

Modular Coil Winding Fabrication

**J. Chrzanowski
and the NCSX Team**

**NCSX Final Design Review
for Modular Coil Winding Form**

Presentation Outline

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- Risk Mitigation Plans- Modular coil fabrication
- Safety
- Fabrication of Modular coils
 - Materials
 - “Inch Worm” and “Twisted Racetrack” coil trials
 - Tooling
 - Winding facility
 - VPI process
- Summary

Risk Mitigation Plans

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- *Risk mitigation for the fabrication of the Modular coils is being handled through an extensive R&D program that has been on-going since the CDR. Critical activities include:*
 - Development of a VPI plan for epoxy impregnating the modular coils
 - Perform conductor “Keystone” testing to determine what tolerance control can be obtained
 - Develop experience in winding compacted copper cable conductor through the use of prototype windings
 - Verify new cooling scheme
 - Wind and VPI prototype coils to gain experience and develop procedures

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

Epoxy Selection

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➤ Resin System selected- CTD-101K (*well characterized for ITER*)

➤ Product of *Composite Technology Dev. Inc.*

➤ 3- Component epoxy system

➤ Excellent performance at cryogenic temperatures with a long pot life and low viscosity

➤ Cure Cycle

➤ 5 hours @ 100 ° C (Cure)

➤ 16 hours @ 125 ° C (Post cure)

➤ Pot Life:

➤ 145 hours @ 25° C..... 1300 Cp viscosity

➤ 60 hours @ 40° C..... 400 Cp viscosity *

➤ 20 hours @ 60° C..... 100 Cp viscosity

**GOOD
WORKING
TIME!!!**

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.]

Keystone R&D Findings

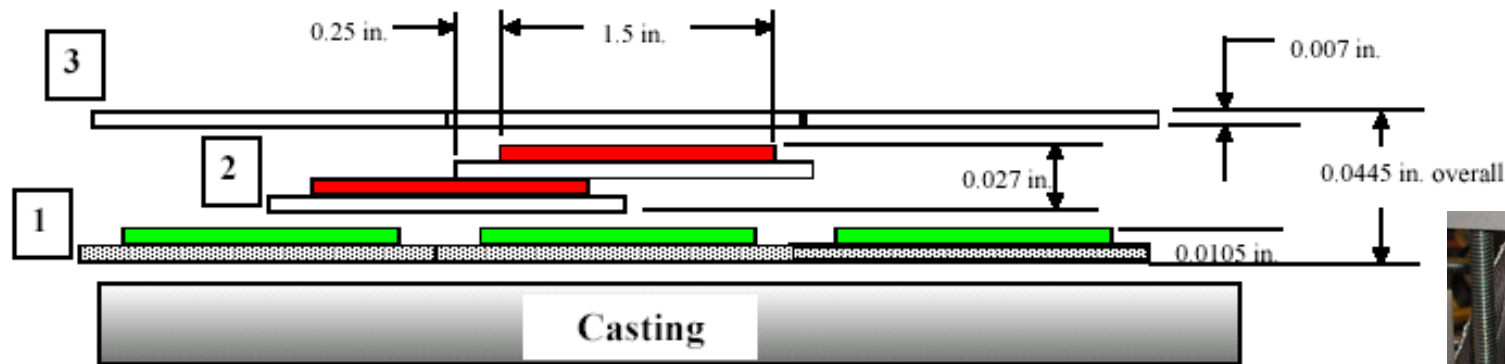
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- New insulation scheme, helps to minimize keystoneing
- Rolling or pre-forming of conductor is not a realistic option, due to the complex and changing geometry of the coils
- Smaller conductor helps to minimize Keystoneing
- *Between the conductor tolerance ± 0.008 in. and dimensional variations due to keystoneing, reproducibility would be difficult without compensating with the use of shimming*
- Proposed method for winding modular coils
 - Wind approximately 6 –8 inch length of pre-insulated conductor
 - Set conductor in place by gently hand tapping in place
 - Measure position of turn using “Romer” arm plus specially designed tools
 - Shim as required to maintain tolerance control

Ground Wrap Insulation Scheme

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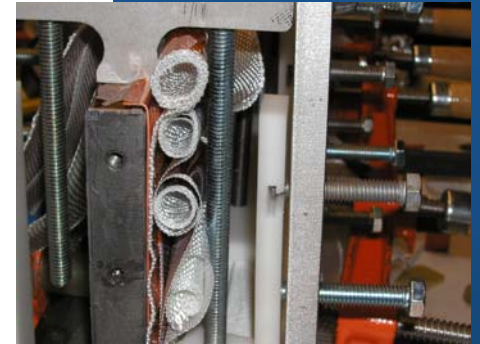


3 (1) Butt lapped layer
0.007 in. thick S-2 glass [2 inch nom. wide]

2 (1) Half-lapped layer of composite:
- 0.007 in. thick glass [2 inch nom. wide] & 0.0065(HN) Kapton [1.5 nom. wide] with adhesive
- X 2 = 0.027 in. thick

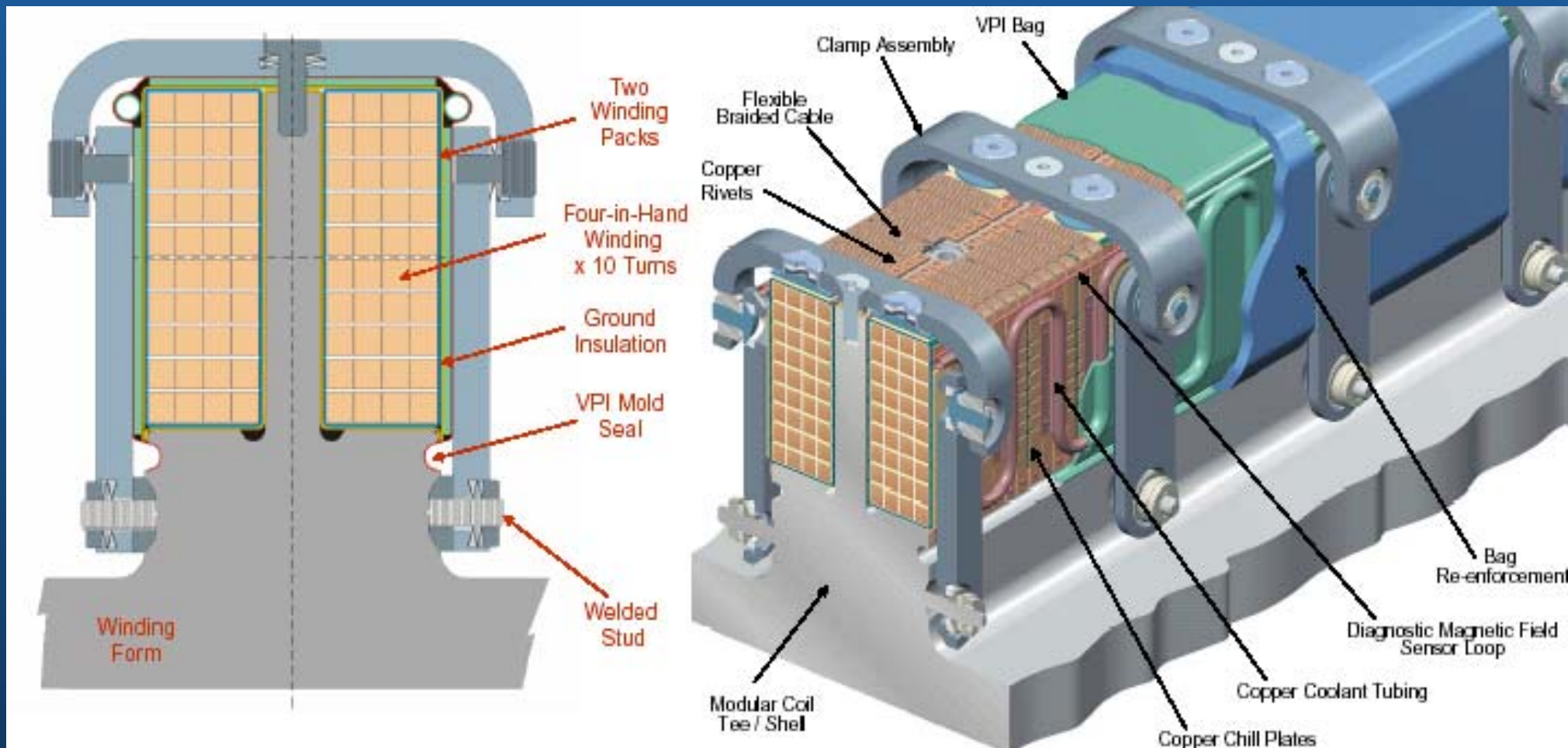
1 (1) Butt lapped layer of composite:
- 0.007 in. thick glass [2 inch nom. wide] and 0.0035 (HN) Kapton [1.5 nom. wide]) with adhesive

Tracking distance = 1.0 inches



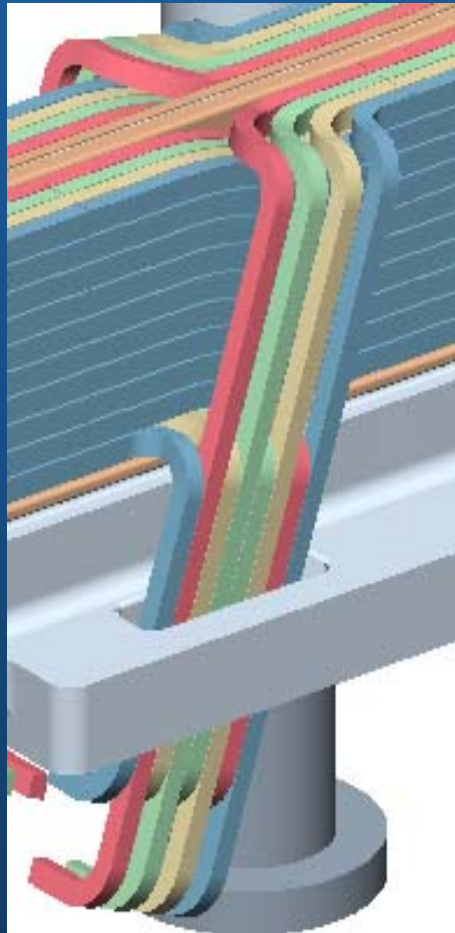
Modular Coil Winding pack Assembly

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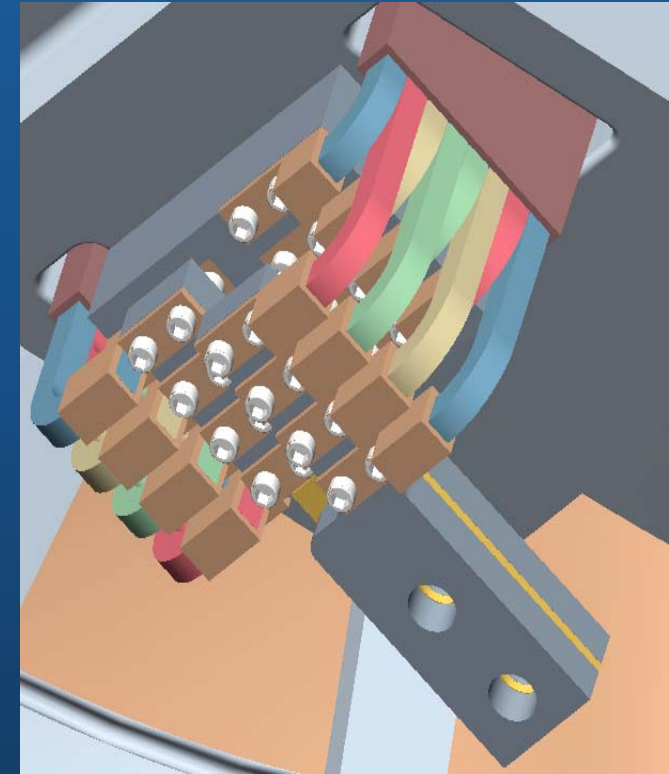


Modular Coil Manufacturing

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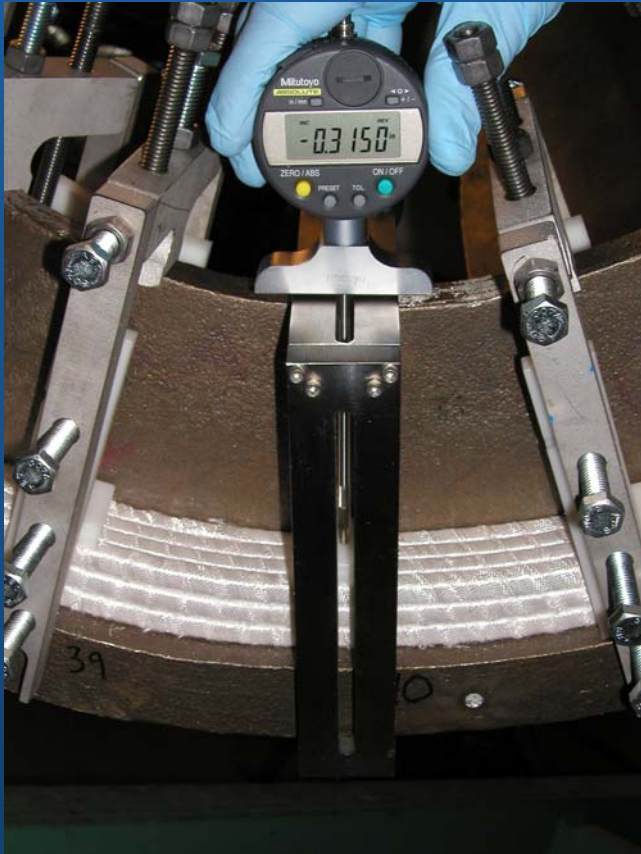


- Compacted copper conductor will arrive pre-insulated.
- Coil layers will be wound 4 conductors in-hand
- The upper and lower leads will join together and run along the side of the coil bundle and through the casting
- Leads will be terminated outside the casting [**First demonstrated on “Twisted racetrack coil”**]



Coil Winding Metrology

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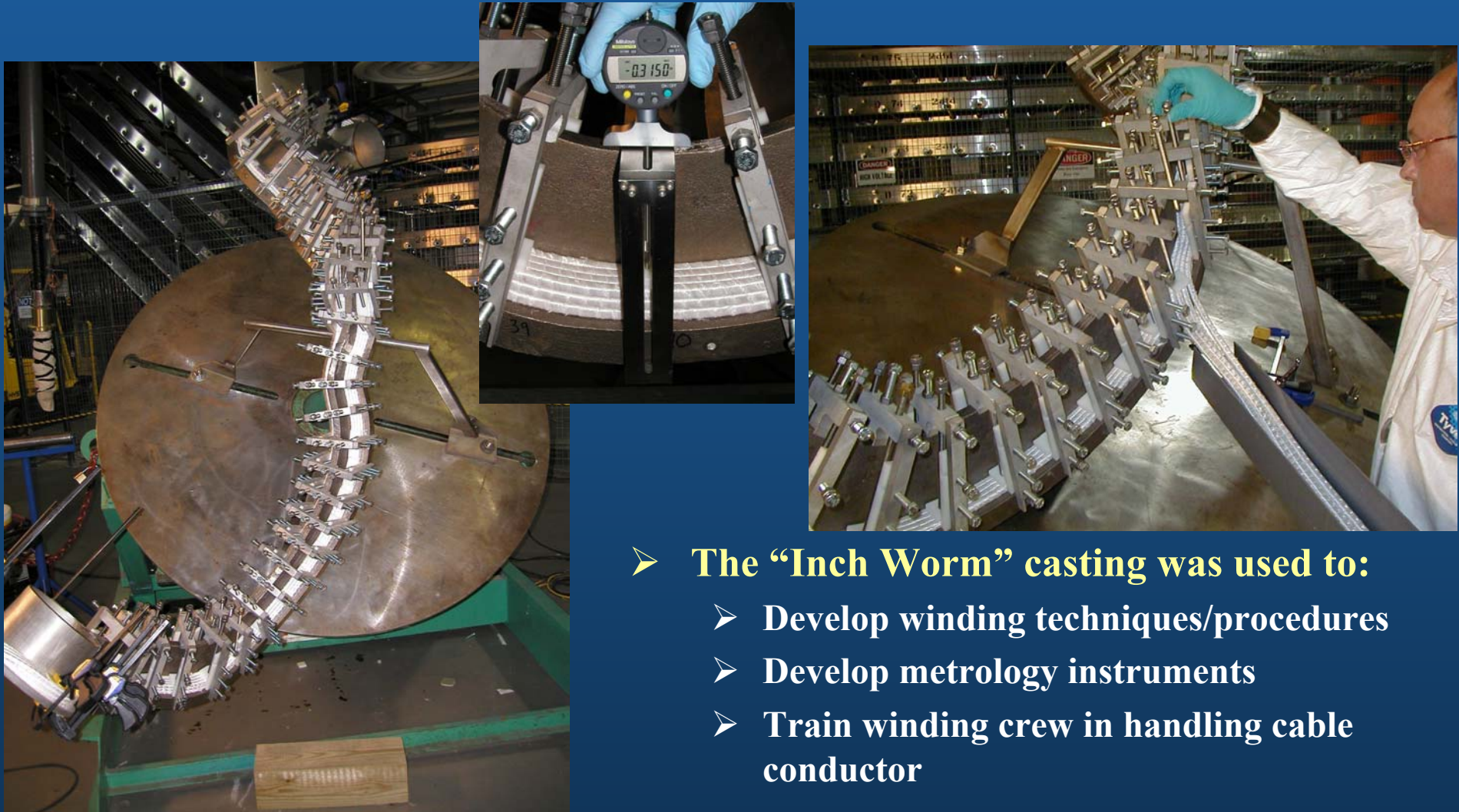


- Initial measurements using “Romer” Arm
- Use mechanical measurement fixture as conductor is being laid in position
- Add or remove shims as necessary
- Periodically remeasure overall height using “Romer” arm



Inch Worm- Winding Trials

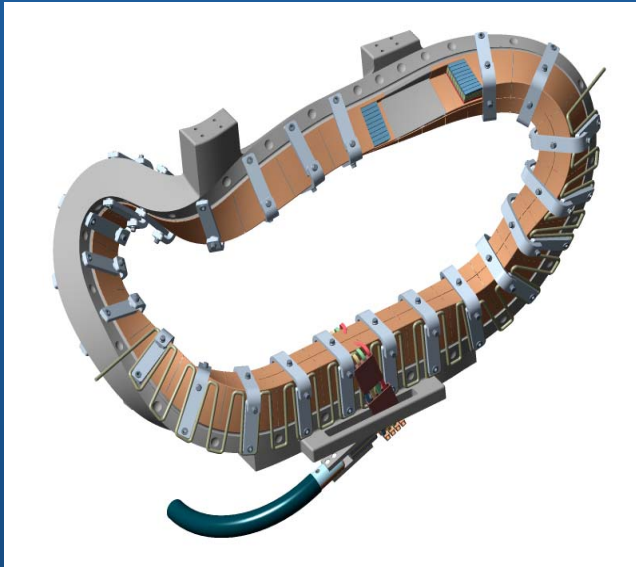
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- The “Inch Worm” casting was used to:
 - Develop winding techniques/procedures
 - Develop metrology instruments
 - Train winding crew in handling cable conductor

Twisted Racetrack Shaped Coil

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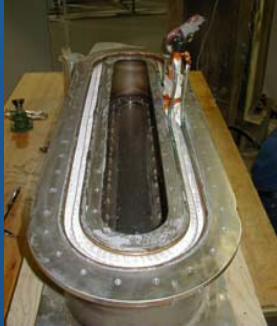
- **Twisted coil will capture many physical features of the NCSX Modular coils including:**
 - Mod coil Cross-section and Transitions
 - Conductor and Insulation scheme
 - Lead arrangement
 - Cooling arrangement (Chill plates)
- **Coil will be instrumented with strain gauges and thermocouples to monitor 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
 - Coil performance under cold condition at full modular coil power
 - First use of Autoclave



Anticipated start mid July

Evolution of R&D Winding / VPI Development

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Univ. of Tenn. Coil

First use of CTD-101K epoxy system for VPI



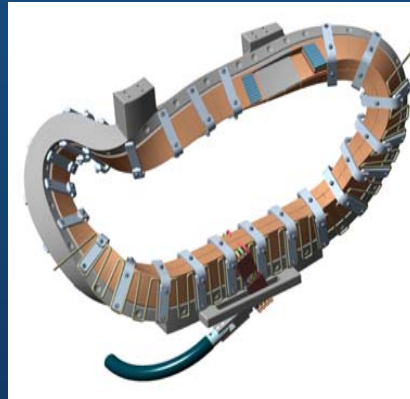
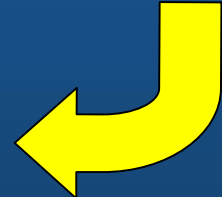
Straight Tee Section

First use of "Bag Mold" for VPI



Racetrack Coil

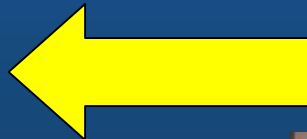
First winding experience & use of copper cladding



Twisted Racetrack

-Final coil lead configuration
-First use of autoclave for VPI

July 04



Full Scale Prototype Coil

First use of manufacturing processes

September 04



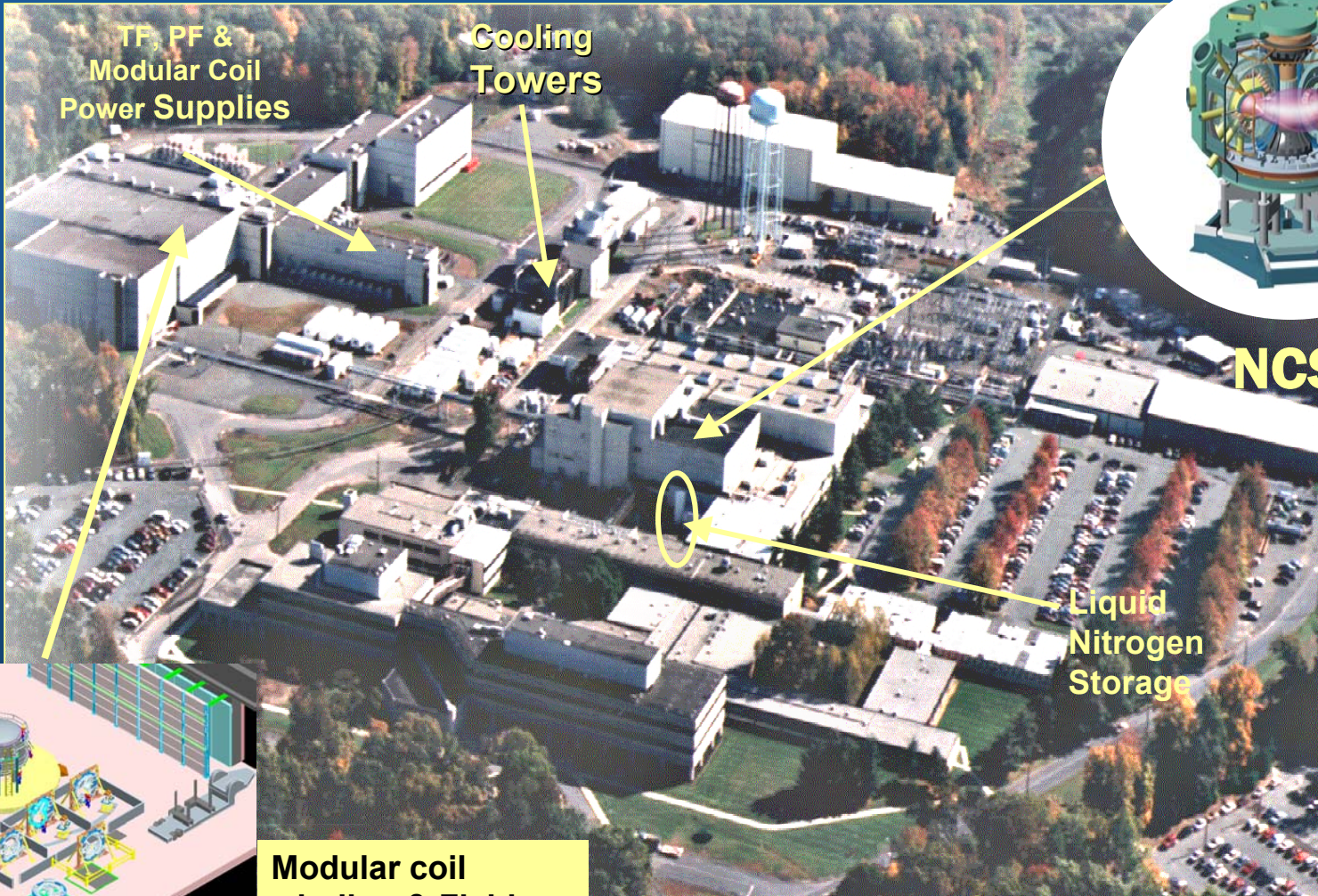
Inch-Worm Winding

-First use of shimming to control tolerance
-First use of 4 in hand conductor

Spring 04

Modular Coil Fabrication

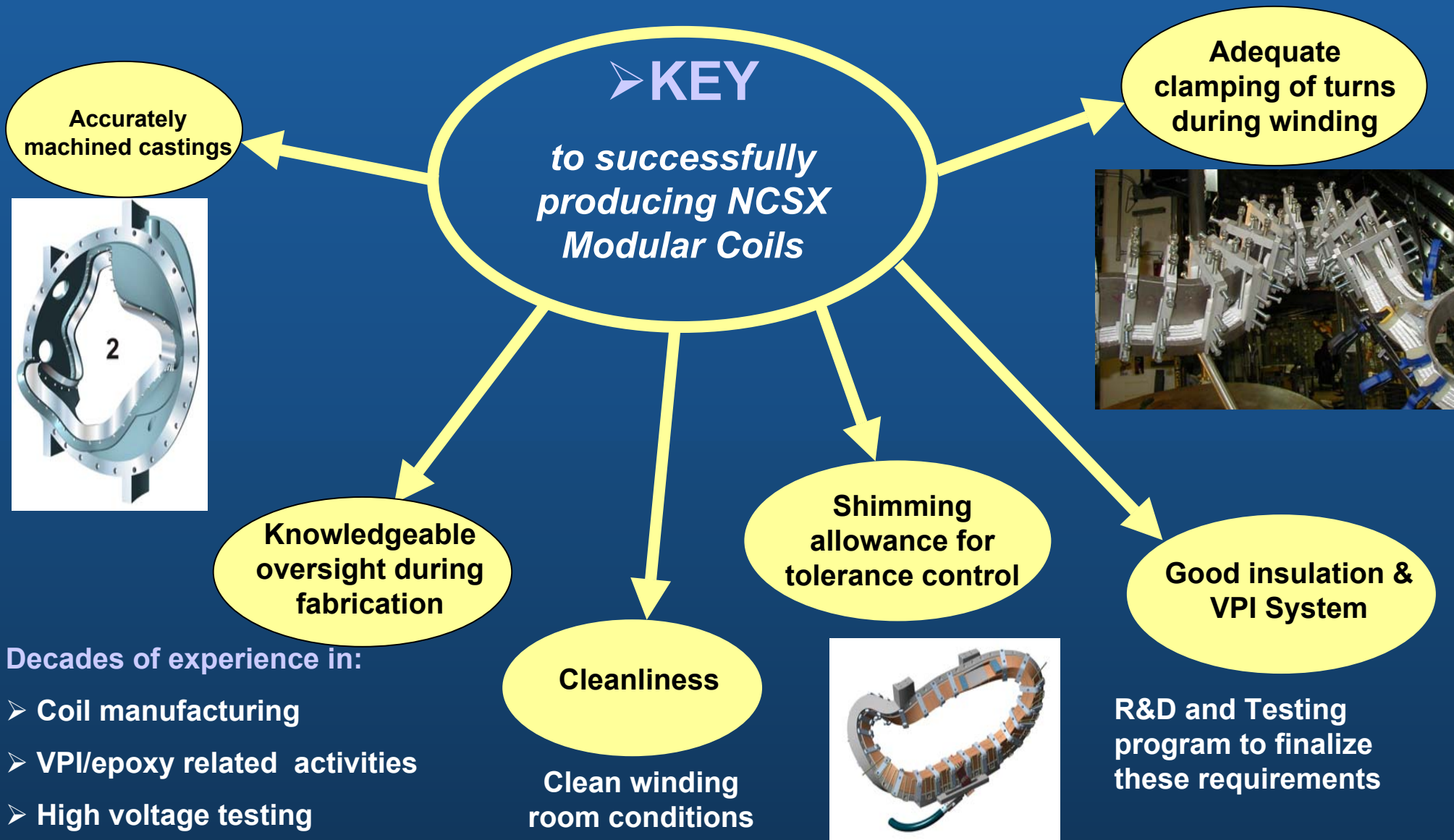
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Modular coil winding & Field Period assy. area

Modular Coil Success

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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

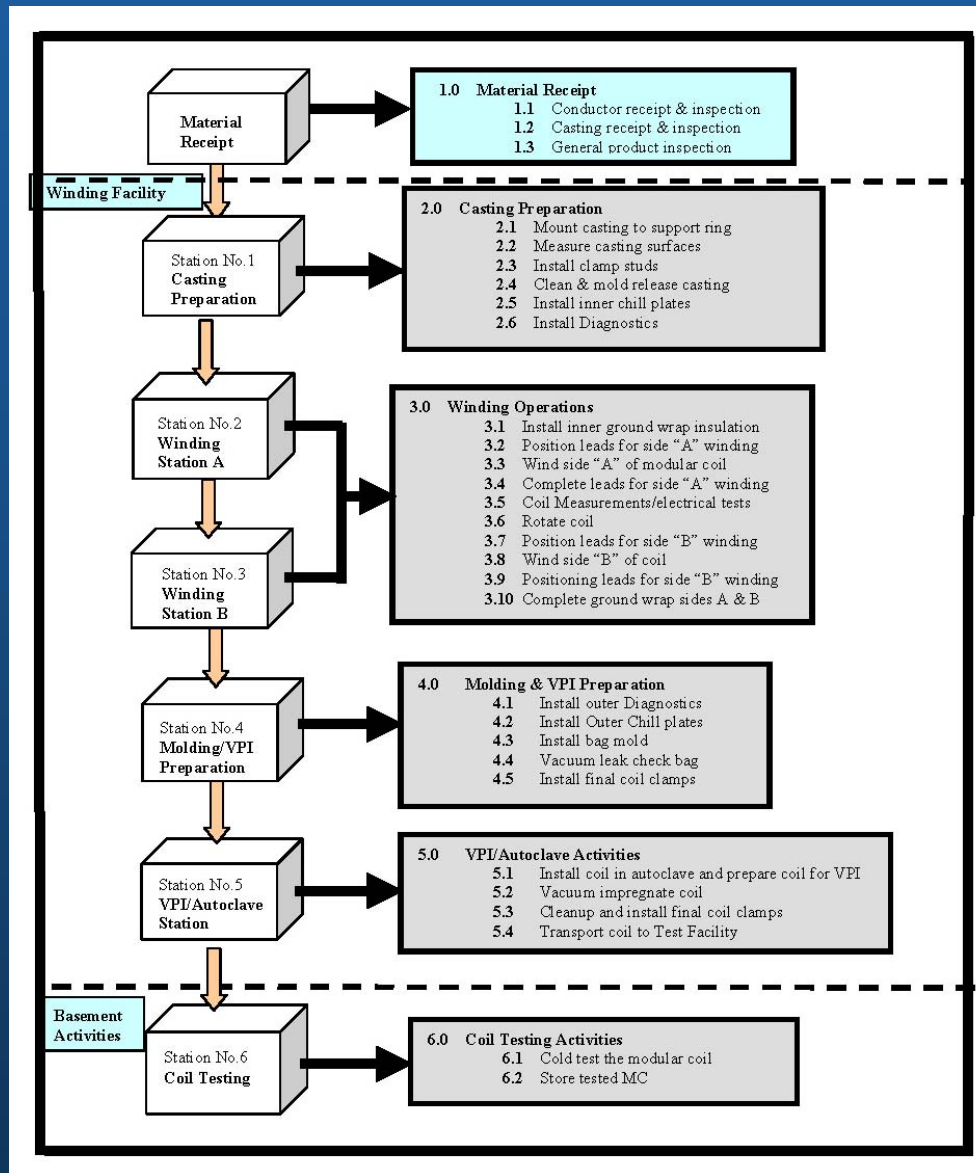
Approved By: _____
Larry Dudek- RLM for Coil Facility

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 Manufacturing Flow Plan

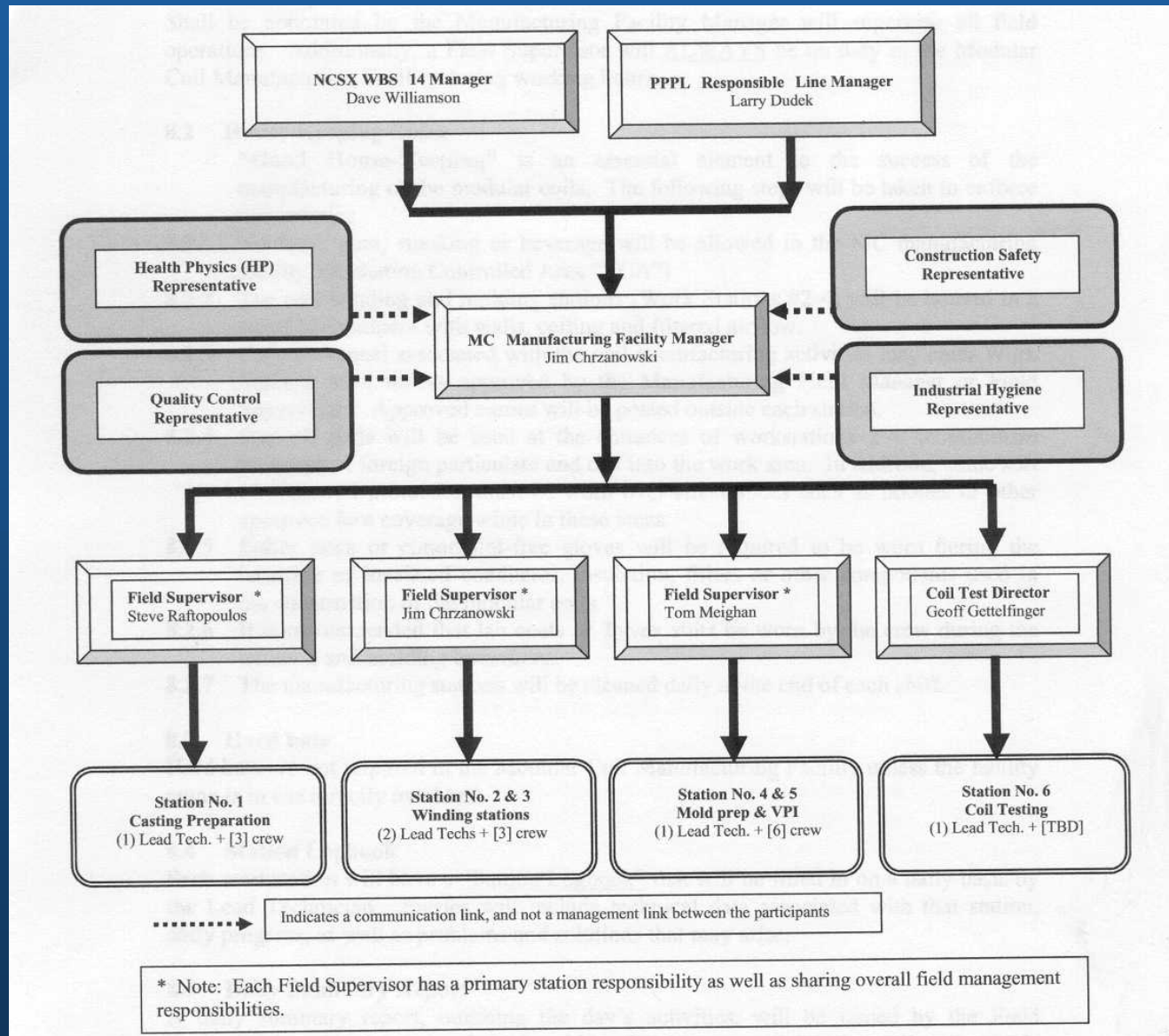
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- Flow plan outlines work stations and manufacturing steps
- Receipt of casting thru final testing

MCWF Organizational Chart

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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**
 - **NCSX-PROC-MCF-001** [MC Material Receipt]
 - **NCSX-PROC-MCF-002** [MC Station 1- Casting Preparation]
 - **NCSX-PROC-MCF-003** [MC Station 2&3- Winding]
 - **NCSX-PROC-MCF-004** [MC Station 4- Mold Preparation]
 - **NCSX-PROC-MCF-005** [VPI and Final Operations]
 - **D-NCSX-OP-G-159** [MC Test Facility Operation]

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- Winding stations
 - Station 4- Mold preparation
 - Station 5- VPI and post VPI
 - Station 6- Cryo test (Located in basement)
- The coils will **vacuum-pressure-impregnated** (VPI) in an autoclave
- Maintain coil current center tolerance of **+/- 0.010 inches** by shimming between turns and layers

Modular Coil Manufacturing Facility

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MCWF Clean Rooms

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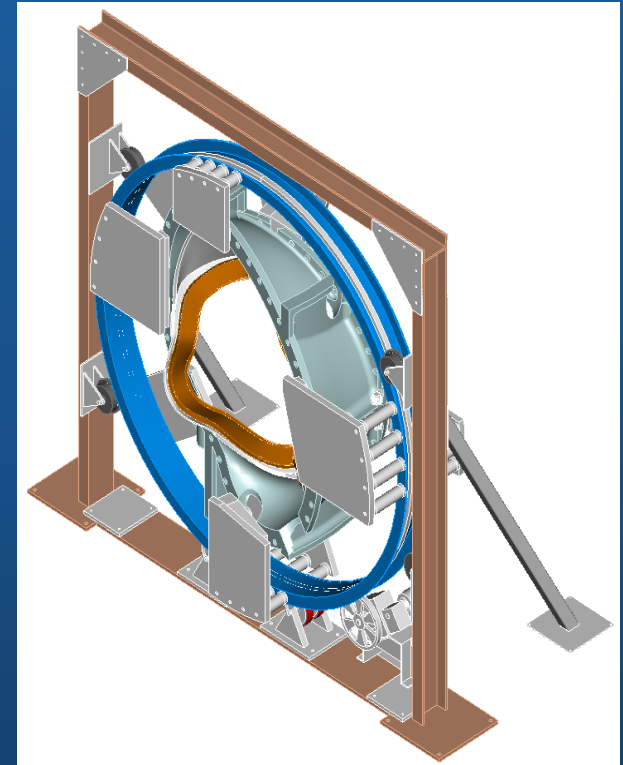


- The winding and mold stations will be located in enclosed rooms where **cleanliness** can be controlled.
- Three clean rooms are being constructed.
- Modular coils will be positioned in the rooms via a sliding roof panel.
- External vacuum system for cleaning purposes, as well as filtered room ventilation



Coil Turning Fixtures

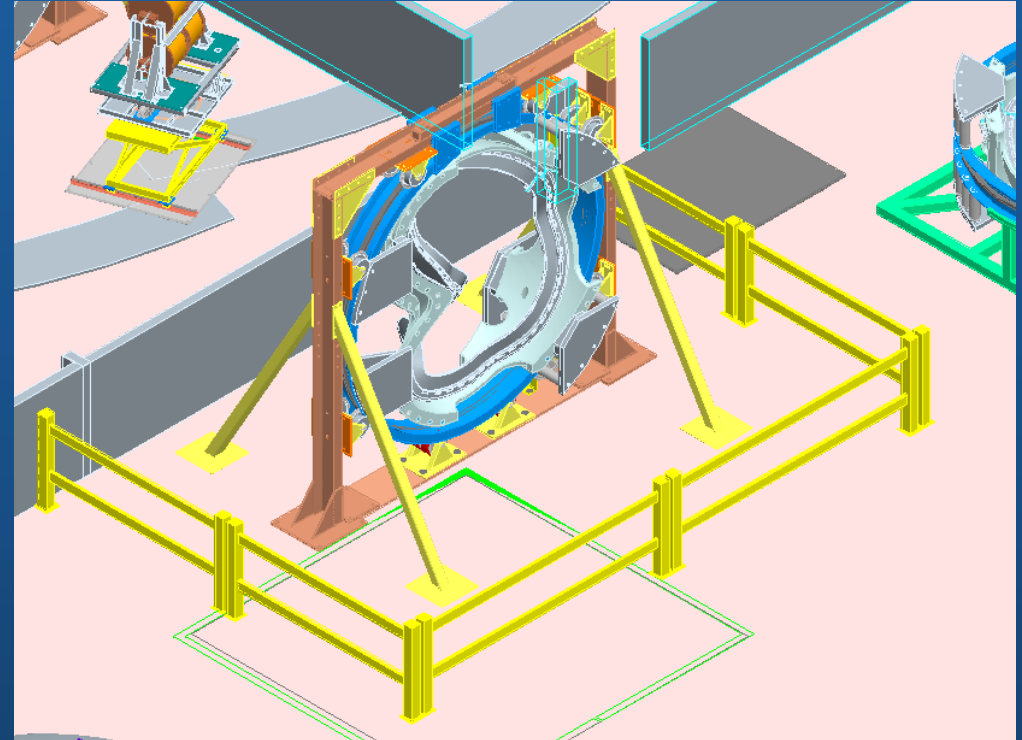
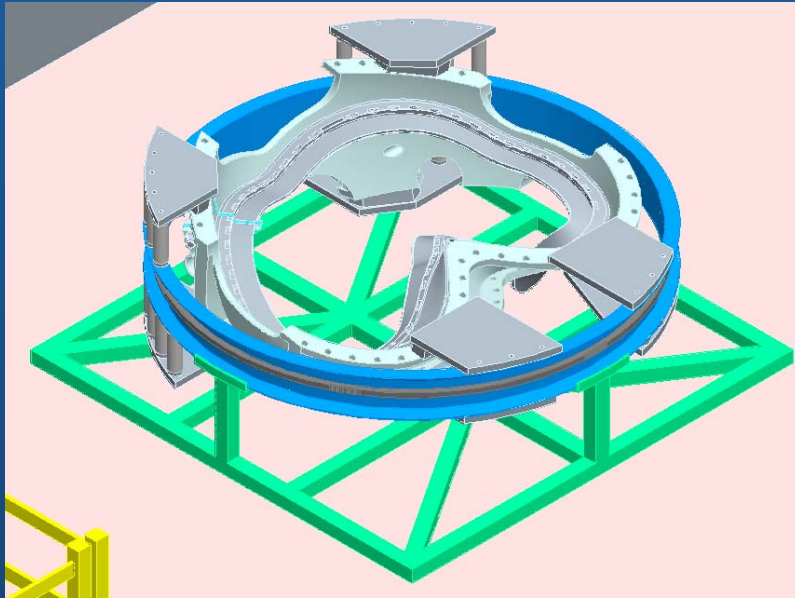
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- Vertical turning fixtures will accommodate (3) types of modular coils
- Turning fixture be used at three stations (Casting Preparation, Winding and Mold Preparation)
- Allows easy work access to both sides of casting
- Motor and gear driven

Casting Preparation Station #1

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Casting Preparation

- Mount casting to support ring
- Measure/inspect casting surfaces
- Install coil clamp studs
- Clean & mold release winding surfaces
- Install inner chill plates & measure

Procedure No. NCSX-PROC-MCF-002

12 working days per coil

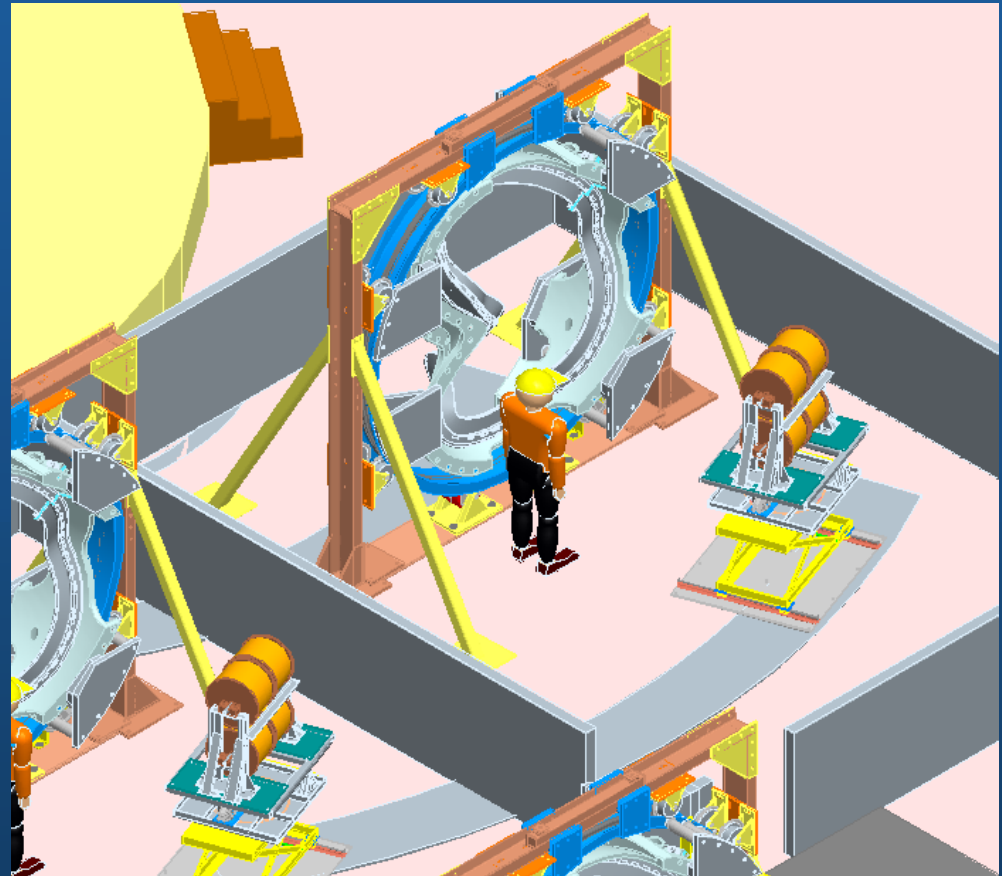
Coil Winding Station #2 & 3

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Winding Operations [2 stations]

- Install inner ground wrap insulation
- Position leads for side “A” winding
- Wind side “A” of modular coil
- Measure turns as wound
- Complete leads for side “A” winding
- Reposition coil in turning fixture
- Position leads for side “B” winding
- Wind side “B” of coil
- Measure turns as wound
- Complete leads for side “B” winding
- Complete ground wrap sides A & B

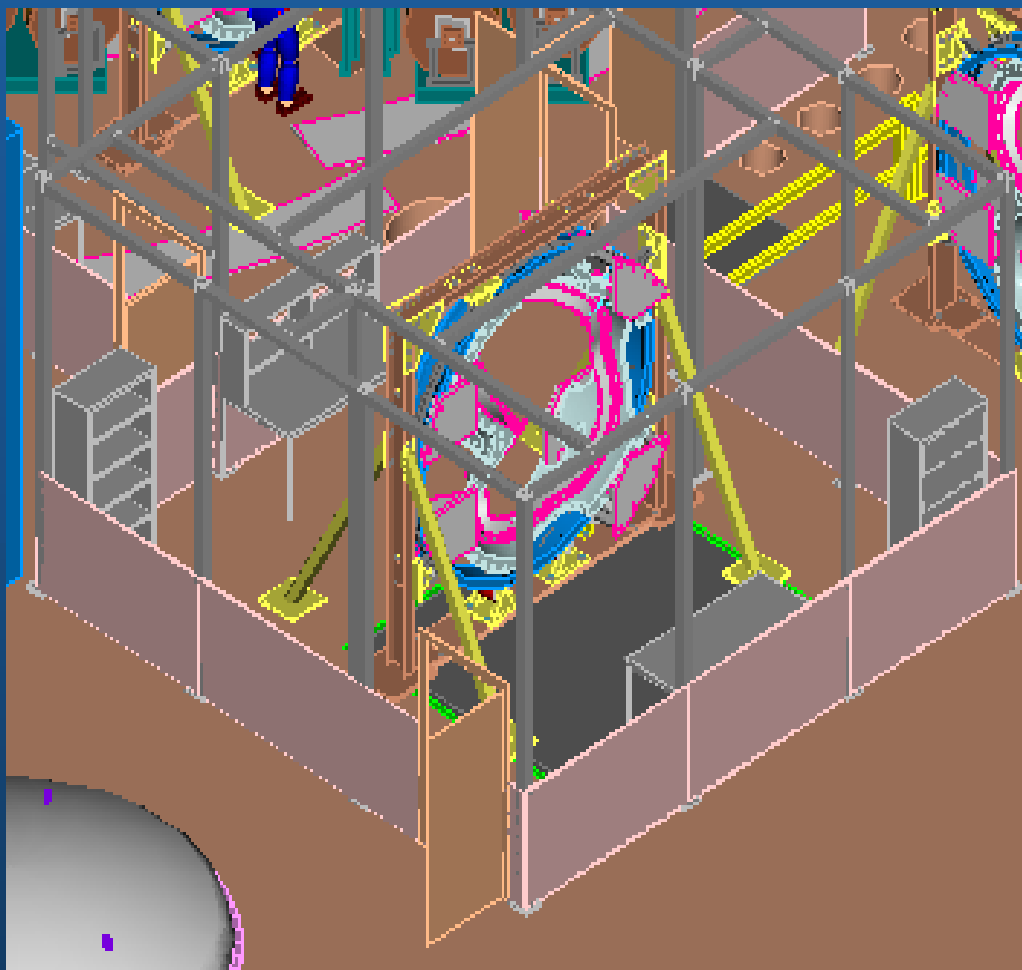
Procedure No. NCSX-PROC-MCF-003



38 working days per coil

Molding/VPI Preparation Station #4

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Molding & VPI Preparation

- Install outer Diagnostics & measure
- Install Outer Chill plates
- Install bag mold
- Vacuum leak check bag mold
- Install coil molding clamps

Procedure No. NCSX-PROC-MCF-004

15 to 25 working days per coil

VPI Station #5

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VPI/Autoclave Activities

- Install coil in autoclave and prep for VPI
- Vacuum impregnate coil
- Cleanup and install final coil clamps
- Transport coil to test facility

VPI- (12) working days per coil

Post VPI- (5) working days per coil

Cold Testing- (5) working days per coil

Procedure No. NCSX-PROC-MCF-005

Autoclave Installation

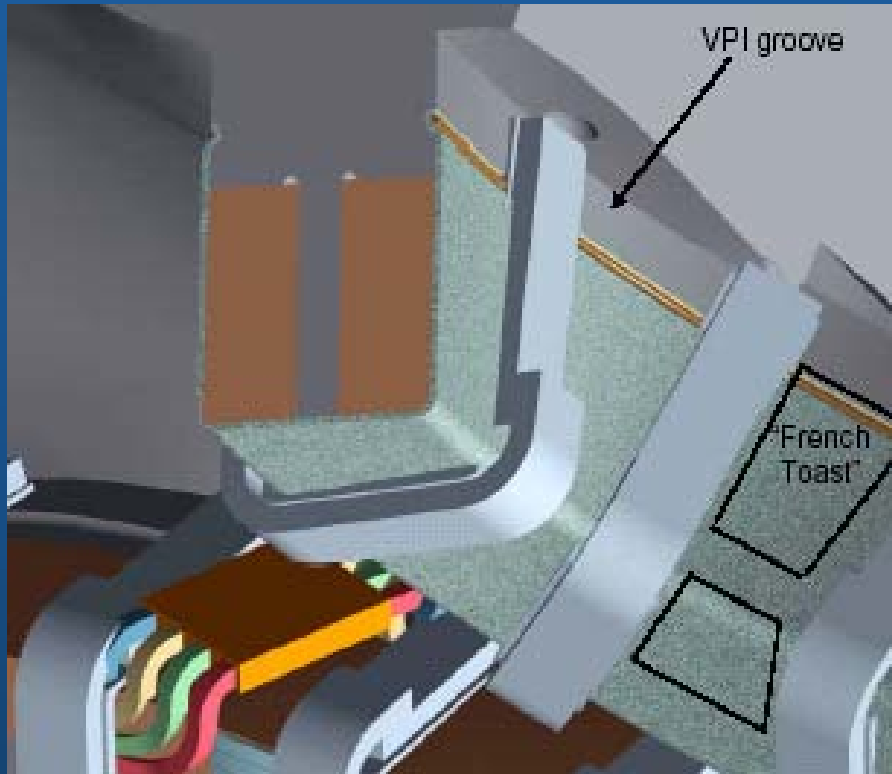
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- Autoclave being transported to coil winding facility

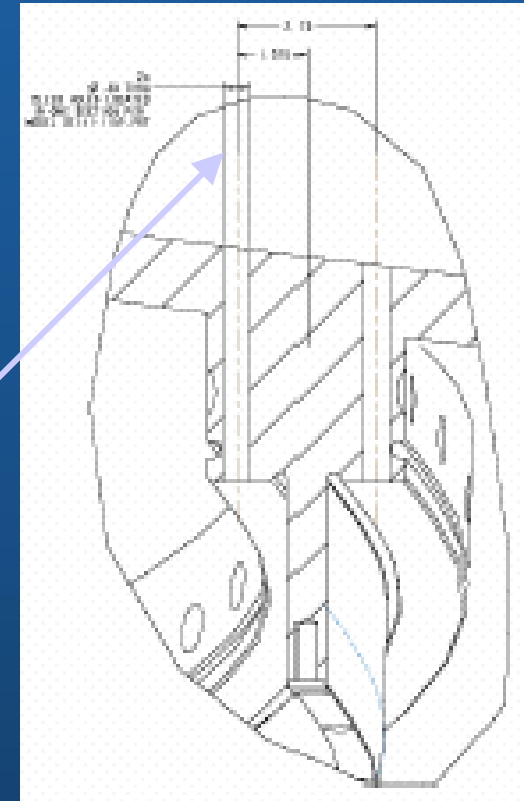
Vacuum-Pressure Impregnation (VPI)

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-Modular coils will be VPI'd in vertical position

-Epoxy bleed holes are provided at the highest point of casting

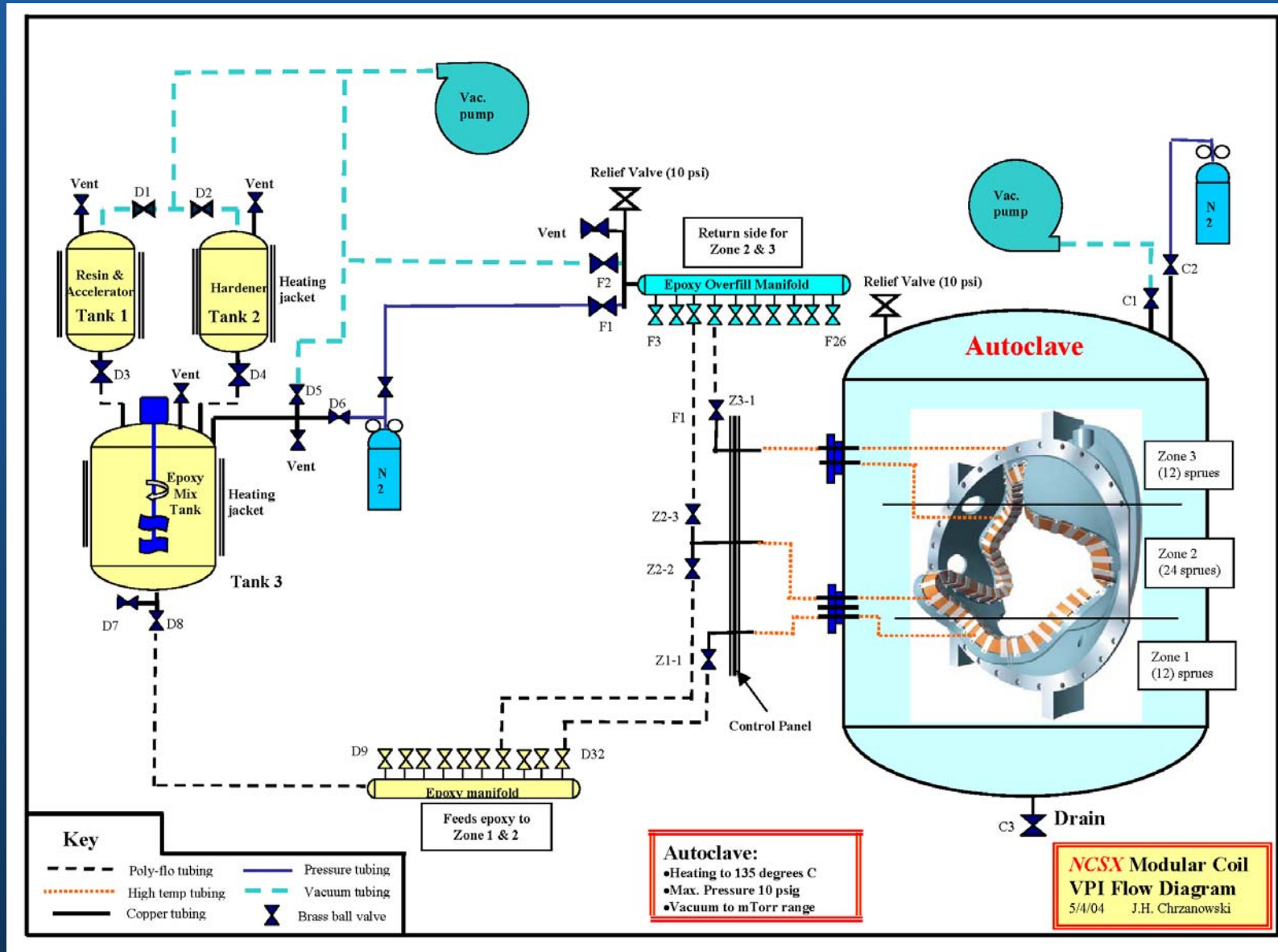


-“Bag Mold” -silicone rubber tape (vacuum seal) and epoxy filled felt (side wall stiffness) is placed over the ground wrap/ chill plates.

-“VPI Grooves”-silicone bag is secured with copper tubing pressed into machined grooves located on the casting.

Modular Coil VPI Flow Diagram

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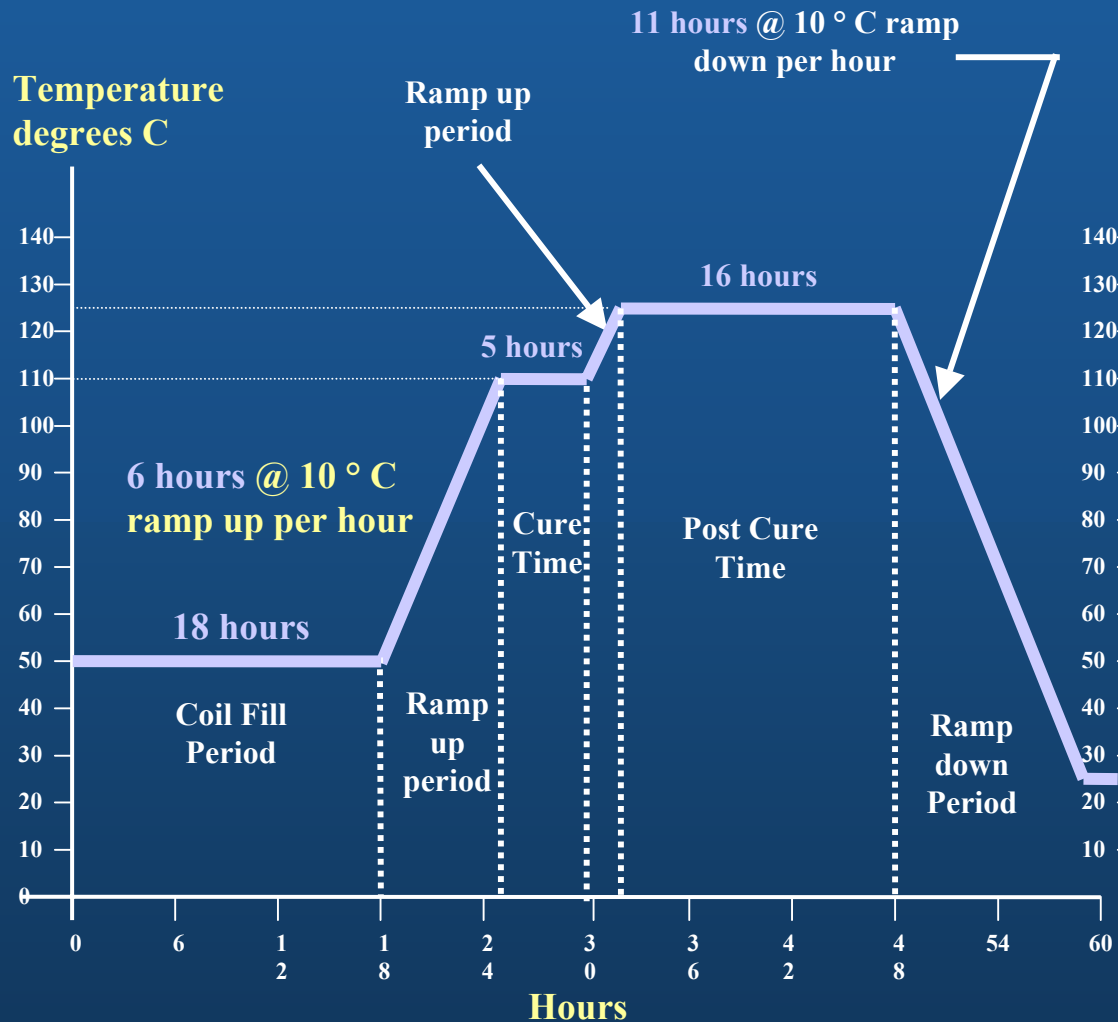


NCSX MODULAR COIL VPI CYCLE

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Epoxy component mixing



Viscosity measurements



"Scrambled Egg" test to verify Gel temperature

Modular Coil Manufacturing Schedule

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Summary- Completions

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- The R&D program has made great progress since the CDR; and has been able to provide the NCSX Project with needed information in the Modular Coil design. These activities include:
 - Determined the mechanical and thermal properties of the epoxy impregnated conductor
 - “Keystone test” have helped to define the conductor size, tolerance control and manufacturing processes
 - Developed and demonstrated a sound “VPI” plan (“Bag Mold” and epoxy delivery method)
 - Developed an Winding Facility Operations Plan and MIT
 - Manufacturing procedures are being written
 - Experience gained in winding Racetrack shaped coil and “Inch Worm” have helped to define the manufacturing plan

Summary- R&D and Manufacturing Preparations

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- **Remaining R&D/ Manufacturing Activities Include:**
 - Complete remaining epoxy/conductor mechanical/thermal tests
 - Complete cooling method R&D activities
 - Wind “Twisted” Racetrack Coil
 - Complete fabrication of tooling and setup of Modular coil manufacturing facility
 - Complete Modular coil manufacturing procedures
 - Perform trial winding operations on “Prototype” Modular coil
- *Progress has been good, and completion of the NCSX Manufacturing & R&D tasks identified above will be completed safely, within budget and on schedule*