Fabrication of the Twisted Racetrack Coil

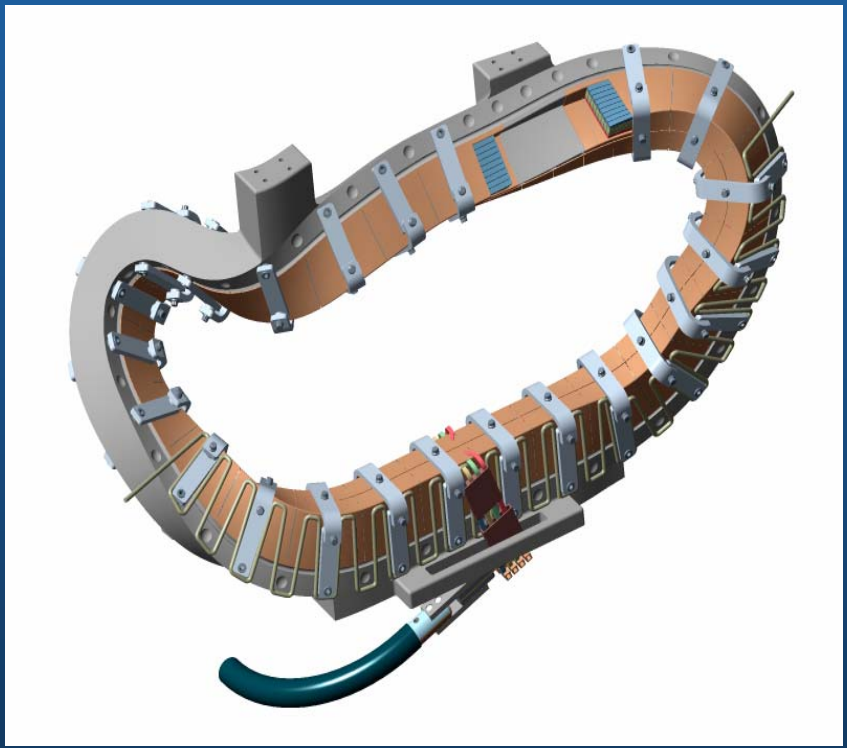
J. Chrzanowski
and the NCSX Team

NCSX Final Design Review
for Twisted Racetrack Coil

NCSX R&D – Safety is Integrated in All Aspects

- 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

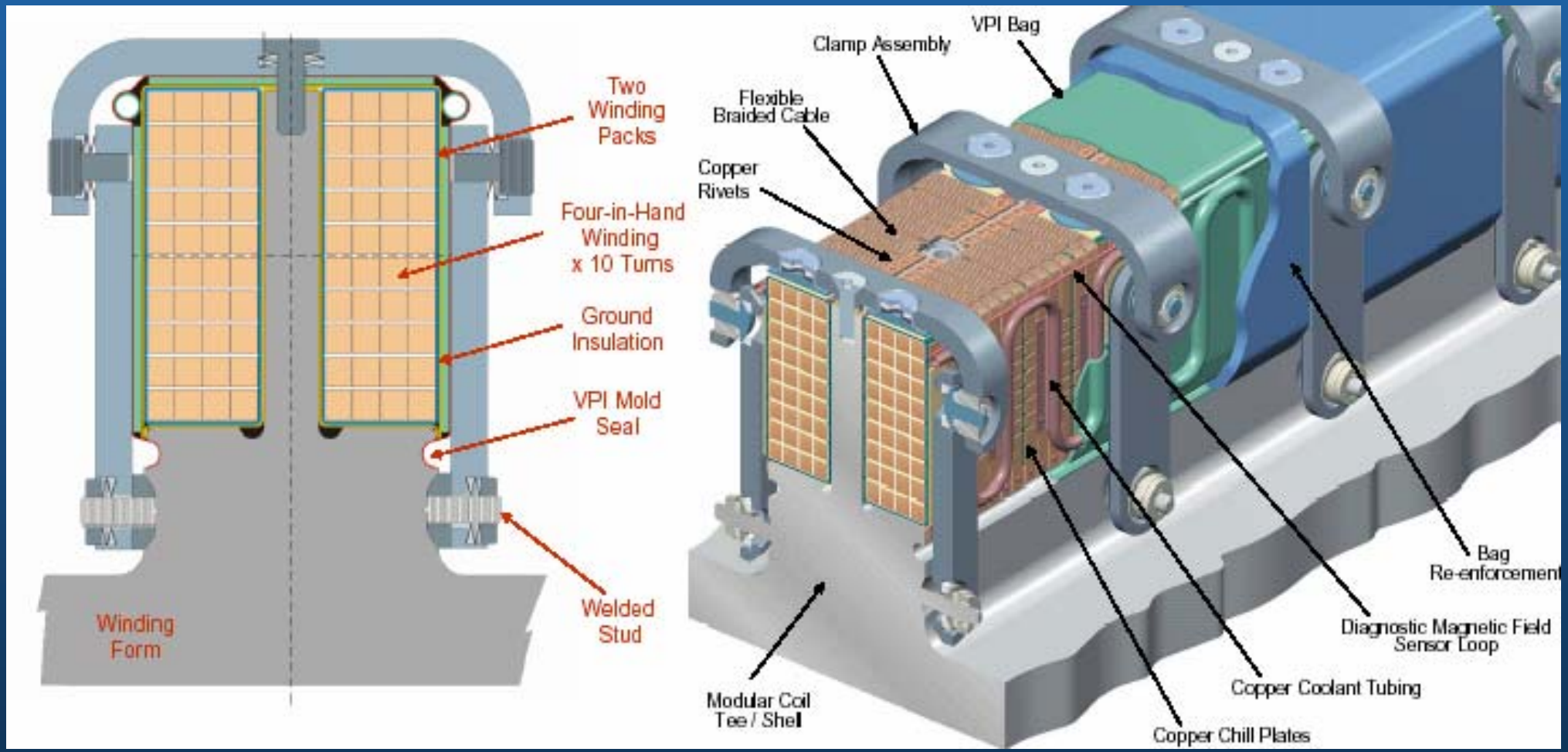
Twisted Racetrack Shaped Coil



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

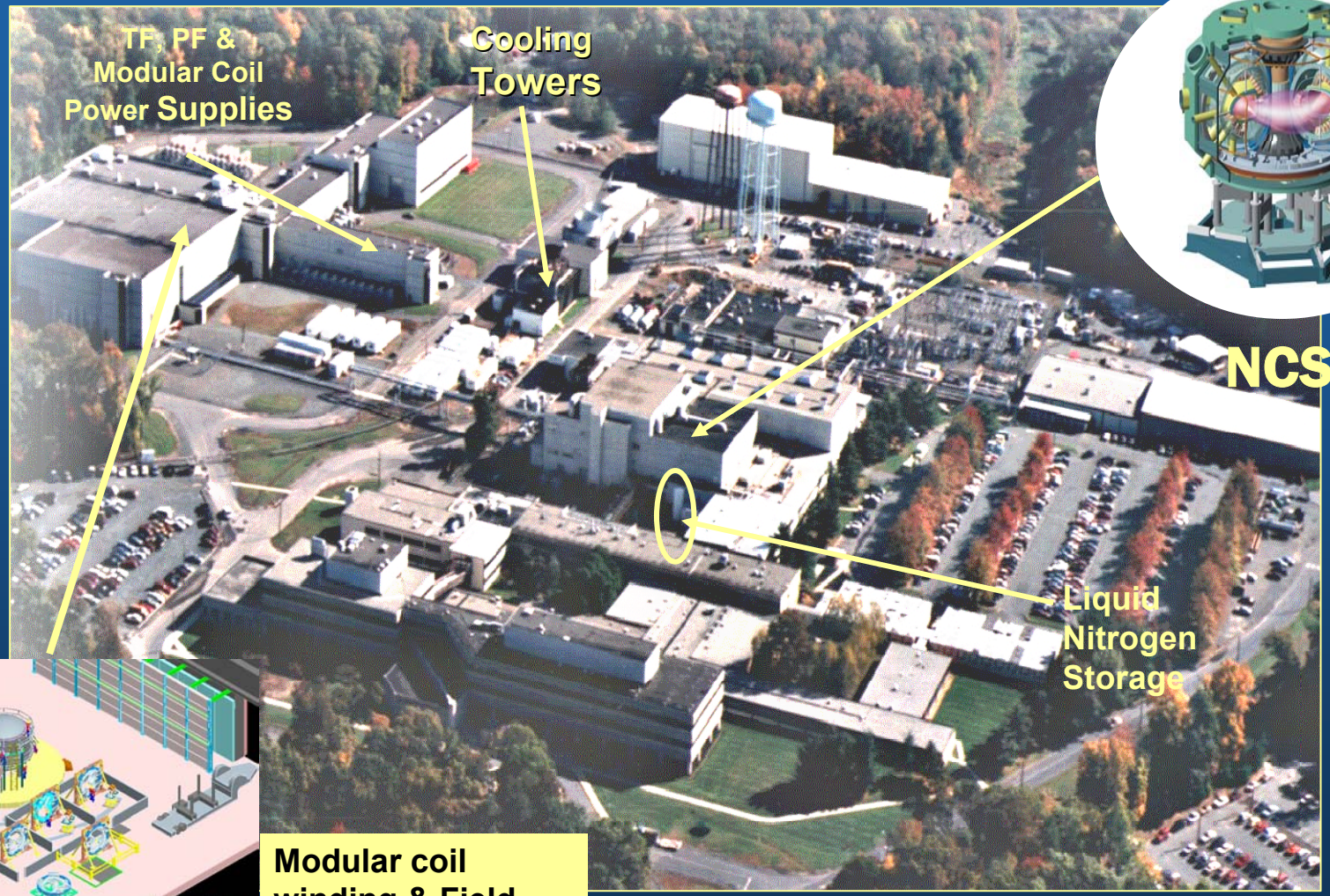


Copper Rope Conductor

- **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 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

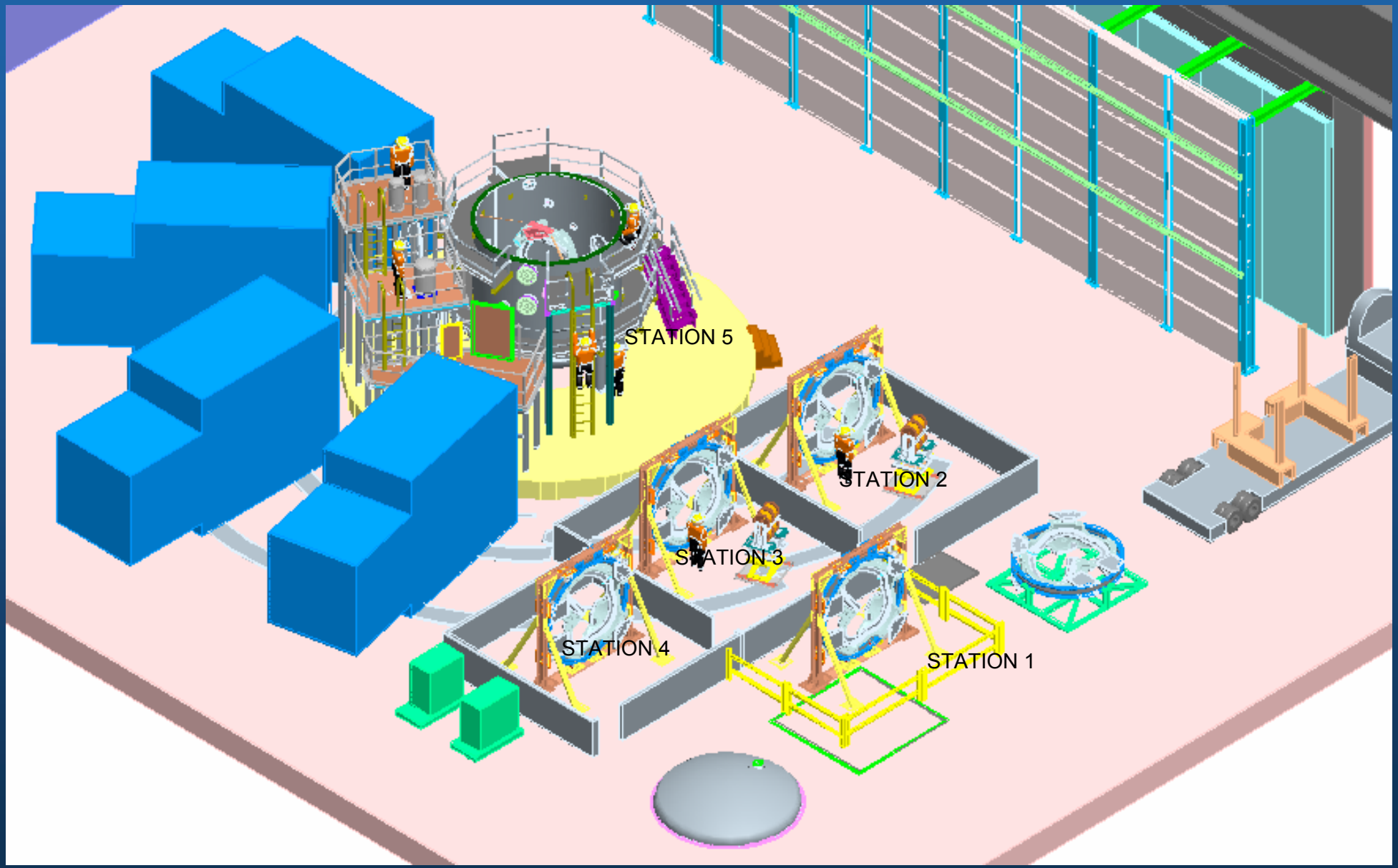
- **Turn Insulation:**
  - Conductor will be insulated with (1) half-lapped layer of nominal 0.004 in. thick S-2 fiberglass tape [0.004 in. center and 0.007 in. at edge- average build = 0.0055 in.]

Modular Coil Fabrication



Modular coil winding & Field Period assy. area

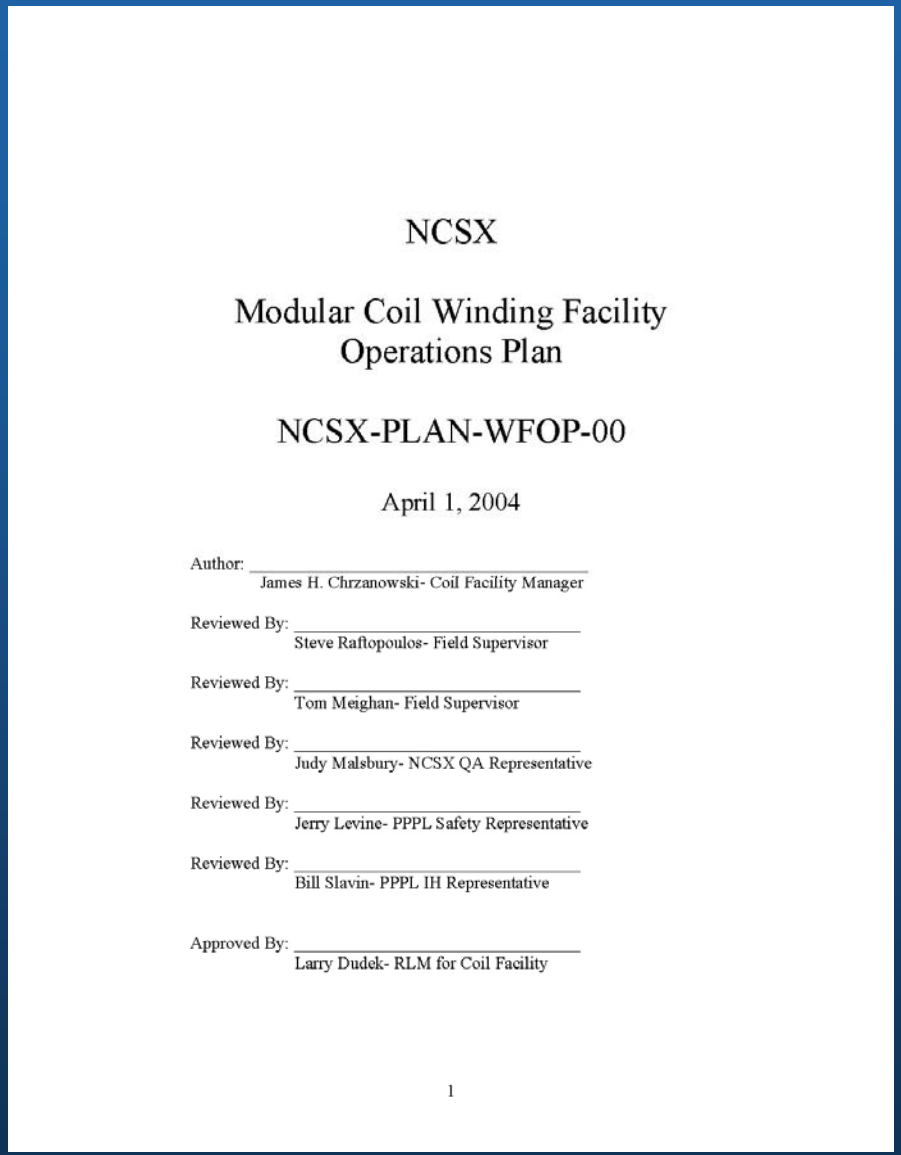
Modular Coil Manufacturing Facility



Modular Coil Fabrication

- 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



NCSX

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

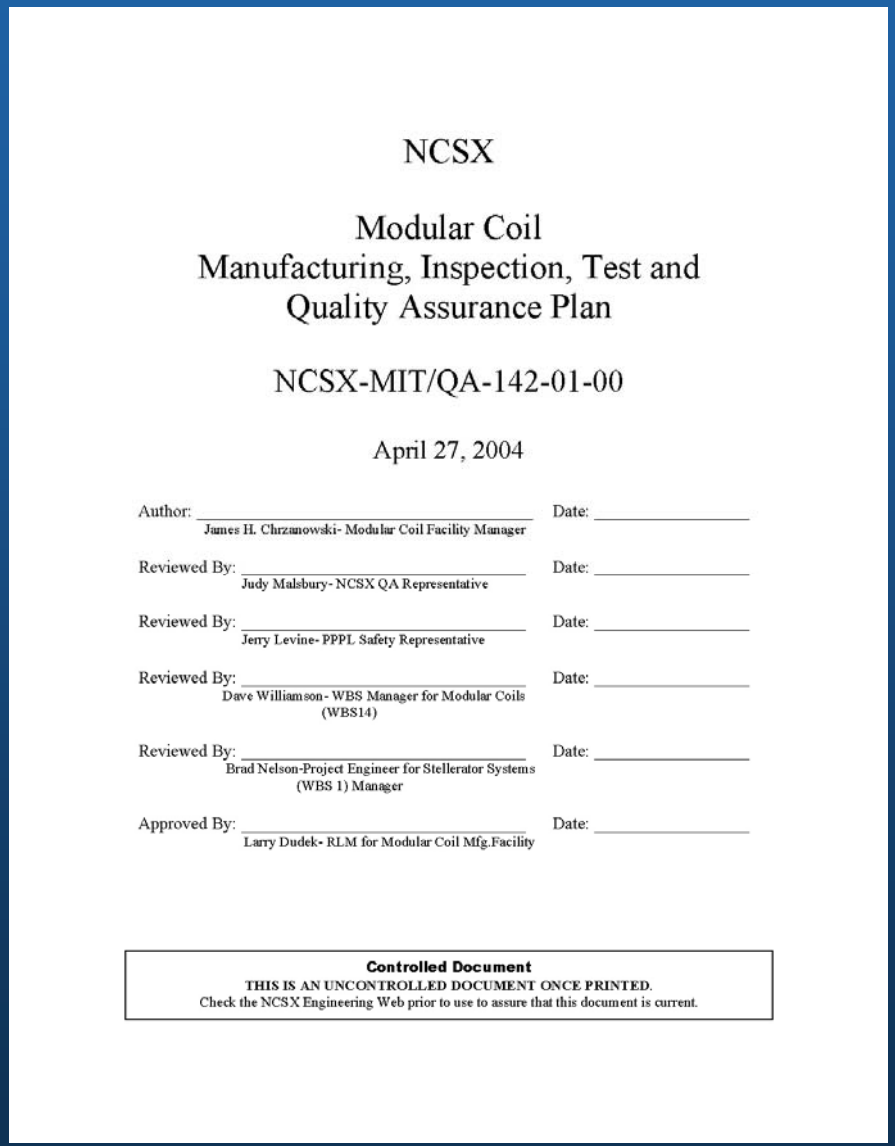
Reviewed By: _____
Bill Slavin- PPPL IH Representative

Approved By: _____
Larry Dudek- RLM for Coil Facility

1

- 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



NCSX

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.

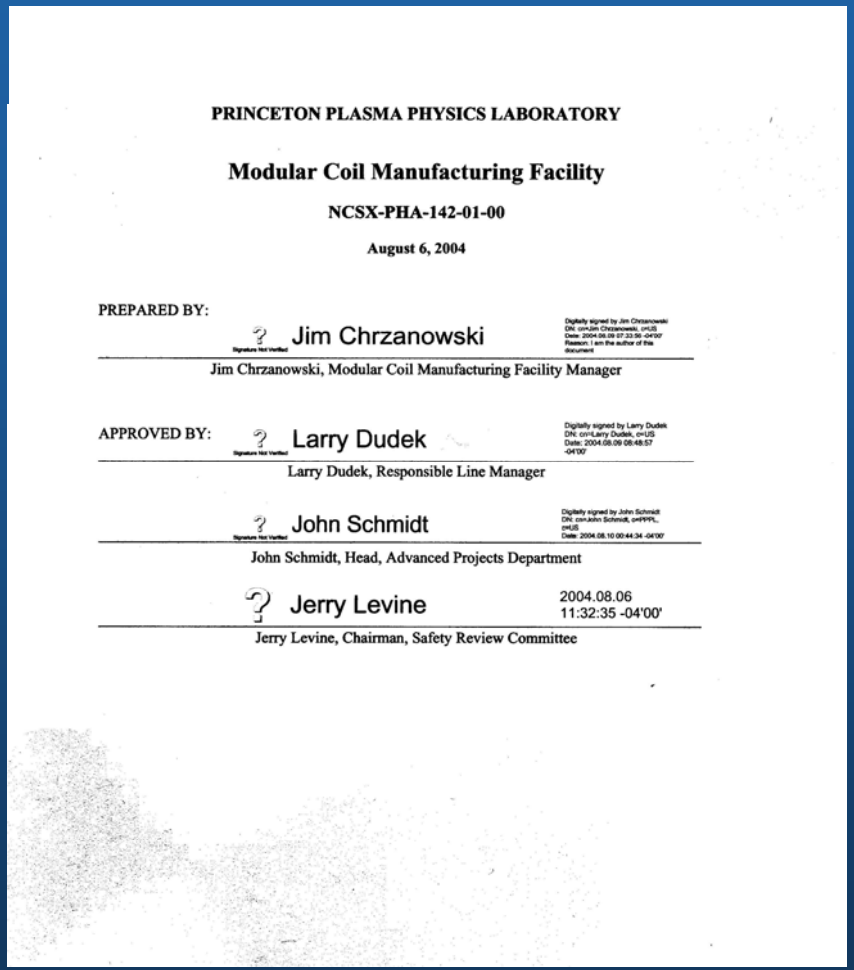
- MIT Plan has been written and reviewed.
- Document will be used during the manufacturing of the Twisted Racetrack Coil, modified and approved for the production coils
- The MIT in conjunction with procedures will dictate the manufacturing process

Manufacturing Documents

- 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

NCSX



PRINCETON PLASMA PHYSICS LABORATORY

Modular Coil Manufacturing Facility

NCSX-PHA-142-01-00

August 6, 2004

PREPARED BY:

Jim Chrzanowski

Jim Chrzanowski, Modular Coil Manufacturing Facility Manager

APPROVED BY:

Larry Dudek

Larry Dudek, Responsible Line Manager

John Schmidt

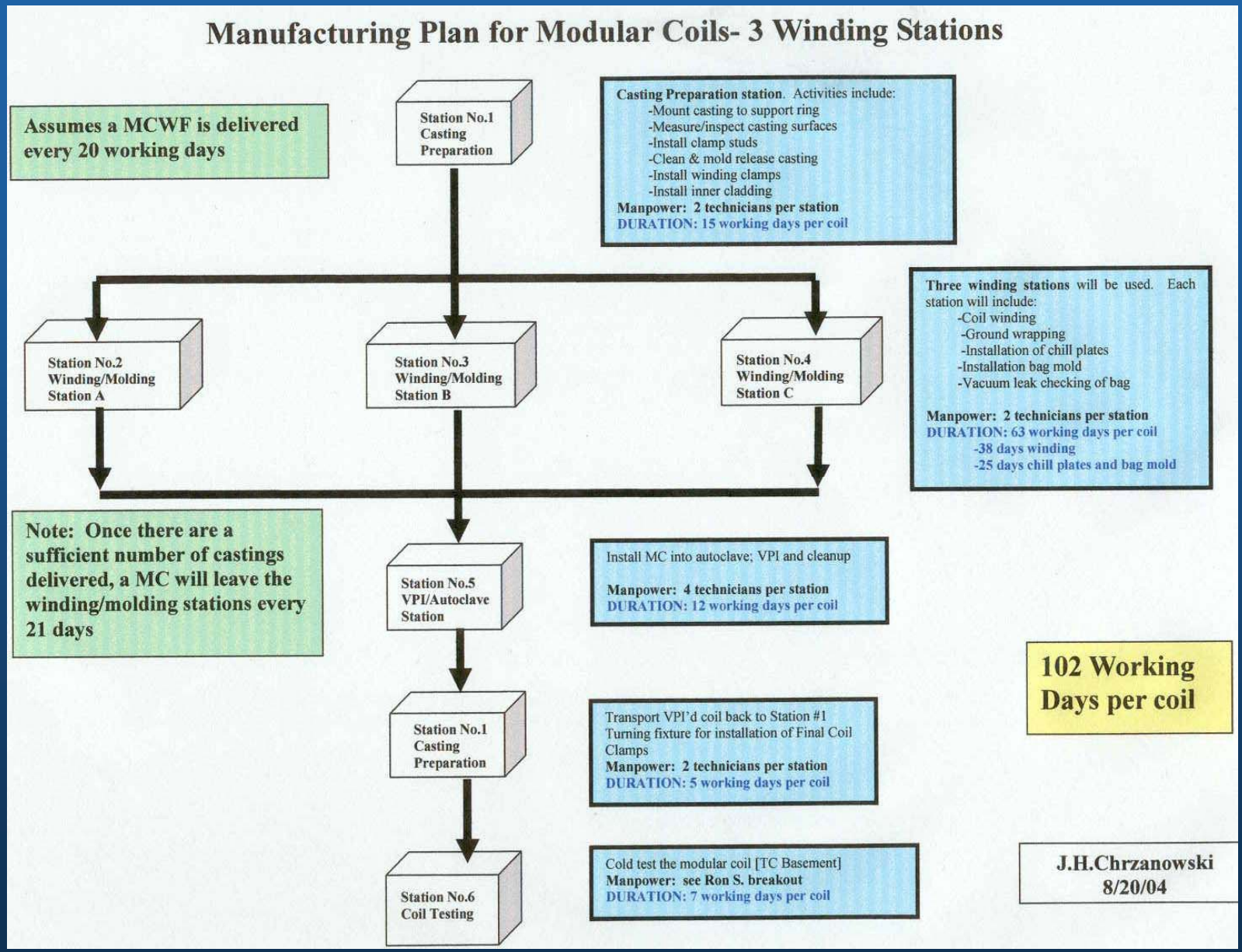
John Schmidt, Head, Advanced Projects Department

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



MCWF Clean Rooms

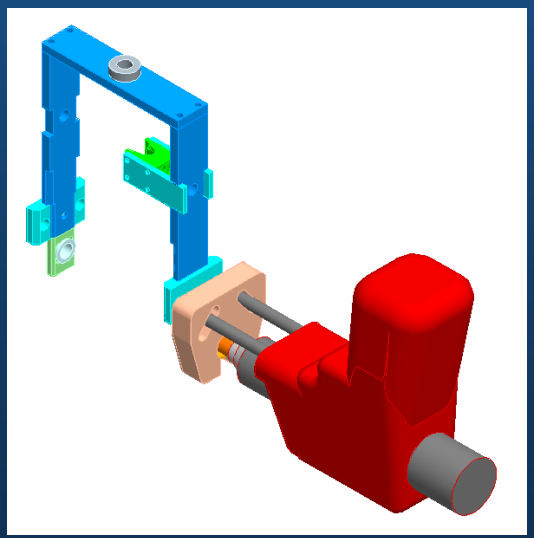
- The winding and mold stations will be located in enclosed rooms where cleanliness can be controlled.
- Three clean rooms were constructed.
- Modular coils will be positioned in the rooms via a sliding roof panel.
- Positive pressure rooms for maintaining cleanliness
- Smoke detectors in each of the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

Metrology

- 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 1st. Layer – "Romer" mechanical arm - shim
  - After 4rd. Layer - "Romer" mechanical arm - shim
  - After 7th. Layer - "Romer" mechanical arm - shim
  - After final layer- "Romer" mechanical arm and scanner

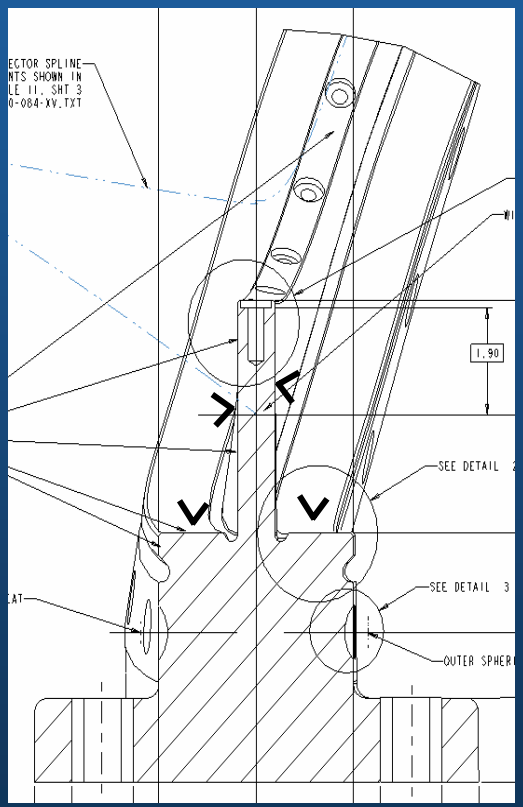
Casting Preparation

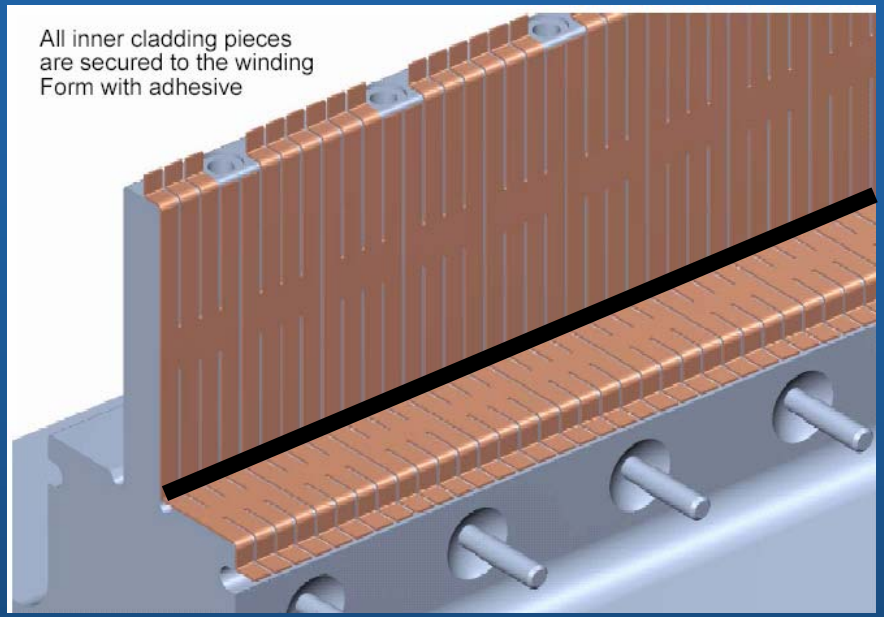
- TRC casting is mounted into the turning fixture
- Perform visual inspection
- Clean all tapped holes
- Using "Romer" scanner, measure winding surfaces
- Install weld studs
- Clean winding form



Casting Preparation-2

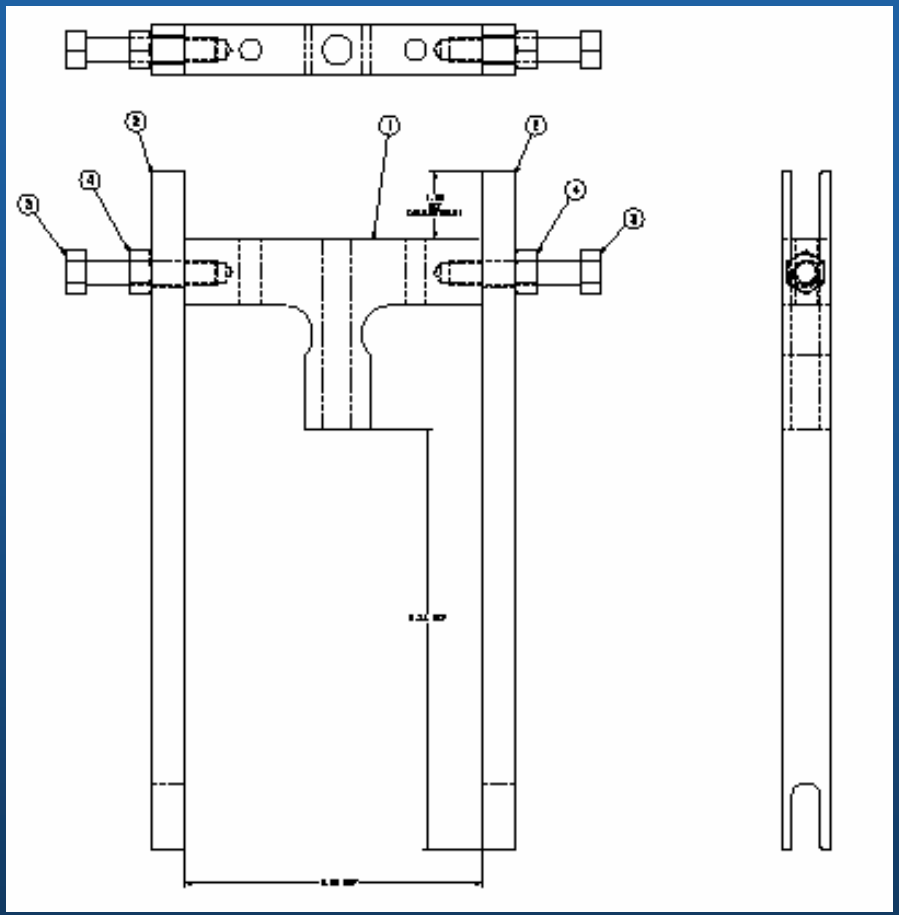
- Mold release winding surfaces





- 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

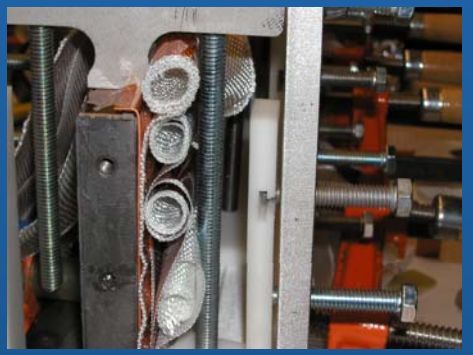
Winding Clamps

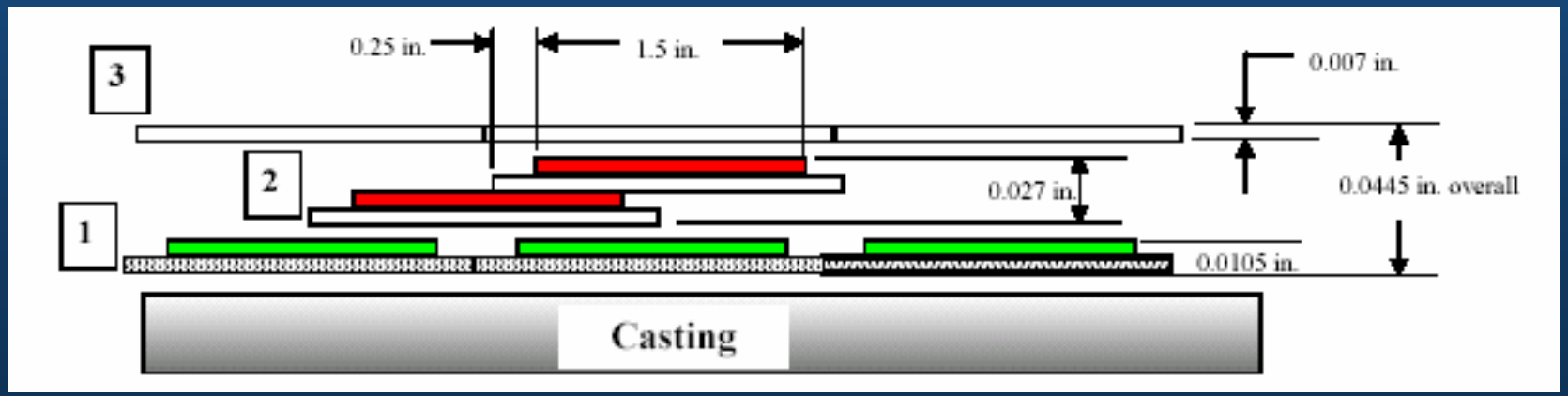


- Install winding clamps using upper tapped holes and studs
- Winding clamps will allow minimal re-clamping operations during winding
- Same clamps will be used during VPI

Ground Wrap Insulation

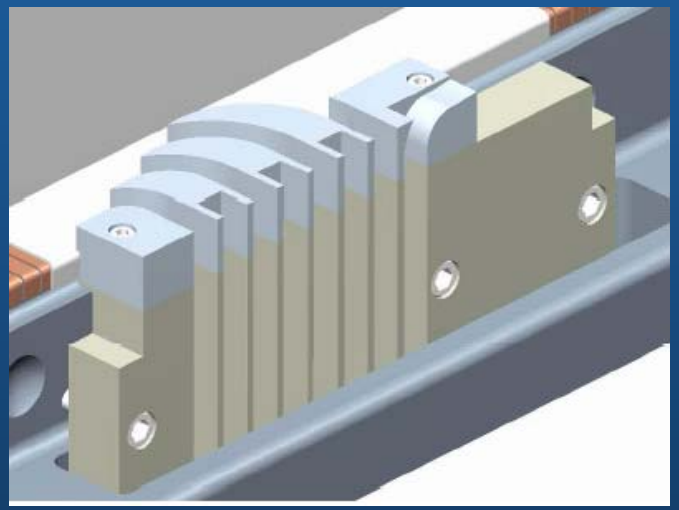
- **Layer 1 (Inner):**
- Apply (1) Butt lapped layer of composite insulation
- 0.007 inch thick S-2 glass [nominal 2 inch wide]
- 0.0035 (HN) Kapton tape [nominal 1.5 inch wide] with adhesive back
- **Layer 2 (Mid):**
- Apply (1) half-lapped layer of composite insulation:
  - 0.007 in. thick glass [2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





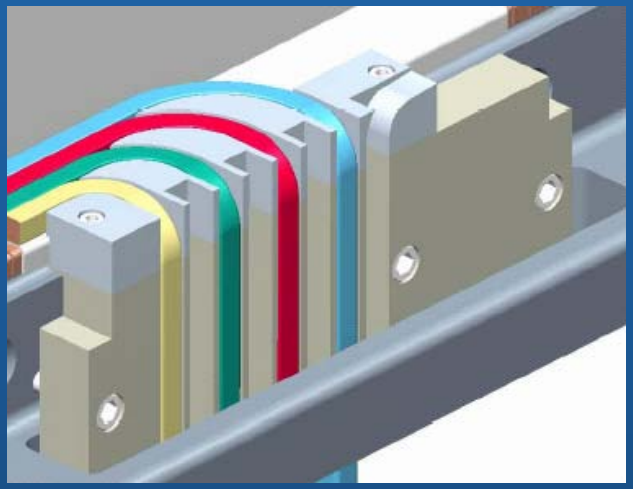
Lead Preparation

- 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

- Insulate and position the leads in the lead guide block



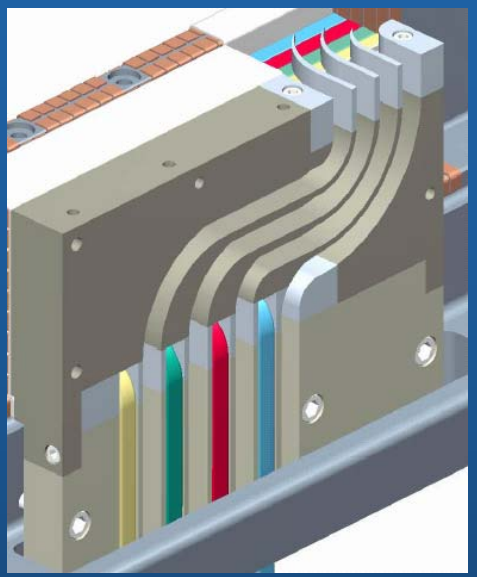
- Begin winding operation with copper conductor being fed from (4) pre-insulated copper spools

General Winding Notes

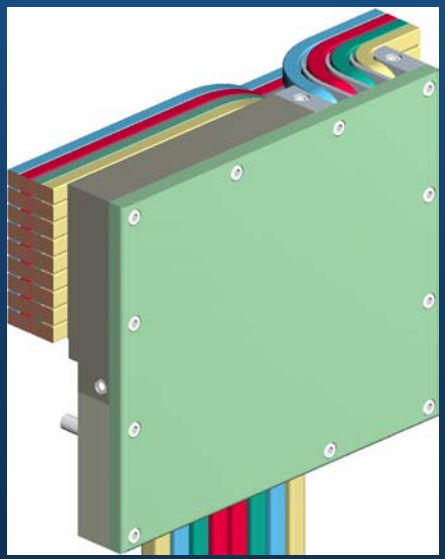
- Conductor will be layed in place 4-in-hand
- Clamps will be removed as the conductor approaches winding form
- All winding will be performed in clean atmosphere
- Latex or cotton gloves will be required/positive pressure room
- No more than (3) adjacent clamps will be removed at any one time
- Conductors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

Complete Winding Side A & B

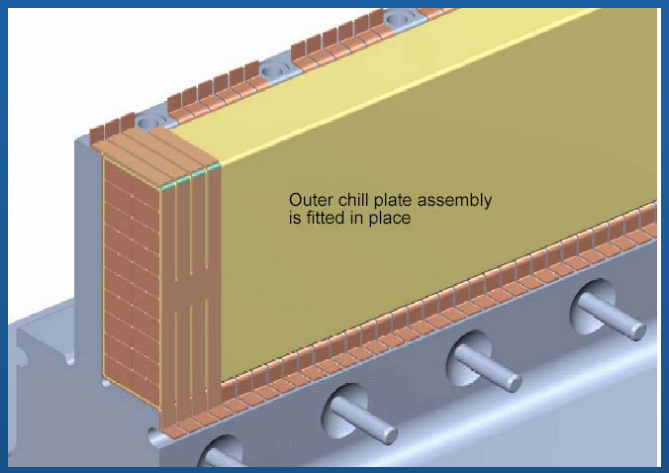
- Complete winding side “A”
- Braze lead terminals
- Install guide blocks and secure the leads
- Rotate TRC and wind side “B”

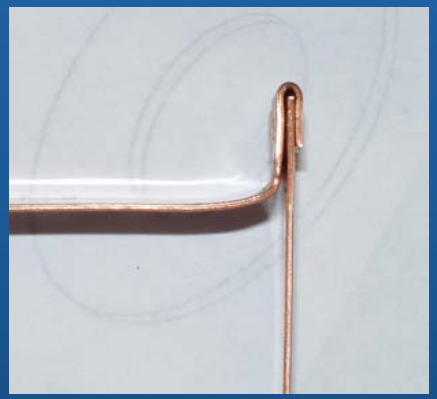


- Complete Groundwrap insulation
- Prepare for external chill plates

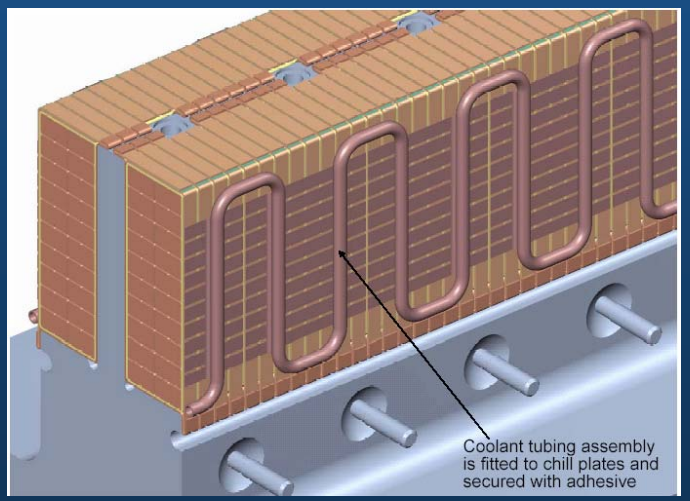


Outer Cooling System

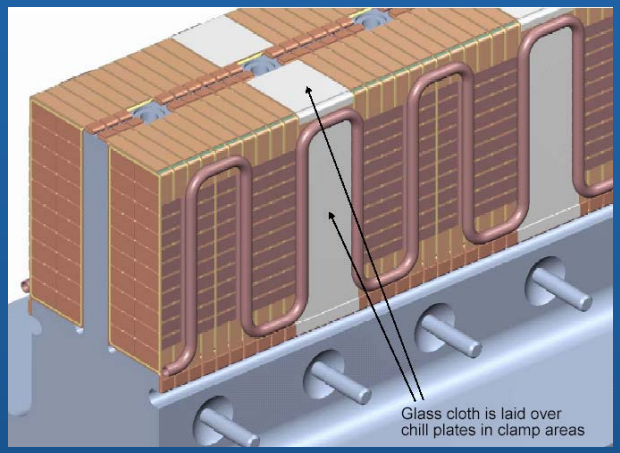


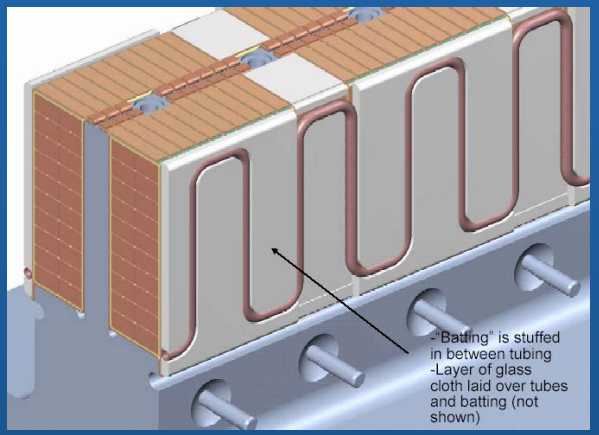


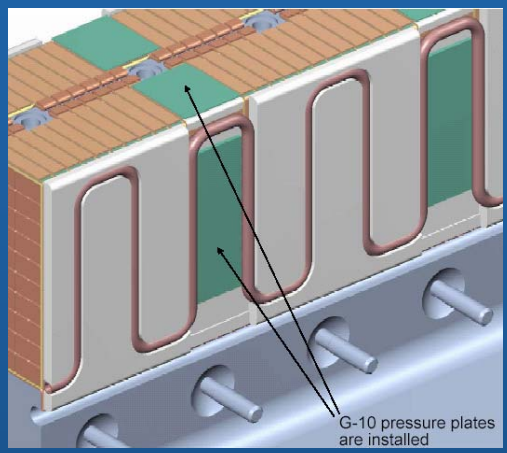
- Install outer chill plates
- Join the cladding and chill plates by staking operation
- Install outer cooling tubes
- Adhere tube assembly to chill plates using 3M adhesive



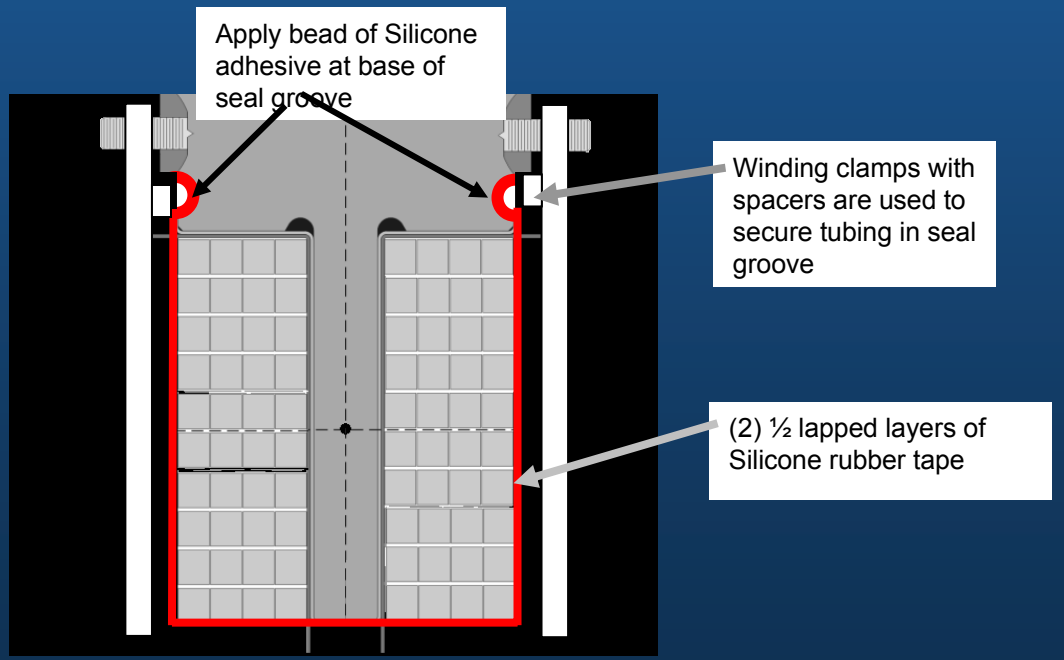
Bag Mold



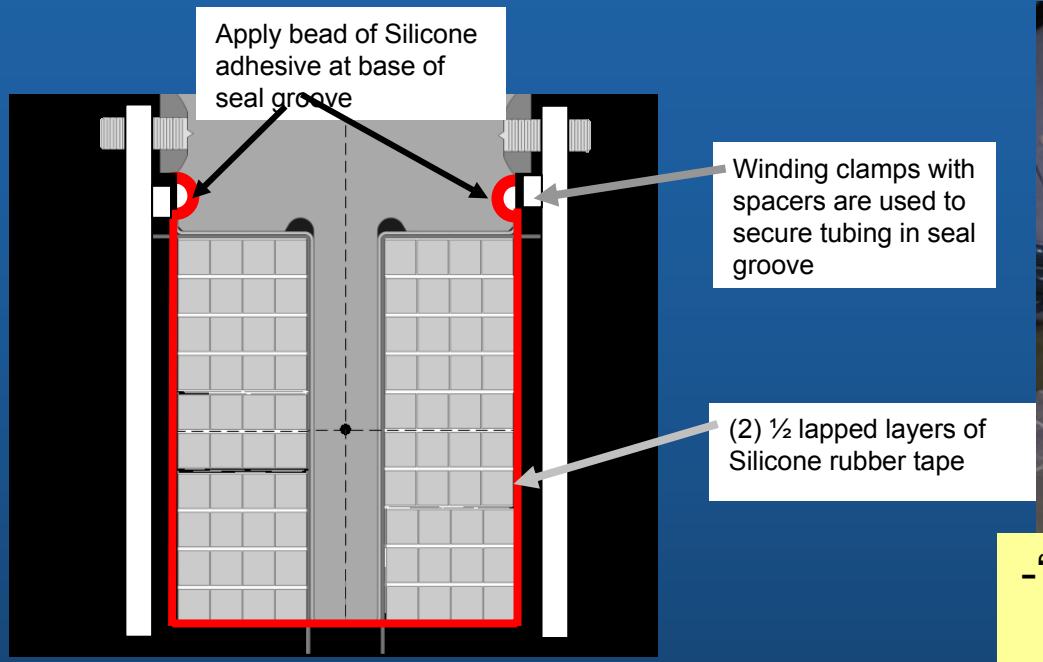




- Construction of the bag mold is completed through a series of steps



Bag Mold-2



-"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

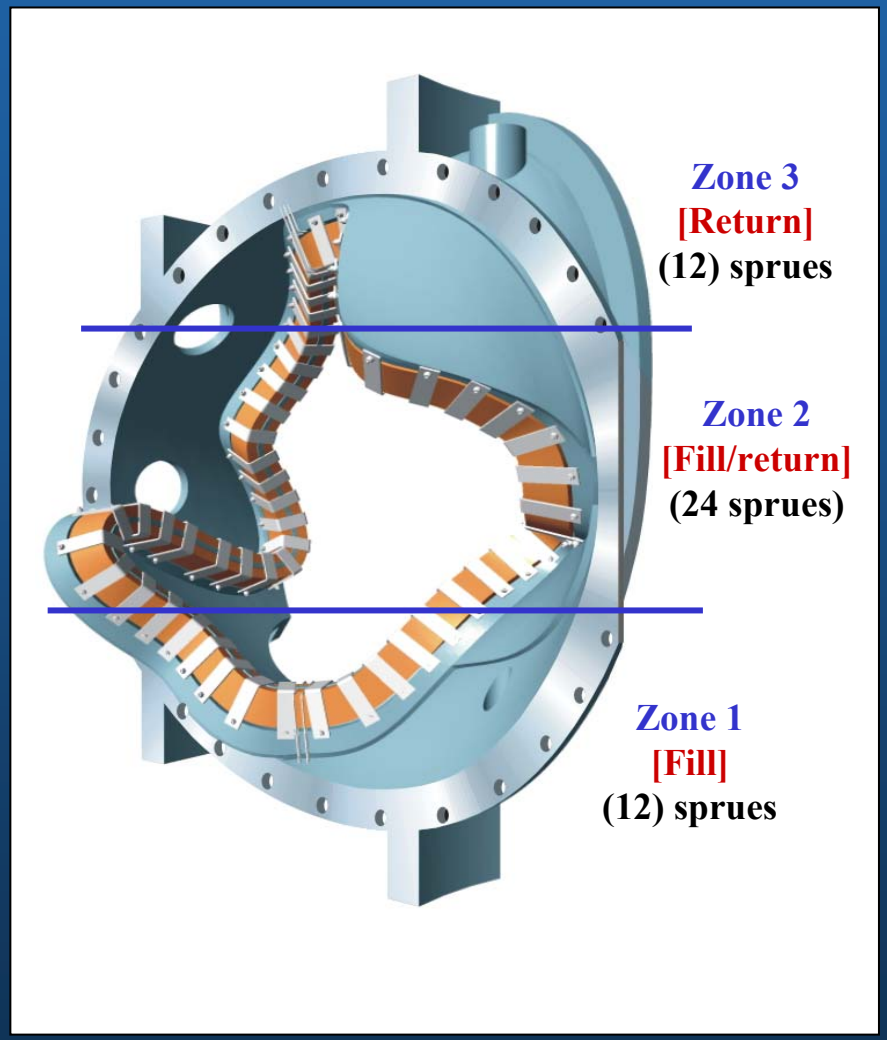
VPI/Autoclave Activities

-Install coil in autoclave and prep for VPI

-Vacuum impregnate coil using CTD-101K

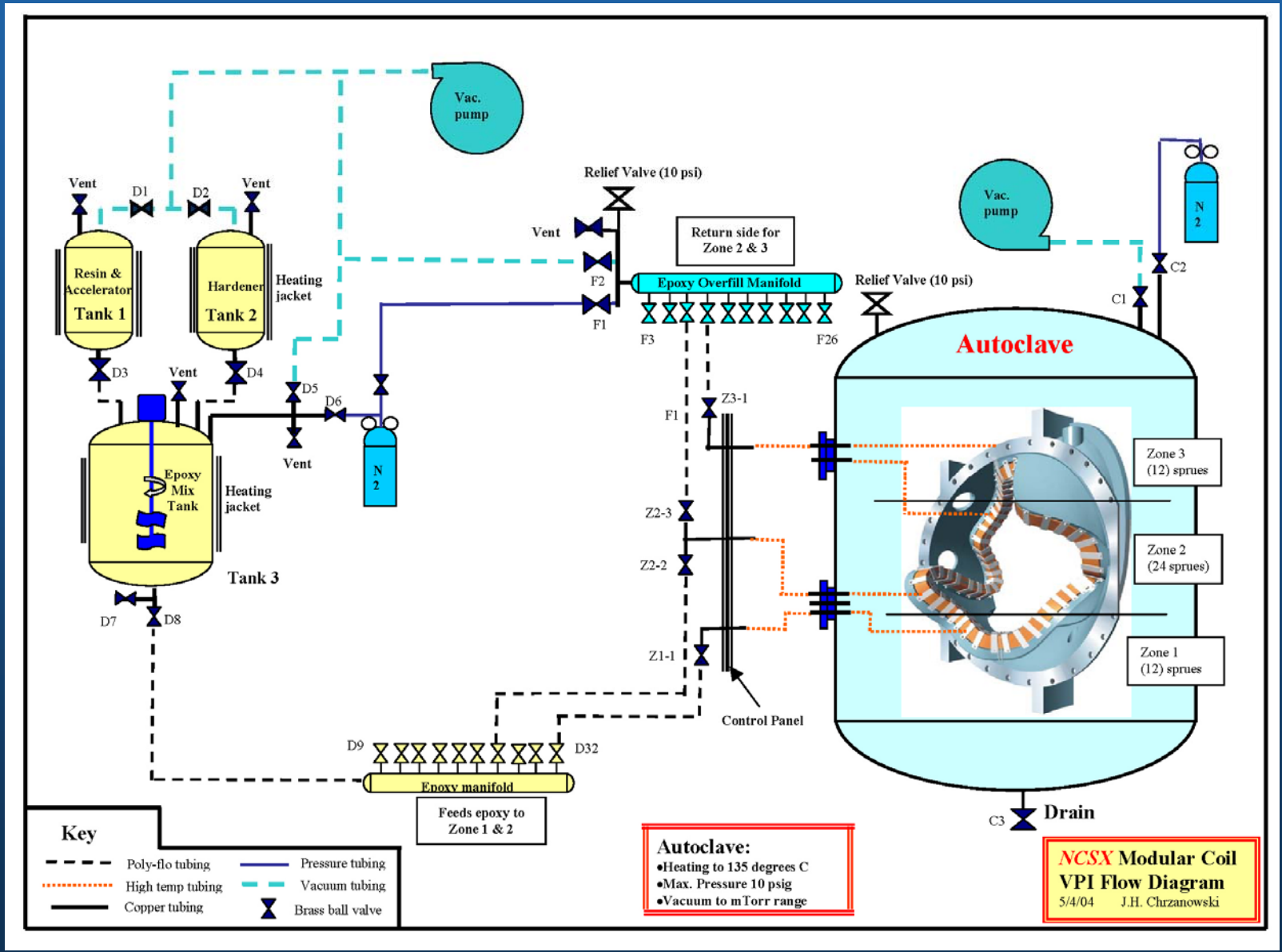
Procedure No. NCSX-PROC-MCF-005

Vacuum-Pressure Impregnation (VPI)



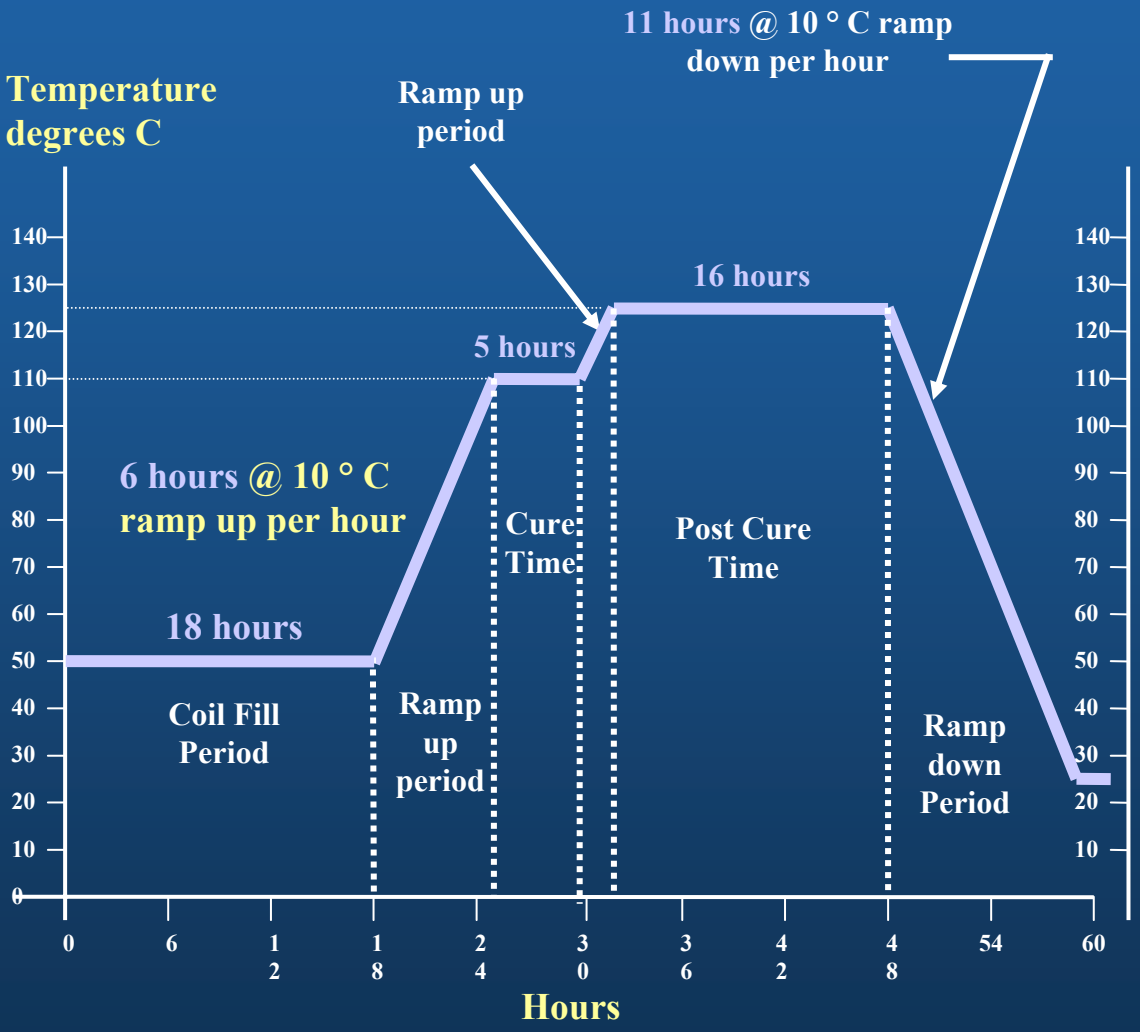
- During the VPI process, the Modular Coil will be divided into 3 zones
  - Zone 1- supply only
  - Zone 2- supply and return
  - Zone 3- return only
- The autoclave will initially be maintained at vacuum matching the vacuum inside of the "bag mold" [minimize potential leaks]
- As the coil reaches the 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



NCSX MODULAR COIL VPI CYCLE

Epoxy component mixing

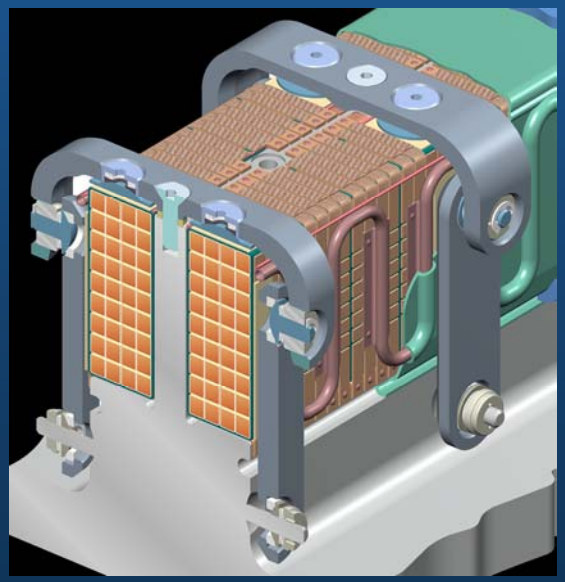


Viscosity measurements

"Scrambled Egg" test to verify Gel temperature

Post VPI Activities

- 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

NCSX

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 Chll 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 & Insll cladding(station 2)	29OCT04	15	18NOV04
1406-017.1	Insll grnd wrap & wind coil(station 2)	19NOV04	30	12JAN05
1406-017.2	Insll chll plates & tubing (station 2)	13JAN05	20	09FEB05
1406-017.3	Cmplt 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	Insll 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

- 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