FIRE Diagnostics (Snowmass)

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INTRODUCTION

- FIRE at pre-conceptual design level.
- ~1/4 ppy physics effort on diagnostics, no engineering:
  - Depend on ITER/ CIT experience,
  - Significant engineering design and integration required to demonstrate feasibility.

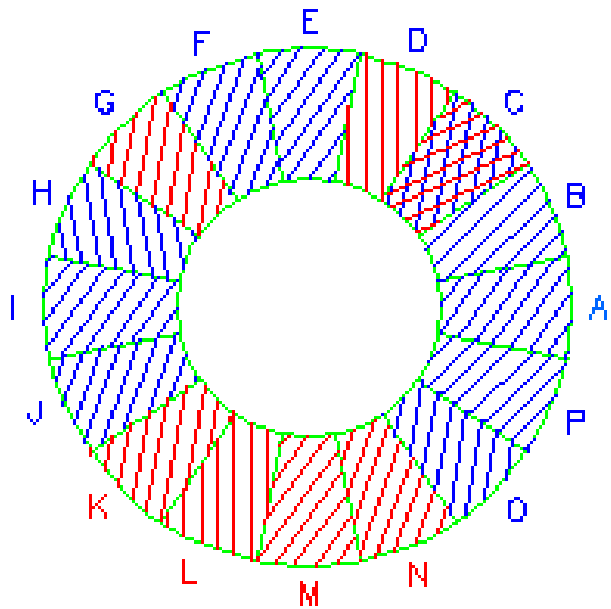
- Talk will address aspects of FIRE diagnostics,
  - Alpha-particle techniques.

Fire Measurement Specifications (Draft: 1/16/02)

(prepared in style used by ITER Group)

MEASUREMENT	PARAMETER	CONDITION	RANGE or COVERAGE	ΔT or ΔF	ΔX or Δk	ACCURACY
1. Plasma Current	I_p	Default	0 – 1 MA	1 ms	Integral	10 kA
			1 - 8.0 MA	1 ms	Integral	1 %
		I_p Quench	8.0 – 0 MA	0.1 ms	Integral	30 % + 10 kA
2. Plasma Position and Shape	Main plasma gaps, Δ_{sep}	I_p > 1 MA, full bore	-	10 ms	-	0.5 cm
		I_p Quench	-	1 ms	-	1 cm
	Divertor channel location (r dir.)	Default	-	10 ms	-	0.5 cm
		I_p Quench	-	1 ms	-	1 cm
	dZ/dt of current centroid	Default	0 – 100 m s^{-1}	0.1 ms	-	0.05 m/s (noise) + 3% (absolute)
3. Loop Voltage	V_{loop}	Default	0 – 30 V	1 ms	4 locations	5 mV
		I_p Quench	0 – 500 V	0.1 ms	4 locations	10 % + 5 mV
4. Plasma Energy	β_p	Default	.01 – 1	1ms	Integral	5 % @ β_p =1
		Thermal Quench	.01 – 1	0.1 ms	Integral	~ 30 %
5. Radiated Power	Main Plasma P_{RAD}	Default	TBD –.2 GW	10 ms	Integral	10 %
	X-point / MARFE region P_{RAD}	Default	TBD – 0.2 GW	10 ms	Integral	10 %
	Divertor P_{RAD}	Default	TBD – 0.2 GW	10 ms	Integral	10 %
	Total P_{RAD}	Disruption	TBD – 20 GW	1 ms	Integral	20 %
6. Line-Averaged Electron Density	$\int n_e\, dl / \int dl$	Default	$1\cdot10^{18} – 1\cdot10^{21}$ m^{-3}	1 ms	Integral	1 %
		After killer pellet	$8\cdot10^{20} – 2\cdot10^{22}$ m^{-3}	1 ms	Integral	100 %
7. Neutron Flux and Emissivity	Total neutron flux		$1\cdot10^{14} – 1\cdot10^{20}$ ns^{-1}	1 ms	Integral	10 %
	Neutron / α source		$1\cdot10^{14} – 5\cdot10^{18}$ $nm^{-3}s^{-1}$	1 ms	a/10	10 %
	Fusion power		0.01 – 0.25 GW	1 ms	Integral	10 %
	Fusion power density		0.1 - 20 MW m^{-3}	1 ms	a/10	10 %
8. Locked Modes	B_r(mode)/B_p		$10^{-4} – 10^{-2}$	1 ms	(m,n) = (2,1)	30 %
9. Low (m,n) MHD Modes, Sawteeth, Disruption Precursors	Mode complex amplitude at wall		TBD	DC – 10 kHz	(0,0) < (m,n) < (10,2)	10 %
	Mode – induced temperature fluctuation		TBD	DC – 10 kHz	0,0) < (m,n) < (10,2) Δr = a /30	10 %
	Other mode parameters		TBD	DC – 30 kHz	Integral	10 %

FIRE Diagnostics:
Radial Port Assignments



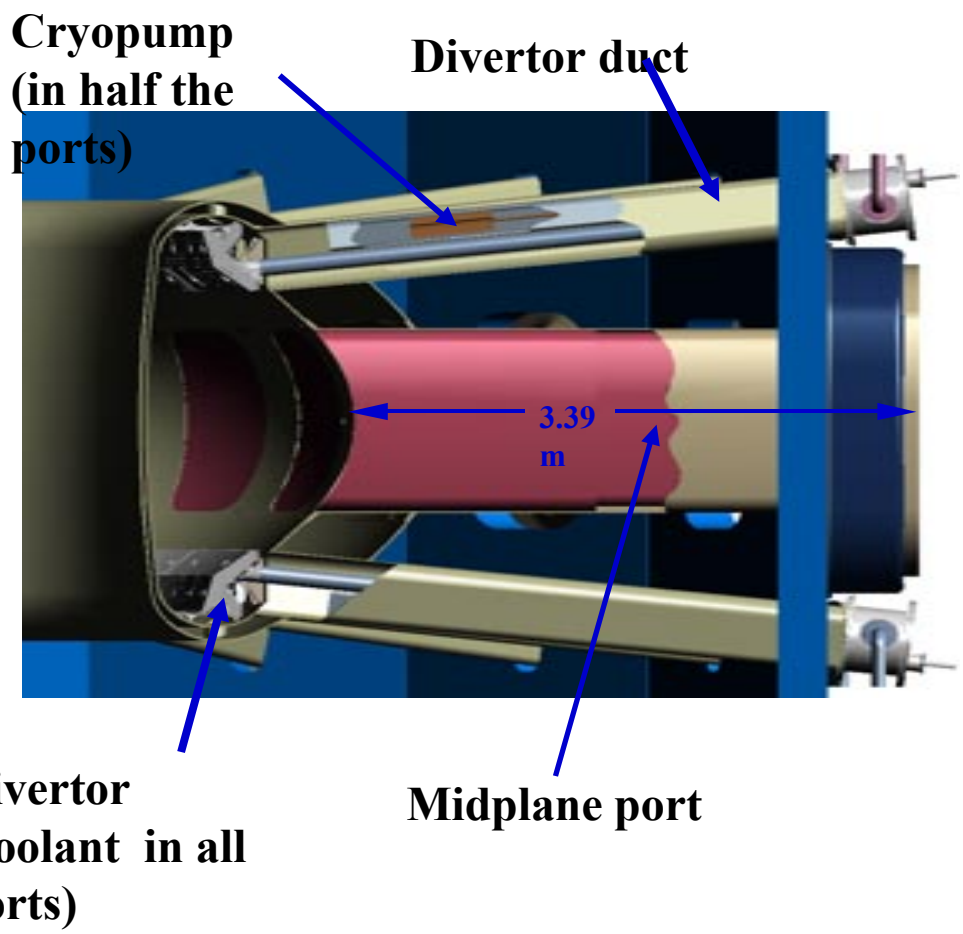
Blue: Diagnostics Components
Orange: Diagnostics-provided Services
Red: Auxiliary Systems
Green: Services

A: MSE (2),
CXRS (2),
Beam Emission Spectroscopy,
Lost-α System
B: Diagnostic Neutral Beam
C: Pump Duct,
Pellet Injector,
UV Survey Spectrometer,
X-ray Crystal Spectrometer,
X-ray PHA,
Ion Gauges,
RGA
D: ICRF/LH Launcher
E: Neutron Camera,
Neutron Fluctuation Detectors
Bolometer Array
Hard X-ray Detector
TVTS Dump
F: TVTS Detection
Plasma TV,
IR TV,
MM-wave Receiver
G: ICRF/LH Launcher
H: ECE Systems,
Reflectometers,
MM-wave Collective Scattering Source and Receiver,
Magnetics Wiring

I: TVTS Detection,
Plasma TV,
IRTV
Soft X-ray Array
J: TVTS Laser,
Pellet Charge Exchange,
Li-Pellet Injector,
Hard X-ray Detector
Synchrotron Rad. Detector
K: ICRF Launcher
L: ICRF Launcher
M: ICRF Launcher
N: ICRF Launcher
O: FIR Interferometer/ Polarimeter,
Plasma TV,
IR TV,
Bolometer Array
P: MSE (1),
CXRS (1),
Visible Survey Spectrometer,
Visible Filterscopes,
Visible Bremsstrahlung,
α-CHERS

Diagnostic Use of FIRE Ports

- Design goal of device is to limit radiation outside dewar so that access is possible within few hours.
- Design philosophy for diagnostic installation must be same as for ITER.
- Neutronics calculations made with 1.1 m shield plugs. Radiation levels at outer end similar to those for ITER.
- Most diagnostics must be designed with labyrinths with 4 90°bends to reduce streaming ~4 orders of magnitude.
- Integration with divertor components in upper and lower ports to be worked out.



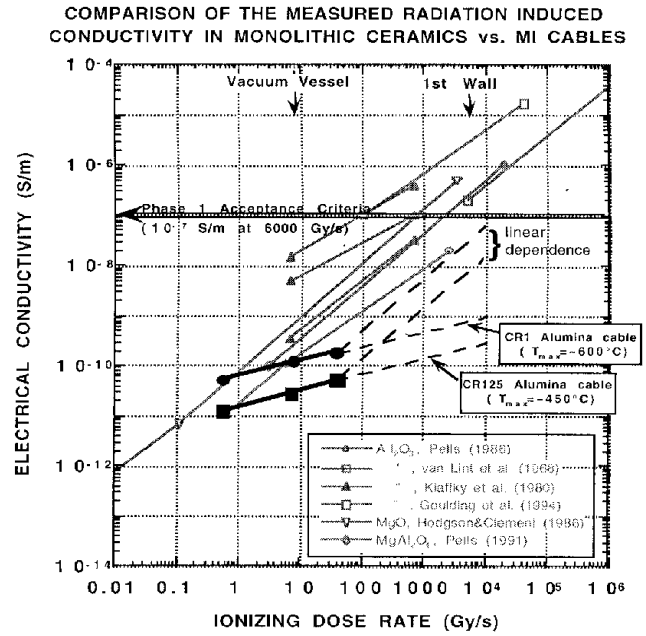
Radiation Effects on Diagnostic Components

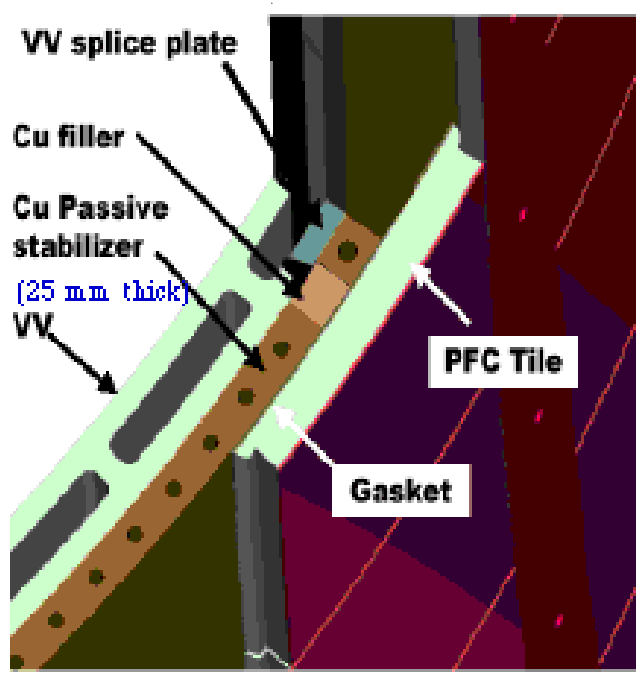
- **Diagnostic Component** **Worst Radiation Problem**

- **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.**
  - **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.**

Magnetic Diagnostics: Issues

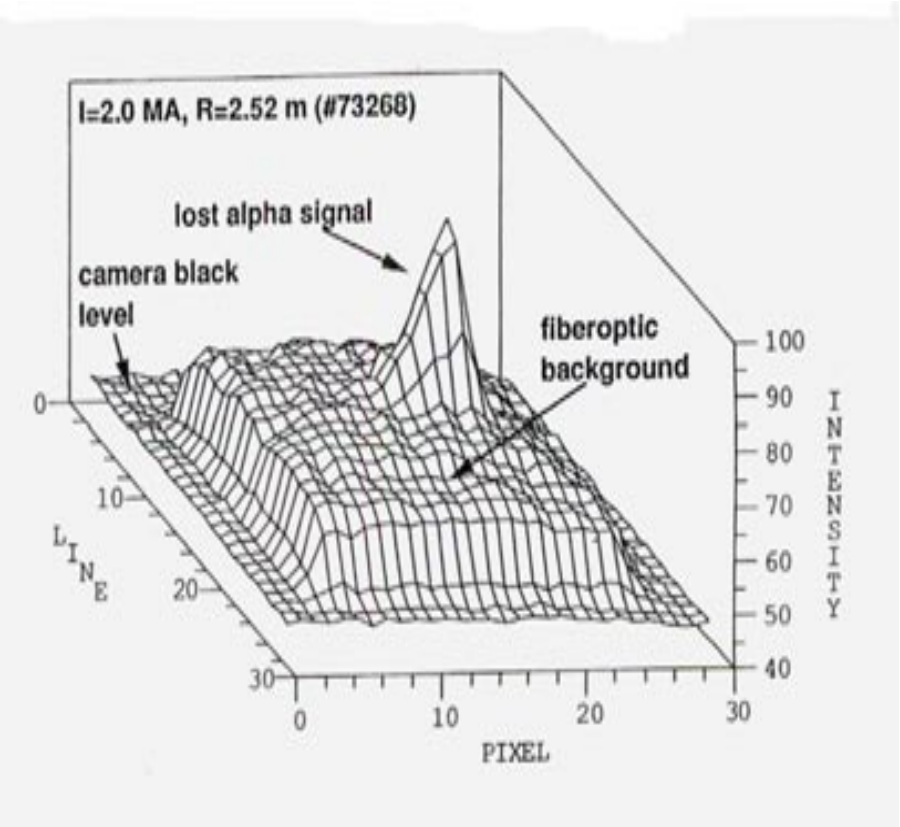
- Loops, coils, MI-cable must be inside vacuum vessel
  - Mineral-insulated cable and electrical connections are concern.
- RIC and RIEMF, temperature, neutral particles.
- Nuclear heating of alumina of coils ~ 30 Wcm^{-3}.
- Very limited space behind tiles;
  - need grooves in tiles, cladding,
  - need clear space between coils and copper .
- Slots must be cut in copper to allow field penetration.





Impact of Radiation-induced Luminescence (and absorption) on Measurement

- Lost-α diagnostic on TFTR with fiberoptic outside vacuum vessel.
- TFTR shot at 5MW ($5x10^{-2}$ MW/m^2 at first wall.
- Dose at front end of fiber (in shielding) ~ 30 Gy/s.

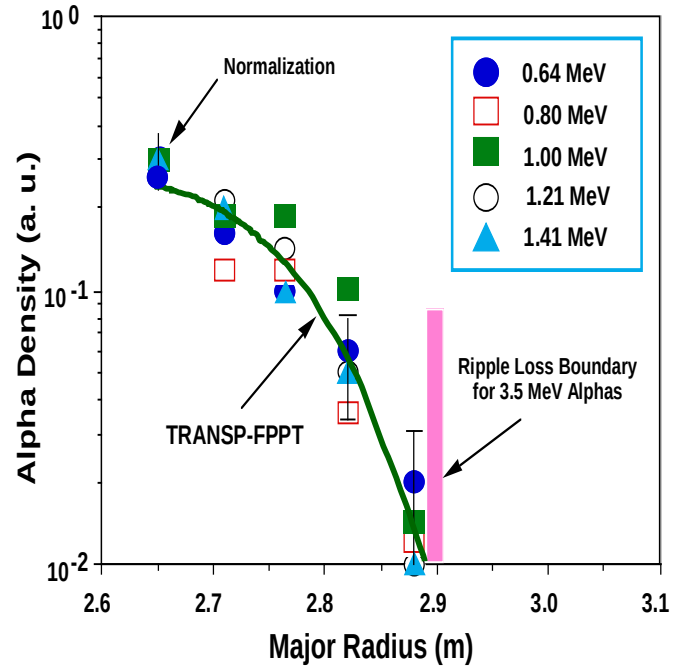


Signal observed from scintillator/fiberoptic during TFTR D-T; "pedestal" is radiation-induced fluorescence (D. Darrow)

Possible Diagnostics for Alpha-Particle Physics

- Upgraded and additional techniques required relative to TFTR
- Confined α-particle diagnostics (Development required).
  - α-CHERS,
  - Pellet charge-exchange (PCX) for radial distribution,
  - Collective scattering (μwave?, CO_2?, FIR?),
  - Knock-on neutron,
  - New confined-α detector???
- Escaping fast-ion detectors and IR camera,
- Mirnov coils, reflectometry, BES for high-frequency mode studies.
- Tests on JET-EP essential.

TFTR



- PCX measurement of the trapped alpha density profile in an MHD-quiescent supershot.
- Only the trapped alphas born inside the stochastic ripple boundary for E_α = 3.5 MeV are confined and can slow down to produce the measured profiles.

Fisher et al.

Evaluation of FIRE Diagnostics:

R&D Required

- Irradiation Tests of Materials
  - Evaluate radiation-induced conductivity (RIC) in selected ceramics and MI cable to define design materials.
  - Determine cause of radiation-induced emf (RIEMF) with MI cables to prevent signal pollution by significant DC offsets.
  - Develop and evaluate 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.
- 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 micro;sec at 30 Hz repetition rate.
  - Extend the operational range of Faraday-cup based and scintillator-based escaping-α diagnostics to FIRE parameters.
  - Seek new technique for measuring the confined fast-αs.
- Development of New Components/Techniques
  - Continue development of small rad-hard high-temperature magnetic probes based on integrated-circuit manufacturing techniques.
  - Evaluate metallic mirror performance and effects on reflectivity of neutral particle bombardment and nearby erosion (ongoing ITER R&D activity).

Development of High Power Pulsed Beam is Necessary

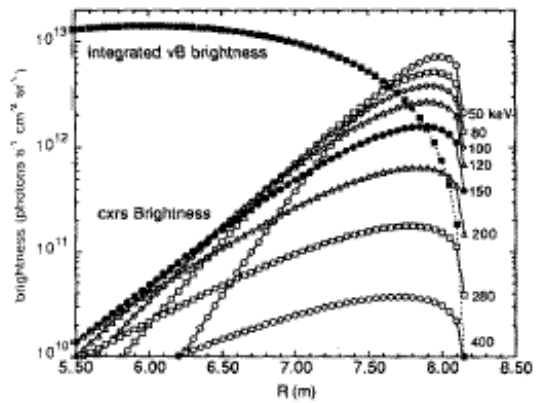
- Spectroscopic diagnostics for measurement of $Ti_{(}r)$, v(r), q(r), $\delta n_e(r)$(by BES) all depend on a neutral beam.

  -Conventional beam provides very little signal from plasma core. Very low signal compared to visible bremsstrahlung.

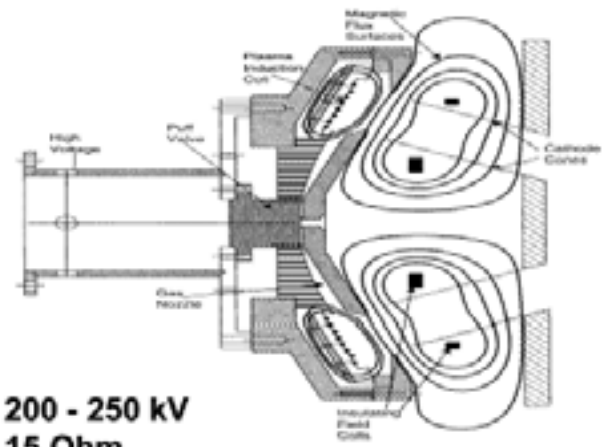
- Need to develop high-power pulsed beam:

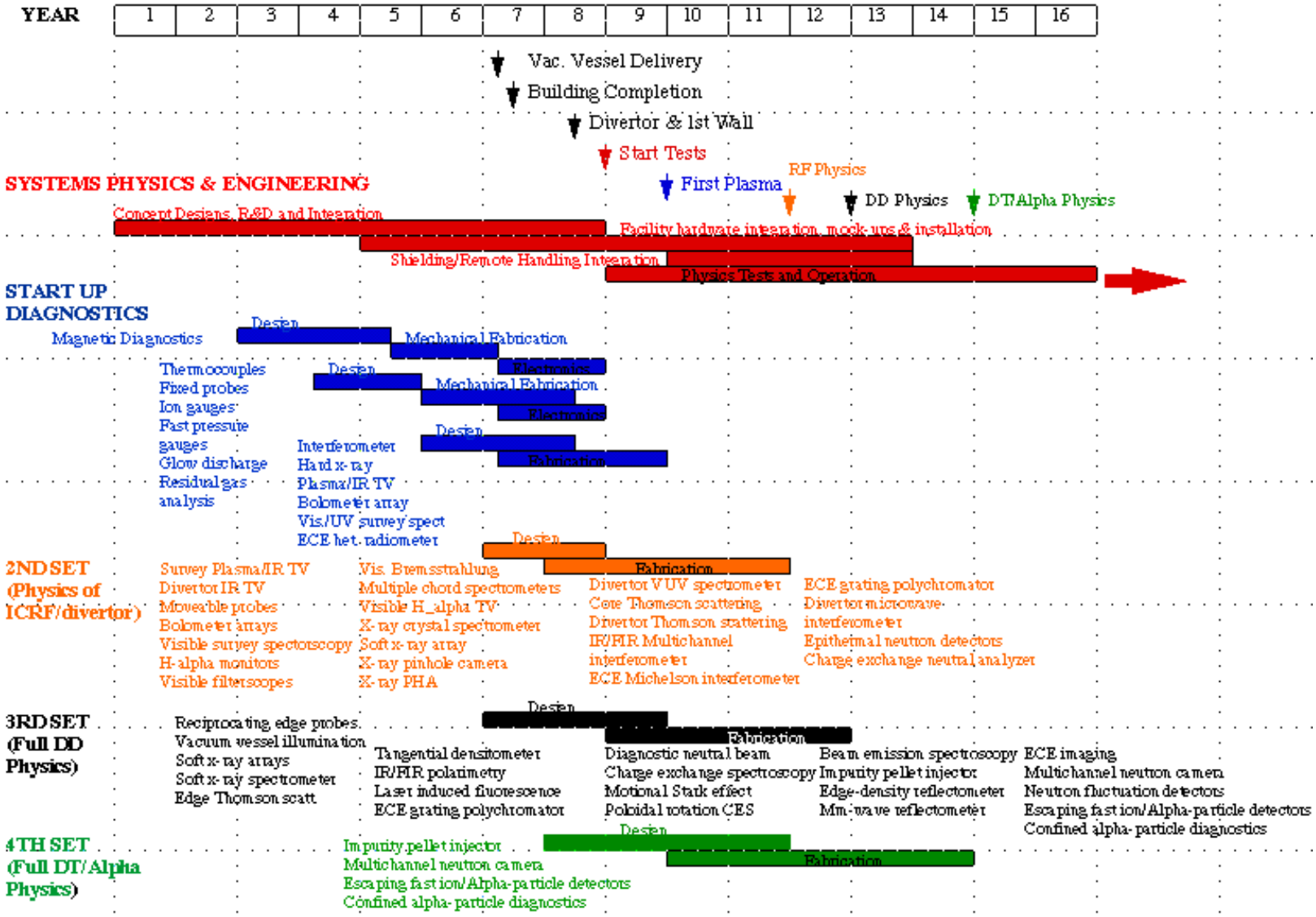
  100 keV/amu,
  1 MAm^{-2} in 0.2 x 0.2 m^2,
  30 Hz repetition rate.

  - Development program at LANL, based on technology developed for a high average-power microsecond pulser (Wurden et al.)
  - Development needs funding..



Schilling and Synakowski, Rev. Sci. Instrum. **63** (1992) 4937 -- 1 A/cm²



200 - 250 kV
15 Ohm
1 μs

FIRE Diagnostics Schedule (Rev 0; Sept 1999)