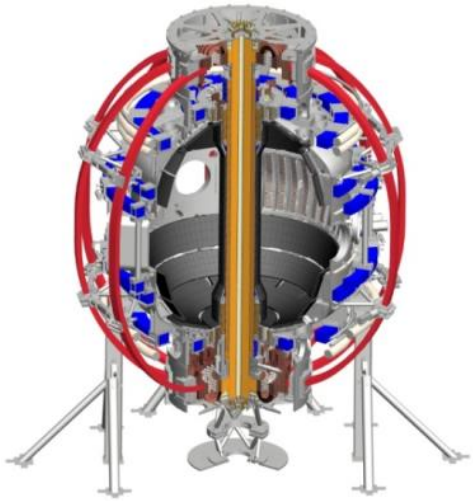
NSTX-U Physics Ops NBI Overview

College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Washington
U Wisconsin

Timothy N. Stevenson

NBI

Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec



Introduction

- *NBI Overview - sources, power, beamline, duct*
- *Operating Parameters*
- *Voltage, Power, and Pulse length*
- *Operations Interfaces*

Please note that the beam clock cycle is <u>every</u> 2.5 minutes so we can do a filament and arc pulse to maintain our source thermal equilibrium. The NSTX clock cycle for a plasma shot synchronizes to the NBI clock and catches the next timepoint so as to inject at t=0. The NBI timer actually starts 16 seconds before t=0 to spool up the arc prior to accel. Requested injection times are referenced to t=0.

•GRD Requirements for NBI System

- *Disassemble & evaluate a TFTR BL* ☑
- *Decon a TFTR DT BL* ☑
- *Refurbish BL* ☑
- *Lift BL over wall – Clearance OK* ☑
- *Add second NBI & Services in NTC* ☑
- *Connect Power & Controls* ☑
- *Aim wider (modify VV)* ☑
- *Rearrange NTC to fit* ☑
- *Capability to run either or both* ☑
- *NBI Power x 2 for NSTXU* ☑

GRD Requirements for NBI Design

NBI BL2 Operating Parameters meet GRD

- TFTR 120 keV capability retained
- 110 keV D service ceiling for full energy species
- NSTX NBI operates up to 100 keV now @ approx. 2.5 MW per source (15 MW total)
- NSTX NBI original spec of 80 keV 5 MW for 5 seconds retained
- Approx. 3 MW per source in deuterium at 110 keV achievable

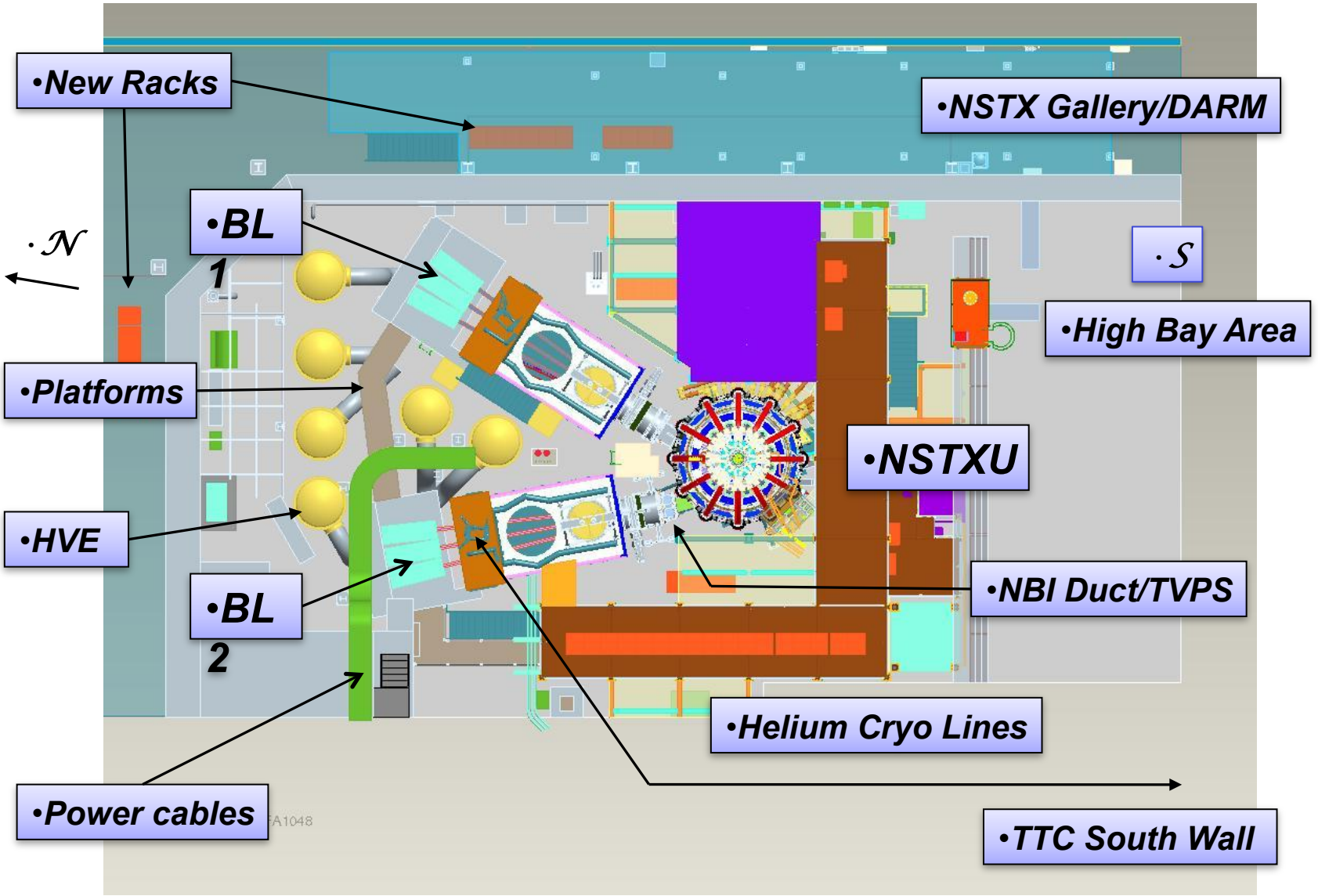
- Ion dump operating limits retained based on TFTR & NSTX operating experience…

NBI Aiming wider tangency radii per GRD achieved

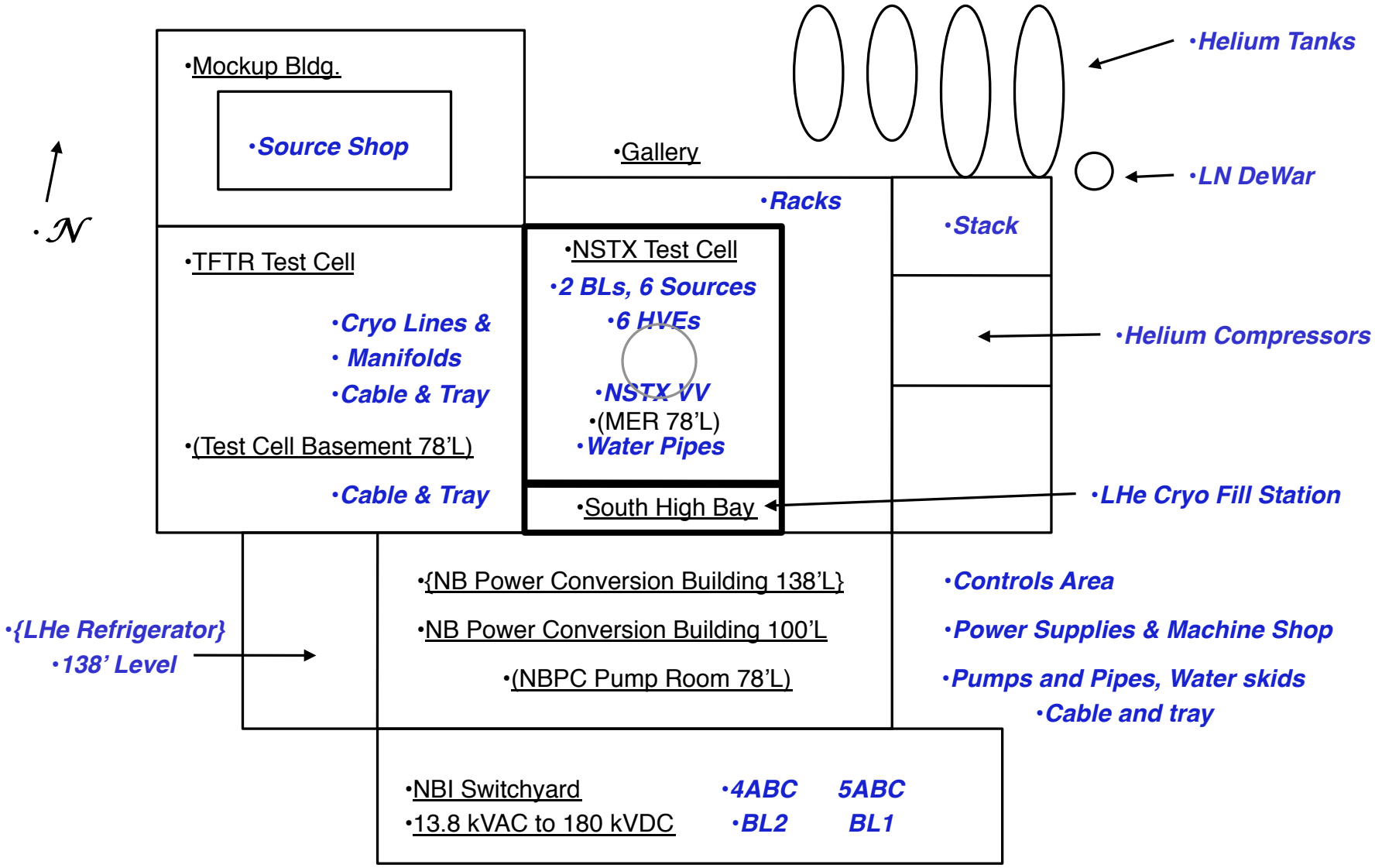
- Existing BL1 Tangency radii [C=50; B=60; A=70] cm unchanged
- BL2 Tangency radii designed to be [C=110; B=120; A=130] cm per GRD

2 BL 6 sources 18 MW possible… 15 MW required ☑

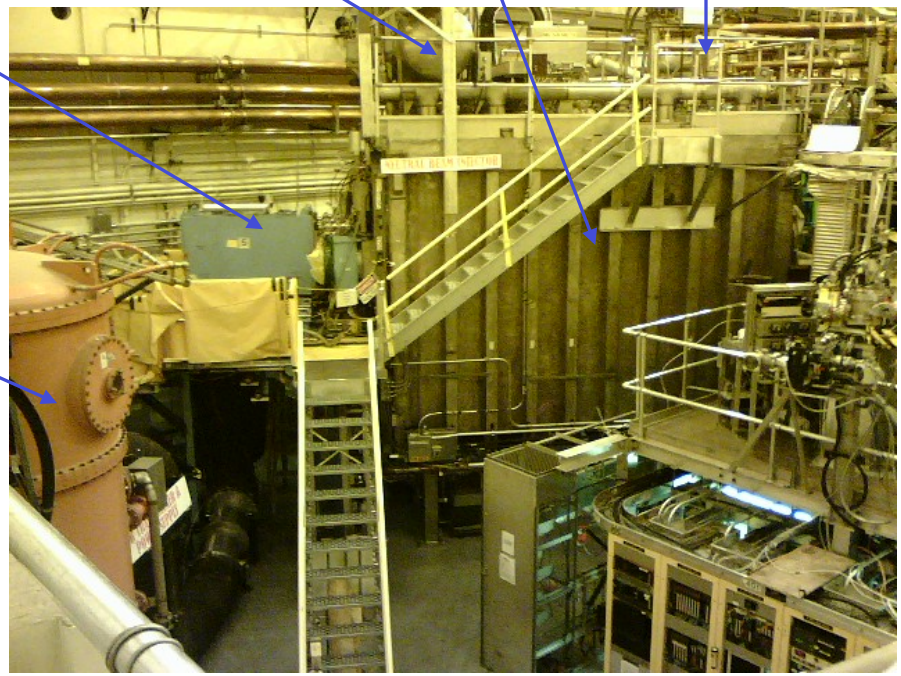
•NSTXU Test Cell General Arrangement



•D Site Buildings - NBI General Arrangement

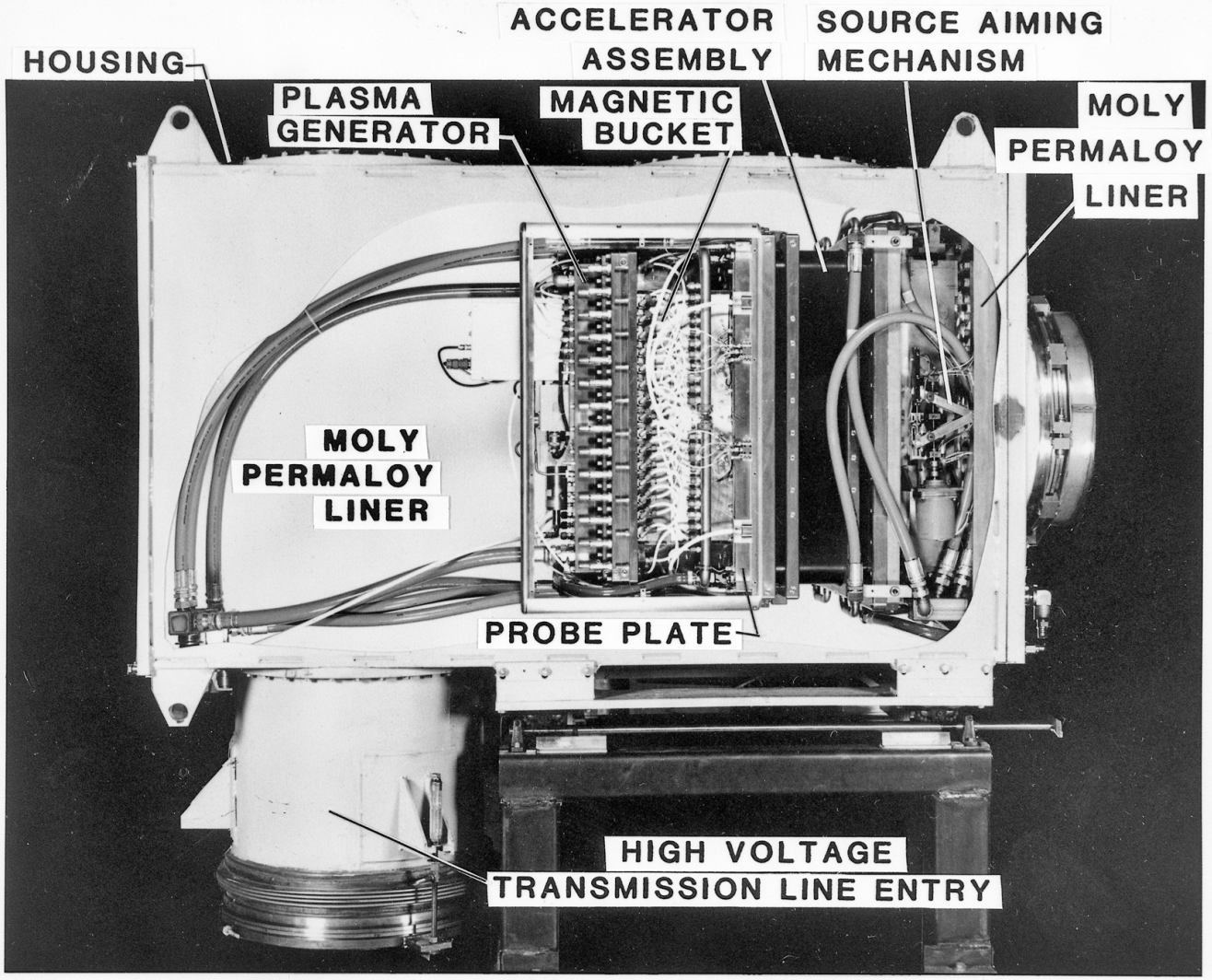


NBI Overview



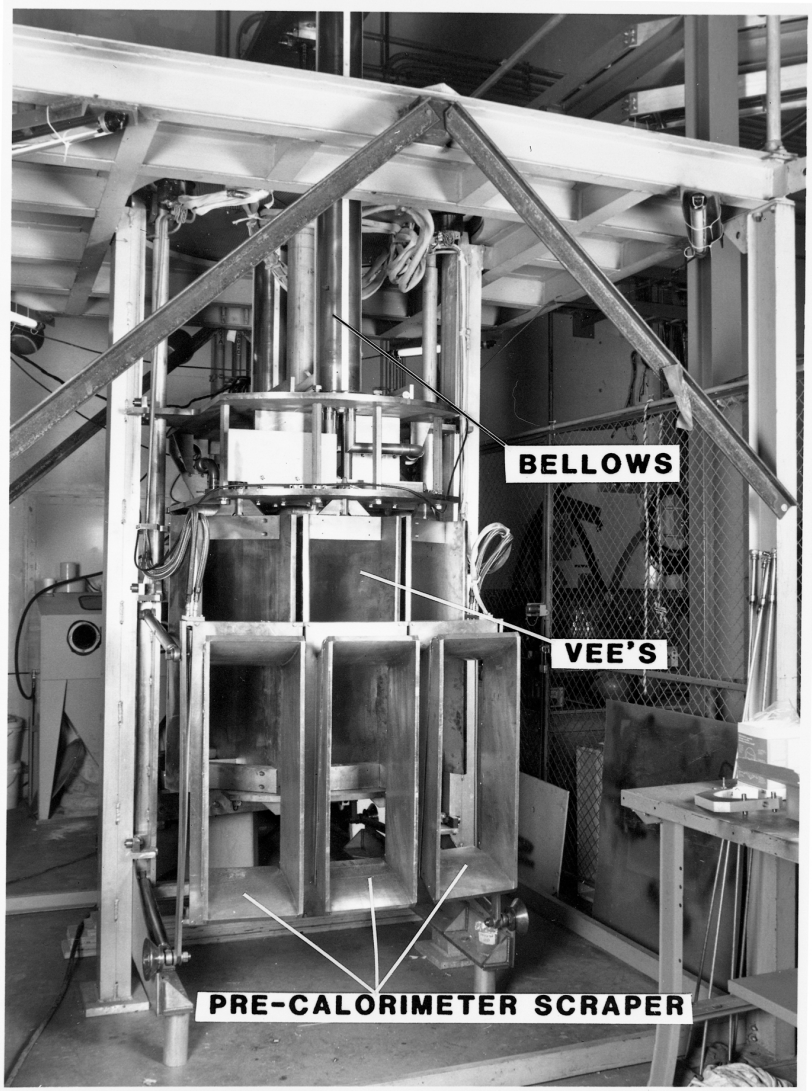
NSTX Beamline 1 operating since 2000

NBI Overview - ion source



SOURCE ASSEMBLY INSIDE HOUSING

NBI Overview - beamline calorimeter



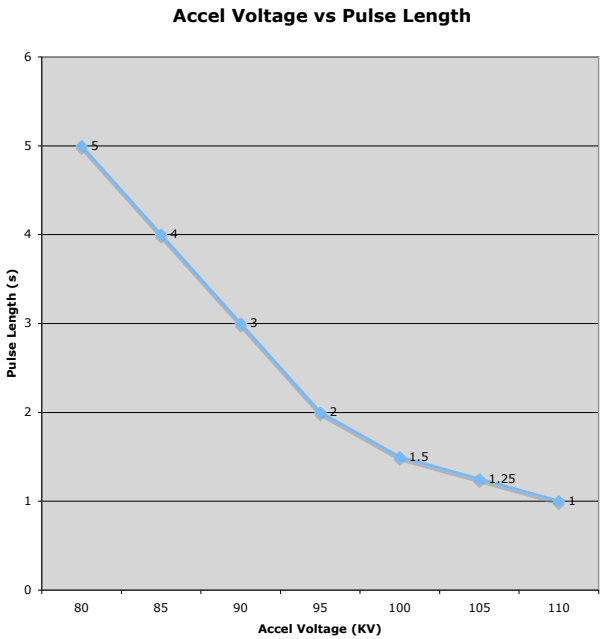
- *Shown at half mast*

NBI Overview

Calorimeter Installation on BL1

NBI Overview - *Operating Parameters & Aiming*

- *NSTX NBI operates up to 100 keV now with 60-90 keV typical*
- *Approx. 3 MW per source in deuterium at 110 keV available (TFTR operating experience)*
- *NSTX NBI original spec of 80 keV 5 MW for 5 seconds retained*
- *Ion dump operating limits retained based on TFTR & NSTX operating experience…*
- *Existing BL1 Tangency radii [C=50; B=60; A=70] cm*
- *BL2 Tangency Radii [C= 110; B=120; A=130]cm*



1.75 MW/source

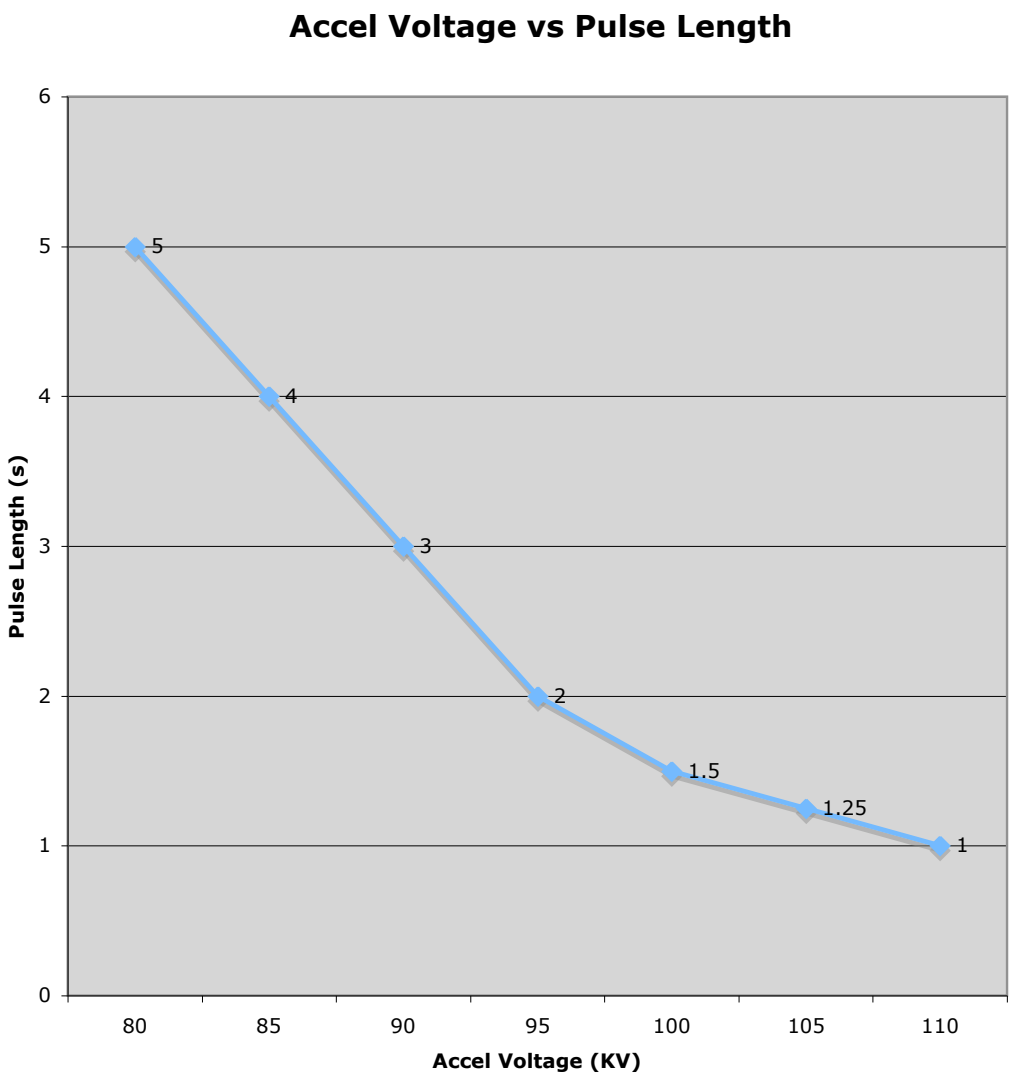
2 MW/source

3 MW/source

Note 1: The NBOS can provide a specific voltage, or a specific current, or a specific power on a per source basis

Note 2: The NBOS can provide a pulse duration, single or multiple notches, cyclic rate modulation, or beam blips for diagnostic purposes on a per source basis

NBI Overview - *keV vs. t & MW*



1.75 MW/source

2 MW/source

3 MW/source

Neutral Beam Power System

- Same design as original TFTR power systems but updated where required
- TFTR N5 power systems A,B, & C used on NSTX BL1
- TFTR N4 power systems A, B, & C used on NSTXU BL2

  (one power system line-up per source)

  ✓ Accel (the requested accelerating voltage & pulse duration)

  ✓ Gradient Grid

  ✓ Decel

  ✓ Arc

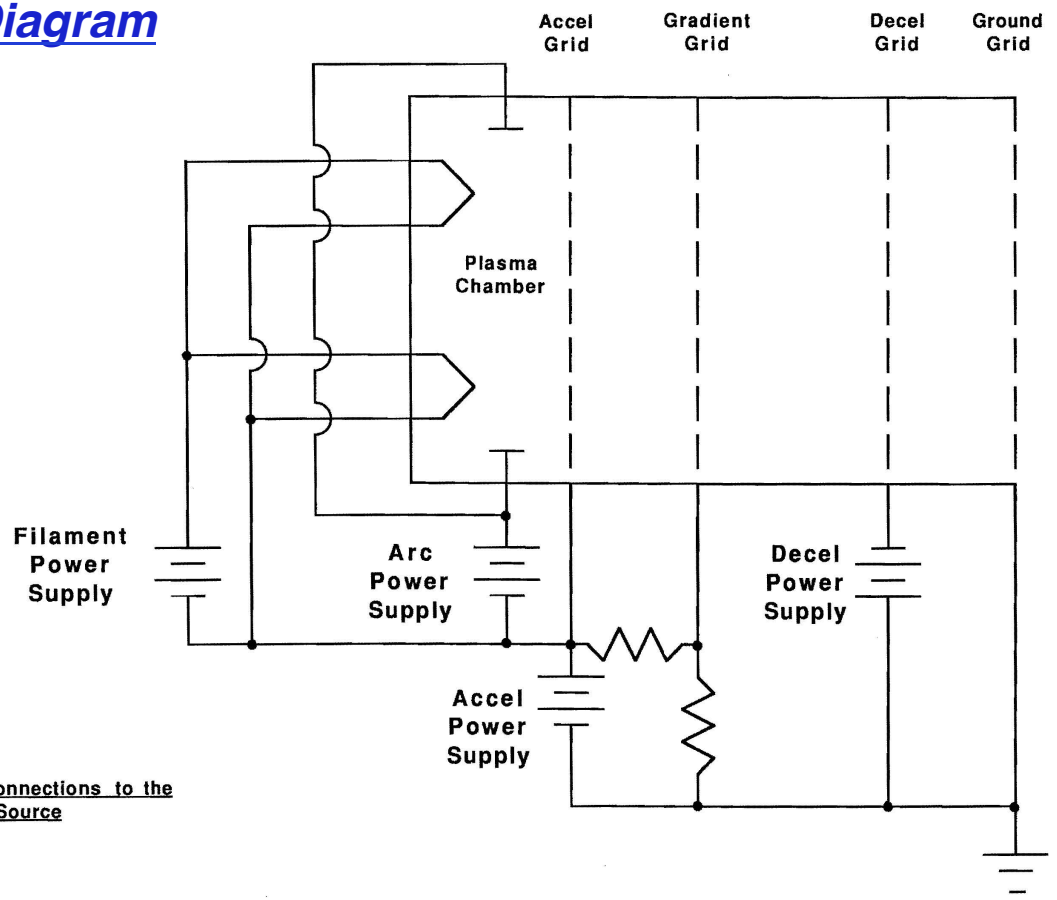
  ✓ Filament

  ✓ Bending Magnet (sweeps unneutralized accelerated ions upward into the ion dump)

- Feedstock gas is deuterium

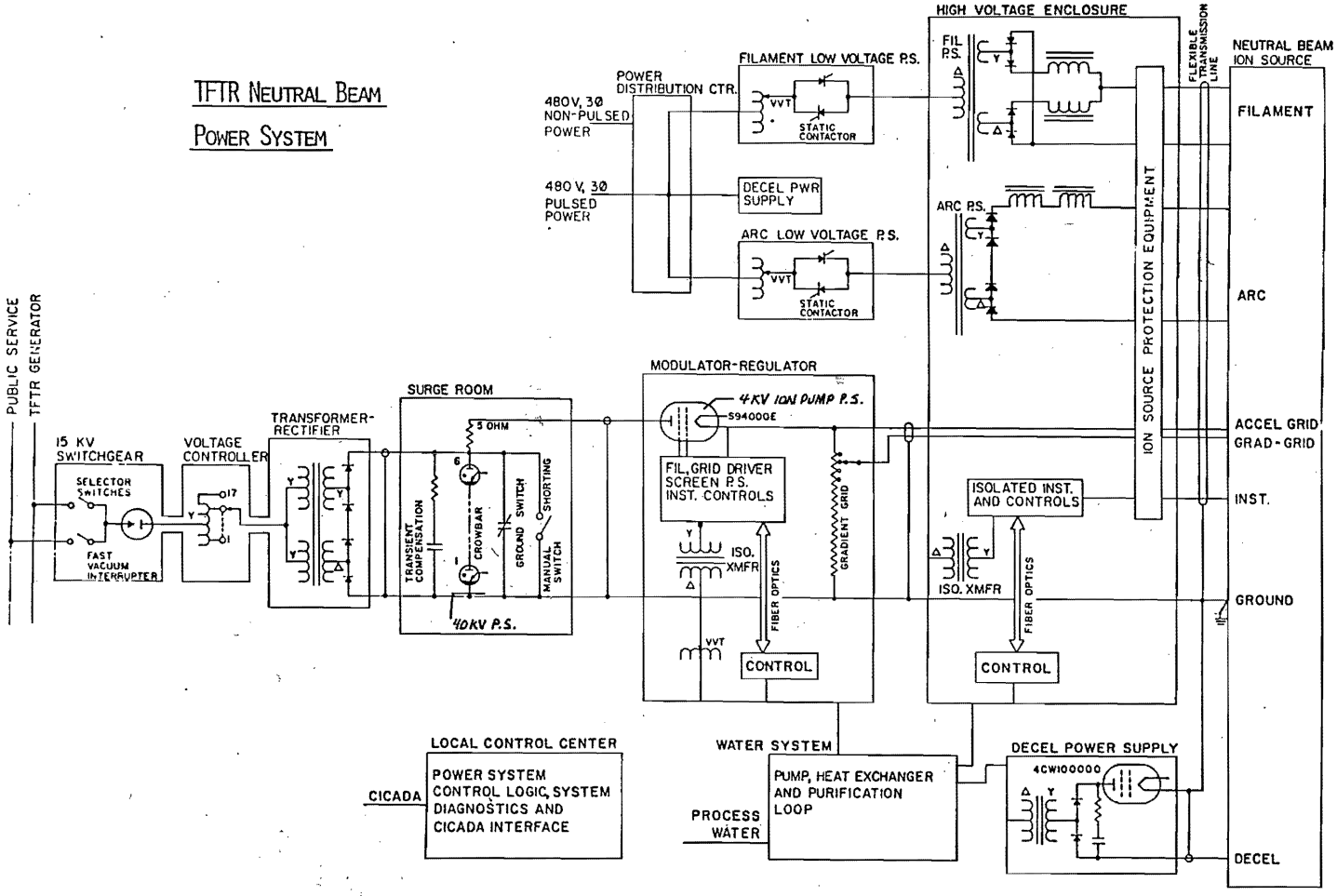
NBI Power & Controls - Battery Diagram

NBI Source Battery Diagram



Power Supply Connections to the Long Pulse Ion Source TNS-11/03/88

NBI Power & Controls - One Line Diagram



NBI NBPS One Line Diagram

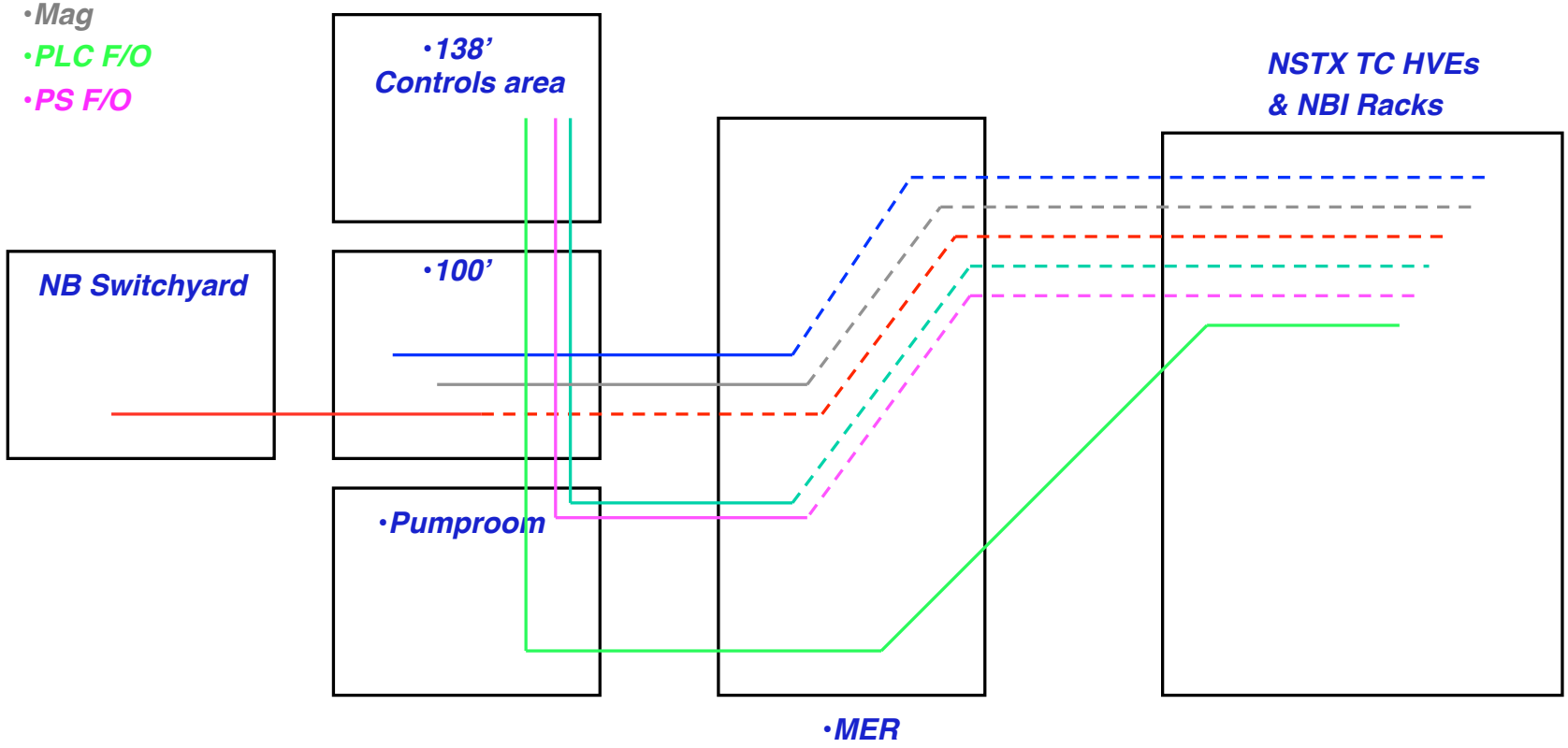
NBI Power System

NBI NBPS Switchgear and Transformers

NBI Power & Controls - Road Map

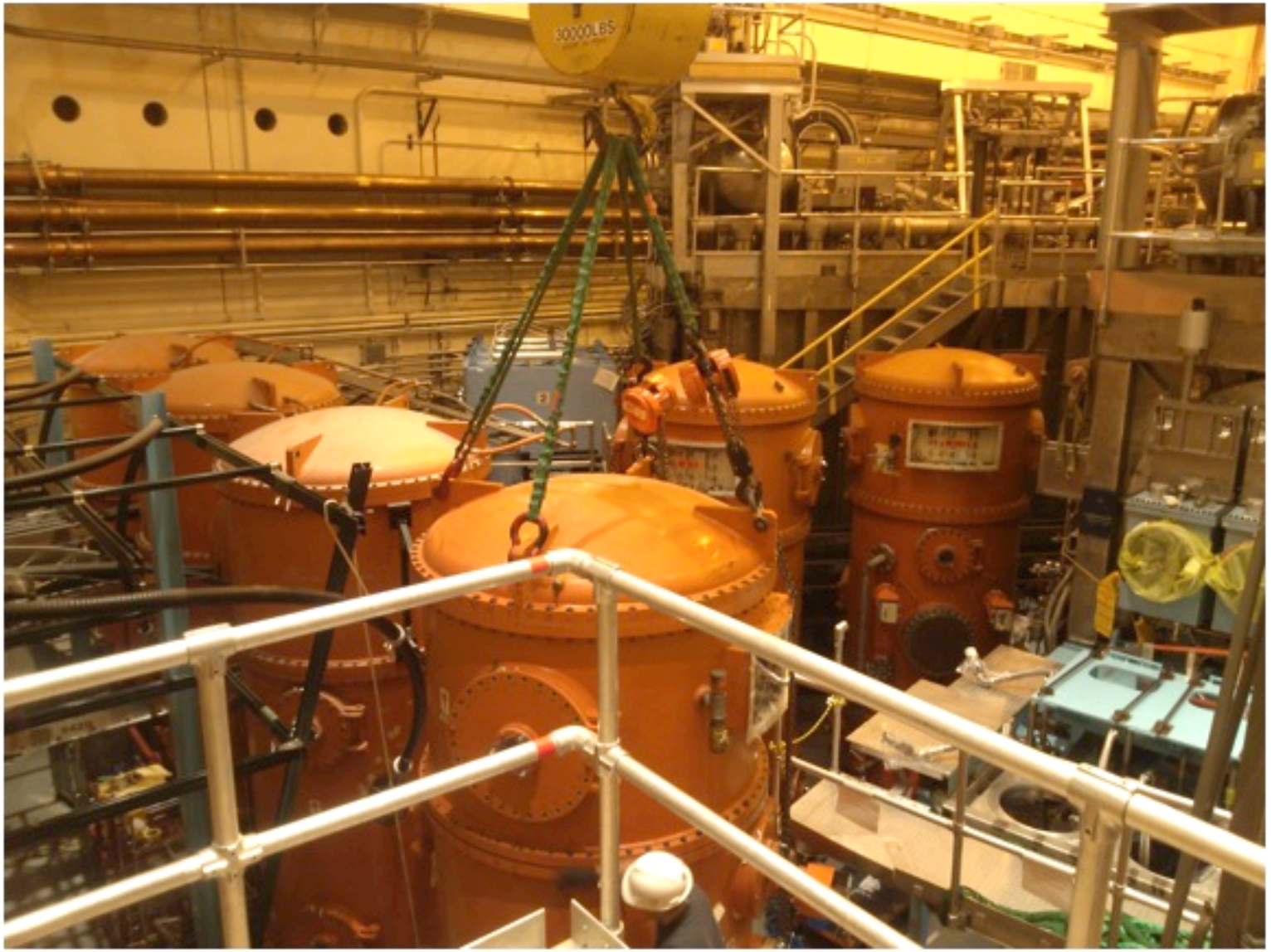
Routing and Installation

- *Accel*
- *Decel*
- *Fil&Arc*
- *Mag*
- *PLC F/O*
- *PS F/O*



N4ABC High Voltage Enclosure relocations completed

·2425

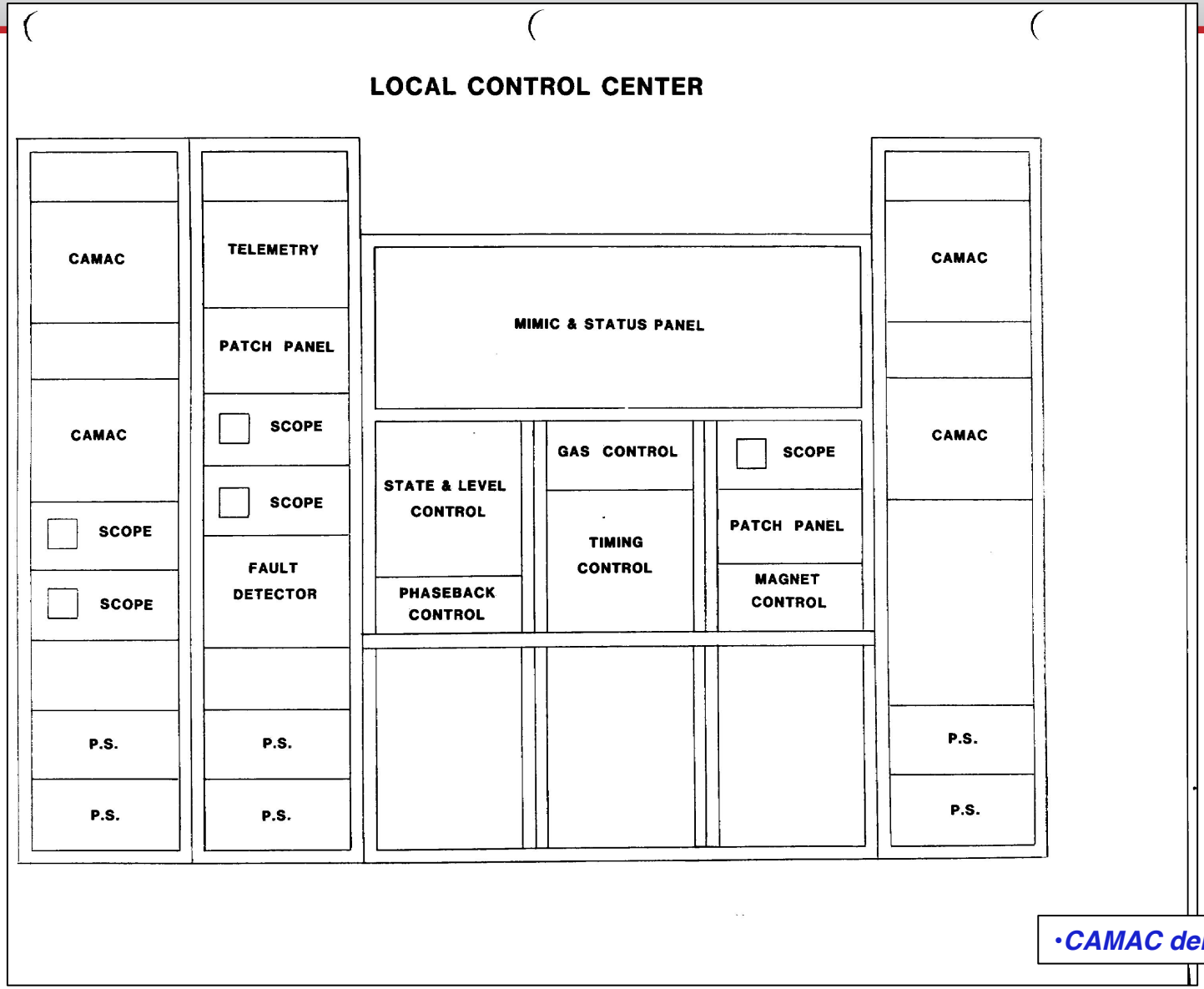


NBI Overview - NBI Power & Control

NB Control Room

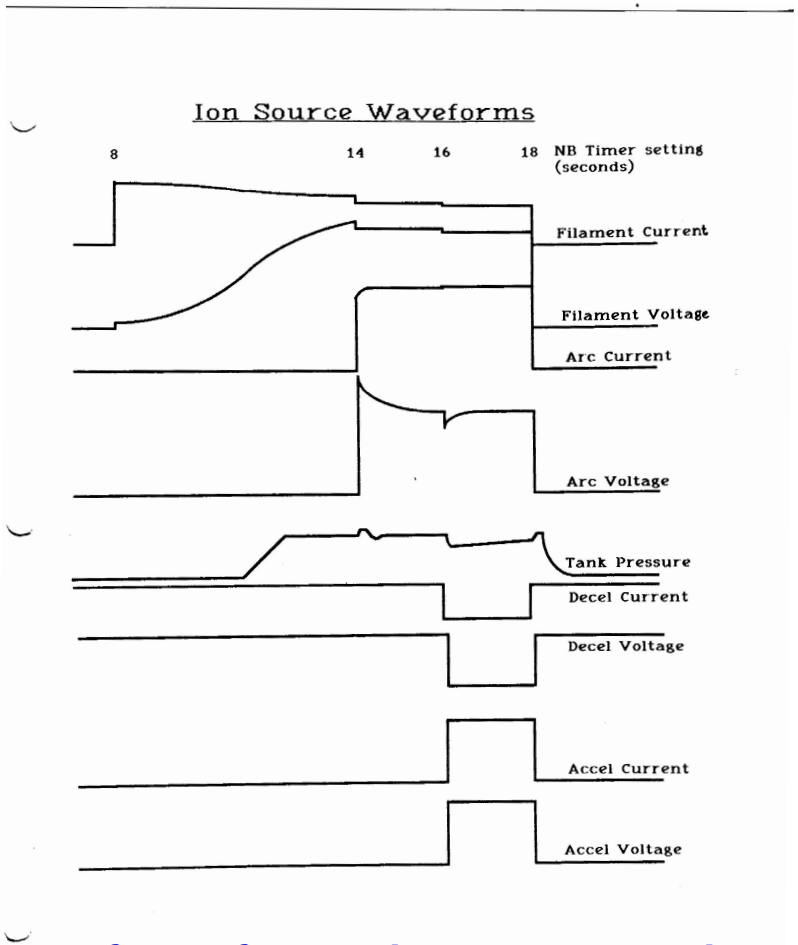
NBI BL2 LCC Controls reactivated

•2475



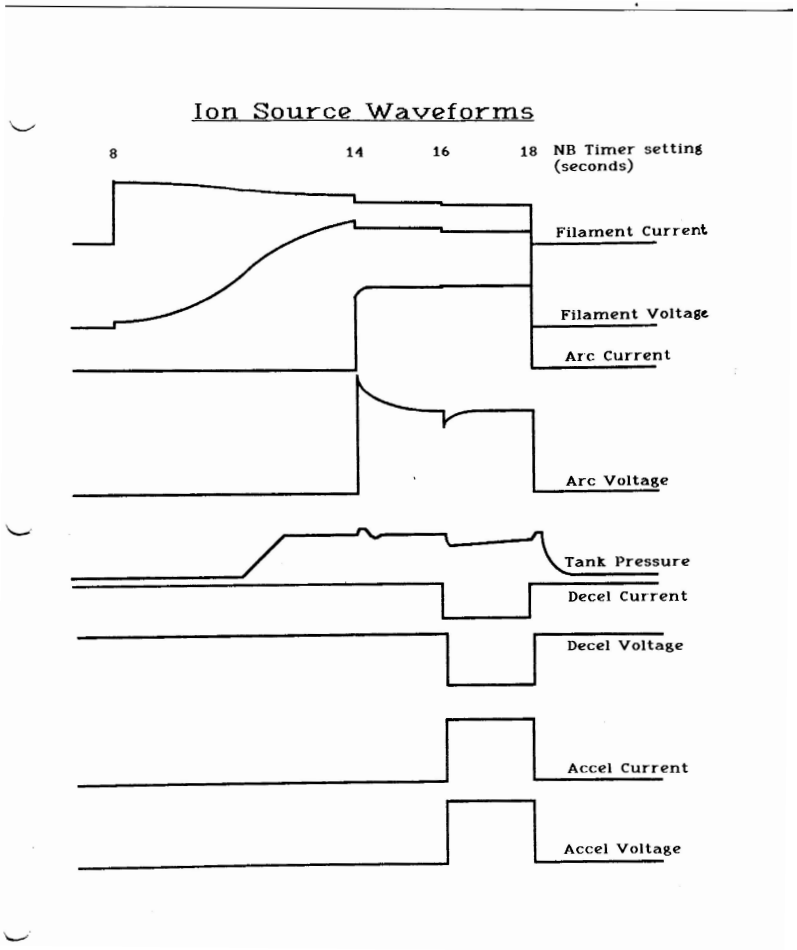
•CAMAC deleted

NBI Power & Controls - Typical pulse



Typical NBI source waveforms for one ion source monitored and adjusted as required every source every shot by NBI Operations staff due to unregulated arc and filament supplies and emission limited ion source design

NBI Power & Controls



Typical faults

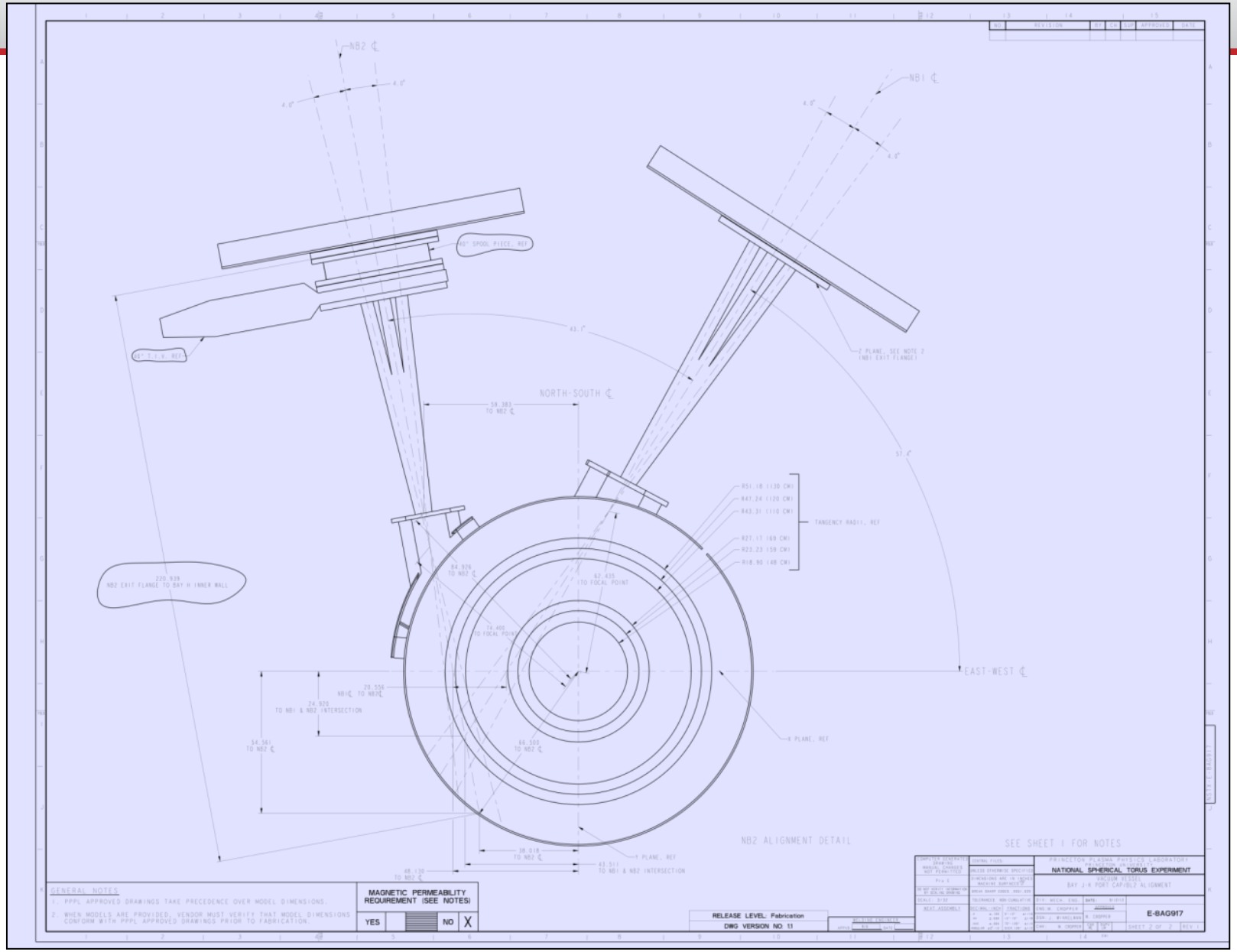
- **Grid fault - 10 ms block up to 20 times then halts accel**
- **Arc fault - disables arc ps; ends source pulse**
- **Crowbar - disables Accel high voltage; ends source pulse**
- **Ip trip - insufficient plasma current; ends NBI**
- **Loss of PLC interlocks - disarms accel ps**
- **Thermocouple trip - disarms accel ps**

NBI Power & Controls - perveance

- *Arc power proportional to accelerated ion source current*
- *Accel voltage well regulated w/ High Voltage Switch Tube => 60-100 keV range*
- *Perveance = Accel current / (Vaccel $^{3/2}$) fixed optics, Pierce geometry, and GG R tap*
- *Operators match arc power to accel voltage for optimal perveance*
  - *~ Approximately 1.73 micropervs*
  - *~ balancing charge density and space charge blowup in beam*
  - *~ optimized at minimum gradient grid current*
  - *~ shot to shot variations as well as all new setpoints for a change in Vaccel*
- *However, Accel can oscillate so high voltage system requires adjustments also*
  - *~ Tune HVST filament current for smooth turn on and sufficient pulse length*
  - *~ Iterative process*
  - *~ HVST Fil I controls have been improved for reliability and rapid response*

•Take dead aim, shoot straight, don't miss…

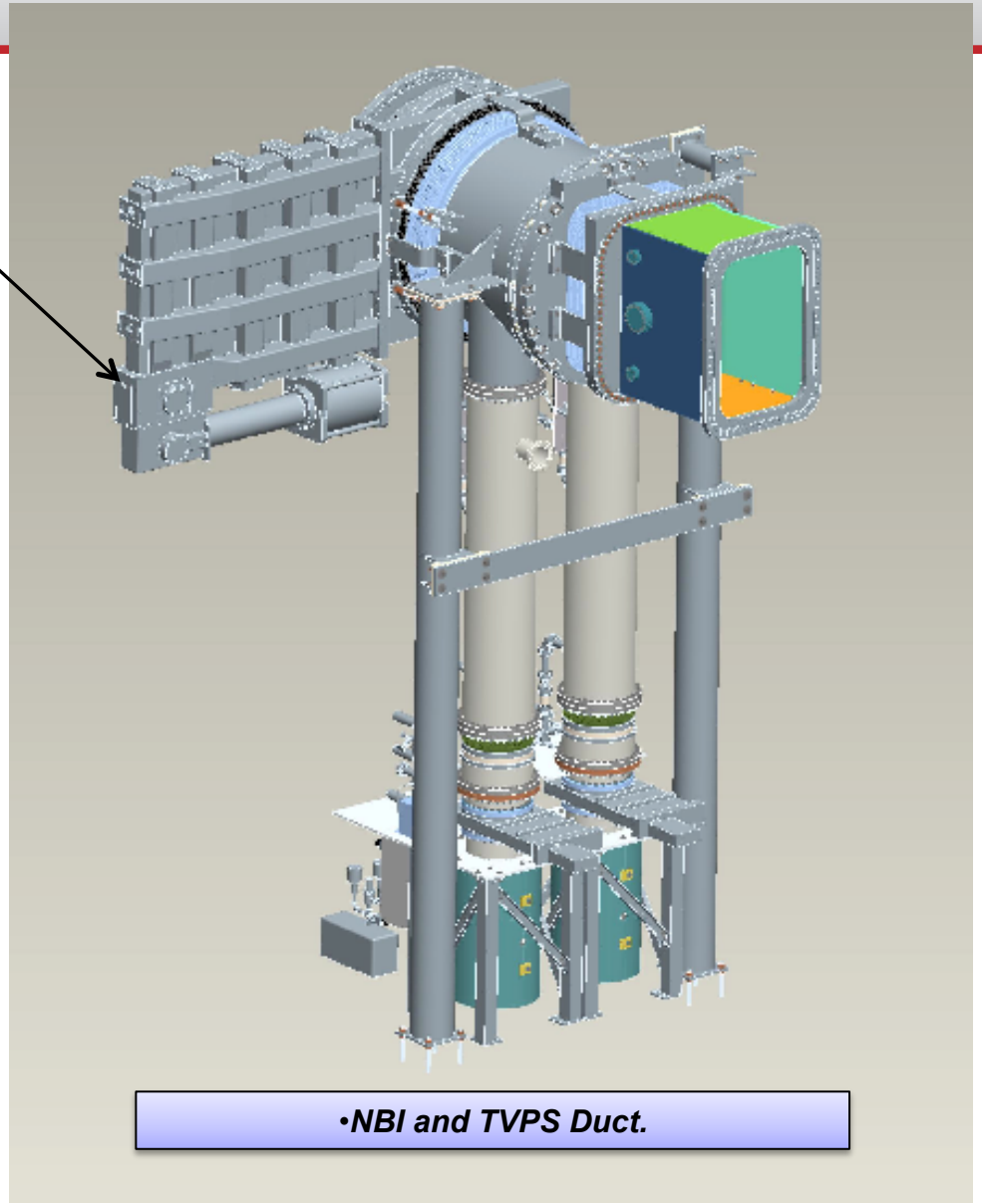
•NBI BL Alignment… 110, 120, 130 cm tangency radii



NBI Duct and Torus Vacuum Pumping System (TVPS)

•2480
•2485

•BL2 TIV

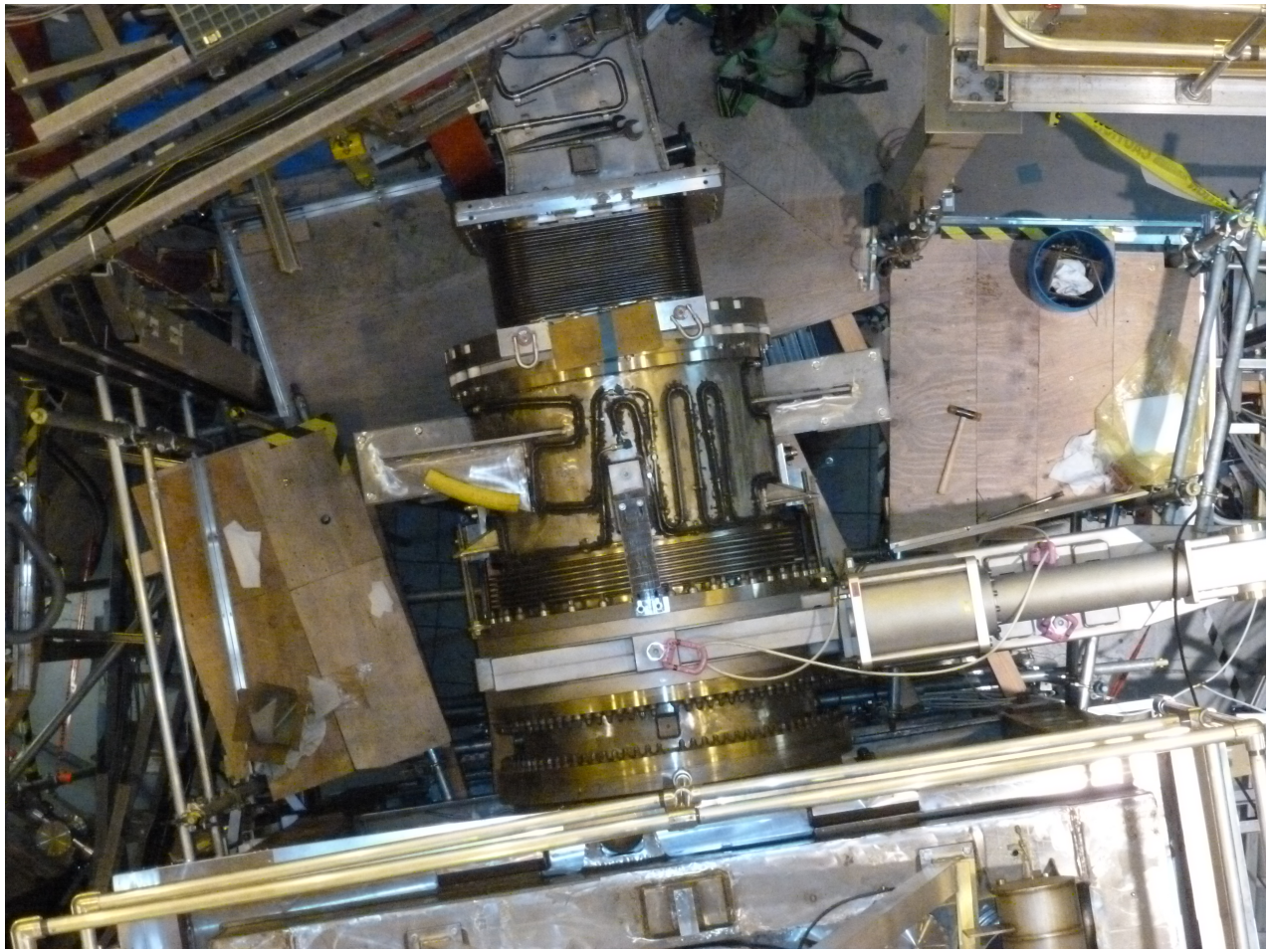


•Bay K side

•NBI and TVPS Duct.

NBI Duct and Torus Vacuum Pumping System (TVPS)

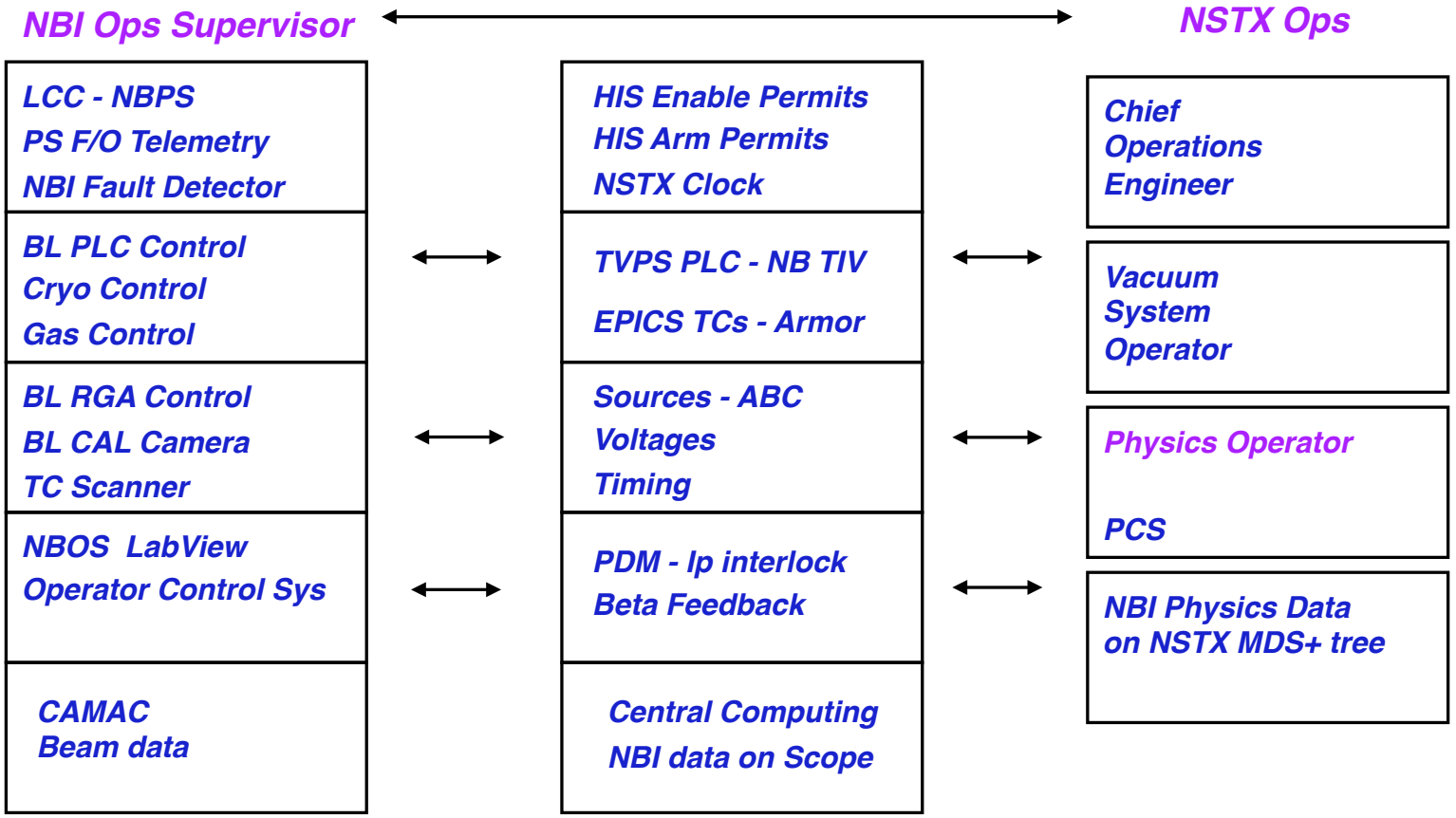
•2480
•2485



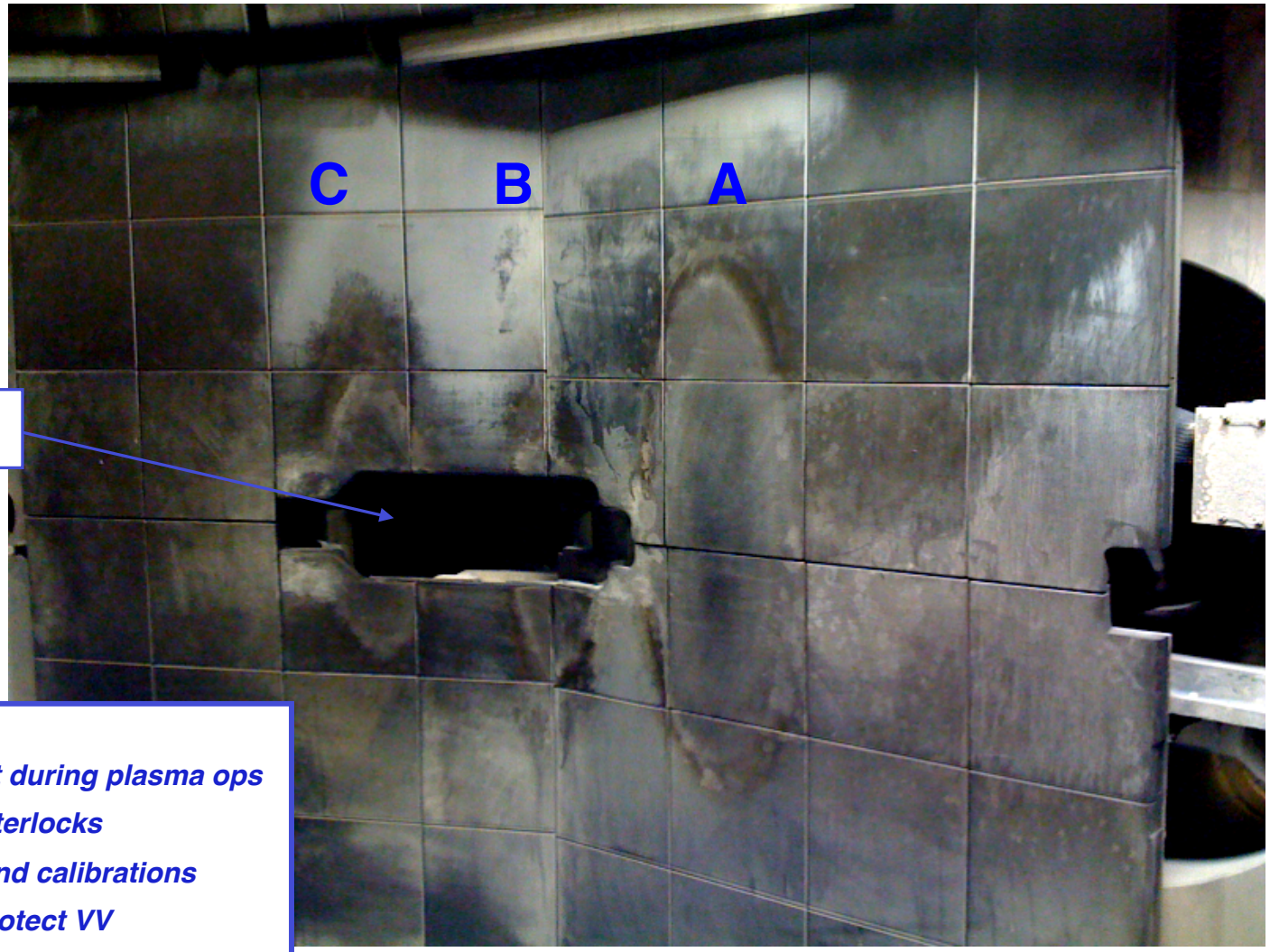
•NBI and TVPS Duct completed

NBI BL 1&2 Upgrade Power & Controls - Handshakes

Neutral Beam Control System & Interfaces to NSTX



Existing Armor: 3 Beam Footprints



Diagnostics viewport with backstop tiles

ATJ Carbon tiles

No beam impingement during plasma ops

Ip and Ip redundant interlocks

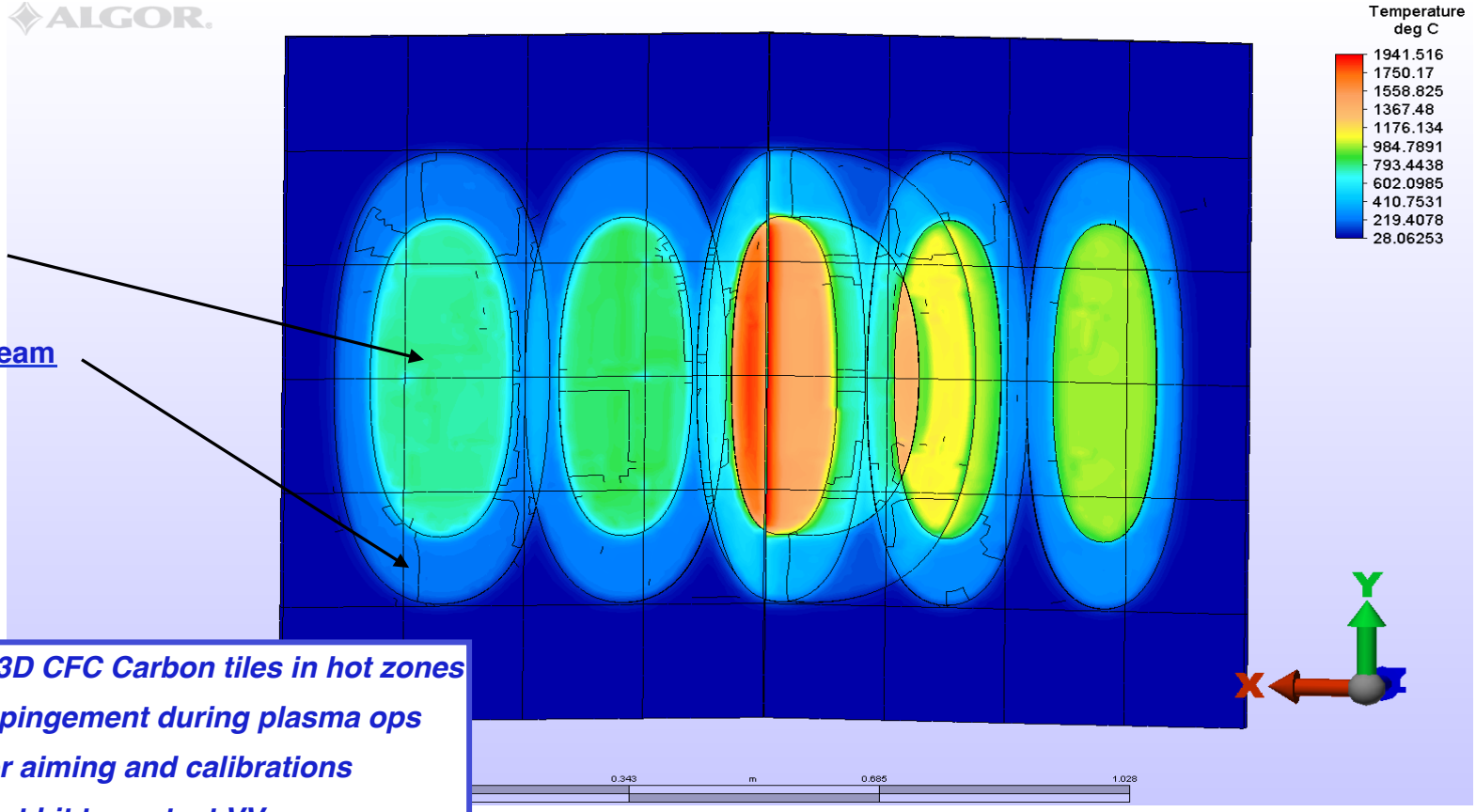
Backstop for aiming and calibrations

Takes a direct hit to protect VV

Sacrificial - might require tile replacements

New NBI Armor Position - 6 Beams

•2460



Upgrade to 3D CFC Carbon tiles in hot zones

No beam impingement during plasma ops

Backstop for aiming and calibrations

Takes a direct hit to protect VV

Sacrificial - might require tile replacements

Added true redundancy to Ip and R Ip

Added Thermocouple Scanner for Armor

Same idea… better tiles

NBI Armor installation complete…

•2460

•Ready for CD-4

- *Call NBOS on our hotline phone or at x2889*

- *For the next shot we want*
  1A at 90 keV @ 60-1000 ms; 1B at 80 keV @ 80-1000 ms
  2B at 80 keV @ 80-1000 ms; 2C at 70 keV @ 120-1000 ms
  Go on the next plasma shot cycle.

- *The NBOS may require multiple beam clock cycles to institute requested changes and retune sources. In many cases conditioning on the calorimeter is required.*

- *When ready direct the COE to go for a shot. When the clock starts, NBOS will raise the calorimeter and the Vacuum Operator will give the permissive to open the TIV.*

- *If the plasma ends early, the NBI will shut off when the plasma current drops below about 250 kA.*

- *NB beta feedback allows for modulating the beam via PCS based on algorithms. 20 ms blocks can be issued to regulate power.*

- *The NBOS can use the NBI timing page to preprogram notches or cyclic modulation also on a per source basis.*

- *NBI sends voltage, current, source power, and total power waveforms to the tree.*

In Conclusion …

- ***The Physics Operator and NBOS work hand in hand to produce correctly configured NBI heated plasma shots and to hold off the beams if they are not requested.***
- ***The Physics Operator needs to provide feedback to the NBOS in anticipation of changes to allow time for adjustments.***
- ***The Physics Operator has to pace the experiment to coordinate activities in the Control Room.***
- ***The Physics Operator is the focal point of the experimental run day and must maintain good conduct of operations, communications, and situational awareness to get the best possible data set for the Session Leader.***
- ***The Physics Operator can and should initiate troubleshooting activities if needed***
- ***The Physics Operator needs to log a sufficient stream of information so that a competent Physics Operator can recreate that shot at a later date.***

Vaya con Dios…