To: M. Zarnstorff **Date: January 5, 2000**

CC: M. Cole, P. Heitzenroeder, W. Reiersen, T. Brown

From: D. Johnson

Subject: Preliminary Assessment of Diagnostic Access Needs on NCSX

1.0 Introduction

This memorandum is a status report summarizing the results of several preliminary discussions that I have had concerning diagnostic access on NCSX. These discussions were aimed at helping me with my charge to develop a definition of diagnostic access needs for NCSX.

As input to my thinking on this topic, I used a list of diagnostics generated by me earlier in various discussions with you and others involved in planning the NCSX project. A modified version of this list appears in Table 1. In order to appreciate the spatial constraints imposed by the current device design, I communicated with M. Cole of ORNL, and T. Brown, P. Heitzenroeder, and W. Reierson at PPPL, and obtained copies of various views of the current model for the vacuum vessel, the shell, the cryostat, and the coil set. I also had a valuable meeting with M. Zarnstorff on this topic.

I will first mention several general issues affecting spatial constraints for diagnostic access. Then I will proceed through the list of previously identified diagnostics to propose detailed access needs. I will define, where appropriate, diagnostic-specific geometrical constraints which optimize diagnostic effectiveness.

2.0 General Issues for Diagnostic Access on NCSX

2.1 Need for a Conformal Cryostat - In the current device concept, the vacuum vessel and the shell are conformal with the plasma shape, and there is considerable volume between the outer surface of the shell and the inside of the PBX TF coils. It would be a shame not to be able to use some of this space for diagnostics. Since compact options for many diagnostic viewing systems exist, that are not sensitive to magnetic fields, this space is prime diagnostic real estate. Many diagnostic systems consist of an optic, such as a pinhole or a lens, followed by a an image plane with a detector, such as a array of bolometers, x-ray detectors, or fiber optics. Generally the optics needs to be close to the plasma to maximize signal strength and field angle. Placement of the image plane depends on many factors, but the location is generally in the range 5-

50 cm from the optic along an axis extending away from the plasma. Wide angle views are generally desirable, and require a comparable distance transverse to the above mentioned axis. With the existing axisymmetric cryostat design, much of the space between the outer surface of the shell and the inside of the PBX TF coils is void space in the cryostat. With this design, cutouts for wide angle views would be awkward and expensive. A close fitting, conformal design for the cryostat would permit more of this space to be accessible to diagnostics, and would permit higher sensitivity and wider fields of view. Since the cryostat will likely be made of fiberglass, layup of a conformal shape should not be difficult.

2.2 Diagnostic Penetrations through Shell Electrical Breaks - Space for diagnostic penetrations through the shell is limited due to the presence of coils embedded in the shell. If diagnostic penetrations also have to avoid dielectric breaks in the shell, the size and location of diagnostic penetrations becomes substantially more limited. Therefore, I propose that diagnostic penetrations through the shell be allowed to cross dielectric breaks in the shell, provided that the electrical isolation between segments is maintained.

2.3 Relocation of Outer PF Coils - The NCSX coil set is not likely to need to reuse all of the PF capability from PBX-M. Access could be significantly improved, particularly in the midplane region, if the PF coils in this region could be eliminated or moved away from the midplane.

2.4 Protection of In-vessel Diagnostic Sensors and Sensor C abling - Many electrical feedthrus are needed for in-vessel magnetic pickup coils, flux loops, thermocouples, and Langmuir probes. On other devices the in-vessel sensors are embedded in protective tiles or on other internal structures, and the leads between the feedthrus and the sensors are routed behind in-vessel structures, such as protective tiles or passive stabilizer plates. Some means to protect sensors and leads needs to be identified for NCSX. If the sensors and leads need to be attached to the vacuum flange carrying the feedthru, the placement of the sensor is tied to the placement of the flange, and the number of flanges necessary to serve a given number of sensors will greatly increase. If a means of mounting sensors and protecting sensor leads is identified, leads from many sensors can be routed to a single feedthru flange, and commercial high density electrical feedthrus can be used, greatly reducing the number of flanges needed. If beam armor and limiters are planned, these internal structures could possibly be used to mount sensors and protect sensor leads.

2.5 3-fold symmetry in engineering of diagnostic penetrations - There is a 3-fold symmetry of the vessel and shell, and thus in spatial constraints imposed on diagnostics. To minimize design and fabrication effort, is natural to impose 3-fold symmetry for most of the diagnostic penetrations.

There will certainly be a few exceptions to this, which I will try to note in what follows.

3.0 Specific Diagnostic Access Needs

3.1 Magnetics and other in-vessel sensors - Sensors such as B-dot coils and flux loops are used to determine the plasma position and shape and are frequently used in feedback loops for real time control of these parameters. The coils are also valuable to characterize the MHD activity in the plasma. Other in-vessel sensors include thermocouples for measuring the temperature of plasma facing components and Langmuir probes for measuring scrape-off layer plasma parameters. Typically 2-3 conductors are needed per sensor, and commercal, high density feedthrus are used. Pin densities up to 41 pins per feedthru are available. .On NSTX there are ~ 60 2.75”- 3.38” diameter ports available for this purpose, about two thirds of which are in reserve for future use. I doubt that will ever use more than half of these ports for in-vessel feedthrus.

A systematic, physics-based assessment of the number and type of in-vessel sensors needed has not yet been done for NCSX. There are several issues which would be involved in such an assessment. One issue is the number of “views” of the plasma needed. A “view” consists of a poloidal or toroidal array of sensors. Another is the presence and number of divertor regions, limiters, and neutral beam armor regions, and the need to diagnose these surfaces, and to characterize the plasma and the magnetic fields in their vicinity.

Another technical issue, relevant to the number and location of feedthrus, is the strategy for mounting the sensors in the vessel, and for protecting the sensor leads, as mentioned above.

At this early stage, it would seem reasonable to plan on an in-vessel complement of sensors similar to NSTX (a similar scale project) requiring 30 - 2.75” flanges. Provided means for mounting and routing leads is provided, these flanges can be located in “non-critical” locations, since they are not tied geometrically to specific sightlines.

3.2 Visible and IR Cameras - Compared to tokamaks, and particularly to spherical tokamaks, seeing a given fraction of the inside of the vessel will require many more ports on NCSX, because of the high aspect ratio and the complex vessel shape. Assuming that periscopes with steerable, adjustable fields can be utilized, and that there is not a requirement to see everywhere in the vessel, I estimate that 3 - 6” ports for visible inspection would be a minimum complement. For IR camera views of limiters, divertor regions, RF antennas and NBI armor, I estimate 6 - 4.5” ports would be needed, with proper viewing geometries.

3.3 Microwave Interferometer - Two 4.5” ports should be reserved for interferometry. The optimum geometry would be opposing inboard-outboard views on a line through the plasma core. However, this may not be possible because of the density of inboard coils in the shell.

3.4 Poloidal Tomagraphy Diagnostics - The need for multiple measurements in similar poloidal planes is shared by a number of diagnostics. If 2 locations could be found in each of the three toroidal periods where 4 - 6” ports could be distributed around the outer 2/3 of the perimeter of the vessel in the same poloidal plane, these tomographic requirements would be satisfied. This would be a total of 24 ports. I would allocate at least 3 of these 6 toroidal locations to **x-ray imaging** (12 ports). The remainder I would allocate to the **VB array** (1 port), **bolometry** (3 ports) and **passive spectroscopy (VIPS, SPRED, filterscopes)** (4 ports) and **future needs** (4 ports).

3.5 Neutral Beam Spectroscopy - In order to achieve good spatial resolution, several diagnostics require sightlines which intersect the beam at a point where the sightline is nearly tangent to a flux surface. Ideally this would mean sharing with the beam the end of the long rectangular midplane port which is closest to the beam. An 10” port at this location could be shared by **charge exchange recombination spectroscopy** (**CHERS) and motional Stark effect polarimetry (MSE)**. If a second set of beams is installed, an 10” port at a similar location could be used by **beam emission spectroscopy BES**. Opposing vertical views of a beam trajectory as it penetrates the outer half of the plasma would be necessary for **poloidal CHERS**. Ideally these would be racetrack shaped ports ~ 4” wide, elongated along the beam trajectory. These large viewing ports will require custom shutters and ports for mechanical feedthrus to drive them.

3.6 Thomson Scattering - The best geometry for the Thomson system would use a radial midplane laser beam at the oblate symmetry plane. This would require a 2.75” laser input port and, at the opposing point on the inboard surface, an in-vacuum cavity with a depth of 4-6” for a laser beam dump. The laser input port should be at a location where a radial port extention can fit between TF coils and extend radial outward 3-4 meters, so that the laser input window can be placed far from the laser focus to avoid laser damage. The viewing port for this system should be an 10” port with an associated shutter drive port. The first choice for viewing geometry would be to view the beam from above or below. Another option would be to view the beam from the midplane.

3.7 ECE Diagnostics and Reflectometry - The best geometry for these diagnostics would be the outer midplane at a symmetry plane. Four 6”

ports should be allocated to these systems. Provision for an edge reflectometer should be designed into the RF antenna design.

3.8 X-ray PHA and Neutral Particle Analyzer These diagnostics require a flight tube which extends outside the TF coils defining a sightline which passes through the plasma core. Horizontal or vertical sightlines are most convenient. Each would require a 6" port.

3.9 Scannable Probes - Probes with a 18-24"travel would require 6" ports at locations where the probe drive mechanisms can extend normal to the plasma surface and avoid the TF coils and other structures for a distance of ~ 2 meters from the vessel. Diagnostics which would use these ports would be a **fast scanning Langmuir probe** and a **fast ion loss probe.**

3.10 Future Reserve - I have allocated an assortment of ports for "**future use**" in Table 1. I view these as minimums in this area to permit growth in the diagnostic complement as the program evolves and measurement needs are fully realized. Every effort should be made to place diagnostic penetrations where feasible on this device because of its 3-D plasma shape and the large variety of plasma parameters which are critical to understanding its operation. .

Table 1 - Summary of Diagnostic Port Needs on NCSX Preliminary Assessment

diagnostic	#ports	size	comments
in-vessel sensors	30	2.75	location dependent on method for mounting sensors, protecting leads
visible cameras	3	6	assumes retractable periscopes for inspection, top best
IR cameras	6	4.5	provide sightlines to limiter, divertor regions, RF antenna, NB armor
interferometer	2	4.5	opposing on line through core will use commercial flapper shutter
x-ray imaging arrays	12	6	part of "tomagraphy" complement
VB array	1 1	6 2.75	part of "tomagraphy" complement will use commercial flapper shutter
bolometer arrays	3	6	part of "tomagraphy" complement
VIPS, SPRED, filterscopes	4	6	part of "tomagraphy" complement will use commercial flapper shutter
CHERS/MSE	1 2	10 2.75	shares large miplane slot with NB for shutter drive
BES	1 2	10 2.75	shares large miplane slot with NB for shutter drive
poloidal CHERS	2 2	4x10 2.75	racetrack shape above/below NB for shutter drive
Thomson Scattering	1 1 1	2.75 10 2.75	outer midplane, oblate sym. plane top or midplane for shutter drive
ECE	2	8	outer midplane, symmetry plane
reflectometry	2	8	outer midplane, symmetry plane
x-ray PHA	1	6	horiz. or vert. flt. tube out of TF
NPA	1	6	horiz. or vert. flt. tube out of TF
fast ion loss probe	1	6	needs clear path to outside of TF
fast scanning probe	1	6	needs clear path to outside of TF
future needs	8 4 4 2 2	2.75 4.5 6 8 10	initially blanked part of "tomagraphy" complement initially blanked initially blanked initially blanked