NCSX Engineering Design Document

Auxiliary Systems (WBS 2) Design Description

NCSX CDR

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1 INTRODUCTION

The Auxiliary Systems scope includes several subsystems which are critical to plasma performance. The NCSX project includes gas fueling, torus vacuum pumping, glow discharge cleaning, and neutral beam injection heating subsystems. Future upgrades that can be accommodated include pellet injection, boronization, lithiumization, and radiofrequency wave heating subsystems, as well as an augmented neutral beam system.

2 FUELING SYSTEMS (WBS 21)

NCSX will re-use the existing Gas Fueling System from PBX-M. In its initial configuration, the Gas Fueling System will have 2 to 4 injectors capable of providing about 200-400 torr-liter/s of H_2, D_2, or He fueling. This initial configuration will have the flexibility to allow the easy changing of gas plenum volumes, or the adding of additional injectors, at selected vessel locations, as required by the experimental program.

NCSX will be designed to accommodate a pellet injector as a future upgrade. Guide tubes can be installed to facilitate pellet launch from the inboard (high field) side of the plasma. The PBX-M pellet injector has been saved for future use on NCSX.

The existing PBX-M Gas Fueling System hardware will be used as much as possible for the configuration needed for NCSX. This hardware consists of fast pulsed valves, control valves, instrumentation, manifolds, miscellaneous vacuum hardware, and an optional hydrogen purification system. The controls, however, will be upgraded with a modern PLC using the proven NSTX design. As in the case of NSTX, this PLC will also control the vacuum vessel pumping system, glow discharge cleaning (GDC) system, and (as a future upgrade) the boronization system.

PBX-M hardware will be repaired and refurbished. The NSTX Gas Fueling System drawings and design materials will be reviewed to determine the modifications needed for application to NCSX. Procurement and fabrication records used to implement the operational NSTX Gas Fueling System will be used to expedite a similar system for NSCX. Based on experience on PBX-M and NSTX, the Gas Fueling System should operate reliably and be readily maintainable.

The cost of the Fueling Systems (WBS 21), tabulated in Table 2-1, is $142K in year-of-expenditure dollars and is based on the cost of implementing the Gas Fueling System (WBS 211). The contingency for WBS 21 is 18%. Substantial cost savings are realized by re-using existing equipment and capitalizing on recent NSTX experience in designing, procuring, and installing a similar system. The schedule for implementing the Gas Fueling System (WBS 211) may be seen in the **Project Master Schedule**, provided as part of the Conceptual Design Report. Title II design will be completed by the end of FY05. Installation will be completed by the end of FY06.

Technical, cost, and schedule risks have been minimized by re-using existing equipment, testing the equipment off-line before it needs to be installed, and capitalizing on the recent NSTX experience in designing, procuring, and installing a similar system.

Table 2-1 Fueling Systems Costs

Total Estimated Cost (K$)		
		21 Total
Manufacturing Development	Labor/Other	
	M&S	
	Total	
Design (Title I & II)	Labor/Other	36
	M&S	
	Total	36
Fabrication/Assembly (incl Title III)	Labor/Other	5
	M&S	
	Total	5
Installation/test	Labor/Other	21
	M&S	80
	Total	101
Grand Total		142

3 TORUS VACUUM PUMPING SYSTEM (WBS 22)

NCSX requires a Torus Vacuum Pumping System in order to achieve the base pressure requirements. The device is required produce high vacuum conditions with a base pressure of less than or equal to $2x10^{-8}$ torr. In order to achieve these pressures, the device will be equipped with the four PBX-M 1500 l/s turbo-molecular pumps, configured to provide a total pumping speed at the torus of at least 2600 l/s.

The required NCSX base pressure was achieved at room temperature during PBX-M operations using the proposed pumping system with a total net pumping speed of 2600 l/s. Three additional design features will actually improve the pump-down rate to this base pressure on NCSX. First, the pumping port, located at the bottom of the Auxiliary Systems Duct (Figure 3-1), will increase the gas conductance to the 4 turbo-molecular pumps by about a factor of 1.8. Second, the planned electro-polishing of the vacuum vessel inner wall surface will reduce the ratio of the atomic surface area to geometric surface area. This will significantly decrease the amount of surface adsorbed gas, and also surface metallurgical impurities ("mill slag") that become chemically reduced to release the predominant residual gases observed during operations (H_20 and CO). The effectiveness of electro-polishing the vessel inner surface to accelerate pump-down to low base pressures, and to also accelerate the removal of fueling gas between discharges was demonstrated mostly recently on the Phaedrus ST. Finally, the 150°C bakeout of the vessel, and the 350°C bakeout of the PFCs will greatly accelerate the removal of mass 18 (H_20) and mass 28 (CO) from the residual gas spectrum.

The NCSX Torus Vacuum Pumping System will use as much as possible of the existing PBX-M vacuum pumping system hardware. The PBX-M Torus Vacuum Pumping System consists of:

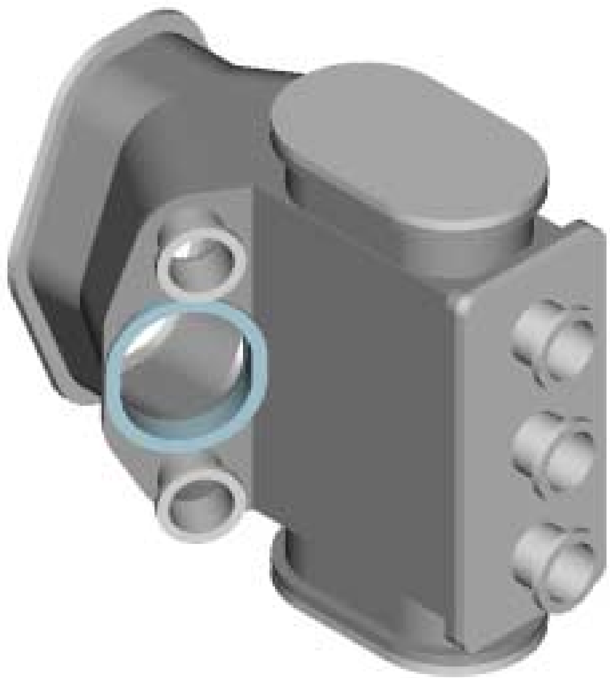
- Four (4) Leybold Heraeus TMP 1500 turbo-molecular pumps
- Four (4) Model 1398 belt driven backing pumps
- One (1) Kinney KT 500 belt driven roughing pump
- Gate valves, flanges, and instrumentation

A new Residual Gas Analyzer (RGA) will be provided. In addition, the existing pumping system controls will be replaced with a PLC based system, which will also control the gas fueling GDC, and a future boronization system.

The design will adopt as much as possible of the recently engineered, proven and operational NSTX Torus Vacuum Pumping System.

Work will be performed to repair and refurbish the PBX-M hardware. The NSTX Torus Vacuum Pumping System drawings will be reviewed to determine the modifications needed for the NCSX application. Procurement and fabrication records used to implement the operational NSTX Vacuum Pumping System will be used to expedite a similar system for NSCX. The Torus Vacuum Pumping System will be assembled and tested off-line prior to first operation on NCSX in order to eliminate uncertainties associated with re-using the existing hardware. Based on experience on PBX-M and NSTX, the Torus Vacuum Pumping System should operate reliably and be readily maintainable.

Figure 3-1 Auxiliary Systems Duct



The cost of the Torus Vacuum Pumping System, tabulated in Table 3-1, is $295K in year-of-expenditure dollars. The contingency for WBS 22 is 18%. Substantial cost savings are realized by re-using existing equipment and leveraging off the recent experience on NSTX in designing, procuring, and installing a similar system. The schedule for implementing the Torus Vacuum Pumping System (WBS 22) may be seen in the **Project Master Schedule**, provided as part of the Conceptual Design Report. Title II design will be completed by the end of FY04. Repair and testing of existing components will take place in FY05. Installation will be completed by the end of FY06.

Technical, cost, and schedule risks have been minimized by re-using existing equipment, testing the equipment off-line before it needs to be installed, and capitalizing on the recent NSTX experience in designing, procuring, and installing a similar system.

Table 3-1 Torus Vacuum Pumping System Costs

Total Estimated Cost (K$)		
		22 Total
Manufacturing Development	Labor/Other	
	M&S	
	Total	
Design (Title I & II)	Labor/Other	77
	M&S	
	Total	77
Fabrication/Assembly (incl Title III)	Labor/Other	24
	M&S	106
	Total	130
Installation/test	Labor/Other	89
	M&S	
	Total	89
Grand Total		295

4 WALL CONDITIONING SYSTEMS (WBS 23)

NCSX is required to have a Glow Discharge Cleaning (GDC) System for wall conditioning to be used during bakeout and between shots as required by the experimental program. The system will have the capability to perform GDC with hydrogen, deuterium, or helium, or other gases.

NCSX is required to accommodate (as a future upgrade) a boronization system for all surfaces with line-of-sight to the plasma. The present concept for this upgrade is to use a trimethylboron (TMB) system such as is used on NSTX. The TMB System will make use of the existing Gas Fueling, GDC, and Torus Vacuum Pumping Systems.

NCSX is also required to accommodate (as a future upgrade) a lithiumization system. The lithiumization system shall provide the ability to apply lithium coatings, either via Li pellets or spray, or other techniques. The NCSX Project has not selected a technique for lithiumization at this time. Much work is going on in the fusion community in implementing lithiumization on existing machines. NCSX will adopt a proven concept from that experience base.

The GDC configuration on NCSX will consist of one fixed wall anode and one dual biased pre-ionization filament unit installed in each of the 3 NCSX Sectors. A positive bias will be applied between each filament and the vessel so electrons fill the vessel volume. The vessel will be filled with He, H_2, or D_2 to a pressure of about 2-4 mTorr. A bias of about positive 500V will be applied between each anode (+) and the vessel walls (-). The pre-ionization electrons will facilitate the ignition of the GDC at the desired operating pressure and voltage, thereby simplifying both manual and automatic control.

The GDC process will be controlled remotely by the same PLC used to control Torus Vacuum Pumping and Gas Fueling Systems PLC. An operator will be able to control this process manually, as is done routinely on NSTX between discharges. This manual control has been found to provide more flexibility during operations than an automated system.

The design of the GDC System will capitalize on the recent NSTX experience in designing, procuring, and installing a similar system. Based on experience on NSTX, the GDC System should operate reliably and be readily maintainable.

The cost of Wall Conditioning Systems (WBS 23), tabulated in Table 4-1, is $99K in year-of-expenditure dollars and is based on the cost of implementing the GDC System (WBS 231). The contingency for WBS 23 is 18%. The schedule for implementing the GDC System may be seen in the **Project Master Schedule**, provided as part of the Conceptual Design Report. Title II design will be completed by the end of FY05. Installation will be completed by the end of FY06.

Technical, cost, and schedule risks have been minimized by capitalizing on the recent NSTX experience in designing, procuring, and installing a similar system.

Table 4-1 Wall Conditioning System Costs

Total Estimated Cost (K$)		
		23 Total
Manufacturing Development	Labor/Other	
	M&S	
	Total	
Design (Title I & II)	Labor/Other	69
	M&S	
	Total	69
Fabrication/Assembly (incl Title III)	Labor/Other	2
	M&S	
	Total	2
Installation/test	Labor/Other	19
	M&S	9
	Total	28
Grand Total		99

5 NEUTRAL BEAM INJECTION (NBI) SYSTEM (WBS 25)

Requirements

Two of the four beamlines previously used on the PBX-M project will be installed and tested as part of the NCSX Fabrication Project. One will be configured in the co-direction (the nominal direction of the plasma current) and one in the counter-direction. These beams have an energy of 50 keV, a power of 3 MW H° (4 MW D°), and an initial pulse length of 0.3s at maximum power. The tangency radius will be inside the magnetic axis for the nominal 1.7T high beta equilibrium and located such that the beam does not intercept the inboard first wall.

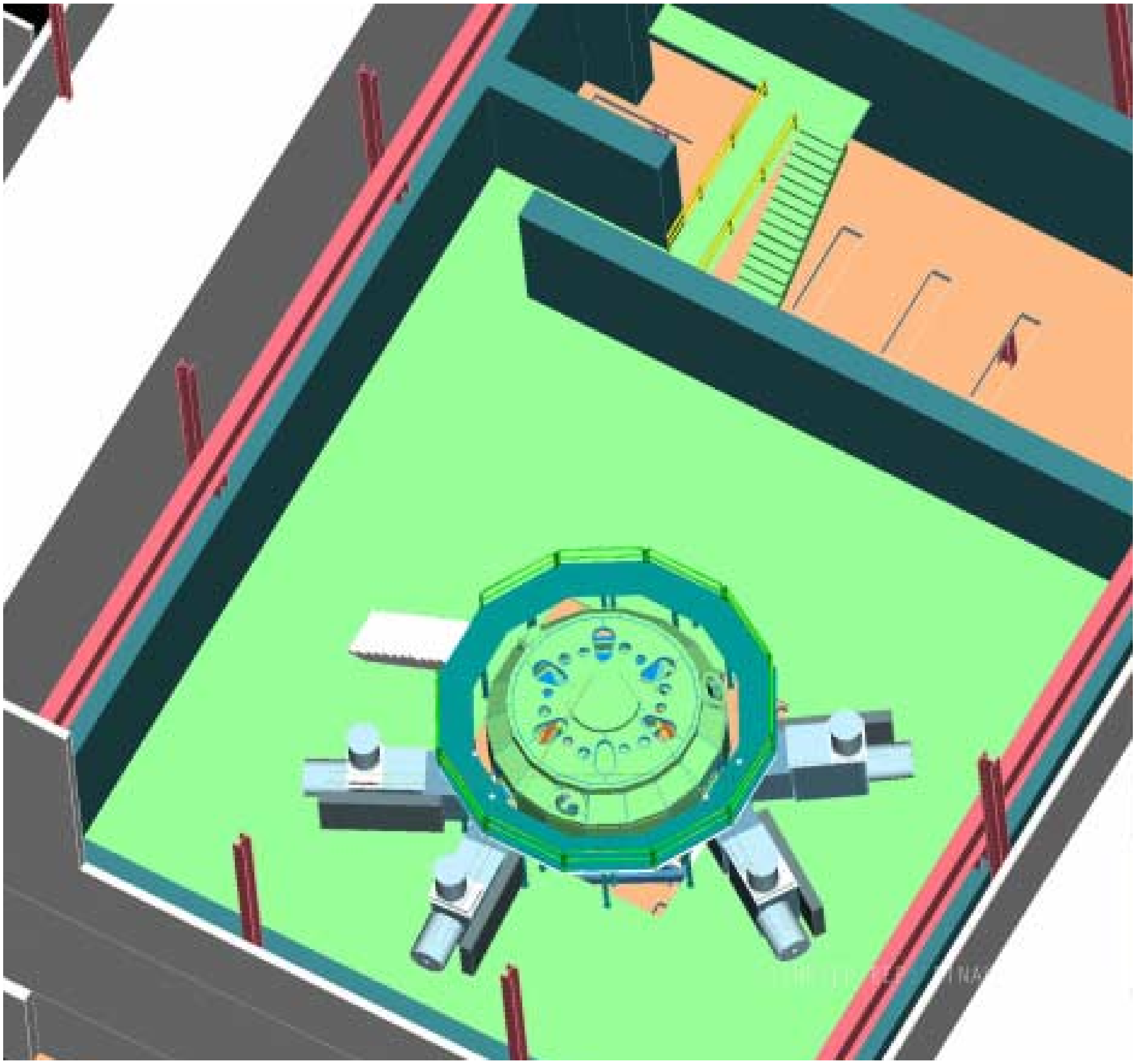
The facility shall be designed to accommodate neutral beam heating using the four (4) beamlines previously used on PBX-M (as a future upgrade) in two possible configurations: [1] 2 co- and 2 counter-directed beamlines and [3] co- and 1 counter-directed beamlines. The facility shall also be designed to accommodate an extended heating pulse duration of 1.2 s.

Design Description and Performance

NCSX in its initial configuration will utilize two of the four existing PBX-M neutral beams. The other two will be installed as a future upgrade. The PBX-M Neutral Beam Systems (power, vacuum, cryogenic, water, air, instrumentation, PLC control, computer control, computer archiving, and diagnostic subsystems) have not been maintained since PBX-M FY93 Operations. In addition some of the nitrogen cryopanels and programmable logic controllers (PLCs) will be replaced. The required maintenance, repair, and replacements will be performed, to the extent possible, at a maintenance location away from their final location on NCSX.

Next, installation on NCSX and integrated subsystem testing must be performed. The beamline base-plates will be moved to the NCSX location. There is ample space for the beamlines around the perimeter of the machine as shown in Figure 5-1. The required ion source power junction box and cables to be located under the platform will be re-fabricated for the NCSX base-plate location. All control and diagnostic cables will be reinstalled. The air, water, cryo, and vacuum lines will be extended to the NCSX location. A beamline will then be lifted from its maintenance location, and placed on its base-plate at the NCSX location. All required mechanical and electrical connections would be made. Commissioning of the NBI System will be performed during NCSX operations.

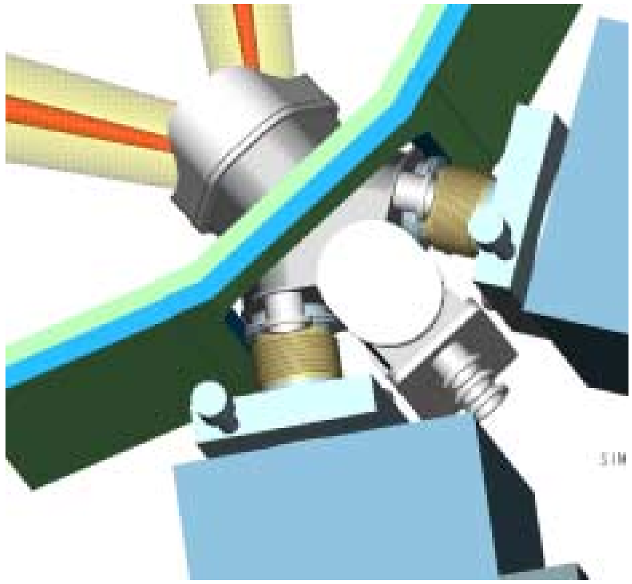
Figure 5-1 NB Arrangement in Test Cell



The beamlines will be connected to the torus through the Auxiliary Systems Duct (Figure 3-1). The Auxiliary Systems Duct serves several functions:

- Accommodates Transition Ducts for 2 beamlines,
- Accommodates a Torus Vacuum Pumping System pumping port,
- Provides view ports for diagnostics, and
- Provides ports for personnel access into the torus.

Figure 5-2 Neutral beamlines Connected to Auxiliary Systems Duct



The NBI Transition Duct connects the beamline to the Auxiliary Systems Duct, as shown in Figure 5-2. The beam first passes through the Torus Interface Valve (TIV). The duct has a ceramic break providing electrical isolation of about 3 kV, and a bellows to decouple vessel motion during operation and bakeout. The bellows is shielded with a metal sheet fastened to the vessel and floating on the beam side.

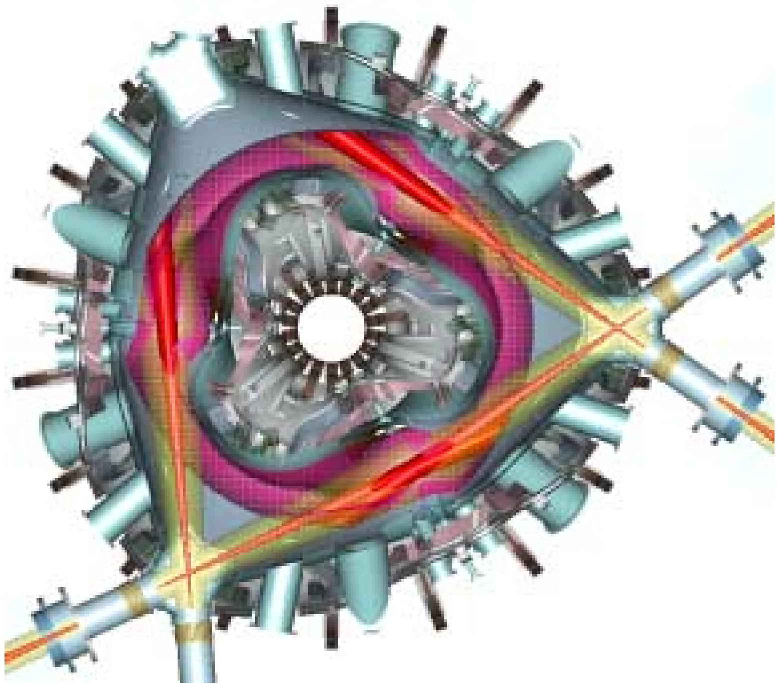
All vacuum seals will be bakeable to 150°C. Ports will be provided for a duct ion gauge to monitor re-ionized power losses, for species measurements, beam emission spectroscopy calibrations, etc. The NCSX design will include a GDC electrode to facilitate duct conditioning. The far wall beam armor design will include beam power and position diagnostics.

The location and design of the NB ports was influenced by several considerations:

- <u>Maximizing the absorption of injected beam power over the desired plasma region</u>. The absorbed power is determined by the beam focusing (perveance), the distance of the ion source from the deposition region, the aiming angle, and target plasma parameters.
- <u>Minimizing effects on injected neutral particle species</u>. Neutral Beam ion sources produce three ionic species [H^+(E), H^+(E/2), H^+(E/3), or D^+(E), D^+(E/2), D^+(E/3)]. The ion source and neutralizer, which are operated so as to maximize the full energy operation, determine the net neutral species fractions entering the transition duct [H^0(E), H^0(E/2), H^0(E/3), or D^0(E), D^0(E/2), D^0(E/3)].
- <u>Minimizing beam power deposition on ports on the opposite wall</u>. The port locations will allow the mounting of far-wall armor to absorb shine-through power and allow full-power, short-pulse beam injections in the absence of plasma for calibrations. Hence, far-wall armor provides wall protection and functions as an instrumented NBI diagnostic (IR camera views and thermocouples).

Balanced co- and counter-tangential NB injection is needed to provide control of the neutral-beam driven currents, and to provide control of the driven rotation (and thus electric field) for transport studies. The initial NBI installation will have 1 co- and 1 counter-injecting NBI mounted on the same Auxiliary Systems Duct. Figure 5-3 shows a candidate configuration for the final upgraded 2 Co and 2 Counter NBI System. The facility will also accommodate beam configurations with three co- and one counter-injected beam.

Figure 5-3 Plan View of Beam Injection into Plasma



The work in implementing this design concept involves repairing, refurbishing, and re-installing existing PBX-M hardware. Methodologies and procedures developed during the previous 17 years of operating history of the NBI System, including reorientation (1983 conversion from PDX to PBX), will be applied. NB controls will be re-used. Procurement and fabrication records used to implement operational NSTX subsystems (vacuum, cryo, PLC, etc.) will be used to expedite similar NBI subsystems for NSCX. The NBI systems will be installed. All required mechanical and electrical connections would be made. Commissioning of the NBI System will be performed during NCSX operations. Based on experience on PBX-M, the NBI System should operate reliably and be readily maintainable.

The cost of the NBI System, tabulated in Table 5-1, is $1668K in year-of-expenditure dollars. The contingency for WBS 25 is 18%. Re-using the existing NBI System rather than developing a new system realizes major cost savings. The schedule for implementing the NBI System (WBS 25) may be seen in the **Project Master Schedule**, provided as part of the Conceptual Design Report. Refurbishment of the beamlines will take place in FY04 and FY05. Installation in the Test Cell will be completed in FY06.

Technical, cost, and schedule risks in the NBI System have been minimized by re-using existing equipment and testing the equipment off-line before it needs to be installed.

Table 5-1 NBI System Costs

Total Estimated Cost (K$)				
				25 Total
		251	252	
Manufacturing Development	Labor/Other			
	M&S			
	Total			
Design (Title I & II)	Labor/Other	426	132	558
	M&S			
	Total	426	132	558
Fabrication/Assembly (incl Title III)	Labor/Other	373	39	412
	M&S	398		398
	Total	771	39	810
Installation/test	Labor/Other	2	181	183
	M&S		117	117
	Total	2	298	300
Grand Total		1200	469	1668

6 ION CYCLOTRON HEATING (ICH) SYSTEM (WBS 24)

NCSX is required accommodate up to 6 MW of ICH (as a future upgrade) with a pulse length of 1.2s and frequency of 20-30 MHz. Three launchers will be provided on the inboard side, one at each of the three v=0.5 cross-sections. Space has been allocated for these launchers as shown in Figure 6-1. Existing RF sources at C-site can be modified to power these launchers.

The ICH system is planned as a future upgrade for the latter phases of NCSX operation. There are no costs associated with this system in the Fabrication project.

Figure 6-1 Inboard ICH Launcher Concept