Diagnostics Issues for FIRE

Kenneth M. Young

Princeton Plasma Physics Laboratory

NSO PAC 3 Meeting

July 10 - 11, 2001
University of Wisconsin
Madison, WI

Aspects of Plasma Diagnostics to achieve Burning Plasma Physics Goals in FIRE

- The diagnostic set should provide the same quality of data as in best present-day devices.
- High quality, reliable information on many plasma parameters will be used to provide control signals.
- New information about the alpha-particles.
- The neutron radiation environment must be considered in design of the diagnostic system.

Outline of Talk

- Reminder of the impact of the radiation environment
- Reminder of the FIRE configuration
- Design Issues for Diagnostics
  - Port assignments
  - Magnetics/first wall concerns
  - Integration design issues
- Comments on the summary of the 2nd UFA Burning Plasma Workshop
- Draft of R&D requirements (FIRE Engg. Des. Review).

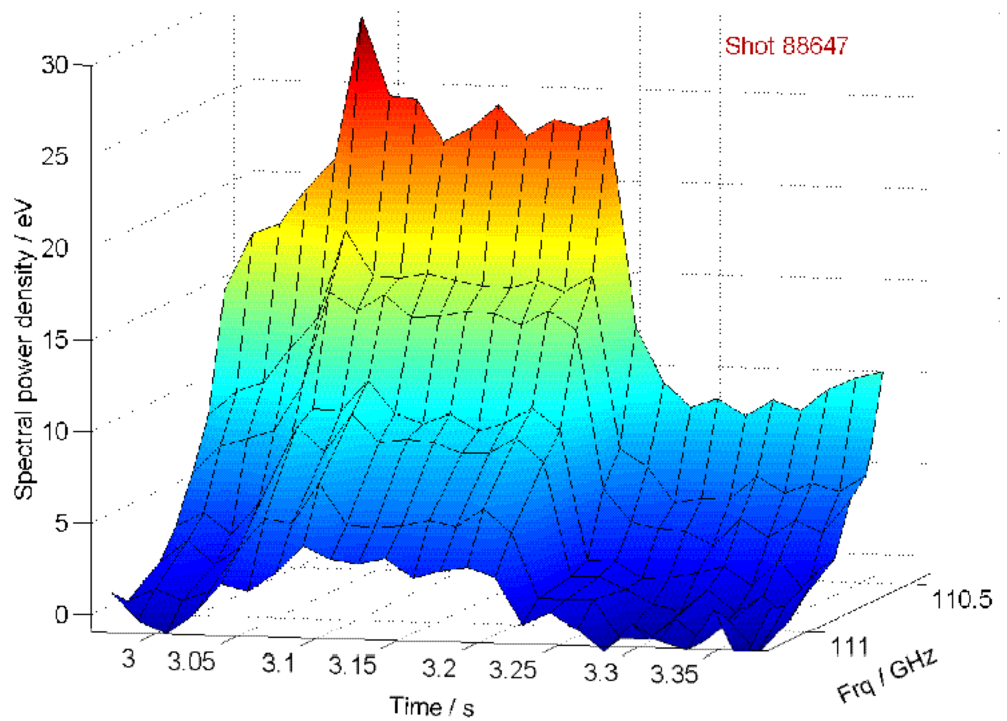
Examples of Target Plasma Measurement Capability proposed for ITER-FEAT

PARAMETER	PARAMETER RANGE	SPATIAL RESOLUTION	TIME RESOLUTION	ACCURACY
Plasma current	0.1 – 17.5 MA	Not applicable	1 ms	1% (I_p>1 MA)
Total neutron flux	$1x10^{14}$ - $1x10^{21}$ n s^{-1}	Integral	1 ms	10%
Neutron & α-particle source	$1x10^{14}$-$4x10^{18}ns^{-1}m^{-3}$	a/10	1 ms	10%
Divertor surface temperature	200 - 2500°C	-	2 ms	10%
Core electron temperature profile	0.5 - 30 keV	a/30	10 ms	10%
Edge electron density profile	(0.05 - 3) x 10^{20} m^{-3}	0.5 cm	10 ms	5%
Radiation profile in main plasma	0.01 - 1 MWm^{-3}	a/15	10 ms	20%
Radiation profile in divertor	≤100 MWm^{-3}	5 cm	10 ms	30%

Red indicates that these spatial resolutions may be hard to achieve in FIRE

Diagnostics for Alpha-Particle Physics

- Lost fast-ion detectors and IR camera,
- α-CHERS,
- Collective scattering (μwave offers best spatial distribution (& rcfraction), CO_2, FIR?),
- Knock-on neutron,
- New confined-α detector???
- High-frequency Mirnov coils, reflectometry.



Fast-ion spectra from Collective Scattering in TEXTOR (Bindslev, Woskov et al.)

The Impact of the Neutron (Gamma) Environment

- Special design and materials to be used for in-vessel systems
  - Also prevents the use of many present-day diagnostic components.
- Requirement for thick shielding, penetrated by complex labyrinths.
- Constraint on the use of optical components, especially lenses and fiberoptics.

Radiation Effects
(Ceramics (1), Optical components (2), Mirrors (3))

	First Wall (Gy/s)	Interspace Structure/ Shielding	Outside Vac. Vess. Port (Gy/s)	Fluence
ITER-FEAT (700 MW, 0.8 MW/m^2)	**4×10^3 + neutrals →**	**<---------------> →**	**5**	**Issue at 1st wall (long-term damage) Few x 0.1 dpa**
FIRE (220 MW, 3.6 MW/m^2)	**2×10^4 + neutrals →**	**<---------------> →**	**20**	**Non-issue**
Components	**Magnetics (1) -----** **<-------MI-cable (1)--** **Lost-Alpha** **Retroreflectors (3)** **Thermocouples (1)** **Gauges (1)**	**------>** **Mirrors (3)** **---------------->**	**Windows (2)** **Fiberoptics (2)** **Optical comp-onents ? (2)** **Vacuum-diag. Detectors? (1)**	

Numbers are approximate and average

Radiation Effects on Diagnostic Components

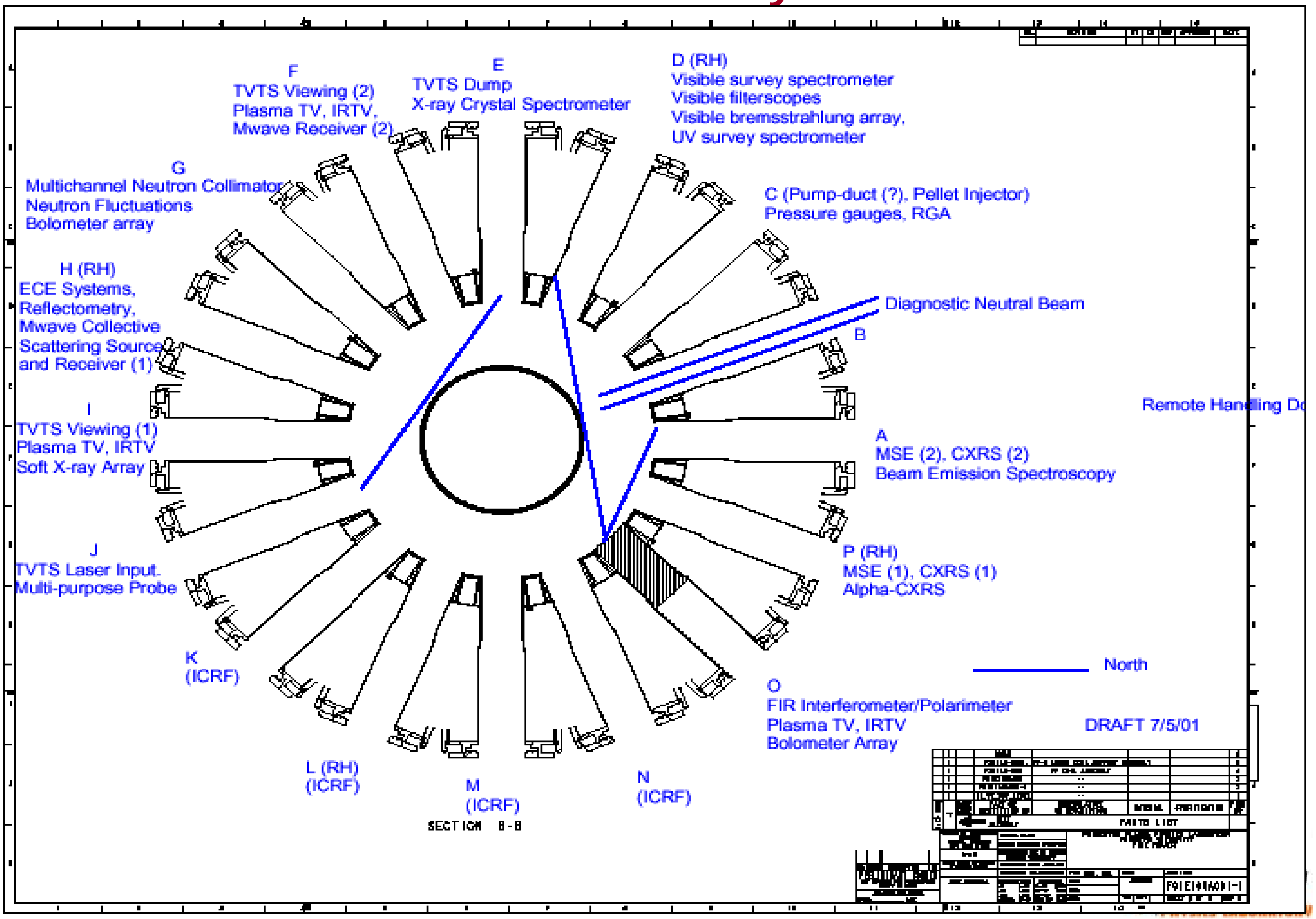
- **Diagnostic Component   Worst Radiation Problem**

- **Ceramics (and Detectors)   Electrical (RIC, RIED, RIEMF)**
  - **RIC, and potentially RIEMF, are most severe issue for ceramics and MI cable used in magnetic diagnostics**
- **Fiberoptics (and Windows)   Absorption, Luminescence, Numerical aperture**
  - **Developments of new doped fibers in progress for reducing absorption,**
  - **Luminescence problem for low-light level signals.**
- **Mirrors   Mechanical + Neutrals in Surface Modification (near first wall)**
  - **Studies of surface damage impact and of surface preparations in progress.**

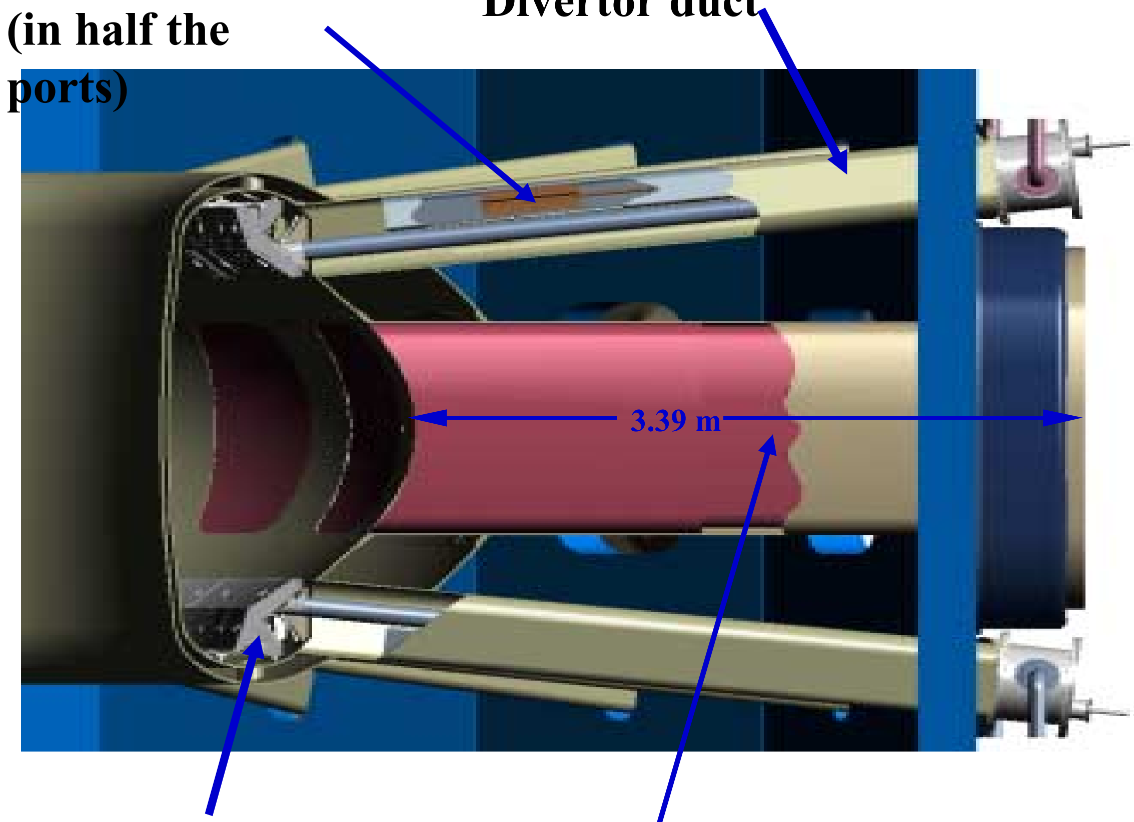
Radiation Effects on Optical Systems

- Radiation discolors/blackens optical components,
- Hence must use reflective optics in high-radiation areas.
- Optical fibers suffer from:
  - Prompt luminescence,
  - Prompt absorption,
  - Long - term absorption damage,
  - Effective change in numerical aperture.
- Running fibers hot only controls the long-term absorption.
- Great disparity in radiation effects on nominally identical fibers.

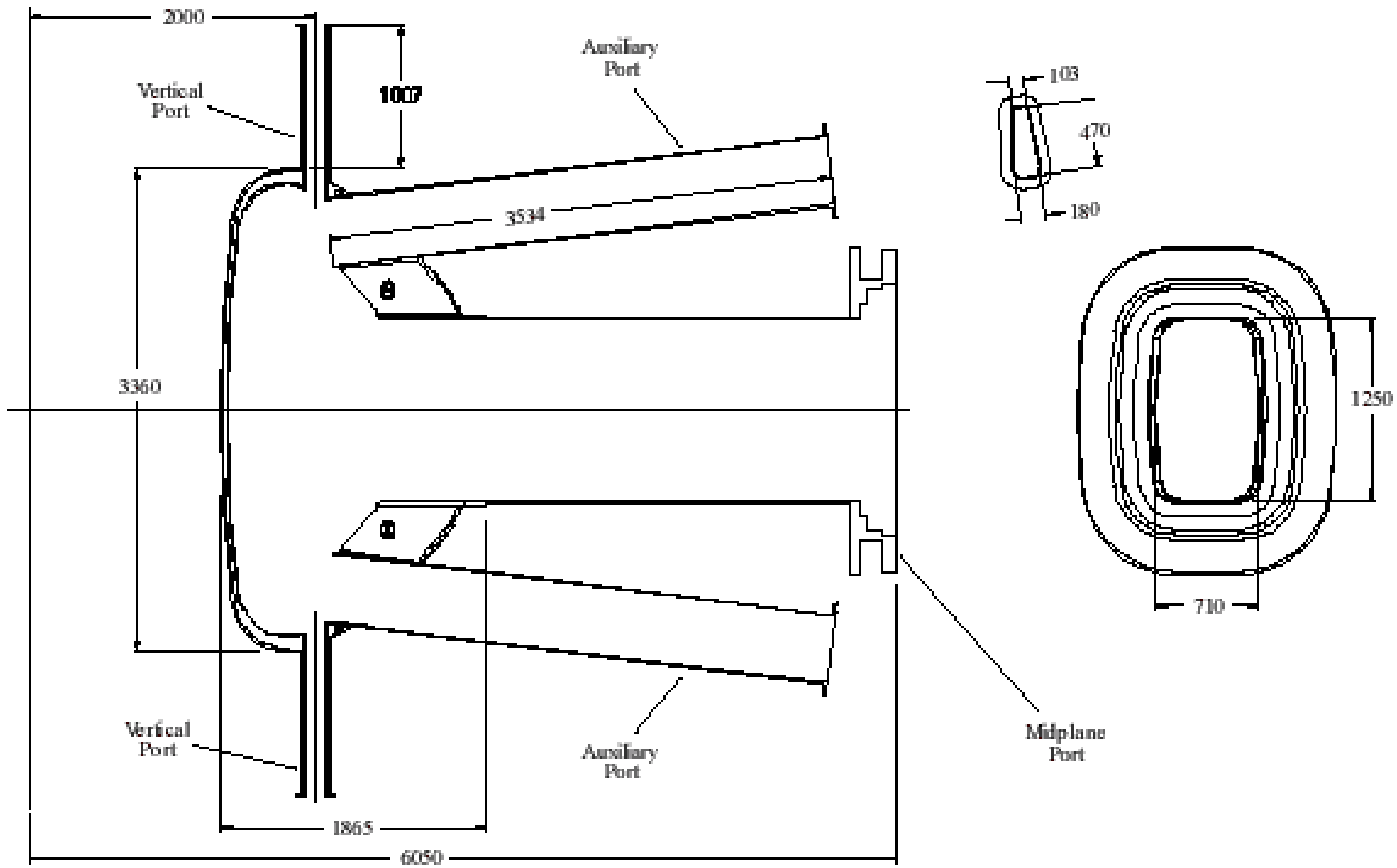
Possible Radial Port Layout for FIRE



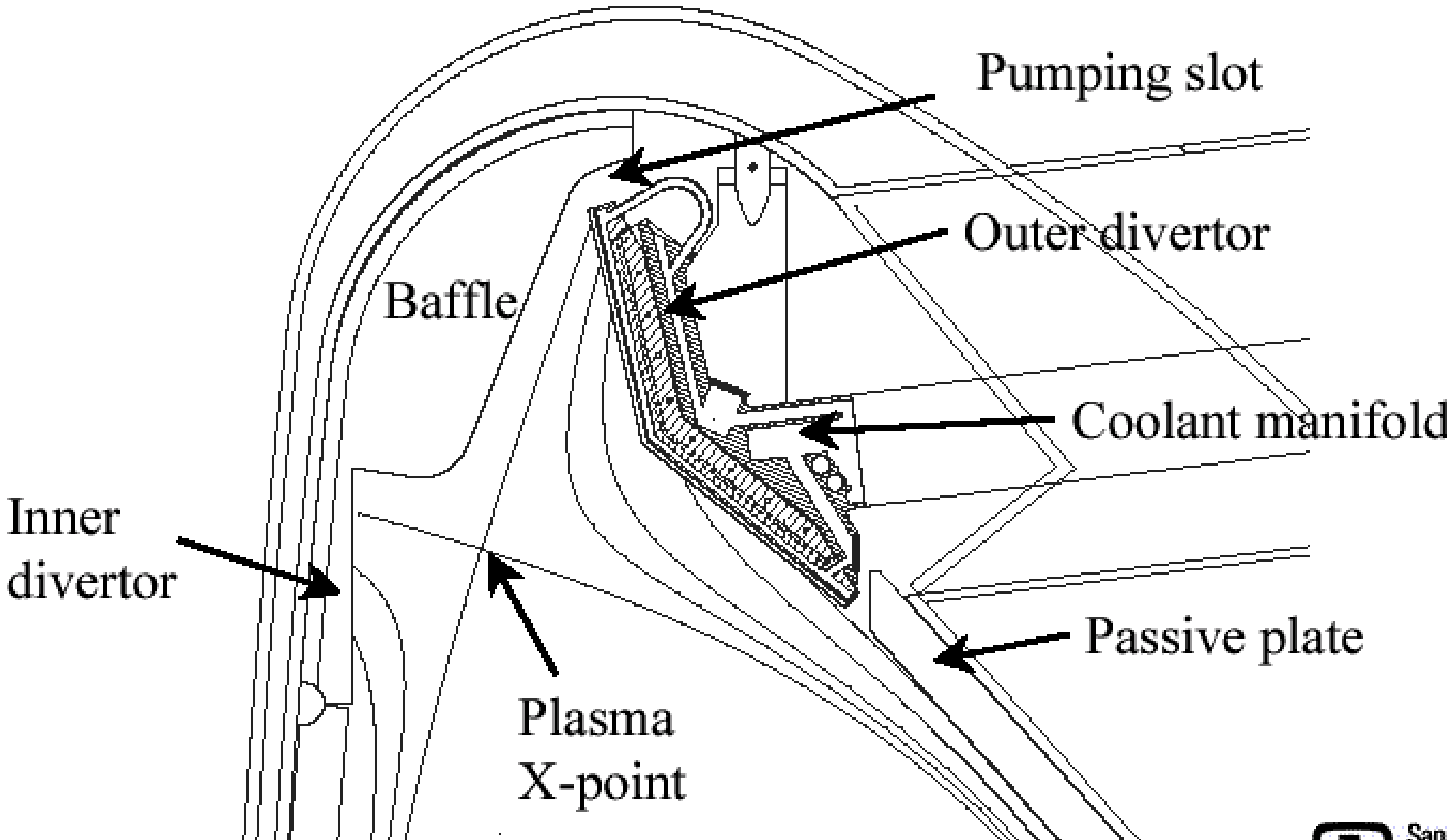
FIRE Port Configuration



Vessel port configuration



FIRE Divertor Design



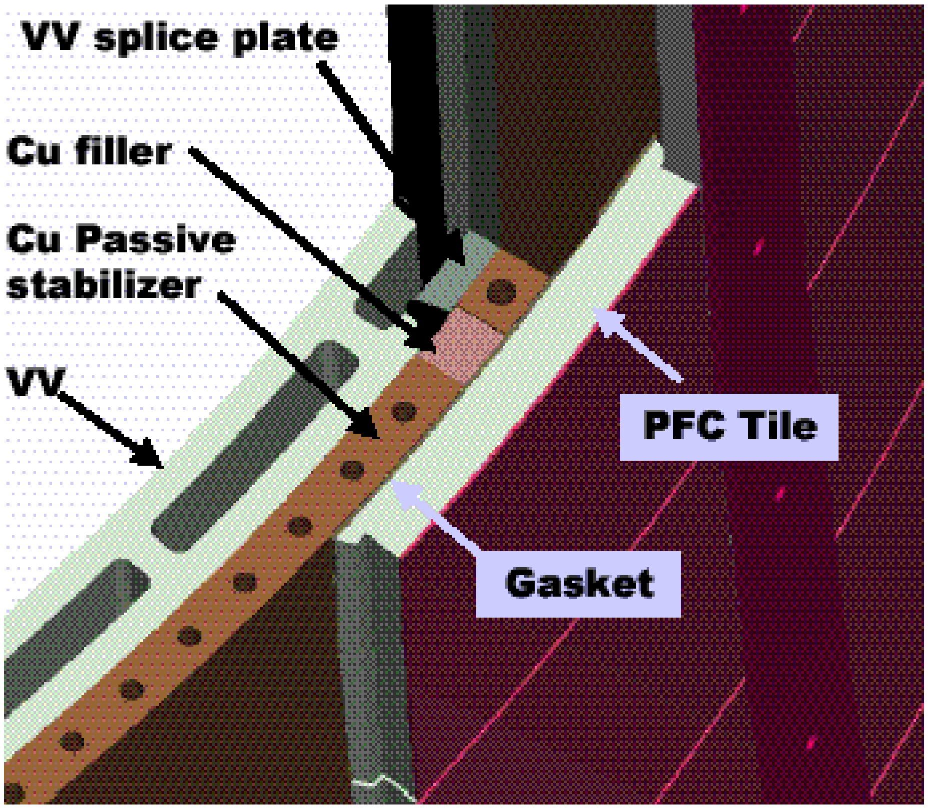
Diagnostic Integration Design Issues

- It is essential to carry diagnostic design along with other in-vessel system designs:
  - Magnetic diagnostics have specific integration needs with the first wall.
  - Sightlines through and past the divertor must be assured (3cm poloidal slot possible by removing row of tungsten brushes; >5cm toroidal gap possible between outer divertor and passive tiles; 5 cm x 15 cm slot in outer divertor to match top port sought.
  - Diagnostic "plugs" for all ports assure diagnostic operation and limit external radiation levels.
  - Potential interferences with water piping for divertor and first wall.

Magnetic Diagnostics: Design Issues

- Loops, coils, MI-cable must be inside vacuum vessel,
- Maximally unfriendly environment; RIC and RIEMF, temperature, neutral particles,
- Very limited space behind tiles will require grooves to be cut in tiles, cladding,
- There are potential poloidal locations at vessel segment boundaries
- R&D support for design essential.

Passive conductor is also heat sink



- **Copper layer required to prevent large temperature gradients in VV due to nuclear heating, PFCs**
- **Passive plates are required in most locations anyway**
- **PFCs are conduction cooled to copper layer**
  - Reduces gradient in stainless skin
  - Extends pulse length

Thoughts from UFA Burning Plasma Science Workshop II

- The small size, high field, high density FIRE plasma does provide some measurement difficulty relative to the ITER-FEAT device.
- The determination of the spatial resolution required for some measurements has to await some conceptual design. Even "standard" measurements like n_e and T_e may not meet requirements for ITBs.
- A diagnostic beam is essential for control and physics: profiles of q, ion temperature, rotation, He-ash, slowing-αs, and possibly E_r require it. A short pulse beam does not permit BES fluctuation measurement.
- Microwave scattering has been adopted for measurement of confined-αs: TEXTOR data shows promise. Development of new techniques should be encouraged.
- Development of a technique for measuring the escaping-αs is necessary; test should be done on JET-EP.
- Polarimetry for support of core q measurements is not possible, but edge-q using polarimetry of a Li-beam may be possible.

COMMENTS ON THE FEASIBILITY OF DIAGNOSING THE DIFFERENT BPX OPTIONS (HIGH FIELD TOKAMAK (IGNITOR, FIRE) AND ITER)

Aspect	ITER	IGNITOR/FIRE
Access - upper - mid-plane - divertor	Upper: Good Mid-plane: Good Divertor: Poor	Upper FIRE: Probably good at upper ports but poor in vertical ports. IGNITOR ? Mid-plane: Good but long narrow ports can limit spatial coverage Divertor (FIRE) Poor
Radiation effects - prompt - longterm (ie dose)	Potentially serious: careful choice of materials and component testing essential. It is believed that solutions exist for most of the required systems.	Prompt effects worse because of much higher (x 60 – 600) neutron flux at diagnostic sensors. Exact situation unknown.
Lifetime of key components	ditto	Dose effects much less but basically unknown.

8 top and bottom outer ports shared with divertor cooling

Problem is to have sufficient shielding

True

Comment is correct but increase in dose rate is only ~ x 5. Much further shielding will be needed for diagnostics outside the vacuum vessel

Lifetime issues should be minimal, with proper component selection.

(continued)

Aspect	ITER	IGNITOR/FIRE	
Maintainability	Techniques have been developed	Needs to be designed. Some elements may be transferable from ITER	**Clearly correct**
Neutron Streaming	It has been shown that adequate screening can be achieved but impacts the number of systems that can be installed per port.	Needs to be designed along with the shielding for the basic machine. Should not be considered as an 'add-on'.	**Agreed; more difficult without blanket**
Diagnostic Neutral Beam	Design developed based on heating beam and performance of Active CXRS established.	No DNB hence no Active CXRS. Serious loss of measurement capability. Eg no He ash measms.	**~125 keV/amu beam is required**
Integration	Preliminary integration complete at all three levels. Most of necessary systems (> 90%) are accommodated	Needs to be designed in conjunction with the design of other relevant machine systems	**Agreed**

Summary from Diagnostics Break-out Session at BPS Workshop II

CONCLUDING REMARKS

1. Advanced diagnostics are the window for physics understanding of fusion plasmas

2. The challenging environment of a BPX requires detailed advanced planning of diagnostics into the machine design

3. ITER has developed a fully integrated diagnostic set closely linked to the defined measurement requirements and the other tokamak systems.   FIRE and IGNITOR need to do so.

4. It is essential that we continue (in the case of the US restart!) the design and R&D on the identified problem areas. In some cases many years will be required to solve the problems and it is misleading at least to talk about the information and knowledge that will be gained from a BPX while key diagnostic problems remain unsolved.

DRAFT R&D Proposals

- Irradiation Tests of Materials
  - Evaluation of radiation-induced conductivity (RIC) in selected ceramics and MI cable to define design materials
    - Test coil ceramics to FIRE first-wall flux levels and temperatures,
    - Test MI cable in realistic configurations.
  - Determine cause of radiation-induced emf (RIEMF) with MI cables to prevent signal pollution by significant DC offsets (continuing work involving ORNL) .
  - Evaluation of electrical connection techniques for remote handling and insulation properties.
  - Test selected optical fibers for performance in realistic radiation environment at relatively low light-signal levels (continuing work being done for ITER) .
- Development of New or Improved Diagnostic Techniques
  - Develop an Intense Diagnostic Neutral Beam: specification ~125 keV/amu, $1x10^6$ A/m^2 in a cross-section of 0.2m x 0.2m at the plasma edge for 1 μsec at 30 Hz repetition rate (LANL started development for ITER R&D) .
  - Complete demonstration of fast-wave reflectometry for measuring hydrogen isotope ratios in the core (continuing work started by GA for ITER) .
  - Extend the operational range of Faraday-cup based and scintillator-based escaping-α diagnostics to FIRE parameters (U.Colorado/PPPL program through JET) .
  - Seek new technique for measuring the confined fast-alphas.

DRAFT R&D Proposals (continued)

- Development of New Components
  - Continue development of small rad-hard high-temperature magnetic probes based on integrated-circuit manufacturing techniques.
  - Develop a prototype "plug" to incorporate required tolerances, alignments, assurance of ground isolation, actuation of shutters, etc.
  - Evaluate metallic mirror performance and effects on reflectivity of neutral particle bombardment and nearby erosion (ongoing ITER R&D activity).