CLOSE OUT NOTES- Modular Coil Manufacturing Jobs 9450-1***-1408/ 1451 and 1459

TO: **Larry Dudek**
FROM: **James H. Chrzanowski**

SUBJECT: **Modular coil Winding Operations: 9450-1***-1451**
Modular Coil Supplies: 9450-1*-1408**
Modular Coil Punch List Items: 9450-1*-1459**

Date: July 18, 2008

Scope
This job includes all Modular Coil manufacturing activities including materials and punch list items.

Status
Manufacturing operations are nearly complete except for the installation of strain gauges and balance of thermocouples. All of the (18) modular coils will be completed including VPI'd, and Post VPI by September 30, 2008. Procurement of materials and supplies will be complete by August 30, 2008 and all punch list items [machining/grinding] will be completed by September 30, 2008.

Interfaces
N/A – interfaces were addressed in the modular coil design jobs and not these fabrication jobs.

Specifications
All specifications are complete and current versions are post on NCSX Web Site.

Schematics and PIDs
N/A

Models
All models are complete.

Drawings
All modular coil drawings are complete and posted on the Engineering View Drawing Web Site

Analyses
N/A – required analyses were prepared and approved as part of the design jobs.

Testing
All final electrical test data is posted on the NCSX Web Site. Only final test results from modular coils B6 and A6 need to be completed. These tests will be completed by September 30, 2008, once all Post VPI activities are complete.

Costs
No pending costs following Post VPI activities are planned for closeout.

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Remaining Work

- VPI A6 [7/22/08]
- Complete Post VPI activities including testing [9/30/08]
- Punch list items- will all be completed by 9/30/08, except for remaining thermocouples and strain gauges.

Closeout Documentation

Attachment A provides a generic index of the Modular Coil closeout files.

Lessons Learned:

R&D:

The R&D work that was performed up front was essential in getting a foot hold in the manufacturing process. Working with and understanding the copper rope conductor was extremely important. The development of epoxy filling methods was also invaluable. Even with all of this R&D work a total understanding of all manufacturing activities was not fully realized until the first modular coil was completed.

Drawings:

One of the biggest problems throughout the manufacturing was the impact of concurrent engineering. For example, fully approved coil drawings were never completed until coil #15, although some preliminary drawings were available. Nonetheless, time and problems could have been saved if the design was fully complete prior to the start of manufacturing.

Safety:

Safety was a high priority from day one with bi-weekly safety meetings and constant safety conversations and reminders used throughout manufacturing process.

Casting Preparation Activities:

The stud welding operations went extremely smooth. These studs were used for the winding clamps, but had to be removed following VPI. Even though the studs were removed after VPI, the cleanup due to high magnetic permeability was time consuming. By changing to Inconel studs these cleanup costs were reduced, but the initial costs for materials were increased.

If better/complete models were available early in the process, much of the interference grinding on the wings and the machining of the bolt holes could have been completed prior to winding the coils or at the casting manufacturer.

The turn stations with support rings worked well. The rings were able to be used for any of the modular coil types and provided both a means for rotating the coils and lifting them from station to station.

Chill Plate/Cladding:

The cooling system used for the modular coils was by far the costliest of activities. There were over 1500 individual pieces of copper cladding that had to be handled several times for each coil. The extensive cleaning and insulating of the cladding was not originally anticipated. Hopefully, a different design for cooling will be incorporated in future stellarator designs.

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Coil Winding:

The coil winding activities went very smooth with very few problems. A good decision was winding the coils in the vertical position. This allowed many of the manufacturing tasks to be performed in parallel [both sides]. All of the tooling including the clamps, payout spool, lead brazing activities etc. worked out extremely well. Maintaining vigilance with cleanliness and extreme care throughout the winding tasks was crucial to the successes that we had. The procedures were very detailed and provided a solid basis for the repetitive operations. These procedures were regularly updated to reflect process or tooling changes throughout the operations of the first few coils.

Metrology:

This was an area that was entirely underestimated. The crews got better as time went on, but metrology support was light. One engineer had to address all of the problems, and at times that individual was overloaded. Also the equipment was not reliable. We had numerous breakdowns during crucial times in the operation.

VPI Operations:

In general the mold installation and VPI operations went smoothly. The bag mold concept worked well, but was very sensitive to damage that in turn could cause leaks. During the VPI operations repairs had to be made approximately 1/3rd of the time. Small cuts or sharp edges would cause unsuspecting leaks once the bag began to expand.

The epoxy filling of the coils went well. Adequate fill points were added to the coil due to its complex geometry. Perhaps fewer feeds could have been used, but having the extras gave us flexibility during the filling. No changes are recommended.

Conclusion:

The manufacturing of the modular coils is complete. Other than those items outlined above, no other recommendations are noted.

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Attachment A

This section contains the closeout notes and index for Modular Coil closeout files. These files are located under the Coil/VVSA Tab on the NCSX Engineering Web : http://ncsx.pppl.gov/NCSX_Engineering/ModCoil_VVSA_Fab/ModCoil_VVSA_Fab_index.htm

- **MC R&D Activities (001) -** This section includes all of the R&D files for the work that was completed prior to manufacturing. Activities include VPI trials; trial windings; conductor keystoning activities; plus the Twisted Racetrack Coil.
- **MC Materials (002) -** This section includes information on the materials used for the modular coils including insulation; epoxy and conductor. It does not include information on the MC castings
- **Modular Coil Photographs & Measurements (003) -** This section includes specific information on each modular coil including photographs and coil measurements.
- **Metrology Plans for Modular Coils (004) -** This section includes information about the metrology plans for the modular coils.
- **Modular Coil Tooling (005) -** his section includes the equipment, tools and facility for manufacturing the modular coil.
- **Specifications (006) -** ***The final approved specifications are located on the Engineering Web under the heading of "Specifications" :(http://ncsx.pppl.gov/SystemsEngineering/Requirements/Specs/WBS1/WBS14/index_Specs_WBS14.htm).***
- **Thermocouples & Strain Gauges (007) -** This section provides information on the thermocouples and strain gauges that were for the modular coils.
- **Statements of Work (SOWs) (008) -** ***The final approved SOWs are located on the Engineering Web under the heading of "SOWs": (http://ncsx.pppl.gov/SystemsEngineering/SOW/SOW_index.htm).***
- **VPI Actvities (009) -** This section has the information for the VPI activities including pictures, equipment and plans.
- **MC & TRC Manufacturing Documents (010)** - This section includes all of the manufacturing documents used to fabricate the modular coils including MIT, procedures and operations plan.
- **May FDR NCSX (011) -** This section copies of the FDR presentations for the modular coils. ***This is posted on the NCSX Engineering Web under the heading of "Design Reviews". This file contains pertinent backup information.***
- **Hazard Analysis (012) -** ***This is posted on the NCSX Engineering Web under the heading of "ES&H": (http://ncsx.pppl.gov/NCSX_Engineering/ES&H/HazardAnalyses/index_HazardAnalyses.htm).***
- **Lead Braze (013) -** This sections has photos and information for the lead brazes – lug to copper cable.
- **Lacing (014)** - This section contains information on the development of the lacing technique used to hold the turns in position.
- **Lead Block Jumpers (015) -** This section contains information on the modular coil leads.
- **Cooling of Cladding & Chill Plates (016) -** This section contains reference information on the cooling tubes for cooling the cladding/chill plates.
- **MC Joint Concerns (017) -** This section contains information about the joint concerns and corrective actions taken to improve quality and reliability of joint.
- **Safety Items (018) -** This section contains general safety notes, etc from the modular coil manufacturing program.

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- **MC Coil Lead Short (019) -** This section contains information on the lead short and steps that were taken to correct the problem.
- **Audit 0609 (020) -** ***This is posted on the NCSX Engineering Web under the heading of "Audits" (http://ncsx.pppl.gov/NCSX_Admin/QualityAssurance/index_QA.htm).***
- **MC History (021) -** This section contains general information of winding times, coil history and manufacturing tasks.
- **Posters (022) -** This section has several posters that were generally depicting the modular coil R&D and manufacturing operations.
- **Groundwall & Floating Hardware (023) -** This section contains two studies that discuss the floating hardware in the modular coils and the integrity of the groundwall insulation.

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NCSX
National Compact Stellarator Experiment

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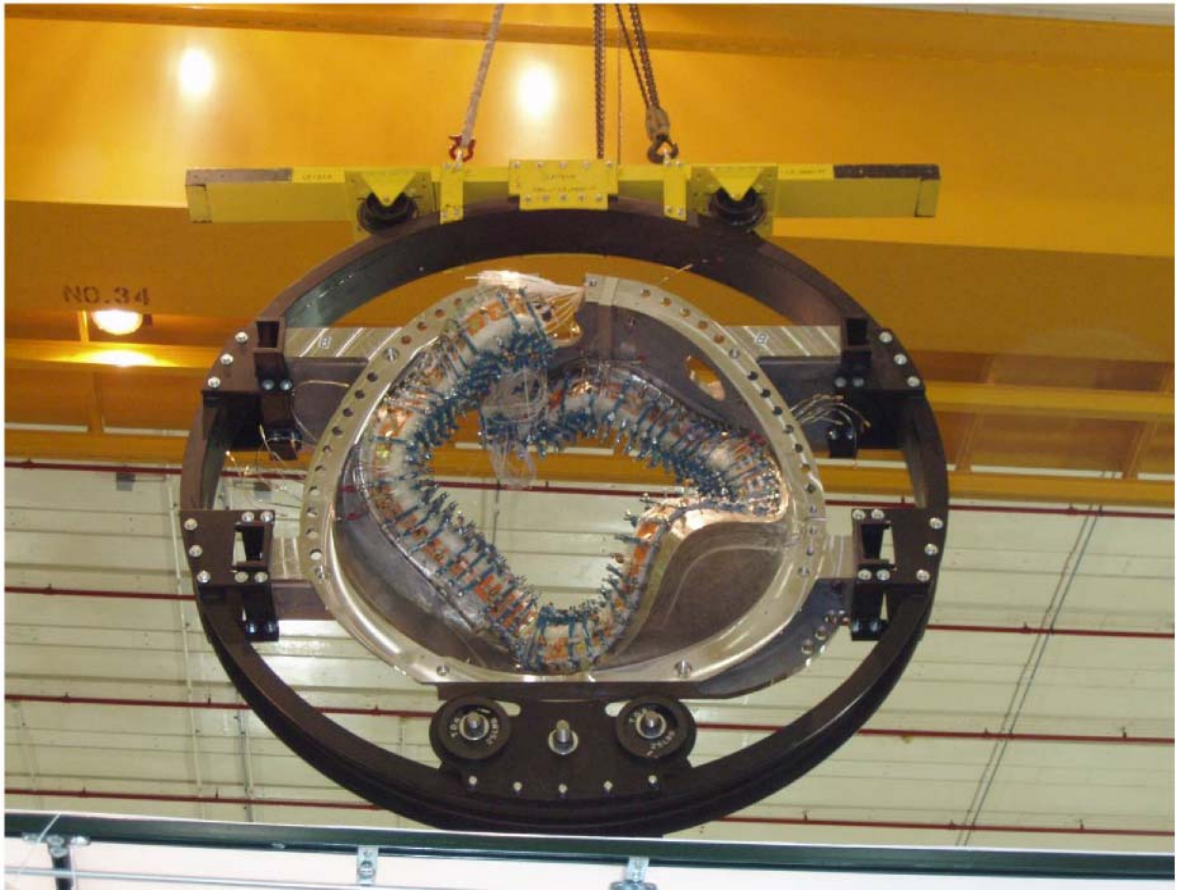
Modular Coil Manufacturing Update



J. H. Chrzanowski for the NCSX Project

Requirements, Design & Interfaces

- Requirements:
  - Manufacture 18 modular coils that meet the design requirements as defined in the GRD and SRD.
    - Maintain Stellerator symmetry
    - Maintain tight current center tolerances [+/-0.5 mm accuracy]
    - Operate at liquid nitrogen temperatures
- Design:
  - Design documents are complete
    - SRD, Specifications, drawings, manufacturing procedures
- Interfaces:
  - MC interfaces with numerous systems as outlined in SRD
    - These interfaces are continuing to evolve as machine assembly is completed
    - Vacuum vessel, TF coils Cryo-systems, FPA, etc.

Modular Coil Status

- **Progress at last Project Meeting- August 16, 2007 : – 13 Coils have been Vacuum Pressure Impregnated (VPI) and 14 through the winding process**
- **Today's Status [April 8, 2008] – 16 Coils have been VPI'd and 17 are through the winding process**

MC ID Number	VPI Date	VPI Status	Post VPI Completion Date	Post VPI Status
A5	9-20-07	Complete	Complete	Complete
C6	2-14-08	Complete	4-18-08	In progress
B5	2-28-08	Complete	5-9-08	Not started
B6	5-15-08	Bag Mold Prep	6-23-08	Not started
A6	7-15-06	Pre-winding	9-1 7-08	Not started

- **The last modular coil will be VPI'd by July 15, 2008**
- **All Post VPI work will be completed by September 17, 2008**

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Tracking Punch List Items

- Majority of punch list items have been completed.
- Remaining items include: Strain gages, additional thermocouples, flange interface modifications [as req'd]

Coil	Wound/ VPI Comp	[1]Coil Post-VPI Items	[2]Initial Elect. Testing	Ground Poloidal Break	Final Clamps (incl short clamps)	T-Couples Installed (coil area)	Insul Installed	Bushing Fab	Premeasure Metrology	Metrology (as cast)	Location	New Holes	Grind/ Mill (Nut Clearance)	Grinding (Overcast)	Comments
A-1	X	X	X	X	X	X	X	X	X	X	CWF		X	X	FPA
A-2	X	X	X	X	X	X	X	X	X	X	CWF		X	X	FPA
A-3	X	X	X	X	X	X	X	X	X	X	RWSF		X	X	
A-4	X	X	X	X	X	X	X		X		RESA		X	X	
A-5	X	X	X	X	X	X	X	X	X		RWSF				
A-6	W			X				X			CWF		X	X	
B-1	X	X	X	X	X	X	X	X	X	X	CWF		X	X	FPA
B-2	X	X	X	X	X	X	X	X	X	X	CWF		X	X	FPA
B-3	X	X	X	X	X	X	X	X	X		RWSF		X	X	
B-4	X	X	X	X	X	X	X	X	X	X	RESA		X		Grinding for gross fits
B-5	X										CWF				
B-6	W			X							CWF				
C-1	X	X	X	X	X	X	X	X	X	X	CWF	X	X	X	PRE FPA STEPS
C-2	X	X	X	X	X	X	X	X	X	X	RWSF	X	X	X	
C-3	X	X	X	X	X	X	X	X	X	X	RWSF	X	X	X	
C-4	X	X	X							X	RESA	X	X	IP	Grinding for gross fits
C-5	X	X	X	X	X	X		X	X	X	CWF				
C-6	X										CWF				

KEY

X	Done	IP	In Progress	W	Winding	1	Diag box, loops, lock clamps etc.
2	Includes hipot to 7.5 kV						

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Cost and Schedule

- Modular Coil cost estimate is based upon detail task breakdown and actual in-field times to complete coils
  - Based on: 17 coils wound and 16 VPI'd
- Budget increased for procurement and installation of additional thermocouples that were added to the design
- Budget increased additional shop hours - unidentified work associated with modifications of winding forms during fit-up in support of FPA
- Last Modular Coil will be VPI'd by 7/15/08 [target date]
- Post VPI items complete by 9/17/08
- Punch list items complete by 11/6/08

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Schedule

NCSX National Compact Stellarator Experiment

Job: 1408 - MC Winding Supplies-CHRZANOWSKI

1408-2		Epoxy (existing order)	256*		23MAY07A	02JUN08	1,605	19,002.60
1408-3		Misc and safety supplies ($7k/mo.)	276*		23MAY07A	30JUN08	1,585	40,476.78
1408-4.0		Order Strain Gages	1		14MAR08*	14MAR08	170	0.00
1408-4.1		Procure Strain Gages	55		17MAR08*	02JUN08	170	37,260.00
1408-5		Epoxy/glass for mold shell	255*		23MAY07A	30MAY08	1,606	5,439.96
1408-6		VPI clean manifold contract	276*		23MAY07A	30JUN08	1,585	4,818.96
1408-8		Cutting hardware for flange bolts	276*		23MAY07A	30JUN08	1,585	1,440.72
1408-7		Misc tech shop support	276*		23MAY07A	30JUN08	1,585	19,609.83

Job: 1451 - Mod Coil Winding-CHRZANOWSKI

Station 2-Winding, Instl Chill Plates,Tubing,Bag

P3-080		Instl Chill Plates,Tubing,Bag B5	38*	1	20DEC07A	20FEB08	216	8,048.62
P3-161		Wind coil B6	78*	1	01NOV07A	29FEB08	149	12,169.27

Station 3-Casting Prep & Winding

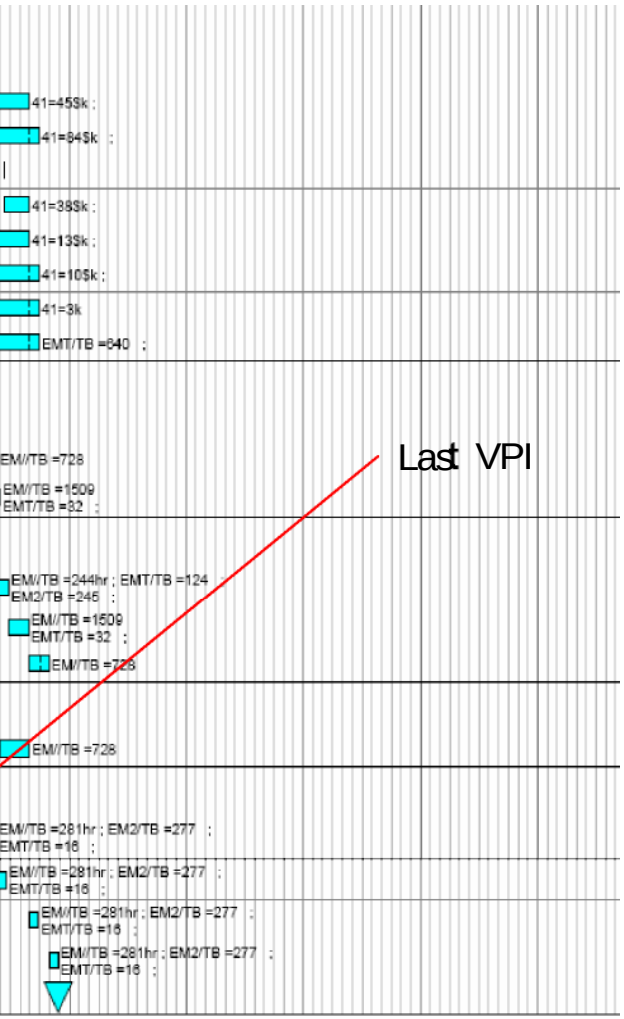
P1-151		Receive A6, Prep& Instl Cladding	97*	1.5	01NOV07A	27MAR08	93	30,206.03
P1-161		Wind coil A6	75	1	28MAR08	27MAY08	93	121,692.77
P1-170		Instl Chill Plates,Tubing,Bag A6	44	1	28MAY08	29JUL08	93	57,490.16

Station 4-Winding, Instl Chill Plates,Tubing,Bag

P3-170		Instl Chill Plates,Tubing,Bag B6	42	1	31JAN08A	02JUN08	149	57,490.16

Station 5-VPI

P2-051V		VPI (Station 5) C6	12*	1	31JAN08A	15FEB08	193	34,225.58
P2-171V		VPI (Station 5) B5	19*	1	21FEB08	18MAR08	216	47,514.31
P3-171V		VPI (Station 5) B6	19	1	03JUN08	27JUN08	149	47,514.31
P1-171V		VPI (Station 5) A6	19	1	30JUL08	25AUG08	93	47,514.31
P3-171VM	2	COMPLETE VPI OF 18th MOD COIL	0	1		25AUG08	93	0.00



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Schedule-continued

NCSX National Compact Stellarator Experiment

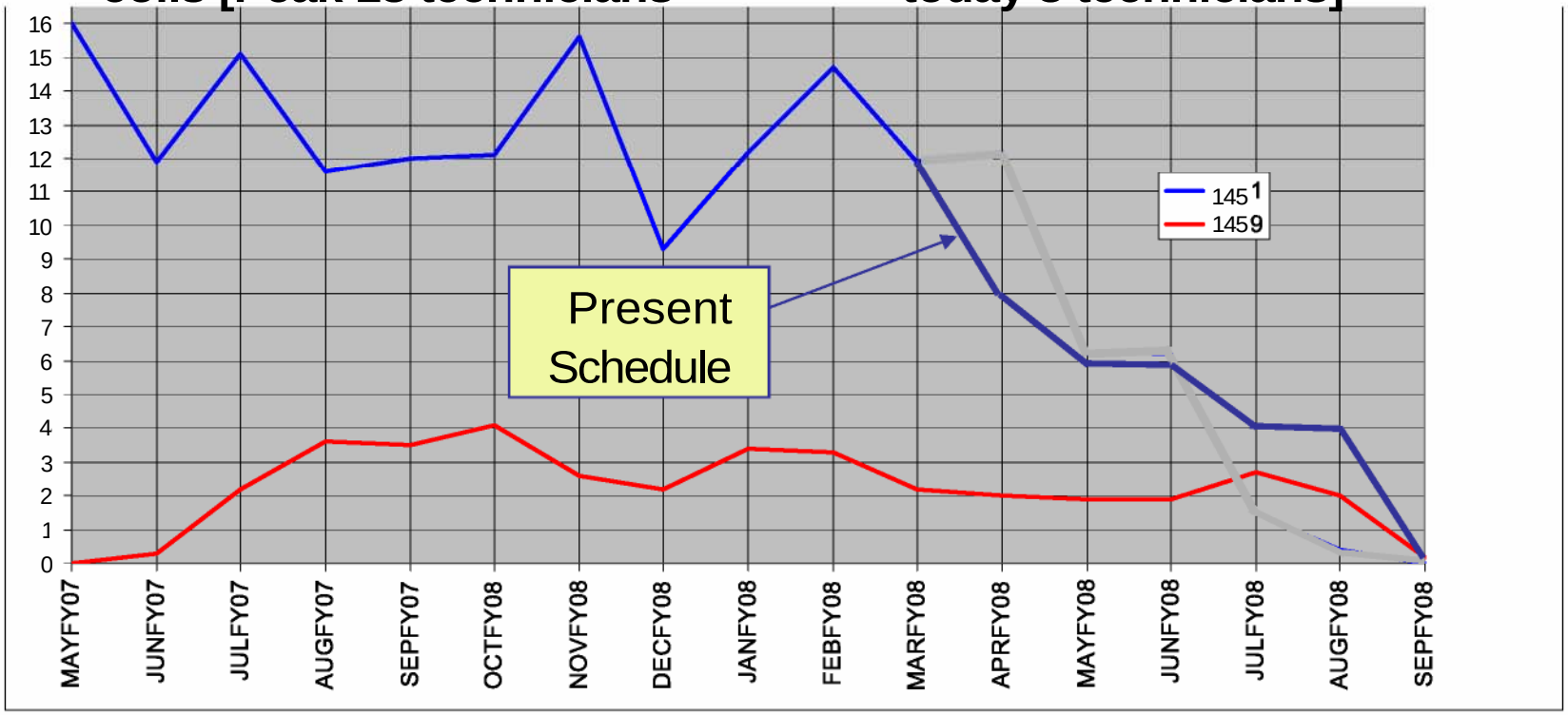
Station 1 Post VPI									
P2-051C		Final Clamps & Warm Test (Station1) C6	43	1	18FEB08	16APR08	193	24,006.88	EM/TB =272 EMT/TB =32
P3-171C		Final Clamps & Warm Test (Station1) B5	16	1	17APR08	08MAY08	195	24,006.88	EM/TB =272 EMT/TB =32
P2-171C		Final Clamps & Warm Test (Station1) B6	16	1	30JUN08	22JUL08	149	24,006.88	EM/TB =272 EMT/TB =32
P1-171C		Final Clamps & Warm Test (Station1) A6	16	1	26AUG08	17SEP08	93	24,006.88	EM/TB =272 EMT/TB =32
LOE Oversight & Supervision									
145XSPRV-2		Winding Engineering oversight and supervision	314*		01MAY07A	31JUL08	1,563	74,971.74	Raftopolous=70hrs/mo.
145XSPRV-3		Winding Engineering oversight and supervision	356*		01MAY07A	30SEP08	1,521	84,886.56	Languish=70 hrs/mo.
145XSPRV-A		Winding Engineering oversight and supervision	185*		01NOV07A	31JUL08	1,563	189,776.65	Chrzanowski=120hrs/mo.;Meighan=120 hrs/mo.
Job: 1459 - Mod Coil Fabr.Punch List-CHRZANOWSKI									
Punchlist Tech shop/RESA									
PLTS-C3		Grinding & Drill Holes -C3	102*	1	01OCT07A	03MAR08	187	8,339.23	EM/TB =240hr
PLTS-C4		Grinding & Drill Holes -C4	5	1	01OCT07A	10MAR08	214	17,815.63	EM/TB =240hr
PLTS-C5		Grinding & Drill Holes -C5	5	1	01OCT07A	17MAR08	1,659	18,763.27	EM/TB =240hr
PLTS-B5		Grinding -B5	5	1	09MAY08	15MAY08	195	3,869.53	EM/TB =49hr
PLTS-A6		Grinding -A6	5	1	01OCT07A	19SEP08	93	270.87	EM/TB =49hr
PLTS-B6		Grinding -B6	5	1	23JUL08	29JUL08	149	3,869.53	EM/TB =49hr
PLTS-C6		Grinding & Drill Holes -C6	20	1	17APR08	14MAY08	193	18,952.80	EM/TB =240hr
PLTS-GRIND		Coil to coil fitup modifications (grinding/cp)	165*	1	01DEC07A	31JUL08	1,563	69,177.72	EM/TB =876hr
Punchlist- Coil Technicians									
PLCT-A3		Insul,measure,TC, other punch list-A3	17	1	05JUL07A	14FEB08	174	2,854.77	EM/TB =241hr
PLCT-A4		Insul,measure,TC, other punch list-A4	17	1	06JUL07A	05MAR08	174	11,990.02	EM/TB =241hr
PLCT-B3		Insul,measure,TC, other punch list-B3	14	1	01OCT07A	20MAR08	174	2,114.82	EM/TB =206hr
PLCT-C3		Insul,measure,TC, other punch list-C3	18	1	01OCT07A	07APR08	174	10,431.15	EM/TB =259hr
PLCT-B4		Insul,measure,TC, other punch list-B4	14	1	01OCT07A	21APR08	174	1,464.10	EM/TB =206hr
PLCT-C4		Insul,measure,TC, other punch list-C4	14	1	25JUL07A	02MAY08	184	10,461.95	EM/TB =276hr
PLCT-A5		Insul,measure,TC, other punch list-A5	14	1	30JUL07A	12MAY08	184	13,502.29	EM/TB =206hr
PLCT-A6		Insul,measure,TC,SG other punch list-A6	14	1	01OCT07A	09OCT08	93	13,895.54	EM/TB =206hr
PLCT-B5		Insul,measure,TC, other punch list-B5	14	1	01OCT07A	09OCT08	93	14,288.80	EM/TB =206hr
PLCT-C5		Insul,measure,TC, other punch list-C5	18	1	01OCT07A	06NOV08	93	4,475.17	EM/TB =258hr
PLCT-B6		Insul,measure,TC,SG other punch list-B6	14	1	01OCT07A	18AUG08	149	13,502.29	EM/TB =206hr
PLCT-C6		Insul,measure,TC,SG other punch list-C6	14	1	01OCT07A	04JUN08	193	13,436.75	EM/TB =205hr
PLCT-C6M		COMPLETE MODULAR COIL FABRICATION	0	1		04JUN08	193	0.00	
PLCT-CRANE		Crane support	207*	1	01DEC07A	30SEP08	1,521	31,310.03	EM/TB =480hr

Post VPI items complete

Punch list items com plete

Manpower Down Sizing Plan

- **MC Manpower Plan:**
  - **Presently working single shift x 5 days a week**
  - **We have a plan for the orderly down sizing of modular coil manufacturing team**
  - **Size of production team will vary as required to complete modular coils [Peak 18 technicians → today 8 technicians]**



CLOSE OUT NOTES- Modular Coil Manufacturing Jobs 9450-1***-1408/ 1451 and 1459 Manufacturing Area

- We have begun transferring real estate to FPA teams as MC stations are shut down.
- Station 2 winding station was transferred to FPA on 3/1/08
- By 7/31/08 all areas except for Station 4 and the autoclave will be transferred to FPA

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Uncertainty of Estimate

NCSX June 2007 ETC

TABLE IV - Uncertainty of Estimate and Residual Risk Assessment

WBS Number: 142
WBS Title: Windings and Assembly
Job Numbers: 1408, 1451, & 1459
Job Title: Modular Coil Winding Supplies (1408)
Job Title: Modular Coil Winding Operations (1451)
Job Title: Modular Coil Punch List Items (1459)
Job Manager: Jim Chrzanowski

Uncertainty of the Estimate

	High	Medium	Low	Uncertainty Range (%)	Comments/Other Considerations
Job 1408				-5%/+10%	
Design Maturity	X				Mostly off-the-shelf items
Design Complexity			X		Mostly off-the-shelf items
Job 1451				-10%/+15%	
Design Maturity	X				Known and proven procedures and processes
Design Complexity		X			Have built & Test 14 coils and have proven processes even with tight metrology and tolerances.
Job 1459				-10%/+15%	
Design Maturity		X			Still uncertainty on number of field changes (e.g., number of holes, etc.)
Design Complexity			X		Standard field work.

Note: High/Medium/Low uncertainty assessment from Job Manager. Uncertainty range based on AACEI recommended practice 18R-97 as amended for NCSX

High level of confidence in estimate

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Residual Impact

NCSX June 2007 ETC
TABLE IV - Uncertainty of Estimate and Residual Risk Assessment

Residual Impacts

Job	Risk Description	Likelihood of Occurring	Mitigation Plan	Basis of estimate	Cost Impact Low	Cost Impact High	Schedule Impact Low	Schedule Impact High		
1408	NONE									
1451	Damage or loss of modular coil during VPI or testing requiring the conductor to be stripped off and re-wound (Please see Assumptions)	U	Continue to use same rigorous process used for first 12 coils during which there were no fabrication mishaps requiring re-winding a path.	~$35K in materials; ~$380K in labor. 7.5 months to do work with the potential for a 2 month impact on the critical	+ $400	+ $450	+ 0.00	+ 2.00	RR#6	16 of 18 coils successfully wound.Remaining 2 coils in winding process.
1451	Failure of major piece of winding equipment (e.g., motor, gear box, etc.) resulting in extended downtime in a winding station	U	Critical spare components are availble from winding station #2 that is no longer being used	~$5K for repair costs	+ $5	+ $10	+ 0.00	+ 0.00	RR#7	Future risk, has not occurred yet - N/A
1451	Insulation on modular coil fails during initial cooldown and testing requiring stellarator core disassembly	NC	C1 tested at full current at cryogenic temperature. All modular coils will be tested at RT at elevated (50% higher) voltage for faults to ground. In addition, routine field tests will be performed on each assembly station to ensure that the electrical	*High impact-low probability event not covered by contingency*					RR#17	16 of 18 coils successfully wound.Remaining 2 coils in winding process.

Notes:
[1] Low cost and schedule impacts are considered the minimum (0-percentile) impacts should the event occur.
High cost and schedule impacts are considered the maximum (100-percentile) impacts should the event occur
[2] Cost impacts should be entered as man-hours (by demographic) and M&S direct cost under basis of estimate.
Cost impacts should NOT include standing army costs which are separately calculated from the schedule impact
Project control is reponsible for quantifying the low and high cost impacts based on the labor hours and M&S identified
[3] The schedule impacts should be entered as the min and max impacts on the critical path.
If there is no critical path impact then the schedule entries should be zero.
[4] Likelihood of occurrence should be entered consistent with our risk classification methodology, i.e.
VL= Very Likely (P>80%), L=Likely (80%>P>40%), U=Unlikley (40%>P>10%), VU=Very Unlikely (P<10%), NC=Non-credible (P<1%)

Use three remaining winding

Assumptions

Cost: Would need ~$4.5K of Expoxy + ~$3K of insulation + $1.5K of shell + ~$5K of other misc components/materials + cost of new lead blocks of ~$15K => round off to ~$35K. Labor ~$380K assuming ~4.5 months to rework and redo coil.

Schedule: To redo the coil: Need 138 shifts x 3 men/shift x 8 hours/shift => 3 months + To rework of ~65 shifts x 3 men/shift x 8 hours/shift => 1.5 months. Need an additional ~3 months to order lead blocks if needed. Anticipate ~3 months to re-order and obtain new lead blocks. If Type B coil is the one to fail, could add 1-2 months to critcal path at an added "standing army" cost of ~$260K/months or ~$520K.

2-3 month impact on project schedule [If coil 18 had to be replaced]

Results in highest impact [7.5 months to replace coil]

[14 coils have been electrically tested]

CLOSE OUT NOTES- Modular Coil Manufacturing Jobs 9450-1***-1408/ 1451 and 1459

In Summary….

- 17 modular coils have been wound and 16 VPI'd
- Have begun down sizing of coil manufacturing team from peak level of 18 technicians to today's level of 8 technicians
- Have begun transferring manufacturing real estate to FPA teams
- Successfully addressed all of the technological challenges.
- Safety continues to be in the forefront of all planning and performance of field activities
- *The NCSX Project is committed to completing the manufacturing of the Modular coils by September 2008. (inc. final electrical tests)*