Status of NCSX Diagnostic Preparations

David Johnson

December 9, 2002

1. Review of plan phasing diagnostics with research program
   - Changes since last PAC meeting
2. Diagnostics tasks in preparation for upcoming PDRs
   - Identify space envelopes for in-vessel sensors and ex-vessel magnetic (sensors not housed in diagnostic ports).
   - Identify optimized diagnostic port orientations for integration into vacuum vessel design. Show several examples.
   - Refine port allocation plan
3. Infrastructure for diagnostics
4. Other integration activities

Planned Diagnostics Phased with Research

1. Initial Operation (150° C bake, GDC)		
I_p	Roqowski coils	Baseline
conductivity	flux loops + Ip	
boundary position and shape	magnetics + 3-D EFIT	
total stored energy	diamagnetic loop	
image of plasma/wall	video cameras with filters	
$n_e l$	1 mm interferometer	
2. Field Mapping (no plasma)		
vacuum flux surfaces	e-beam probe + fluorescent rod/screen probe + high dyn. range CCD camera	
3. Ohmic (3 poloidal limiters)		
n_e profile	FIR interfer./ polarim., Thomson scattering	
T_e profile	Thomson scattering	
T_i profile	imaging X-ray crystal spectrometer	
P_{rad} profle	core foil bolometer array	
low (m,n) MHD modes	multiple compact SXR arrays	
magnetic axis position	comp. SXR arrays + 3-D EFIT	
impurity identification	visible spectrometer	
impurity concentration	abs. UV spectroscopy	
Z_{eff} profile	use Thomson scattering system	
hydrogen recycling	filtered 1D CCD camera	

Planned Diagnostics (Cont'd)

4. Initial Aux. Heating (3 MW NBI, PFCs, bake)	
T_i,v_θ,v_ϕ profiles	DNB+toroidal, poloidal CHERS
iota profile	DNB+MSE polarim.+ 3-D EFIT
higher (m,n) MHD modes	additional compact SXR arrays
flux surface topology	tang. x-ray camera + 3-D EFIT
fast ion loss	fast ion loss probe
ion energy distribution	neutral particle analyser
neutron flux	epithermal neutron detector
high frequency MHD(<5Mhz)	high frequency Mirnov coils
first wall temperature	compact IR camera
SOL T_e and n_e	movable Langmuir probe
edge neutral pressure	fast gauges
5. Confinement & β Push (6 MW NBI, full div.)	
divertor Prad profile	divertor bolometer arrays
divertor plate temperature	fast IR camera
target T_e, n_e	plate mounted Langmuir probes
core n_e fluctuations	fluctuation diagnostics (TBD. HIBP?)
SOL/edge T_e and n_e	fast scanning edge probe
core helium density	DNB + He CHERS system
divertor target temperature	divertor thermocouples
divertor recycling	divertor filtered CCD camera
divertor impurity conc., flows	divertor UV spectroscopy
6. Long Pulse (pumped divertor)	
divertor T_e, n_e profiles	divertor Thomson scattering

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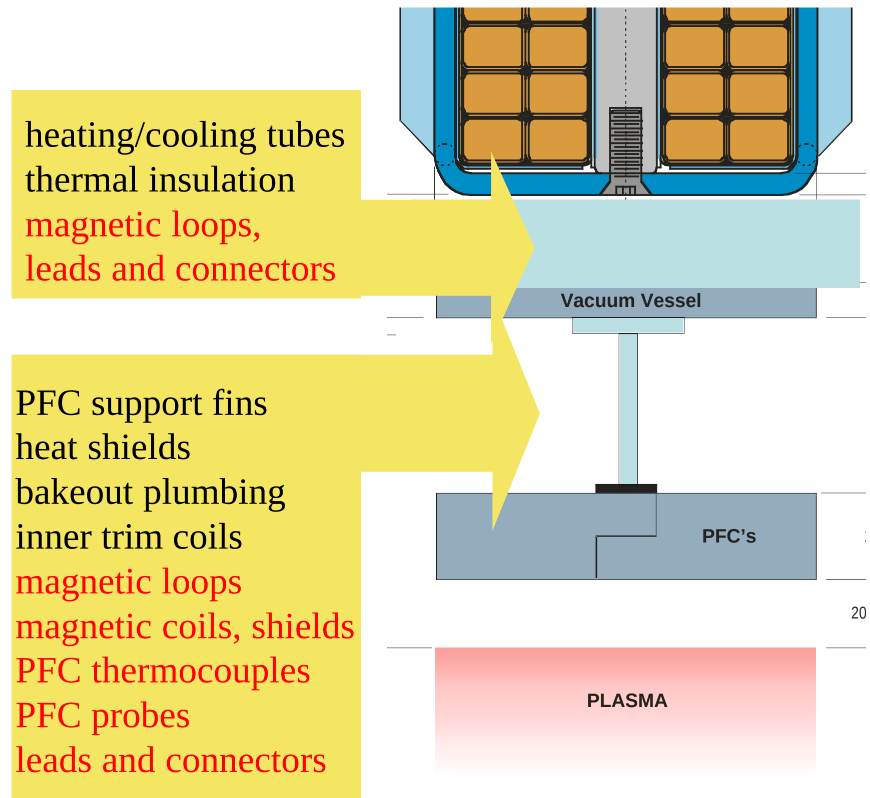
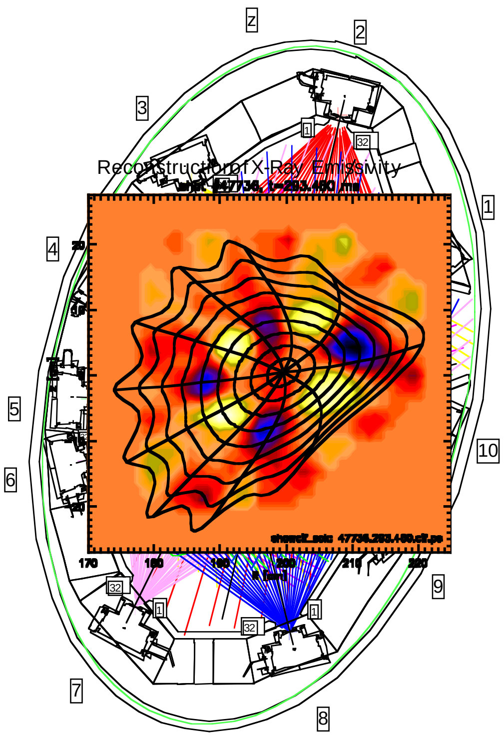
Space for Magnetic Sensors

- Clearances on the inside (~5 cm) and outside (~2.5 cm) surfaces of the vessel appear adequate for magnetic sensors with CDR design.
- May change with new vessel design.
- Robust sensor loops need to be in place on outside of vessel and on modular coils before assembly.

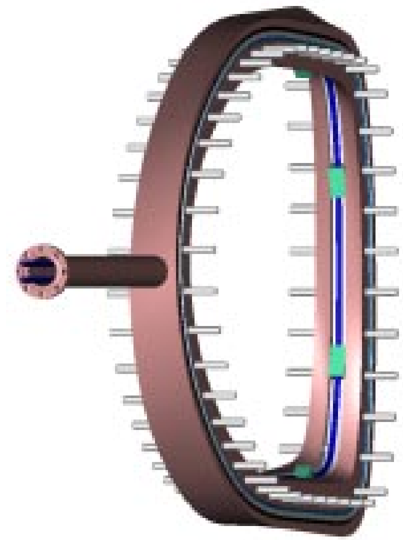


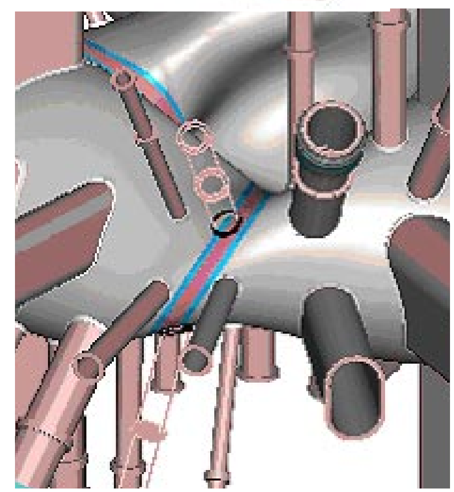
Space for X-ray Tomography Arrays



W7-AS

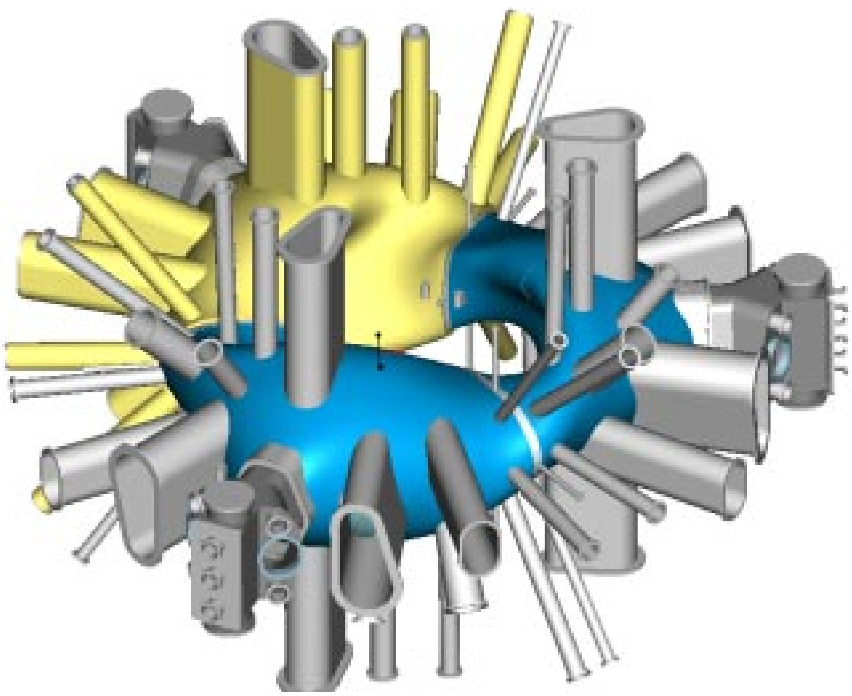
- For adequate coverage, need to install compact arrays between the first wall and the vessel, as shown at left for W7-AS.
- Currently, there is not a design that is compact enough to fit within the 50 mm space between PFCs and the inside of vessel.
- Tomography is best done near the bullet x-section where the plasma is least elongated, and can be viewed from all sides.
- Once design of slanted wedge to facilitate machine assembly is more mature, will revisit feasibility of camera integration.





Another Urgent Task is to Optimize Port Orientations

- Port extensions in existing designs:
  - lie in radial planes
  - have axes which are in line with magnetic axis
  - have uniform cross-section
  - have lengths defined by cryostat outer boundary
- These constraints could be relaxed to improve diagnostic access.
- This should be done with specific diagnostics in mind.
- This task is complicated since reorienting one port generally affects five others. (to preserve stellarator symmetry)



Plan for Optimizing Port Orientations

1. Prioritize diagnostics according to 1) sensitivity to specific geometry, 2) required viewing aperture, and 3) required field of view.
    - Examples of high priority diagnostics:

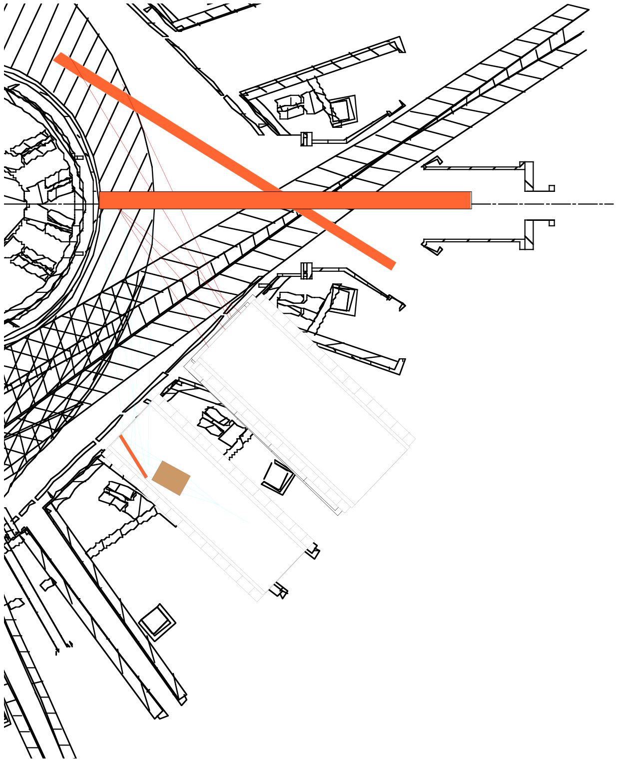
Thomson scattering	MSE	Toroidal CHERS	Poloidal CHERS
Multichord FIR interferometry/ polarimetry	E-beam probe	Imaging x-ray crystal	Tangential x-ray pinhole camera

2. Propose layouts to diagnostic experts, possibly with reoriented ports.
3. Once layout accepted by experts, input port orientation to vacuum vessel designers, who will assess feasibility. Iterate on 2 and 3
4. Consider impact on other diagnostics that may use similar ports. Iterate 2 - 4.

- Currently on step 2 for several diagnostics.
    - Steps 3 and 4 to occur Jan., Feb. 03

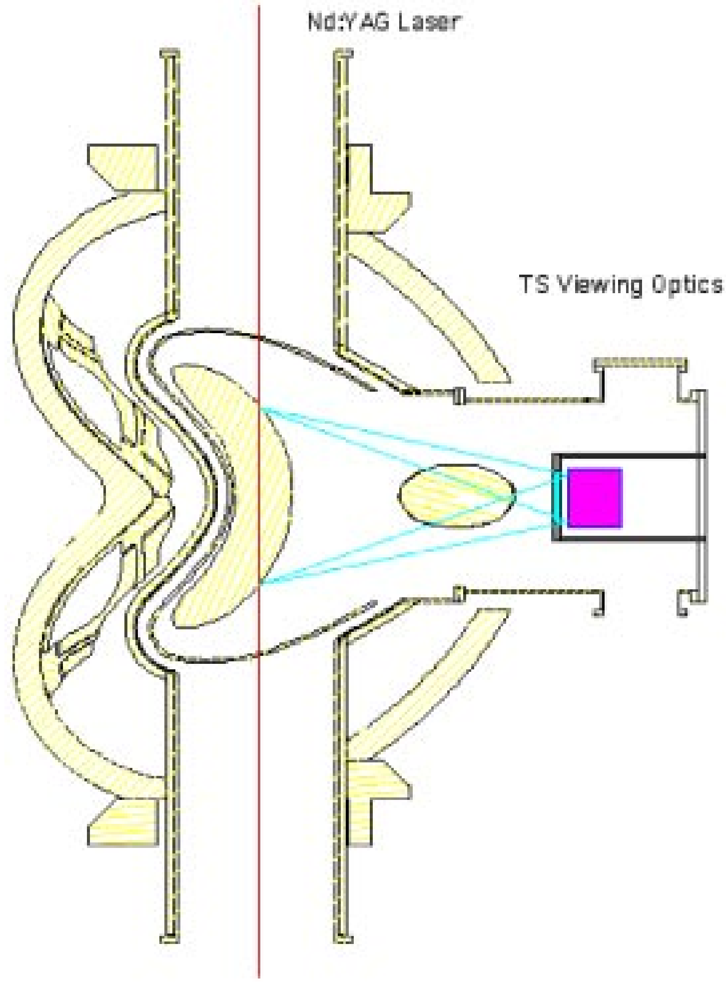
Port Reorientation to Optimize Active Spectroscopy

- There are no views of NCSX heating beams which can provide high spatial resolution for active spectroscopy.
- A DNB will be necessary for active spectroscopy.
- High throughput views of the DNB with sightlines tangent to flux surfaces are necessary for good spatial resolution.
- In this concept, CHERS and MSE would share a view of the DNB using a large reoriented port.
- The same type of port could be used to provide very high throughput for a Thomson scattering view of a vertical beam at the symmetry plane.
- The reoriented port actually has a more normal connection with the vessel.



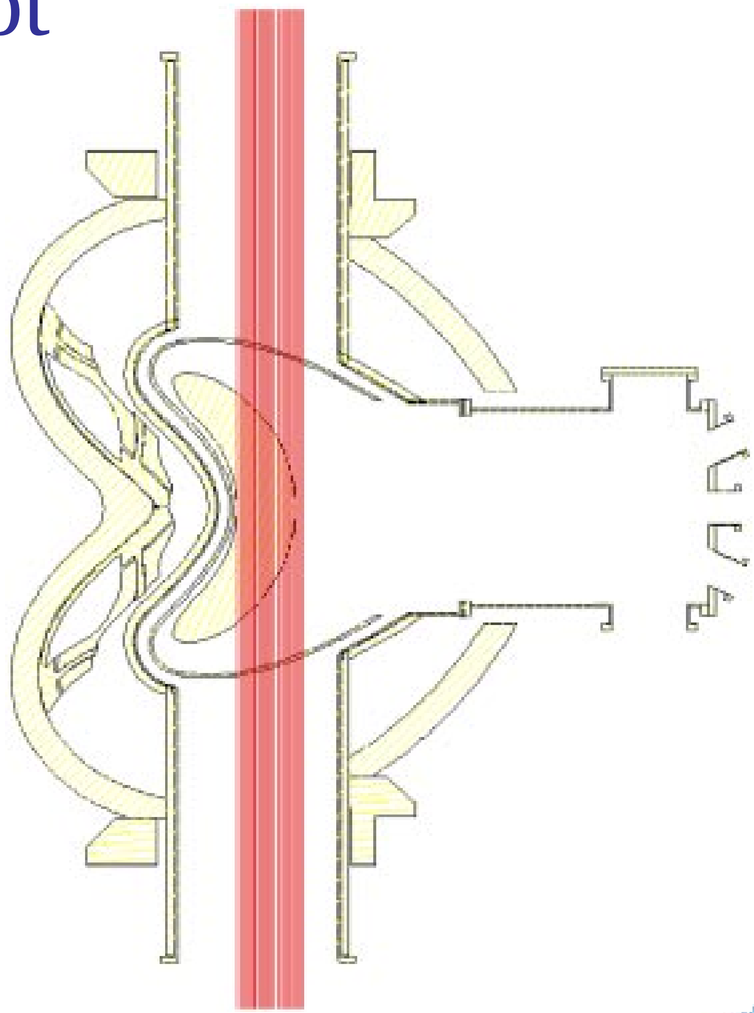
Another Thomson Concept Uses Re-entrant Port on NB Port

- Either viewing option would facilitate
  - straightforward optical design
  - high resolution (50 - 100 ch)
  - high optical throughput (f/5 - f/7)
- Research issues
  - laser not always thru axis
  - 2-D capability (scan laser R)
    - definitely between plasma shots
    - perhaps within between laser shots
- For geometry shown, need to assess impact on:
  - pumping
  - manhole access

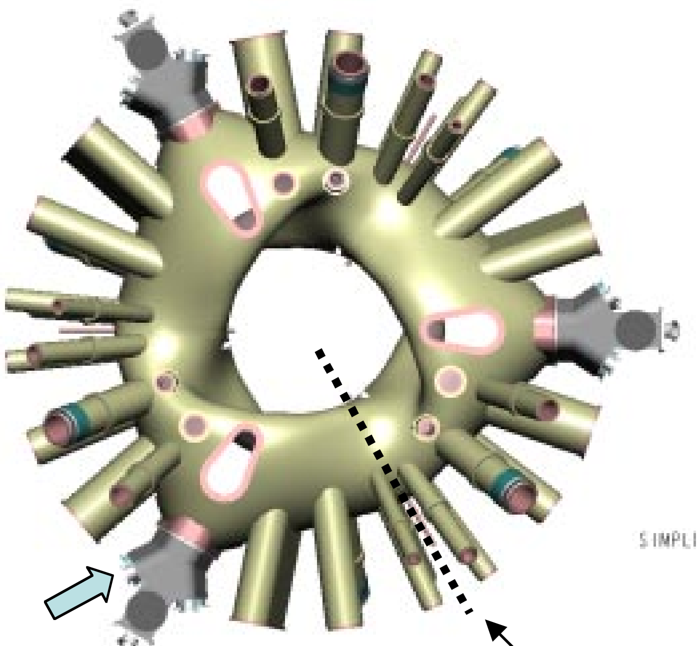


FIR Interferometer/Polarimeter Concept

- To measure j(R), n_e(R), and B_p(R) fluctuations.
- This system would use a vertical sheet FIR laser beam similar to systems used on TEXT and MST.
- Would make use of large vertical ports in this location. (beam port OK)
- Estimate 1.0 - 1.5 cm radial channel spacing may be possible with 20 - 30 channels. (Brower UCLA)

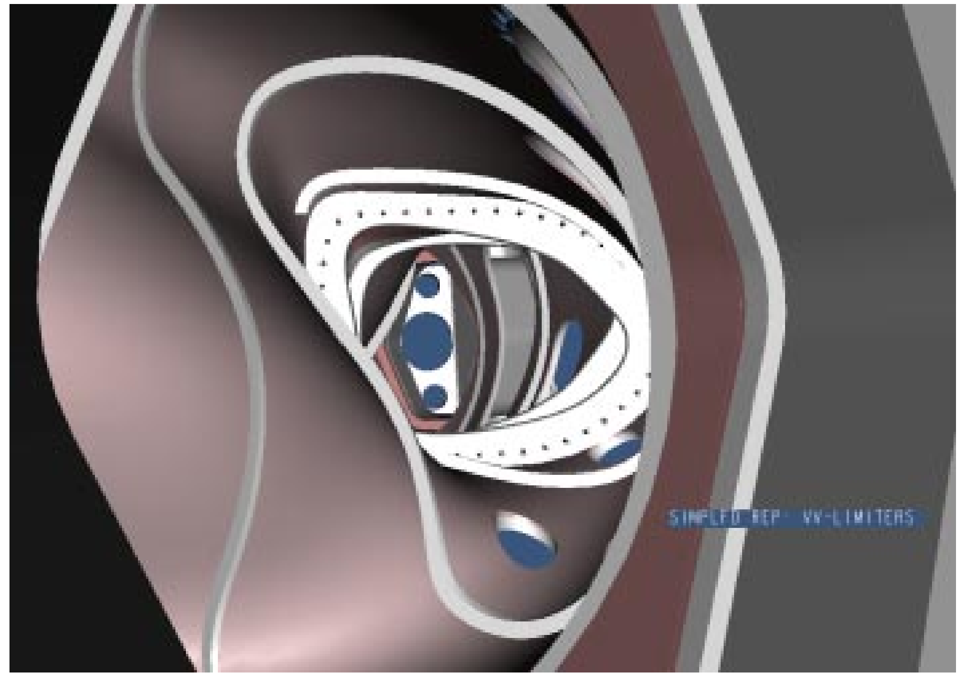


Possible Camera View from Beam Port



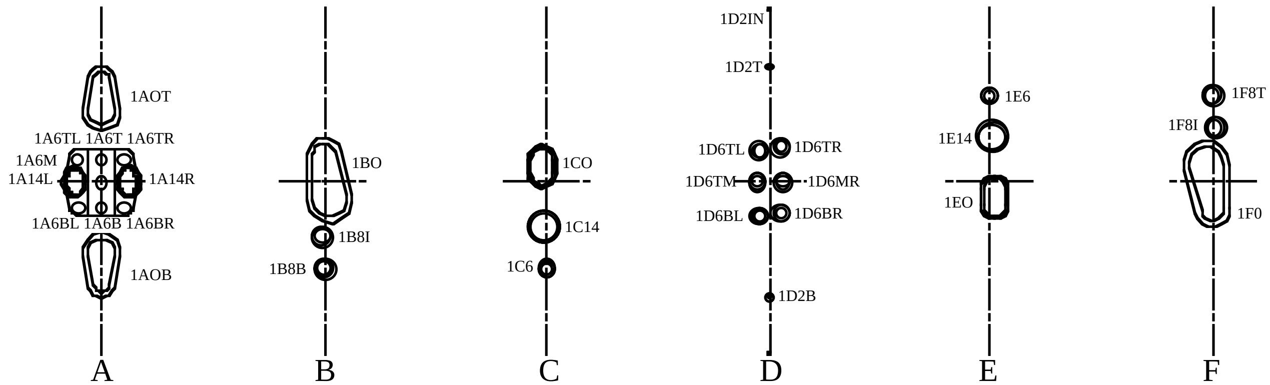
View taken from this location looking into the port

Initial limiter location



- Candidate location for tangential visible and x-ray cameras.
- Good views to see plasma interaction with initial limiters near bullet cross-section.

Preliminary Diagnostic Port Allocation



	A						B		C		D				E		F	
Period 1	1AOT	div bolometer div camera	1A14L	neutral heating beam	1AOB	div. Bolometer IR camera	1BO	multichannel interf./ polarim.	1C0		1D2T		1D2B		1E6	magnetics	1F8T	magnetics
	1A6TL		1A6M		1A6BL		1B8I	high frequency Mirnov coils	1C12		1D6TL	x-ray tomography	1D6BL	x-ray tomography	1E12	TS view	1F8I	
	1A6T	divertor thermocouples	1A14R	fast tang. Xray camera	1A6B	divertor UV spectrometer	1B8B	magnetics	1C6	magnetics	1D6TR	x-ray tomography	1D6BR	x-ray tomography	1EO		1F0	
	1A6TR				1A6BR						1D6ML	TS laser	1D6MR	visible filterscope				
													1D2IN	TS dump				
Period 2	2AOT	divertor TS	2A14L	visible camera	2AOB	divertor TS	2BO	fluorescent rod probe	2C0		2D2T		2D2B		2E6	magnetics	2F8T	magnetics
	2A6TL		2A6M		2A6BL		2B8I		2C12		2D6TL	movable Langmuir probe	2D6BL	high frequency Mirnov coils	2E12	CHERS, MSE, He CHERS view	2F8I	
	2A6T	visible filterscope	2A14R	visible camera	2A6B	visible filterscopes	2B8B	magnetics	2C6	magnetics	2D6TR	visible spectroscopy	2D6BR	UV spectroscopy	2EO		2F0	fluctuation diagnostic
	2A6TR				2A6BR						2D6ML	DNB	2D6MR	e-beam probe				
													2D2IN	DNB dump				
Period 3	3AOT	plate probes thermocouples	3A14L	visible camera	3AOB	fast IR camera	3BO	fluctuation diagnostic	3C0		3D2T		3D2B		3E6	magnetics	3F8T	magnetics
	3A6TL		3A6M	high frequency Mirnov coils	3A6BL	fast neutral pressure gauges	3B8I	fast ion loss probe	3C12	fluctuation diagnostic	3D6TL	x-ray tomography	3D6BL	x-ray tomography	3E12		3F8I	
	3A6T	visible camera	3A14R	neutral heating beam	3A6B	divertor visible camera	3B8B	magnetics	3C6	magnetics	3D6TR	x-ray tomography	3D6BR	x-ray tomography	3EO		3F0	
	3A6TR				3A6BR	fast neutral pressure gauges					3D6ML	core bolometer	3D6MR	fast scanning edge probe				
													3D2IN					

Access Summary

- The number of ports available for diagnostics appears adequate:
  - 96 ports, including 4 for neutral beam injectors
  - currently ~ 60 allocated to the diagnostics in this plan
  - can accommodate auxiliary systems (fueling, wall conditioning, etc.) and future diagnostic needs
- The orientation of the ports is being optimized for specific diagnostic views.
  - holding meetings with specialists to consider proposed layouts
- Long port extensions will drive diagnostic design to compact, re-entrant assemblies capable of:
  - tolerating thermal excursions
  - semi-remote alignment/calibration

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Diagnostic Infrastructure Needs

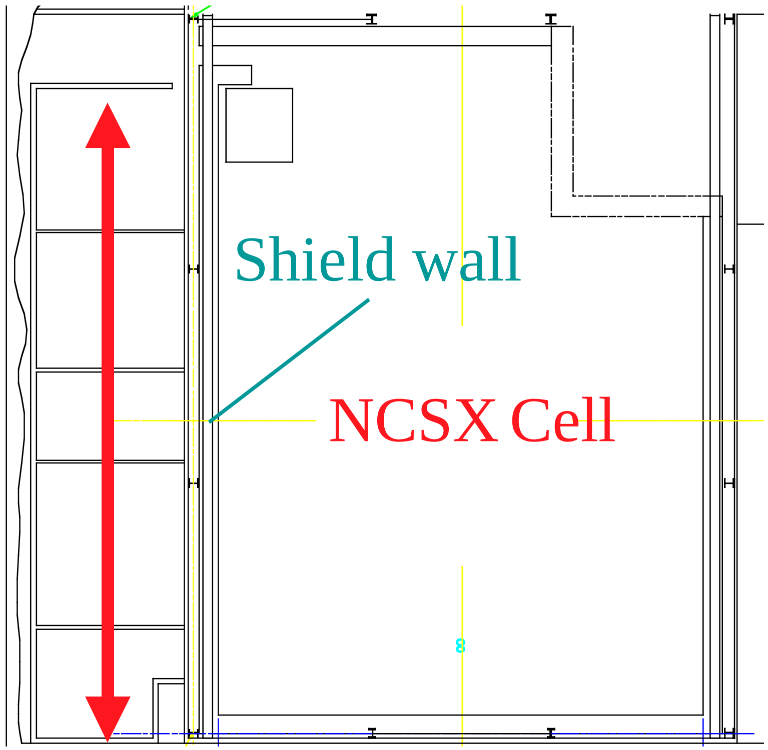
Infrastructure needs (eg. AC power, field cabling and cable trays, data acquisition, platform space, shutter pneumatics, etc):

- Have been budgeted in other WBS areas for diagnostics in Construction Project (red)
- Have been anticipated for upgrade diagnostics.

DIAGNOSTIC	DESCRIPTION	WBS	CHAN	SPEED	PORT	WIND SHUT	ELEC FDTH	MECH FDTH	TIV	RACK
1. Initial Operation										
magnetics	100 sensors + integrators, etc	31	100	100 kHz	12		200			3
visible cameras	3 cameras (1 fast) with filters	361	3	frm grb	3	3		3		1
1 mm interferometer	with inner wall reflector	350	2	200 kHz	1	1		1		1
2. Field Mapping										
e-beam probe	retractable, radially scanning	38	4	10 kHz	1		6	2	1	0.5
fluorescent rod probe	retractable, pivoting	38	4	10 kHz	1		2	2	1	0.5
high dynamic range CCD	standard frame rate	38	2	frm grb	1	2		2		0.5
3. Ohmic										
Thomson scattering	ultimate 60 spatial ch., 100 Hz	351	100	500 MHz	2	2		2		4
multich. FIR interf./ polarim.	# chords, λ, geometry TBD	356	24	100 kHz	1	2		2		4
compact SXR arrays	3 arrays of 16 channels	341	48	200 kHz	1		48	3		1
core foil bolometer array	16 channel array	334	16	10 kHz	1		32	1		0.5

Diagnostic Areas

- Several rooms adjacent to the NCSX Cell have been requested for diagnostic use.
- Diagnostics with fiber-coupled detectors, sensitive to x-rays and gammas, can be located behind radiation shield. (eg. TS, CHERS, MSE, visible spectroscopy)



Measurement Requirements will be used in Evaluating Diagnostic Concepts

MEASUREMENT	RANGE	RESOLUTION		ACCURACY	DIAGNOSTIC TECHNIQUE
1. Initial Operation					
plasma current	1-400 kA	1 ms	integral	1% + 0.1KA	Roqowski coils
conductivity		1 ms	integral	1%	flux loops + Ip
plasma boundary position and shape	??	5 ms		2.0 cm on gap	magnetics + 3-D EFIT
total stored energy	10 kJ - 500 kJ	1 ms	integral	10 kJ	diamagnetic loop
visible image of plasma/wall	2 views	2 ms	0.5 cm		video cameras with optional filters
fast visible image of plasma/wall	1 view	0.1 ms	2 cm		fast video camera
line integrated density	1018 -5x1020 m-2	1 ms	integral	5-10%	1 mm interferometer
2. Field Mapping					
vacuum flux surfaces	v = ? plane	10 ms	0.2 cm	0.2 cm	e-beam probe + fluorescent rod/screen probe + high dyn. range CCD camera
3. Ohmic					
core electron density profile	5xl0l8-5xl02O m-3 with inversion	.01 ms	10-15 cm with inv.	1 fringe	multichord FIR interferometer/ polarimeter
core electron temperature profile	0.05-3.0 keV full profile	10 ms	1 cm	5%	Thomson scattering
core electron density profile	5xl0l8-5xl02O m-3	10 ms	2 cm	5%	Thomson scattering
core radiated power profile	0-30 w/cm3 with inversion	1 ms	integral	15%	core foil bolometer array
low (m,n) MHD modes, ST, disrupt.		100 kHz	3 cm with inv?	10%	multiple compact SXR arrays

Diagnostics Will be a Collaborative Effort

- Have begun to communicate with experts regarding sightlines for diagnostics:
  - MSE (Levinton - NOVA)
  - Compact SXR arrays (Stutman - JHU)
  - FIR inteferometry/polarimetry (Brower - UCLA)
  - HIBP (Schoch - RPI)
  - CHERS (Bell, Stratton - PPPL)
  - Thomson scattering (Johnson, LeBlanc - PPPL)
  - DNB (Schilling - PPPL)
- As this plan evolves, it will clearly benefit from more community input.
- Diagnostics are an entry point for establishing collaborative participation in NCSX, as they have on NSTX and many other devices.
- Diagnostic Working Groups should be an important component of the Research Forums, which may begin in FY2005.

Summary

- A diagnostic plan has been developed which is phased to satisfy the needs of the research program.
- The access available for diagnostics appears to be adequate, but further optimization of port extensions is required and is underway.
- Using recent experience on NSTX as a basis, detailed cost estimates for baseline diagnostics have been developed, and resource needs for diagnostics have also been planned based on phased implementation.
- Diagnostic infrastructure needs have been integrated into project planning.
- Beginning to consult with experts on design concepts.
- Ongoing near-term diagnostic effort is focused on PDR needs:
  - define space envelopes for sensors not using ports (magnetics, sxr arrays, etc.) with particular emphasis on ex-vessel sensors
  - optimize port orientations for specific diagnostic sightlines
  - produce preliminary port allocation map

Motivation for Early Decision on Port Orientations

- June PDR feeds into FDR next fall, where fabrication drawings will be produced for procurement packages for the vacuum vessel.
- Since port extensions define penetrations through modular coil support castings, the design of these components also needs port orientation information.

Diagnostics Deserving Early Access Consideration

- magnetics
- video cameras with filters
- 1 mm interferometer
- e-beam probe + fluorescent rod/screen probe + high dyn. range CCD camera
- FIR interfer./ polarimeter
- Thomson scattering
- imaging X-ray crystal spectrometer
- core foil bolometer array
- multiple compact SXR arrays
- visible spectrometer
- abs. UV spectroscopy
- filtered 1D CCD cameras
- DNB
- toroidal, poloidal CHERS
- MSE polarim.
- tang. x-ray camera
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- epithermal neutron detector
- high frequency Mirnov coils
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- movable Langmuir probe
- fast gauges
- divertor bolometer arrays
- fast IR camera
- plate mounted Langmuir probes
- fluctuation diagnostics (TBD. HIBP?)
- fast scanning edge probe
- He CHERS system
- divertor thermocouples
- divertor filtered CCD camera
- divertor UV spectroscopy
- divertor Thomson scattering

Port Orientation Optimization Plan

The following diagnostics judged to be highly deserving of early consideration due to one or more of the following criteria:

1. special geometry required
2. large viewing aperture required
3. wide field of view required

Thomson scattering	MSE (DNB)	Toroidal CHERS (DNB)	Poloidal CHERS (DNB)
Multichord FIR interferometry/ polarimetry	E-beam probe	Imaging x-ray crystal	Tangential x-ray pinhole camera
SXR tomography arrays (2 pos)	Heavy ion beam probe	Divertor Thomson scattering	

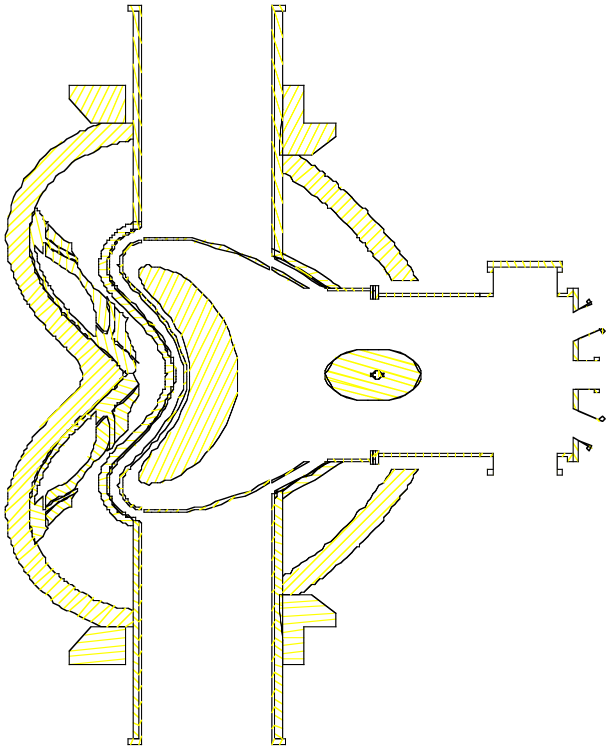
propose layouts → discuss with diagnostic experts → verify engineering feasibility

consider impact on other diagnostics

Access for Divertor Diagnostics

- Access to proposed divertor region is excellent on NCSX, with large vertical ports and multiple ports between the beam ports at the midplane.

- Diagnostic views of the divertor region will have to be integrated into other divertor needs, such as baffles, cryopumps, and PFC bakeout plumbing.



Port Reorientation to Optimize Active Spectroscopy

- There are no views of NCSX heating beams which can provide high spatial resolution for active spectroscopy.
- A DNB will be necessary for active spectroscopy.
- High throughput views of the DNB with sightlines tangent to flux surfaces are necessary for good spatial resolution.
- In this concept, CHERS and MSE would share a view of the DNB using a large reoriented port.
- The same type of port could be used to provide very high throughput for a Thomson scattering view of a vertical beam at the symmetry plane.
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