Extent of condition reference materials

Meeting with engineers to determine their concerns for extent of condition 5/19/2015

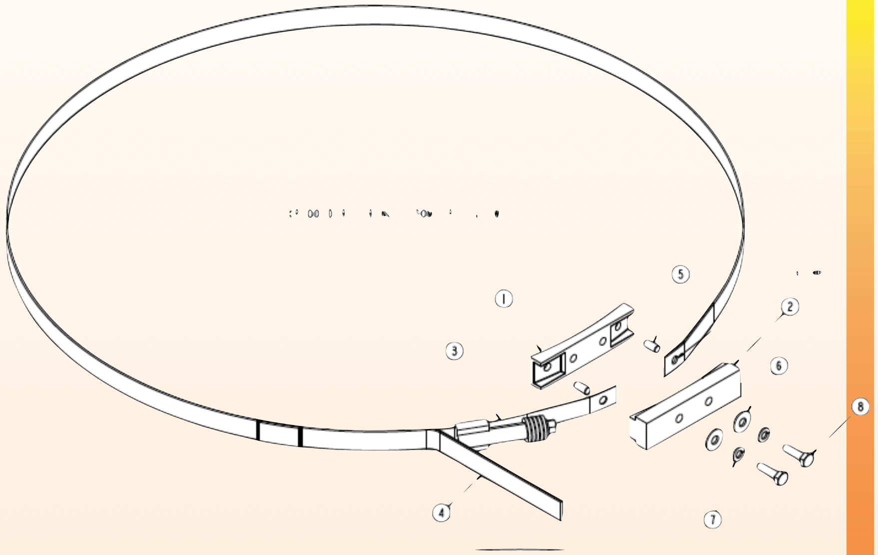
9:00 Center Stack Project - Larry Dudek (discuss walk downs)
9:30 Center stack configuration and hookup (Raftopoulos)
  TF connections (Raftopoulos)
10:00 Ground plane connections (Raki)
10:30 TF connections (Raftopoulos)
11:00 Water connections (Atnafu / Titus)
11:30 Integrated testing/startup – C. Gentile / Al von Halle
1:00 Test Cell Ground fault detector (Schneider)
1:30 DCPS System – S. Gerhardt / Tim Stevenson

Analysis of bakeout conditions

A. Brooks

Larry Dudek

White Paper

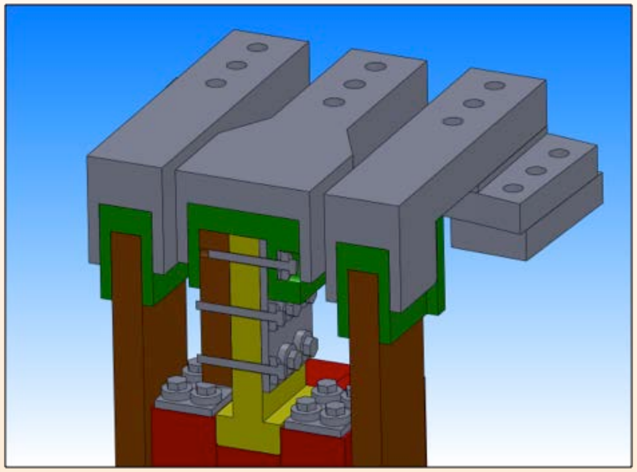


- Following included in white paper
  - Grounding Clamp - NEW design (Raftopoulos)
  - Grounding of OH Preload Assy - Design to solve underway (Raftopoulos)
  - OH Water tube insulator/ supports - New Design passed electrical tests (Atnafu)
  - Grounding conductors missing on floor mounts to busswork (Atnafu)

PPPL

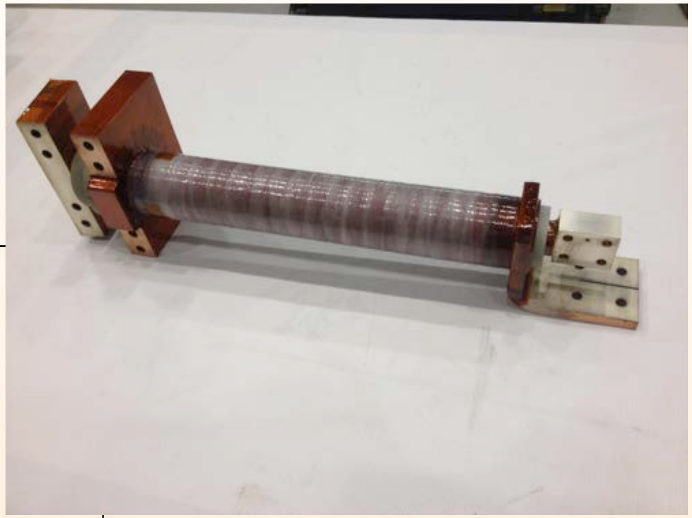
White Paper

- –OTF Finger Supports (Sibilia)
  - ✦Newly identified cracking of G10 cups.
  - ✦Adding structural adhesive should eliminate the problem but will make future disassembly more difficult
- –Electrical Contact Surfaces (Sibilia)
  - ✦Stains found on TF joints
  - ✦Have price quote from local tester to perform analysis



PPPL

White Paper



- OH Coaxial Bus (Atnafu)
  - Design change to eliminate epoxy potting of the
  - Concern regarding bending in center conductor
  - Plan to inject epoxy after installation to fill gap between G10 and copper

PPPL

Lead Extensions

- Original plan was to use brazed assemblies
- Relatively highly stressed parts required CuCrZr which could not be brazed and maintain strength - went to ebeam weld joint
- Tested E-Beam with Class 2 CuCrZr material
- Production parts were specified with harder grade of CuCrZr
- First set of parts were unmanufacturable with specified alloy. Weld cracking due thermal stresses of E-beam welds
- Second set also required redesign due to as-built conditions found in the umbrellas requiring shortening by 1 inch
- Fatigue life of one Type (12 pcs) was insufficient due to as-built location of weld.
  - Replacements ordered with new weld location for changeout after first year.
- Changes were expected to allow for final fitup via field drilling of holes. Last minute decision to drill holes at supplier required relocating holes during installation.
  - No indication of any issues with these pieces, but they will also be replaced during installation of parts above.

PF1C Can Heat Load

- Late in the design, discovered can had line of sight to divertor area
- Space is extremely limited
  - Heat shield was eliminated due to CHI concerns
  - Decision was to “scan” the plasma to avoid large heat build up
- Countermeasures
  - Added TCs to monitor
  - Added belly band around coil to minimize stress at welds due to thermal excursions
  - Added weld in the corner area to maximize strength

PPPL

EXTENT OF CONDITIONS

IP-3572

Final Center Stack Installation Activities

IP-3565

NSTX-U Outer TF Lead Supports

Tuesday, May 19

Steve Raftopoulos

D-NSTX-IP-3572

- IP-3572 guided installation of and connections to the Center Stack:
  - Install Centerstack Assembly
  - Install ceramic break assemblies
  - Install upper and lower CHI flag assemblies
  - Connect Organ Pipe Diagnostics
  - Install OH bus
  - Install Upper and Lower PF1 Buss
  - Install cooling hoses for- inner PF coils, ceramic breaks, CHI and IBD
  - Pre-assemble TF Flex buss to OTF lead extensions
  - Install TF Flex Buss and supports- upper and lower
  - Install upper and lower umbrella lids
  - Connect TF bundle cooling hoses

D-NSTX-IP-3565

- IP-3565 guided the installation of the TF Lead Support System.
  - Support segments and weld gussets
  - G-10 insulating boxes (3 types)
  - Connection stiffeners (3 types)
  - Shimming and/or potting
  - Bolts and spherical washers

Managing Field Work

- Procedure approvals (both)
  - Author – Steve Raftopoulos
  - ATI – Joe Winston
  - RLM – Erik Perry
- Coordinated via the work control center
  - Daily coordination meetings with larger audience
  - Twice weekly meetings with WCC group
  - Constant communication between WCC group
- When a field change or engineering input was needed someone from WCC group (typically Raftopoulos) would interface with appropriate parties in the MED and FOM divisions.
  - Custom shimming the TF flex straps to achieve alignment
  - Super-bolt lubrication and torque determination
  - Cooling tube support brackets
  - TF Connector support brackets

Field decisions

- Difficulty: TFOL flags and the Inner TF leads did not point at each other.
  - Solution: Custom machine angles onto the spacer blocks and/or add wedge-shaped spacers to get the electrical faces to connect.
- Difficulty: Specified structural adhesive not available:
  - Solution: Hysol/glass bead slurry was substituted, but abandoned for shimming when the fit between parts was deemed tight enough.
- Difficulty: Support brackets for the OH cooling hoses not included in design.
  - Solution: Design based on the support brackets used during NSTX campaign, was field fit.

Concerns

- Cracked G-10 in the TF Lead connector support.
  - Four (of 12 in upper umbrella) middle support G-10 isolator are cracked. None appear to be cracked in the lower umbrella.
  - Structural shim is now available. This should alleviate concerns with fit-up and cracking
- OH Coax connector – Pot with Hysol epoxy to eliminate all motion between conductors.
  - Will add safety factor to OH electrical connection, however holes will be drilled through the coax outer wall and the G-10 insulation. If the potting leaves voids in the G-10 holes, insulation may be compromised.
- OH ground plane - lower grounding point.
  - Has benefit, however the installation of a lower grounding location is not without risks. Many energized components in the area (PF-1A and PF-1B leads are to the left/right and the OH coax is below the only location that we can add a lower grounding point.
- Tarnished silver plated TF electrical flags
  - Silver plated electrical contact faces have discolorations. Present at both upper and lower umbrella locations.
  - Contacted vendor for analysis.

OH Ground Plane Lower Grounding option

OH GROUND PLANE CONNECTIONS

S.RAMAKRISHNAN

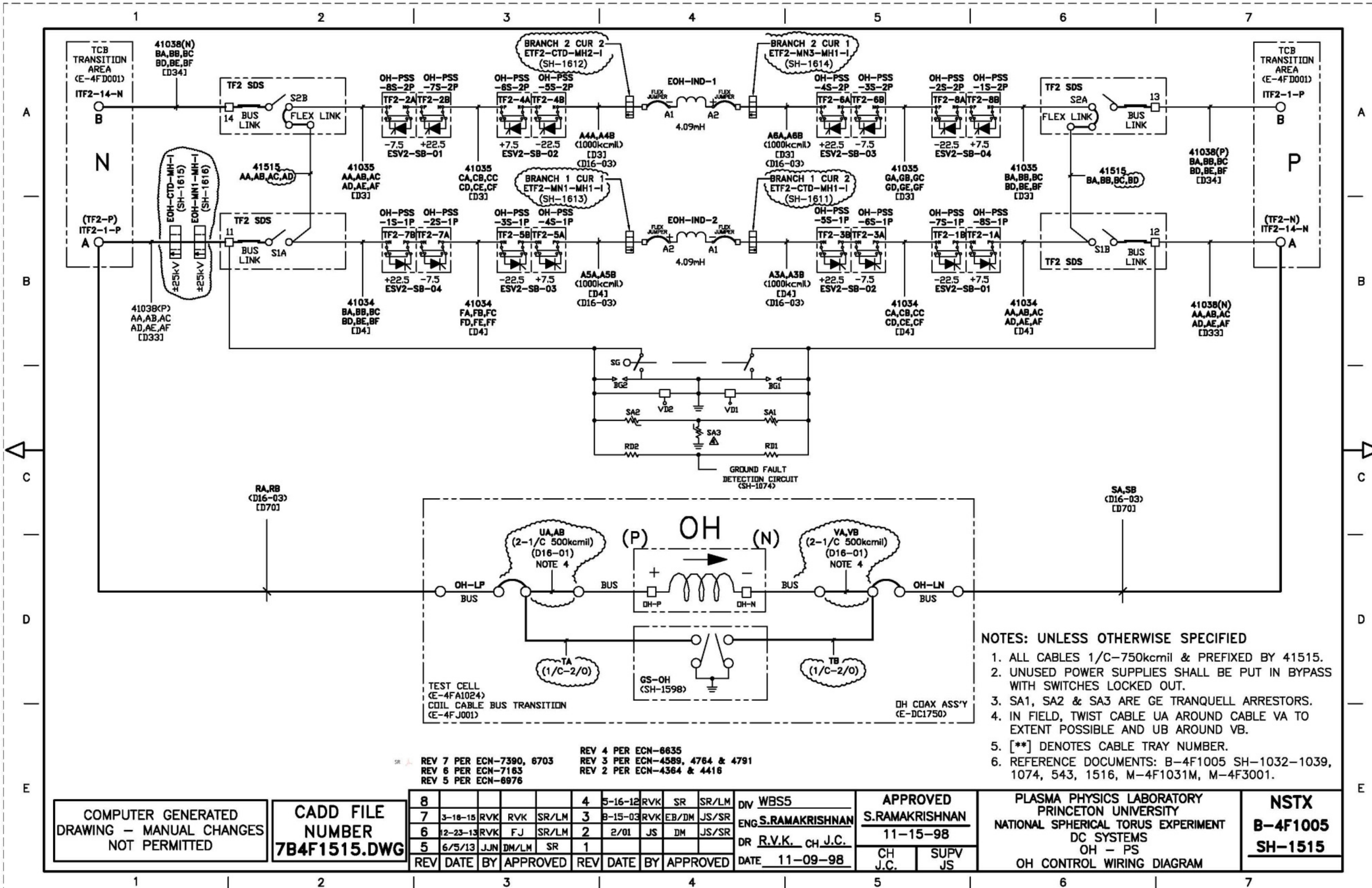
NSTX U Power System

May 19 2015

OH GROUND PLANE

- OH POWER LOOP WAS DESIGNED TO PROVIDE 6KV +/-24KA.
- SIX TRANSREX POWER SUPPLY SECTONS EACH OF 1KV ARE CONNECTED IN SERIES IN BOTH THE FORWARD AND REVERSE BRANCHES – IN ANTI-PARALLEL

OH SCHEMATIC (6KV +/-24kA)



OH GROUND PLANE

- Floating Circuits
- Artificial Null through resistance network
- In OH maximum ground leakage current < 500mA (about)
- Total of four ground detection devices in all circuits
- One Ground fault
  - One timed OC (DBB)
  - One device for Positive
  - One device for Negative
  - One Instantaneous (In TF added in 1989; in OH added in 2002)
- TF, OH have dedicated ground detection devices; All PFs are grouped together

OH GROUND PLANE

- Purpose
  - Industry practice is to provide Ground plane in electrical apparatus above 5kV,

    a) uniform distribution of electrical stresses

    b) Corona effects and

    c) facilitate proper insulation testing.

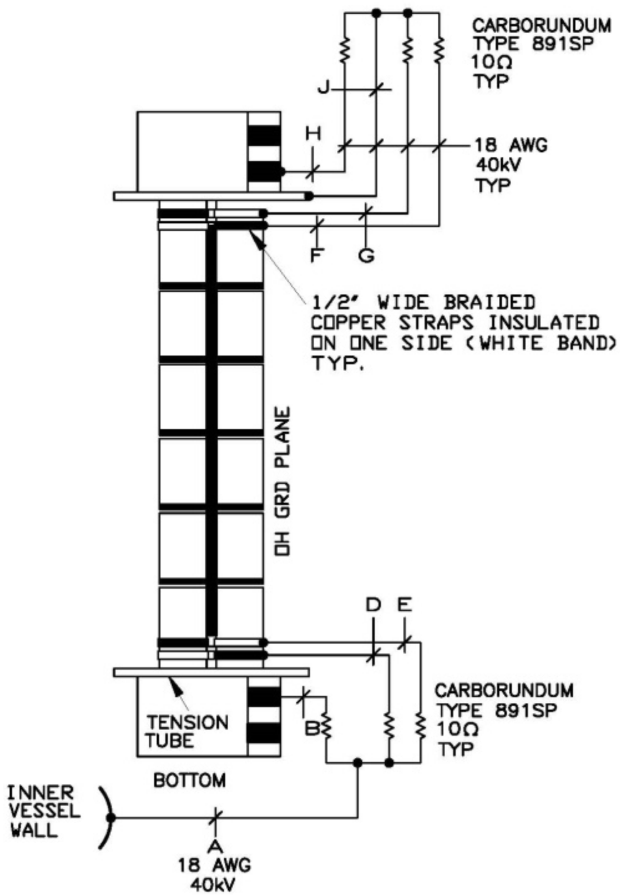
    d) facilitates ground fault detection

In NSTX OH system the operating voltage is 6kV and is a candidate for the provision of a ground plane.

OH GROUND PLANE

- Pre-Upgrade
  - Braid was provided around (without forming a loop).
  - This was connected to Inner vessel via 10 ohm resistors
  - After the first OH ground problem in 2001 the design was reviewed and a new design was recommended – see Charlie Neumeyer's memo.

OH GROUND PLANE
PRE-UPGRADE DEPICTION



RELEASED FOR
FABRICATION / INSTALLATION
PPPL Drafting: jerome siegel

LEGEND

A – INNER VESSEL WALL
B – TF HUB ASSY

D – OH G.P. SOUTH
E – OH G.P. NORTH
F – OH G.P. SOUTH
G – OH G.P. NORTH
H – TF HUB ASSY
J – OH TENSION TUBE

NOTES:

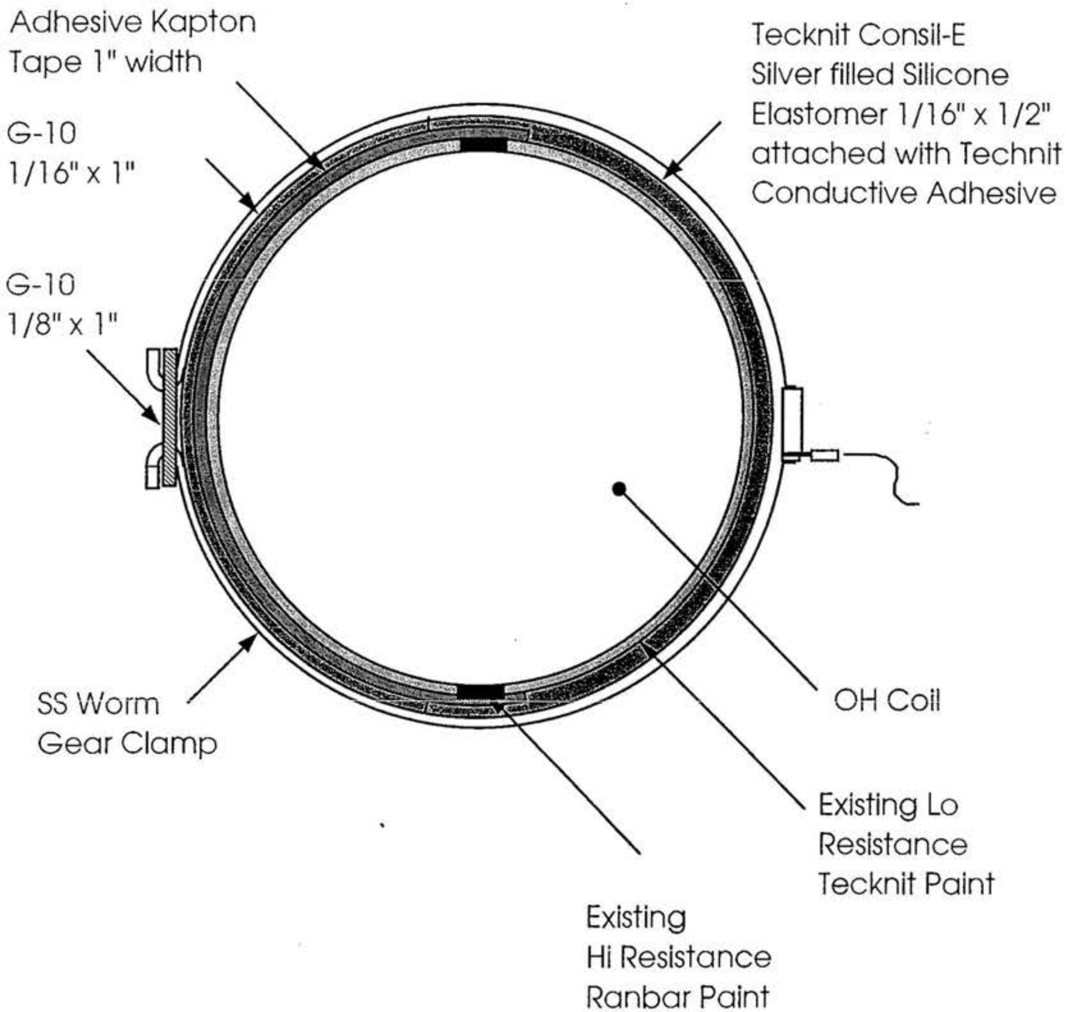
1. THE OUTER SURFACE OF THE OH COIL IS PROVIDED WITH CONDUCTIVE PAINT AS FOLLOWS:

A) A HIGH RESISTANCE SIMICONDUCTIVE VANISH (RANBAR B-2-135, 2000-5500 ohms PER SQUARE) OVER THE ENTIRE SURFACE.

B) 12 SEGMENTS OF LOW RESISTANCE PAINT (TECKNIT P/N 73-00081 FOR 1 GALLON CAN – SAME AS P/N 73-00025 FOR 16Oz CAN) OF CONDUCTIVITY 1 OHM PER SQUARE. THE BANDS PROVIDED BY THE HIGH RESISTANCE LIMITS THE INDUCED TOROIDAL AND POLOIDAL CURRENTS.

C) THE UPPER TWO SEGMENTS AND THE LOWER TWO SEGMENTS OF LOW RESISTANCE PAINT IS CONNECTED TO THE INNER VESSEL VIA TEN ohm RESISTORS.

OH GROUND PLANE



OH GROUND PLANE

- Apparently there was not enough time to implement the new design
- The braid per old design continued
- Per Jim Chrznowski's request the writer conveyed the recommended ground plane requirements

OH GROUND PLANE

- 1. Provide a ground plane for the OH Coil using a conducting paint of 200 Ohms per square.
- 2. Provide leads to ground (Inner V) from this plane using a 10 ohms. 20W resistors.
- 3. Provide an overcoat on the ground plane using a non-conductive paint.
- 4. Provide insulation for diagnostics/ instrumentation in the vicinity

I want to add that two ground connections be provided – one at the top and another at the bottom

OH GROUND PLANE

Extract from JC's procedure for the upgraded center stack

7.6.4 Mask off eight inches from either end of the OH solenoid. (See Figure 8)

7.6.5 Using a roller, carefully paint uniformly the outer surface of the OH solenoid with the conductive paint. Be sure not to paint either end of the masked off areas of the OH coil.

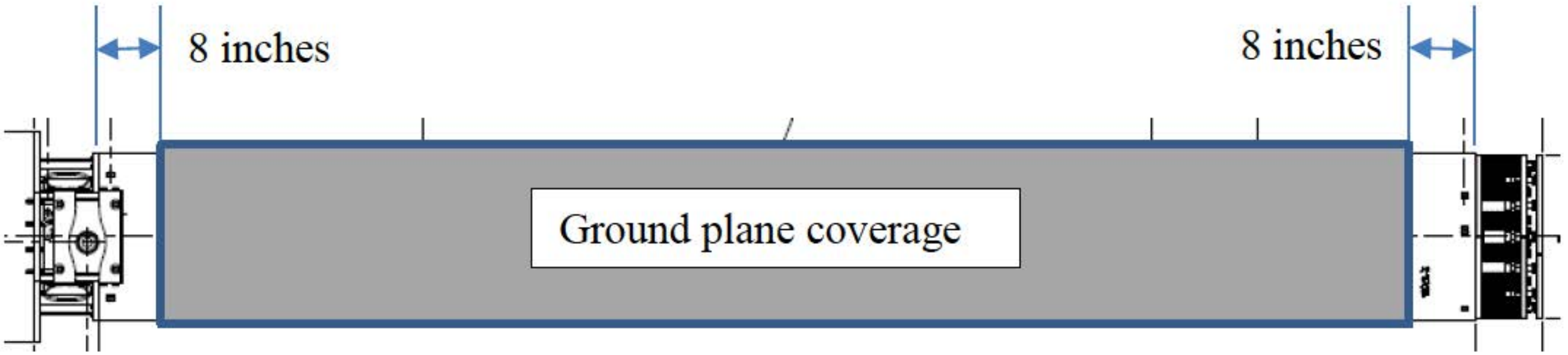


Figure 8- Outer OH Ground Plane

13.78 ft long x 21.6 dia.

OH GROUND PLANE

- I understand that per Steve's directions following drawings are being generated:
  - E-DC1942 - Center Stack Grounding Scheme
  - E-DC1943 - Upper OH Coil Coolant Tube Support Details (model & details complete, pending review/approval)
  - E-DC1944 - Installation of OH Coil Coolant Tube Supports
  - E-DC1945 - OH Ground Plane Braid and Clamp Assembly (model started)
  - E-DC1946 - OH Compression Ring Insulator Spacer (model & details complete, pending review/approval)
- Height over which the paint is applied: 13.8' (approx)
- Diameter of the surface: 21.6" (approx.)
- Approx. resistance top to bottom – 500 Ohms

OH GROUND PLANE

Charlie's memo in 2001:

- Upon removal of the OH coil to repair the ground fault, some pitting and was noticed on the surface of the Tecknit ground plane paint over which the existing ground plane connector was installed. See figure 1, area just above flexible braid.

Figure 1 - Pitting Under Existing OH Ground Plane Connector

It appears that the existing ground plane connector, consisting of a flexible braid pulled tight around the coil and secured with a G-10 clamp, does not make good contact with the ground plane. Although the current should be small (around 100 mA) and short lived (see reference [1]), it appears to be sufficient to cause the observed arcing and pitting if the contact is poor. In fact, during recent troubleshooting activities related to the characterization of the OH ground fault, the two connectors on the top of the coil were very loose and virtually open circuited

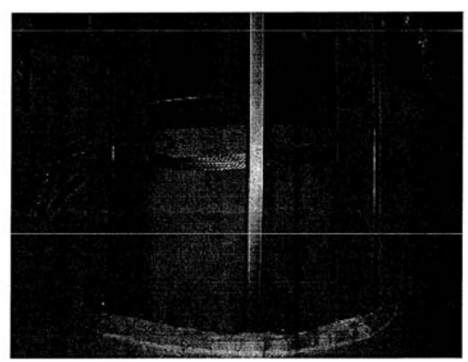


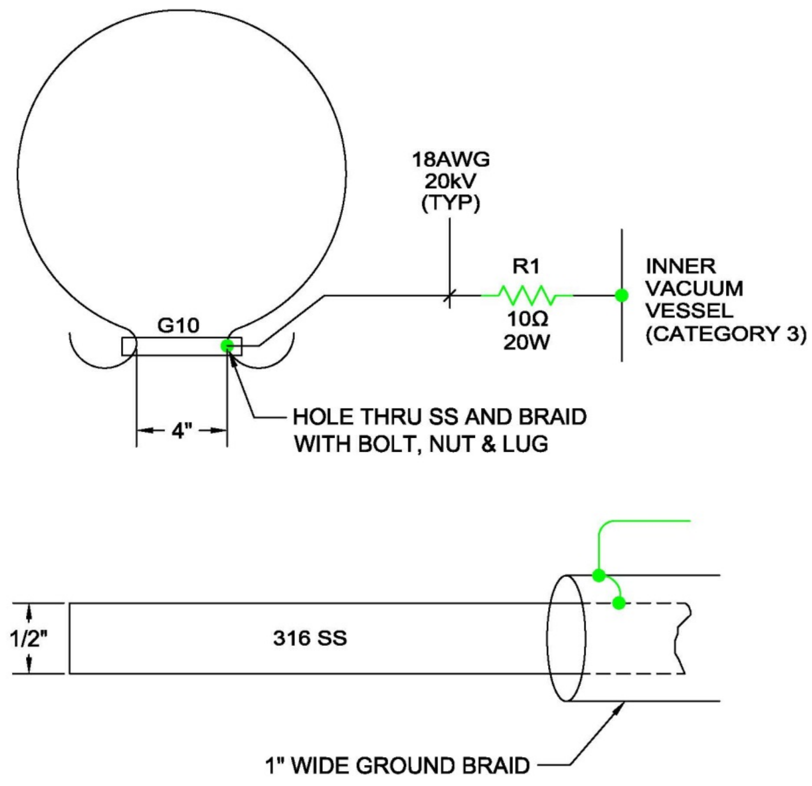
Figure 1 – Pitting Under Existing OH Ground Plane Connector

OH GROUND PLANE

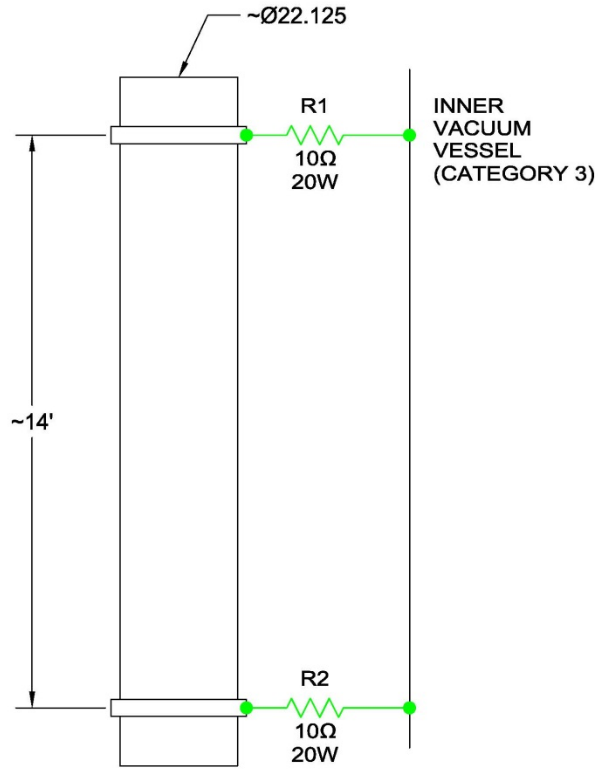
- Better to provide connections to paint from a) Top and b) Bottom
- Periodic resistance measurements of the paint from top to bottom can be taken.
- Good approach is to use a design shown in slide 8. If Technit is not available 3M products can be used – conductive rubber tape. Check temp. withstanding capability
- Tinned tubular (flexible) copper braid can be used as an alternative approach
- Spring steel ½" wide SS strip – approx 6' long
- Insert the SS strip through the braid (Spring Steel - Stainless Spring Steel Strip | Precision Steel ...)
- Bend the ends of the strip
- Bolt the braid on to the projecting portions of the SS
- Keep 4" gap after going around the painted portion
- Provide G10 strip
- Provide insulating bolts clamping the strip with springs
- Connect one end of the SS ring to the I V through a 10 ohm resistor – one at top and another at bottom.

OH GROUND PLANE

OH GROUND PLANE



OH GROUND PLANE



OH GROUND PLANE

Search Keywords, part numbers, etc

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3M™ XYZ-Axis Electrically Conductive Adhesive Transfer Tape 9764

Part Number 9764

- Print
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3M™ XYZ-Axis ECATT 9764 is a double sided tape with one side removable, conductive fabric based isotropically electrical conductive tape. Conducts electricity through the thickness (Z-axis) and in the plane of the adhesive (X, Y planes)

- Easier rework as greater face side to back side adhesion delta
- Easier rework version of 9732
- High and Low adhesion sides
- Isotropic XYZ-axis electrical connectivity

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Overview | Documents

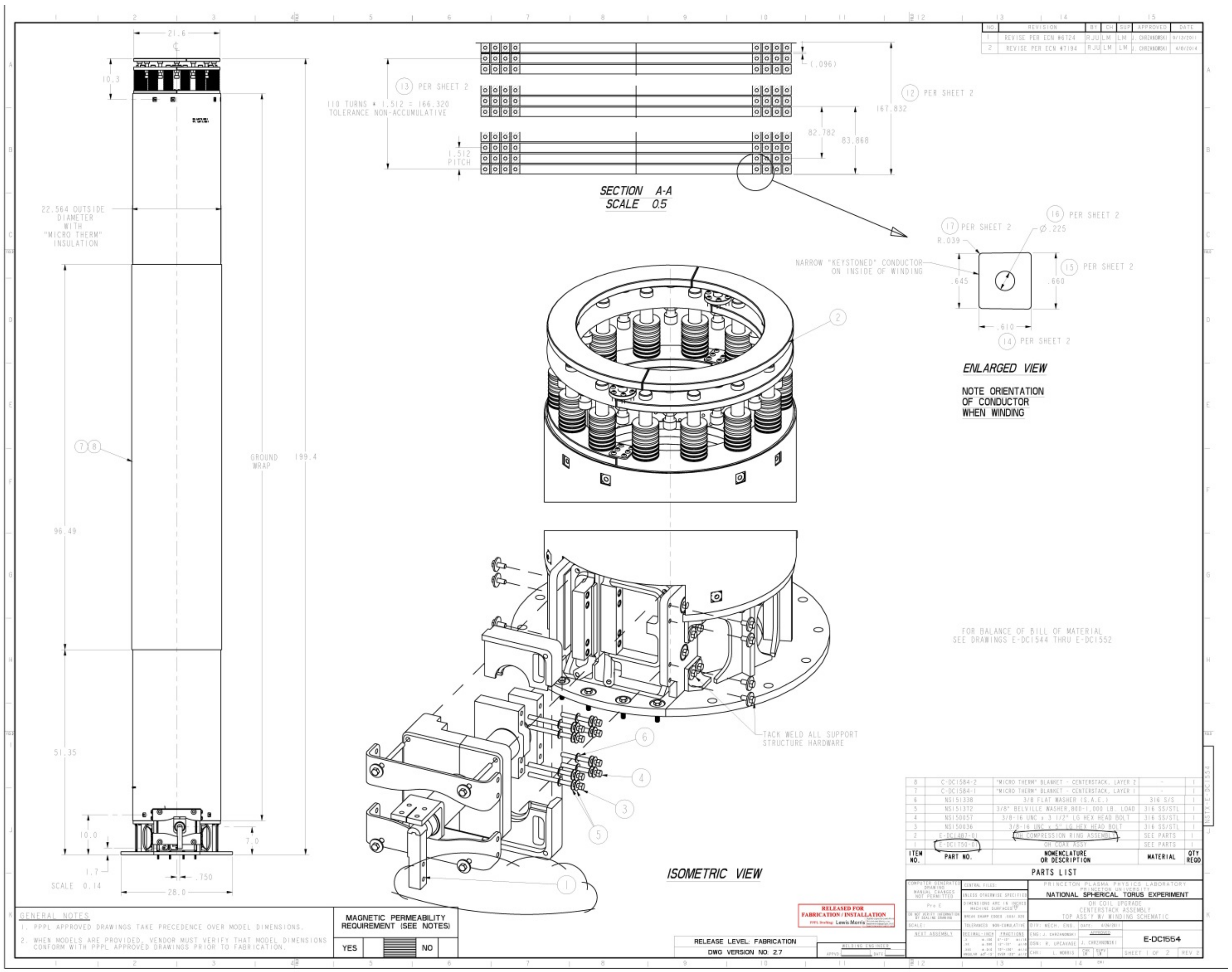
Specifications

Adhesive Type	Conductive Acrylic
Application Category	EMI/EMC Applications , Bonding
Applications	Antenna Bonding (with Grounding) , Flex Stiffener Bonding (with Grounding) , Grounding , Static Dissipation , Flex Bonding (with Grounding) , EMI Shielding (with Grounding) , Metal to Metal Bonding (with Grounding)
Conductivity Direction	XYZ-Axis Conductive
Conductivity Filler Type	Scrim
Product Series	9764
Total Tape Thickness without Liner	6 mil
Total Tape Thickness without Liner (metric)	0.15 mm

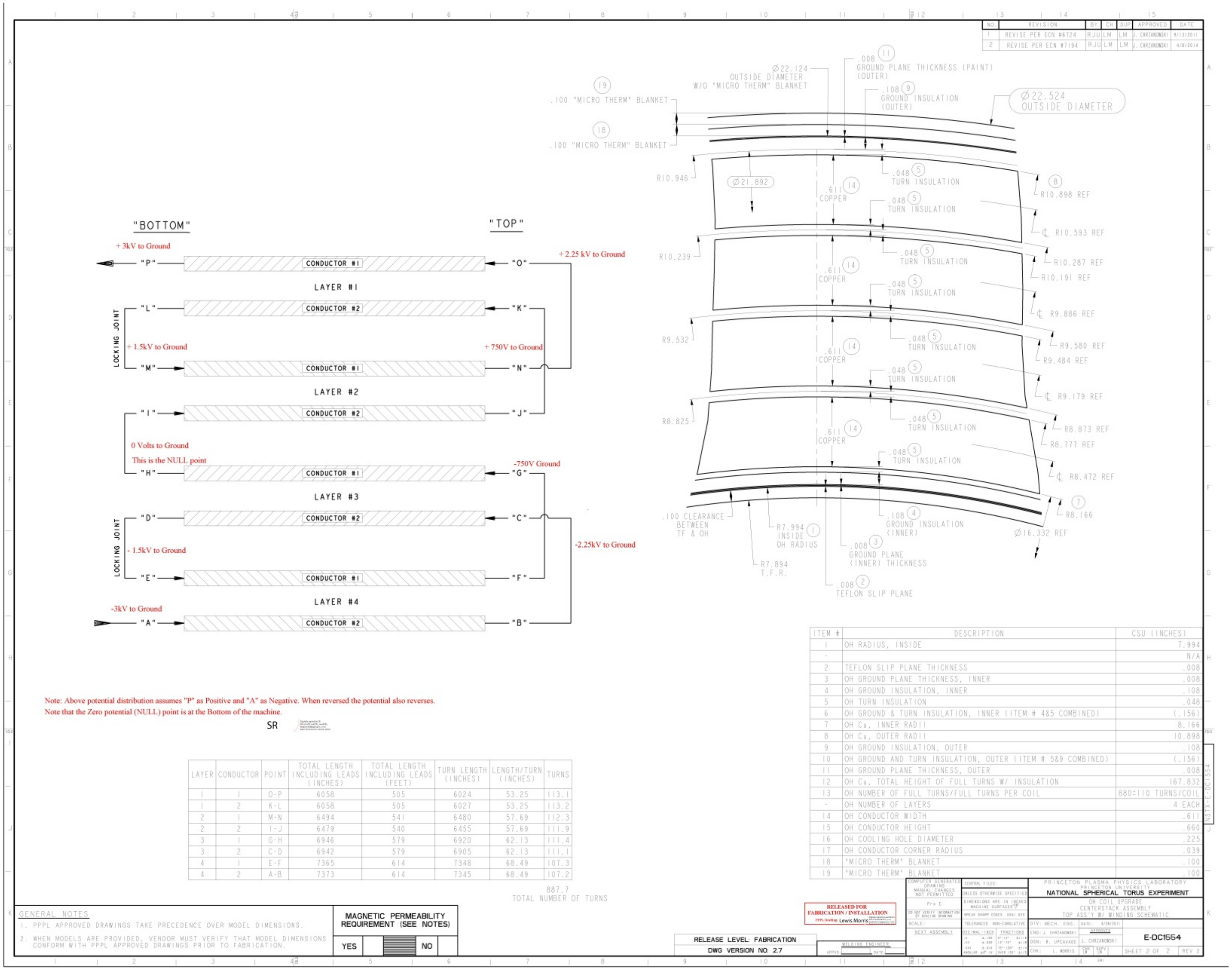
Product Disclaimer

- The technical information and data shown on this page should be considered representative or typical only and should not be used for specification purposes.

OH GROUND PLANE



OH GROUND PLANE



LAYER	CONDUCTOR	POINT	TOTAL LENGTH INCLUDING LEADS (INCHES)	TOTAL LENGTH INCLUDING LEADS (FEET)	TURN LENGTH (INCHES)	LENGTH/TURN (INCHES)	TURNS
1	1	O-P	6058	505	6024	53.25	113.1
1	2	K-L	6058	505	6027	53.25	113.2
2	1	M-N	6494	541	6480	57.69	112.3
2	2	I-J	6479	540	6455	57.69	111.9
3	1	G-H	6946	579	6920	62.13	111.4
3	2	C-D	6942	579	6905	62.13	111.1
4	1	E-F	7365	614	7348	68.49	107.3
4	2	A-B	7373	614	7345	68.49	107.2

887.7 TOTAL NUMBER OF TURNS

ITEM #	DESCRIPTION	CSU (INCHES)
1	OH RADIUS, INSIDE	7.994
-		N/A
2	TEFLON SLIP PLANE THICKNESS	.008
3	OH GROUND PLANE THICKNESS, INNER	.008
4	OH GROUND INSULATION, INNER	.108
5	OH TURN INSULATION	.048
6	OH GROUND & TURN INSULATION, INNER (ITEM # 4&5 COMBINED)	(.156)
7	OH Cu, INNER RADII	8.166
8	OH Cu, OUTER RADII	10.898
9	OH GROUND INSULATION, OUTER	.108
10	OH GROUND AND TURN INSULATION, OUTER (ITEM # 5&9 COMBINED)	(.156)
11	OH GROUND PLANE THICKNESS, OUTER	.008
12	OH Cu, TOTAL HEIGHT OF FULL TURNS W/ INSULATION	167.832
13	OH NUMBER OF FULL TURNS/FULL TURNS PER COIL	880=110 TURNS/COIL
-	OH NUMBER OF LAYERS	4 EACH
14	OH CONDUCTOR WIDTH	.611
15	OH CONDUCTOR HEIGHT	.660
16	OH COOLING HOLE DIAMETER	.225
17	OH CONDUCTOR CORNER RADIUS	.039
18	"MICRO THERM" BLANKET	.100
19	"MICRO THERM" BLANKET	.100

EXTENT OF CONDITIONS

Water Systems and Connections

&

Coils Bus Bars

Tuesday, May 19

By: Neway Atnafu

Water Systems Overview

NSTX-U Water Systems Installation was completed using the following documents:

- Job Number: 9417****3200
- Work Planning Number: 1920
- P&ID Drawing #5GA522, Rev-2
- Procedures: D-NSTX-IP-3598 Rev-1, D-PTP-WS-08 Rev-3, D-PTP-WS-011
- NSTX Failure Mode and Effects Analysis: NSTX-FMEA-71-10 Rev-11

Water Systems Overview

NSTX-U Water Systems Installation took the following steps:

- IP, JHA, Work Permit and Blue Package was prepared
- Pre-job briefing was given to all personnel involved in the work
- All fabricated hoses and fittings were tested before installation
- The installation was completed in a step-by-step technique and using check lists to verify that all work was covered
- Hydrostatic and leak test was done on all installed systems and PTP performed

Problems and Solutions

The issues encountered during the installation of NSTX-U Water Systems and the stapes taken to resolve the issues:

- There was overflow in the TF Coils which reduced the amount of water flowing into OH and PF Coils. Temporary Fix: The flow in each TF lines were set manually using the ball valves. Permanent Fix: Currently Orifices are being installed per #D-NSTX-IP-3710

- There were some confusion with the flow requirement for the PF coils. The requirements were made clear and the flow was set within acceptable range.

- The flow switches on the PF-1 (BU, CU & CL) coils were not sensitive enough to measure the low flow rates. The flow switches were replaced with unibody flow switches

Problems and Solutions

The issues encountered during the installation of NSTX-U Water Systems and the stapes taken to resolve the issues:

- The flow switches on the PF-2, PF-4 & PF-5 coils were not sensitive enough to measure the flow rates. Temporary Fix: The return lines of two coils were teed into one venturi which doubled the flow rate and enabled the flow switches to read. Permanent Fix: There is a plan to install new venturis and re-arrange the flow switches

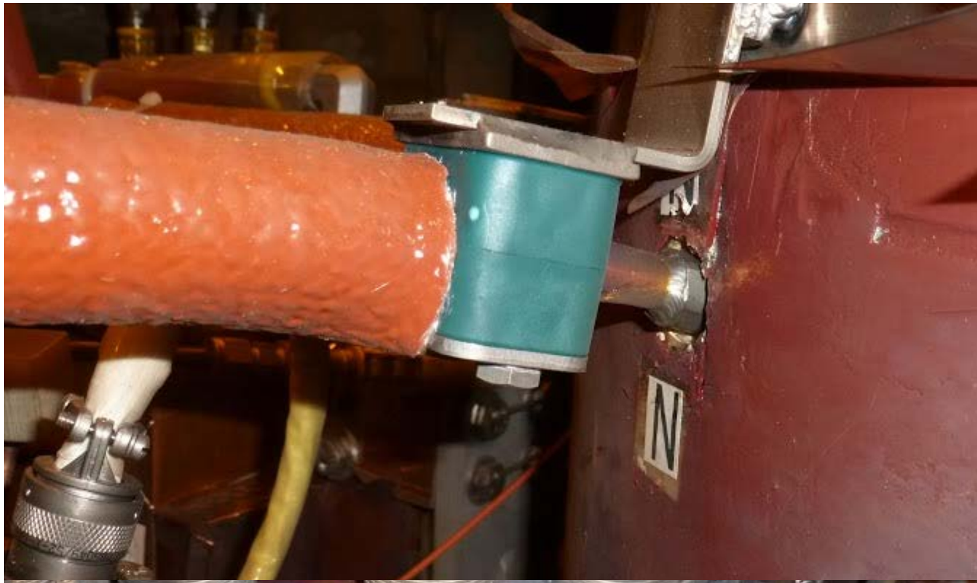
- The jumper hose between the outer and inner OH buses was too short (<1 ft) which created leakage during hi-pot testing of the machine. The jumper was replaced with a long hose which eliminated the leakage

- The issue with the thickness of insulation and thermal gradient between the OH and Inner TF Coils. There is a work going on to install PLC-Controlled water heater which will be able to provide OH Coils with a profile water temperature

Problems and Solutions

The issues encountered during CD-4 Shots and the stapes taken to resolve the issues:

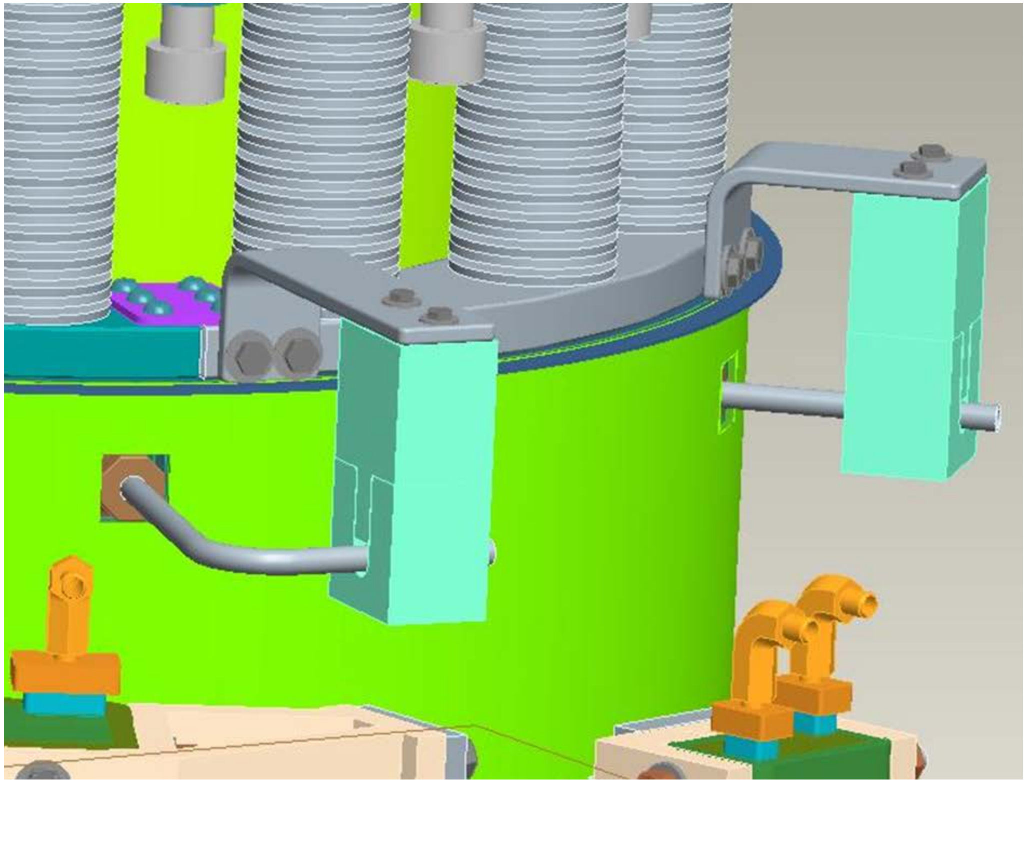
- Four of the eight Upper OH Coil Fittings were burned during the recent incident related to the OH Grounding Cable.
- The clamps which was holding the fittings were also damaged.
- The SS Braided hoses were intact.



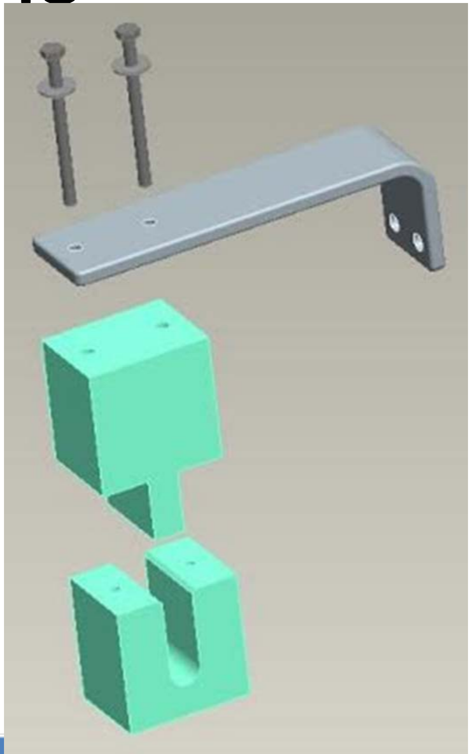
Problems and Solutions

The issues encountered during CD-4 Shots and the stapes taken to resolve the issues:

- Inspections and leak tests proved that no damage occurred to the OH Coils
- Hydrostatic test was performed and the coils passed the test
- New clamps are being designed
- The new clamps will replace all existing ones



Problems and Solutions



The issues encountered during CD-4 Shots and the stapes taken to resolve the issues:

- The New clamp drawing #E-DC1943
- Sample clamps were fabricated and passed 26 KV hi-pot test

New OH Clamps Hi-Pot Test Result					
Hi-Pot Voltage (KV)	0	5	9	17	26
Duration (Min.)	1	1	3	5	5
Measured Current (µA)	0	0	0	0	14
Calculated Resistance (GΩ)	∞	∞	∞	∞	1.86
The acceptable resistance is >= 1 GΩ					

Bus Bars Overview

NSTX-U Bus Bars Installation was completed using the following documents:

- Job Number: 9417****5501
- Work Planning Number: 1903
- Drawings E-DC1761, E-DC1758, E-DC1760 and E-DC1498
- Procedures: D-NSTX-IP-3525
- NSTX-CALC-54-01 and NSTX-CALC-55-01

Bus Bars Overview

NSTX-U Bus Bars Installation took the following steps:

- IP, JHA, Work Permit and Blue Package was prepared
- Pre-job briefing was given to all personnel involved in the work
- All fabricated bus bars were tested before installation
- At completion of the installation, joint resistances checked and hi-pot tested.
- The buses had gone though PTP with no issue.

Problems and Solutions

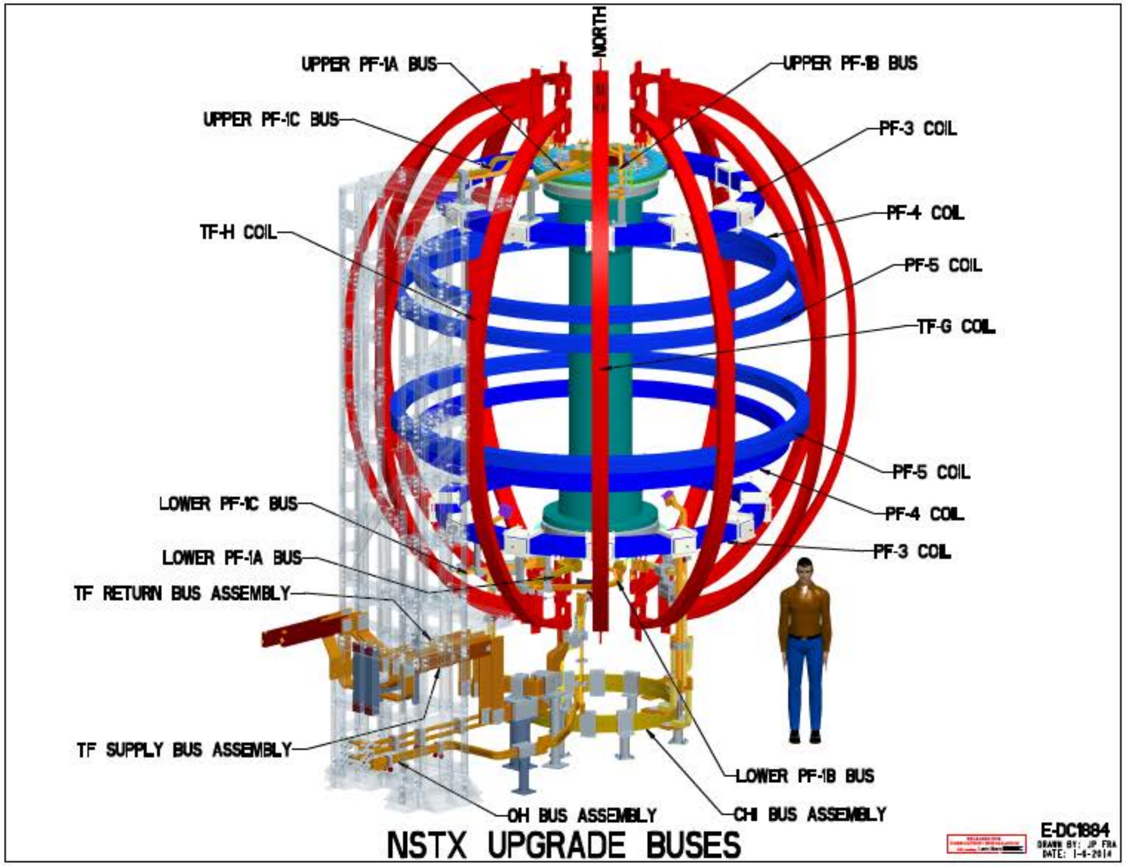
- The insulation on the Outer CHI Bus Bars changed color.
- Discussions were held between EEs, MEs and construction personnel.
- It was discovered that bakeout was done at 8 KA. Bakeout usually done at 4-6 KA
- The plan is to install temperature stickers and measure how hot the conducts get.
- If necessary, the insulation can be replaced with high-temperature materials.

Problems and Solutions

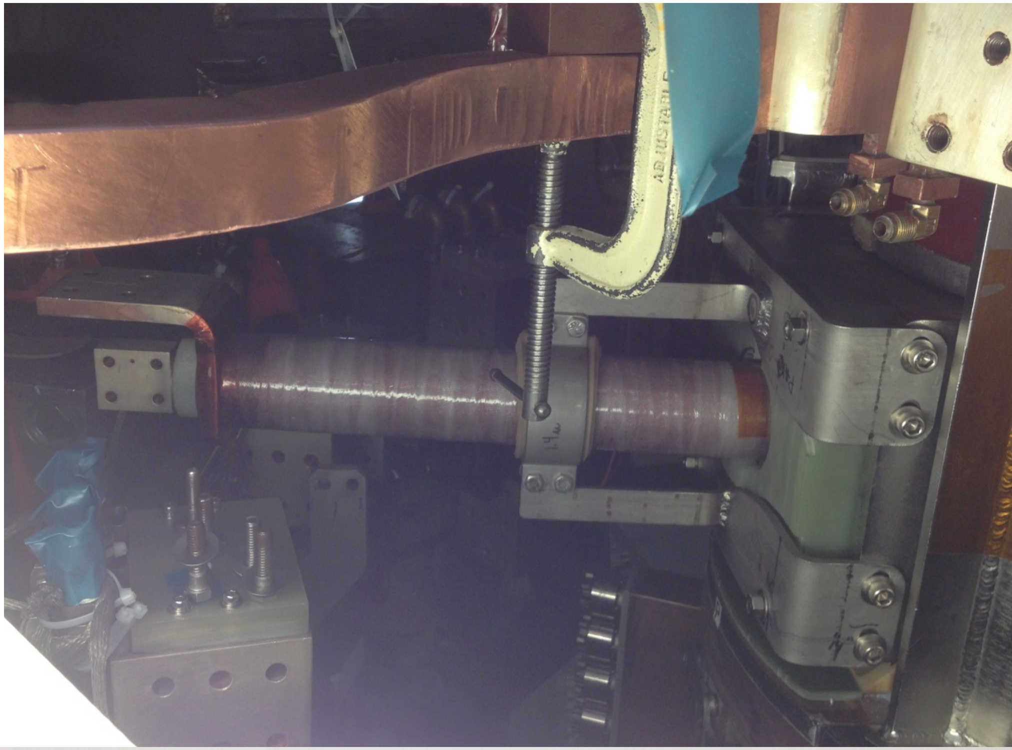
- The bus supports to the ground were not grounded appropriately.

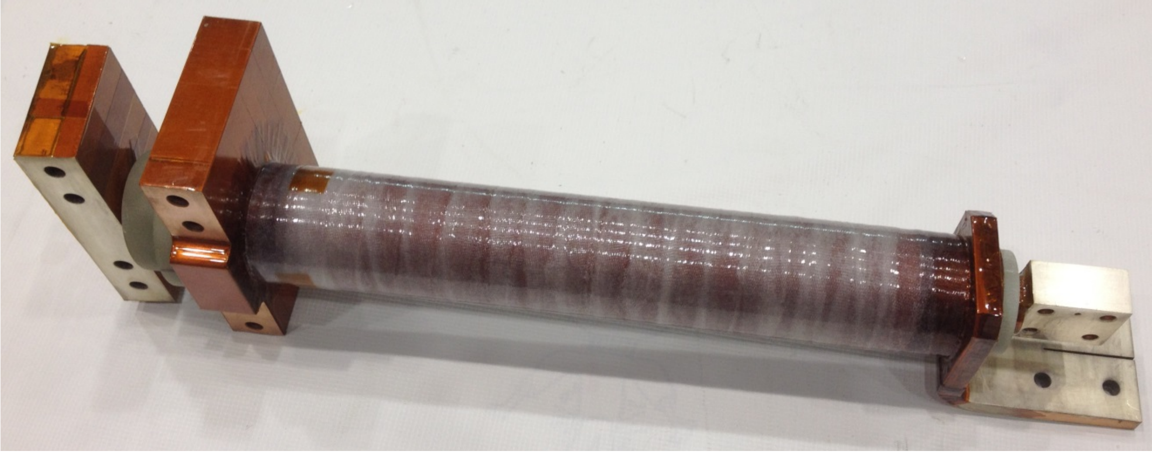
- Discussions were held between EEs, MEs and construction personnel.

- There is work going on to generate electrical drawings and install grounding cables which will connect these supports to the umbrella structure.



Problems and Solutions





- The OH Co-Axial Bus was not filled with Expoy as the parts were needed to be removable. #E-DC1750
- The radial clearance between mating parts was 0.01”
- Discussions were held regarding the need to fill the gap.
- The detail will have to be worked out, but there is a plan to fill the gap with epoxy in the field.

THANK YOU!!!

NSTX-U OH Fault
Extent of Condition Review

NSTX U
Integrated Testing / Startup

C. Gentile & D. Mueller

May 19, 2015

U.S. DEPARTMENT OF ENERGY Office of Science PPPL NSTX-U

Coll of Wm & Mary
Columbia U
CompX
General Atomics
FIU
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Lehigh U
Nova Photonics
Old Dominion
ORNL
PPPL
Princeton U
Purdue U
SNL
Think Tank, Inc.
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U Colorado
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U Maryland
U Rochester
U Tennessee
U Tulsa
U Washington
U Wisconsin
X Science LLC

Culham Sci Ctr
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Inst for Nucl Res, Kiev
Ioffe Inst
TRINITI
Chonbuk Natl U
NFRI
KAIST
POSTECH
Seoul Natl U
ASIPP
CIEMAT
FOM Inst DIFFER
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

NSTX-U CS Installation – Documentation Package Items

- NEPA 1466
- Work Package 9417 **** 8250
- Work Planning Form 1672
- Final Design Review Committee Report for the National Spherical Torus Experiment (NSTX) Upgrade Project
- Engineering Work Package 229M
- Procedure # D-NSTX-IP-3572 "Final Center Stack Installation Activities"
- Lift Procedure Number D-L-NSTX-1047
- NSTX Failure Modes & Effect Analysis / NSTX-FMEA-71-10
- ISTP-001 – copy of run copy with external review committee
- NSTX-02, Rev 14 – copy of run copy with external review committee

→ Documentation package is fairly comprehensive. Some technical details could be improved – **in the works**

NSTX-U Startup Documentation

- Run Copy of ISTP-01 – Approved and in place
- Run Copy of NSTX-02 – Approved and in place
- Blue Folder Package

Documentation

- There is a well documented (blue folder) work package for the installation of " Final Center Stack Installation Activities"

- Design reviews appear to be comprehensive , but lacks details associated with coil grounding strategy

- ECN's appear to be well documented in the drawing(s) package

- No details associated with the OH Ground Plane Braid are depicted in system engineering drawings. The Ground Plane Braid is not shown on Center Stack drawings. While detailed mechanical drawings exist, there is only an old drawing (from the first center stack) to show the electrical grounding in the CS

Recommendations, Conclusions, Actions

- Provide better / more specific depictions of the OH in the system drawings – **in the works**
- There is a lack of policy regarding referencing (grounding) of machine structures. This needs be developed – **in the works**
- There is no design drawing depicting machine structure referencing (grounding) – **in the works**
- There is no detailed engineering design for OH ground plane clamp and ground strap – **in the works**

Final Conditions / Actions

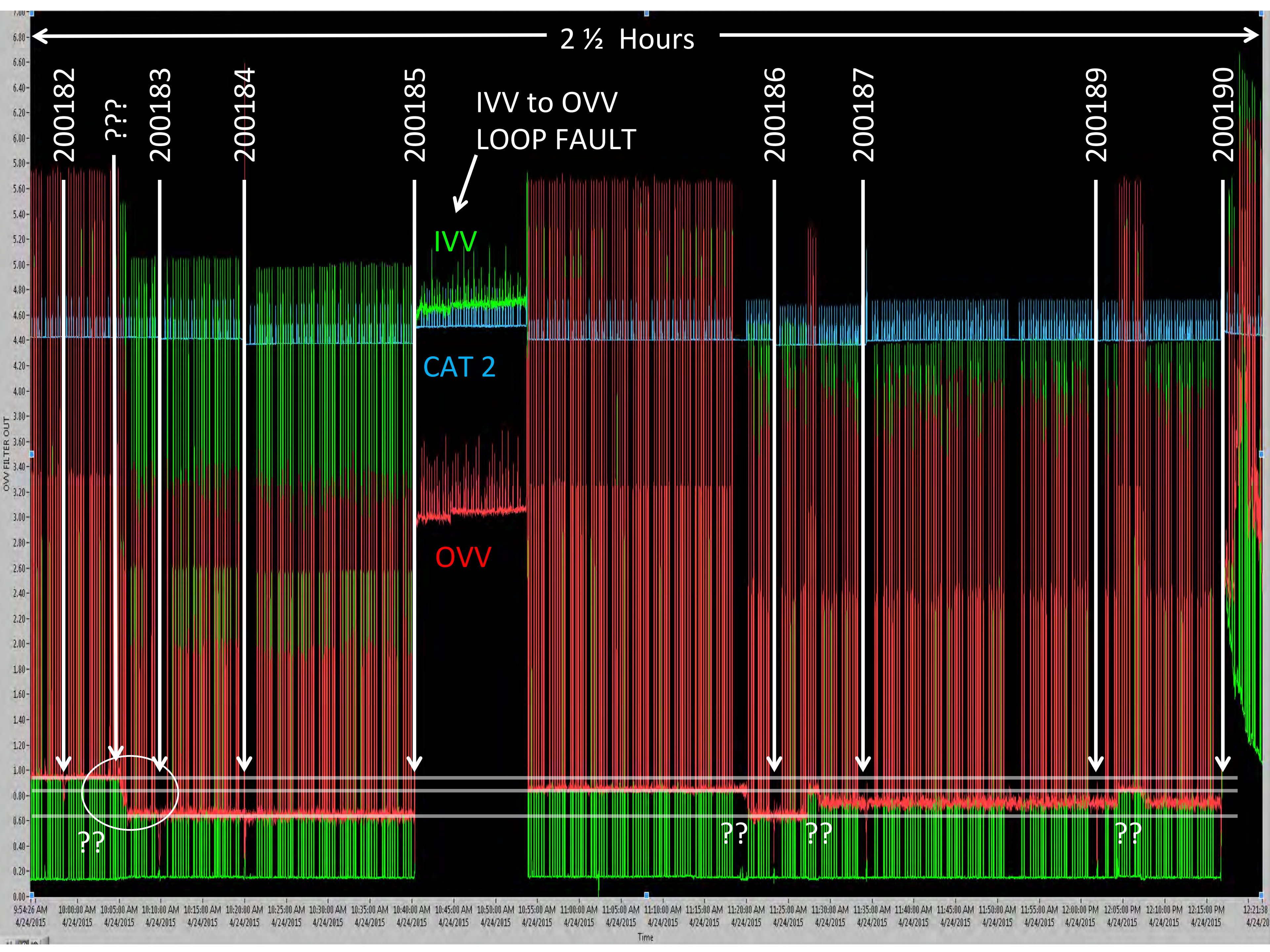
- NSTX-U ACC will convene to review those actions performed to address the OH fault issue(s)

- Report, post ACC review will be sent to Deputy Director of Operations

NSTX Test Cell Ground Fault Monitor Event Data 4/24/15

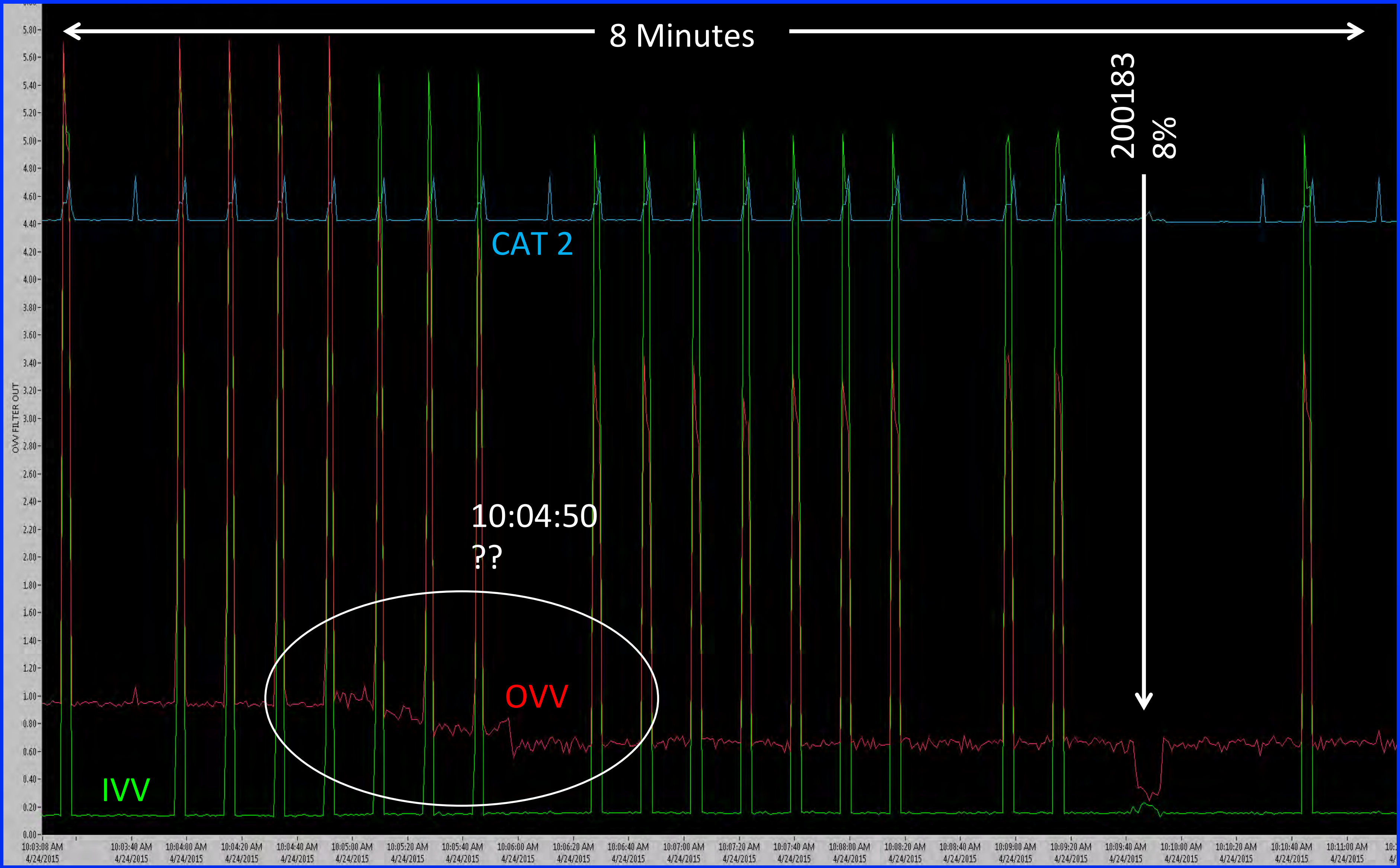
Hans Schneider

(609) 243-2017
hschneid@pppl.gov
5/15/15

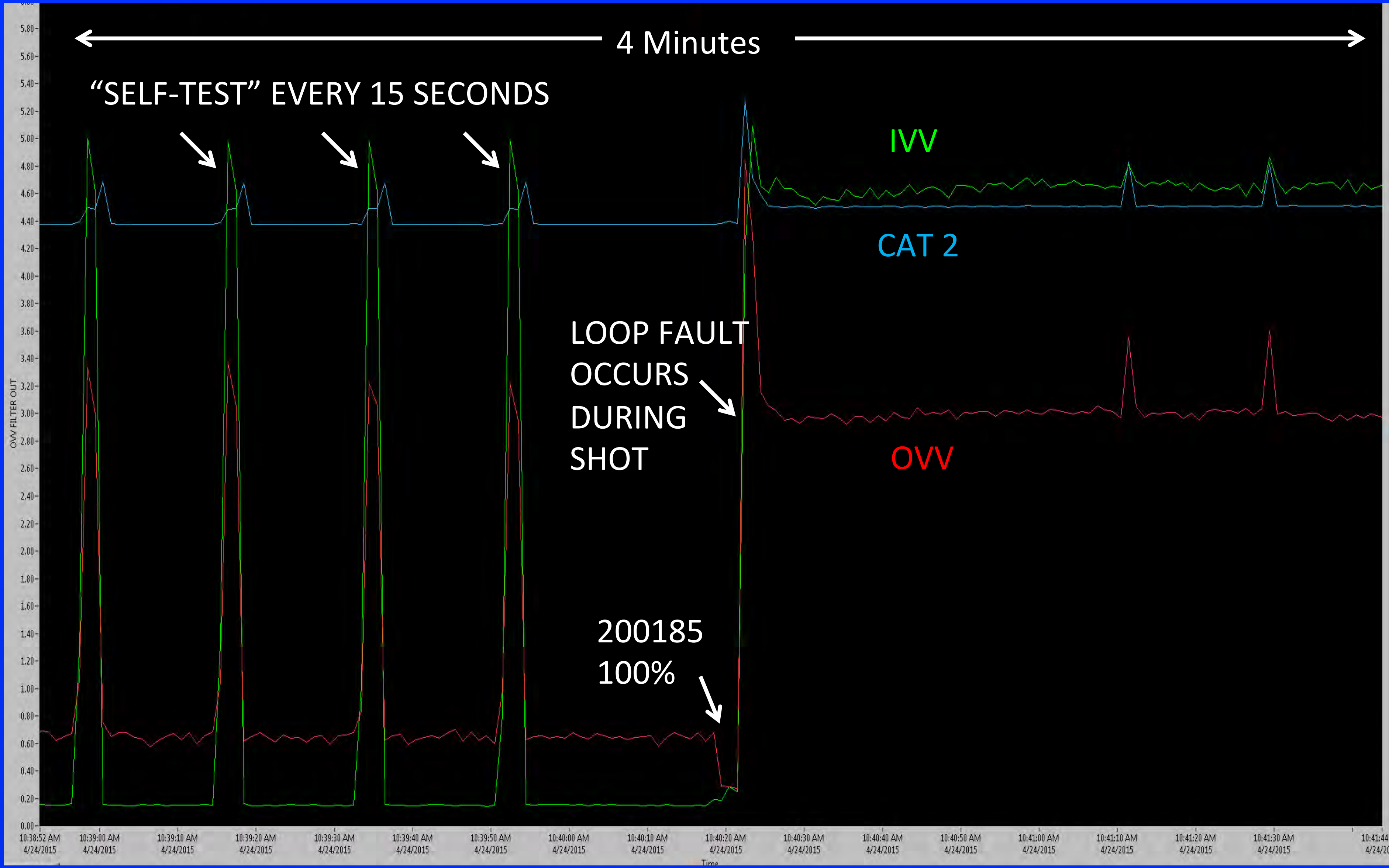


2 ½ Hours
200182
???
200183
200184
200185
IVV to OVV
LOOP FAULT
200186
200187
200189
200190
IVV
CAT 2
OVV
??
??
??
??
OVV FILTER OUT
Time

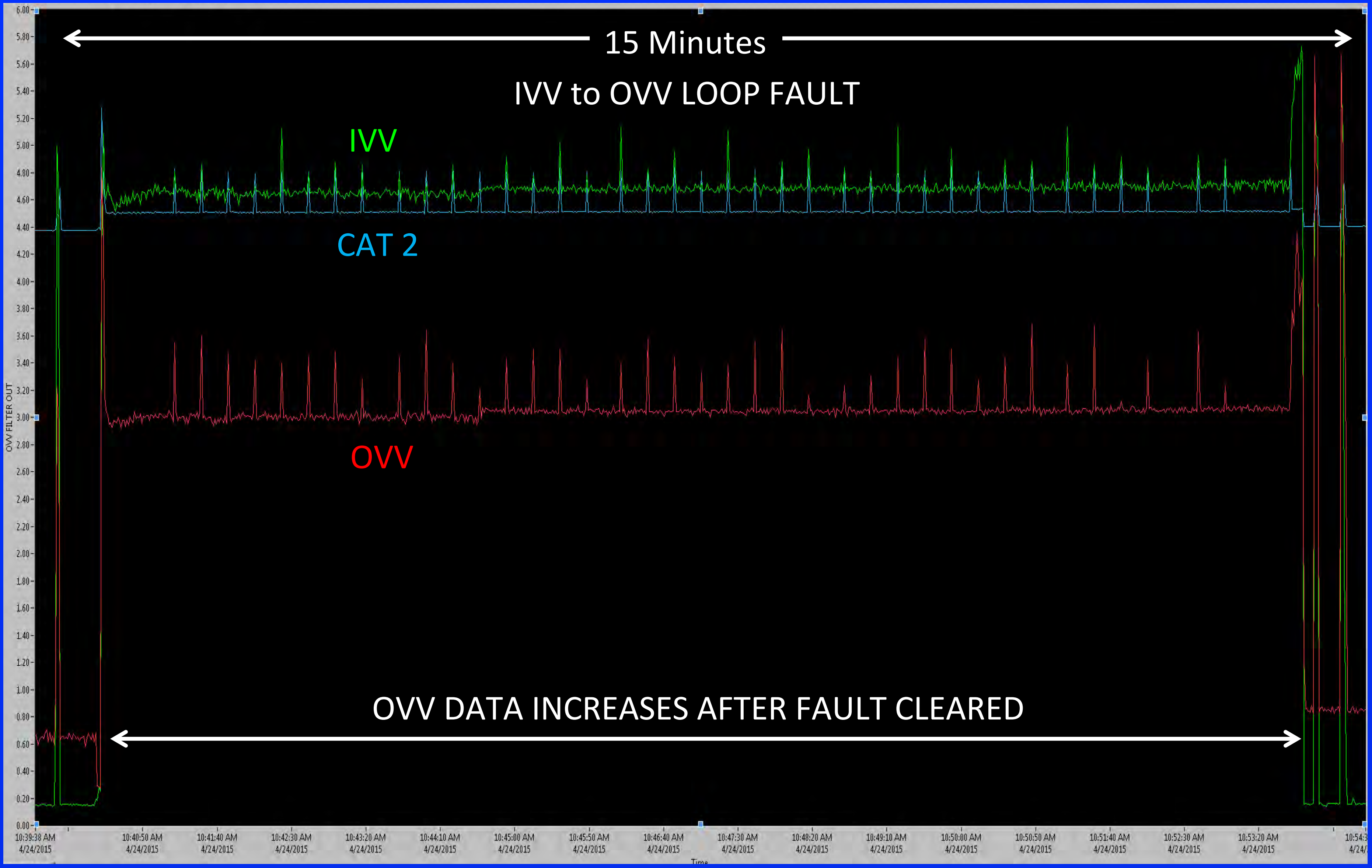
Unknown OVV Data Change Pre Shot 200183



SHOT 200185 OVV to IVV LOOP FAULT



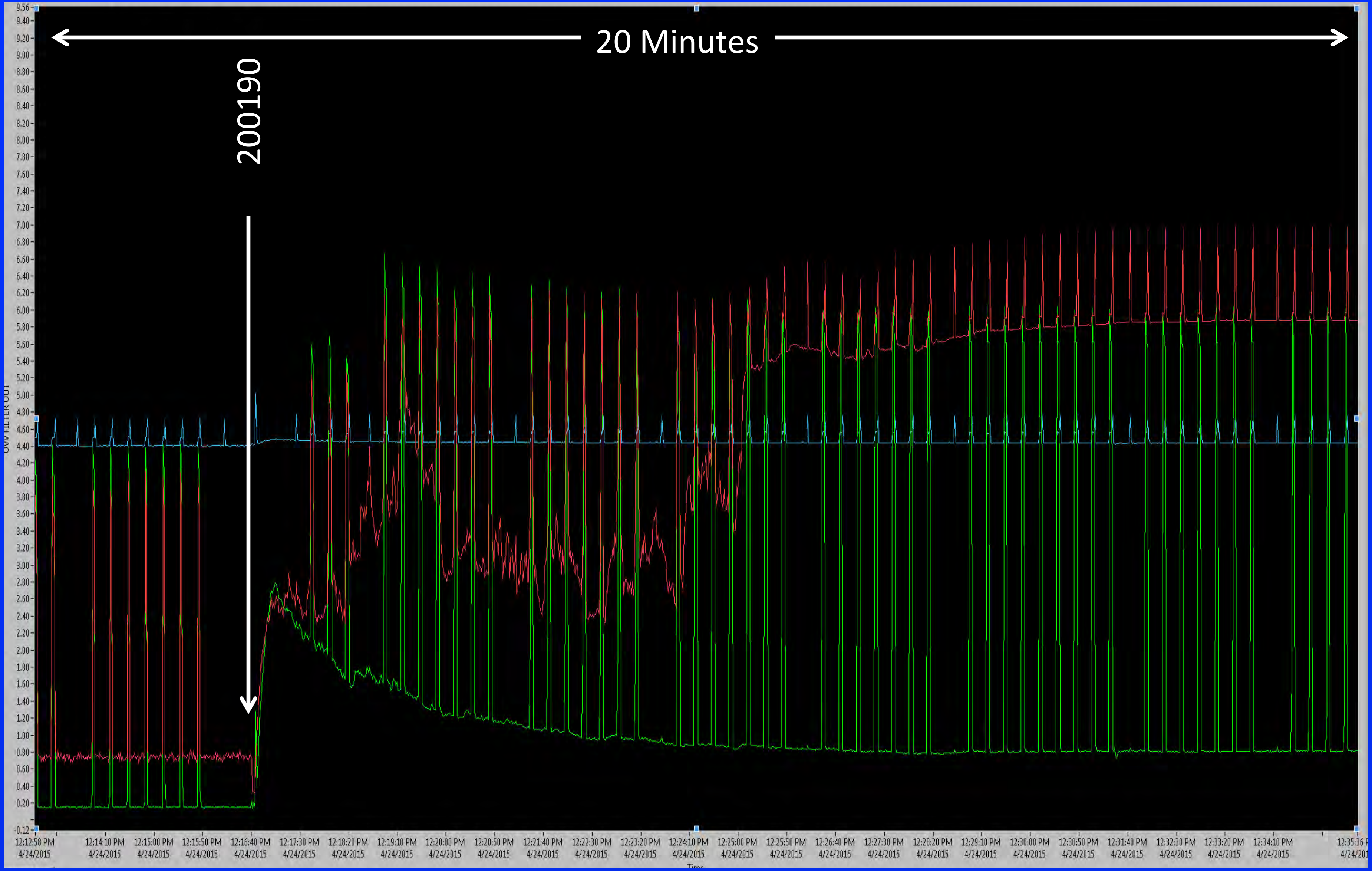
SHOT 200185 OVV to IVV LOOP FAULT



Hans Schneider
Engineering Operations

PPPL
PRINCETON PLASMA PHYSICS LABORATORY

SHOT 200190



Hans Schneider
Engineering Operations

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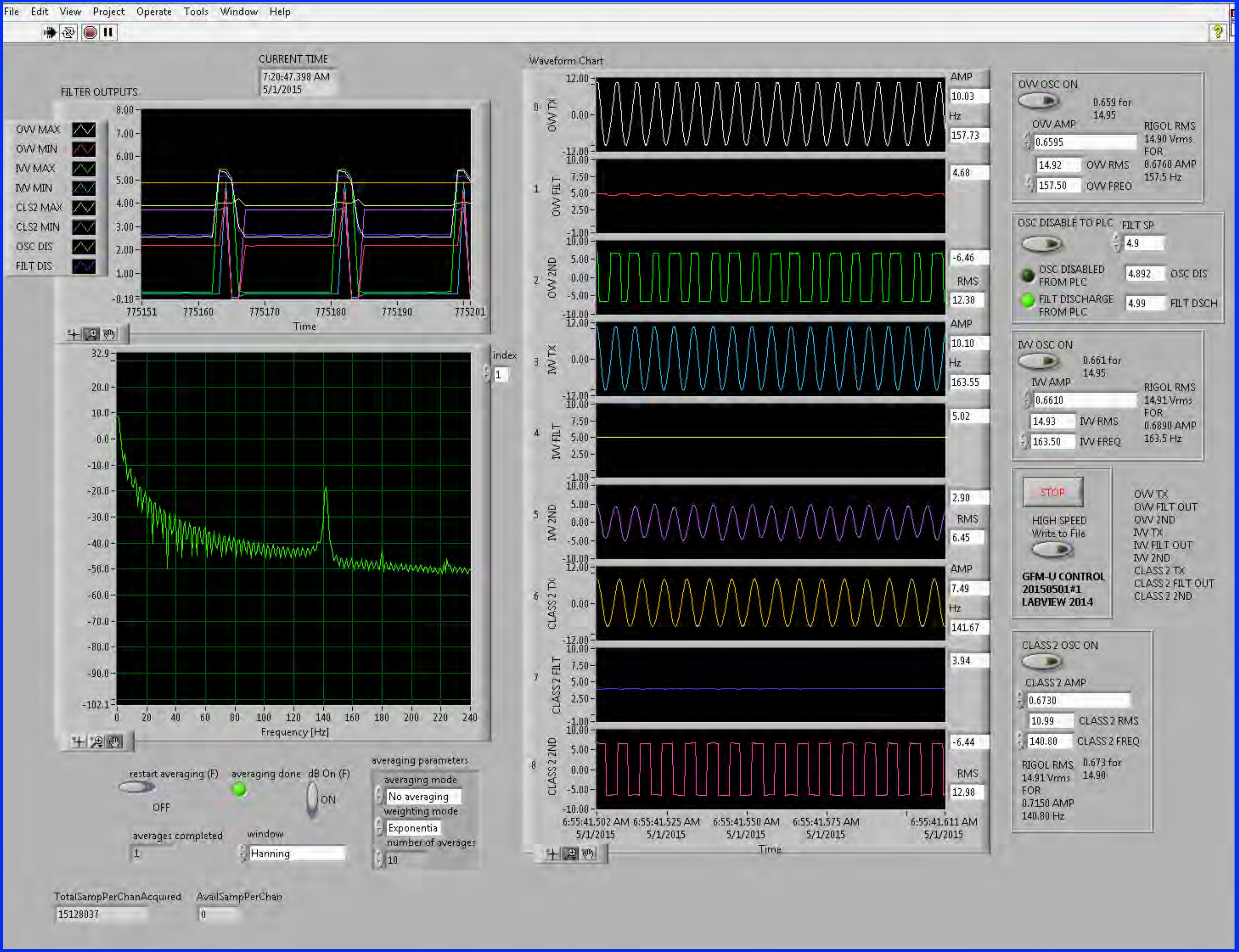
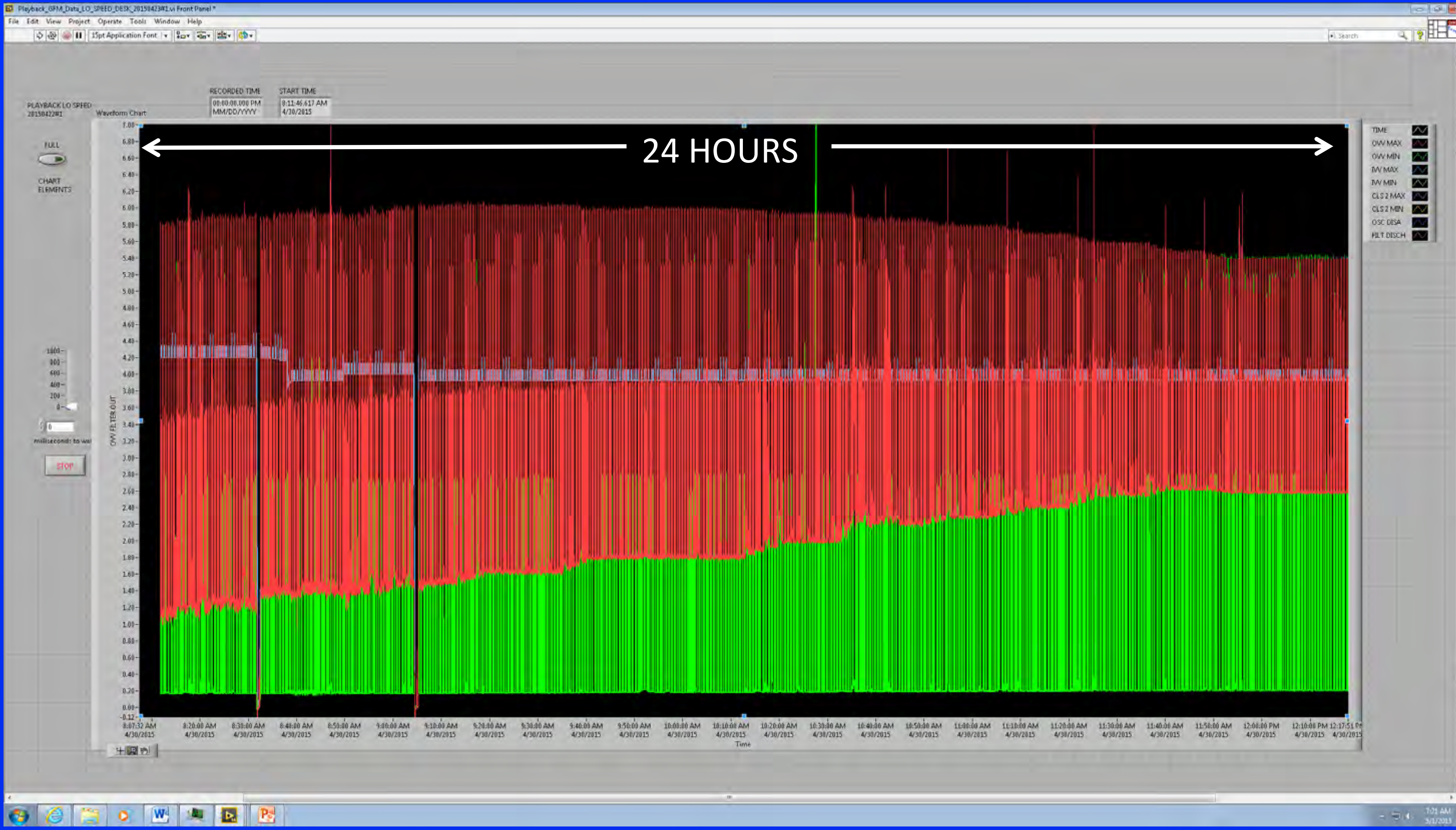
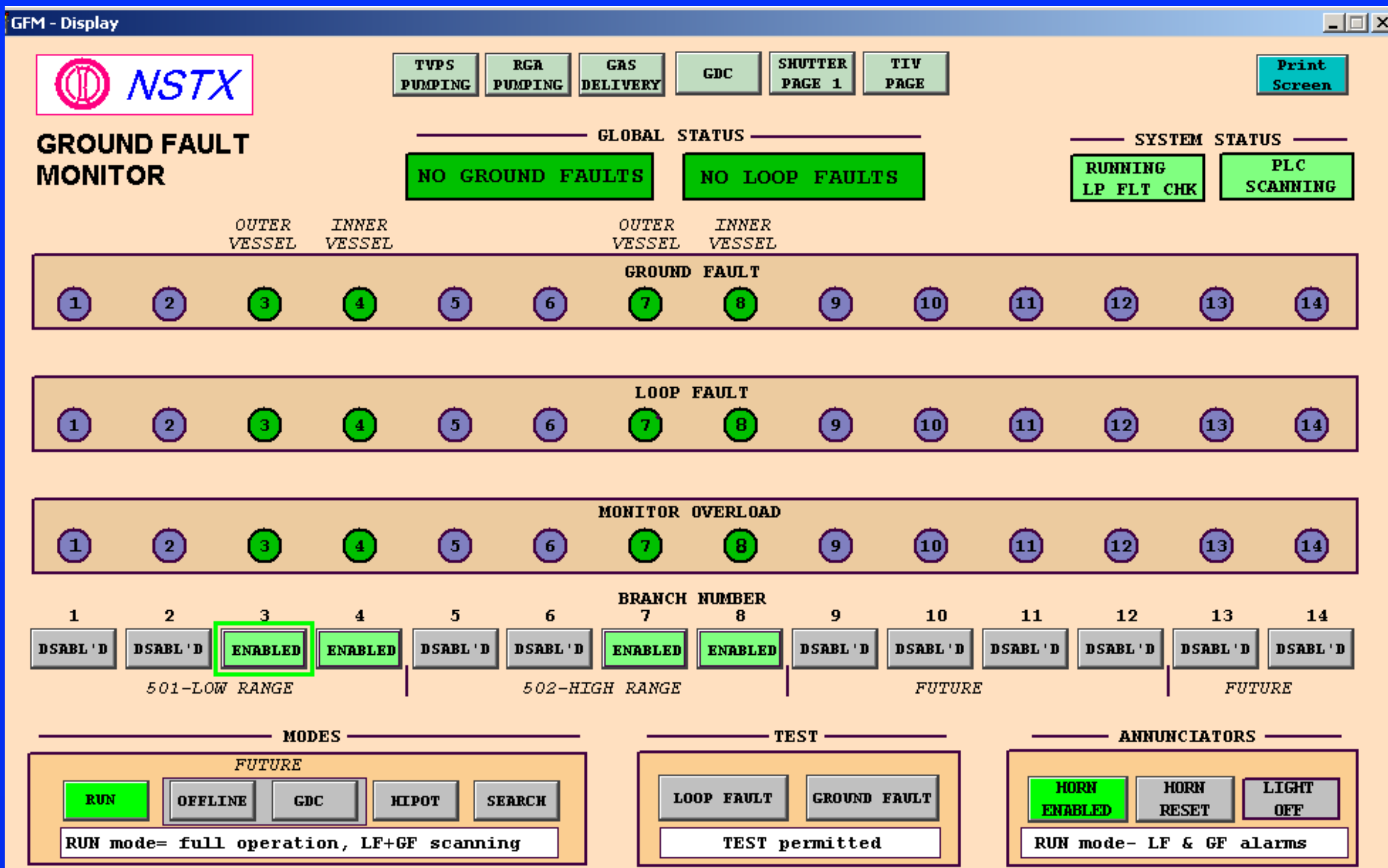
Data Acquisition User Interface



Data Playback User Interface



CONTROL ROOM GFM USER INTERFACE



Definitions

- GROUND – An electrical connection to Earth
  - In an electric circuit, a common return path may not necessarily be connected to Earth
- SINGLE POINT GROUND – Circuit Grounds returned to a common point
  - Where not practical a Ground Bus can be an adequate substitute

Definitions
(continued)

- GROUND LOOP – Unwanted current flowing in a conductor connecting two points that are supposed to be at the same potential
  - Sometimes called a Current Loop

- GROUND FAULT - Circuit with a compromised (high impedance) or open Ground connection
  - Note: Ground Monitor System Self Test failures are also called Ground Faults

Fault Definitions

- Loop Fault – Ground Loop Current above set threshold
- Ground Fault -
  - Ground connection impedance above a set threshold
  - Ground Monitor System Self Test failure
- Over Voltage Fault – Receiver coil circuit saturated
  - Receiver circuit output above a set threshold
  - Caused by "Hard" Loop Fault or extraneous external signal

Ground Monitor System Purpose

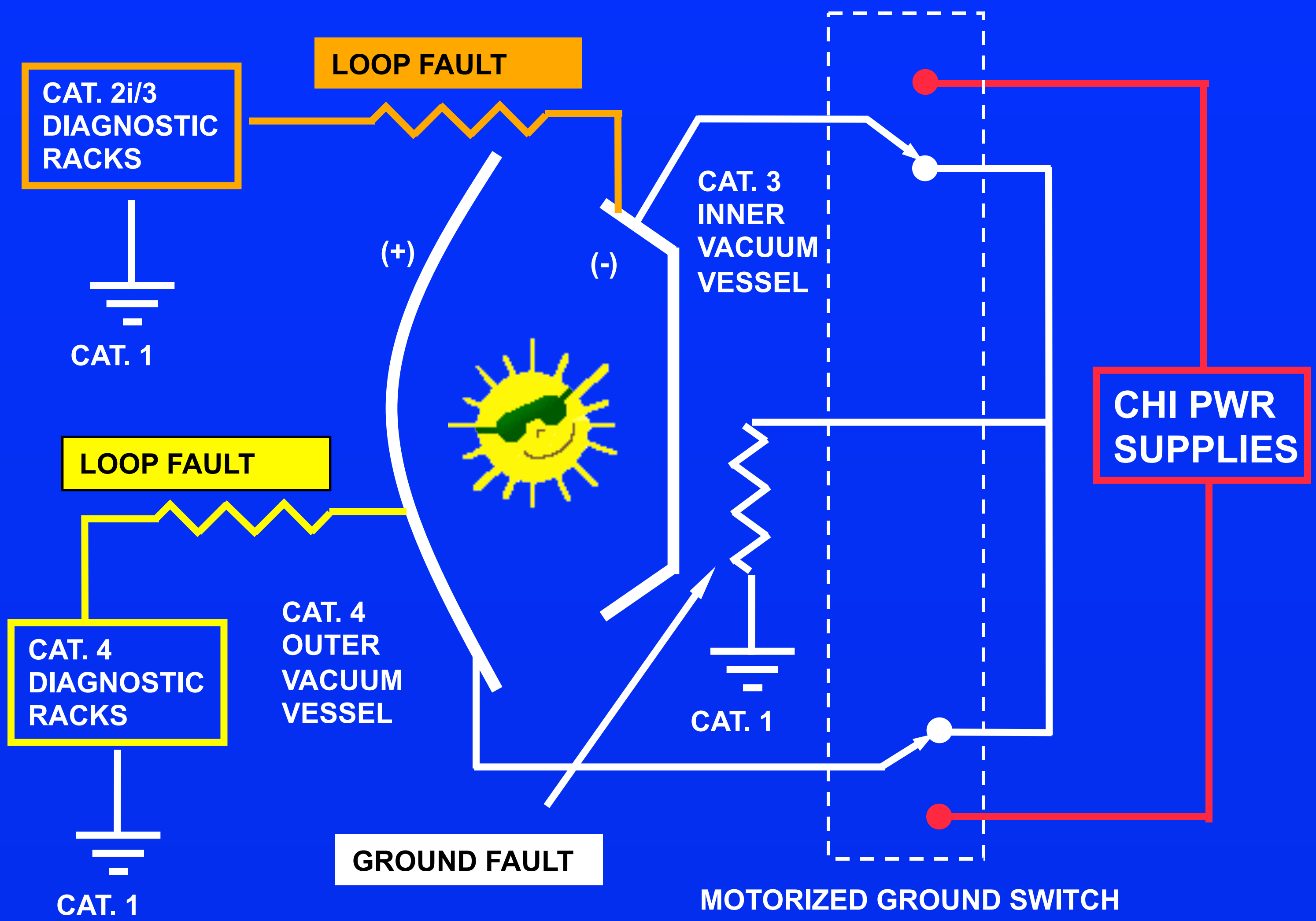
- Ground Loop & Ground Fault Detection
  - Real Time indication during installation, maintenance and machine operation
    - Inner & Outer Vessel walls cannot be monitored during CHI operations

- Ground Loop & Ground Fault Troubleshooting
  - Assists in determining Fault cause and location

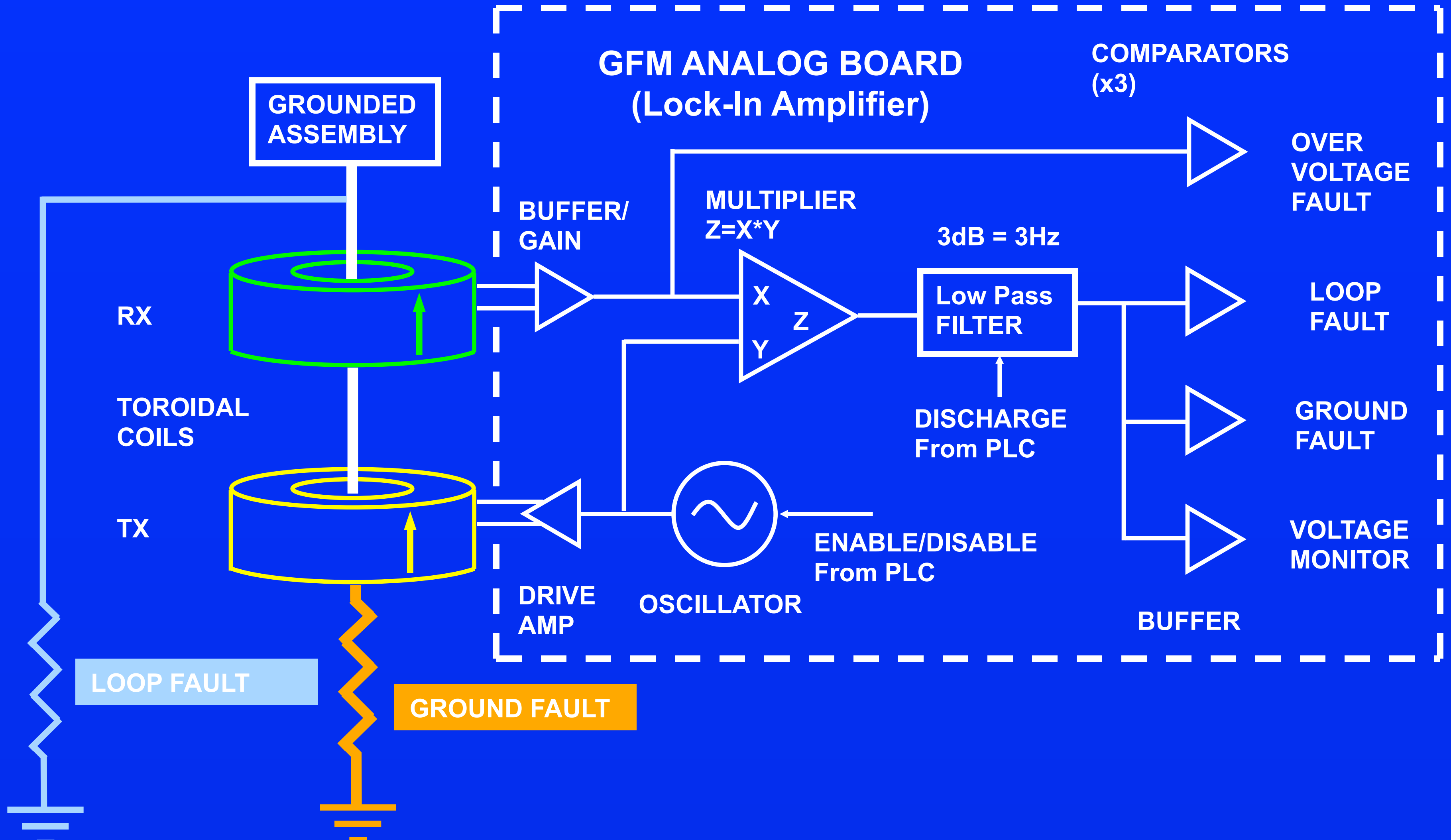
NSTX Ground Categories

CATEGORY	Description
1	General Purpose AC Systems (outlets) – Building Steel Common
2	General Purpose Diagnostics – TFTR Ground Pit Common
2i/3	Inner Vacuum Vessel Common
4	Outer Vacuum Vessel Common
5	Neutral Beam Grounds

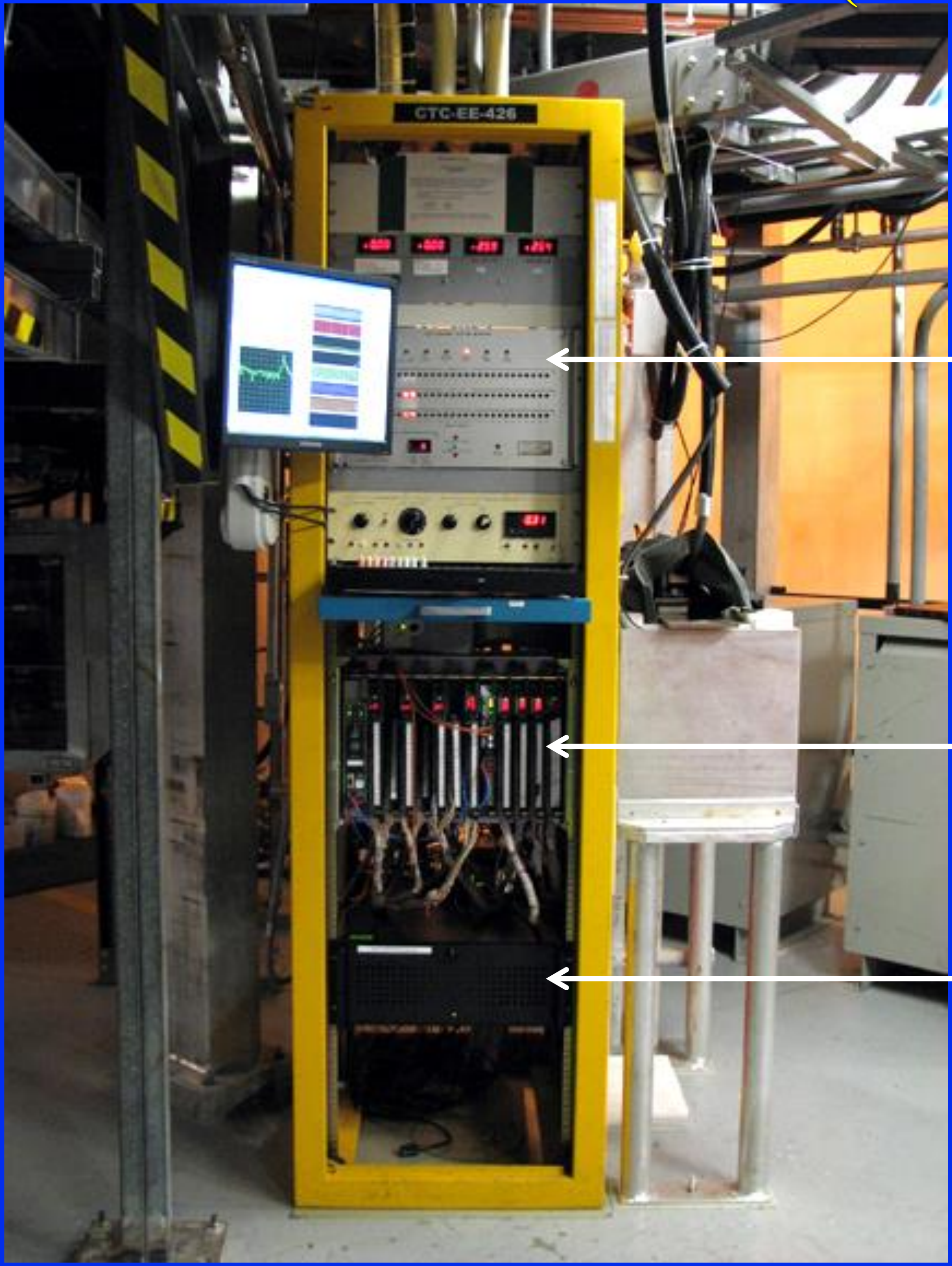
NSTX Vessel Grounds with Faults



Theory of Operation



Test Cell Ground Fault Monitor (GFM)

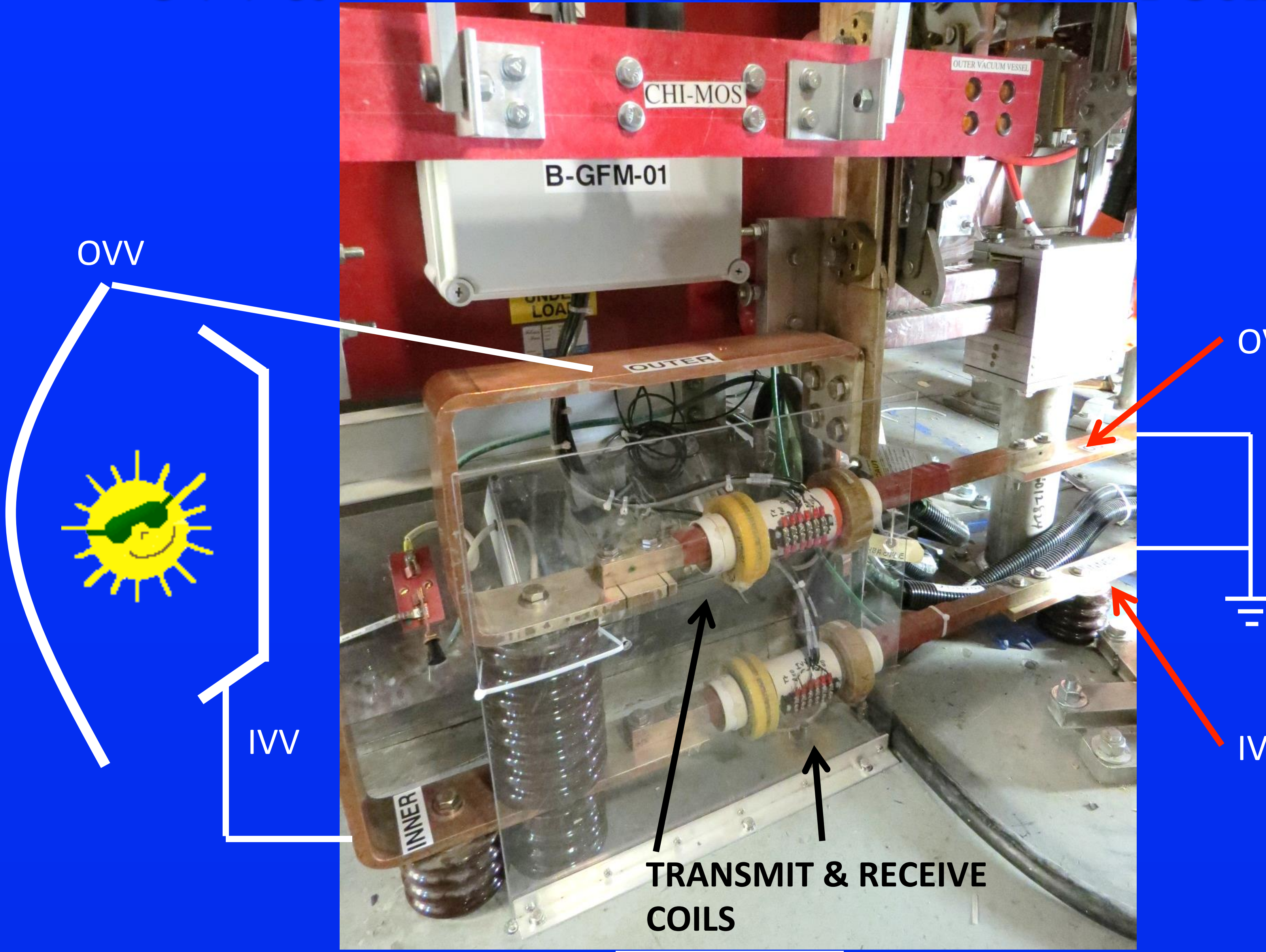


TFTR GFM 1982

GFM PLC 2002

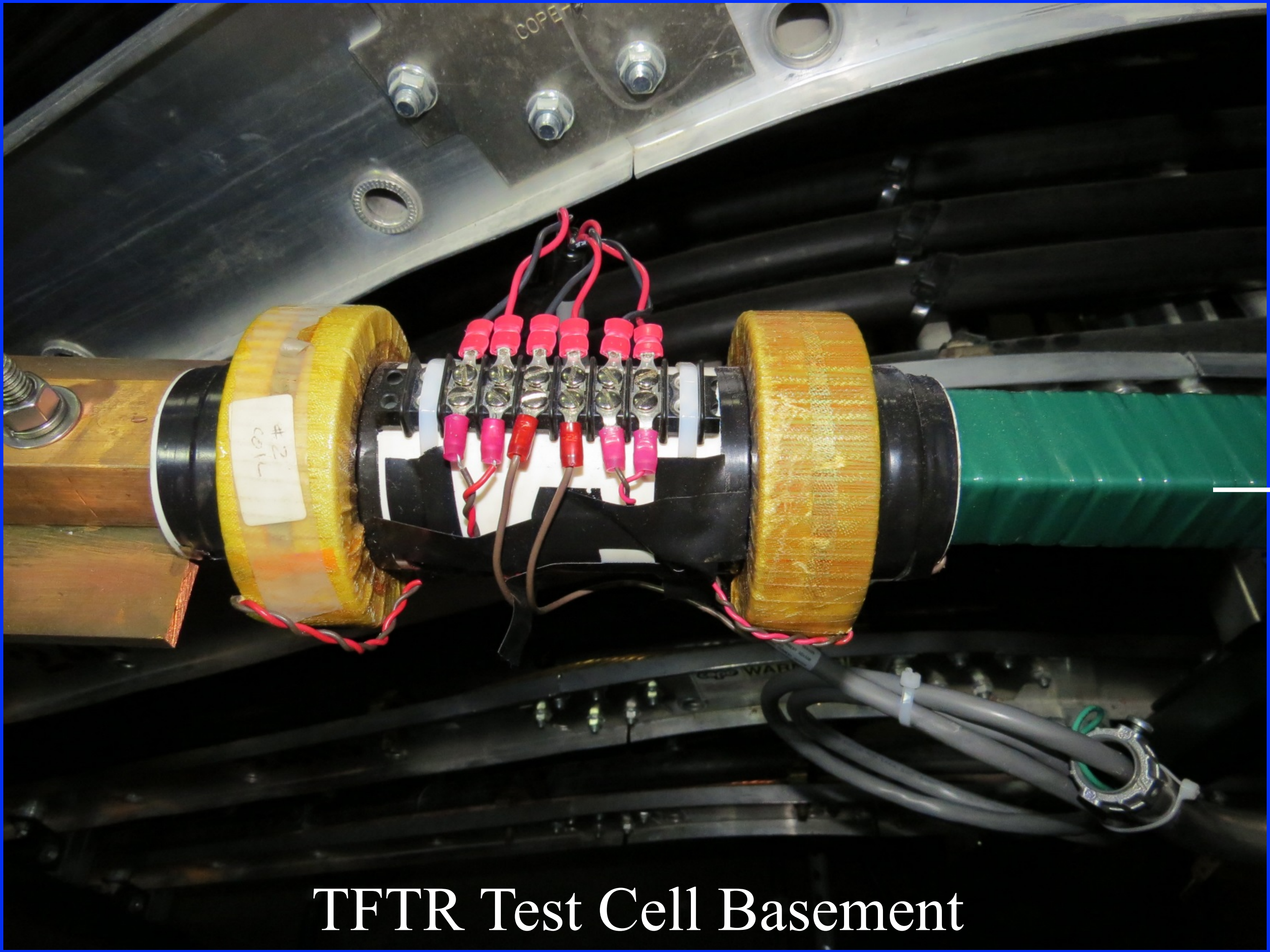
LABVIEW
DATA ACQUISITION
PC 2007

OVV & IVV GND BUSES with TX & RX Coils



Category 2 GND BUS with TX & RX Coils

TO
NTC
CAT. 2
EAST
&
WEST
WALL
GND
PLATES



Hans Schneider
Engineering Operations

PPPL
PRINCETON PLASMA PHYSICS LABORATORY

NTC EAST WALL CAT. 2 GROUND PLATE

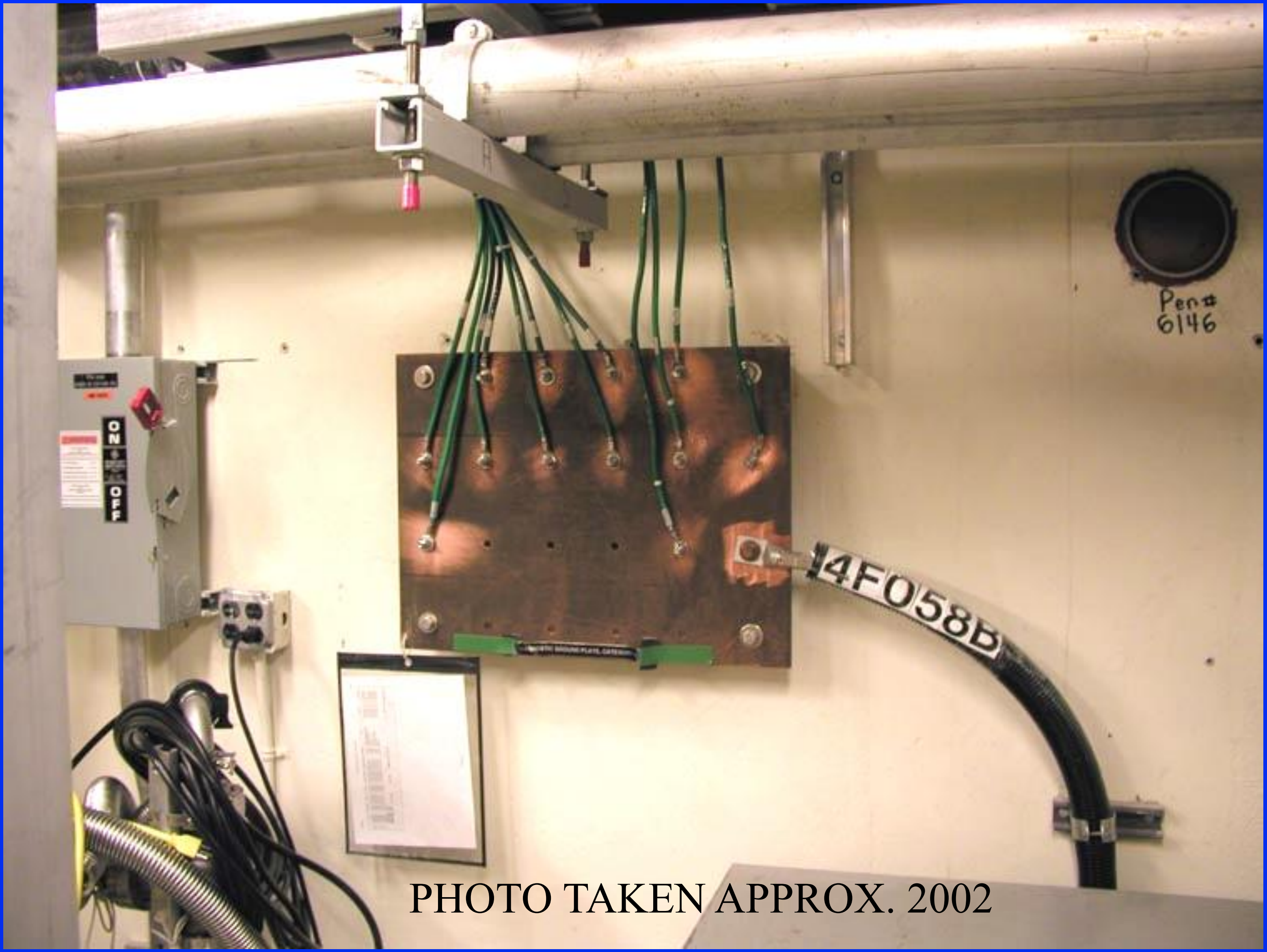


PHOTO TAKEN APPROX. 2002

NTC WEST WALL CAT. 2 GROUND PLATE

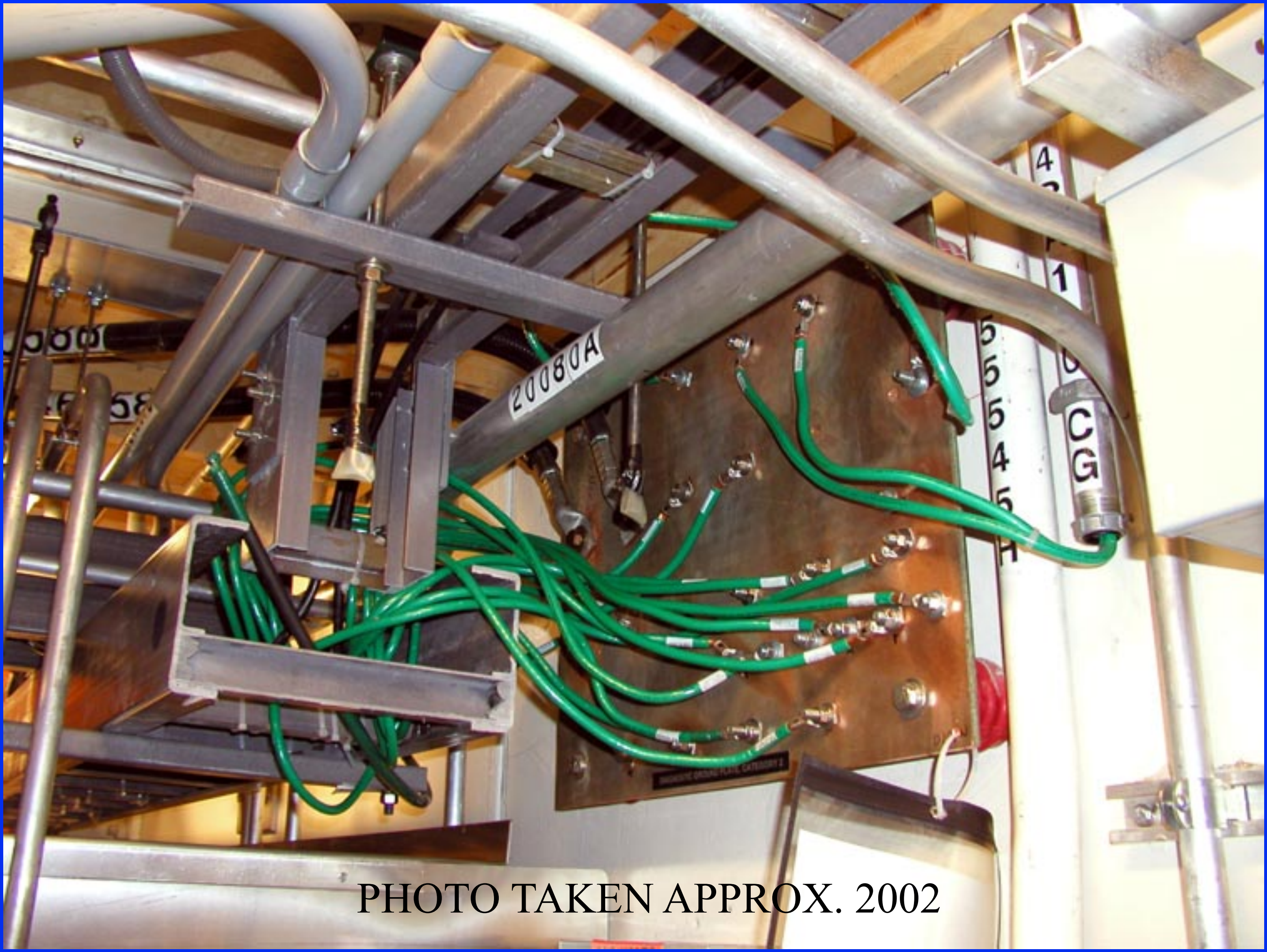
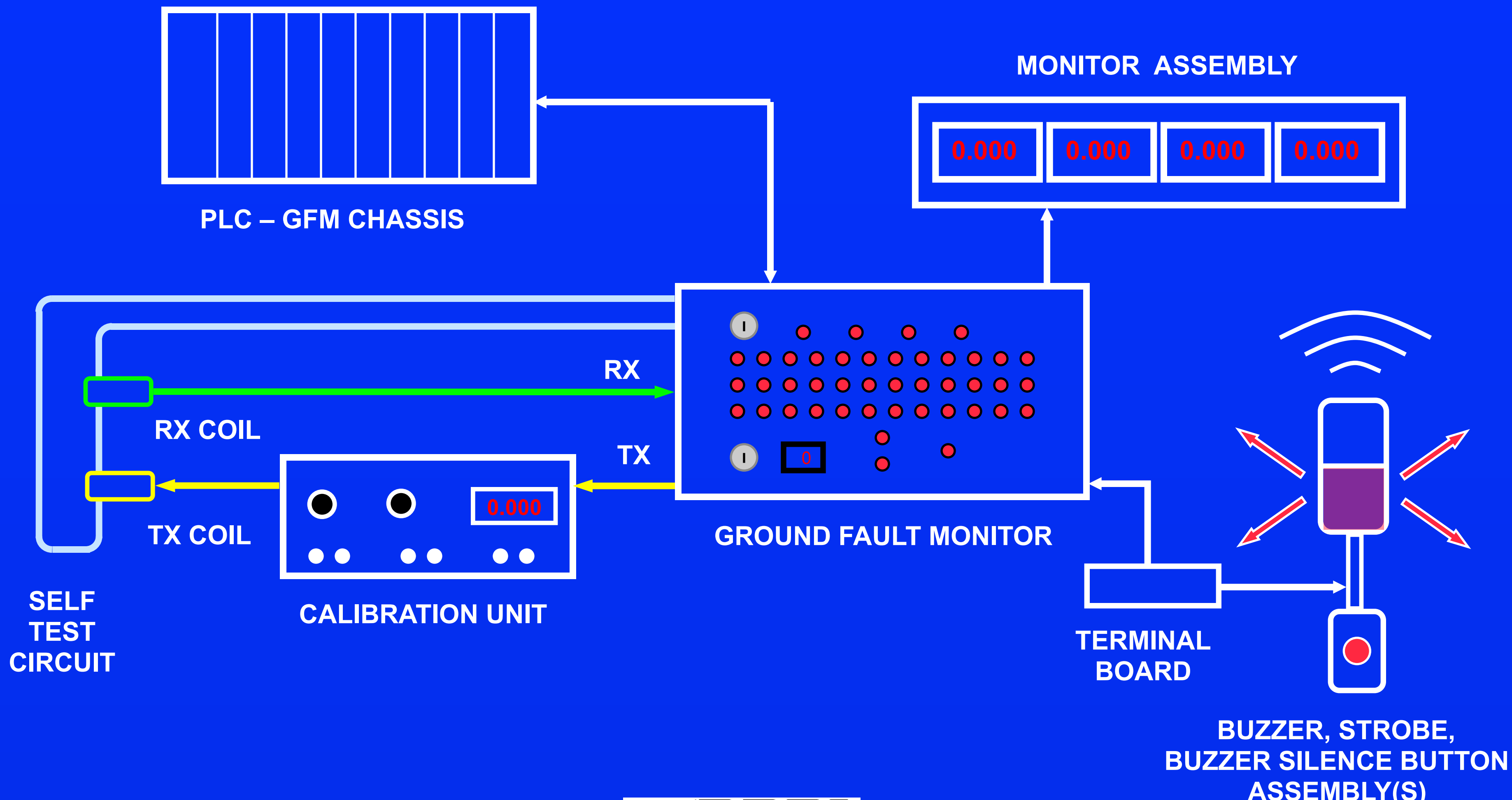
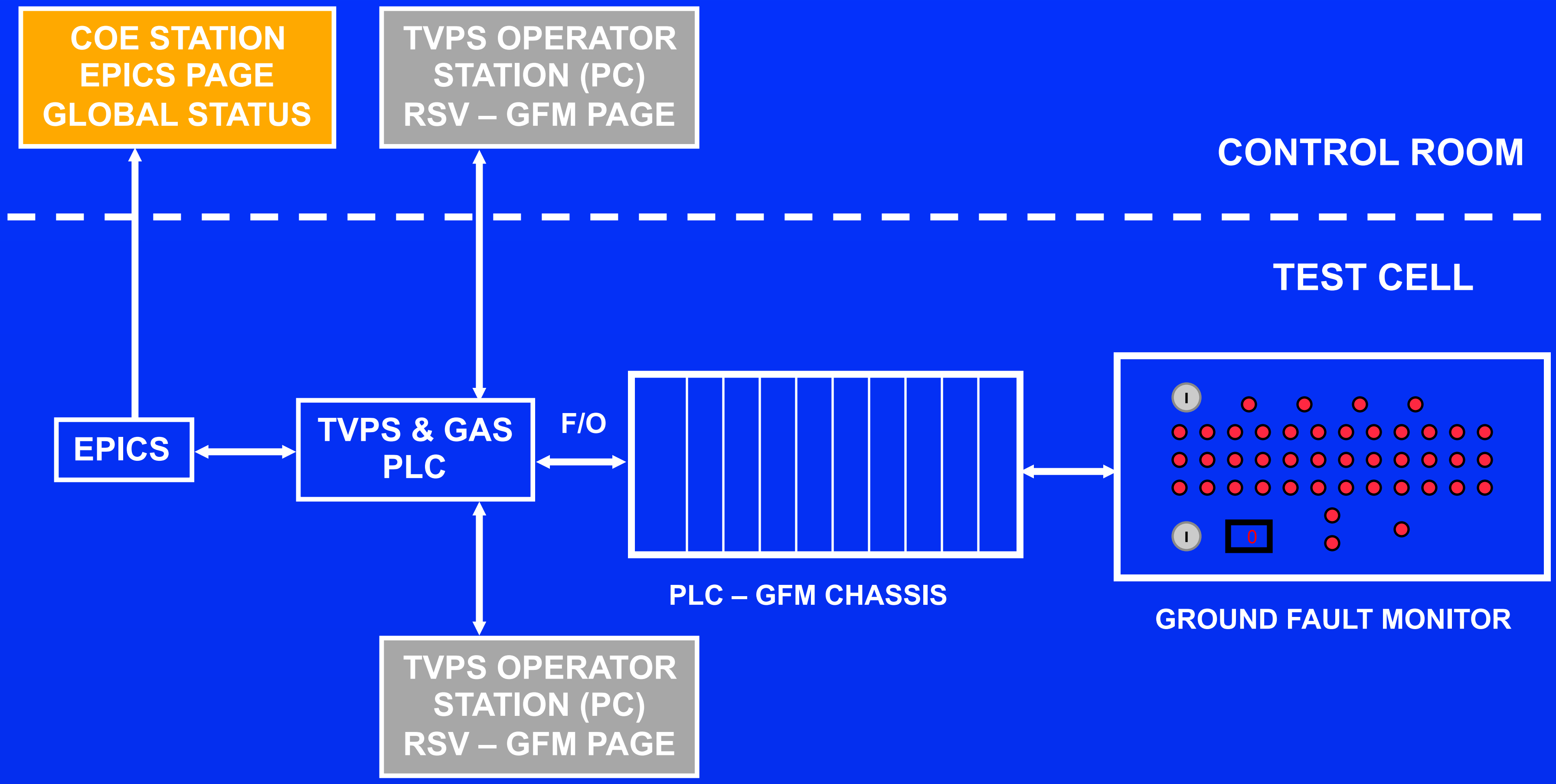


PHOTO TAKEN APPROX. 2002

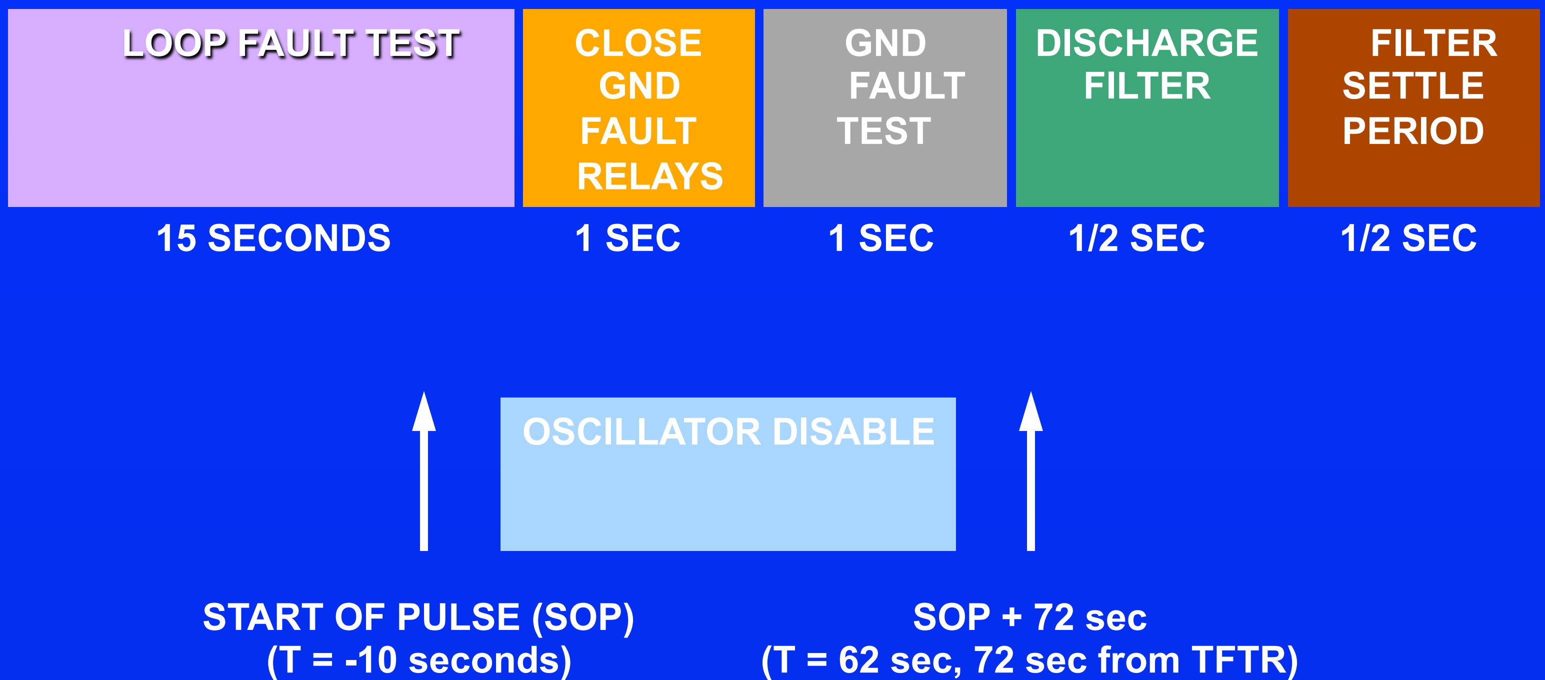
System Block Diagram (GFM)



System Block Diagram (PLC)



Timing Cycles
RUN & SEARCH MODES



Operational Modes

Mode	Name	Description
0	RUN	Full Operation
1	OFFLINE	Same as RUN but NO Permissives (Not Used on NSTX)
2	GDC	Same as RUN but NO GDC Permissive (Not Used on NSTX)
3	HIPOT	OFF (can run Ground and Loop Fault Tests)
4	SEARCH	Same as RUN, NO Permissives, Loop Faults Only

TFTR to NSTX Modifications

- Increased Loop Fault sensitivity
- Glow Discharge and Machine Permissive hardware functions remain but are not used. PLC software can be modified for future use.

TFTR to NSTX Modifications
(continued)

- Fault Buzzer & Light changed from 120 vac to 24 vac
  - New Buzzers, Lights & Buzzer silence Buttons
  - Configured for up to 6 Buzzers, Lights and Buttons
  - BUZZER - Fast Intermittent Sound, 2500 Hz at 85 dB
  - LIGHT - Xenon Strobe with Clear Lens, 1 Hz Flash Rate
- All NSTX faults produce same Buzzer sound and Light flash rate
  - For TFTR Ground Faults the Light & Buzzer were pulsed on and off.

NSTX-U

Supported by U.S. DEPARTMENT OF ENERGY | Office of Science

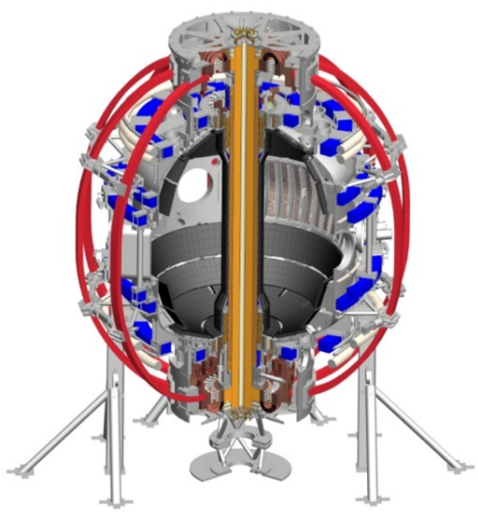
DCPS

Stefan Gerhardt, Tim Stevenson

and the DCPS Team

Extent of Conditions Review
DoE Conference Room
5/18/2015

Coll of Wm & Mary
Columbia U
CompX
General Atomics
FIU
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Lehigh U
Nova Photonics
ORNL
PPPL
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Tennessee
U Tulsa
U Washington
U Wisconsin
X Science LLC



Culham Sci Ctr
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Inst for Nucl Res, Kiev
Ioffe Inst
TRINITI
Chonbuk Natl U
NFRI
KAIST
POSTECH
Seoul Natl U
ASIPP
CIEMAT
FOM Inst DIFFER
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

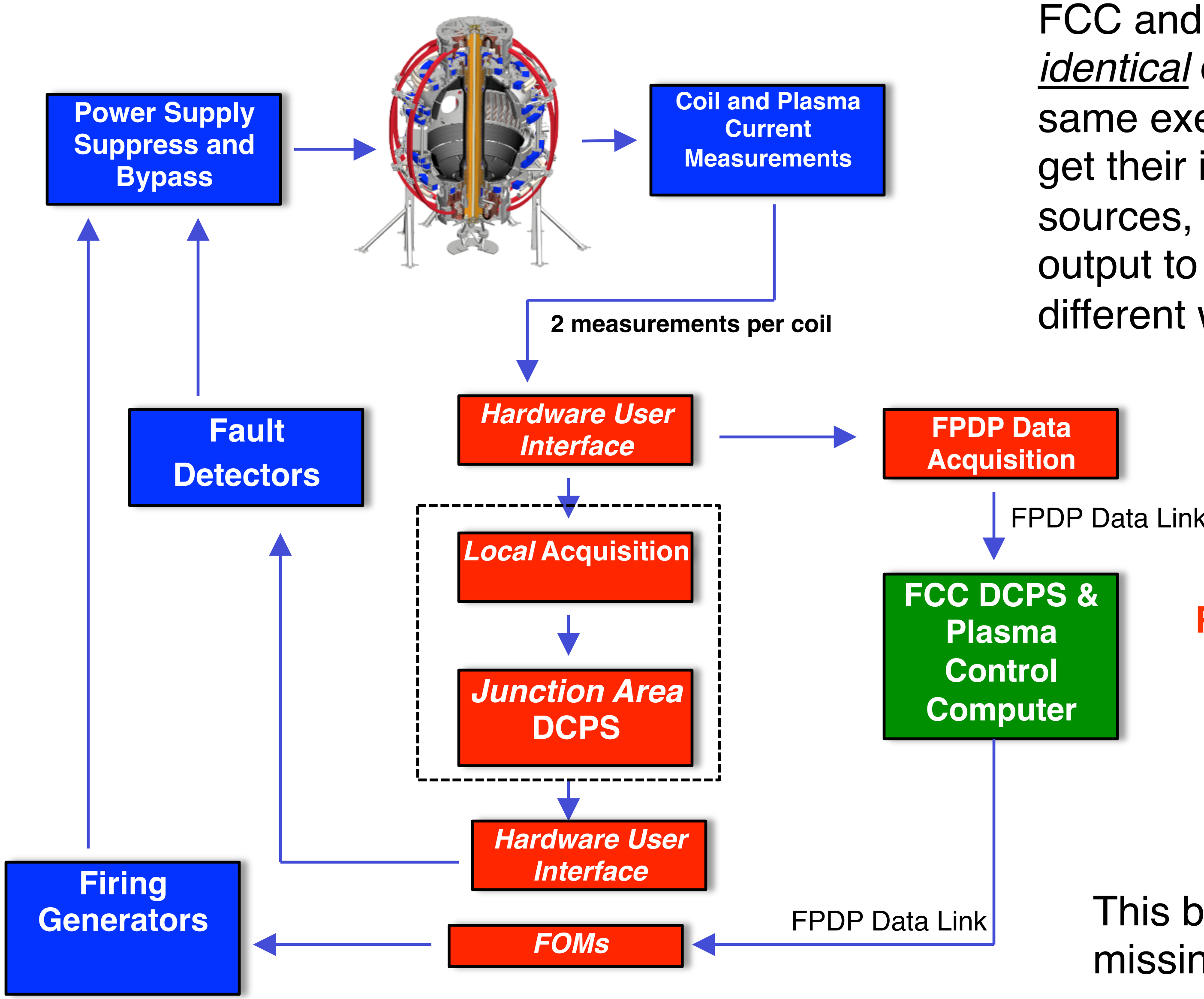
Contents

- DCPS Primer
- Concerns about DCPS
- A new “damage avoidance” feature added to PSRTC

What is DCPS

- DCPS is the “Digitial Coil Protection System”
- It is a suite of computers, data acquisitions systems, custom software, custom hardware, automated testing systems, procedures, and parameter data.
- The DCPS is primarily designed to protect the NSTX-U coils and their mounting hardware against excessive mechanical loads.
- It is NOT a global machine protection system.
- It is NOT a rectifier protection system.

Simplest Block Diagram



FCC and JA DCPS have *identical* code, and are the same executable file, but i) get their input from different sources, and ii) send their output to the rectifiers different ways

Red for Junction Area
Green for FCC
Blue for FCPC

This block diagram is missing A LOT of details!

Input Data to DCPS

- Parameter data that controls all of the DCPS function is stored in the "DCPS Configuration Spreadsheet".
  - Ask for a copy if you want one.
  - One instance of the Configuration spreadsheet contains the information to make for FCC and JA DCPS parameter files.
- Realtime data is limited to some limited digital status and timing information, and 2 measures of the coil current for each coil system.
  - No line-switch positions, no coil voltages, no water temperatures

Both DCPS Instances Can Shut Down a Shot

- JA DCPS
  - Two ways to abort the shot:
    - If a overcurrent/stress/torque/force/temperature/moment is exceeded, the “SW L1 Fault” lines go low.
    - If it detects too large a difference between Cur1 and Cur2 for any given coil, code aborts
      - This is called an “auctioneer error”
      - the 5 kHz watchdog timer is thus stopped.
      - the code does not archive any post-shot data in this case.
  - These changes (SW fault, WD timer stopping) are processed by the hardware in the JA and turned into FCPC L1 Faults.
- FCC DCPS
  - Two possible actions:
    - If a overcurrent/stress/torque/force/temperature is exceeded, then suppress and bypass is forced onto the FPDP stream.
    - If too large a difference in Cur1 and Cur2, the code would again abort, stopping the WDT.
  - On 4/24/2015, the FCC DCPS heartbeat was not being listened to.
    - This was a vulnerability, that *has since been addressed by Keith, Ed Lawson, Hans*.
    - We now get a L1 fault if the FCC DCPS is not running.
- Both cases: the WDT also stops if:
  - The code freezes, or has internal timing glitches
  - The code aborts due to certain clock-cycle indicators being out of sequence.

List of DCPS Algorithms

- Overcurrent
- I^2t integrals
- T_{TF}-T_{OH}
  - Must limit this due to aquapour.
- Vertical and radial forces on coils
- Combinations of vertical forces
- Local stresses in OH, PF-4, PF-5
- Torsional Shear Stress
- TF outer leg moments

Including the heating after a suppress and bypass (applies to: I^2t integrals; T_{TF}-T_{OH})

Including calculations of the forces following a disruption with a simple model for the post-disruption currents. (applies to: Vertical and radial forces on coils through TF outer leg moments)

DCPS has been Tested and Used

- Numerous test procedures
  - PTP-DCPS-001: Software Testing
  - PTP-DCPS-002: Board Bench Testing
  - PTP-DCPS-003: HUI testing
  - PTP-DCPS-004: Real world testing
  - PTP-DCPS-005: Buffer Chassis Testing.
- Dummy Load Testing
  - Both DCPS instances generated overcurrent & I^2t trips
- ISTP-001
  - Both DCPS instances generated overcurrent & I^2t trips
- Configured daily via OP-DCPS-779

We Polled the DCPS Team to See if There Were Outstanding Issues…Get Three Replies

DCPS questions/issues   Inbox x

Stefan Gerhardt <sgerhard@pppl.gov>   May 16 (2 days ago)

to Keith, Hans, Greg, Paul, Gretchen, Roman, Weiguo, Andy, Pet(

All,

The "Extent of Conditions" review panel has cast a wide net.

The are interviewing people, including Tim and I, on Tuesday, and here are the instructions we got from Larry Dudek:

"With regard to the meeting on Tuesday, Joel is looking for a brief presentation (20 min.) on areas you believe to be problematic. Items that need another look."

So, with regard to DCPS, are there any items you would like us to mention? This could be hardware, software, testing, procedures,...any of it.

Feel free to email Tim and/or I, or talk to Joel yourself if you want to go that way.

And you can forward this email to anybody relevant that I may have missed?

...

Reply #1

- DCPS:
  - 1. No GUI (if you don't count hanscam01)
  - 2. Data Acquisition stops on some WDT "Faults"
  - 3. WDT not really used as a WDT

- T-Mods:
  - 1. Ip L1 Fault overridden
  - 2. Water PLC Permissive, Flow Ok and Over Temp - all overridden.

Reply #2

- I do think that we should get that BZ fixed and delivered that makes the auctioneer log output more useful by listing the actual coil.

- Translation:
  - BZ = “Bugzilla”, an electronic means of tracking bugs in codes.
  - When there is an auctioneer fault, the code aborts (previously noted), and it does not tell you which coil system had the transducer mismatch.
  - This is a statement to update the code to document which coil system drove the abort.

Reply #3

- …the startup procedure for PCS (and/or related codes) was missing or inadequate. I take this to be an efficiency issue, one that might cause delays in starting up, rather than cause damage, but it should be rectified at some point.

- Noted…

SPG List of Concerns (I)

- PCEiCs and CoEs are not comfortable determining the exact nature of DCPS faults.
  - Lack of an integrated DCPS GUI is partly an cause.
  - We do have a GUI that looks at post-shot data and determines the causes of faults; not a lot of comfort using it.
- The DCPS configuration spreadsheet is very complicated, well documented, but…
  - …not sure that it has been thoroughly checked by anybody other than its creator.
  - Tim found a few bugs once, and Bob Woolley checked a bit that he was asked to look at, but I don't think there has been a comprehensive review.
  - I am afraid that this could be a vulnerability at a future external review.
- Similarly, there is no external check that modifications/ updates to the spreadsheet don't have bugs/errors.

SPG List of Concerns (II)

- We still need to do algorithm benchmarking.
  - DCPS algorithms are based on the various models of the NSTX-U mechanical structures.
    - And thus assumptions about the material properties, assembly tolerances,…
  - The DCPS algorithms are only as good as the models.
  - Model validation task has bounced between engineers.
    - Not a high-priority job at any one time, and so it falls to the side.
  - But both the instrumentation, and the follow-up comparisons, are significant tasks that will need meaningful amounts of time (and $$).

SPG List of Concerns (III)

- The DCPS model for how the currents evolve after a disruption is rather simple, and not accurate.
  - It may end up being more restrictive than necessary.
  - There may be a request to turn this model off….TBD.
- The DCPS assumes that the plasma is always perfectly centered in the vessel.
  - It has no way of knowing the vertical position of the plasma.
  - If the plasma is shifted downward, this will result in an actual vertical force that is not captured in the calculations.
    - Nobody has, to my knowledge, made an assessment of how a 2 MA plasma sitting on the divertor floor/ceiling would impact vertical forces.

New “Damage Avoidance” Feature Added to PSRTC Algorithm (Roughly…)

- Compute the measured coil current derivative

$$(dI/dt)_{measured} = (I_{filter,i}-I_{filter,i-1})/dt$$

- Compute a model for what the derivative should be

$$(dI_{coil}/dt)_{model} = (V_{coil,filter} - I_{coil}R_{tot})/L_{coil}$$

- Compute the error

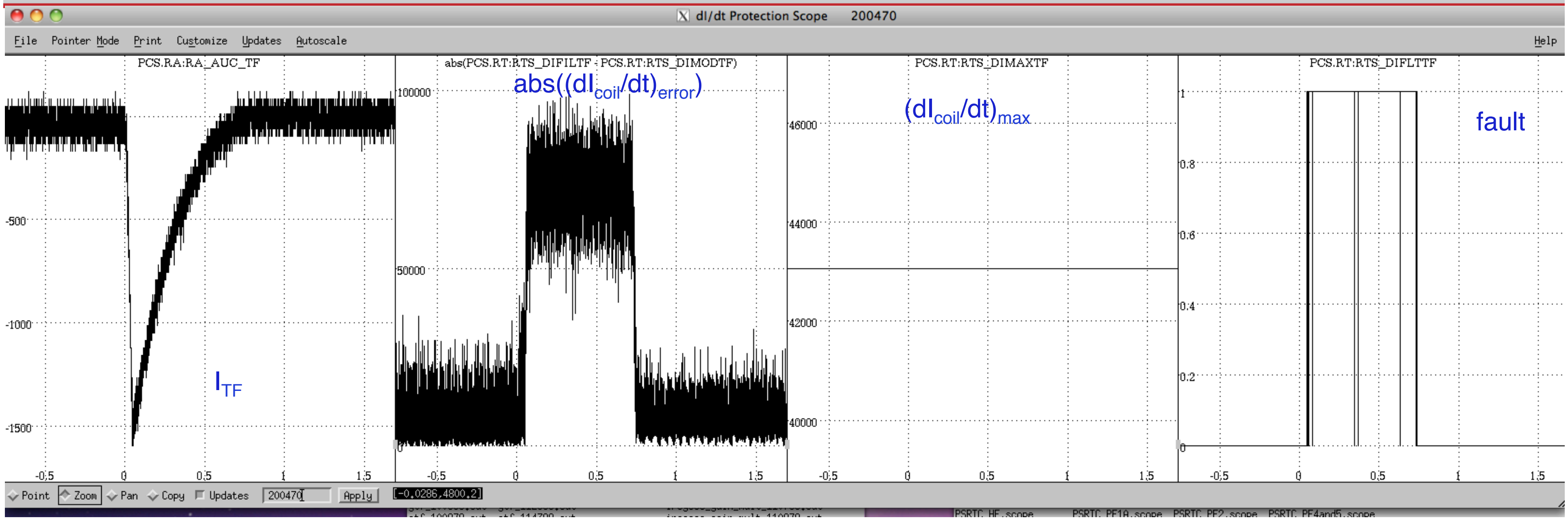
$$(dI_{coil}/dt)_{error} = (dI_{coil}/dt)_{measured}-(dI_{coil}/dt)_{model}$$

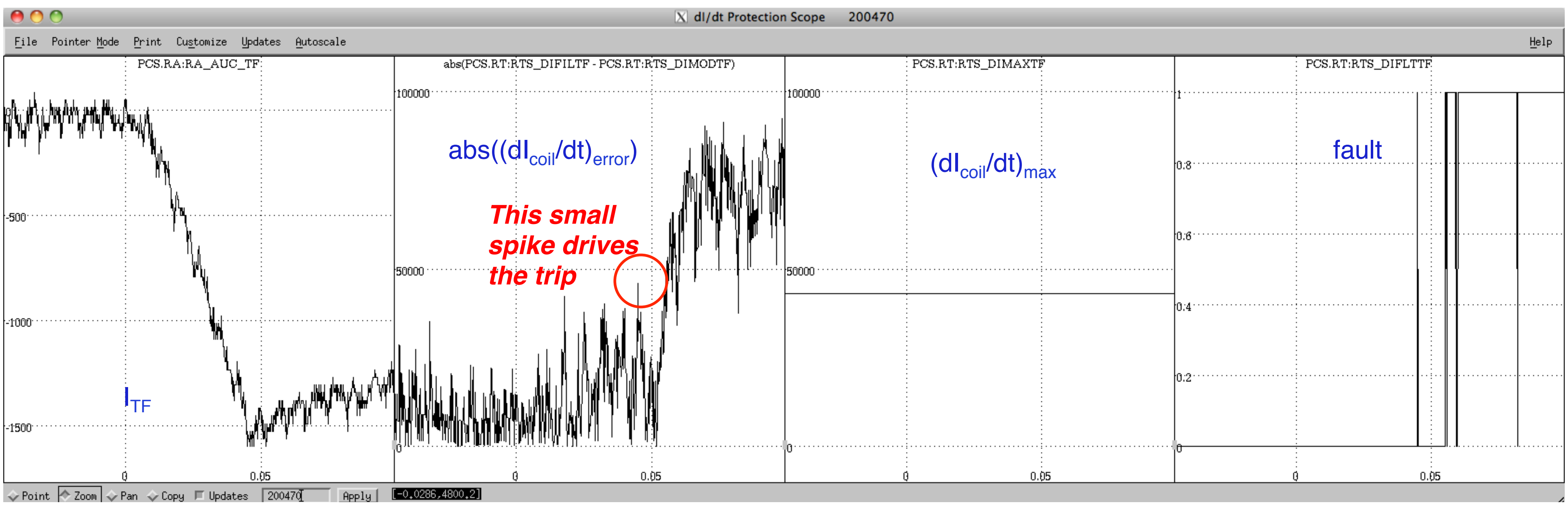
- Compare it to a limit value

$$(dI_{coil}/dt)_{max} = f_{dI/dt}V_{objectiveMax}/L_{coil}$$

- Note: cannot implement this in DCPS because DCPS does not know the coil voltages.
- Algorithm deliberately “detuned” during DL testing to provide drive a suppress and bypass.

New "Damage Avoidance" Feature Added to PSRTC Zoom Out (top) and Zoom In (bottom) on Demonstration Shot

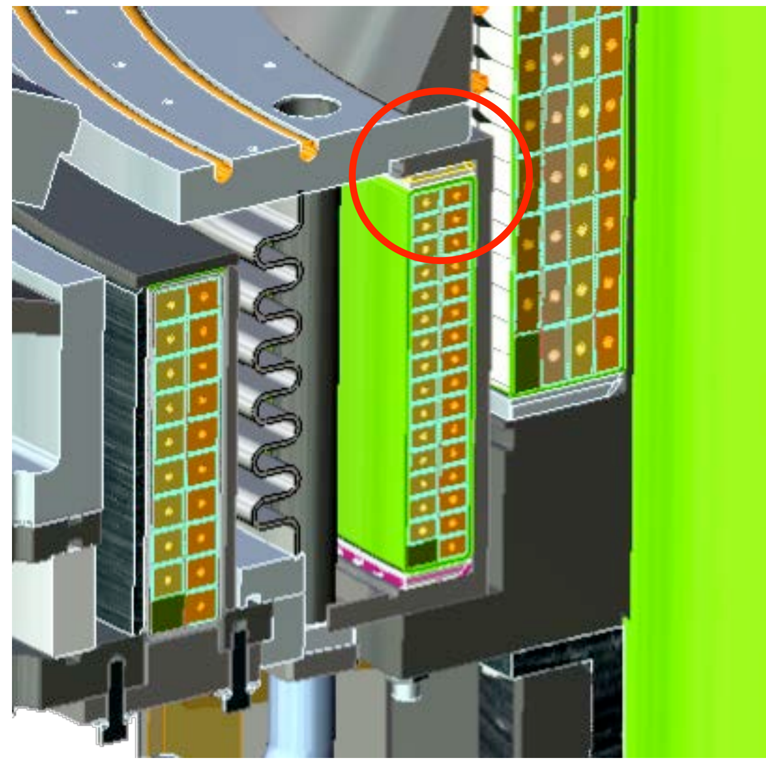




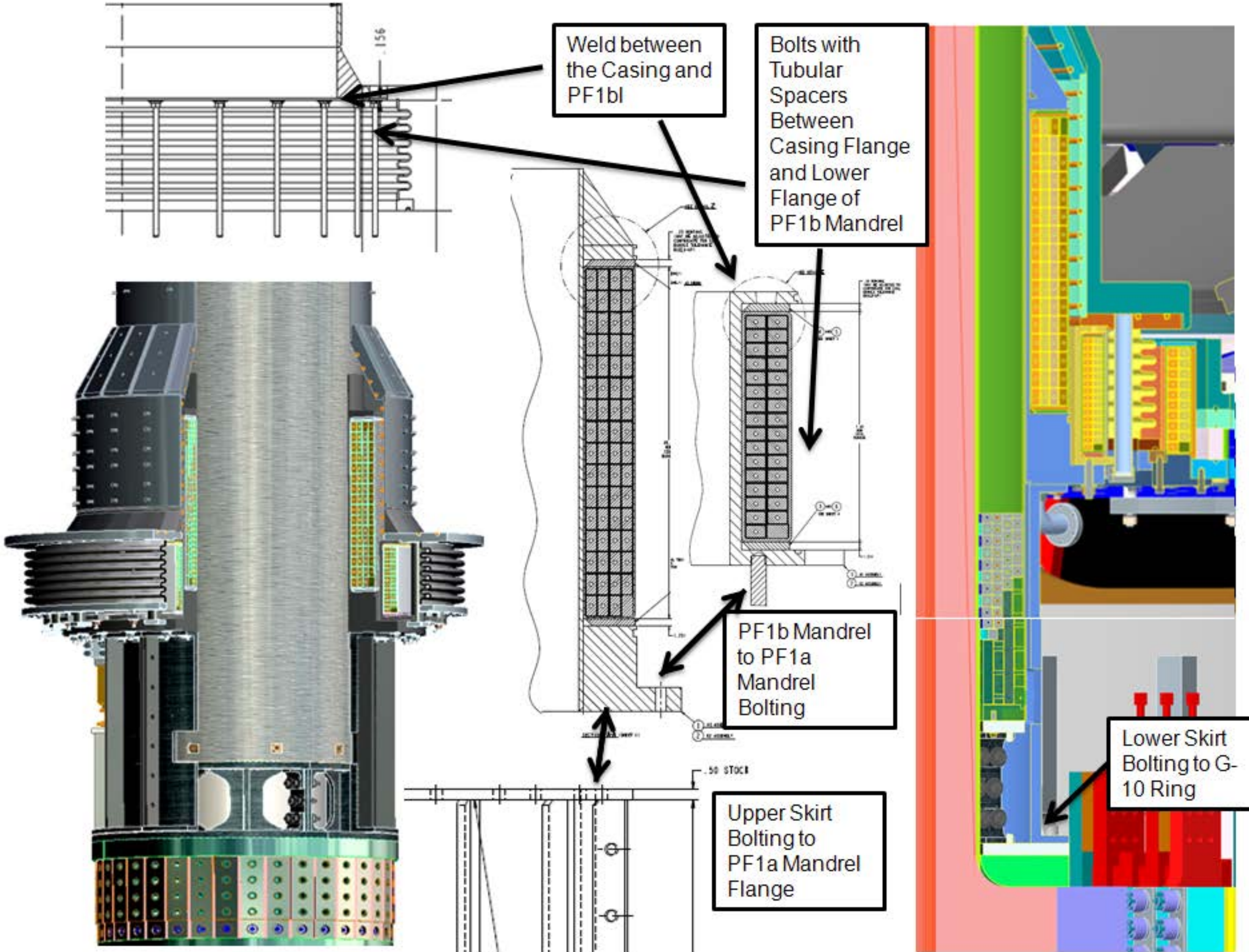
Art Brooks Bakeout Analysis

Impact of PF1b Coil on Inboard Divertor Bakeout

- The temperature to which the Inboard Divertor can reach during Bakeout of NSTX CS may be limited by heat loss to the PF1b coil which is welded to the CS Casing
- G10 Insulation in PF1b is at risk
- Everywhere else (OH, PF1a) the CS is insulated from the CS Casing with MicroTherm to reduce heat loss
- PF1b is part of the load path that supports the CS Casing and is in direct contact with the flange on which the Horizontal Inboard Divertor Tile is mounted
- There is also concern over the shear strength of the weld when subject to the large temperature differences
- Tile is in good thermal contact with the flange with Grafoil to limit ratcheting with consecutive pulses



Geometry Details at Inboard Divertor and PF1b



Analysis Overview to Assess Issues

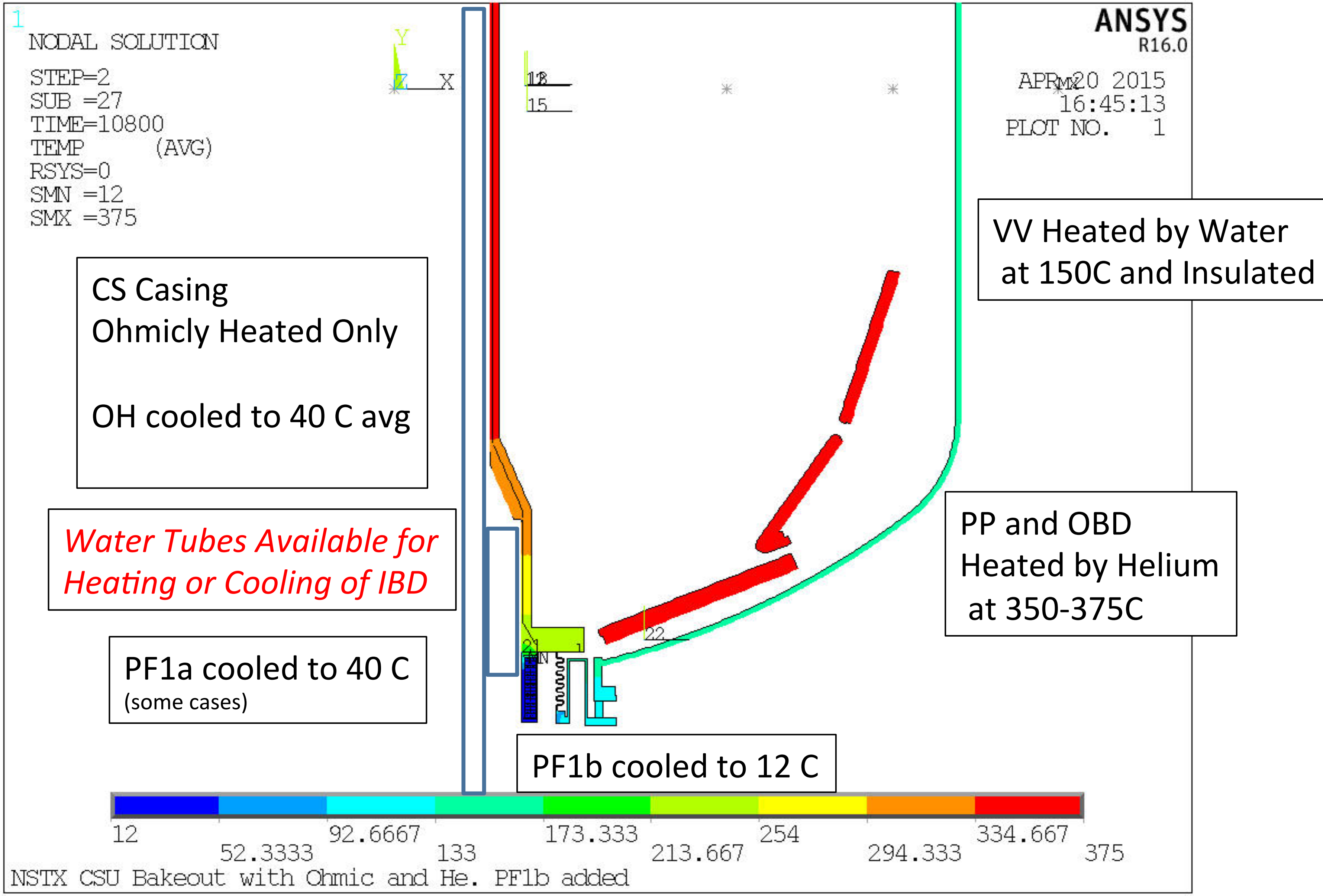
- Thermal Analysis of the Bakeout of the Vacuum Vessel and internals done to provide guidance on options

- Options split into two categories:
  - Near Term where only cooling changes are made (ie on/off)
  - Longer Term where changes to Tile mounting are made

<u>Goals</u>

- Determine Temperature obtained at Inboard Divertor Tile and at PF1b G10 (Shim, Groundwrap and Turn Insulation)
- Assess weld stress

Model Assumptions



Options Assessed

Near Term Options

1) CS casing ohmically heated 8 kA without any cooling in IBD, OBD, PPP, SPP or VV – Only heat leak to OH and PF1b (and VV insulation)
   - This simulates the initial bakeout performed
2) Add PPP, SPP & OBD (ie normal He system turned on)
3) VV Cooling/Heating at 150 C
4) Add IBD He at 350C

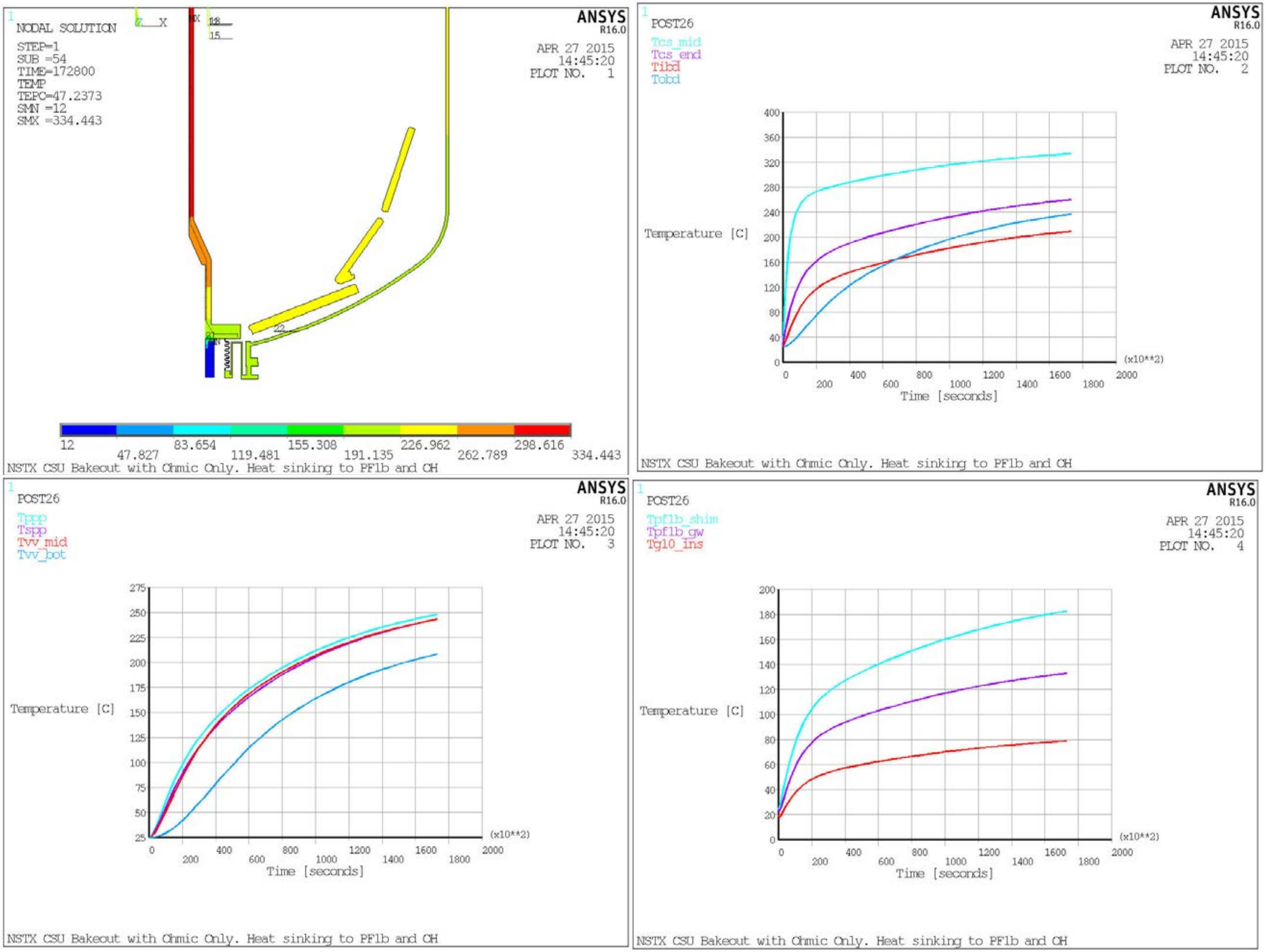
Longer Term Options

5) Remove IBD He at 350C and Remove conduction path (but not radiation to flange) at IBD to let tile float thermally
6) For IBDhs Tile Only - No Conduction or radiation to flange
7) Add leakage to pf1a at 40C, h=6.3w/m2
   - Repeated with Conduction between IBDhs and IBDvs removed
8) IBDhs & IBDvs Tiles No Conduction or radiation to flange (leakage to pf1a at 40C)
   - Repeated with Conduction between IBDhs and IBDvs removed
9) From (4) but added contact resistance and conduction thru weld
10) Contact resistance artificially increased to see impact. Still conduction thru weld

Note: Above were done sequentially. Small leakage to PF1A and conduction between tiles ignored in initial simulations. Some cases in later runs found to be impacted when included (ie 6 vs 7)

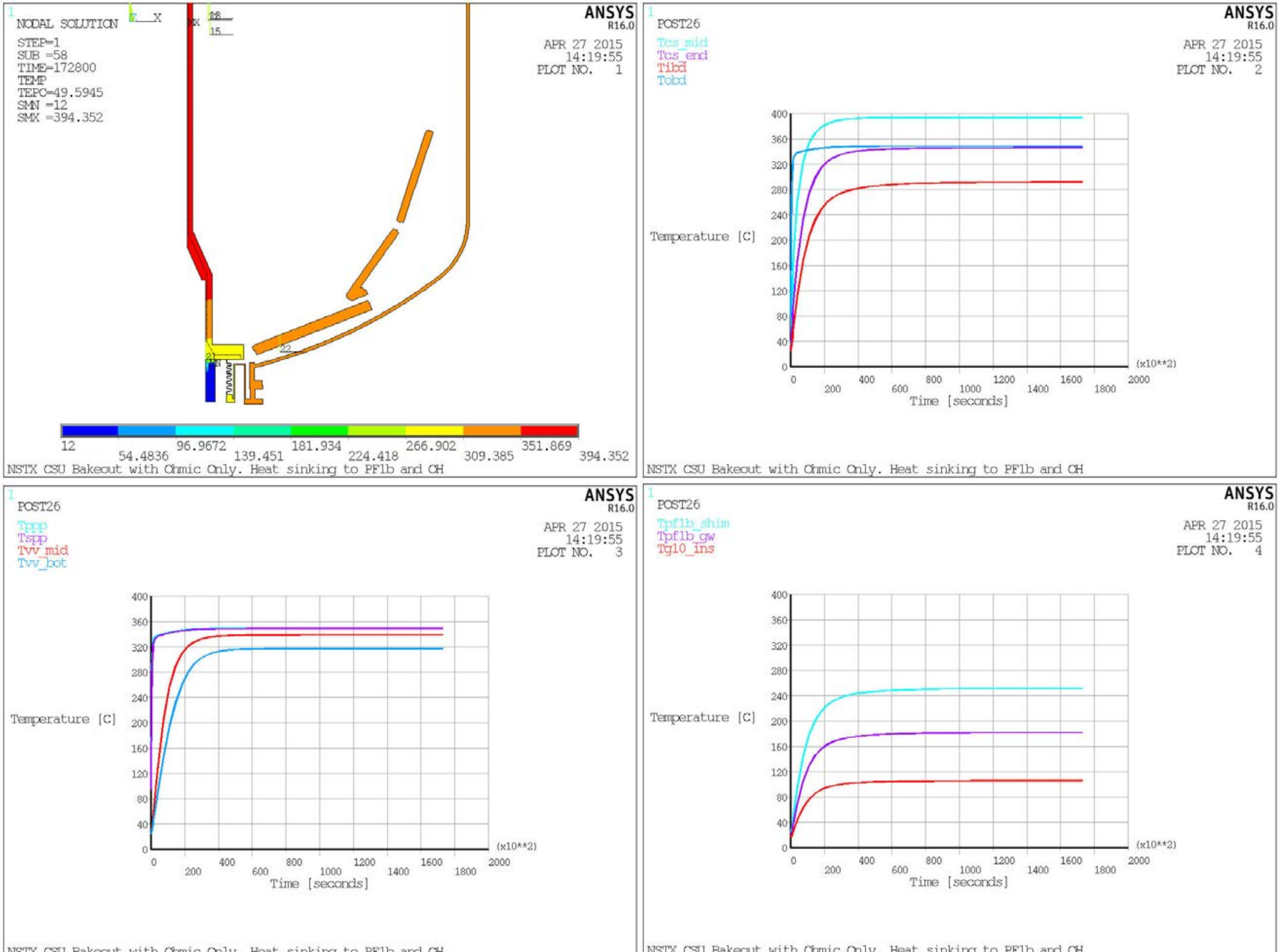
CS casing ohmically heated 8 kA without any cooling in IBD, OBD, PPP, SPP or VV

Only heat leak to OH and PF1b (VV perfectly insulation)



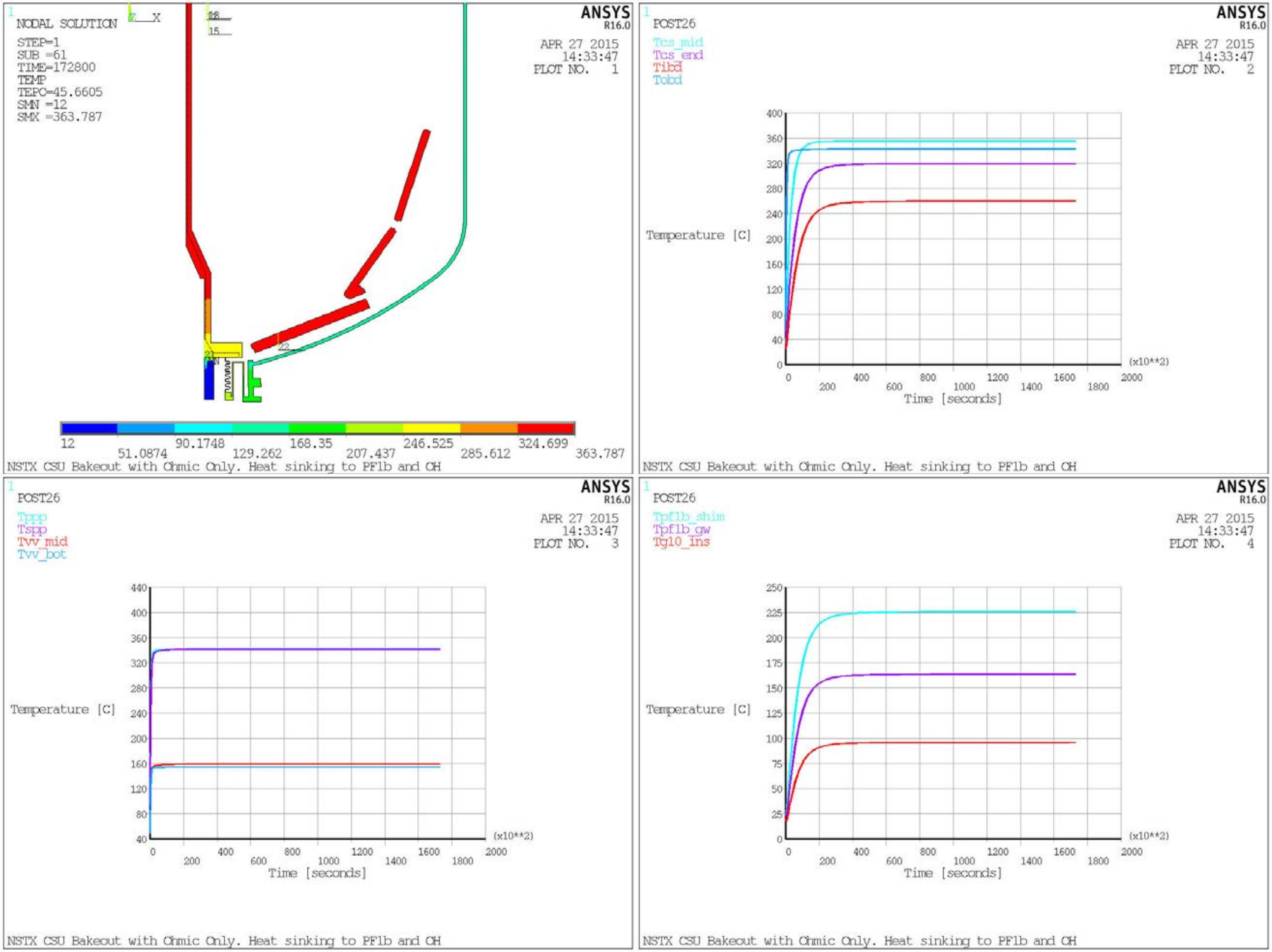
C

Add PPP, SPP & OBD (ie normal He system turned on)



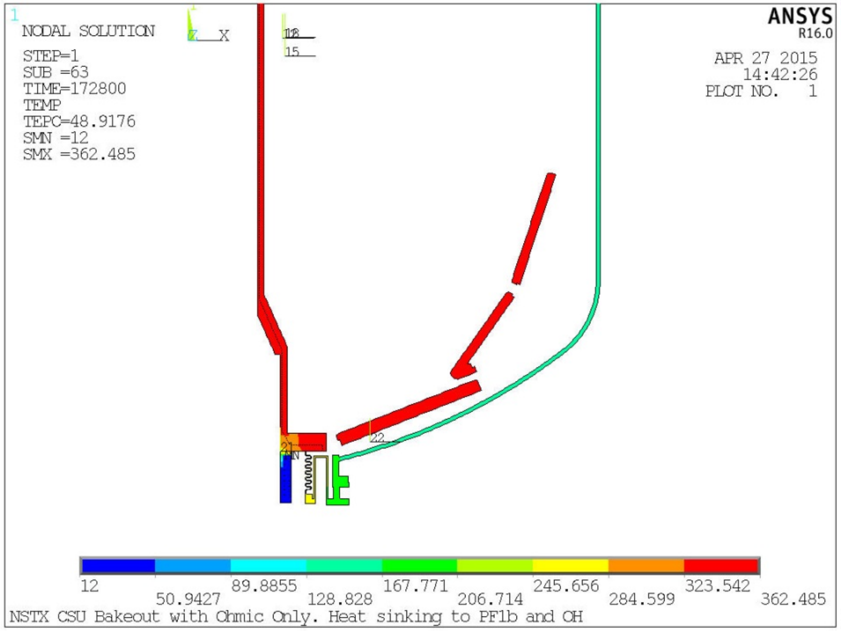
d

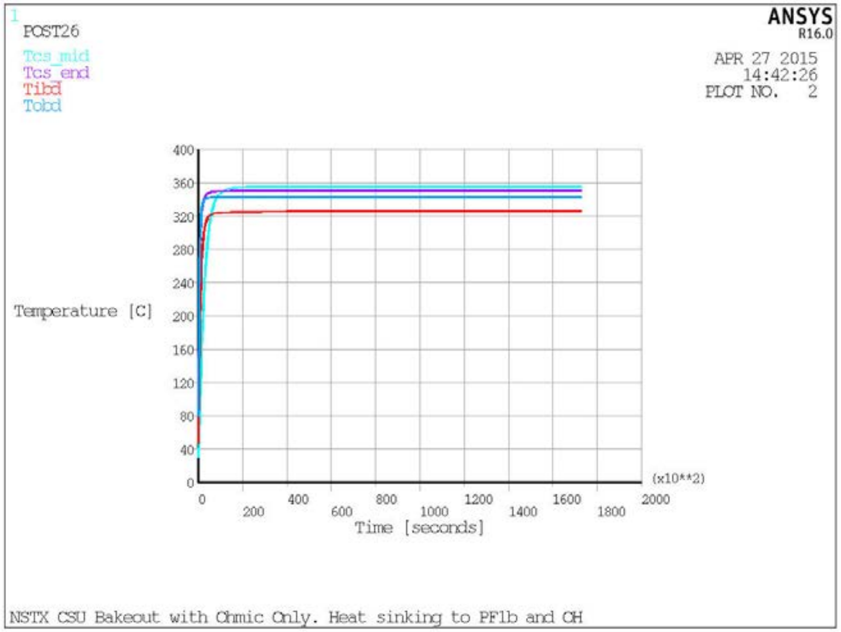
VV Cooling/Heating at 150 C

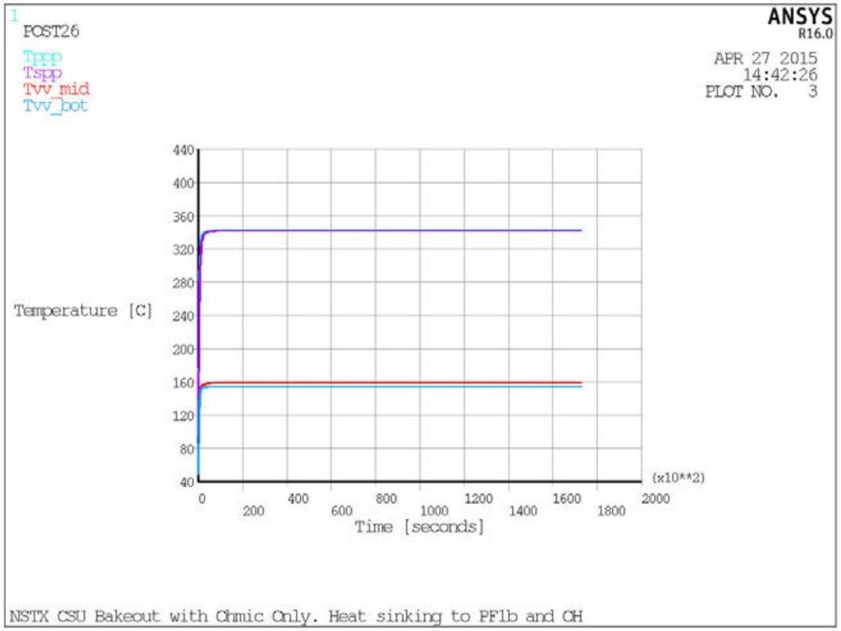


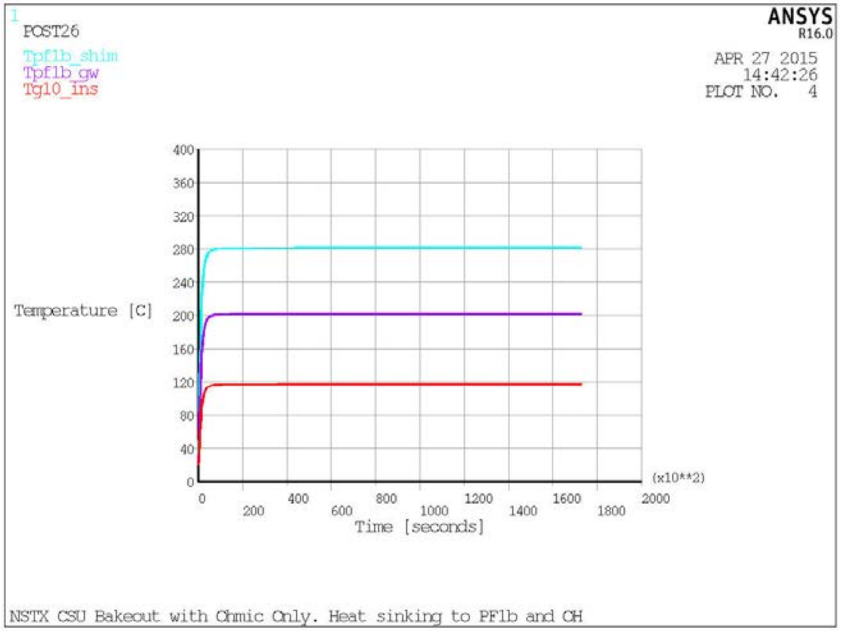
e

Add IBD He at 350C



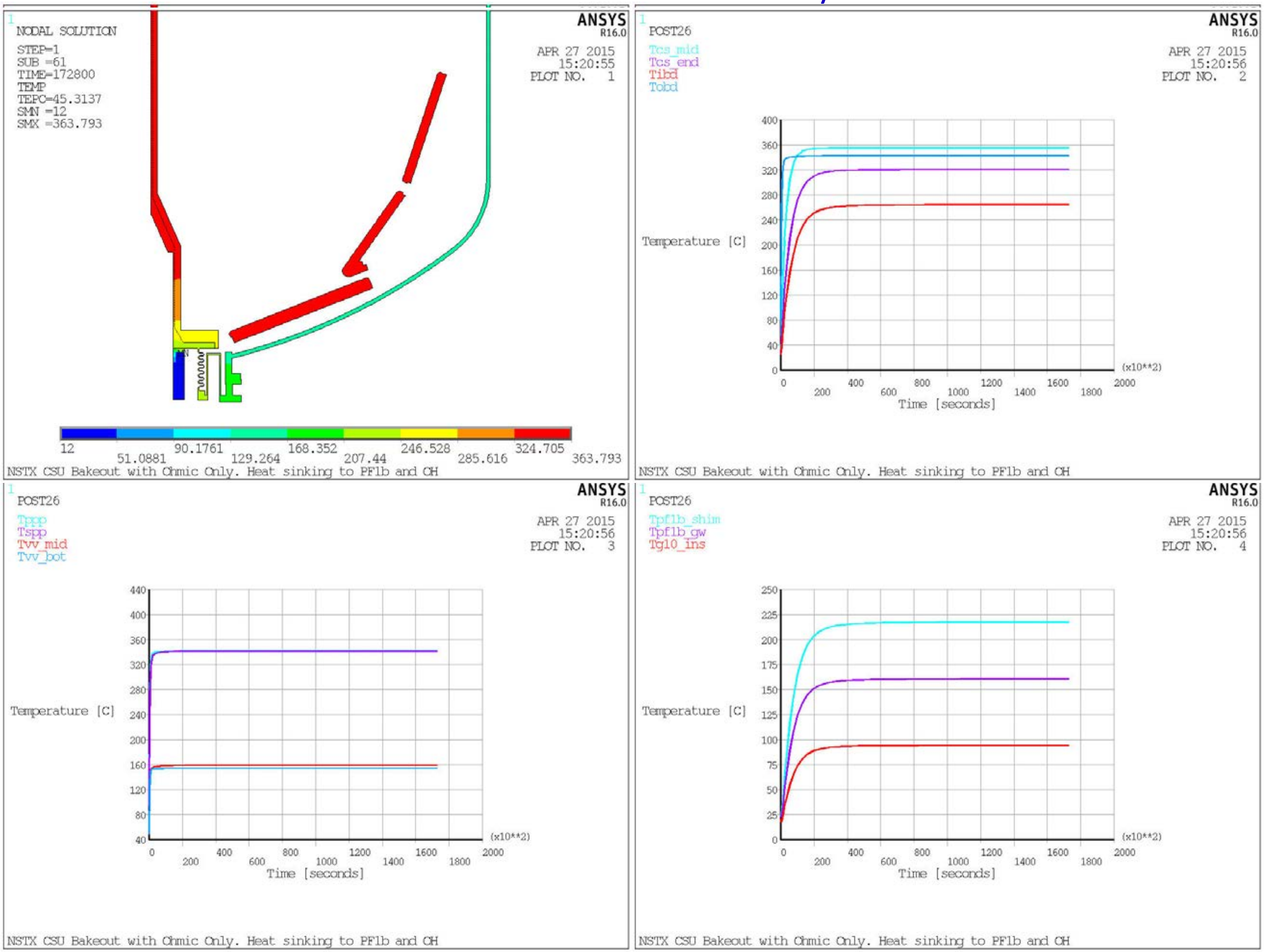




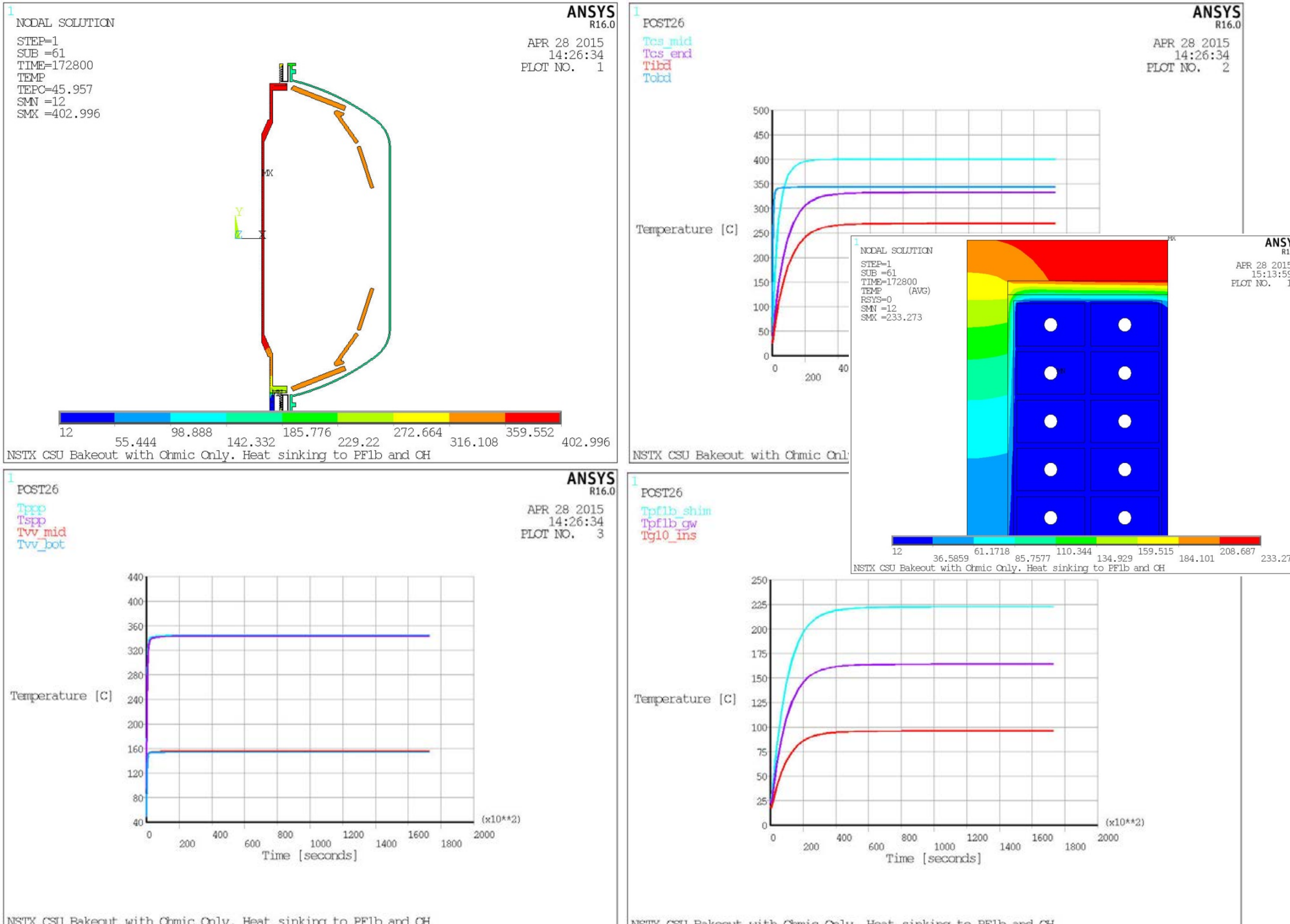


f

Remove IBD He at 350C and remove conduction path at IBD to let tile float thermally

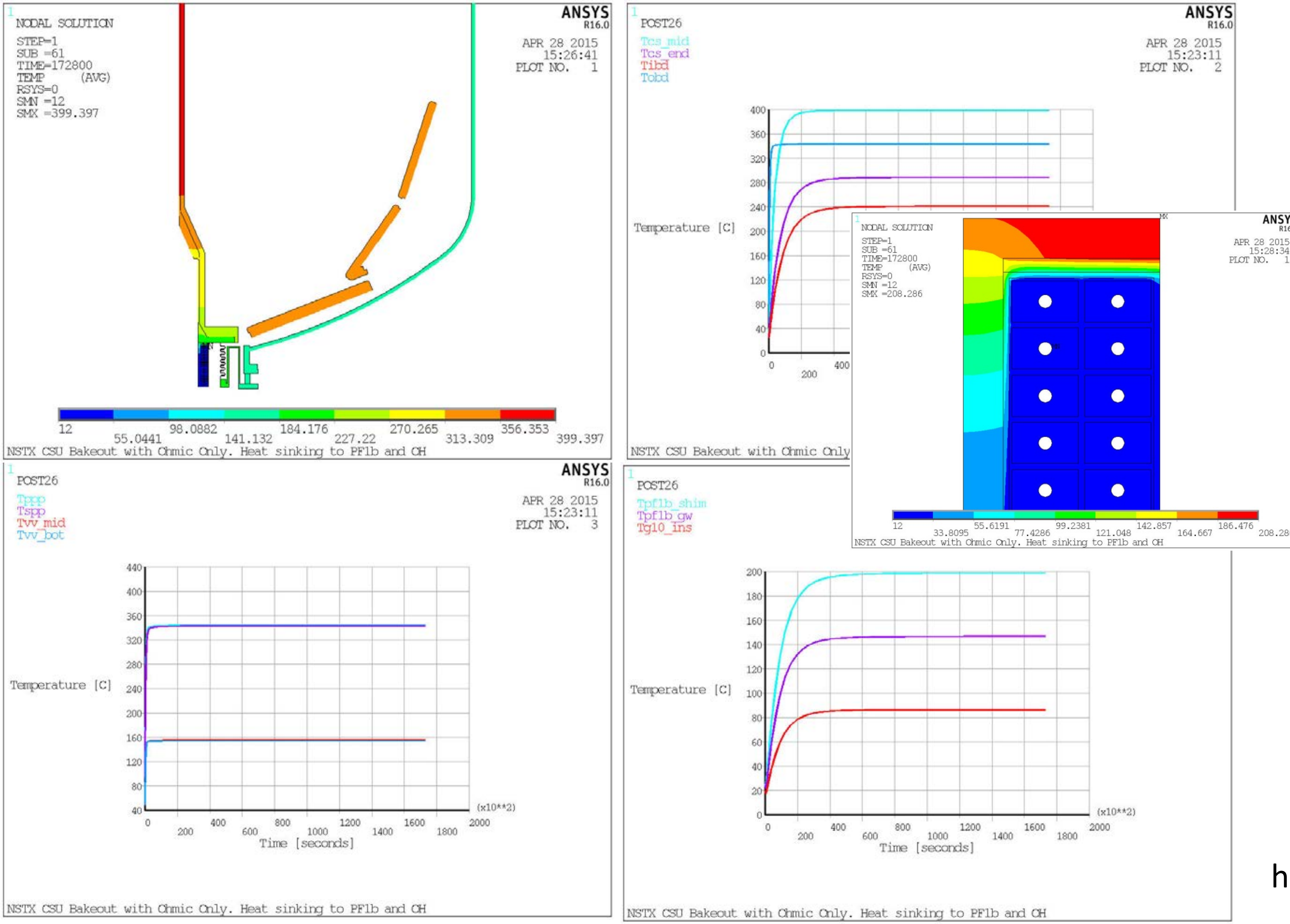


For IBDhs Tile Only - No Conduction or Radiation to flange



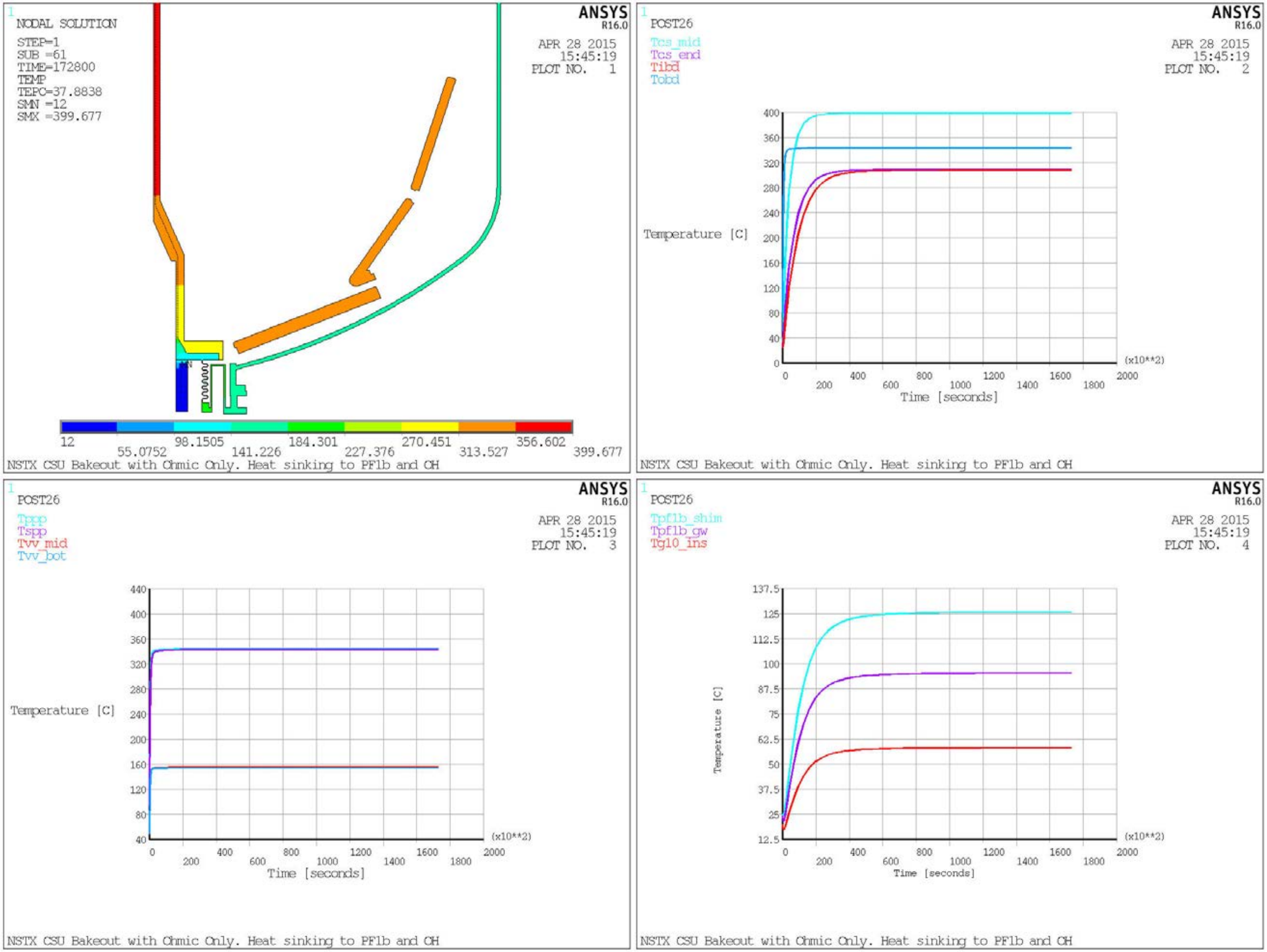
h

Add leakage to pf1a at 40C, h=6.3w/m2



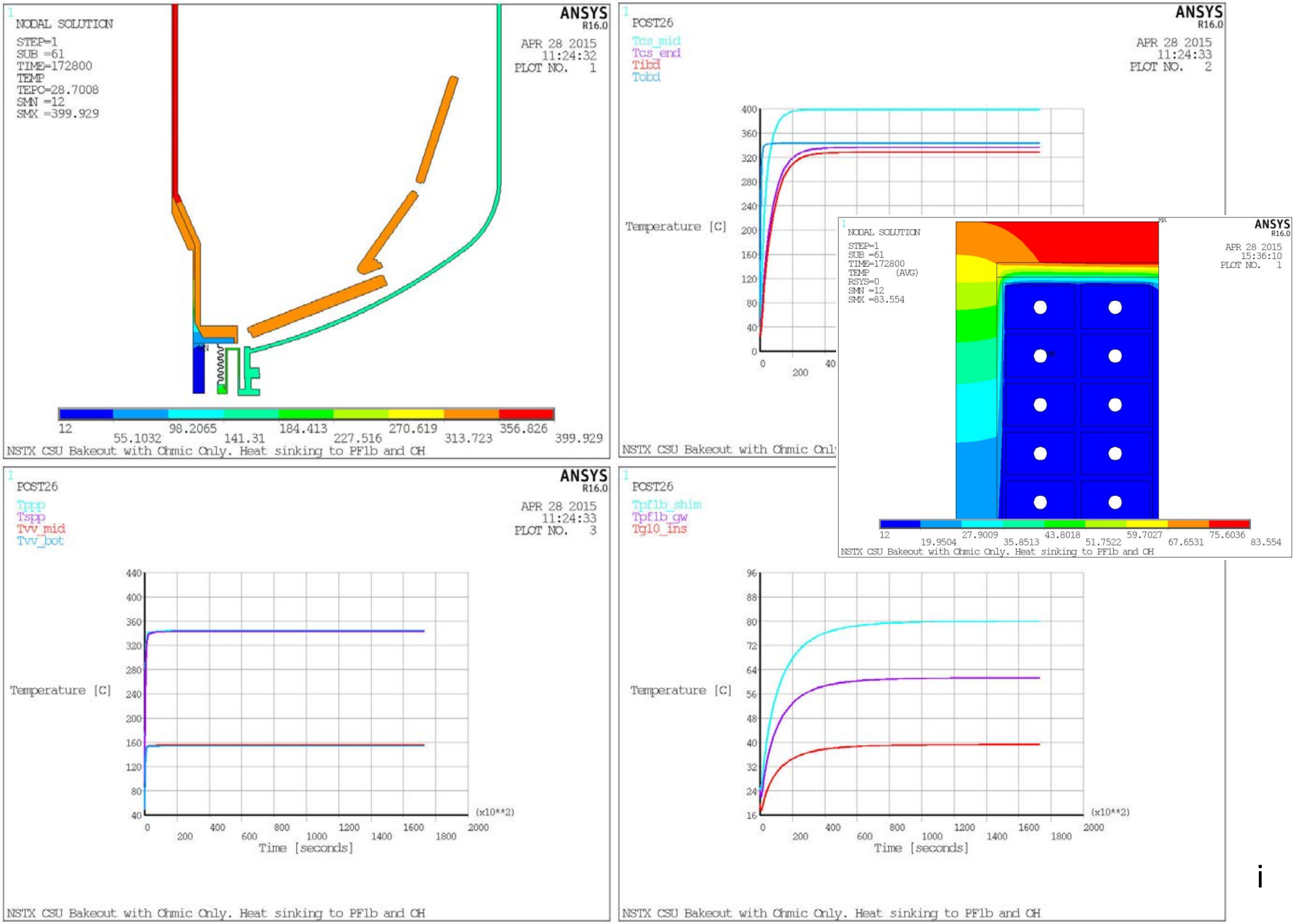
h2

Conduction between IBDhs and IBDvs removed



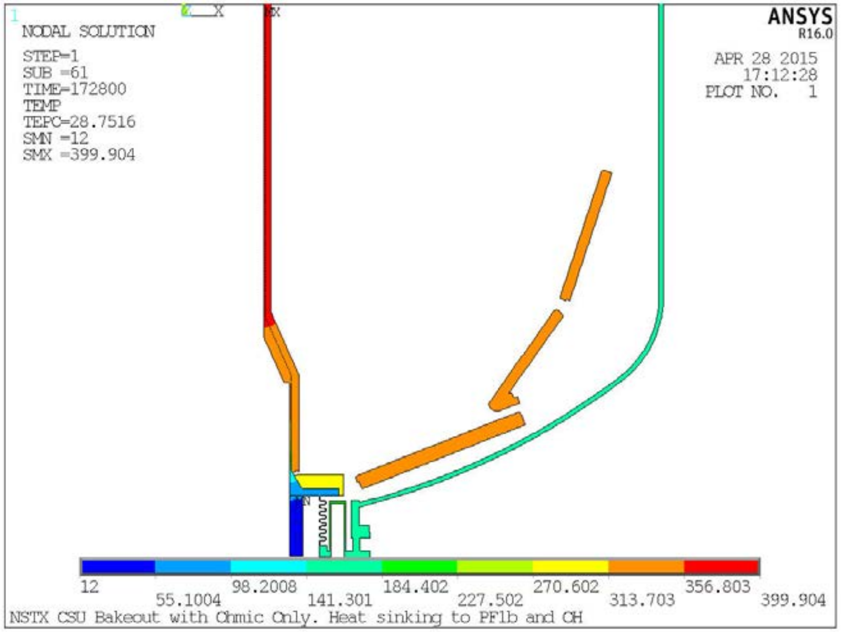
h3

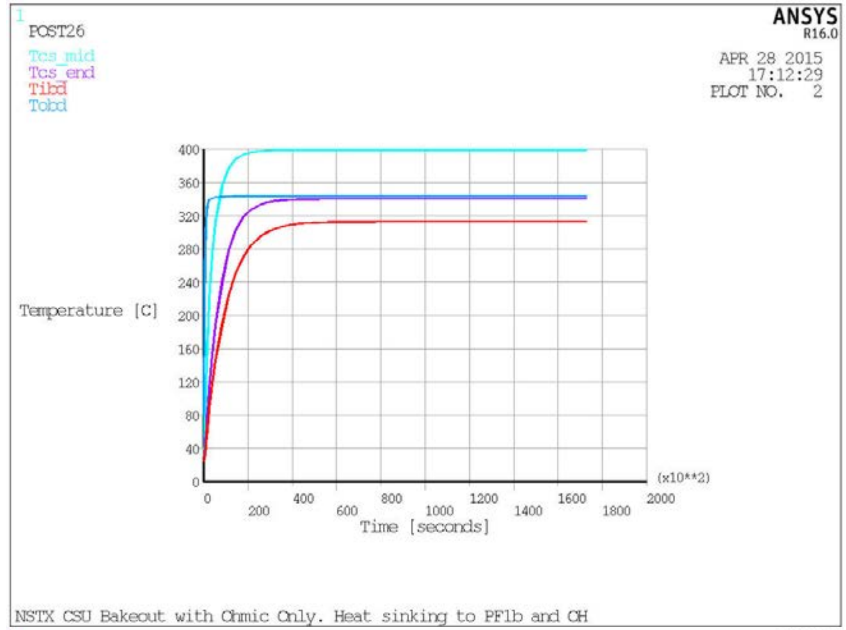
IBDhs & IBDvs Tiles No Conduction or radiation to flange (leakage to pf1a at 40C)

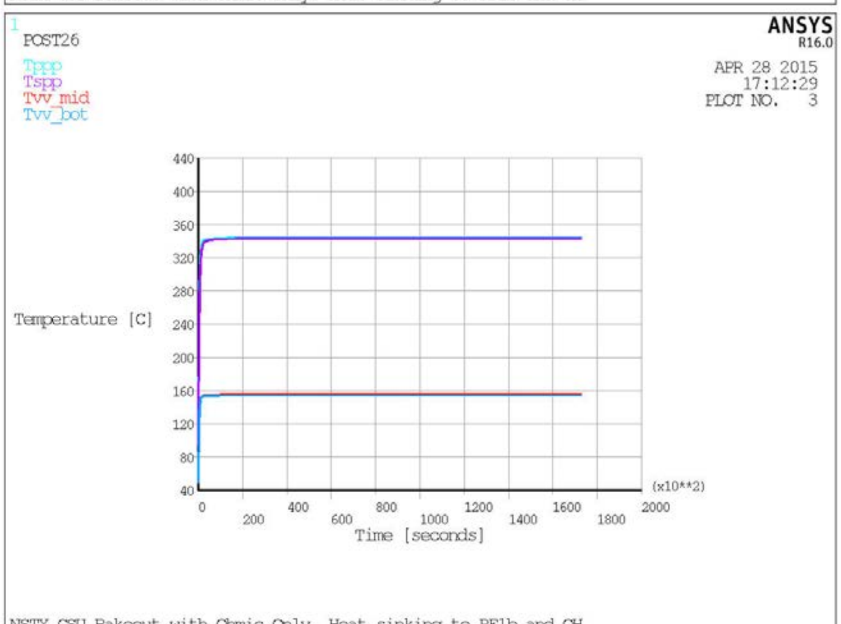


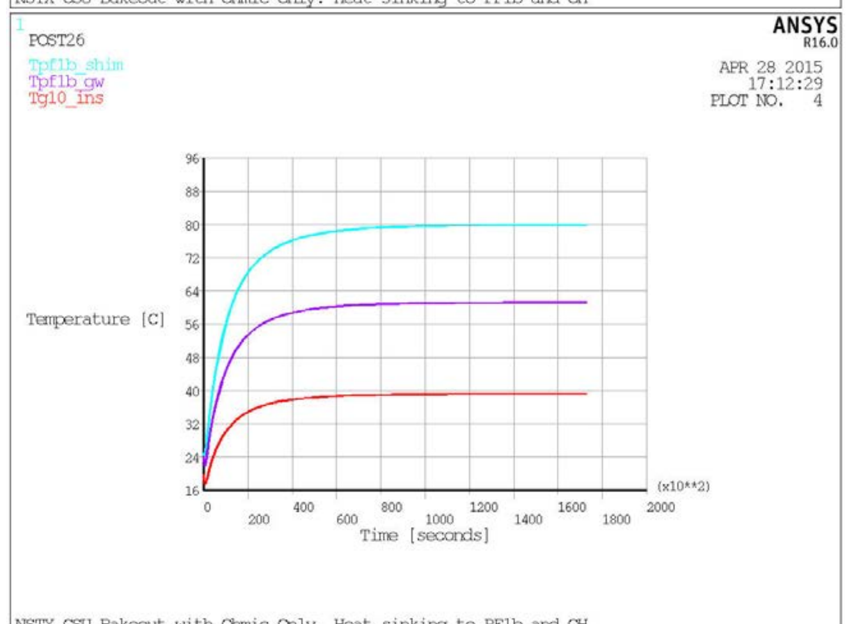
i

Conduction between IBDhs and IBDvs removed

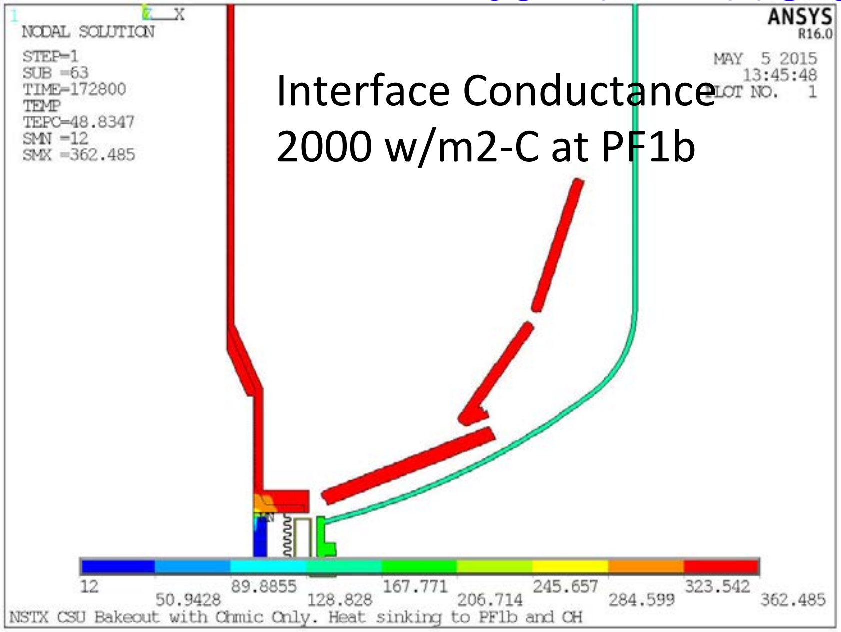


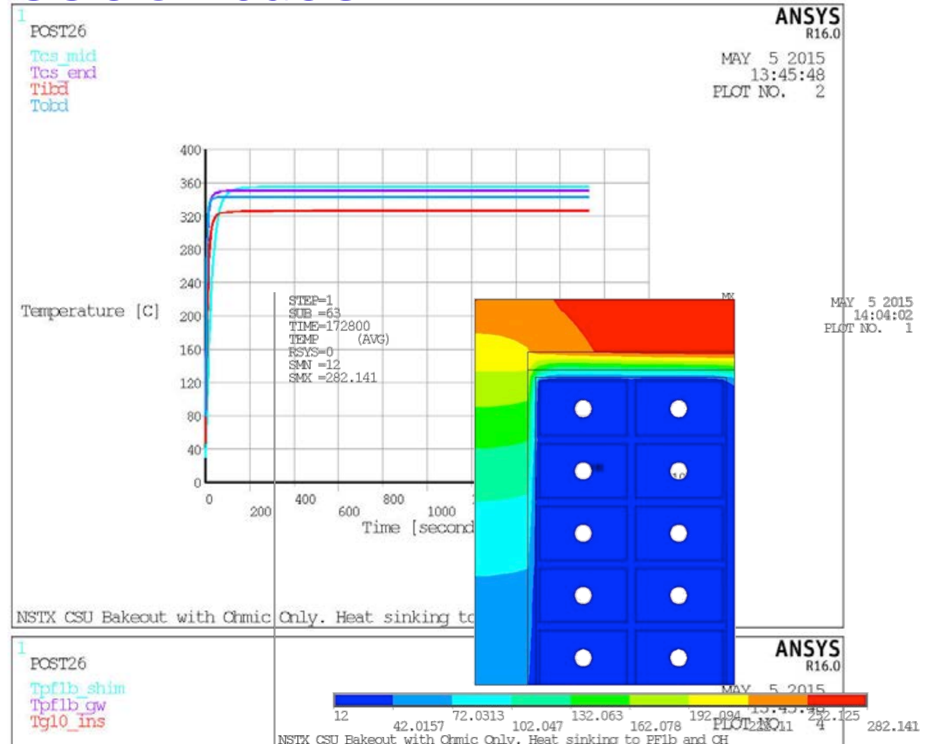


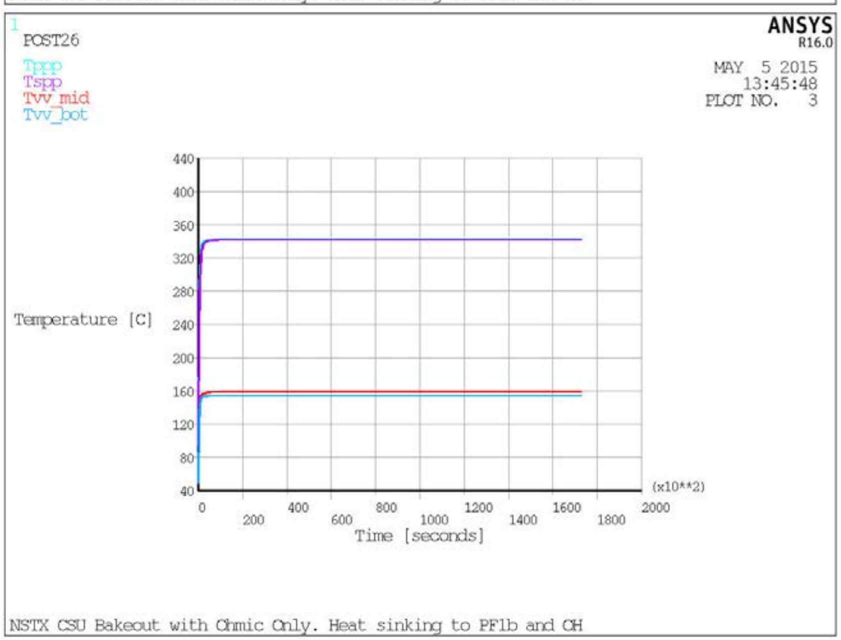




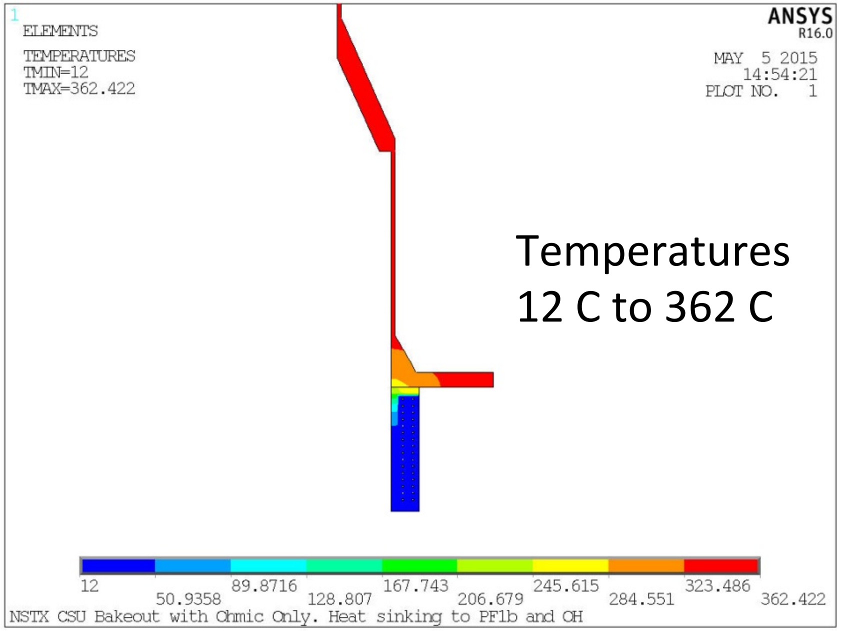
Contact Resistance and Weld Added to “IBD He at 350C” case

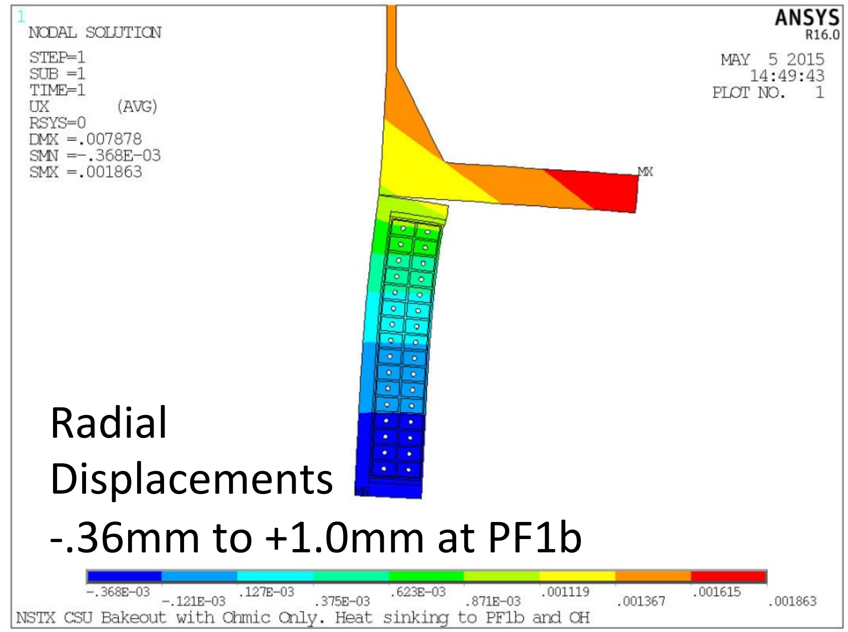






Shear At Weld from Thermal Growth



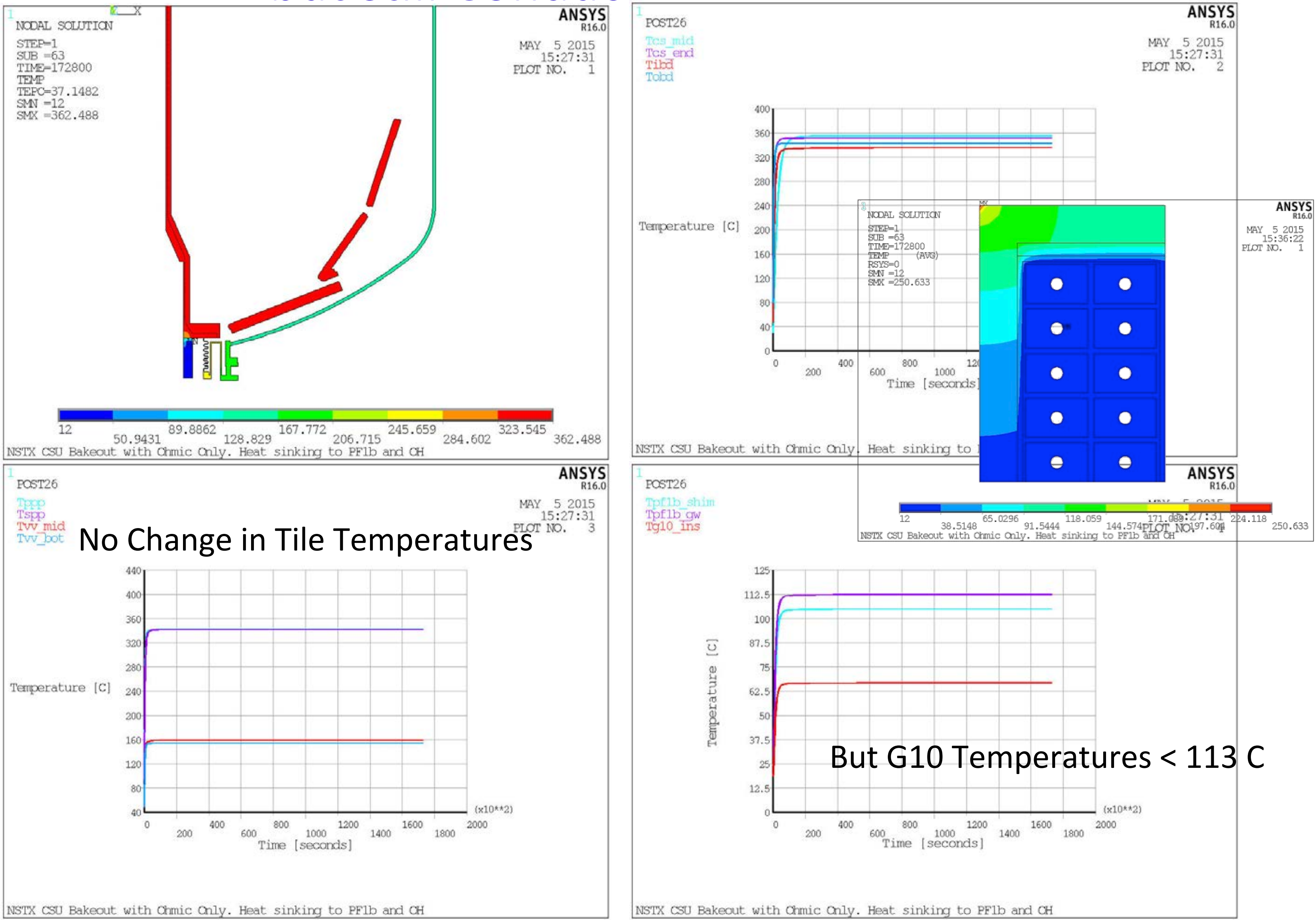


Weld Shear from Thermal Growth		
Radius	0.381	m
Weld Depth	0.003175	m
Weld Fraction	0.5	
Weld Area	0.0038	m2
Radial Force, 360deg	1.75	MN
Shear	**460.49**	**MPa**

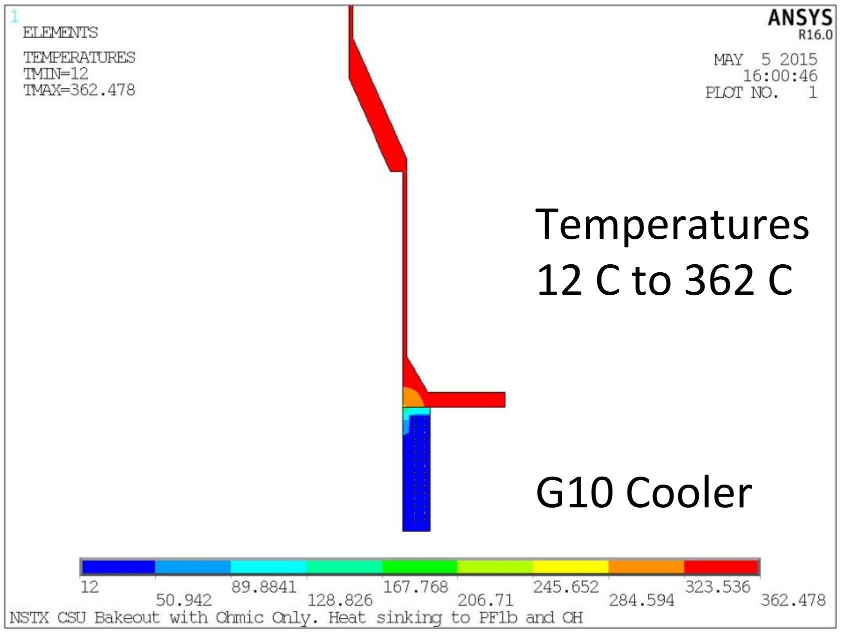
460 MPa is taken as a limit on weld shear stress bases on (limited) testing

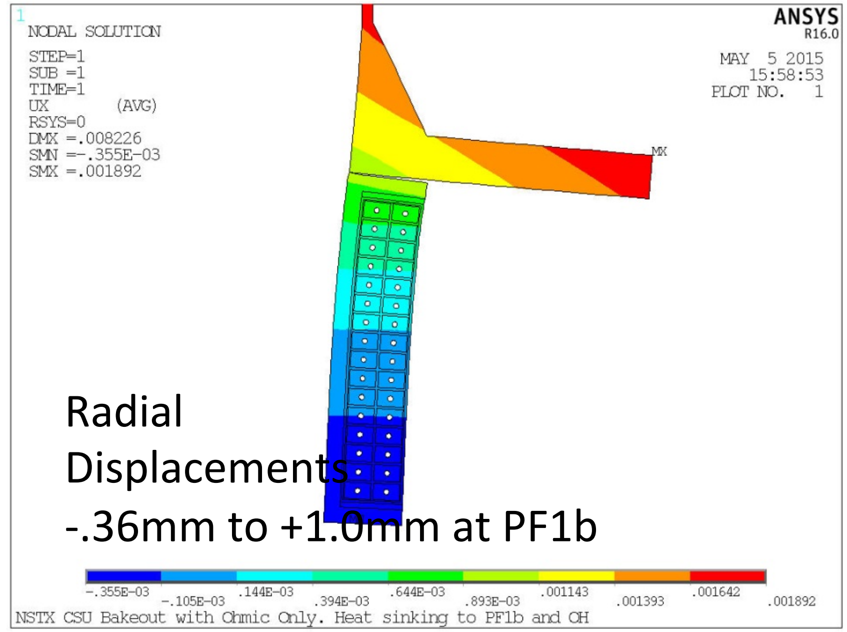
All options meet this limit except last (next slides)

Low Interface Conductance, but still Conduction thru Weld



Shear At Weld from Thermal Growth





Weld Shear from Thermal Growth		
Radius	0.381	m
Weld Depth	0.003175	m
Weld Fraction	0.5	
Weld Area	0.0038	m2
Radial Force, 360deg	2.75	MN
Shear	**723.63**	**MPa**

Assuming separation of PF1b from Flange (near 0 conductance) produces a larger temperature gradient and higher shear stress

Summary Table

	Case	Description	IBDhs Tile Temp	G-10 PF1b Coil Shim Temp	PF1b Ground Wrap Temp	PF1b Conductor Insulation
Near Term	1	No Heating or cooling of IBD, OBD, PP or VV	205	180	135	80
	2	PP & OBD He Heating Turned On	290	240	180	110
	3	VV Heating/Cooling at 150 C turned on	260	225	162	95
	4	IBD Heating at 350 C	325	280	200	120
Long Term	5	No IBD Heating, Grafoil Removed from Tile	265	215	160	95
	6	Radiation Shield added behind IBDhs Tile	270	225	165	100
	7a	Heat Leakage to PF1a at 40 included	240	200	148	87
	7b	Repeat assuming no conduction between Tiles	310	125	95	60
	8a	Radiation Shield added behind IBDvs Tiles also	325	80	60	40
	8b	Repeat assuming no conduction between Tiles	315	80	60	40
Near Term (Modified Assumptions)	9	Starting with (4) above, contact resistance and conduction thru weld	325	270	195	115
	10	Contact resistance artificially increased to see impact. Still conduction thru weld	330	113	105	65

Observations

- Results to date show that attempts to bake the Inboard Divertor Tile to near 350 will result in G10 temperatures exceeding 150 C by a significant margin
- Initial Bakeout already performed may have already driven G10 above 150 C with the Tile just breaking 200 C
  - Consequences of the shim exceeding 150 C may not be as severe as if turn insulation does
- The weld does not appear to be at risk

- Attempts to float the tile and reduce conductance to PF1b can reduce the G10 to acceptable levels but the flange still runs hot. The result jeopardizes the weld.

- Need to review analysis assumptions (here). How well insulated is PF1a from the CS? Do the Tiles as installed contact each other?

- The temperature of any fluid in the IBD system will control the Tile temperature. To limit G10 temperature to 150 C at the shim, the fluid temperature is limited to 175 effectively setting the tile temperature near term

Summary Table

Case	Case Ohmic 8kA	Heat Leak to IV	Heat Leak to PF1A	Heat Leak to OV	PP Heating	Conduction between IBDhs and IBVvs	IBDhs With Graphoil and Bolt Conduction	IBDhs Insulated	IBDvs Insulated	IBDhs Heated with Helium at 350C	OV Maintained at 150C	IBDhs Tile Temp	G-10 PF1b Coil Shim Temp	PF1b Ground Wrap Temp	PF1b Conductor Insulation
1	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	No	No	205	180	135	80
2	Yes	Yes			Yes			No	No	No	No	290	240	180	110
3	Yes	Yes						No	No	No	Yes	260	225	162	95
4	Yes	Yes			Yes	Yes	Yes	No	No	Yes	Yes	325	280	200	120
5	Yes	Yes						No	No	No	Yes	265	215	160	95
6	Yes	Yes						Yes	No	No	Yes	270	225	165	100
7a	Yes	Yes	Yes 40C			Yes		Yes	No	No	Yes	240	200	148	87
7b	Yes	Yes	Yes 40C			No		Yes	No	No	Yes	310	125	95	60
8a	Yes	Yes	Yes 40C			Yes		Yes	Yes	No	Yes	325	80	60	40
8b	Yes	Yes	Yes 40C			No		Yes	Yes	No	Yes	315	80	60	40
9	Yes	Yes			Yes	Yes	Yes	No	No	Yes	Yes	325	270	195	115
10	Yes	Yes			Yes	Yes	Yes	No	No	Yes	Yes	330	113	105	65