# STATEMENT OF WORK

For

# NCSX Modular Coil

## Winding Development Activities

## NCSX-SOW-142-01-00

**Dated:** January 29, 2003

**APPROVALS**

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REVISIONS

| Revision No. | Affected Pgs. | Date |
|---|---|---|
| **0 (Initial Release)** | **All** | |
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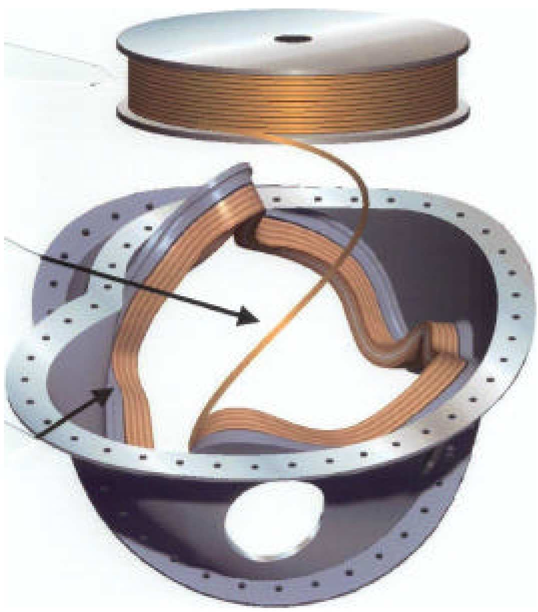

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# TABLE OF CONTENTS

## 1.0 SCOPE:

The scope of this Statement of Work (SOW) includes those activities associated with the development of a sound plan for the winding and vacuum impregnation of the NCSX modular coils. Specifically it includes the development of the necessary tooling and equipment for winding and impregnating the modular coils; the selection of an epoxy resin system for impregnating the modular coils plus the development of a vacuum-pressure-impregnation (VPI) plan including delivery system. Additional work includes a study of tolerance control during the coil-winding phase.

## 2.0 APPLICABLE DOCUMENTS

**2.1** ES&H 5008 PPPL Health and Safety Manual
**2.2** NCSX-CSPEC-142-00 Specification for the Modular Coils Windings
**2.3** ENG-032 Work Planning Procedure
**2.4** ESH-014 NEPA Review System
**2.5** ESH-014 Job Hazard Analysis
**2.6** Integrated Safety Management (ISM).

## 3.0 REQUIREMENTS

### 3.1 STATEMENT OF WORK ACTIVITY

The tasks described below are not necessarily in the order that they are to be completed. It is expected that several of these activities will be worked in parallel. Delivery requirements are described later in the SOW. (Section 4.0)

#### 3.1.1 Development of the necessary NEPA and WP documentation for completing the winding development activities.

Work Planning Form (WP): This procedure is used to plan the anticipated requirements of a job, to define the scope of work, to perform hazards analysis, to provide for all environmental, safety, and health issues as part of the work planning and review process, to establish procedural and testing requirements, to make other determinations as necessary, and to provide clear approvals indicating ownership of the work. It is one of the systems that implement the requirements of P-001, Graded Approach. (Reference document ENG-032 “Work Planning”)

NEPA (National Environ. Policy Act): This document will be generated to assure compliance with NEPA through independent review of activities. (Reference document ESH-014 “NEPA Review System”)

### 3.1.2 Generation of Job Hazard Analysis (JHA) Forms

Generate the necessary JHA's to identify existing and potential workplace hazards and to evaluate the risk of worker injury or illness associated with the winding development efforts. JHA's will be generated for all work activities associated with this SOW. (Reference document ESH-014 "Job Hazard Analysis")

### 3.1.3 Selection of epoxy resin system for Impregnating the Modular Coils

Involves the process of review and selection of epoxy systems that will meet the electrical, thermal, mechanical, and processing requirements of the Modular coils. (Ref: NCSX Modular Coil Specification No. NCSX-CSPEC-142-00). Activities will include:

3.1.3.1 Selection of various epoxy systems for evaluation

3.1.3.2 Develop a SOW for obtaining the services of an outside epoxy consultant to provide epoxy consultation and testing facilities to the NCSX project. Consultant will help determine the mechanical and thermal properties of epoxy/insulation scheme.

3.1.3.3 In-house characterization and testing of the epoxy resin systems selected for evaluation.

### 3.1.4 Mechanical and Thermal Properties of Resin System

Involves the preparation and testing of epoxy-impregnated samples to determine the mechanical and thermal properties of the epoxy system selected. Both PPPL and an outside consultant will complete this work. Tests will be performed to:

3.1.4.1 Determine the yield and ultimate strengths of the epoxy-impregnated conductor via tensile testing. Also determine the modulus of elasticity and shear modulus.

3.1.4.2 Determine the flexure strength and failure mode of cable and insulation.

3.1.4.3 Determine the coefficient of thermal expansion for a temperature range of 77 K to room temperature.

3.1.4.4 Determine the thermal conductivity and specific heat.

3.1.4.5 Determine the bond strength of the cable-to-cable epoxy via shear and flexure testing

### 3.1.5 Development of VPI Process for impregnating Modular coils

Develop and demonstrate a process plan for vacuum impregnating the modular coils. Activities include:

3.1.5.1 Design/develop an <u>encapsulating system</u> that would provide an external shell around the modular coil during the VPI process. The system must be able to withstand pressure levels between milli-torr (vacuum) to a maximum 20-psia pressure, while operating in a heated autoclave environment (130 deg C) with the autoclave pressure tracking the mold pressure.

3.1.5.2 Design and fabricate <u>short and long coil beam specimens</u> to be used during the VPI trial. These specimens would be representive of various sections of the modular coils. Insulated copper conductors would be placed onto the winding form per the present modular coil design specifications. Beam specimens would also be used in the development of the mold and tooling. The beam specimens will include the following:

*3.1.5.2.1* <u>*(1) Straight length tee-section (see figure 1)*</u>
Will be used to develop initial VPI and external mold concepts.

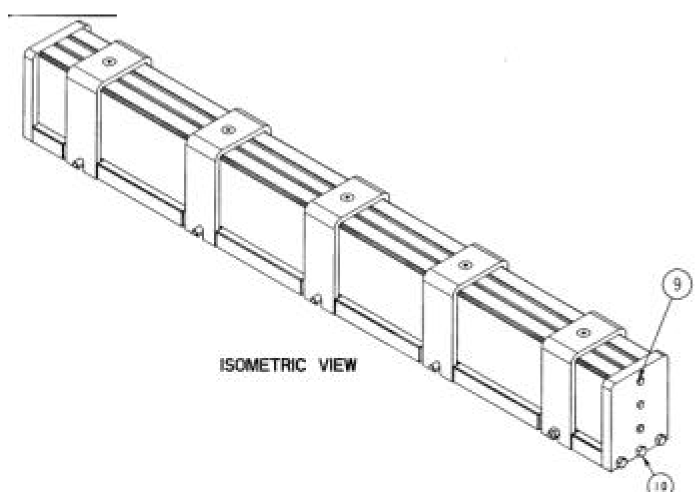


**Figure 1-** Straight Length Tee

*3.1.5.2.2* *(2) Cast formed tee-sections*

Two different cross sectional designs representative of difficult areas (reverse twists, etc.) from the modular coils will be cast from stainless steel. Each section will approximately 36 inched in length. These samples will be used to develop VPI and external mold concepts. (See figures 2 & 3)

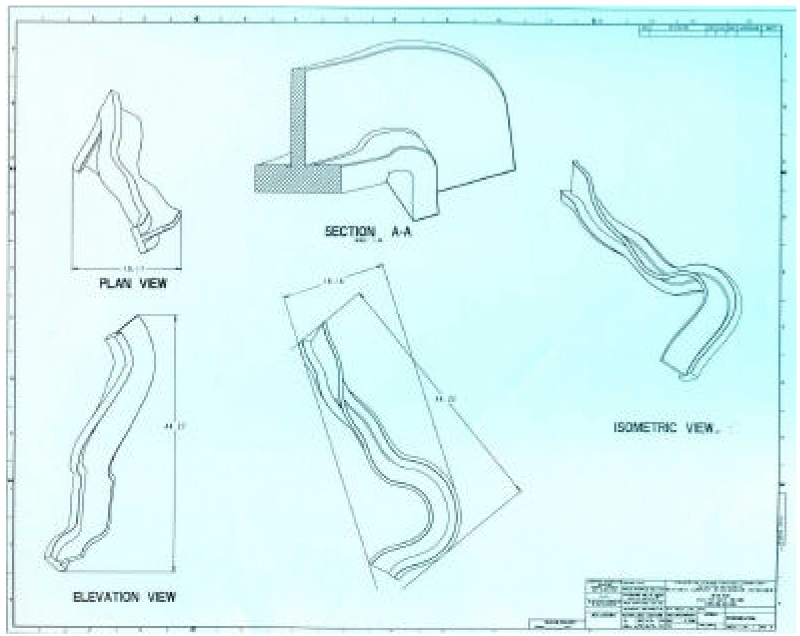


**Figure 2-** Tee Section Type I

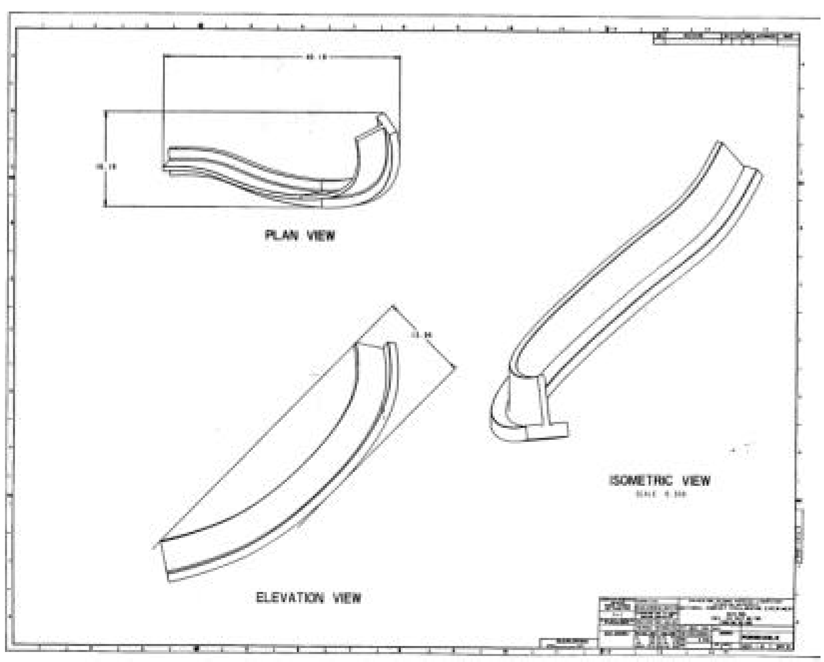


**Figure 3-** Tee Section Type II

*3.1.5.2.3 (1) Full length cast specimen*

This will be the final VPI trial prior to fabricating the prototype coil. A coil cross-section comprised by combining the (2) cast tee-sections approximating the height of a modular coil will be impregnated using the autoclave bakeout oven. This test will verify the VPI process as well as the operational readiness of the autoclave. (See figure 4)

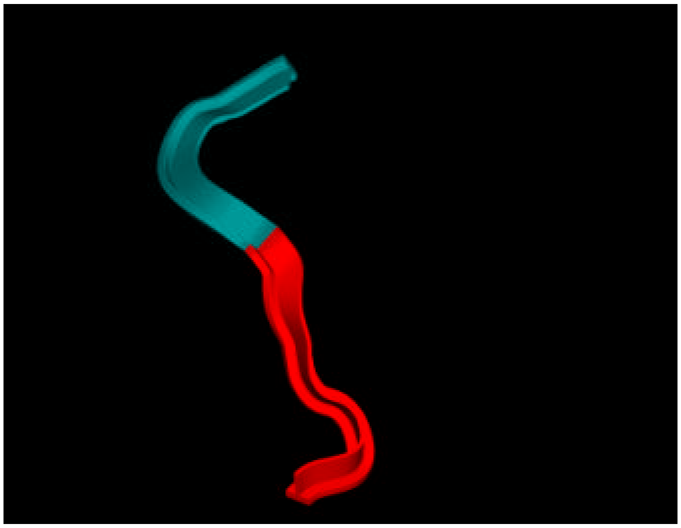

**Figure 4-** Full Length Cast Specimen

3.1.5.3 Vacuum-pressure-impregnate the short and long coil beam specimens, which will be used to develop the VPI process for epoxy impregnating the modular coils.

3.1.5.4 Develop an epoxy delivery process and system for introducing the epoxy into the modular coil bundle during the epoxy impregnation process.

3.1.5.5 Generate a complete process plan for vacuum impregnating the modular coils including mold assembly, coil preparation, epoxy preparation, delivery system assembly, and VPI steps including cure cycle and epoxy characterization during the VPI.

### 3.1.6 VPI of Test Coil from University of Tennessee (UT)

Princeton Plasma Physics Laboratory (PPPL) will work together with ORNL to prepare and VPI canned coil specimens in support of the QPS and NCSX project.

3.1.6.1 VPI of Test Coil from University of Tennessee (UT)

Prepare and vacuum-pressure-impregnate a canned coil from the University of Tennessee. This coil will be constructed using comparable conductor and insulation as will be used for the NCSX modular coils. The UT coil will be impregnated using one of the epoxy systems being evaluated by the NCSX project. Once completed the coil will be removed from the stainless steel and shipped to ORNL. Complete process records will be documented and provided to UT following VPI completion. (See figure 5) This coil will be used for VPI trials only. No electrical tests are planned.

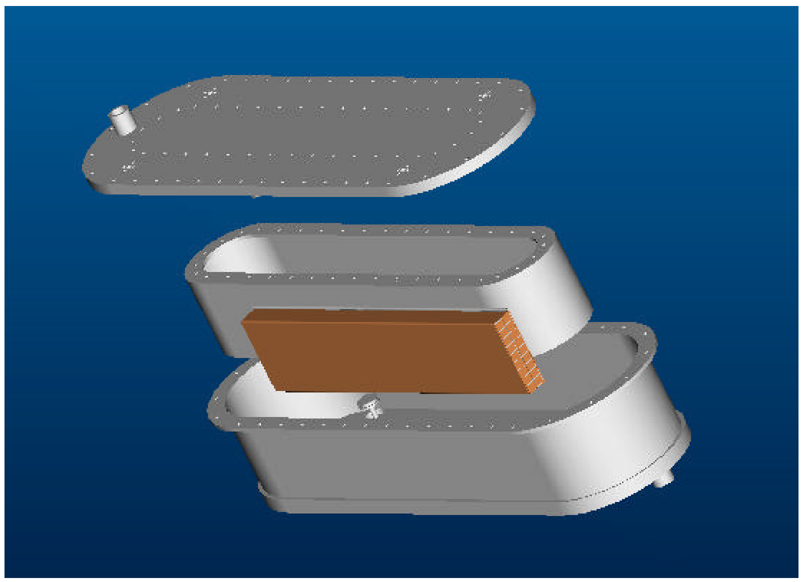

**Figure 5-** University of Tennessee Test Coil

3.1.6.2 VPI of 2nd. Test Coil PPPL Fabricated (QPS activity)

A second coil will be fabricated at PPPL using the same conductor and insulation as used in coil #1. The coil will be wound directly into the same winding can. Following VPI this can will be shipped to ORNL for testing.

3.1.6.3 VPI of 3rd. Test Coil PPPL Fabricated (QPS activity)

A third coil will be fabricated by PPPL using a 4-conductor concept, similar to that being planned for NCSX.

**Final electrical tests will be performed on the impregnated coils per written agreement with ORNL.**

### 3.1.7 Fabrication of Tensile Test Specimens

A minimum of (12) straight length (approximately 45 inch length) compacted copper rope conductor specimens (both single and multiple conductors) will be insulated using the proposed modular coil insulating scheme and vacuum impregnated using one of the epoxy systems being evaluated by the NCSX project. (See Figure 6)

These specimens will be used for tensile tests and the development of baseline for the modular coil copper conductor data. This activity includes the design and fabrication of a mold for impregnating the specimens.

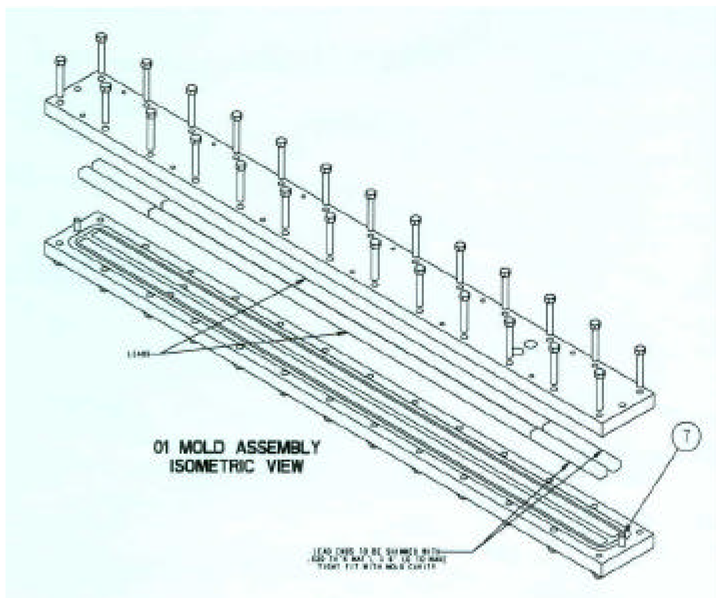


**Figure 6** VPI Mold for Conductor Tensile Specimens

### 3.1.8 Keystone Tests

These tests will be used to study tolerance control during the winding process. Maintaining tight current center tolerances is essential during the winding process to ensure efficient operation and performance of the modular coils. Keystoning of the copper braid conductor will occur during the winding process due to the number of tight bends and twists in the modular coils.

***<u>Keystoning</u>*** is a term used for the cross-sectional changes that occurs to a conductor during the winding operation.

A model of a typical modular coil will be designed/fabricated and used in these trials. (See Figure 7) Insulated compacted copper rope conductor will then be wound onto the winding form. A "FARO" mechanical measuring arm will be used to determine the degree of conductor growth as a result to winding. These tests will be performed using various conductors as determined by the NCSX project. Use of a single vs. multiple conductors will also be evaluated. A result of these tests may require special tooling to compensate/correct keystoning. The data obtained from these tests will be provided to the modular coil form design group in support of the PDR.

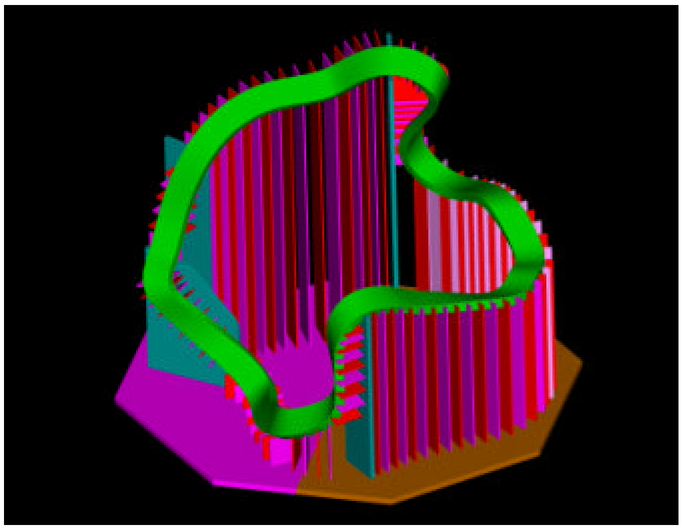

**Figure 7** Keystoning Winding Form

### 3.1.9 Develop Lead Routing Configuration for Modular Coils

This activity will review various options for routing the current carrying leads from the modular coil bundle. Options being considered include:

3.1.9.1 Coaxial leads exiting from the bottom of the coil along the sides to the outside area.

3.1.9.2 Routing the leads out between the winding pack via the tee section

3.1.9.3 Routing the leads out the top of the casting, but would include a locking joint on the bottom of the bundle

3.1.9.4 Additional options may be reviewed

***A recommendation for routing the leads will be made at the conclusion of this study.***

### 3.1.10 Design and Fabrication of Tooling and Equipment

Design, fabricate and demonstrate the tooling necessary for winding, handling and vacuum impregnating the modular coils. The present plans for final modular coil fabrication plan will require (2) winding stations plus (1) vacuum-pressure-impregnation station. Some of the major tooling will include:

3.1.10.1 Autoclave (vacuum/bakeout system)

Used during the epoxy impregnation of the modular coils. System must be able to be operated in either a vacuum or pressurized atmosphere while maintaining the required oven temperatures.

3.1.10.2 Winding station (support coils plus misc. winding tooling)

All miscellaneous tools and equipment not specifically identified that will be required to fabricate the modular coils.

3.1.10.3 Conductor Payout System

Provides support for the copper conductor from the payout spools, through the taping machine and finally to the modular coil structure.

3.1.10.4 Automatic Taping head

Equipment used to automatically apply multi layers of electrical insulation onto the selected copper conductor.

3.1.10.5 Hold-down winding clamps

Special clamps designed to securely hold the individual turns of modular coil in place during the winding operation.

3.1.10.6 Epoxy delivery system

Includes all elements of the system required to prepare and deliver the epoxy to the modular coils for VPI operation.

3.1.10.7 Coil handling equipment (lifting, etc.)

Any special equipment and fixturing required to handle the coils during fabrication.

#### 3.1.11 Winding and VPI of Prototype Modular Coil

The final activity for the winding development program will include a full demonstration of winding and vacuum impregnating a modular coil. A prototype modular coil will be wound onto one of the prototype stainless steel coil forms. The final NCSX project copper conductor, insulation and epoxy systems will be used. This activity will be used to verify/develop the fabrication procedures, verify the efficiency of the winding/VPI equipment, and to train the lead technicians responsible for the winding and VPI stations.

#### 3.1.12 Procedures & Process Plan for Winding and VPI of Prototype Modular Coil

Develop the final process plan and procedures for winding, vacuum impregnating and testing of the modular coils.

## 3.2 MATERIALS

### 3.2.1 Epoxy Resin

3.2.1.1 CTD-101K (primary candidate)

Modified (3-part) anhydride cured epoxy system with excellent performance at cryogenic temperatures.

| **Materials:** | **Designation:** | **Parts By Weight:** |
|---|---|---|
| Resin: | Part A | 100.0 |
| Hardener: | Part B | 90.0 |
| Accelerator: | Part C | 1.5 |

**Cure:**

| | |
|---|---|
| Initial Cure: | 5 hours @ 110 deg. C |
| Post Cure: | 16 hours @ 125 deg. C |

3.2.1.2 Alternate epoxy systems

TBD

### 3.2.2 Copper conductor

"Rectangular compacted copper cable": Various conductor sizes and numbers may be tested. TBD

### 3.2.3 Insulation

3.2.3.1 Glass Tape

S-glass (Harness Satin Weave) with reactive amino silane finish

Temperature class: 180 deg. C

Nominal thickness: 0.007 inches (0.1778 mm) tape

Nominal width: 1.0-inch tape

3.2.3.2 Glass Tape/co-wound with Kapton
S-glass (as noted in 3.2.3.1)
Kapton:
1 mil treated to assure epoxy bonding
Nominal thickness: 0.0035 inch (0.089 mm)
Nominal width: 0.75 inch
Dielectric strength: 7.5 KV per layer
Temperature Class: 180 deg. C

## 3.3 ENVIRONMENT, SAFETY, AND HEALTH (ES&H)

3.3.1 All work activities associated with this SOW shall comply with PPPL safety procedures and programs.

3.3.2 All personnel shall be adequately trained and have the appropriate certifications as required.

3.3.3 Proper use of JHA's, Confined Space Permits, Flame permits, Radiation Work permits, Lock-out/Tagout of energy sources, and restrictions on working alone shall be complied with.

## 3.4 QUALITY ASSURANCE PROVISIONS

3.4.1 Manufacturing, Inspection, and Test (MIT) and Quality Assurance (QA) Plans - The Job Manager shall provide an MIT plan to identify processes and materials and show their integrated flow into end items. The plan shall also identify critical manufacturing operations and inspections and tests. Procedures and/or protocols for contaminant control and cleanliness shall be included with the MIT. Preparing the Plan may include developing a flow chart and generating Process Sheets/Shop Travelers, etc. The Quality Assurance Plan shall describe the specific quality assurance and quality control procedures and practices to meet relevant PPPL and NCSX QA requirements and those of associated specifications. If the requirements of the QA Plan are addressed in the MIT Plan, then a separate QA Plan is not required.

3.4.2 Inspection and Test Procedures - Inspections and tests shall be performed in accordance with written procedures referencing criteria for acceptance or rejection. Actual data and accept/reject status for each inspection and test shall be documented.

3.4.3 Document Traceability and Records - The Job Manager shall maintain a system of documentation whereby objective evidence of required operations, inspections, examinations, and tests is systematically compiled, indexed and stored. Such objective evidence may include "travelers"; and material test, certification, inspection, examination, test and nonconformance reports; which shall be complete, legible, and validated by responsible personnel and shall be traceable to subject items.

3.4.4 Equipment/Material Identification and Status - Material and equipment identification shall be maintained throughout the program and be traceable to records. Status of acceptability shall be readily discernible through the Job Manager's use of tags, stamps, serial numbers or other positive means.

3.4.5 Calibration of Test and Measuring Equipment - Inspections and tests shall be performed using properly calibrated measuring and test equipment. The Job manager shall have in his/her possession the necessary equipment to perform the required inspections and tests. Calibration standards shall be traceable to the National Institute for Standards and Technology (NIST) or equivalent and shall not be used for shop inspections, but instead be protected against damage or degradation.

3.4.6 Control of Special Processes - The Job Manager shall use trained and qualified personnel and qualified written procedures in accordance with specified requirements for the performance of certain special processes, including but not limited to, welding, dimensional inspection, heat treatment, nondestructive examination, etc.

## 4.0 DELIVERABLES

The section identifies the activities being completed per this SOW. It also includes activity completion dates, and identifies the project milestone that activity is supporting.

4.1 Development of NEPA and WP documentation (Reference section 3.1.1)
Completion Date: **Nov. 1, 2002**

4.2 Generation of Job Hazard Analysis (JHA) Forms (Reference section 3.1.2)
Completion Date: **Prior to the start of all new R&D activity**

4.3 Selection of epoxy resin system for impregnating the Modular Coils. (Reference section 3.1.3)
Completion Date: **March 1, 2003**
Supports: **Modular Coil Winding PDR (June 03)**

4.4 Mechanical and Thermal Properties of Resin System
Completion Date: **April 14, 2003**
Supports: **PDR for Modular coil winding (June 2003)**

4.5 Development of VPI Process for Modular coils (Reference section 3.1.5)
Completion Date: **August 31, 2003**
Supports: **Modular Coil Winding PDR (June 2003) –*preliminary report***
**Modular Coil Winding Facility for Prototype FDR (September 2003)**

4.6 VPI of Test Coil from University of Tennessee (UT) (Reference section 3.1.6)
Completion Dates: Coil #1 **January 10, 2003**
Coil #2 **TBD**
Coil #3 **TBD**
Supports: **N/A**

4.7 Fabrication of Tensile Test Specimens (Reference section 3.1.7)
Completion Date: **February 14, 2003**
Supports: **PDR for Modular coils (June 2003)**

4.8 Keystone Tests (Reference section 3.1.8)
Completion Date: **April 1, 2003**
Supports: **PDR for Modular coil winding forms (June 2003)**

4.9 Develop Lead Configuration for Modular Coils (Reference section 3.1.9)
Completion Date: **April 30, 2003**
Supports: **PDR for Modular coil winding (June 2003)**

4.10 Design and Fabrication of Tooling and Equipment (Reference section 3.1.10)
Completion (*Design*) Date: **April 30, 2003**
Supports: **PDR for Modular coil winding (June 2003)**

Completion (*Fabrication*) Date: **February 2004**
Supports: **Winding of Prototype Modular coil**

4.10.1 Autoclave (vacuum/bakeout system) ***highest priority***
4.10.1.1 **PDR: January 8, 2003**
4.10.1.2 **FDR: January 31, 2003**
4.10.1.3 **Fabrication complete: August 1, 2003**
Supports: **Development of VPI Process** (activity 4.4)

***Note: Individual design reviews will be held as required for remaining tooling.***

4.10.2 Winding station (support coils and misc. tooling during winding)
4.10.3 Conductor Payout System
4.10.4 Automatic Taping head
4.10.5 Hold-down winding clamps
4.10.6 Epoxy delivery system
4.10.7 Coil handling equipment (lifting, etc.)

4.11 Winding and VPI of Prototype Modular Coil
Reference section 3.1.9
Completion Date: **May 31, 2004**
Supports: **FDR for Modular coil winding (TBD)**

4.12 Final Procedures & Process Plan for Winding and VPI of Prototype Modular Coil
Reference section 3.1.10
Completion Date: **July 31, 2004**
Supports: **Start of Modular Coil Fabrication (October 1, 2004)**