NCSX Coil Services

P.L. Goranson

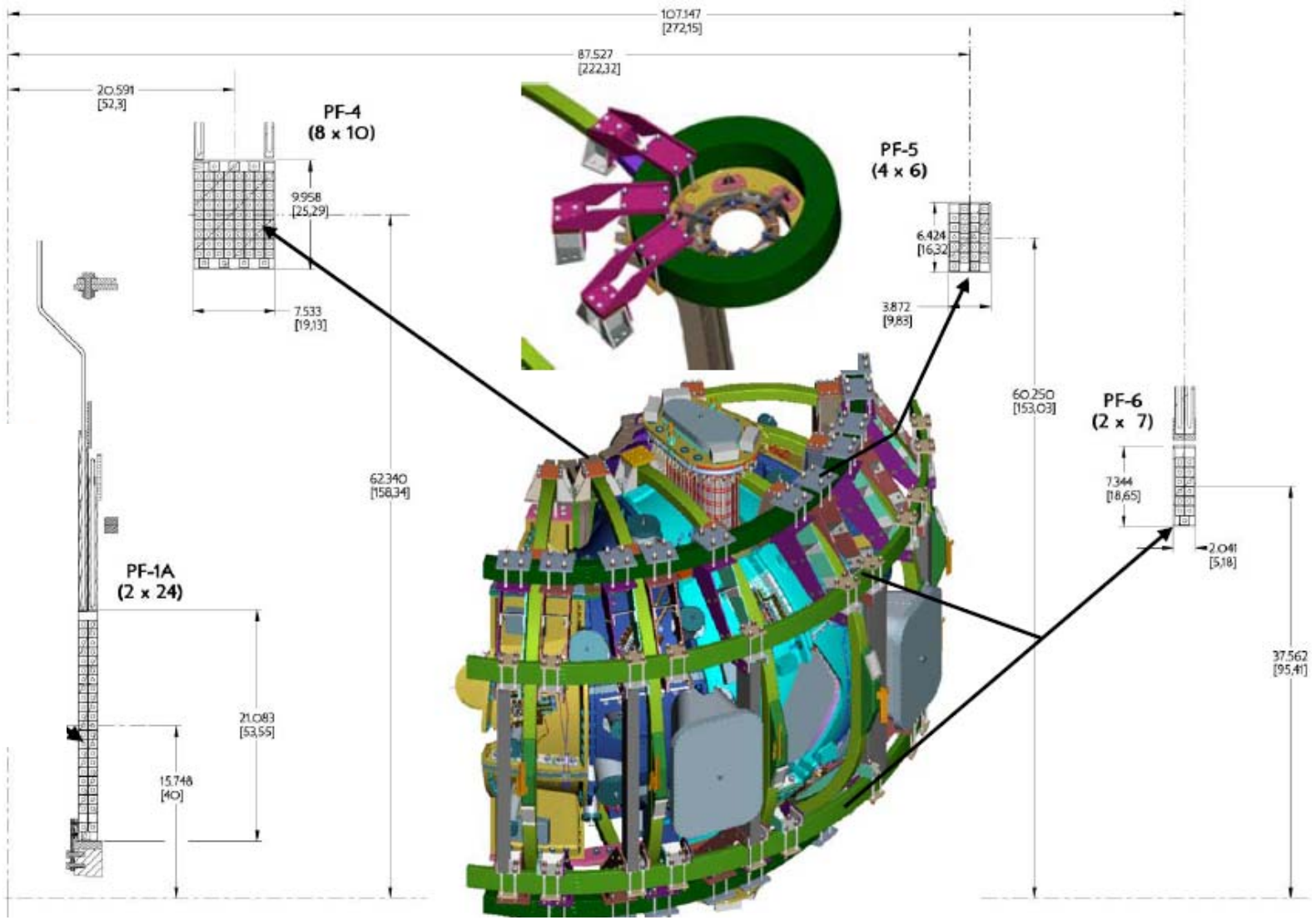
Work Package 161, 162, and 163

Coil Services System Description

The coil services consist of the **cryogenic feeds** and **electrical leads** inside the cryostat, serving all of the coils, including conventional.
It includes the specification of requirements
for the coil protection system.

Lower-level elements include:
LN2 Distribution System (WBS 161);
Coil Electrical Leads (WBS 162); and
Coil Protection Requirements (WBS 163)

NCSX Coils


107.147
[272,15]
87.527
[222,32]
20.591
[52,3]
PF-4
(8 x 10)
9.958
[25,29]
7.533
[19,13]
PF-5
(4 x 6)
6.424
[16,32]
3.872
[9,83]
60.250
[153,03]
PF-6
(2 x 7)
7.344
[18,65]
2.041
[5,18]
37.562
[95,41]
62.340
[158,34]
PF-1A
(2 x 24)
21.083
[53,55]
15.748
[40]

WBS 161 LN2 Distribution System

Description

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 132)
Modular (WBS 14)

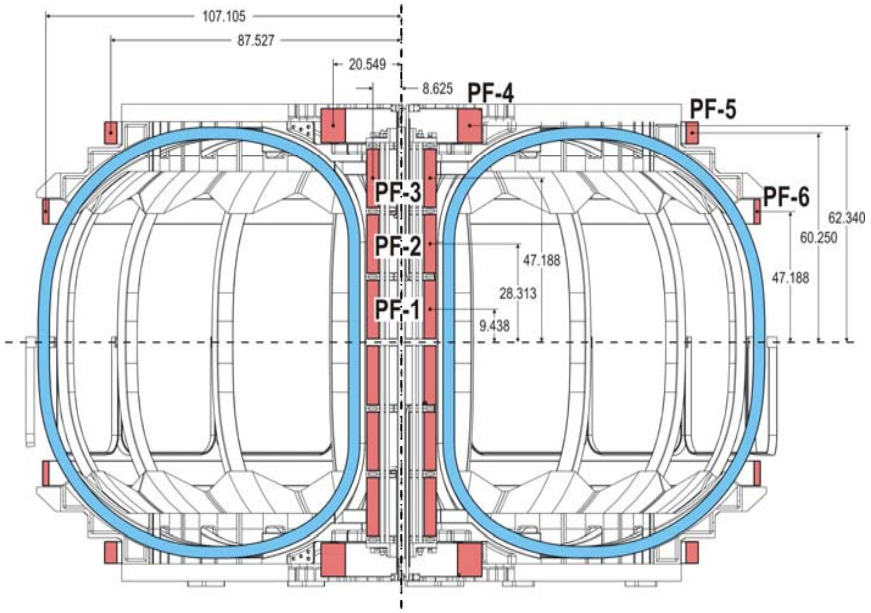
Scope

Work includes engineering design, procurement, and fabrication of manifolds, cooling hoses, jumper hosing, valving, and associated supports. Work in this WBS ends with delivery of components to machine assembly operations.

Interfaces

I&C is procured in 1408. WBS161 includes routing and distribution of coolant between coil input/output terminations and the supply/return manifolds. WBS17 provides supply/return headers and hook up interfaces in the Cryostat. Valves are included in WBS161.

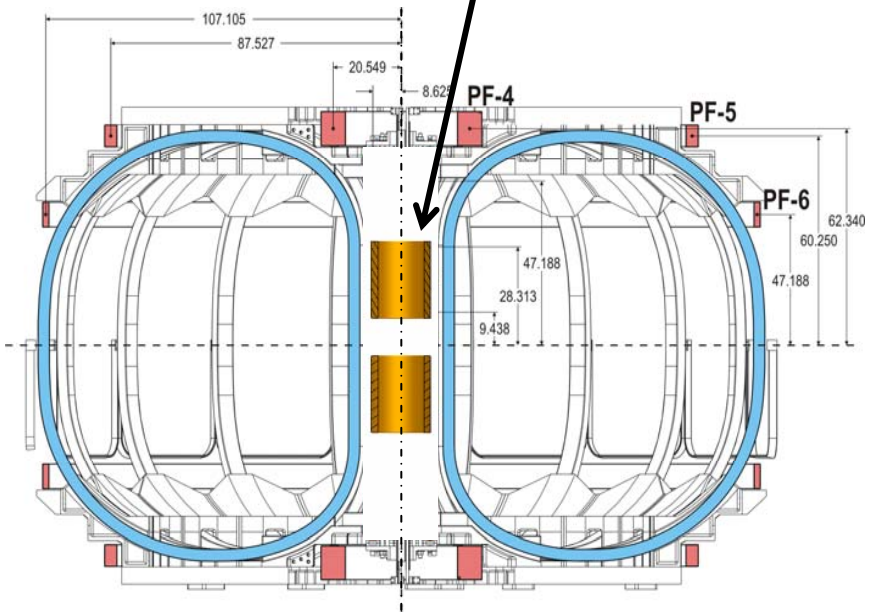
Central Solenoid, TF, and PF Configurations



Upgrade Configuration

- Baseline is PF1a, PF4, PF5, and PF6 (2 each, upper and lower).
- Device can be upgraded if desired, where PF1a is replaced by PF1, PF2, PF3.

PF1a coils from NSTX are baseline



Baseline Configuration

Modular Coil and Conventional Coil Cooling

Requirements

- Operate at 77 K with LN2.

- Operating pressure minimum 5 atmospheres absolute.

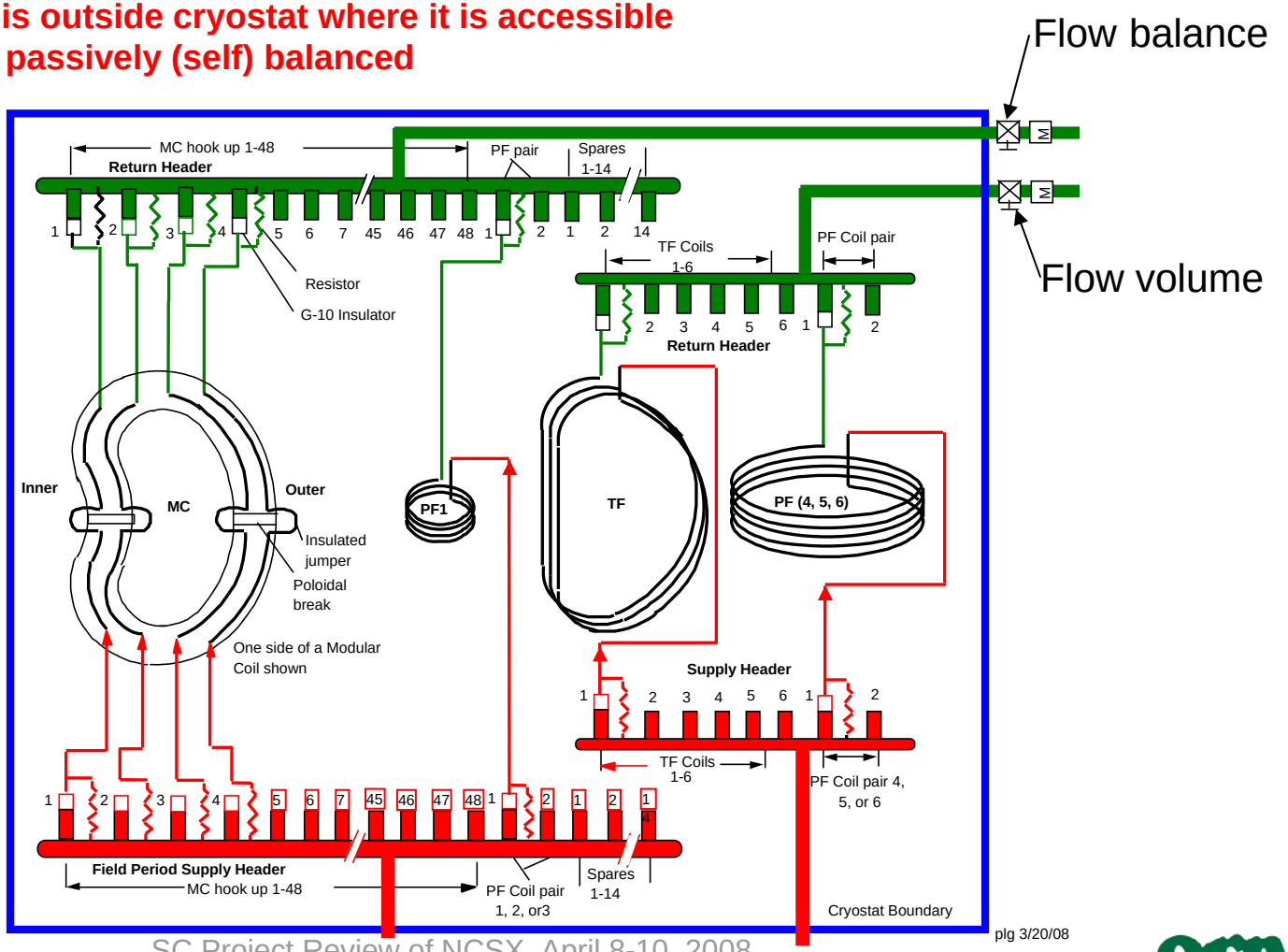
- Electric breaks in MC coil coolant lines poloidally.

- Electrical current limitation between cooling components. (bypass resistors isolate hoses to ground)
  - TF and PF hoses electrically isolated at coil terminations as well as headers

- Provide flow balance between systems.

Costs reflect design in Cooling System Diagram shown below

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**



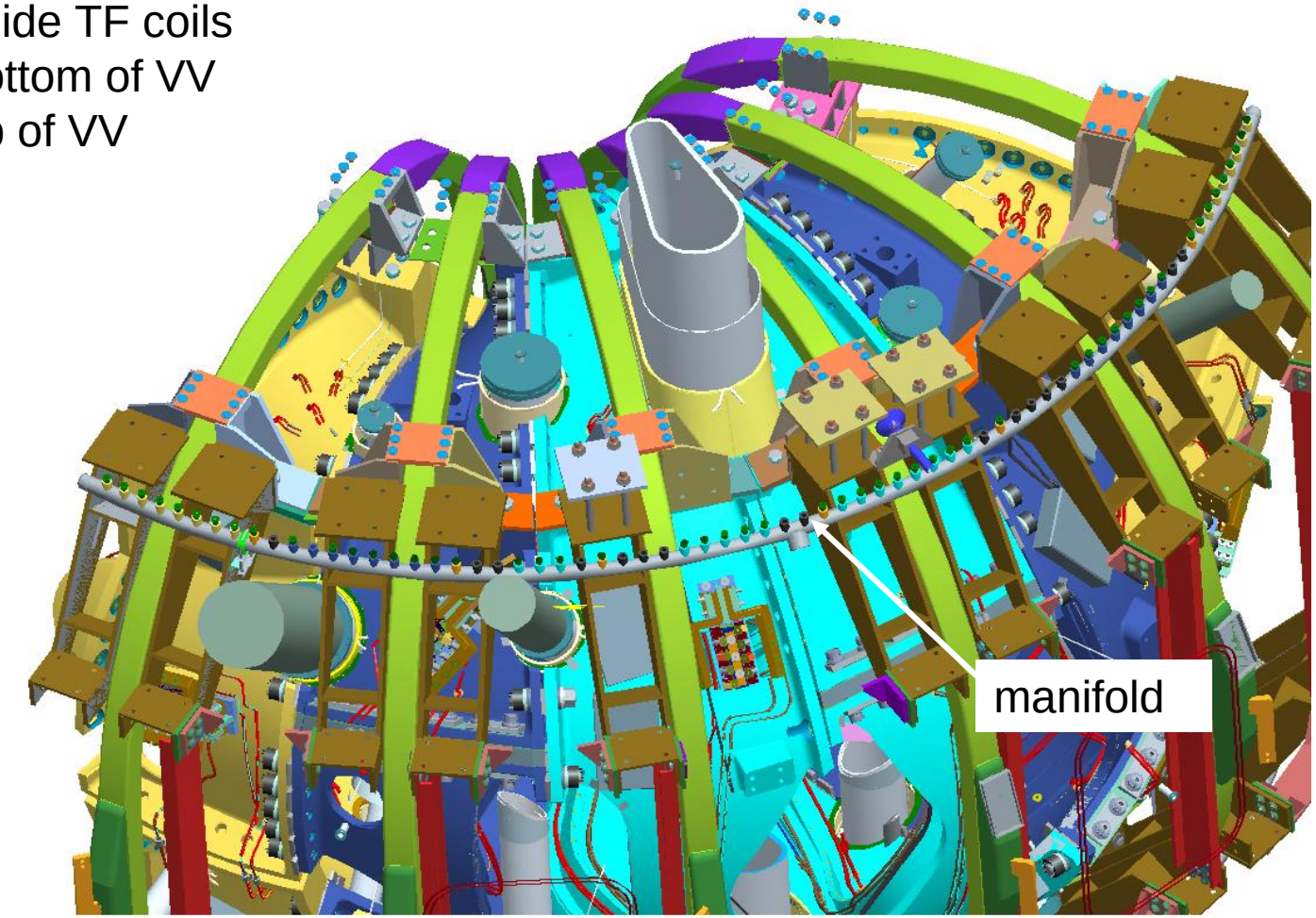
Flow distribution

PF1A is used in CD4, replace by PF1, PF2, and PF3 in future operation.
Pressure drops fall in two well defined groups.

	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	**2.42**
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**

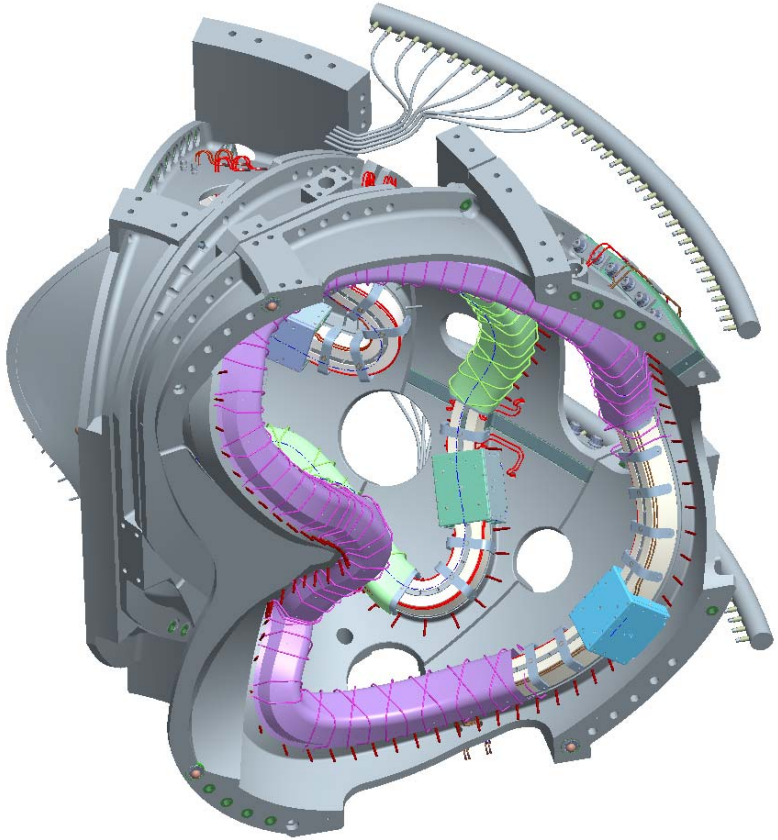
Typical manifold

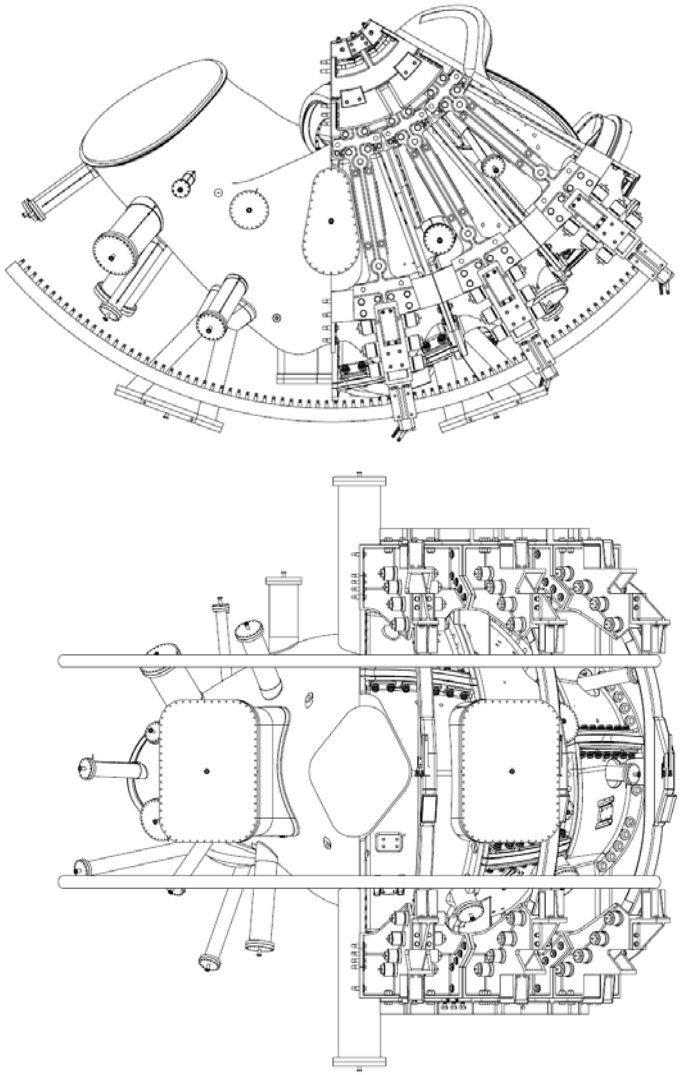
- Manifolds lie outside TF coils
  - supply near bottom of VV
  - return near top of VV



Manifold Jumpers

Transition to flex hosing at the winding form



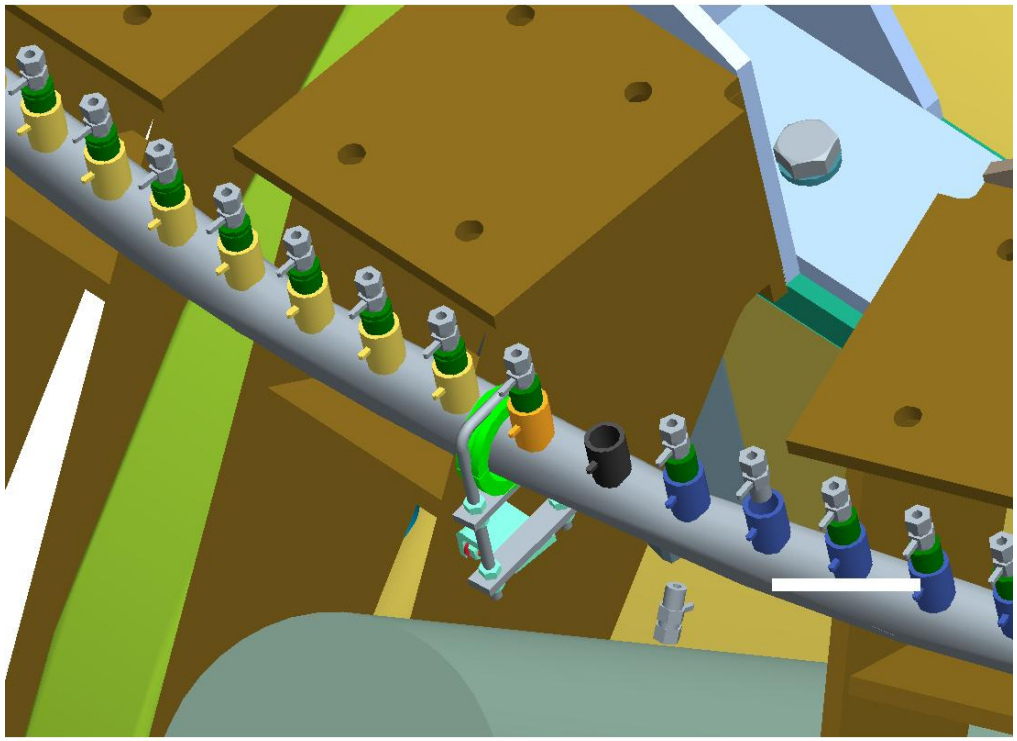


Manifold hose insulators

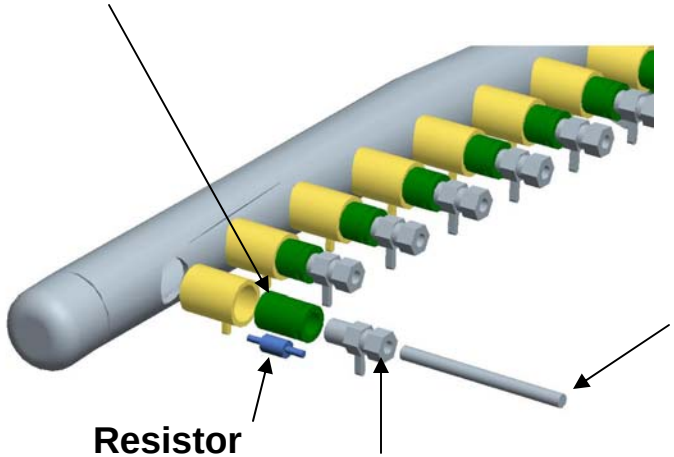
NCSX National Compact Stellarator Experiment

Hoses are isolated from the manifolds by G10 plugs

- prototype will be tested at 77K
- orientation of individual connections is TBD



G10 CR Male / Female coupling



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

316 SS Yor-Lok 5/16 OD tube one end and ¼" NPT on other end

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

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 pressurized LN2 and valve. Design of test

Materials and Supplies

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	**$19,800**	**see notes below**
Insulating Jumper hoses	**$4,320**	
Manifolds for cooling lines	**$9,085**	
valves	**$9,000**	**see notes below**
orifices & other hardware	**$10,000**	
Thermocouples	**$0**	**included in job 1408 for**
R&D material and labor from below	**$18,000**	**the modular coil**
subtotal, purchased parts	**$70,205**	**fabrication**

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

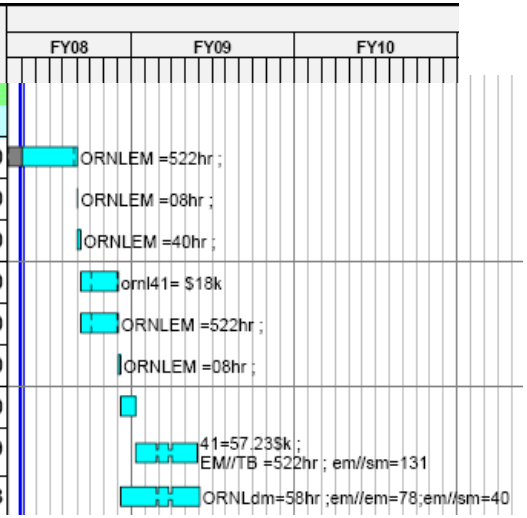
Assume 2 pairs of 1.5 inch manifolds for each field period, one above and one below the midplane inside the PF5 coil
Each set of manifolds will have 1/3 of the required cooling connections plus 25% spare
The manifolds will connect via vertical pipes to the supply system below the cryostat

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

Schedule

Activity ID	MILE -STONE LEVEL	Activity Description	Duration (work days	SHIFTS	Forecast Start	Forecast Finish	Total Float	Cost to Complete
161 - LN2 Distribution								
191-001		Title I design WBS 161 LN2 manifolds&piping	166*		01OCT07A	02JUN08	197	48,937.50
191-002	3	LN2 manifolds&piping- PDR	1		03JUN08	03JUN08	197	1,208.00
161-003	3	Resolve PDR comments	5		04JUN08	10JUN08	197	6,040.00
161-011A		R&D build mounts & lead terminations	60		11JUN08	04SEP08	197	24,040.00
191-011		Title II design WBS 161 LN2 manifolds&piping	60		11JUN08	04SEP08	197	65,250.00
191-012		LN2 manifolds&piping - FDR	1		05SEP08	05SEP08	197	1,208.00
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
191-031		Title III engr WBS 161	118		08SEP08	03MAR09	1,420	24,040.53



Staff

Jobs	start	end	days	weeks	Paul Goranson 40% hrs	Sorin Homescu 100% hrs	Scott Dixon 100% hrs	total work hours available	Total WAF hours
leads(162)	14-Mar	1-Feb-09	324	46.3	692.6	1351.4		2044	2044
headers(161)	1-Jan	1-Oct-08	274	39.1	522.3	500	1565.7	2088	1934

Cost Estimate Risks

- LN2 Distribution System (WBS 161)

  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.

  Maturity – medium

  Routing and interfaces are in early design phase and design is pre PDR. R&D required.

  Complexity – low

Risk Mitigation

Schedule Milestones

- **An extra full time designer was assigned to Coil Services to assure schedule is met.**
- **Hoses will be 100% leak checked at delivery to prevent delays after installation. (lesson learned from VV)**

Design Integrity

- **R&D at MDL will confirm functionality of G10 insulators and flow rate in corrugated hoses.**

WBS 162 Coil Electrical Leads

Description

This element covers the electrical leads within the cryostat, serving all the coils: the TF, PF, External Trim (WBS 133), and Modular Coils.

Scope

Work includes engineering design, procurement, and fabrication of cables, mounting brackets, thermal transition boxes, and associated supports. Work in this WBS ends with delivery of components to machine assembly operations.

Interfaces

The WBS161 interface begins at coil terminations and ends at the cryostat thermal transition/terminal box. It does not include I&C, bus work, or routing in the test area.
Requires penetration of cryostat.
Share real estate used by core structural support, floor mounted utilities, bus supplies, diagnostics, etc.

Lead Requirements

- **Connect between bus supply in test cell and coil terminals inside cryostat.**
- **Operate nominally at 77-80 K but no active cooling is required, Cryo environment is sufficient to return temperature to operating level between shots.**

- **Provide Cryostat seal interface.**
  - **Minimize icing**
  - **Maintain positive pressure in Cryostat**

- **React internal magnetic loads.**

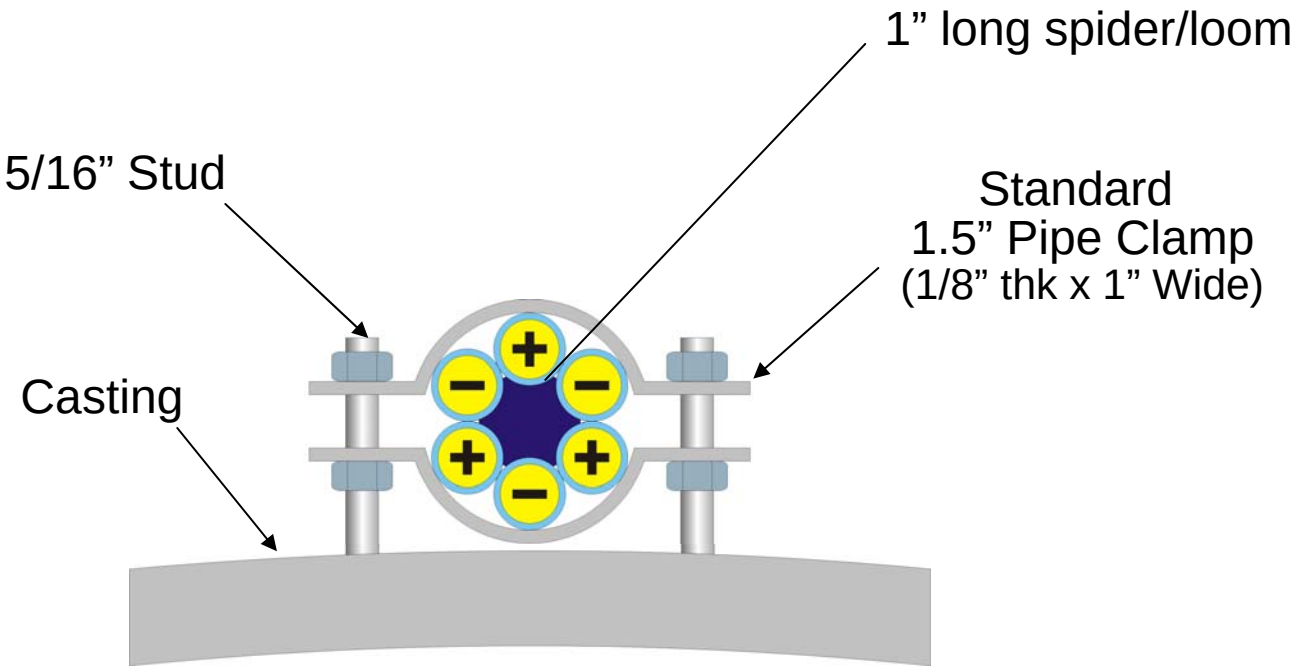
- **Cancel (minimize) field errors.**

Status

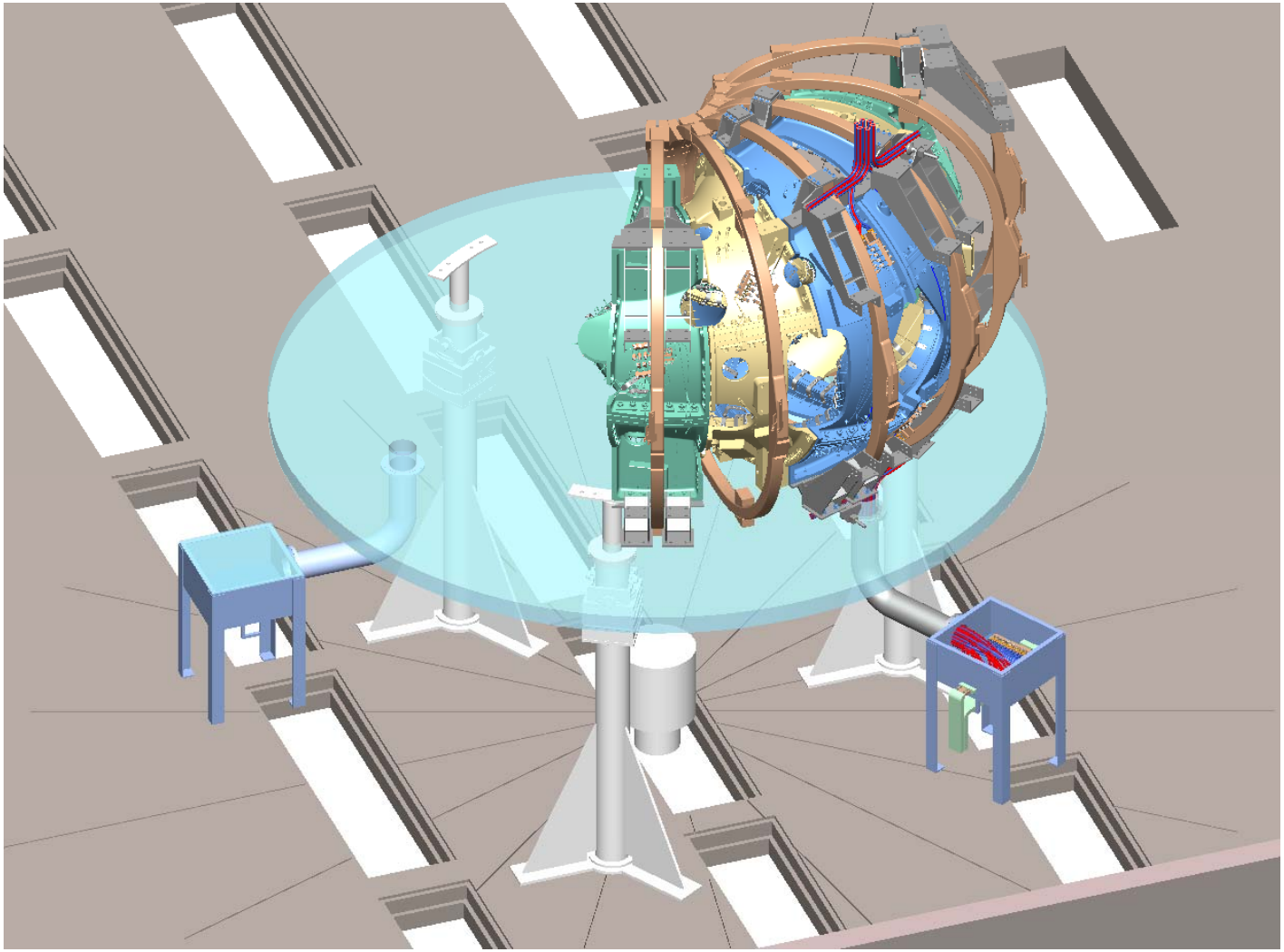
- MC design is most mature.
- To date, most of design effort has concentrated in this area as it is the more challenging.
- Conventional coils will be handled in a similar manner and use similar components.(cable, brackets, terminations, spacers, etc.)

MC Lead Configuration

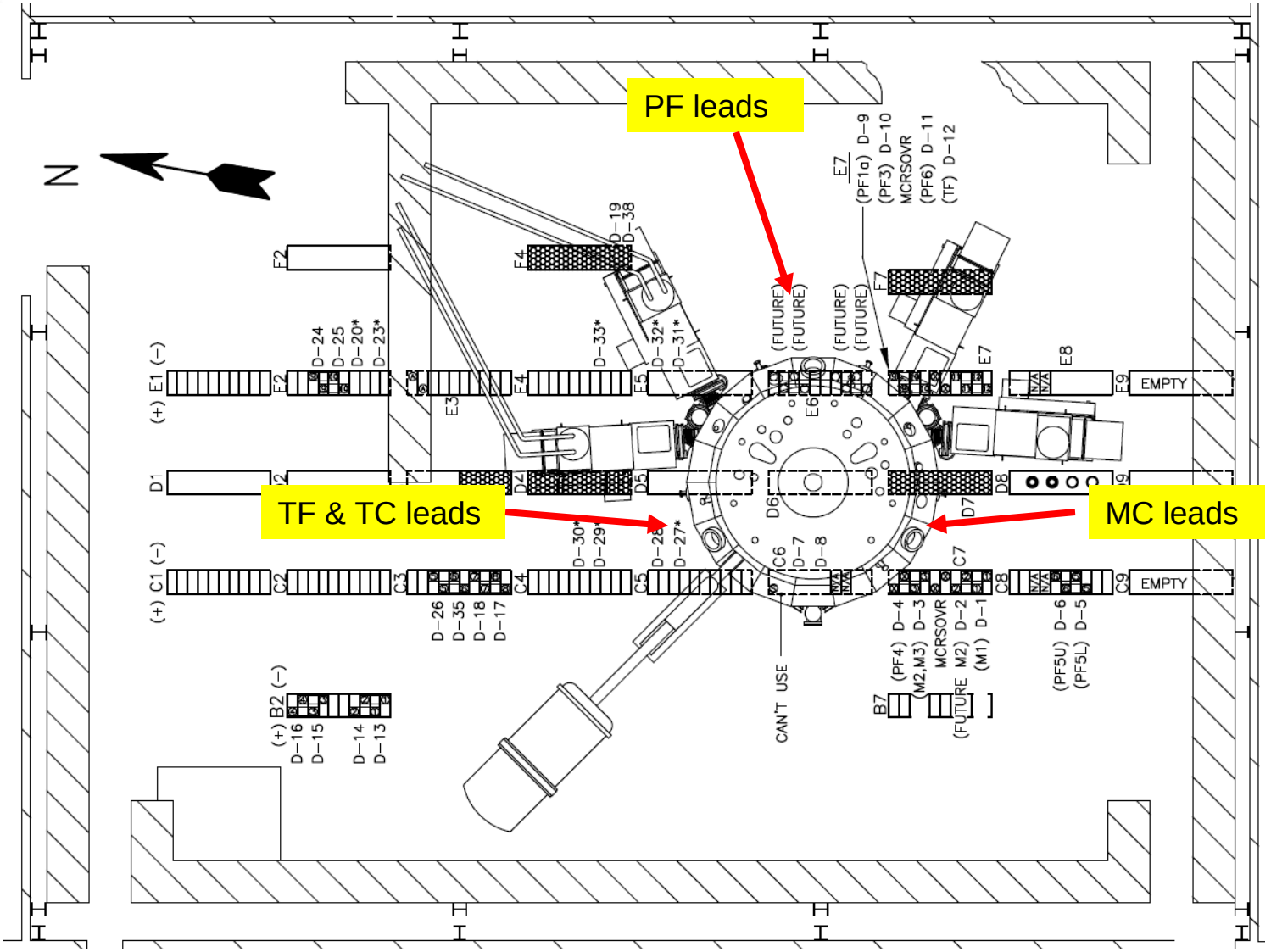
Cable is 250 MCM



System Layout



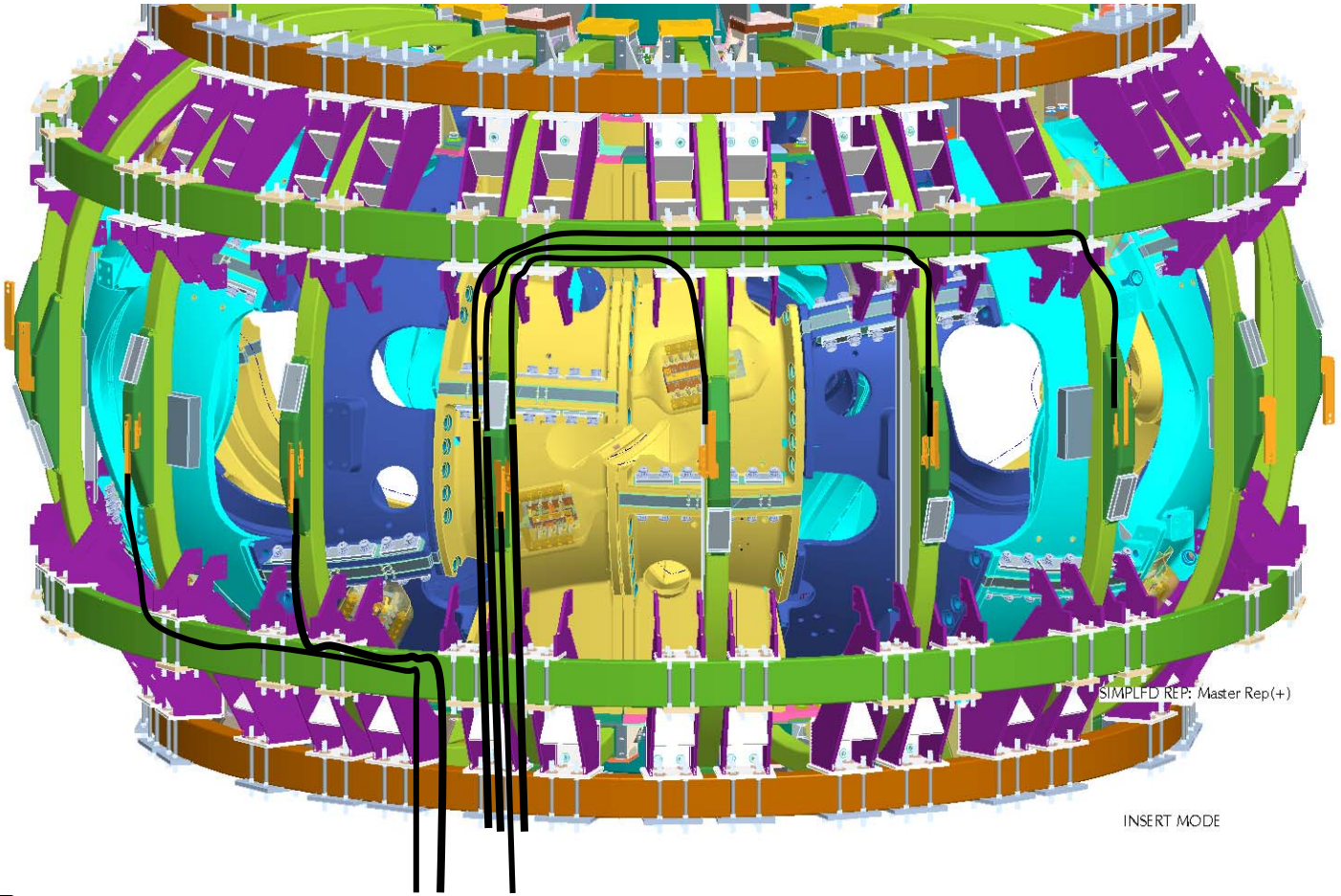
Service routing to test cell penetrations



MC Lead Stub Connections

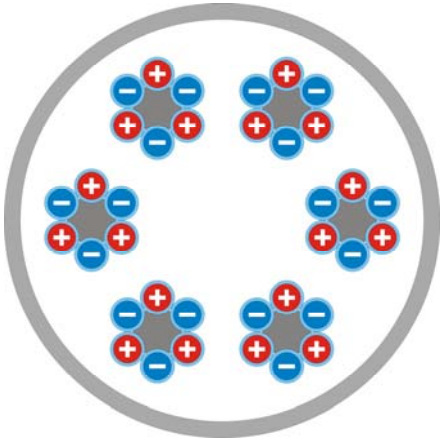
Lead Routing

Services will be routed to each of the three C-C interfaces.

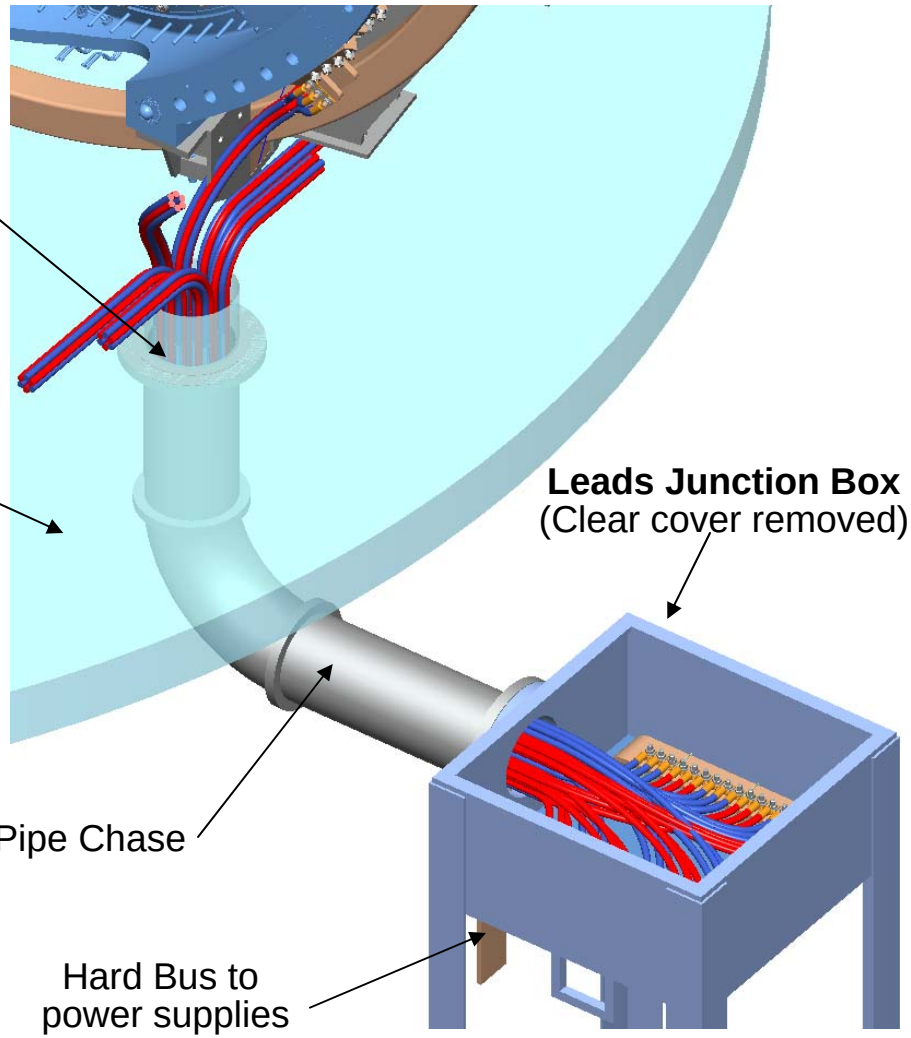


Modular coil Interface at Cryostat

Leads transition thru the cryostat, to room temp.



Top View of an 8” diameter pipe chase showing the (6) modular coil leads cables from a field period



Cost Estimate Basis

- **Cables are catalog items**
  - **Lengths are based on sketches in work sheet.**

- **Material cost of supports, spacers, and terminations is estimated on either:**
  - $ per lb at current market or:
  - $/length of cable.

- **Engineering time is based on number and type of drawings for each element, specifications, and the analyses anticipated.**

Labor

Description:

This effort covers all R&D, Title I, II, and III engineering design of the coil electrical leads inside the cryostat connecting the coils to the power supply bus or cables outside the cryostat.

HOURS

Task ID	Multiplier	Unit	Number of Units	Hours	ORNL EM
Title I an II Design					
Pro-E models (avg)	8	hrs/model	50	400	400
assy dwgs	16	hrs/dwg	15	240	240
Detail drawings	8	hrs/dwg	40	320	320
installation dwg	16	hrs/dwg	29	464	464
cooling schematic	0	hrs/dwg	1	0	0
electrical schematic	8	hrs/dwg	14	112	112
I&C schematic	8	hrs/dwg	0	0	0
stress analysis	0	hrs/calc	0	0	0
thermal analysis	24	hrs/calc	1	24	24
special analysis (electromagnetics)	40	hrs/calc	1	40	40
Procuremnt Specifications	40	hrs/spec	1	40	40
preliminary and final design reviews	40	hrs/rev	1	40	40
Resolve PDR comments	40	hrs/pdr	1	40	40
meetings/reporting/presentations	10%	% of tot hrs		172	172
Subtotal Title I & II Design					***1892***
R&D Activities					
R&D design time to build mounts (clamp, spider), lead terminations				*40*	***40***
Title III					
vendor inspection & oversight	8	hrs per	1	8	8
Disposition of deviation requests and non-conformances	0.5	hrs/wk	20	10	10
In-House fab/assy oversight & inspection	2	hrs/wk	4	8	8
As-built drawings	1	hrs/dwg	84	84	84
Subtotal Title III Design					***110***

Total **2042**

M&S

Description:
This effort covers all coil leads that connect the coil terminals to the buswork at the boundary of the cryostat.

Assumptions:

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

Purchased parts:

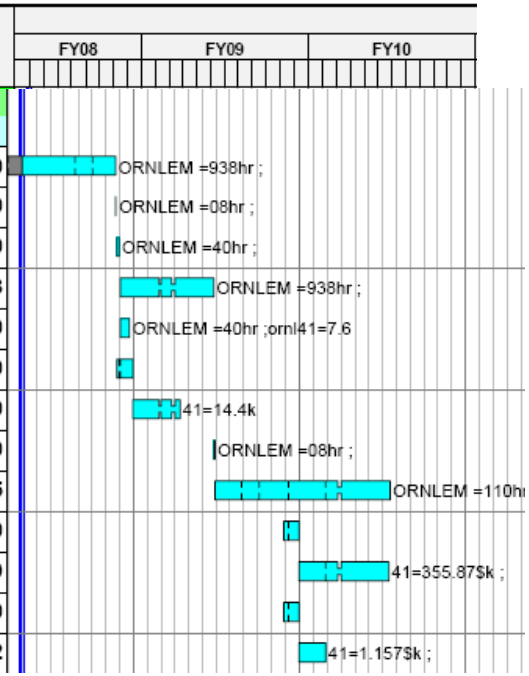
set of cables	$32,552	
misc attachment hardware	$16,162	@10$/ft
thermal transition box material	$0	
subtotal, purchased parts	$48,715	

Lead bundles consist of six, 250 MCM cable with teflon sleeve. Lead ends are cooled by bleed liquid nitrogen supplied by the coil coolant header (WBS 161)
Leads connect from coil terminals to buswork at bottom of machine.
Each coil is connected separately except PF1 and PF2, which are connected in series within the central solenoid assembly

Schedule & Staffing

Schedule

Activity ID	MILE -STONE LEVEL	Activity Description	Duration (work days	SHIFTS	Forecast Start	Forecast Finish	Total Float	Cost to Complete
162 - Electrical Leads								
132-001		Title I design WBS 162 Coil leads	180*		03DEC07A	21AUG08	199	91,800.00
132-002		Electrical Coil leads - PDR	1		22AUG08	22AUG08	199	1,208.00
162-003		Resolve PDR comments	5		25AUG08	29AUG08	337	6,040.00
132-011		Title II design WBS 162 Coil leads	139		02SEP08	26MAR09	337	119,231.03
162-011A		R&D pressure drop simulation	15		02SEP08	22SEP08	461	13,640.00
162-013		Release final drawings for MC lead stubs	26		25AUG08	30SEP08	207	0.00
162-013.1		Procure MC lead stubs	65		01OCT08	12JAN09	207	18,806.40
132-012		Electrical Coil leads - FDR	1		27MAR09	27MAR09	337	1,263.60
132-015		Title III design WBS 162 Coil leads	263		30MAR09	19APR10	337	17,778.35
132-037		Prep Req,Bid,Award Lead hardware and cables	25		26AUG09	30SEP09	340	0.00
132-038		Deliver Lead hardware and cables	130		01OCT09*	14APR10	340	475,798.19
132-047		Prep Req,Bid,Award Material for transition box	25		26AUG09	30SEP09	427	0.00
132-048		Deliver Material for Transition Boxes	40		01OCT09*	25NOV09	427	1,550.92



Staff

Jobs	start	end	days	weeks	Paul G 40% hrs	Sorin H 100% hrs	Scott 100% hrs	total work hours available	Total WAF hours
leads(162)	14-Mar	1-Feb-09	324	46.3	692.6	1351.4		2044	2044

Cost Estimate Risks

Coil Electrical Leads (WBS 162)

Maturity – medium

Routing and interfacing is in early stages of design.

Design of cables is not firmly established, satisfying field error requirements could require more costly solutions and longer lead time.

Complexity – low

Design is straight forward and large ticket procured items (cable and mounts) are commercially stocked.

No complications such as active cooling are required.

Risk Mitigation

Schedule Milestones

- **The Designer was assigned to Leads full time and his LN2 System responsibilities reassigned.**
  - **Permitted acceleration of design schedule to assure critical components (coil stubs) will be procured for Station 5 assembly.**
- **Field error calculations are being performed up front to minimize the risk that designs will have to be redone.**

Design Integrity

- **The terminations and clamps will be prototyped at MDL to confirm their design is acceptable.**

WBS 163 Coil Protection System

Description

This element covers the specification of coil protection requirements for the coil protection system.

Scope

Work covers Title I, II, and III Engineering support for development of the system, including any drawings, electrical and I&C schematics, or analyses. There is no design, fabrication, or hardware included under this package.

The results of thermal, electrical and mechanical analysis will be used to define allowable operating limits for the coils for commissioning, normal research operations, and fault conditions. Appropriate diagnostics and permissive, alarm, and failsafe signals to the power supply controllers and I&C systems will be defined.

Cost

Description:

This effort covers all Title I, II, and III engineering for the Coil Protection System. No hardware is anticipated for this job, only design interface with WBS 4 and 5.

Task ID	Multiplier	Unit	Number of Units		Hours	ORNL EM	ORNL DSN
Title I an II Design							
Pro-E models (avg)	8	hrs/model		0	0	0	
assy dwgs	24	hrs/dwg	120	0	0	0	
Detail drawings	16	hrs/dwg		0	0	0	
installation dwg	16	hrs/dwg		0	0	0	
cooling schematic	0	hrs/dwg		0	0	0	
electrical schematic	8	hrs/dwg		0	0	0	
I&C schematic	20	hrs/dwg	120	4	80	0	120
stress analysis	0	hrs/calc		0	0	0	
thermal analysis	24	hrs/calc		0	0	0	
special analysis (electromagnetics)	40	hrs/calc		2	80	40	
Procurement Specifications	16	hrs/spec		0	0	0	
preliminary and final design reviews	40	hrs/rev		1	40	40	
meetings/reporting/presentations	10%	% of tot hrs			20	20	
Subtotal Title I & II Design					***220***	***100***	***120***

Schedule & Staffing

Schedule

Activity ID	MILE -STONE LEVEL	Activity Description	Duration (work days	SHIFTS	Forecast Start	Forecast Finish	Total Float	Cost to Complete	FY08 FY09 FY10
163.001		Design Coil protection(input to WBS 4 & 5)	65		01OCT08*	12JAN09	435	31,576.20	ORNLEM =100hr ;ornldm=80;ea//em=40

Staffing

Jeff Harris – 270 hours in 2009

Cost Estimate Risks

Coil Protection Requirements (WBS 163)

Maturity – low

Job is at conceptual design stage. It interacts simultaneously with a several other WBS and relies on ongoing analysis. Number of documents is not established.

Complexity – low

Specifications may be replaced with data sheets where procured items are available as stock items.

Many parameters are supplied from other WBS areas and are already available.

Protocols and systems must be compatible with both initial commissioning and full research operations.