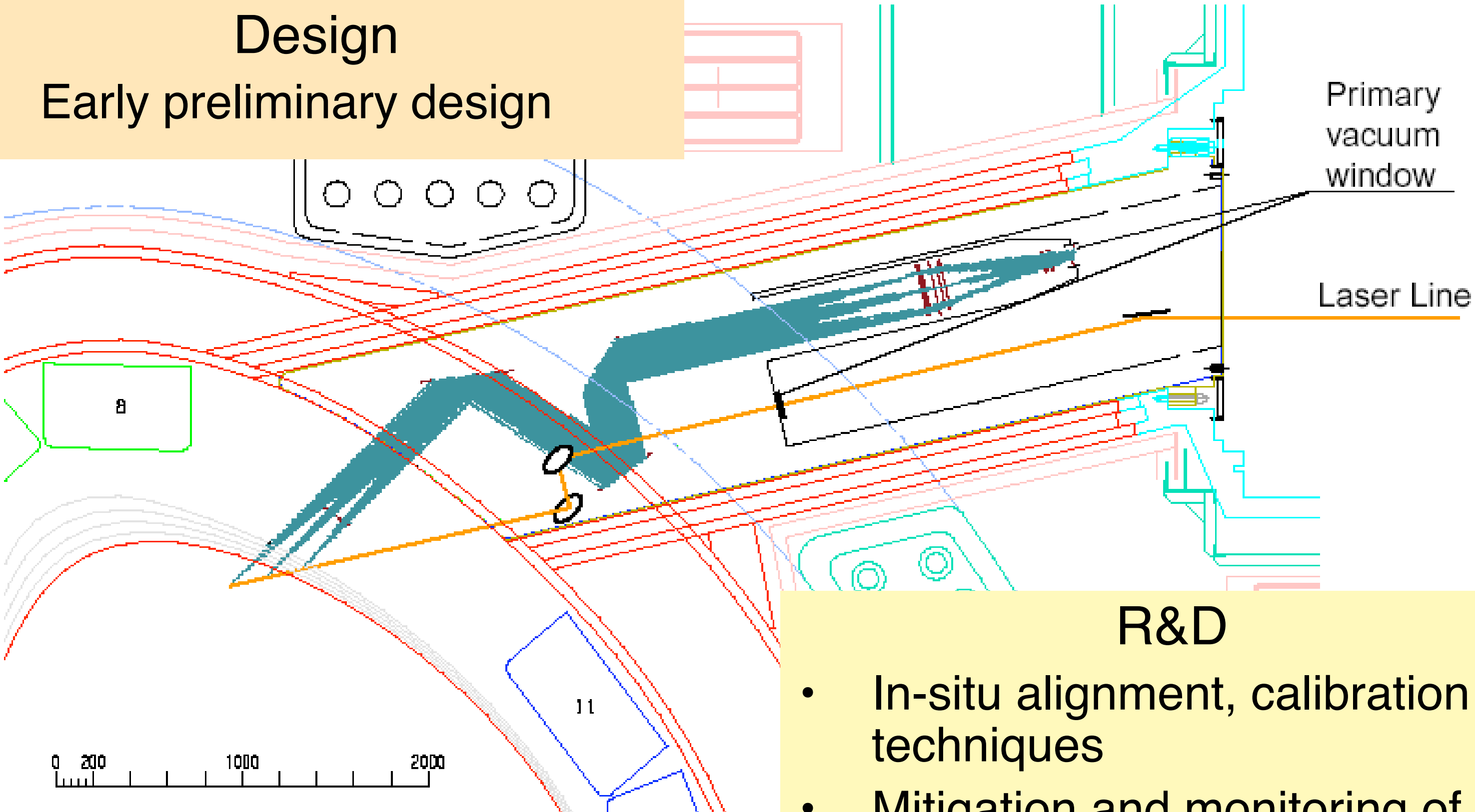
R&D

- Waveguide studies

Physics

- Pedestal formation, control
- ITB formation, control
- Stability

Edge Thomson scattering



Design

- Early preliminary design

R&D

- In-situ alignment, calibration techniques
- Mitigation and monitoring of optical degradation
- Nd:YAG laser 100 Hz, 5 J
- Imaging polychromator
- APD detector arrays

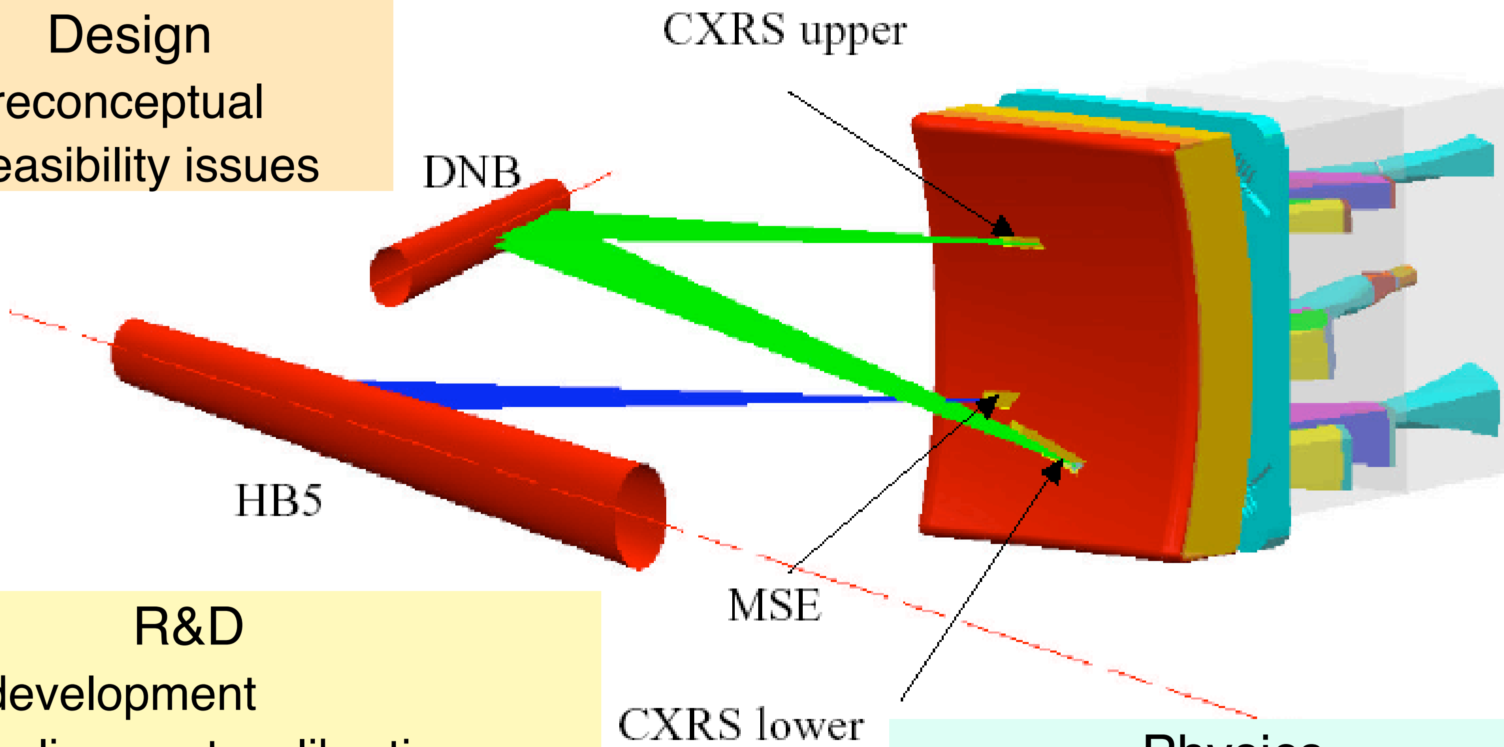
Physics

- Pedestal formation, control
- Edge stability

Active spectroscopy

Design

- Preconceptual
- Feasibility issues



R&D

- DNB development
- In-situ alignment, calibration techniques
- Mitigation and monitoring of optical degradation
- High throughput spectrometers
- Advanced polarimetry

Physics

- Pedestal formation, control
- ITB formation, control
- Stability
- Confined alphas

Other examples of diagnostic R&D

- Steady-state magnetics
- Rad-hard pressure gauges
- Shutter prototyping
- DNB development
- New or improved measurement techniques for:
  - Current profile measurements
  - Confined and lost alpha particles
  - Tile erosion
  - Dust accumulation
  - Core fluctuations

Diagnostic procurement packages

(ITER estimated costs in $M)

Magnetics (5.5.A) $4.7
- Vessel Magnetics (A.01)
- In-vessel Magnetics (A.02)
- Divertor Magnetics (A.03)
- External Rogowskis (A.04)
- Diamagnetic Loop (A.05)
- Halo Current Sensors (A.06)

Neutron Diagnostics (5.5.B} $14.5
- Radial Neutron Camera (B.01)
- Vertical Neutron Camera (B.02)
- Microfission Chambers (B.03)
- Flux Monitor (B.04)
- Activation System (B.08)

Optical Diagnostics (5.5.C) $37.0
- Thomson Scattering, Core (C.01)
- Thomson Scattering, Edge (C.02)
- Thomson Scattering, X-point (C.03)
- Interferometer (C.05)
- Polarimeter (C.06)

Bolometry (5.5.D) $9.6

Spectroscopy (5.5.E) $32.4
- Charge Exch. Recomb. Spect.(E.01)
- H Alpha Spectroscopy (E.02)
- Impurity Monitor for Main Plasma (E.03)
- Divertor Impurity/ Influx Monitor (E.04)
- X-Ray Crystal Spectrometer (E.05)
- Visible Continuum Array (E.06)
- Neutral Particle Analysers (E.08)
- Motional Stark Effect (E.11)

Microwave Diagnostics (5.5.F) $25.5
- Electron Cyclotron Emission (F.01)
- Reflectometry for the main plasma (F.02)
- Reflectometry for plasma position (F.03)
- Reflectometry for the divertor (F.04)
- ECA for the divertor (F.05)

Operational Systems (5.5.G) $15.9
- Cameras – Visible / IR TV (G.01)
- Thermocouples (G.02)
- Pressure gauges (G.03)
- Residual Gas Analysers (G.04)
- Langmuir probes (G.07)

Cost estimates are for fabrication & procurement but not design.

Generic diagnostic procurement packages

(ITER estimated costs in $M)

In-Vessel Services (N.01)	$11.6
Port Plugs and First Closures (N.03)	$19.3
Port Intersp Structures & Closures (N.04)	$8.2
Divertor Components (N.05)	$1.1
Ex-Vessel Services (N.06)	$11.7
Window Assemblies (N.07)	$9.2

- These packages are likely to be shared among parties. For example, the US may build one of six equatorial ports.
- Cost estimates for these packages do include design.
- Work on these packages will be tightly coupled to central team.

ITER estimate of diagnostic costs
(From PDD on Forum Website)

ITER Diagnostic Cost Summary	$M	PDD Reference	Comment
Procurement & Fabrication			1 kIUA=$1.44M
Provider startup	169.8	Table 7.1.5.1	
Provider deferred	60.9	Table 7.1.5.1	
Direct Capital (credited) Total	230.7		
Design, Integration, & Management			1 PPY=$.21M
Provider startup	25.4	Table 7.1.5.1	
Provider deferred	22.3	Table 7.1.5.1	
International Team	13.2	Sect.7.1.6.2	5% of total
Party National Team	20.2	Sect.7.1.6.2	5% of total
R&D during construction phase	5.8	Sect.7.1.6.3	5% of total
Supporting Program (not credited) Total	86.8		

It is reasonable to assume ITER diagnostic effort will span ~10-15 years.
A multi-institutional US team is currently assessing these estimates.

As a diagnostician, why does ITER deserve my attention today?

- It is true that…..
  - ITER plasmas are at least 10 years in future.
  - Today, ITER is a bureaucracy in search of itself.
  - The US commitment to ITER is uncertain.
- Yet…..
  - If ITER is built, it will be an exciting burning plasma project that may make or break fusion.
  - There are interesting diagnostics challenges offered by ITER.
  - A US role in ITER diagnostics could be comparable in budget to the diagnostics component of the current US base program.
  - US researchers are behind foreign colleagues in terms of ITER-specific design experience. Need to:
    - Become more informed on ITER diagnostic designs.
    - Be organized to act (compete?) if given the nod in the next 1-2 years.

US Involvement in ITPA Diagnostics Group

ITPA Committee (Tony Donné (EU), Alan Costley (ITER IT))

- Meets twice/year, 5th meeting in St. Petersburg in July
  - 4.5 day meetings,1 day focused on one topic (e.g. control)
  - Presentations on:
    - design studies for specific ITER diagnostics
    - action items singled out for attention
    - diagnostics development in party programs
  - US is behind in terms of ITER-specific design issues
  - In many measurements, US is ahead in diagnostic innovation
  - Next meeting in the US follows HTPD, San Diego, April ‘04
- US Membership
  - D. Johnson (leader), R. Boivin (deputy)
  - G. McKee, T. Peebles, G. Wurden (members)
  - K. Young, R. Fischer (others attending twice or more)
  - Open to other participants
- Specialist Working Groups in Diagnostics

ITPA Diagnostic Specialist Working Groups

	Japan	RF	EU	ITER IT	US
Neutron	T. Iguchi Takeo Nishitani? Mamiko Sasao	Yuri Kaschuk Anatoli Krasilnikov Sergey Popovichev Victor Zaveriaev	Paula Batastoni Neil Jarvis Jan Källne		Catherine Fiore Lane Roquemore William Heidbrink Ray Fisher
Thomson Scatt.	Kazimuchi Narihara Takai Hatae	Gennady Razdobarin Vladimir Sannikov	Per Nielsen Francesco Orsitto Michael Walsh	George Vayakis	Tom Carlstrom David Johnson
Reflectometry	Kazuo Kawahata Atsushi Mase K. Shinohara	Victor Bulanin Alexey Petrov Vladimir Vershkov	Maria Manso Mathias Hirsch Gerrard Conway Joaquin Sanchez	George Vayakis Chris Walker	Gerrit Kramer Tony Peebles Terry Rhodes
Spectroscopy	Takashi Fujimoto Katsumi Ida Hirotaka Kubo Shigeru Morita	Yuri Gott Alexander Medvedev Dzholinard Shcheglov Mikhail Petrov Sergey Tugarinov	Robin Barnsley Kurt Behringer Ruggero Giannella Albrecht Pospieszczyk	Tasuo Sugie	Dan Thomas Ken Hill Fred Levinton John Rice Glen Wurden
First Mirror	Yoshihiko Hirooka Hidekhi Zushi	Nikolay Klassen Dorian Orlinski Vladimir Voitsenya Konstantin Vukolov	Eric Hodgson Paulo Tartoni	Alan Costley	John Hogan Charles Skinner
Radiation Effects	Toshiyuki Iida Takeo Nishitani Tatsuo Shikama	Sergey Bender Anatoli Krasilnikov Vladimir Stepanov Alexander Tomashuck Konstantin Vukolov	Benoit Brichard Marc Décreton Eric Hodgson Peter Jung	Chris Walker	John Hunn Lance Snead Ken Young Steve Zinkle

http://www.rijnh.nl/ITPA

Possible ITER diagnostic roles and responsibilities

National management & integration team	Lead provider for diagnostic system	Supporting Provider or R&D participant
• Coordinate US activities • Provide parts of generic packages • Interface with IT to get information (e.g. streaming calculations) • Work with IT to integrate systems • Organize reviews of candidate US designs	• Form teams to provide a specific system • Design system • Work with NT to integrate system • Coordinate efforts to procure & fab components • Test and install • Operate system	• Design and prototype specific subsystems or components • Fab subsystem for ITER • Work with lead provider to incorporate subsystem

What can we do in the near-term?

- Assess willingness of experts to be involved in ITER diagnostic effort
- Participate in discussions to define:
  - organization of US effort
  - high priority diagnostic areas for US involvement
- Interested experts in high priority diagnostic areas should:
  - become familiar with ITER designs and factors constraining designs (ITPA process, publications)
  - consider teaming on “expressions of interest” for providing diagnostic systems or generic packages