Liquid Nitrogen Distribution System
Preliminary Design Review

P.L. Goranson

Work Package 161

Outline

CHARGE FOR REVIEW COMMITTEE

SYSTEM DESCRIPTION

ANALYSES

DESIGN

FAILURE ANALYSIS

PROCUREMENT PLAN, COST, AND SCHEDULE

CHITS FROM PREVIOUS REVIEWS

Charge

- Is a current work plan on file?
- Has an SRD been prepared and distributed?
- Do the models and drawings adequately convey the design concept and are they consistent with the supporting analyses?
- Are the analyses and technical requirements clearly defined, reviewed, and documented?
- Have the interfaces been defined?
- Has a Failure Modes and Effects Analysis been performed?
- Have prior review comments/chits been resolved?
- Are the planned manufacturing and constructability approaches compatible with the design and are they practical and cost effective?

WBS 161 LN2 Distribution System Description

NCSX
National Compact Stellarator Experiment

Scope

This element covers the distribution of liquid nitrogen (LN2) coolant within the cryostat. The system serves all the actively cooled coils:

- TF (WBS 131)
- PF (WBS 133)
- Modular (WBS 14)

Work includes engineering design, procurement, and fabrication of ring manifolds, cooling hoses, valves, pressure gauges, and associated supports. Work in this WBS ends with delivery of components to machine assembly operations.

WBS 161 Interfaces

Defined in detail in SRD NCSX-BSPEC-161

- **WBS161 LN2 System**

Includes supply/return manifolds and routing and distribution of coolant between coil input/output terminations and the manifolds.
Presently, the valves and gauges are included in WBS161 estimates but will be installed by WBS 62.

- **Central I&C (WBS 5)**

Central I&C (WBS 5) processes the output from the LN2 distribution system local I&C sensors (i.e. thermocouples)

- **WBS171 Cryostat**

The supply and return lines carrying LN2 to/from the supply/return headers, and leads from local I&C sensors, penetrate the cryostat wall.

- **WBS 15 Coil Support Structures**

The LN2 manifolds and hoses connect to and are mechanically supported by the coil support structures.

- **Cryogenic Systems (WBS 62)**

Supply and return lines carrying LN2 to/from the supply/return headers connecting to the LN2 supply system <u>outside</u> the cryostat wall and outboard of the WBS 161 LN2 valves and pressure gauges, as well as the <u>inside</u> LN2 vertical run headers from cryostat interface to 161 ring manifold connections.

- **Electrical Power Systems (WBS 4)**

Grounding requirements applicable to coolant lines and manifolds.

Requirements

Requirements are defined in the system requirements document NCSX-BSPEC-161.

Include:

- Operation at 77-94 K with Liquid Nitrogen (LN2).

- Operating pressure sufficient to assure single phase liquid flow during operation.

- Sufficient flow to meet cool down requirements of the MC and Conventional coils.
  - handle heat load during standby and bakeout
  - return coils to <80K after shots

- Assure flow balance between the coolant systems.

Requirements Continued

- **Meet electrical isolation and grounding requirements**

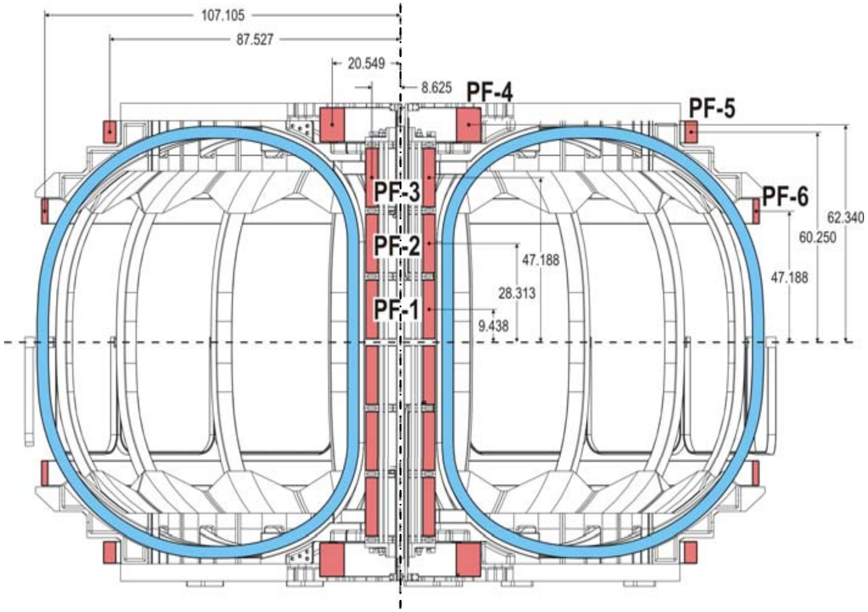
  - Isolate the Conventional coil cooling hoses (insulator breaks on both coil termination end and the supply/return manifold end).

  - Isolate the MC cooling hoses from the supply/return manifold end and connect the hoses to ground through a resistor.

  - Cover all braided hose with insulating tubing. It's purpose is to prevent hose from shorting to surrounding structure and thus permits measuring resistance to ground)

  - Isolate the ring manifolds from mounting structure

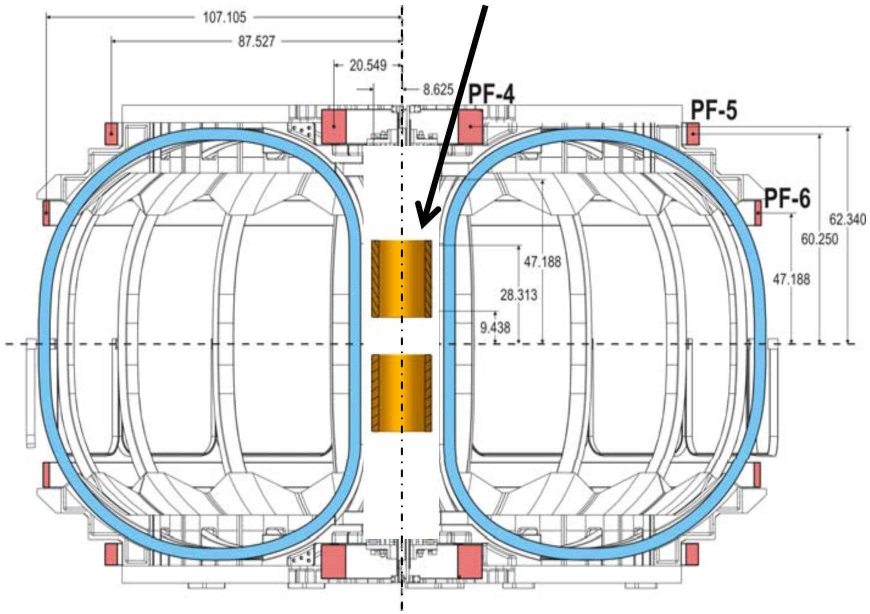
Central Solenoid, TF, and PF Configurations



Full Upgrade Configuration

- Baseline is PF1a, PF4, PF5, and PF6 (2 each, upper and lower).
- Device to be upgradeable to the Full Upgrade Configuration, where PF1a is replaced by PF1, PF2, PF3.

PF1a coils from NSTX are sufficient through Phase 3



Baseline Configuration

Cooling System Diagram

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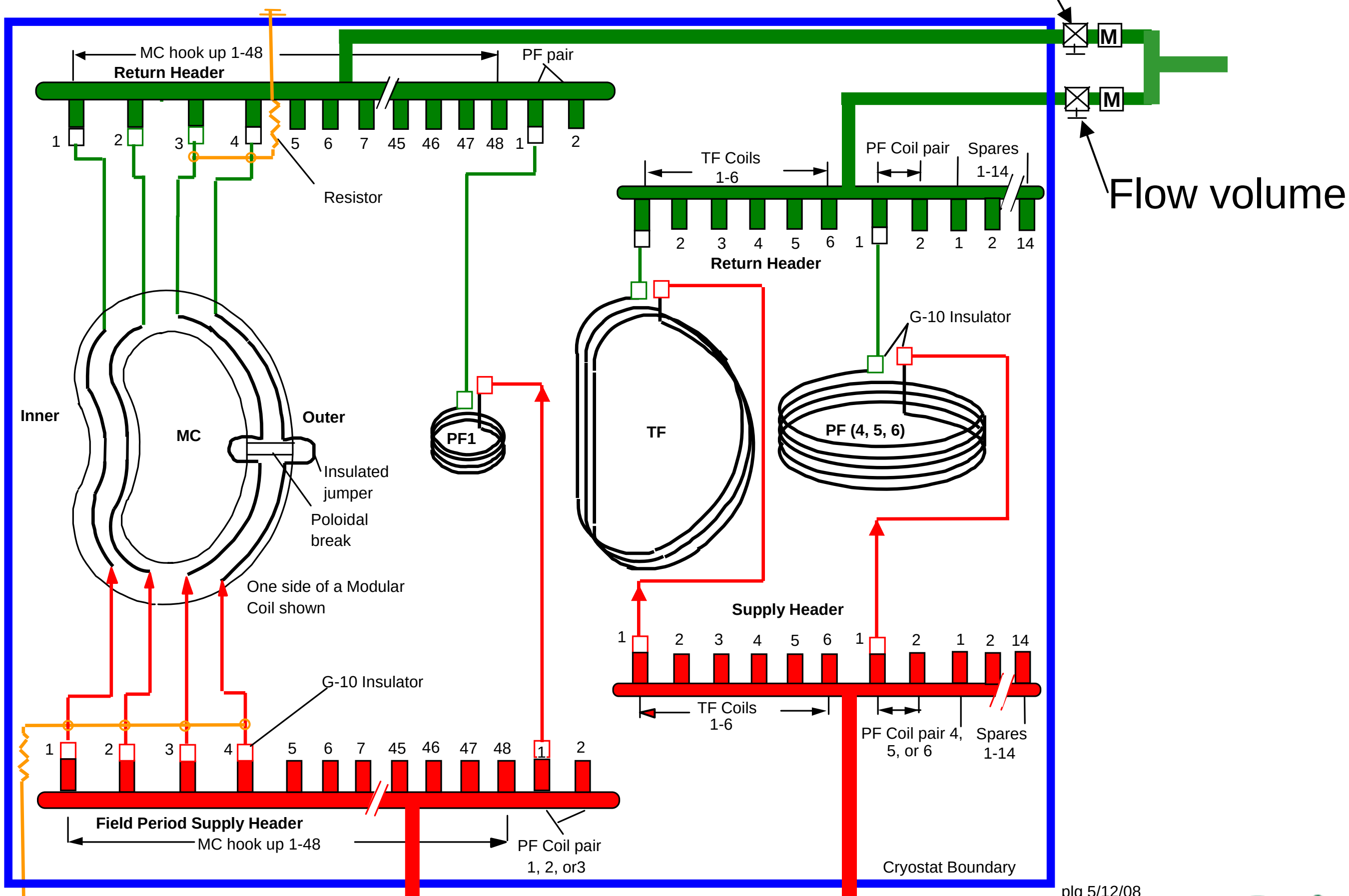
Dual supply and return manifolds

- Individual controls are not required, a single valve in MC return balances both manifolds
- Valve and monitoring is outside cryostat where it is accessible
- Individual circuits are passively (self) balanced

Flow balance (restrictor) valve
~2 atmos drop



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Flow distribution Calculations

- PF1A is used in CD4, could be replaced by PF1, PF2, and PF3 in future operation.
- Pressure drops fall in two well defined groups.
- This thermohydraulic information is incorporated into pending DAC NCSX-CALC-161-001.

	ID (in)	Length of tracing (ft)	Length of hose (ft)	Minimum flow required (gpm)	Actual flow (gpm)	Pressure drop (atmos)
MC	0.18	4	18	1.1	1.2	**2.42**
PF1	0.354	304	24	1.1	1.1	**2.42**
PF2	0.354	304	24	1.1	1.1	**2.42**
PF3	0.354	304	24	1.1	1.1	**2.42**
PF1A	0.354	178	24	1.1	1.2	**2.42**
spares				0.5	0.5	**4.51**
PF4	0.354	861	21	1.1	1.4	**4.51**
PF5	0.354	1100	21	1.1	1.2	**4.51**
PF6	0.354	786	18	1.1	1.4	**4.51**
TF	0.312	355	18	1.6	1.6	**4.51**

Flow in Headers

- Pressure drops in headers and branch manifolds is negligible.

	inside diameter inches	flow rate l/s	maximum velocity m/s	Re	friction	maximum loss per m (atmos)
MC header	2.049	3.7	1.75	481,257	0.012	0.003
MC branch	1.592	1.9	1.45	309,704	0.013	0.003
TF header(upgrade)	2.049	1.2	0.58	158,996	0.016	0.0004
TF branch	1.592	0.6	0.48	102,319	0.018	0.0004

Manifold Configuration

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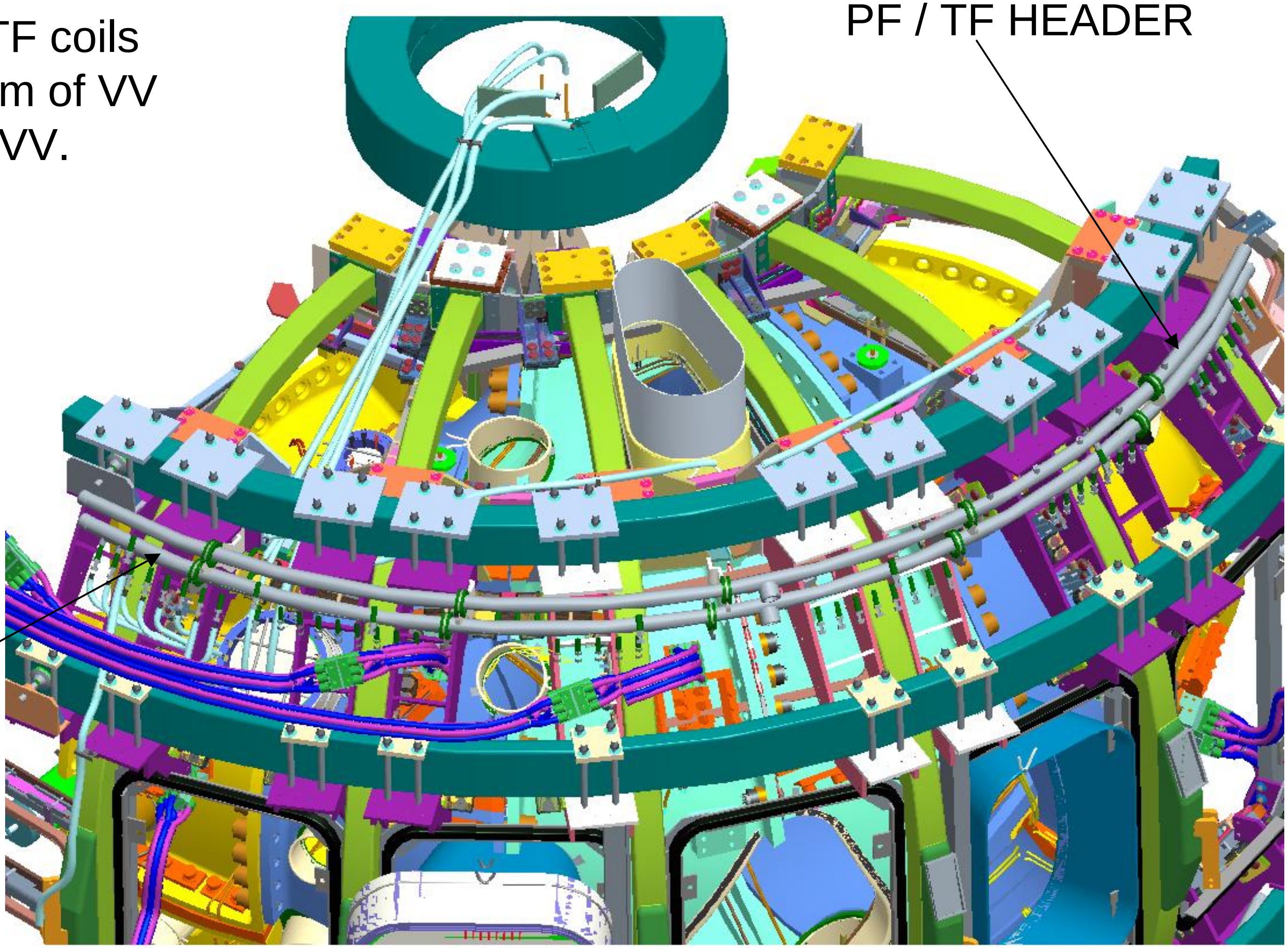
- Manifolds lie outside TF coils
  - supplies near bottom of VV
  - returns near top of VV.



Manifold Configuration

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• Uses four (two supply and 2 return) 115 deg. manifolds per field period made from 316 SS Schedule 40 pipes.

• Total angle per field period will be 117 deg. (including the pipe caps)

• 72 cooling ports supplied by two manifolds – 48 for MC coils + 6 for TF coils + 4 for PF coils + 14 extra

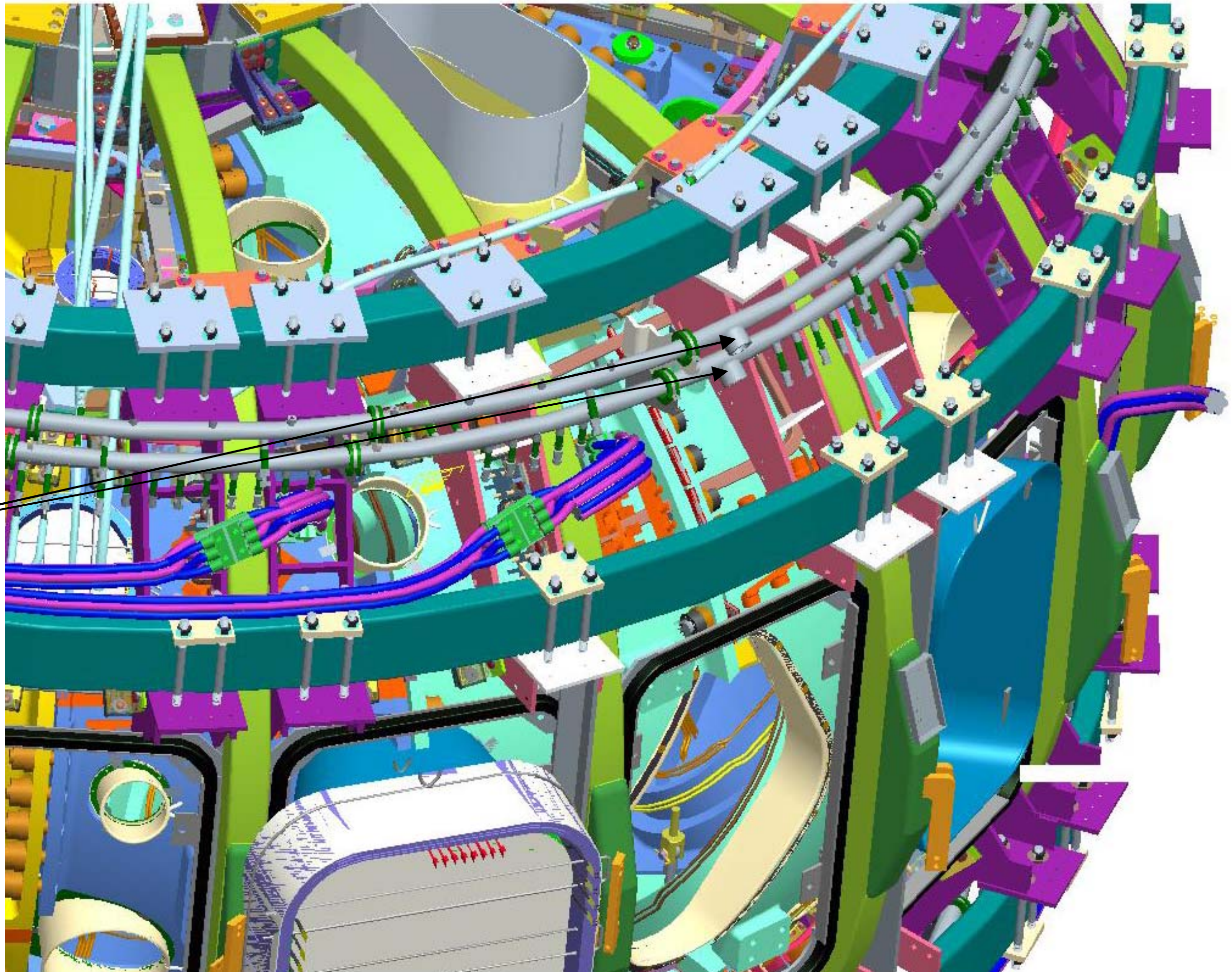
• Uses SS flexible hoses with straight tube ends. (similar to VV)

• Angular orientation of the cooling ports varies along the manifold length for easier hose routing

• Vacuum vessel (extended with 1” insulation added) ports can be cleared

Header Connections

Both upper header connections oriented toward the bottom of the machine



Manifold Hose Insulators

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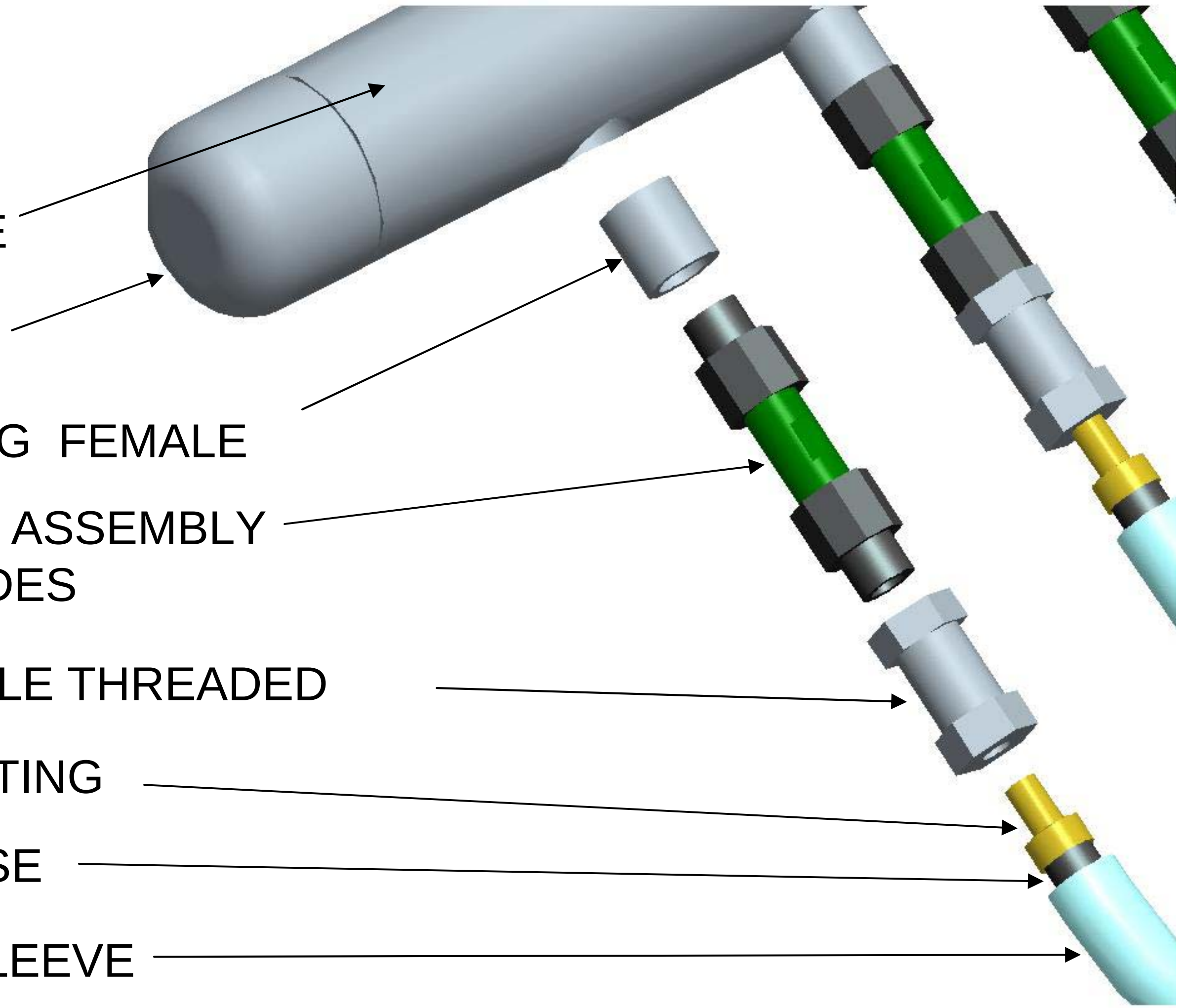
Hoses are isolated from the manifolds by G10 insulating breaks



G10 Insulating Break Design

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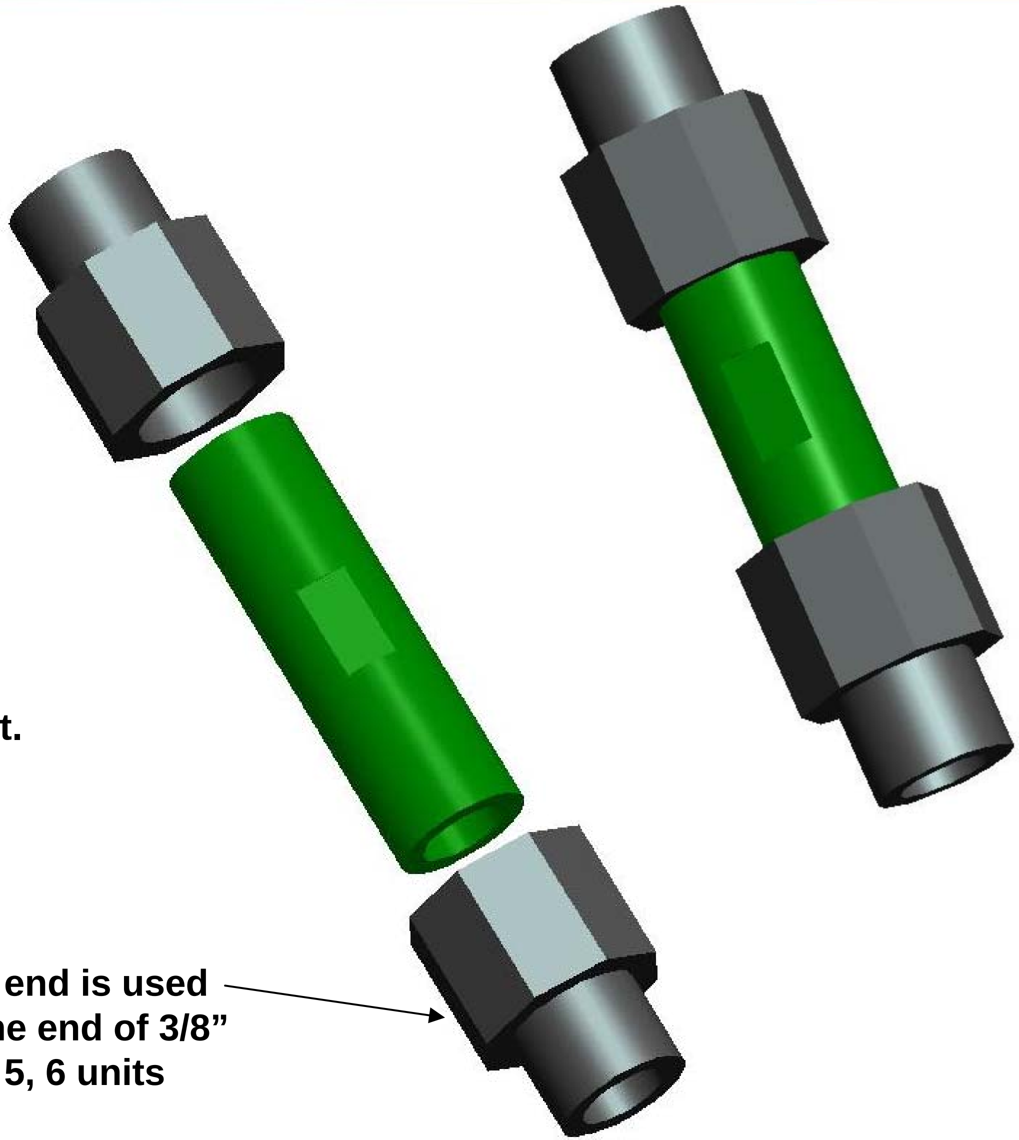
- Unit is leak checked subassembly with fittings attached.
  - two sizes (1/4” and 3/8”)
  - two types, one with male treads and one with tube end

- Configuration is based on proven design, tested on C1 coil.
  - Male pipe threads on G10
  - Female pipe threads on SS fittings
  - Threads sealed with “Formula 8” (Fluoramics Inc.) sealant. Stycast and teflon tape also work.

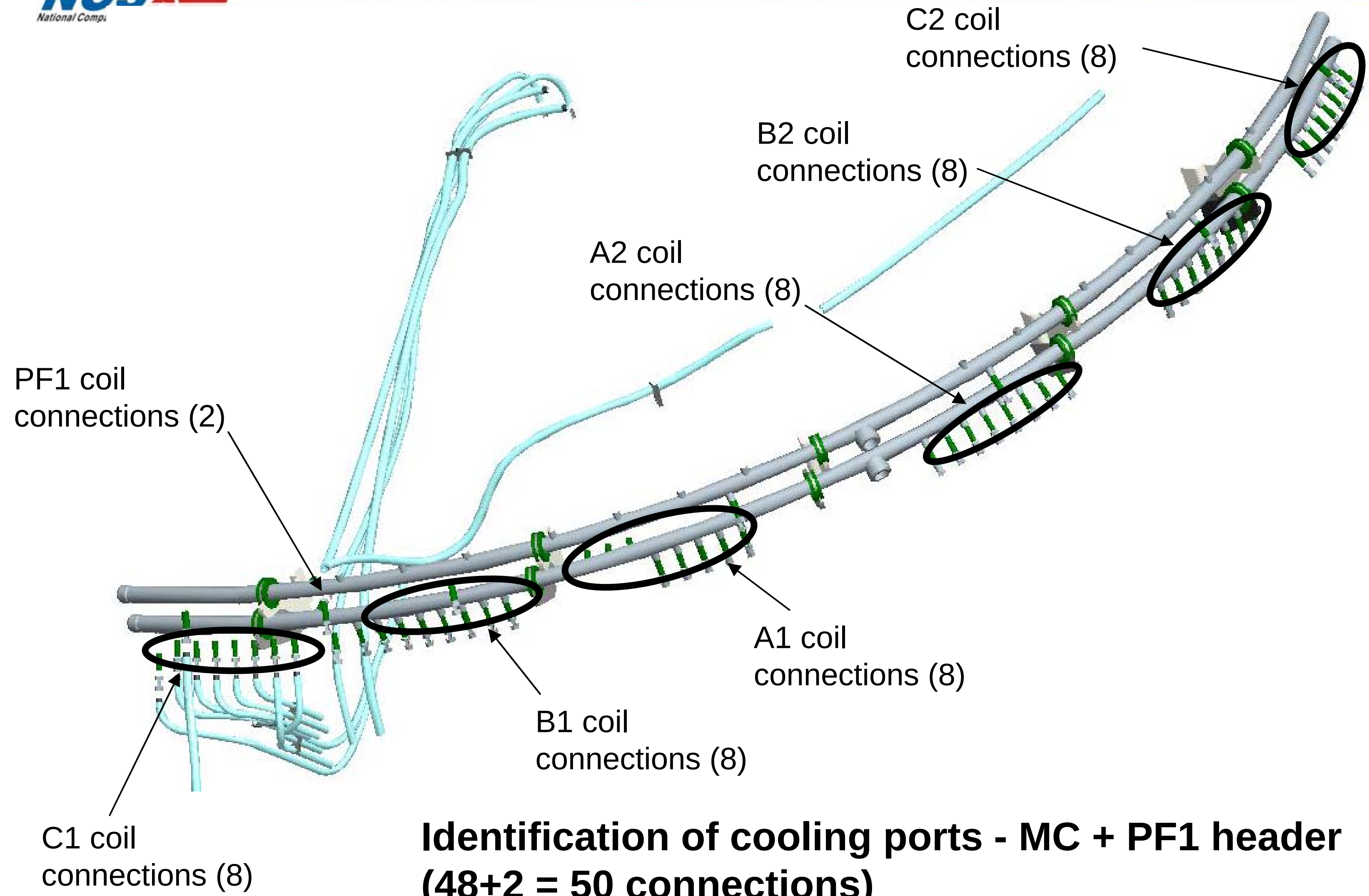
- Prototype fabricated at MDL was submitted to LN2 plunge tests.



Manifold Location and Mounting

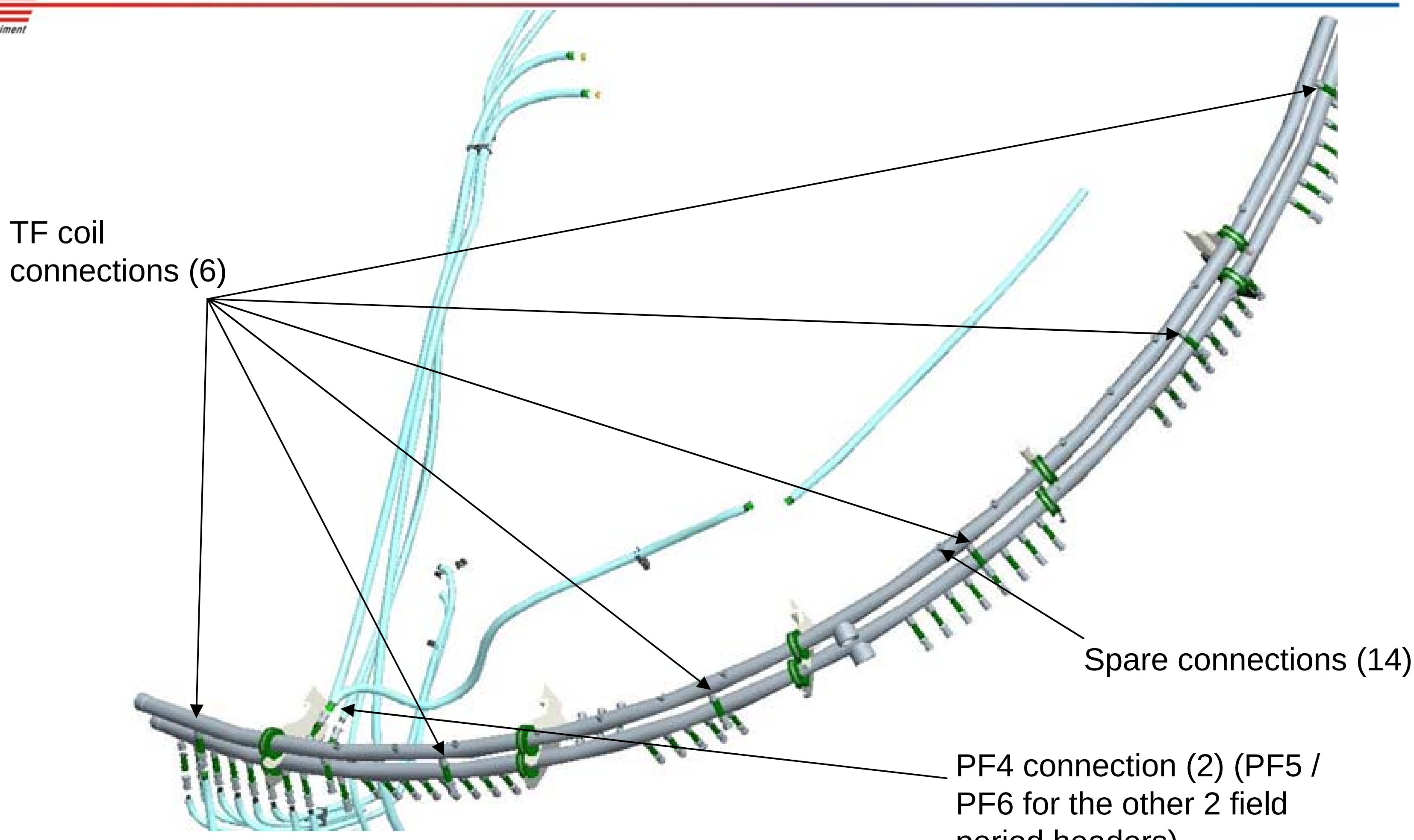
- It was verified that all the vacuum vessel service ports (plus 1” of insulation) are not interfering with the manifold assembly even after they are extended.
- Mounting of the manifolds will be realized with stainless steel pipe clamps and G10 isolator bushings - propose 5 mounting points.
- Studs will be welded on the PF support brackets
- The spacing between the G10 bushings and pipe surface as well as the spacing between the clamps and the G10 bushings is 5/16”
- The mounting brackets are custom due to the various distances between the mounting point and PF support bracket

MC Cooling Manifold Connections



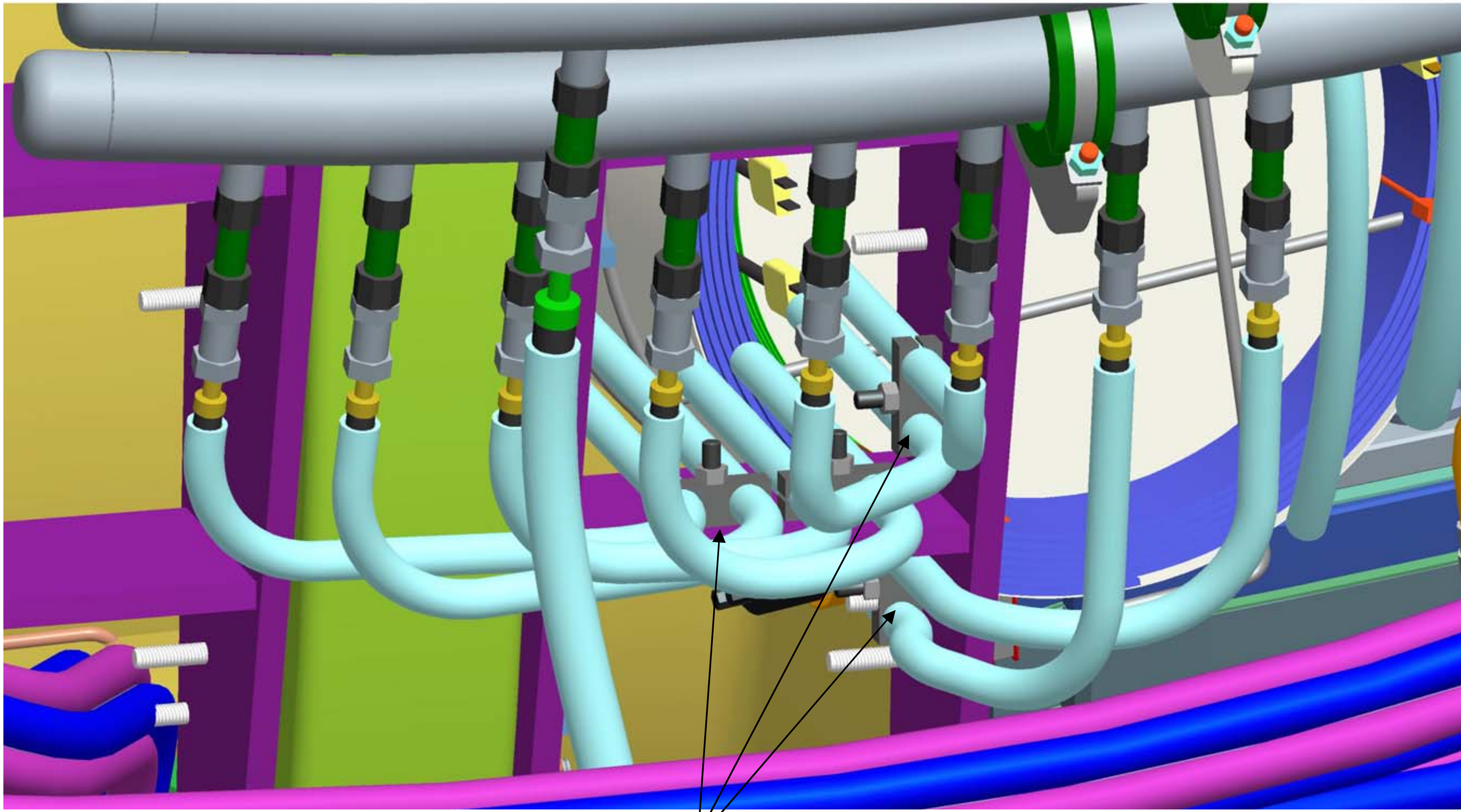
Identification of cooling ports - MC + PF1 header (48+2 = 50 connections)

TF/PF Cooling Manifold Connections



Identification of cooling ports - TF + PF4/PF5/PF6 header (6+2=8 connections + 14 spares)

Mod Coil Hose Routing



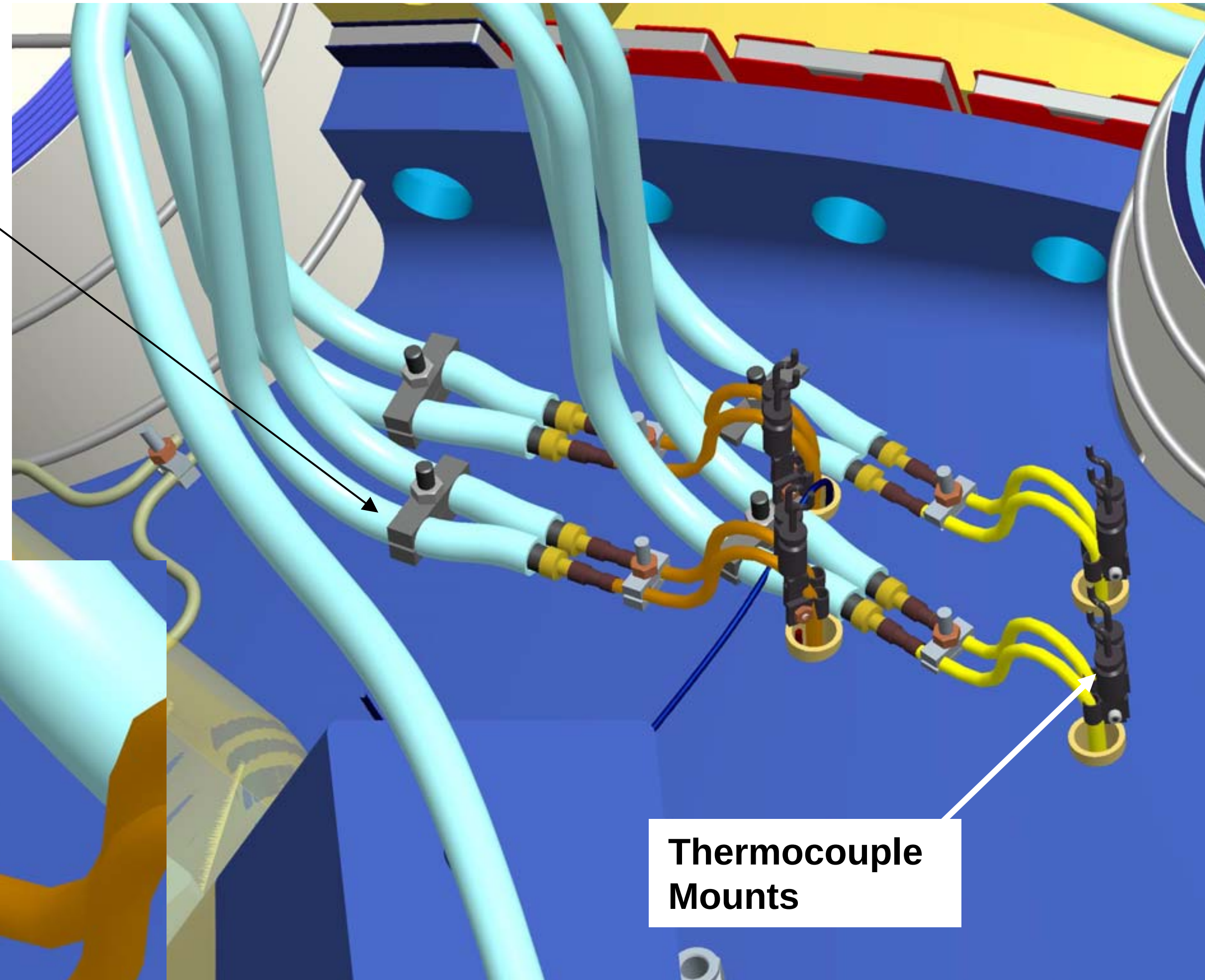
CLAMPS MOUNTED TO
SUPPORT STRUCTURE

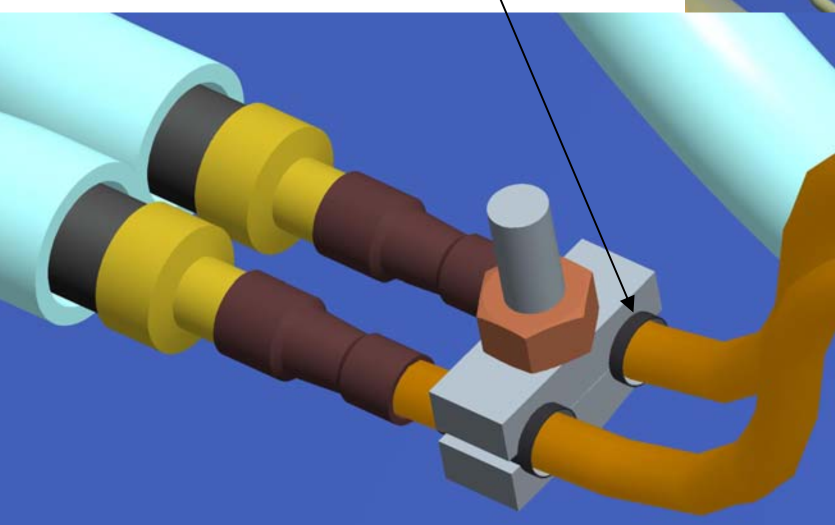
Mod Coil Hose Mounting

National Compact Stellarator Experiment

CLAMPS MOUNTED TO MOD COIL SURFACE (Isolated with Teflon Hose Sleeve)

INSULATING SLEEVES INSIDE TUBE CLAMPS FOR ISOLATION





MC Coil Typical Connection

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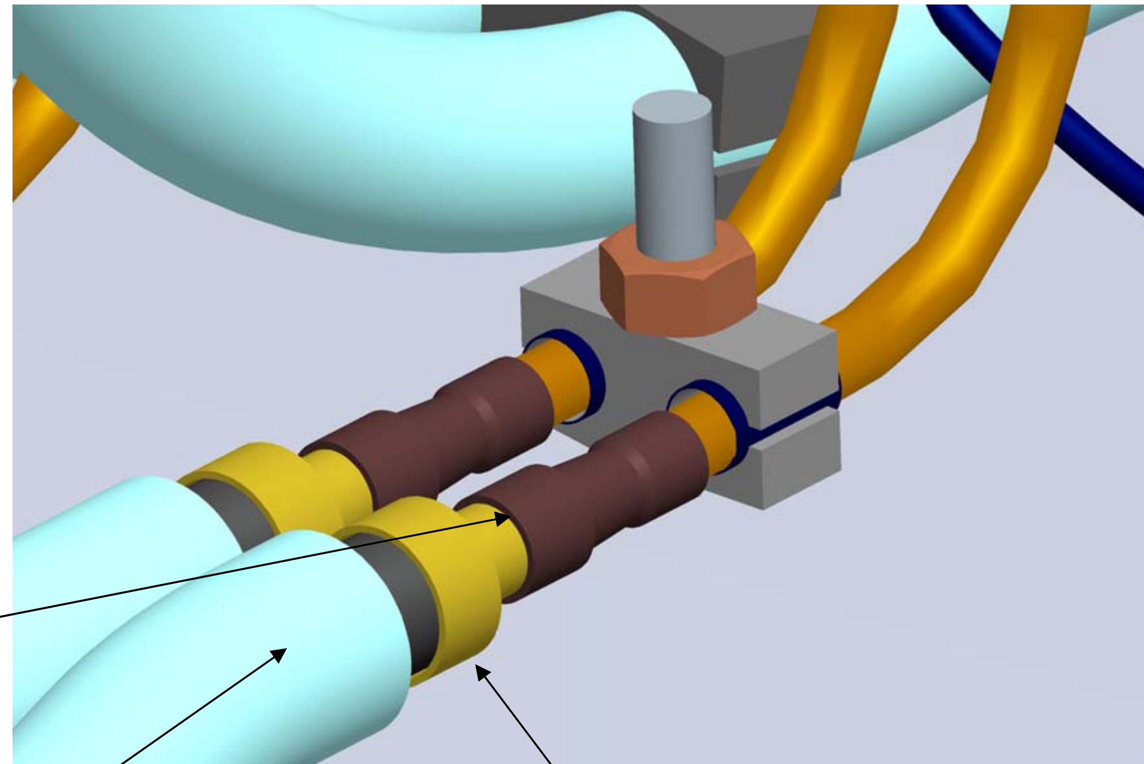
The flexible hose will be connected via the BrazeTyte reducer unions 5FF-5-4 (existing) to the coils cooling circuits



Existing reducer union (5/16” to ¼”)

Teflon Sleeve Over Hose

316 SS braided hose with 5/16 OD straight tube coupling at both ends

PF1 and 4 Hose Routing

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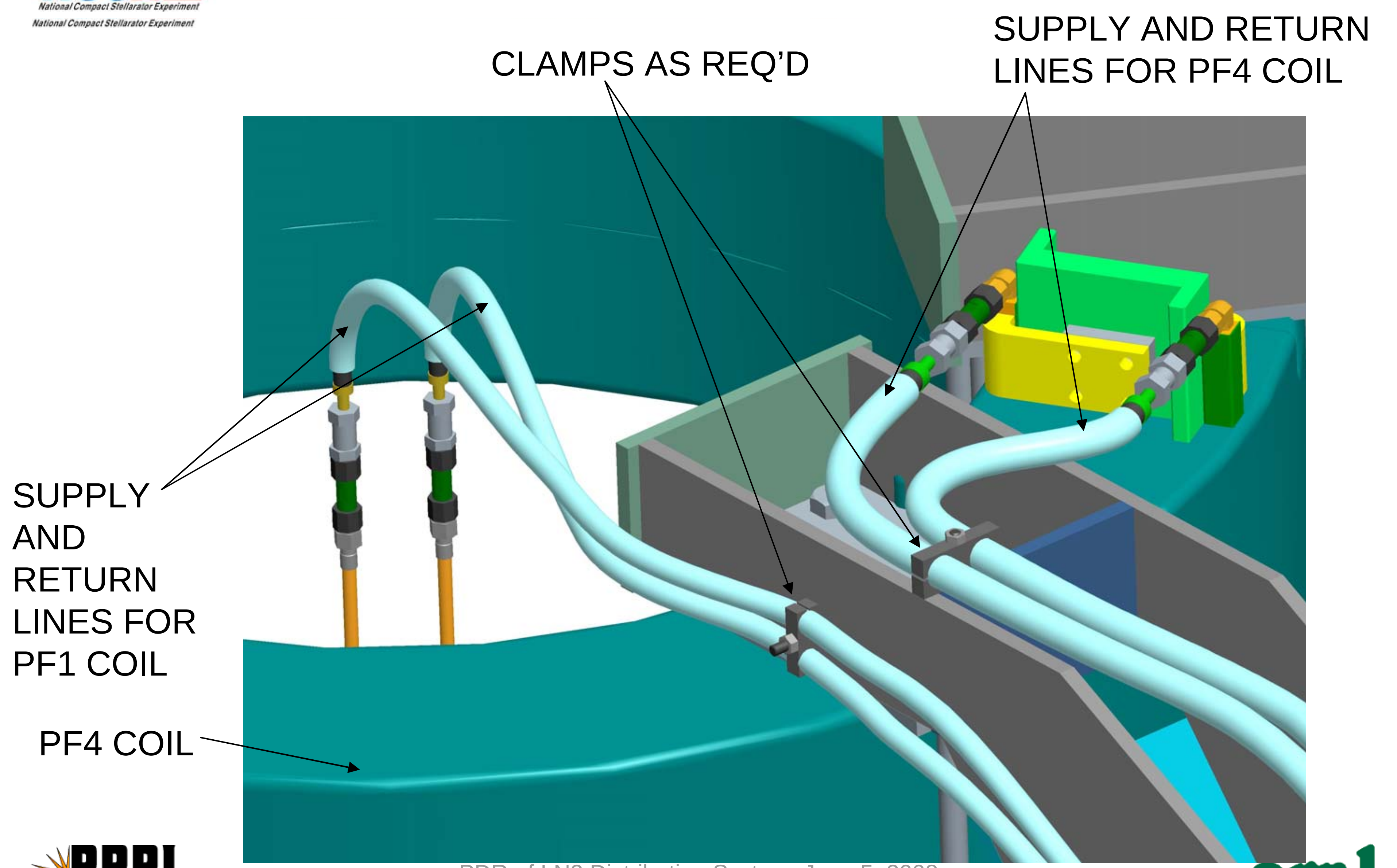

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PF and TF Connection Details

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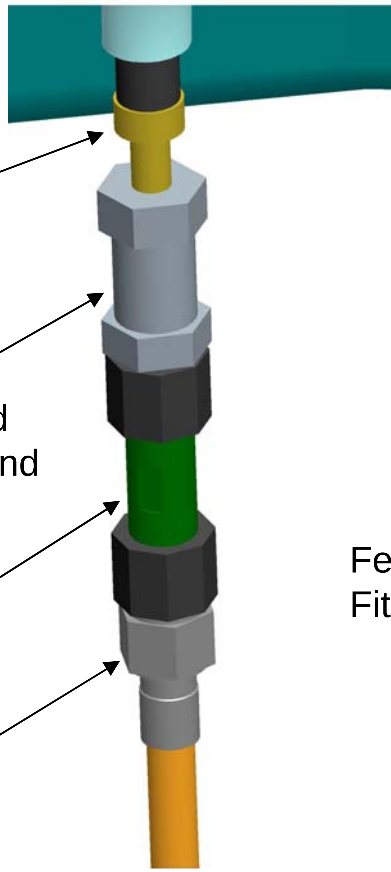
PF1 COIL CONNECTION



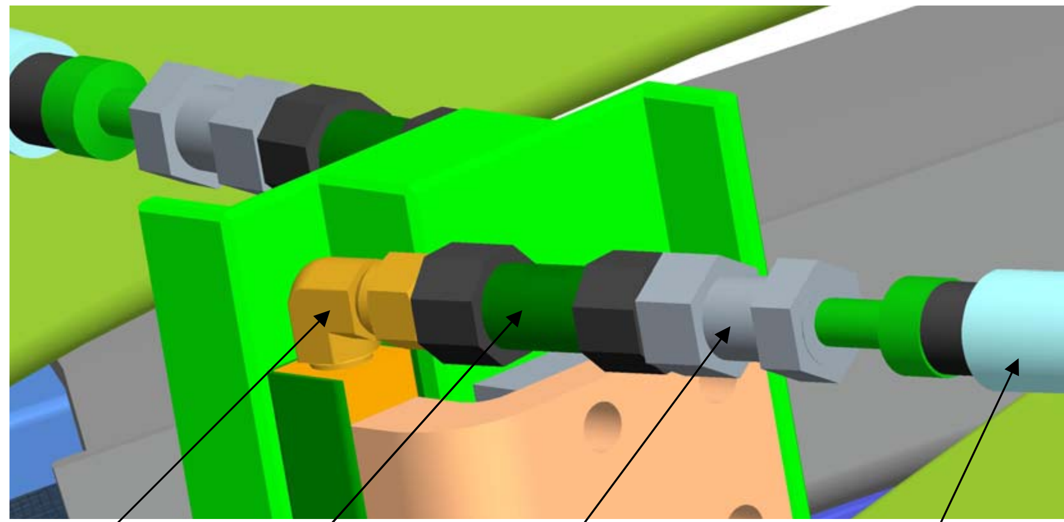
SS Braided Hose with Teflon Sleeve

316 SS Yor-Lok Tube Connector One end and Female NPT on other end

G10 Coupling Assembly

Female Brazetyte Adaptor

TYPICAL PF4, 5, 6 COIL CONNECTION



Female Tube Fitting

G10 Coupling Assembly with tube end

316 SS Yor-Lok Tube Connector One end and Female NPT on other end

SS Braided Hose with Teflon Sleeve

PF1 and 4 Hose Routing to Header

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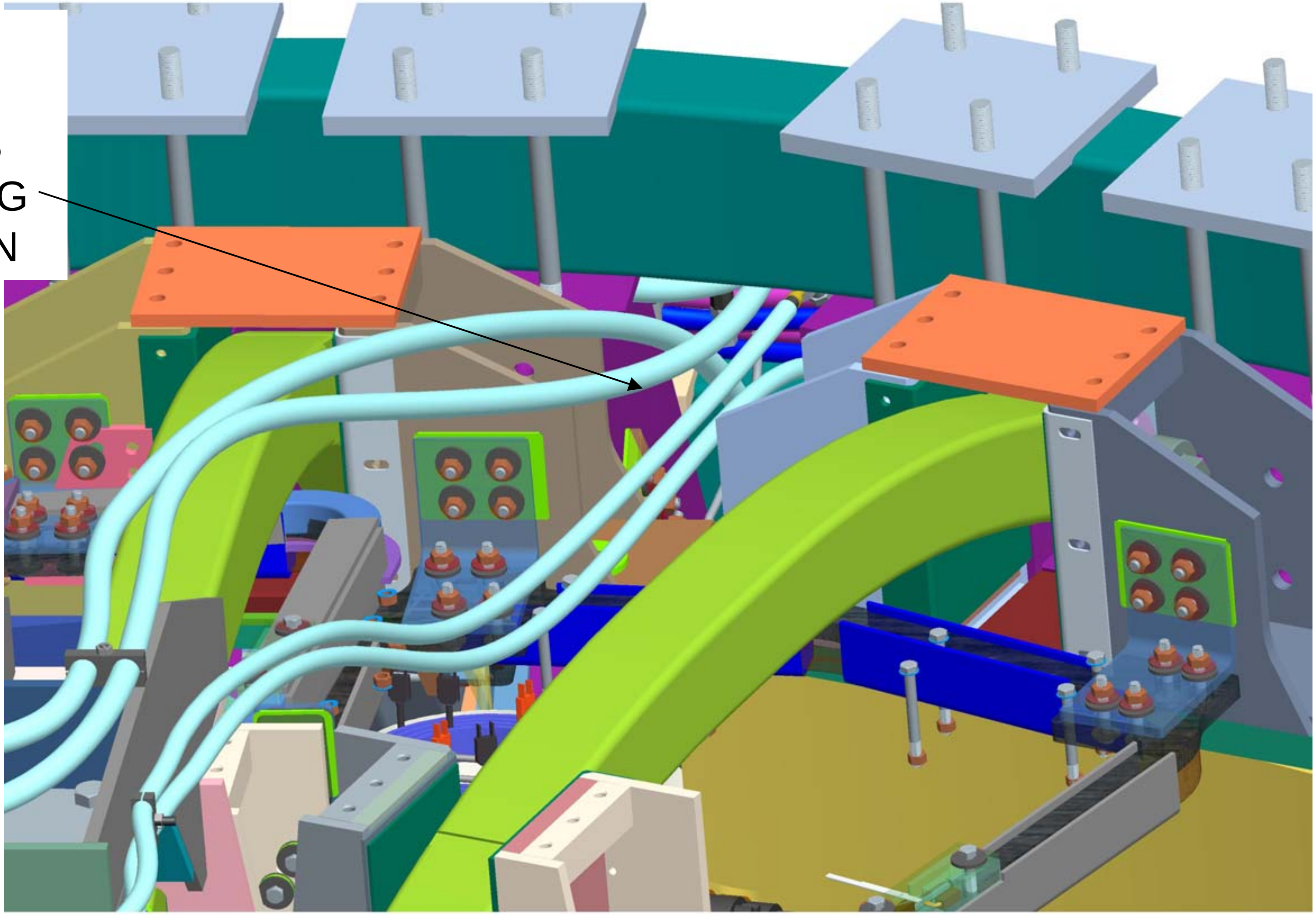
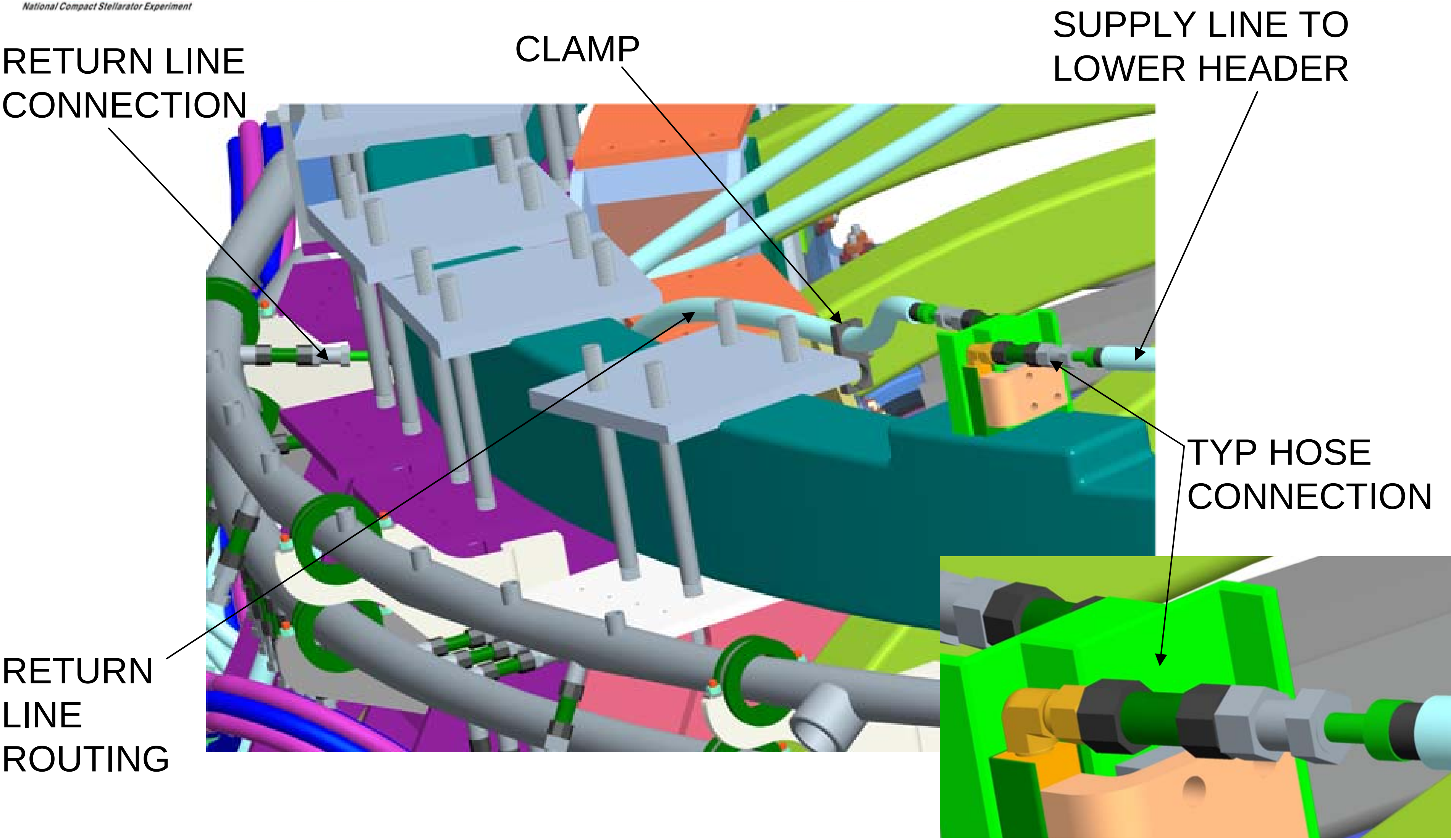
ADDITIONAL CLAMPS MAY BE ADDED AS REQ'D DURING INSTALLATION

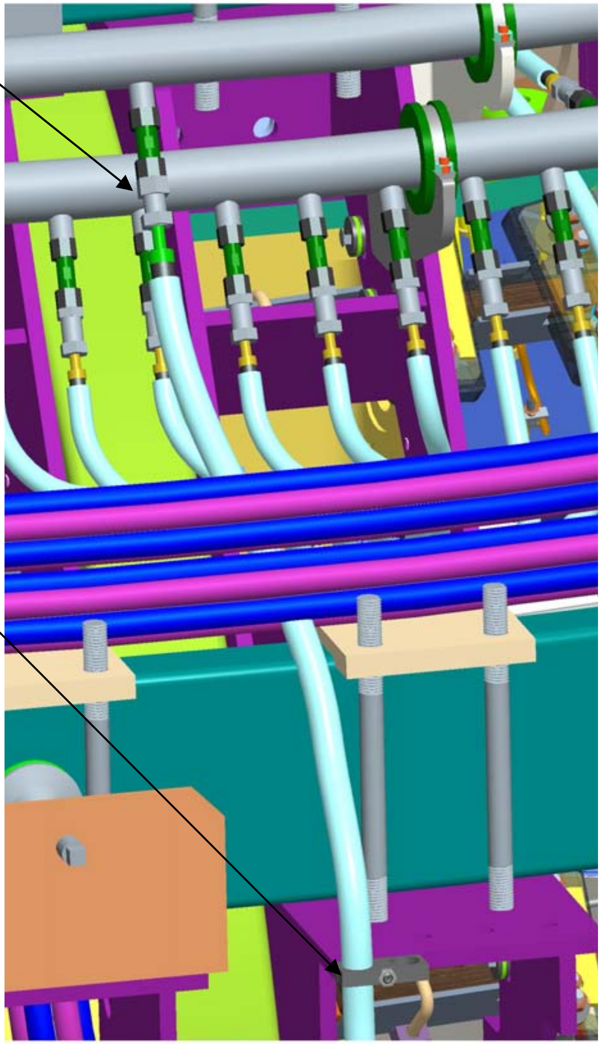


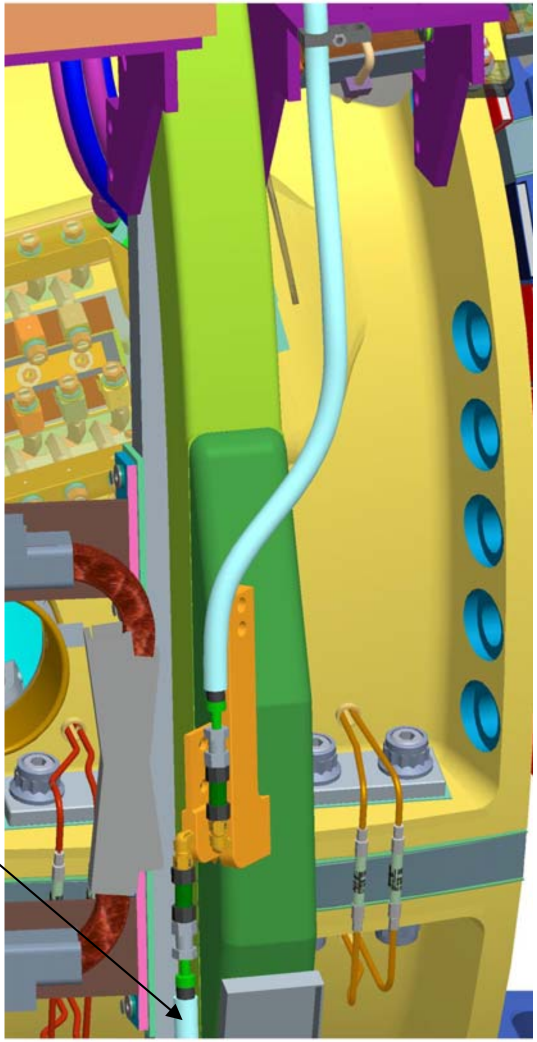
Typical PF5 and 6 Hose Routing



Typical TF Hose Routing

National Compact Stellarator Experiment



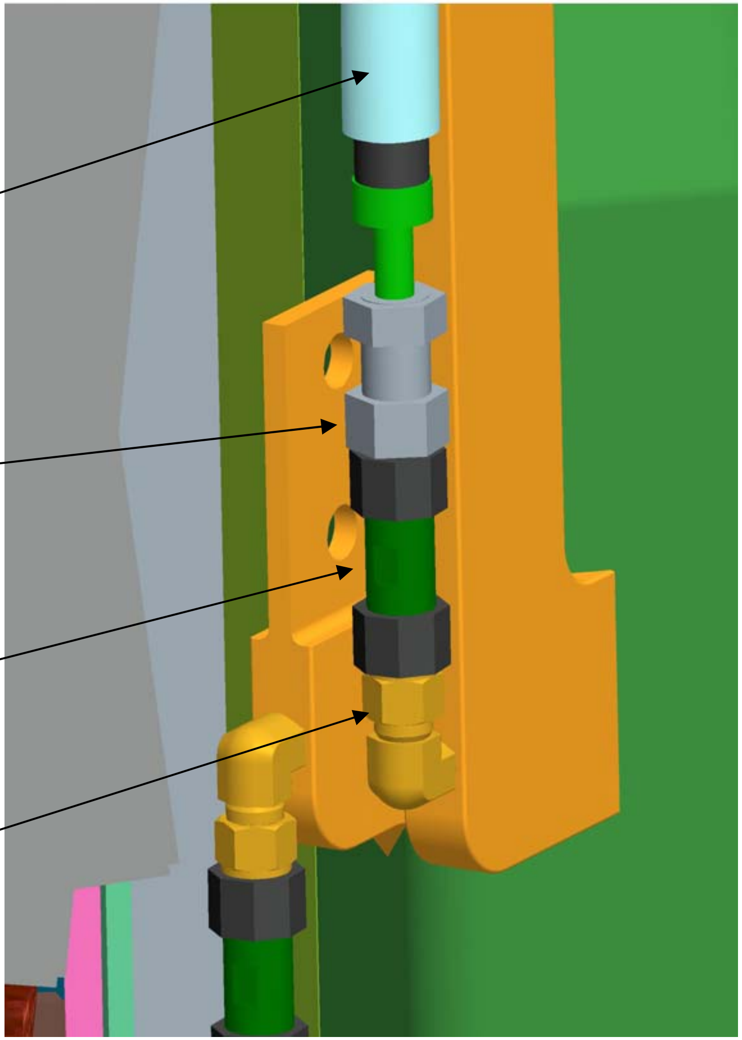


TF Hose Connection Details

NCSX National Compact Stellarator Experiment

National Compact Stellarator Experiment

TF COIL CONNECTION



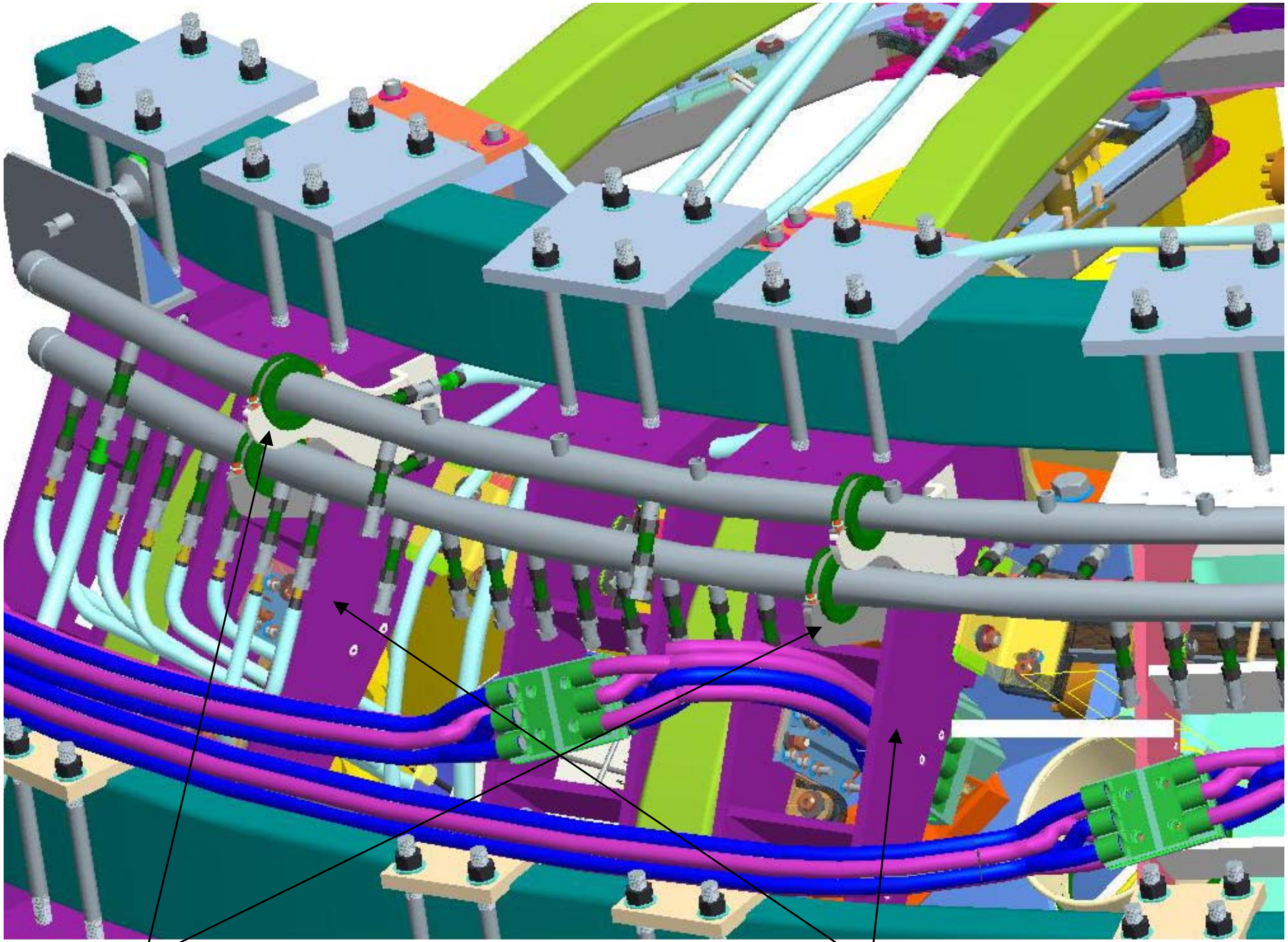
Cooling Manifold Mounting

National Compact Stellarator Experiment

- **Mounting of the headers will consist of welded brackets on the PF support brackets and clamps.**
- **The welded brackets and clamps will be isolated via a G10 bushing to prevent electrical contact. The spacing between the G10 bushing and header surface is TBD.**

Cooling Manifold Mounting

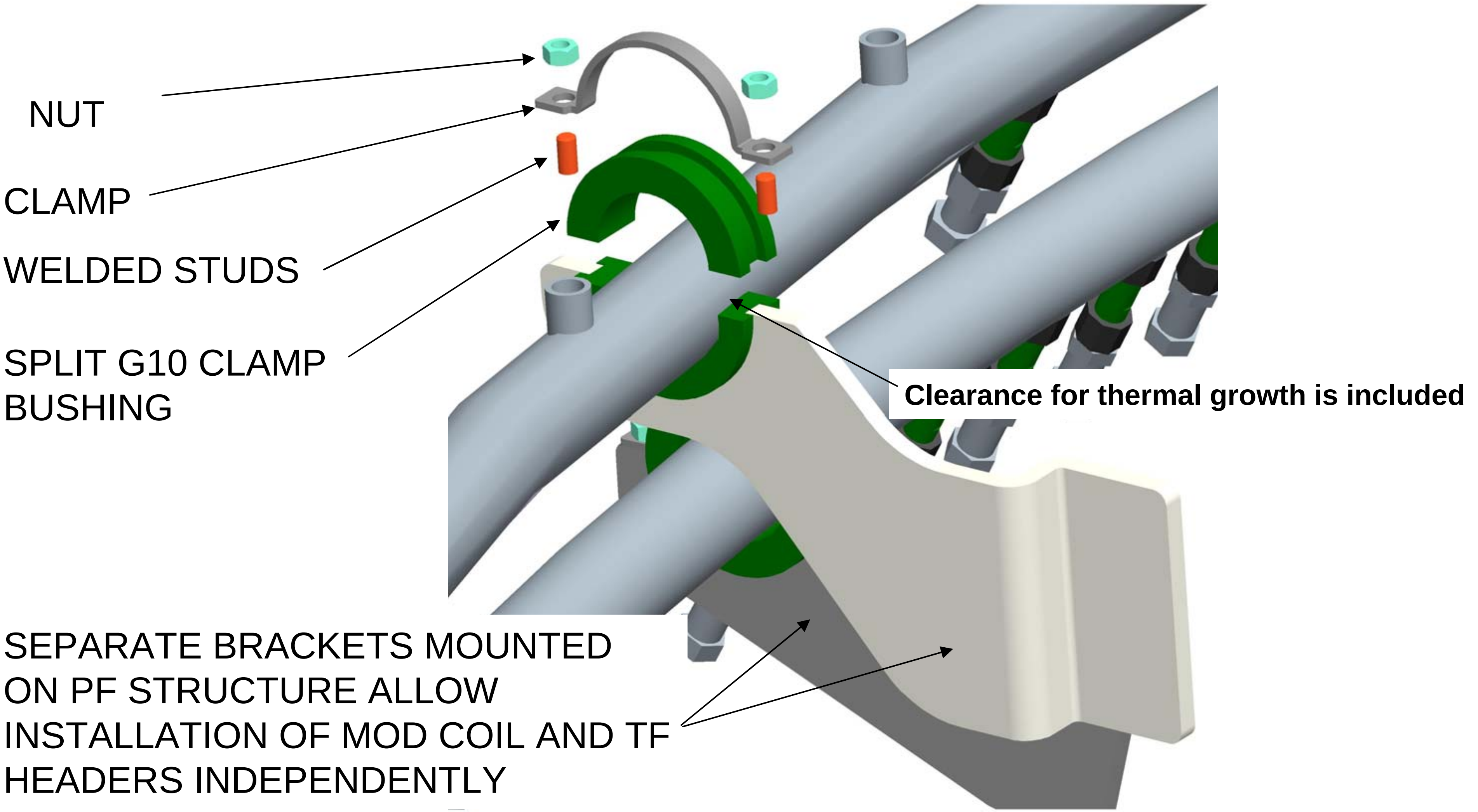
National Compact Stellarator Experiment



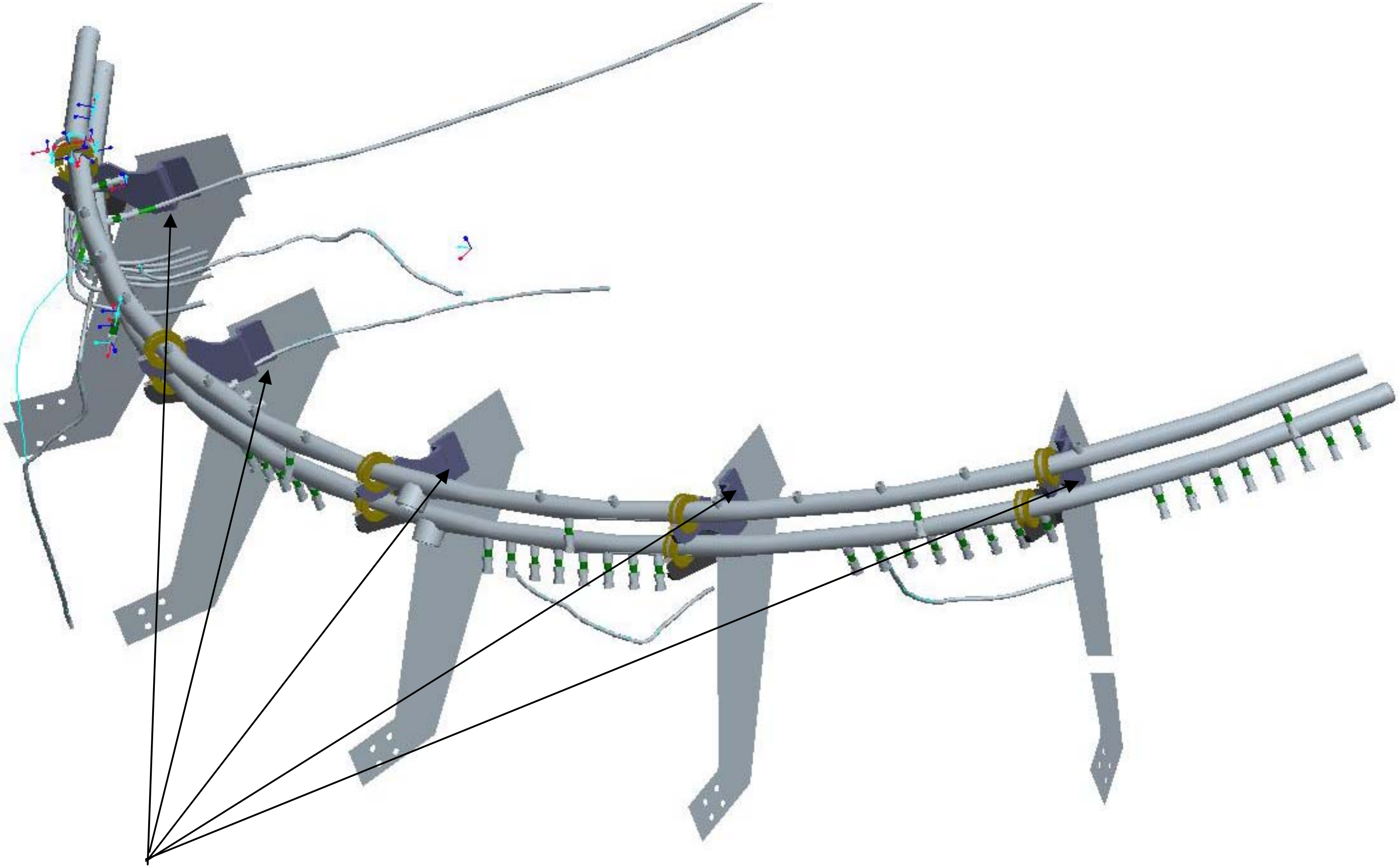
Typical header mounting point

PF support bracket

Mounting Components



Mounting Brackets

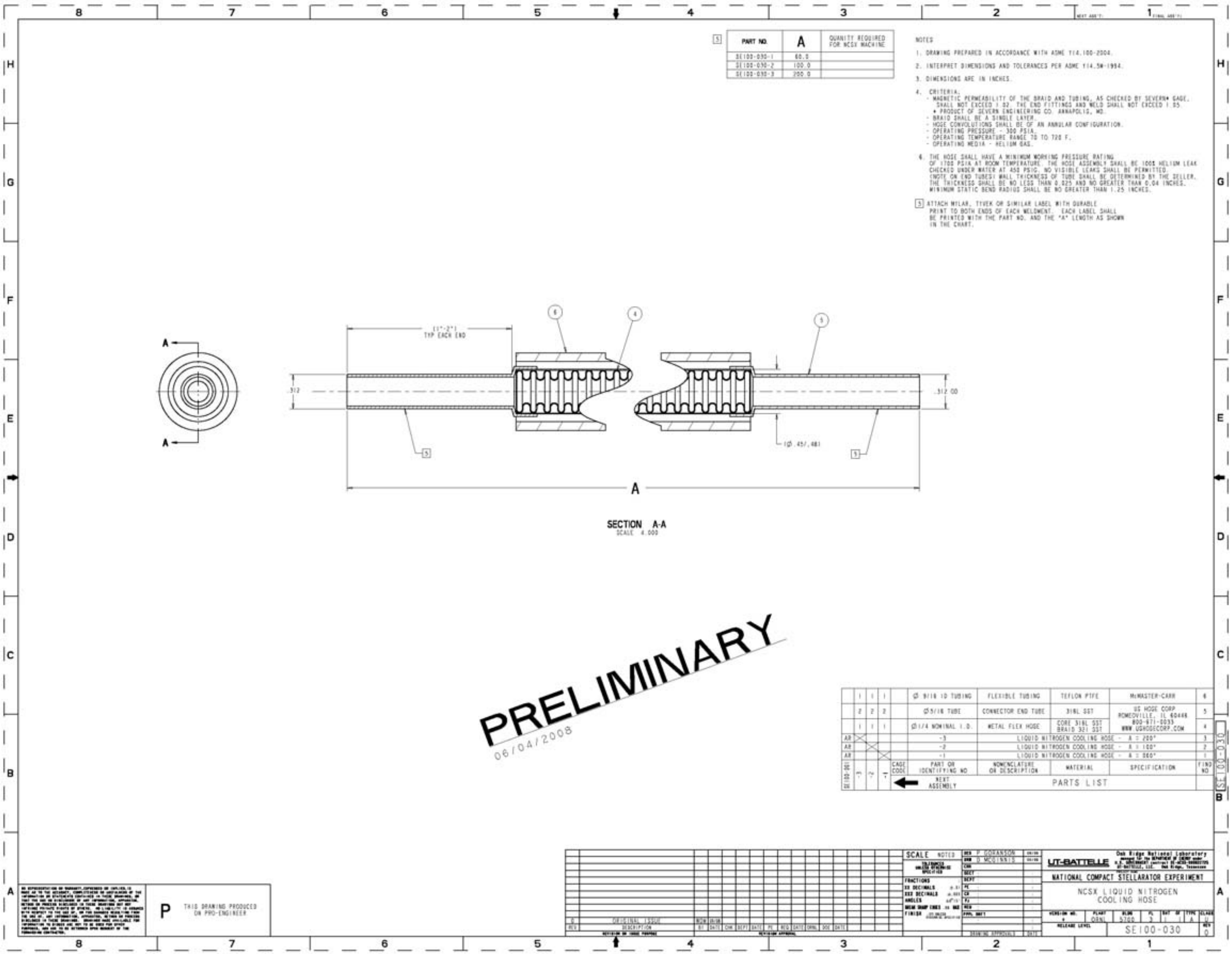


5 mounting points for both headers

Preliminary Hose Drawing

National Compact Stellarator Experiment

National Compact Stellarator Experiment



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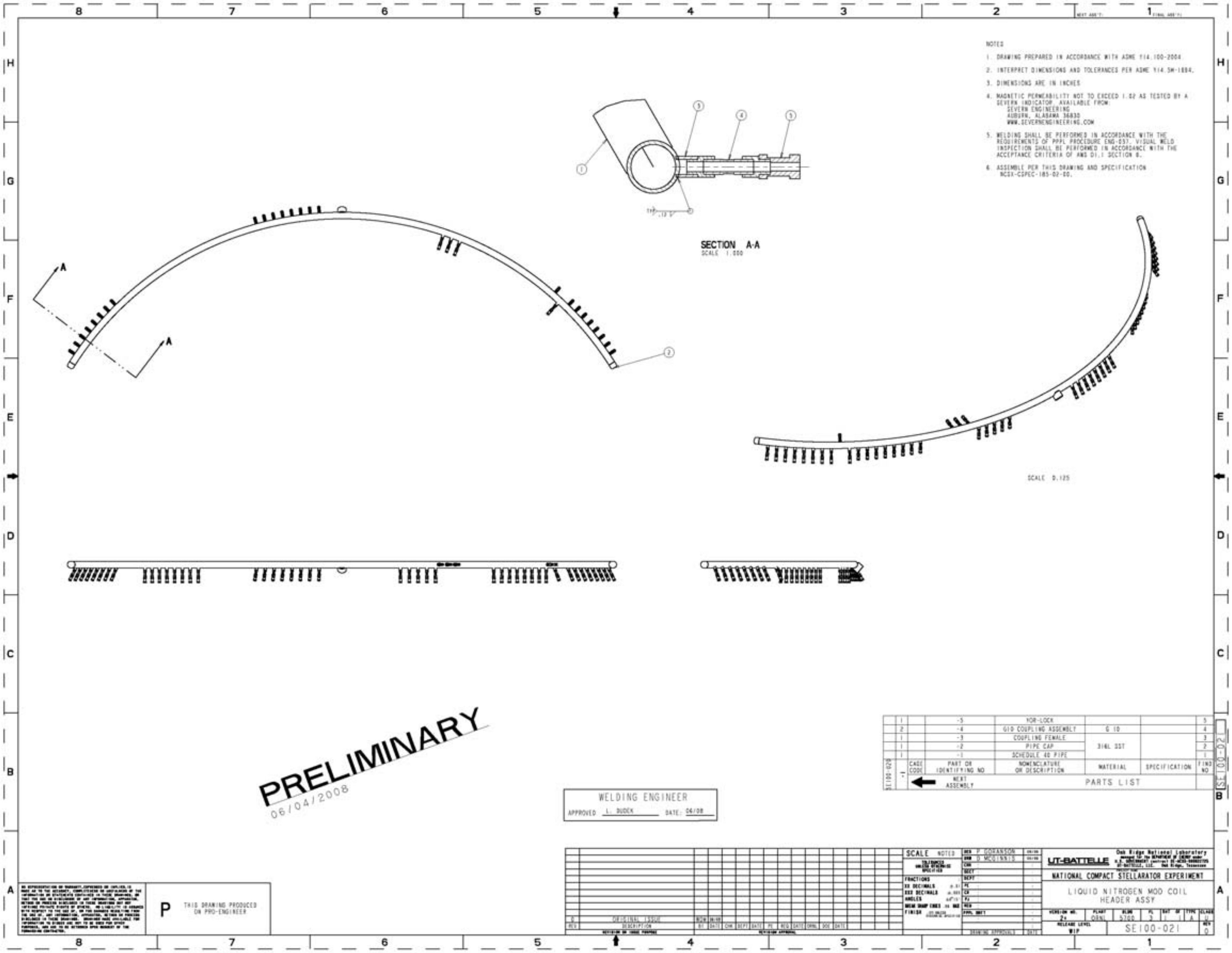
Preliminary Header Drawing



Risks and Mitigation

- **Leaks or failure in hoses**

- Consequence

Small leaks have little consequence since it is nitrogen leaking into nitrogen. It would increase operating cost by cutting efficiency.

Large leaks or breakage could increase pressure in Cryostat, increase cooling time, and imbalance flow.

- Mitigation

Hoses will be 100% tested before installation.

Hoses have huge safety factor (20).

Hoses are cryogenic industry standard with long history of success.

Cryostat will have pressure monitoring and relief mechanisms.

Thermocouples and pressure monitors will be utilized to detect off normal operation.

- Detection and Recovery

System will be shut down if pressure or thermocouple readings are off normal.

Hoses are accessible and replaceable.

Risk Mitigation Continued

- **Loss, low, or restriction of coolant in a hose due to blockage, air trapping, imbalanced flow, break, or lower than predicted flow**

  - Consequence

  Insufficient cooling to meet requirements for cool down time and temperature between shots.
  Inability to maintain temperature at desired operation level.
  The system is not jeopardized nor is safety compromised.

  - Mitigation

  System is designed to work satisfactorily within a large error margin (+/- 25%).
  Nitrogen will be filtered.
  Breaks are unlikely (covered previously).
  System is designed to be passively self balancing and inherently capable of clearing bubbles by using symmetry, restriction in return lines, low velocity in the manifolds, and high system pressure. The two system can be matched using return valve and pressure gauge.
  R&D at MDL will confirm the flow rate in the corrugated hoses.

  - Detection and Recovery

  Monitoring of hose and coil thermocouples should detect ratcheting or off normal temperatures and locate approximate trouble area.
  Hose could be removed and inspected and could be replaced or modified if necessary.

Risk Mitigation Continued

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- **Failure of G10 insulator break due to pressure, temperature induced stress, physical loads.**

  - Consequence
  Same as leaking or failed hose.

  - Mitigation
  Design is based on one tested and proven in C1 coil testing.
  The units survived plunging in LN2. (MDL testing)
  The hoses will be cooled slowly at the same rate as the coils to prevent large gradients in the breaks.
  The hoses have strain relief clamps attached as closely as practical to the G10 breaks.

  - Detection and Recovery
  Same as a failed hose. Units can be replaced.

Cost Estimate Basis

- **LN2 hoses are catalog items.**
  - **Lengths are based on ProE models.**
- **Manifold designs and prices are based on a similar design used on the VV.**
  - **Sizing is based on thermo hydraulics performed by Engineering.**
- **Material cost is estimated on a $ per lb at current market.**
- **Supports are based on a $/length of hose.**
- **Engineering time is based on number and type of drawings for each element, specifications, and the analyses anticipated.**

Labor

NCSX National Compact Stellarator Experiment

Description:

This effort covers all R&D, Title I, II, and III engineering for the LN2 distribution system inside the cryostat, which includes all the necessary manifolding and connections to interface with the ex-cryostat LN2 supply system. This system will be fabricated in-house by PPPL. All Title III engr associated with installation is included in WBS 7.

Task ID	Multiplier	Unit	Number of Units	Hours	HOURS: ORNL EM	ORNL DSN	ORNL RM	EMEM	EMSM	EMSB	EMTB	EAEM	EASB
Title I an II Design													
Pro-E models (avg)	8	hrs/model	21	168	168								
assy dwgs	16	hrs/dwg	24	384	384								
Detail drawings	8	hrs/dwg	13	104	104								
installation dwg	16	hrs/dwg	14	224	224								
cooling schematic	20	hrs/dwg	1	20	20								
electrical schematic	0	hrs/dwg	1	0	0								
I&C schematic	20	hrs/dwg	1	20	20								
stress analysis	40	hrs/calc	1	40	40								
thermal analysis	40	hrs/calc	1	40	40								
special analysis (electromagnetics)	160	hrs/calc	0	0	0								
fab specifications	160	hrs/spec	2	320	320								
preliminary and final design reviews	80	hrs/rev	2	160	160								
Resolve PDR Comments	40	hrs/PDR	1	40	40								
meetings/reporting/presentations	10%	% of tot hrs		152	152								
Subtotal Title I & II Design				***1672***	***1672***	***0***		***0***	***0***	***0***	***0***	***0***	***0***
R&D Activities													
R&D pressure drop simulation with pressurized LN2 and valve. Design of test unit.				***40***	40								
Title III													
Disposition of deviation requests and non-conformances	1	hrs per	38	38				38	0	0	0	0	0
As-built drawings	2	# dwgs	52	104		104	0	0	0	0	0	0	0
Procurement coordination				80		0	0	40	40	0	0	0	0
Subtotal Title III Design				***222***	***0***	***104***	***0***	***78***	***40***	***0***	***0***	***0***	***0***
Total				**1934**									

simulation w pessurized LN2 and valve. Design of t

Materials and Supplies Update

Final configuration of manifolds increases hose length, thus cost, of hose ~$33K from present M&S estimate.

Description:
This effort covers procurement of materials for the LN2 distribution system by fixed price subcontract.

Assumptions:

outside engr rate =	120	$ per hour
outside fab rate =	60	$ per hour
outside inspection/technician rate =	80	$ per hour
MDL labor	80	$per hour

Purchased parts:

coolant line pigtails from coils to manifolds	$57600
Insulating Jumper hoses	0
Manifolds for cooling lines	$9,085
valves	$9,000
orifices & other hardware	$10,000
Thermocouples	$0
R&D material and labor from below	$18,000
subtotal, purchased parts	**$103,685**

Fabrication and Assembly are the Same

Description:

This effort covers all the fabrication of the LN2 system inside the cryostat including headers.

Worksheets

coolant line pigtails from coils to manifolds

Average length of pigtail 3 ft

	Total		TF	**Modular**	PF1	PF2	PF3	PF4	PF5	PF6	Trim
No. of coils	60		18	18	**2**	2	2	**2**	**2**	**2**	12
circuits per coil at header			1	8	**0.5**	0.5	0.5	**0.5**	**0.5**	0.5	0
total circuits	168		18	144	1	1	1	1	1	1	0
Total number of pigtails	336	supply and return per circuit									

Manifolds for cooling lines

Assume 2 pairs of 1.5 inch manifolds for each field period, one above and one below the midplane inside the PF5 coil
Each set of manifolds will have 1/3 of the required cooling connections plus 25% spare
The manifolds will connect via vertical pipes to the supply system below the cryostat

avg toroidal perimeter of field period	16	ft
avg vertical height of connection lines	9	ft
no of headers/FP	4	
cost of tubing	$15	per foot, 316 SSt
cost per field period	$1,488	
total number of coolant connections, all headers	840	
hours to weld each connection	0.5	hr per connection
shifts to form manifold tube	0.5	per manifold pair
crew size for forming	2	
hours to cut vertical pipes	2	hrs per pipe
hours to weld vertical pipes to header	2	hrs per pipe
total shifts for manifolds	71	
tech hours for manifolds	564	hours
technical oversight, inspection	141	hrs
total hours for manifolds	**705**	**hrs**

Schedule & Staffing are Unchanged

NCSX
National Compact Stellarator Experiment

Schedule

Activity ID	MILE-STONE LEVEL	Activity Description	Duration (work days	SHIFTS	Forecast Start	Forecast Finish	Total Float	Cost to Complete	FY08 / FY09 / FY10
161 - LN2 Distribution									
191-001		Title I design WBS 161 LN2 manifolds&piping	166*		01OCT07A	02JUN08	197	48,937.50	ORNLEM =522hr ;
191-002	3	LN2 manifolds&piping- PDR	1		03JUN08	03JUN08	197	1,208.00	ORNLEM =08hr ;
161-003	3	Resolve PDR comments	5		04JUN08	10JUN08	197	6,040.00	ORNLEM =40hr ;
161-011A		R&D build mounts & lead terminations	60		11JUN08	04SEP08	197	24,040.00	ornl41= $18k
191-011		Title II design WBS 161 LN2 manifolds&piping	60		11JUN08	04SEP08	197	65,250.00	ORNLEM =522hr ;
191-012		LN2 manifolds&piping - FDR	1		05SEP08	05SEP08	197	1,208.00	ORNLEM =08hr ;
191-037		Prep Req,Bid,Award-manifolds,hoses,valves etc	25		08SEP08*	10OCT08	197	0.00	
191-038		Fab and deliver-manifold assy,hoses,valves etc	90		13OCT08*	26FEB09	197	136,453.09	41=57.23$k ; EM//TB =522hr ; em//sm=131
191-031		Title III engr WBS 161	118		08SEP08	03MAR09	1,420	24,040.53	ORNLdm=58hr ;em//em=78;em//sm=40

Staff

Jobs	start	end	days	weeks	Paul Goranson 40% hrs	TBD Designer 100% hrs	Sorin Homescu 100% hrs	total work hours available	Total WAF hours
headers(161)	1-Jan	1-Oct-08	274	39.1	522.3	500	1565.7	2088	1934

Cost/Schedule Risks

Design is straight forward and procured items are by and large commercially stocked. Manifolding is similar to gas system on VV, which is complete and costs are well documented.

Schedule Milestones

With two full time designers and half time engineer, the projected schedule could be met.

Chits form Previous Reviews

- **Concern about the integrity of the G10 insulator break design**

Resolution:
Design change recommended by the cryogenic people were incorporated.

- **Concern about flow balance with the parallel flow configuration due to bubble formation or low resistance in some branch lines.**

Resolution:
Consensus among experts was not achieved. Some felt the system would work adequately due to the wide latitude in the flow required, high system pressure, symmetry, and flow restriction at exit. They felt the system would be capable of flushing bubbles.
The system will not switch to liquid until temperature is below 80 K, to avoid pool boiling and bubble formation.

No better configuration was suggested. A valve and gauge at every line would not be accessible, would be very expensive, reduce overall reliability, and could not be shown to impart a mechanism that clears bubbles.

The best resolution is to test the system before final installation.