

# **Fabrication of the Twisted Racetrack Coil**

**J. Chrzanowski  
and the NCSX Team**

**NCSX Final Design Review  
for Twisted Racetrack Coil**

# *NCSX R&D – Safety is Integrated in All Aspects*

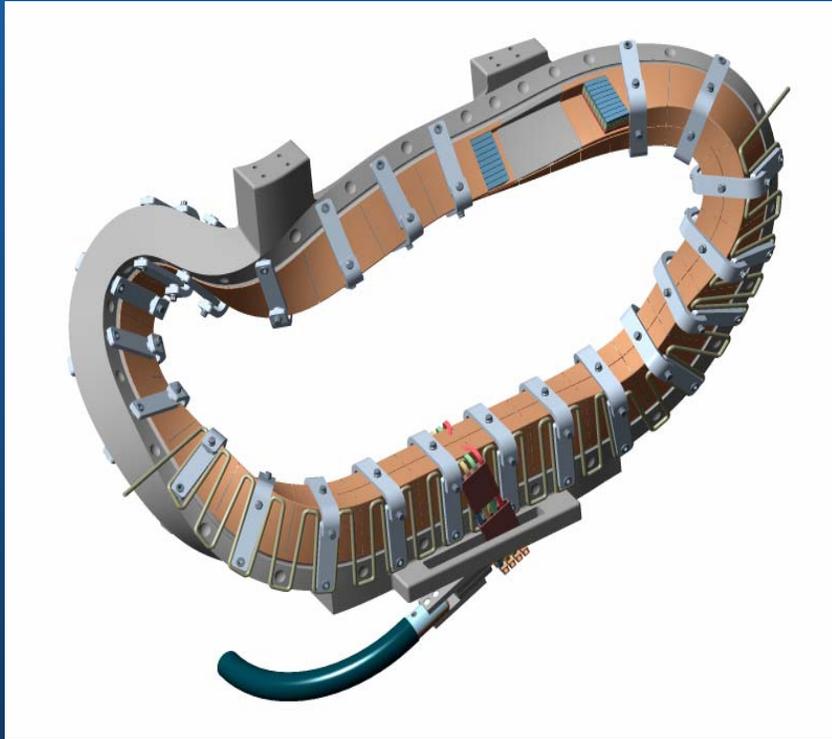
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- **Safety** is an important element of the PPPL culture and is incorporated in all aspects of the development program and will be carried over to production
- **Integrated Safety Management (ISM)**
- **Job Hazard Analysis** surveys (**JHA's**) are developed to identify hazards associated with the various tasks and the personnel protective equipment required
- **Involvement of all safety groups** in developing plans for manufacturing

# Twisted Racetrack Shaped Coil

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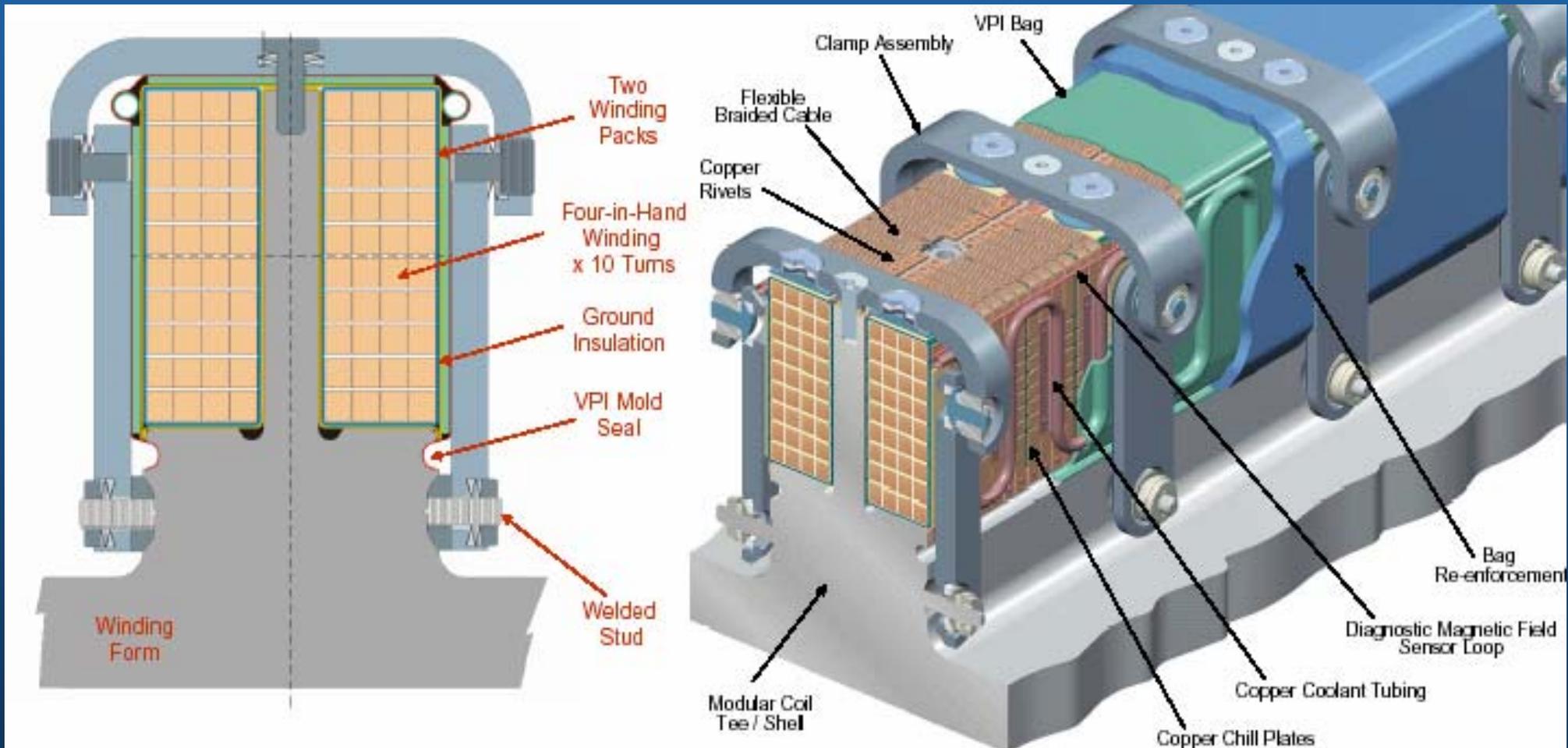


**Anticipated start mid October**

- **Twisted coil will capture many physical features of the NCSX Modular coils including:**
  - Mod coil Cross-section and Transitions
  - Conductor and Insulation scheme
  - Lead arrangement
  - Cooling arrangement (Chill plates)
- **Coil will be instrumented with strain gauges and thermocouples to monitor coil conditions**
- **Coil will be used to demonstrate/learn:**
  - shimming to control tolerance
  - Issues of fabrication using similar features of modular coil
  - Final “Bag Mold” configuration
  - First use of Autoclave
  - Verify thermal performance of the coil

# Modular Coil Winding Pack Assembly

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# Copper Rope Conductor

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## ➤ Conductor Specifications:

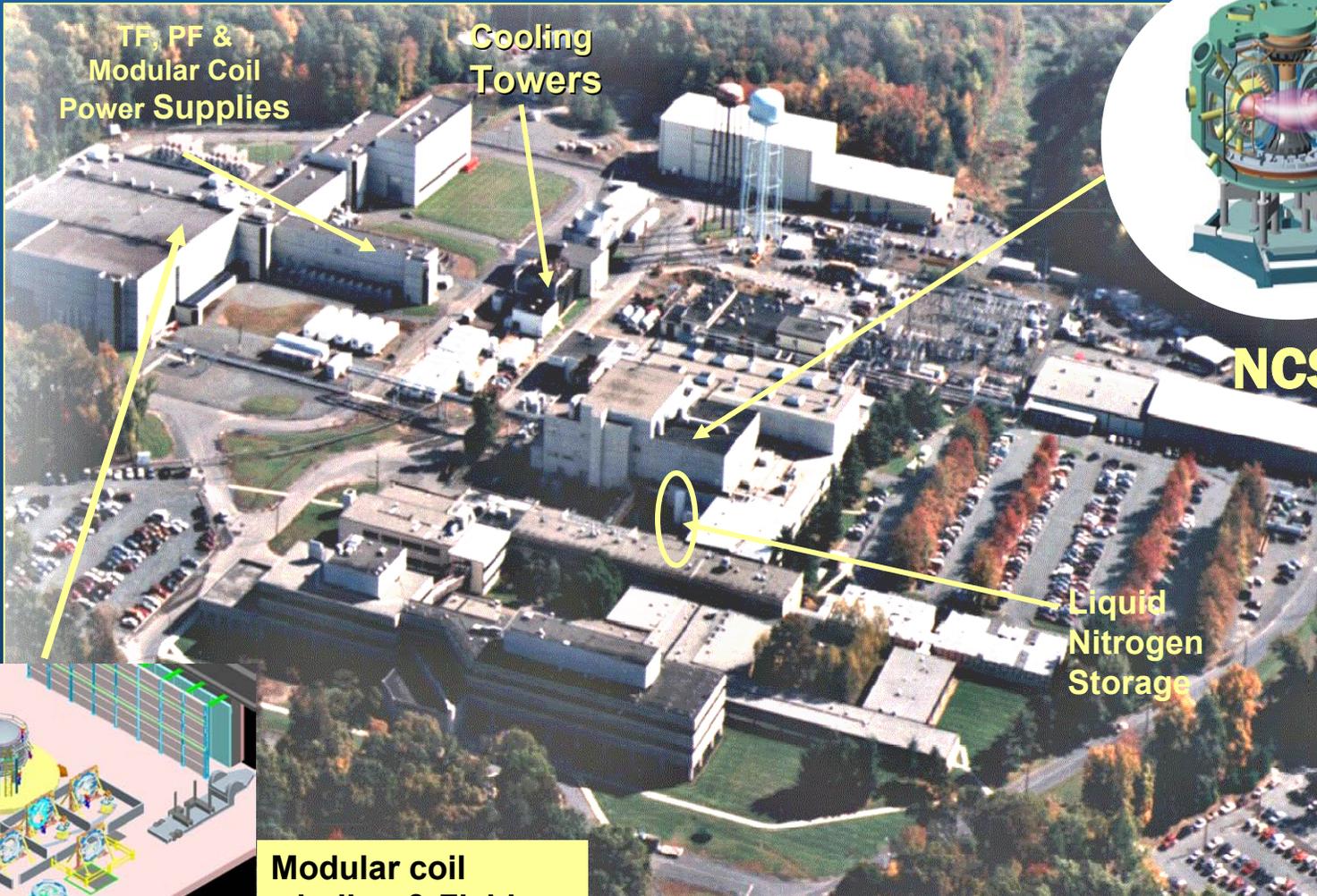
- OFHC copper- 34 AWG bare copper ( 0.0063 in. diameter) per ASTM B-577
- Tolerance ~ +/- 0.008 inch
- 3240 strands
- Cable construction:
  - (54) @ 2.5 in. RHL x (5) @ 3.5 RHL x (9) @ 5.5 in. LHL
  - (54) @ 2.5 in. LHL x (5) @ 3.5 LHL x (3) @ 5.5 in. RHL
- Conductor will be manufactured with no lubricants (clean)
- Conductors will be fabricated using copper rope that was compacted to required dimensions (tolerance +/- 0.008")
- Conductor will have 0.004 in. thick Nylon serve that assists with forming the conductor and helps to minimize loose strands

## ➤ Turn Insulation:

- Conductor will be insulated with (1) half-lapped layer of nominal 0.004 in. thick S-2 fiberglass tape [0.004 in. center and 0.007 in. at edge- average build = 0.0055 in.]

# Modular Coil Fabrication

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# Modular Coil Manufacturing Facility

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# *Modular Coil Fabrication*

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- The Modular Coil Winding Facility will be located in the D-site Test Cell [formerly occupied by TFTR]
- Six manufacturing stations
  - Station 1- Casting Prep
  - Station 2, 3 & 4- Winding/ Mold preparation stations
  - Station 5- VPI and post VPI
  - Station 6- Cryo test (Located in basement)
- TRC- All work will be performed in stations 2 and 5.
- WP-1125
- NEPA 1283

# Modular Coil Winding Facility Operations Plan

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## Modular Coil Winding Facility Operations Plan

NCSX-PLAN-WFOP-00

April 1, 2004

Author: \_\_\_\_\_  
James H. Chrzanowski- Coil Facility Manager

Reviewed By: \_\_\_\_\_  
Steve Raftopoulos- Field Supervisor

Reviewed By: \_\_\_\_\_  
Tom Meighan- Field Supervisor

Reviewed By: \_\_\_\_\_  
Judy Malsbury- NCSX QA Representative

Reviewed By: \_\_\_\_\_  
Jerry Levine- PPPL Safety Representative

Reviewed By: \_\_\_\_\_  
Bill Slavin- PPPL IH Representative

Approved By: \_\_\_\_\_  
Larry Dudek- RLM for Coil Facility

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- A Modular Coil Winding Facility Operations Plan has been written and approved.
- This document describes how the MCWF will function during the coil manufacturing
  - Workstations
  - Responsibilities
  - Safety and Training
  - Operating Guidelines
  - Communication
  - Documentation
  - Quality Assurance

# Modular Coil MIT Plan

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## Modular Coil Manufacturing, Inspection, Test and Quality Assurance Plan

NCSX-MIT/QA-142-01-00

April 27, 2004

Author: \_\_\_\_\_ Date: \_\_\_\_\_  
James H. Chrzanowski- Modular Coil Facility Manager

Reviewed By: \_\_\_\_\_ Date: \_\_\_\_\_  
Judy Malsbury- NCSX QA Representative

Reviewed By: \_\_\_\_\_ Date: \_\_\_\_\_  
Jerry Levine- PPPL Safety Representative

Reviewed By: \_\_\_\_\_ Date: \_\_\_\_\_  
Dave Williamson- WBS Manager for Modular Coils  
(WBS14)

Reviewed By: \_\_\_\_\_ Date: \_\_\_\_\_  
Brad Nelson-Project Engineer for Stellerator Systems  
(WBS 1) Manager

Approved By: \_\_\_\_\_ Date: \_\_\_\_\_  
Larry Dudek- RLM for Modular Coil Mfg. Facility

**Controlled Document**

THIS IS AN UNCONTROLLED DOCUMENT ONCE PRINTED.  
Check the NCSX Engineering Web prior to use to assure that this document is current.

- MIT Plan has been written and reviewed.
- Document will be used during the manufacturing of the Twisted Racetrack Coil, modified and approved for the production coils
- The MIT in conjunction with procedures will dictate the manufacturing process

# *Manufacturing Documents*

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- NCSX-PLAN-WFOP-00 [MC Winding Facility Operations Plan]
- NCSX-MIT/QA-142-01-00 [MC MIT/QA Plan]
- Manufacturing Procedures
  - D-NCSX-MCF-001 [ MC Winding Form Preparation]
  - D-NCSX-MCF-002 [MC Winding Station Activities]
  - D-NCSX-MCF-003 [MC VPI Activities]
  - D-NCSX-MCF-004 [MC Post VPI Activities]
  - D-NCSX-OP-G-159 [MC Test Facility Operation]

# Moderate Hazard Facility

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**PRINCETON PLASMA PHYSICS LABORATORY**

**Modular Coil Manufacturing Facility**

**NCSX-PHA-142-01-00**

**August 6, 2004**

PREPARED BY:  **Jim Chrzanowski**  
Signature Not Verified  
Jim Chrzanowski, Modular Coil Manufacturing Facility Manager

Digitally signed by Jim Chrzanowski  
DN: cn=Jim Chrzanowski, o=NCSX  
Date: 2004.08.06 07:23:51 -0400  
Reason: I am the author of the document

APPROVED BY:  **Larry Dudek**  
Signature Not Verified  
Larry Dudek, Responsible Line Manager

Digitally signed by Larry Dudek  
DN: cn=Larry Dudek, o=NCSX  
Date: 2004.08.06 08:48:57  
-0400

 **John Schmidt**  
Signature Not Verified  
John Schmidt, Head, Advanced Projects Department

Digitally signed by John Schmidt  
DN: cn=John Schmidt, o=NCSX  
Date: 2004.08.10 00:44:34 -0400

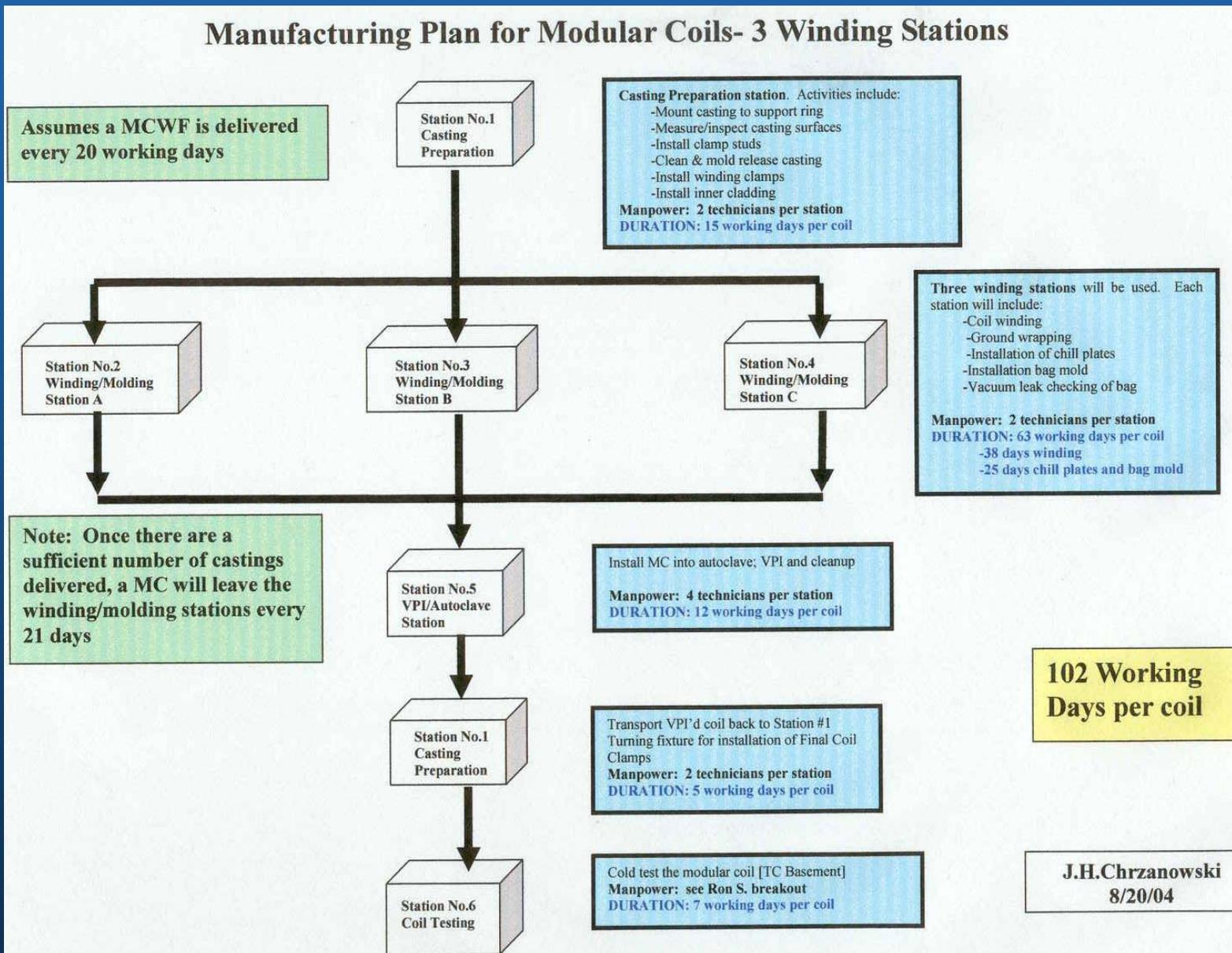
 **Jerry Levine**  
2004.08.06  
11:32:35 -04'00'  
Jerry Levine, Chairman, Safety Review Committee

- The MCWF has been designated a “Moderate” Hazard Facility”
- This a result of the autoclave usage and the activities associated with the VPI of the MC
- “NCSX-PHA-142-01” approved document, documents all of the known hazards associated with then MCWF

# Modular Coil Work Plan

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## Manufacturing Plan for Modular Coils- 3 Winding Stations



# MCWF Clean Rooms

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- The winding and mold stations will be located in enclosed rooms where **cleanliness** can be controlled.
- Three clean rooms were constructed.
- Modular coils will be positioned in the rooms via a sliding roof panel.
- Positive pressure rooms for maintaining cleanliness
- Smoke detectors in each of the (3) clean rooms

# Metrology

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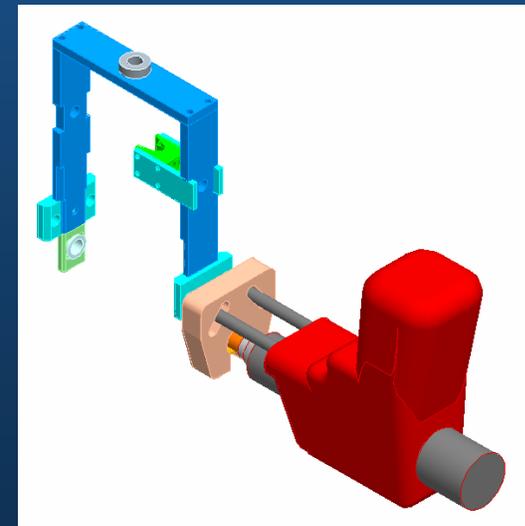
- During the course of fabrication, numerous measurements will be made. (+/- 0.020 in. 0.5 mm)
- A combination of the “Romer” arm and scanner will be utilized
- Measurements will be made:
  - Casting surface- laser scanner
  - Cladding surface- laser scanner
  - After 1<sup>st</sup>. Layer – “Romer” mechanical arm - shim
  - After 4<sup>rd</sup>. Layer - “Romer” mechanical arm - shim
  - After 7<sup>th</sup>. Layer - “Romer” mechanical arm - shim
  - After final layer- “Romer” mechanical arm and scanner



# Casting Preparation

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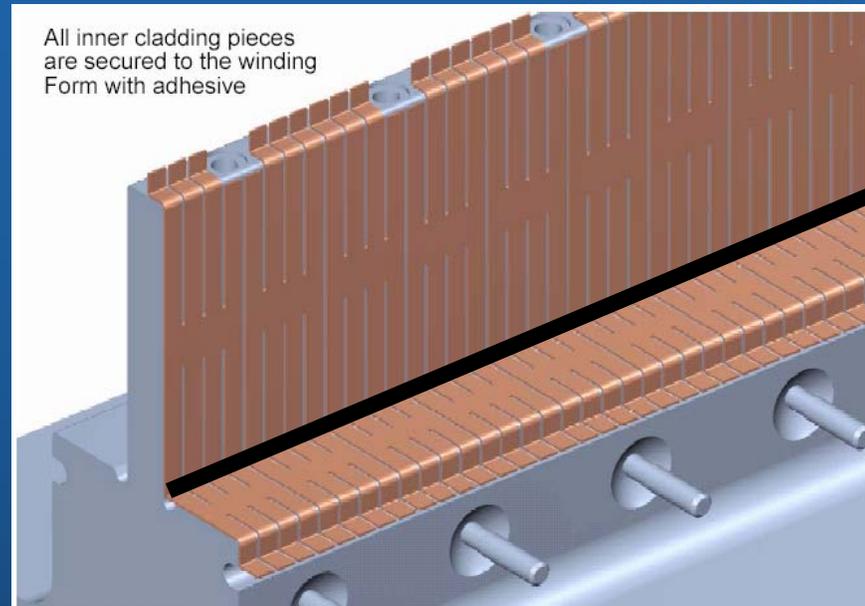
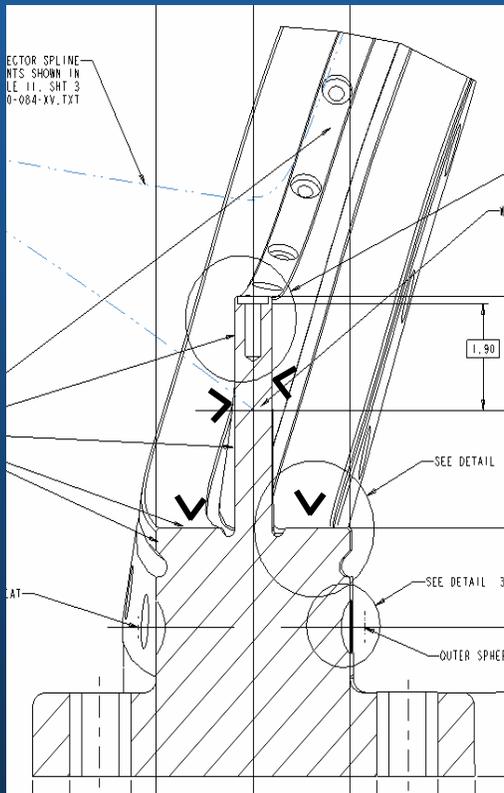
- TRC casting is mounted into the turning fixture
- Perform visual inspection
- Clean all tapped holes
- Using “Romer” scanner, measure winding surfaces
- Install weld studs
- Clean winding form



# Casting Preparation-2

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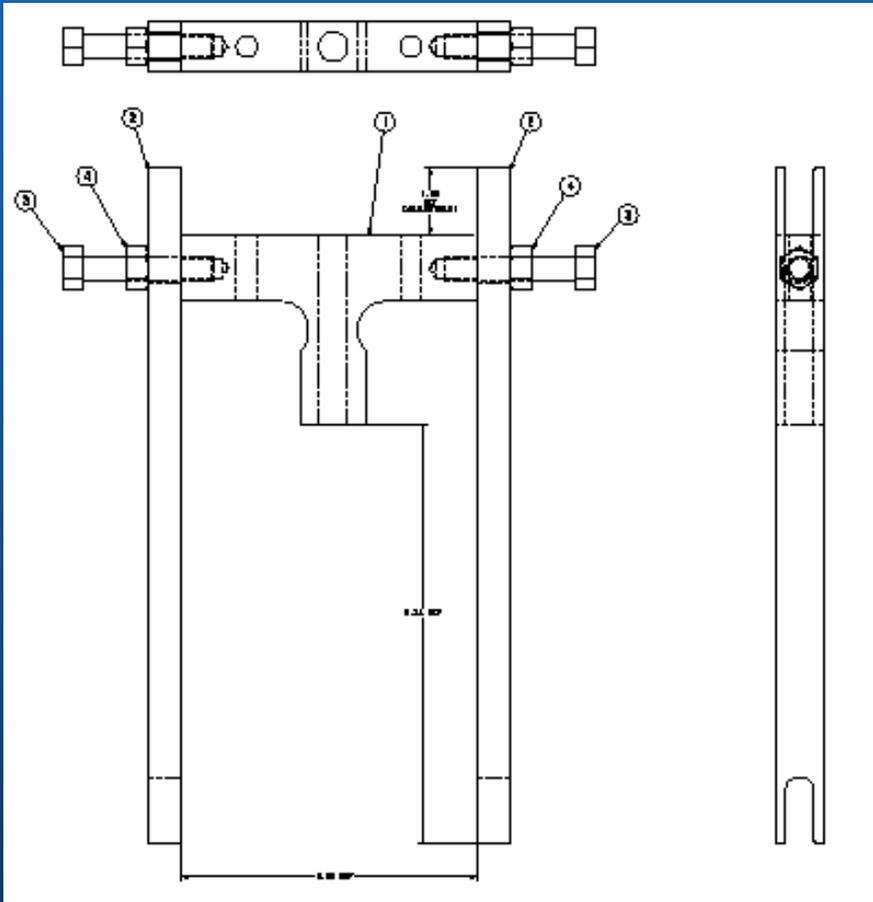
- Mold release winding surfaces



- Clean & debur copper cladding
- Fitup (2) piece copper cladding (custom fitting required)
- Remove/clean
- Apply (2) layers Kapton tape on cladding
- Reinstall using double faced 3M tape
- Remeasure surfaces-cladding

# Winding Clamps

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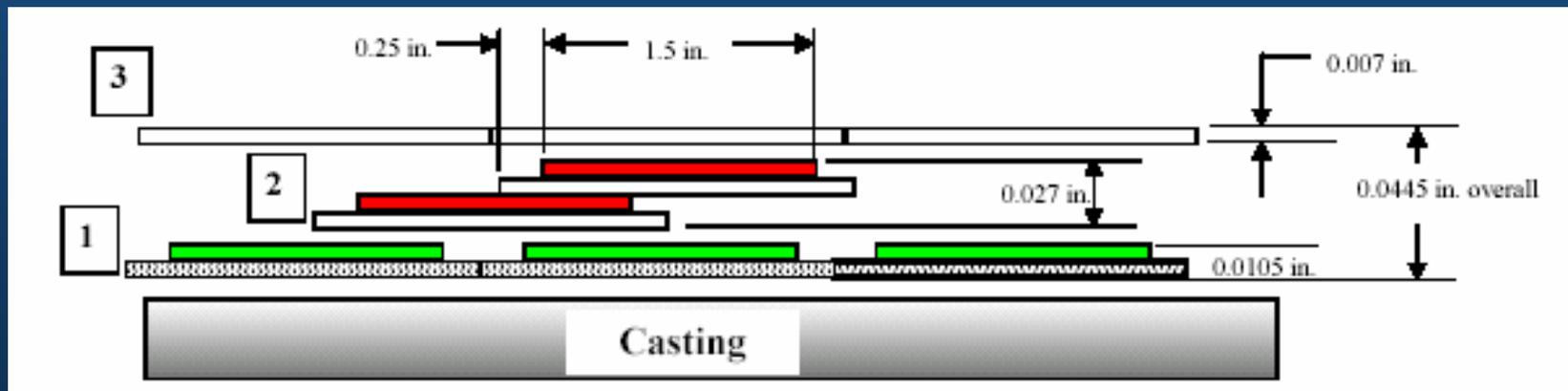
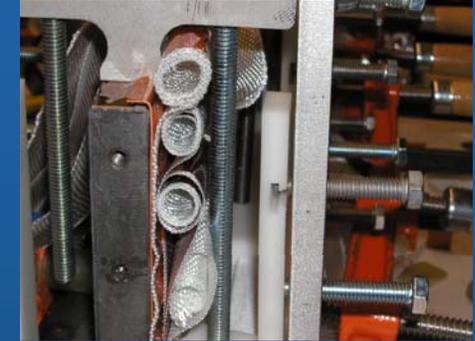


- Install winding clamps using upper tapped holes and studs
- Winding clamps will allow minimal re-clamping operations during winding
- Same clamps will be used during VPI

# Ground Wrap Insulation

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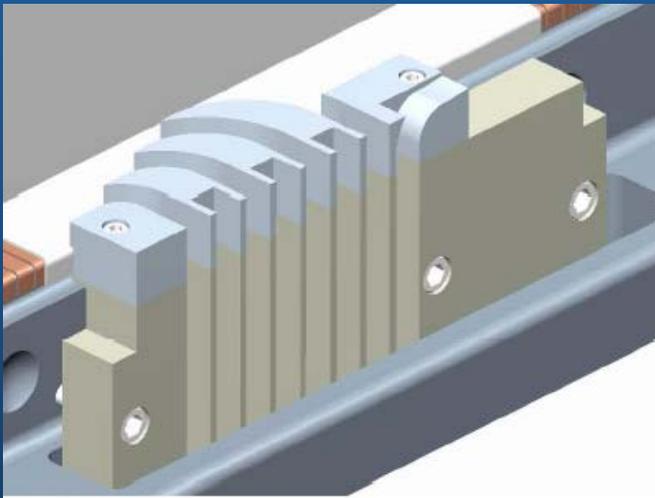
- **Layer 1 (Inner):**
- Apply (1) Butt lapped layer of composite insulation
- 0.007 inch thick S-2 glass [nominal 2 inch wide]
- 0.0035 (HN) Kapton tape [nominal 1.5 inch wide] with adhesive back
- **Layer 2 (Mid):**
- Apply (1) half-lapped layer of composite insulation:
  - 0.007 in. thick glass [2 inch nom. wide]
  - 0.0065(HN) Kapton [1.5 nom. wide] with adhesive
- **Layer 3 (Outer):**
- Apply (1) Butt lapped layer of S-2 glass tape
- - 0.007 in. thick S-2 glass [2 inch nom. wide]



# Lead Preparation

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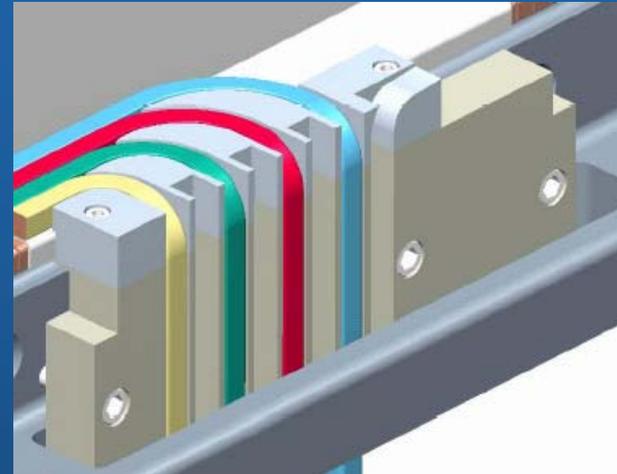
- Position lower lead guide block
- Prepare and braze terminals to copper conductor using “Nibco” resistive heating carbon tongs and Sil-Fos braze material



# Winding Operations

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- Insulate and position the leads in the lead guide block
- Begin winding operation with copper conductor being fed from (4) pre-insulated copper spools



# *General Winding Notes*

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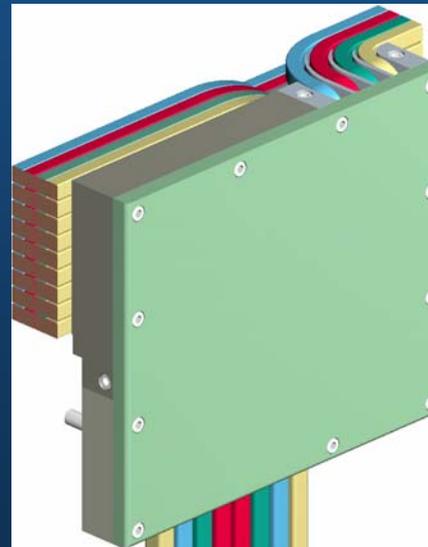
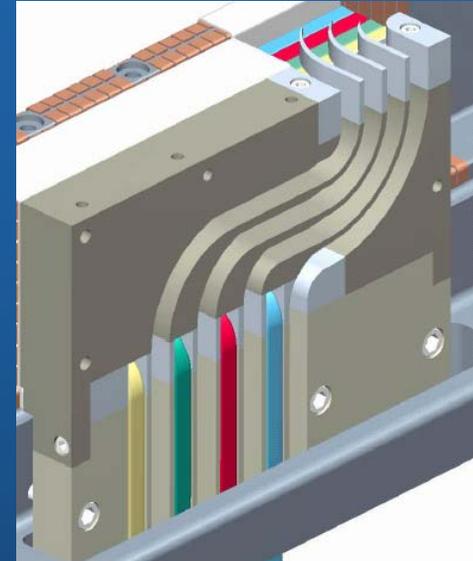
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- Conductor will be layed in place 4-in-hand
- Clamps will be removed as the conductor approaches winding form
- All winding will be performed in clean atmosphere
- Latex or cotton gloves will be required/positive pressure room
- No more than (3) adjacent clamps will be removed at any one time
- Conductors will positioned and hand set in place

# Complete Winding Side A & B

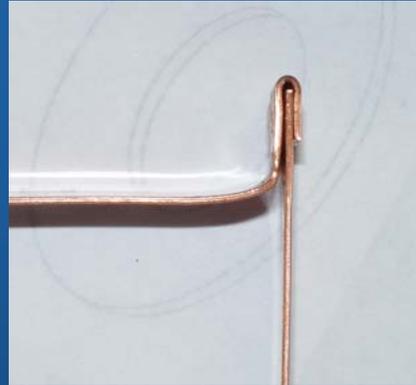
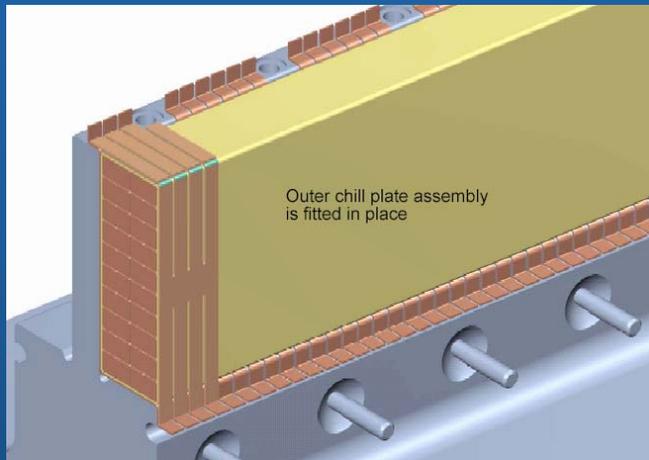
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- Complete winding side “A”
- Braze lead terminals
- Install guide blocks and secure the leads
- Rotate TRC and wind side “B”
- Complete Groundwrap insulation
- Prepare for external chill plates

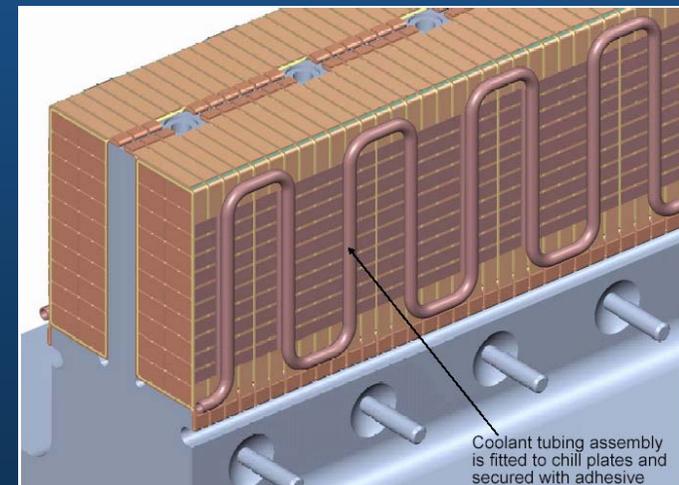


# Outer Cooling System

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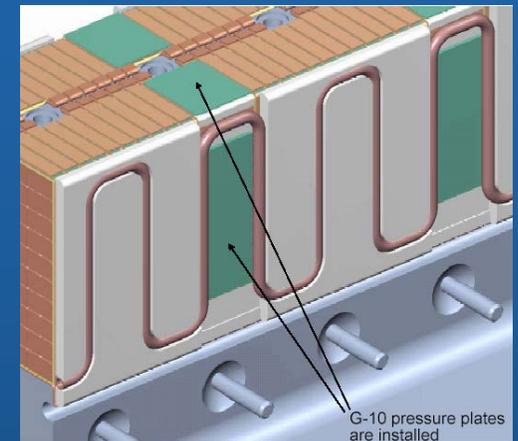
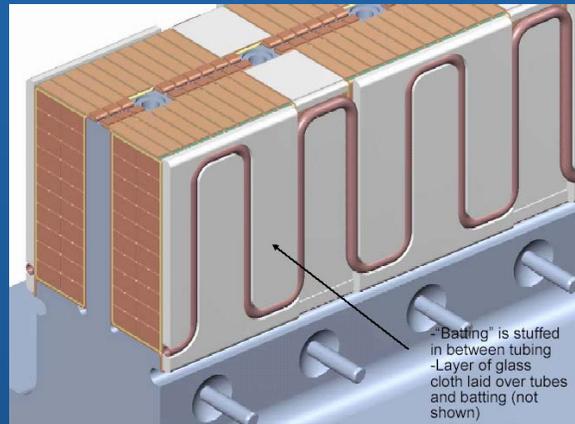
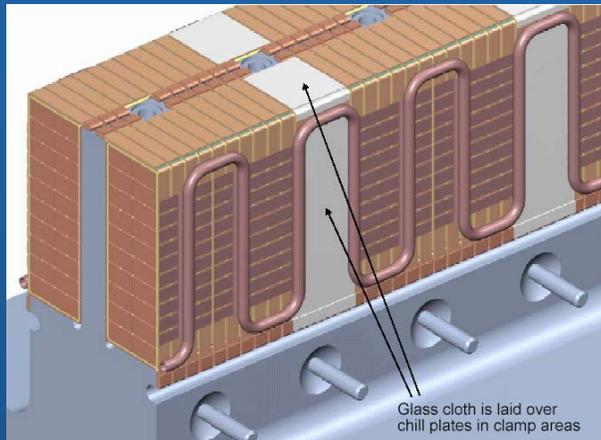


- Install outer chill plates
- Join the cladding and chill plates by staking operation
- Install outer cooling tubes
- Adhere tube assembly to chill plates using 3M adhesive

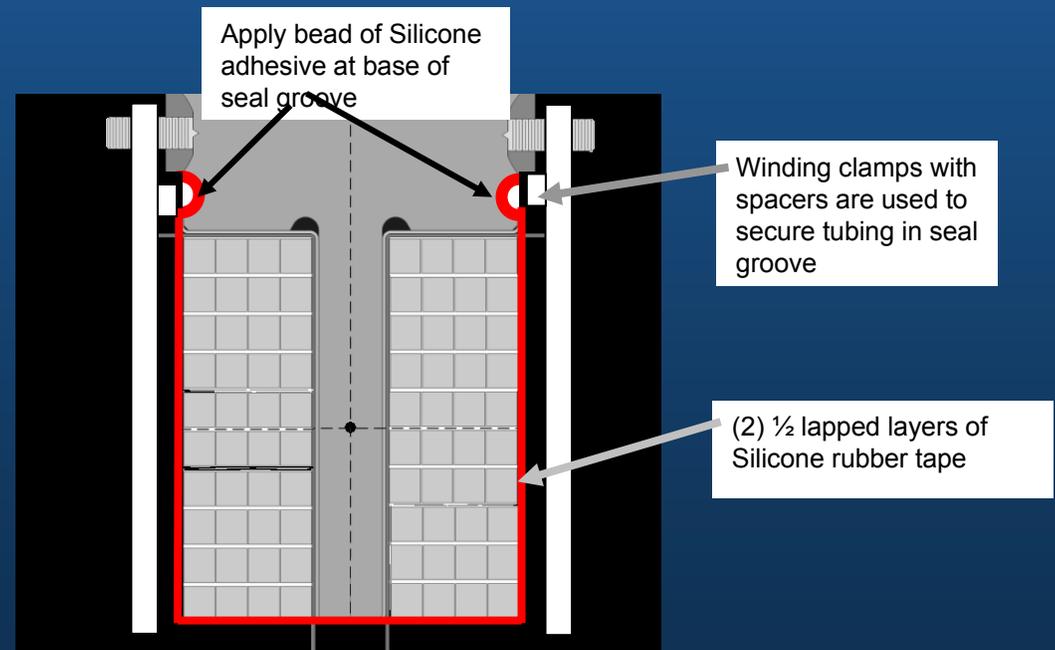


# Bag Mold

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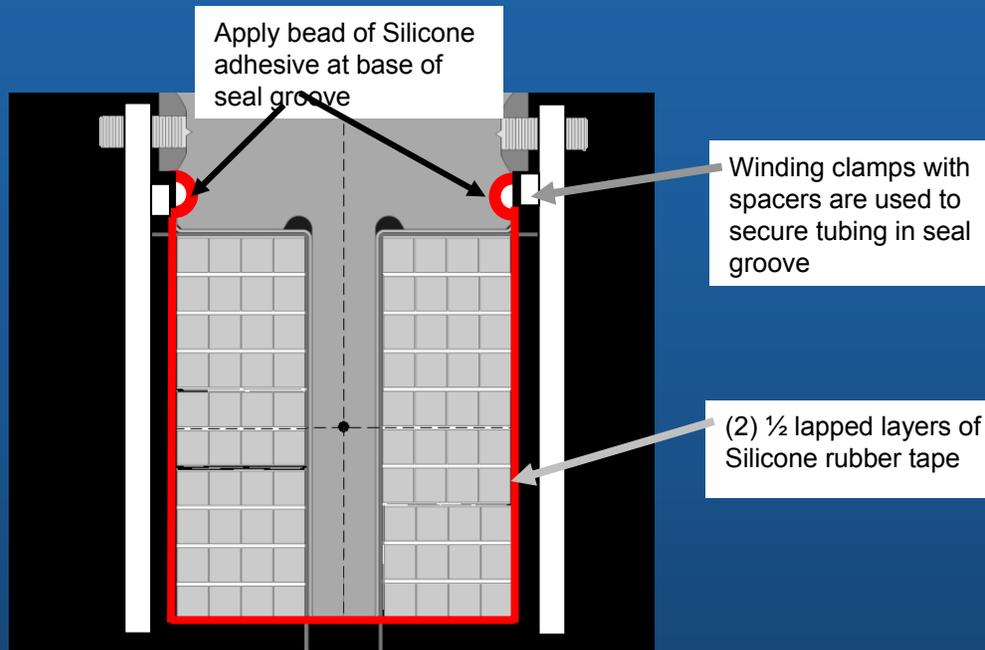


- Construction of the bag mold is completed through a series of steps



# Bag Mold-2

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-“Bag Mold” -silicone rubber tape (vacuum seal) and epoxy filled felt (side wall stiffness) is placed over the ground wrap/ chill plates.

- Bag is installed/painted with RTV 11
- Vacuum pumped down
- Apply shell felt/epoxy “French Toast” (Hysol 2039/3561)
- Secure the edges of French toast with clamps

# Vacuum-Pressure-Impregnation Station #5

NCSX



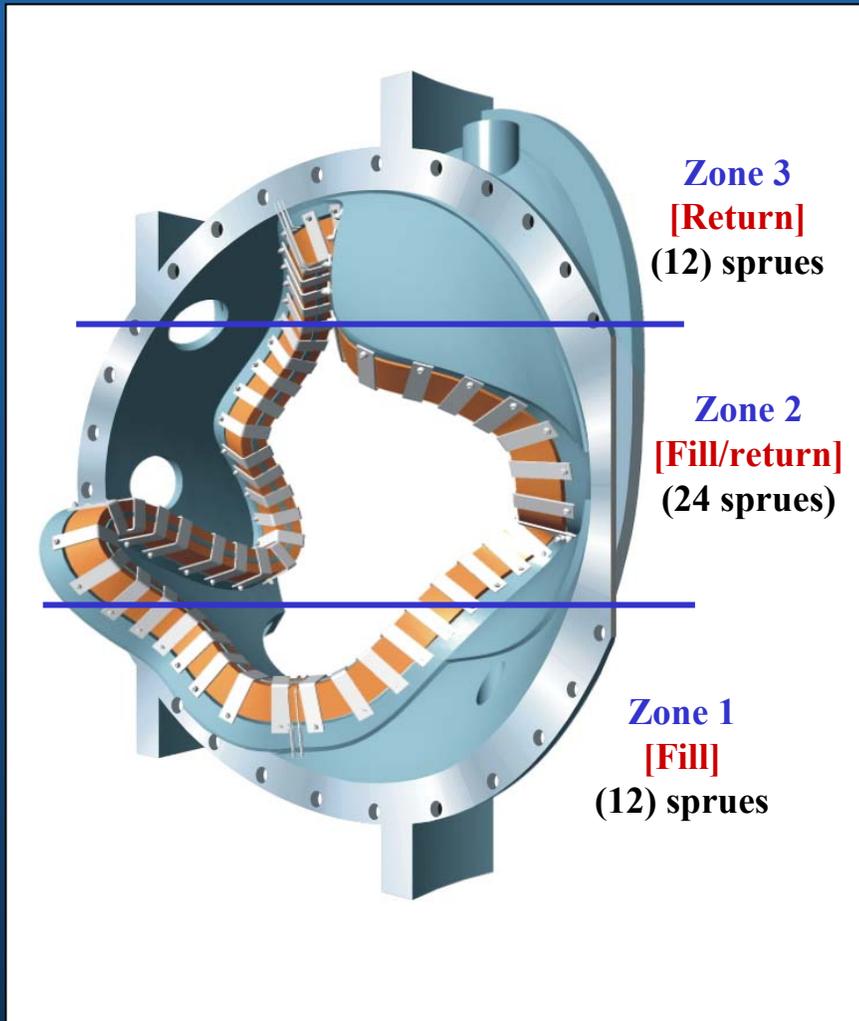
## VPI/Autoclave Activities

- Install coil in autoclave and prep for VPI
- Vacuum impregnate coil using CTD-101K

Procedure No. NCSX-PROC-MCF-005

# Vacuum-Pressure Impregnation (VPI)

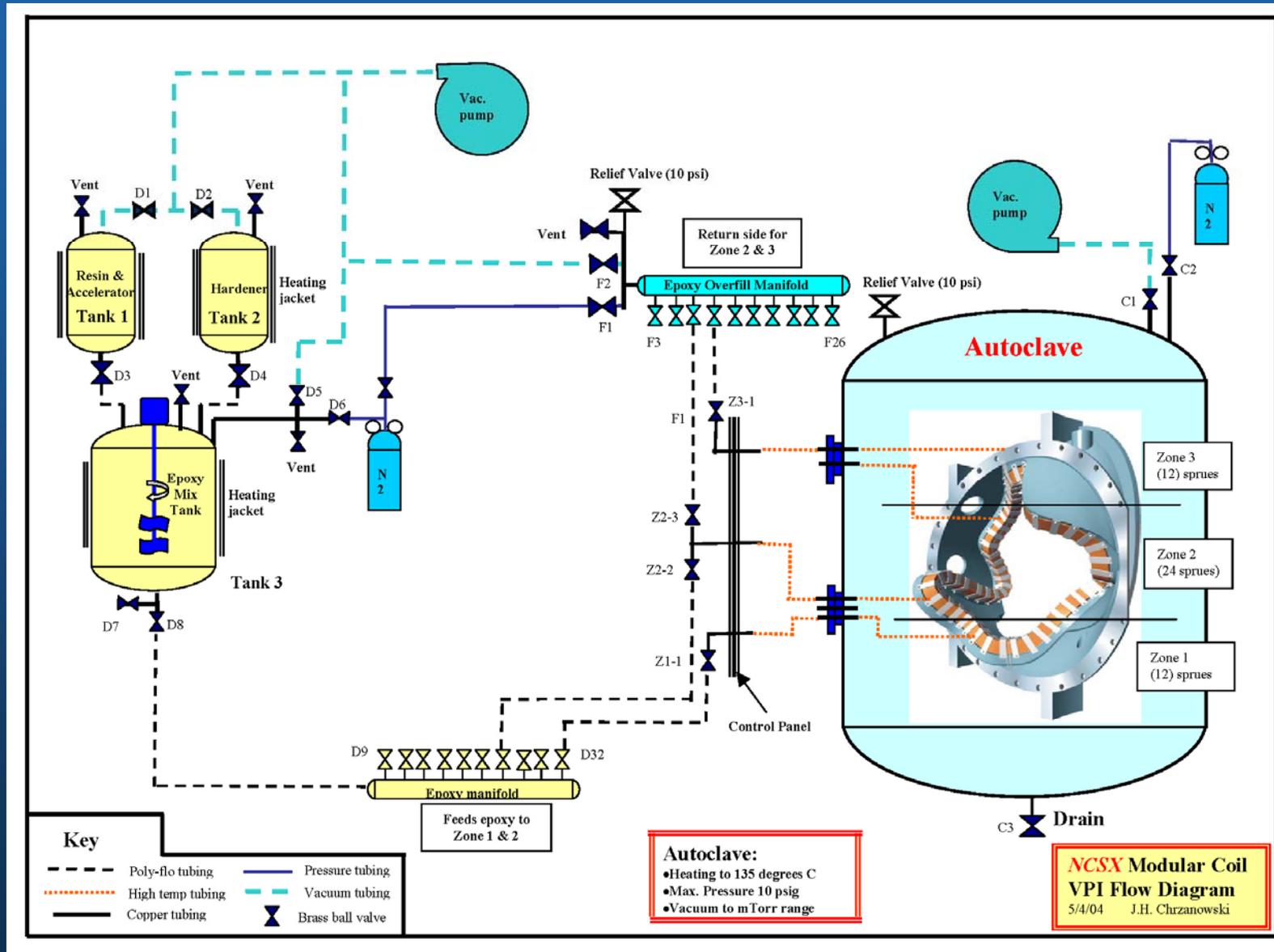
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- During the VPI process, the Modular Coil will be divided into 3 zones
  - Zone 1- supply only
  - Zone 2- supply and return
  - Zone 3- return only
- The autoclave will initially be maintained at vacuum matching the vacuum inside of the “bag mold” [minimize potential leaks]
- As the coil reaches the ½ fill mark, the autoclave atmosphere will slowly shift from vacuum to pressure (5 psig max) to support the bag mold
- Once filled, autoclave will return to atmospheric pressure prior to beginning the ramp up of temperature to cure the epoxy

# Modular Coil VPI Flow Diagram

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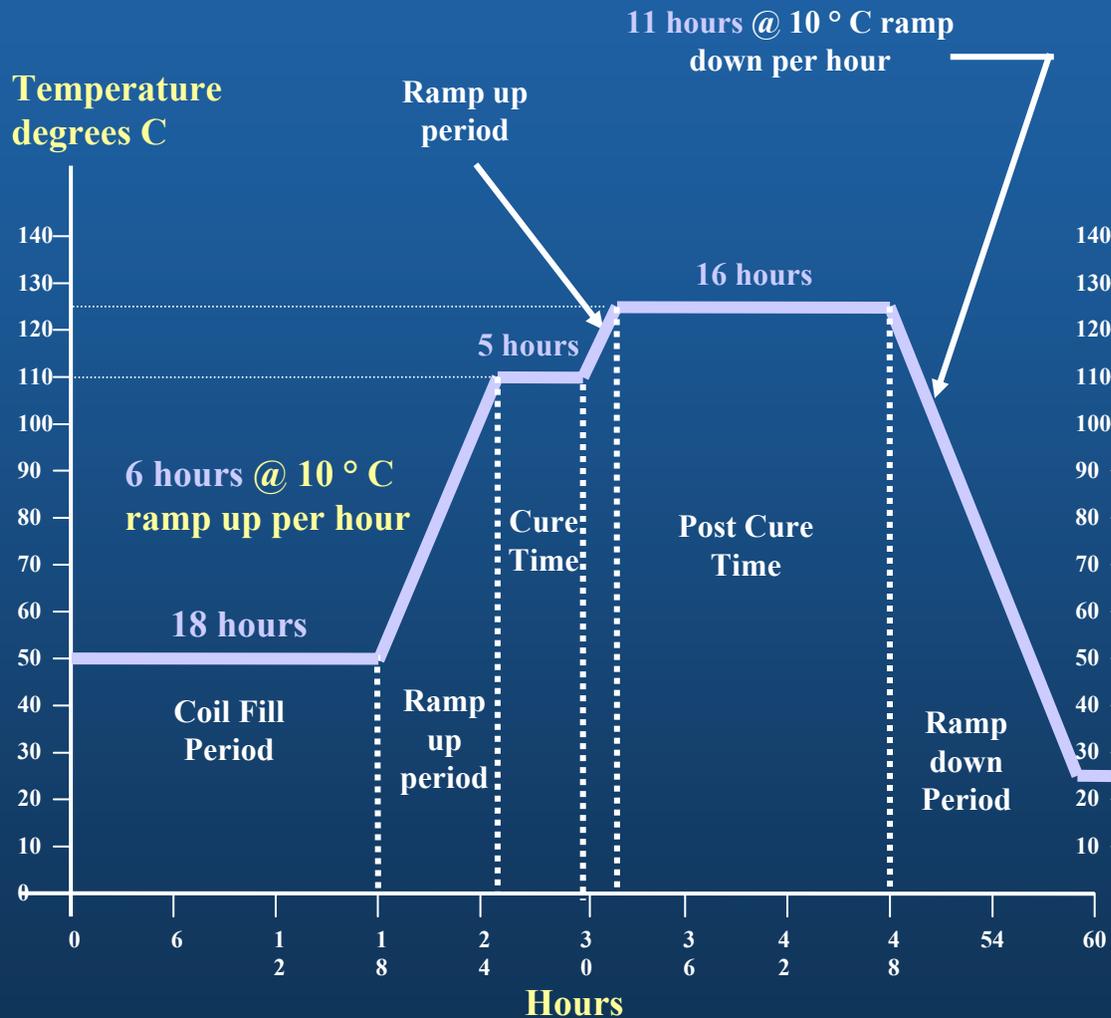


# NCSX MODULAR COIL VPI CYCLE

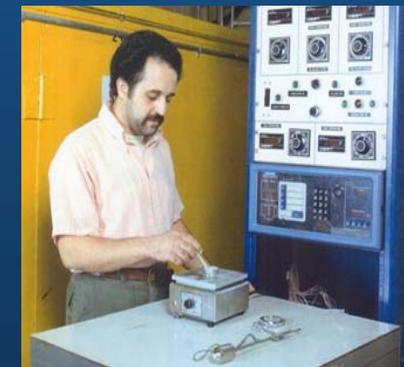
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Epoxy component mixing



Viscosity measurements

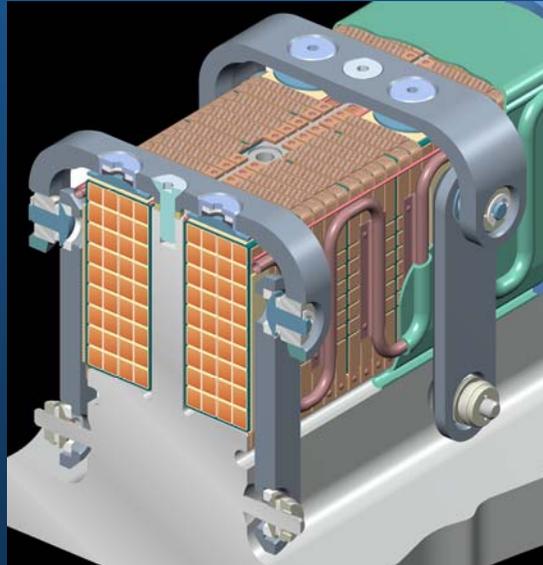


"Scrambled Egg" test to verify Gel temperature

# *Post VPI Activities*

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- Remove the impregnated TRC from the autoclave and reinstall in station #2.
- Remove the temporary clamps and install the final coil clamps
- Transfer the TRC to the test facility for final testing
- Dissect coil following all testing to inspect epoxy impregnation and conductor locations.



# Twisted Racetrack Coil- Schedule

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## Job: 1410 MC Twisted Racetrack Fabr-CHRZANOWSKI

### Twisted Racetrack Hardware Fabrication (Chrzano

1406-016.0	Oversight & Supervision	01NOV04*	121*	29APR05
1406-016.6	PPPL Fabricate TRC Chill plates	05NOV04*	40	12JAN05
1406-016.7	PPPL Fabricate TRC Tubing	05NOV04*	40	12JAN05
1406-016.1	Inspect & Measure Casting	01OCT04*	20	28OCT04
1406-017	Prep TRC casting & Instl cladding(station 2)	29OCT04	15	18NOV04
1406-017.1	Instl grnd wrap & wind coil(station 2)	19NOV04	30	12JAN05
1406-017.2	Instl chill plates & tubing (station 2)	13JAN05	20	09FEB05
1406-017.3	Complt Assy of twisted racetrack. (Joule milestone		0	09FEB05
1406-018	Apply bag mold (station 4)	10FEB05	20	09MAR05
1406-ST1	Fab Straight Tee Specimen	11OCT04*	10	22OCT04
1406-ST2	Straight Tee VPI Prep	25OCT04	10	05NOV04
1406-ST3	VPI Tee Specimen	08NOV04	10	19NOV04
1406-019	VPI TRC in autoclave	10MAR05	20	06APR05
1406-019.1	Instl permanent clamps	07APR05	10	20APR05
1406-020	Begin Testing of Twisted RT in Coil test Stand	21APR05	0	
1406-021	Test Coil	21APR05	5	27APR05
1406-023	Dissect Coil	28APR05	5	04MAY05

# Summary- Completions

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- The equipment and winding station is in place
  - Autoclave has completed its PTP
  - ACC review held this morning
  - Completed Preliminary Hazard Analysis of facility
- Developed Operations Plan and MIT
- Procedures are nearly complete and ready for formal review
- The parts necessary to begin are available
- Ready to begin TRC fabrication