Specification For:

BNL - E951 15T Pulsed Magnet for Mercury Target Development
Neutrino Factory and Muon Collider Collaboration

Draft Sept 27 2002
ORGANIZATION

This specification consists of the following:
Section 1  Information and Requirements
Section 2  Sketches, Data, and Drawings
Section 3  Technical Data by Bidder/Seller

IMPORTANT NOTICE

No change to this specification shall be binding on any party until an addendum to the specification shall be accepted and has been approved by the purchaser, or the purchaser’s agent.

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<td>Arrangement and Bill of Materials</td>
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<td>Winding Dimensions, Internal and External Rib Dimensions</td>
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<td>Ramp and Filler Details</td>
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<td>MIT-BNL-9</td>
<td>Bore Support Tube and Coolant Shroud and Plenum Plate</td>
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<td>MIT-BNL-10</td>
<td>Joint Penetration and Coolant Inlet and Outlet Details</td>
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<td>Vacuum Bore Tube, and Vacuum Jacket Assembly</td>
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<td>Support Frame and Cold Mass Supports</td>
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<tr>
<td>MIT-BNL-13</td>
<td>Instrumentation, Flow Equalization, and Bore Heater</td>
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Section 3
Technical Data by Bidder/Seller

Names of subsuppliers not identified in the Purchaser’s technical documents.

Proposed winding procedures (if different from the Purchaser’s proposed winding procedure.

Deviation Request Forms

Non Conformance Forms
Section 1
Information and Requirements

1.1.0 Introduction and Information for Bidder/Seller

1.1.1 Definitions

**Bidder**  
A company submitting a proposal to fulfill the requirements of this Specification.

**Seller**  
The Company accepting the overall responsibility for fulfilling the requirements of this specification.

**Purchaser**  
Brookhaven National Laboratory

**Purchaser’s Agent**  
Massachusetts Institute of Technology (MIT)

**BNL**  
Brookhaven National Laboratory

**BNL Technical Representative(s)**  
Named BNL individuals, or their designees, who have contractual authority to:

- provide technical interpretation of this Specification and any future MIT supplied drawings and documents for this project,
- participate in key fabrication activities at Seller’s site for timely consultation and quality assurance purposes, and
- Approve the Deviation Request Form, and the Nonconformance Report.

**Non-BNL Technical Representative(s)**  
Named non-MIT individuals who are designated by BNL Technical Representatives to perform the same technical authority as BNL Technical Representatives.

**Pulsed Magnet**  
Short-hand for the BNL - E951 15T Pulsed Magnet for Mercury Target Development for the Neutrino Factory and Muon Collider Collaboration.

**Approved**  
This word, when applied to the Sellers drawings or documents means that the drawings or documents are satisfactory from the standpoint of interfacing with the Purchaser furnished components and that the Purchaser or his agent has not observed any statement or feature that appears to deviate from the specification’s requirements. Except for interface with the rest of the experimental system, the Seller shall retain the entire responsibility for complete conformance with all the specification requirements.

**The Drawing**  
Any and all detail and assembly, fabrication and machining drawings or sketches which are supplied by the Purchaser or his Agent to the Seller.
Codes  Documents that have the weight of law such as the National Fire Protection Association (NFPA), National Electric Code (NEC), ASME Boiler and Pressure Vessel Code.

Standards  Documents that are used as recommended guidelines by the various national standards organization such as ANSI and ASTM.

On Site  Location of the installation site for the pulsed magnet, Brookhaven National Laboratory, Long Island New York

Off Site  Any facility besides on site at which some of the assembly or testing may take place.

VPI  Vacuum Pressure Impregnation
1.1.2 Basis of Design

The principal goal of the E951 pulsed magnet is to provide a bore field of 15T for 1 second in an inertially cooled pulsed mode, with liquid Nitrogen or Helium gas cooling between shots. This will be a component of a Mercury jet target development for eventual use in the Muon Collider. The required bore clear diameter is a minimum of 15 cm with a conical exclusion zone at either end of the bore. Cost issues dictate a modest coil design. Power supply limitations dictate a compact, low inductance, high packing fraction coil. A three segment, layer wound solenoid is proposed for the pulsed magnet. Phased manufacture is supported. The second and or third segments may be purchased and installed in the cryostat later. The conductor is approximately half inch square, cold worked OFHC copper. The coil is inertially cooled with options for liquid nitrogen or gaseous Helium cooling between shots. Coolant flows through axial channels in the coil. The coils are epoxy impregnated in three assemblies. Wound coils of this small radius, using cold worked conductor, retain internal elastic stresses from the winding process, and if not impregnated, require elaborate clamping mechanisms to have the coil retain it’s shape.
1.1.3 Furnished by the Purchaser

Design criteria and requirements
Magnet design, analysis and engineering.
Cryostat conceptual design, and analytic basis for the initial sizing
Receipt handling and inspection at Brookhaven National Laboratory
Application of cryogenic foam after assembly

1.1.4 Furnished by the Seller

The Seller shall fabricate, assemble and ship all components of the E951 pulsed magnet, and its cryostat, and associated components as specified herein. This shall include, but not be limited to:

Manufacturing plan
Manufacturing procedures including a winding procedure
Procurement of all necessary materials in accordance with specified codes and standards
Performance of conductor bending tests prior to winding
Design and fabrication of tooling, winding mandrels, impregnation enclosures, insulation taping heads.
Winding of the required coil segments, Three (or two)
Electrical tests prior to and after impregnation
Electrical tests after assembly of the magnet in the cryostat.
Detailed fabrication of the cryostat and vacuum jacket in accordance with ASME VIII. A code stamp is not required by this specification.
Pressure testing of the cryostat, and it’s fluid connections.
Flow equalization tests, and application of flow corrections.
Acceptance tested cryostat, which satisfies the specifications in this Specification
Manufacturing drawings, Including Purchaser approved changes
Final As-Built Drawings
A documentation package fulfilling the requirements in this SOW, which shall be delivered with the pulsed magnet.
Cleaning and packaging
Delivery to Brookhaven National Laboratory

1.1.5 Milestones and Payment Schedule

The Seller shall submit, prior to award, a fix-priced quote and a Program Plan, which includes the following milestones and payment plan. Payment for completion of each milestone will be shown as a percentage of the total award amount of the fix-priced contract.
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<tr>
<th>Milestone</th>
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<tr>
<td>Fabrication plan, Including winding procedure</td>
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<tr>
<td>Completion of Fabrication and Procurements of Sub-Components</td>
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<td>Conductor Test Bend</td>
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<td>Impregnation of the Inner Coil Segment Winding</td>
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<tr>
<td>Completion of the Middle and Outer Coil Segment Winding</td>
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<td>Completion of all Coil Impregnations</td>
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<tr>
<td>Completion of Pulsed Magnet Cryostat</td>
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<tr>
<td>Completion of Coil insertion, and Cryostat Closure</td>
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<td></td>
</tr>
<tr>
<td>Acceptance Tests of The Pulsed Magnet and Cryostat Off Site</td>
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<td></td>
</tr>
<tr>
<td>Delivery of The Cryostat and Documentation to BNL</td>
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- Final Closeout payments shall not be less than 10%

1.1.6 Change in Cost
No change in cost of this project shall be allowed without a Seller’s revised cost proposal approved in writing by the Purchaser.

1.1.7 Status Reports
The Seller shall provide a short biweekly status report of the progress of the work against the milestones listed in Section 3.6. The Seller shall notify the Purchaser or the Purchaser’s Agent immediately of any changes, which affect the dates of the program milestones from those listed in the Seller’s Fabrication Plan.

1.1.8 Seller’s Technical Contact
The Seller shall assign one technical point of contact with whom all interface discussions between the Seller and Purchaser or the Purchaser’s Agent, shall initiate.

1.1.9 Applicable Documents
The following documents form a part of this specification to the extent specified herein. The issue date shall be the one in effect on the date of bid submittal.

American Society of Mechanical Engineers Boiler and Pressure Vessel Code
Section II Material Specifications
Section VIII Rules for Construction of Pressure Vessels
Section IX Welding and Brazing Qualification
ASME Y14.5M Dimensioning and Tolerancing for Engineering Drawings
American Welding Society (AWS)
A2.4 Symbols for Welding and Nondestructive Testing
A5.9 Corrosion Resisting Chromium and Chromium Nickel Steel Welding Rods
D1.1 Structural Welding Code – Steel
D10.4 Welding of Austenitic Chromium-Nickel Steel
QC-1-88 Certification of Welding Inspectors

American National Standards Institute (ANSI)
ANSI/ASQC C1-1996 General Requirements for a Quality Program
B46.1 Surface Texture

American Society for Testing and Materials (ASTM)
E493 Testing for Leaks Using the Mass Spectrometer Leak Detector in the Inside Out Testing Mode
E 498 Testing for Leaks Using the Mass Spectrometer Leak Detector in the Tracer Probe Mode
E 499 Testing for Leaks Using the Mass Spectrometer Leak Detector in the Detector Probe Mode
B193 Test for the Resistivity of Electrical Conductor Materials
B577 Test of Hydrogen Embrittlement of Copper
E8 Tension Testing of Metallic Materials
E18 Test for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials
B170 Oxygen-Free Electrolytic Copper Wire Bars
B188 Seamless Copper Bus Pipe and Tube
B187 Copper Bus Bar, Rod and Shapes
B353 Chemical Analysis of Copper (Electrolytic Determination of Copper
B342 Electrical Conductivity by Use of Eddy Currents

American Society for Nondestructive Testing, Specification 1A

Copper Development Association


Lawrence Livermore National Laboratory
MEL95-001817-00 Welding of Stainless Steel Components for Ultra-High Vacuum Environment
MEL95-001818-00 Fabrication and Handling of Components for Ultra-High Vacuum Environment
1.1.10 **Procurement, Fabrication, and Cancellation Provisions**

The procurement of material and the fabrication of the Sellers equipment and/or material shall not commence prior to the receipt by the seller of a written authorization from the purchaser, or his agent.

This authorization will be based on approval of the Seller’s manufacturing procedures and drawings.

If the Purchaser cancels the Purchase Order (or Contract) before authorization for fabrication, cancellation charges on this equipment shall be based only on actual expenses incurred, and shall not include fabrication charges.

1.1.11 **Subsuppliers**

The Bidder shall identify subsuppliers for any equipment, material or services covered by this specification at the time of the bid proposal.

The Seller shall submit, for review and approval, the names of all subsuppliers for any equipment, material or services covered by this specification not identified in the Purchaser’s technical documents, or not identified by the seller prior to the award of contract.

To the extent that they apply, the Seller shall impose on each of his subsuppliers the complete requirements of this specification. The Seller shall be directly responsible that subsuppliers are completely aware of the specification requirements.

1.1.12 **Quality Assurance Program Requirements**

**General Requirements**

The Seller shall prepare and implement a Quality Assurance (QA) program covering the procurement, inspection, testing, and fabrication of the BNL pulsed magnet. The Seller’s existing QA program may suffice if it adequately implements the quality requirements specified herein. The Seller’s QA program shall be consistent with guidelines established in ANSI/ASQC C1-1996, General Requirements for a Quality Program.

**Organization**

All organizations responsible for procurement and manufacture of the Product shall be identified. The duties, responsibilities, and authority of each functional group shall be established and the interfaces between them defined.

**Procurement Control**

The QA program plan shall establish procedures to assure that the Seller’s procurement activities are in compliance. All raw materials shall be procured with a material certification. The material of all procured components shall be identifiable. All raw materials and components shall be stored in a controlled area.
Process Control, Inspection and Testing

Quality requirements for manufacturing functions and the associated material handling and control, inspection and testing activities, and process equipment identification shall be planned, performed to written procedures, and documented.

Deviation and Non-Conformances

The QA program plan shall provide for disposition and resolution of departures from approved drawings, specifications, data, procedures, and standards. No work shall proceed on the proposed deviation, which has no impact on the project cost, until approved in writing from the Purchaser or his Agent. No work shall proceed on the proposed deviation, which changes the project cost, until approved in writing from the Purchaser or his Agent.

Deviations (Planned Departures Before The Fact)

Any planned deviation in material, workmanship, dimensional tolerances, procedures, records, or qualifications shall require written approval from the Purchaser or his Agent before proceeding. The Seller shall insure proper description, documentation, and response in requesting a deviation, as follows:

1) Complete the information of the type of deviation, the quantity of items involved, and other identification information.

2) Identify the requirements, which would be violated by the deviation, such as a violation of manufacturing drawing dimensions, specifications, codes, and/or standards, process procedures, QA verification, etc.

3) Describe the deviation.

4) Propose a disposition of the item, and detail justifications or facts to validate why subject planned deviation is an acceptable alternative.

5) Estimate the cost or schedule impact based on the recommended disposition.

6) Use the following terms to initiate response to the Deviation Report:
   - Routine: Seven days response required
   - Urgent: Three day response required
   - Emergency: 24 Hour response required

Nonconformances (Unplanned Departures)

A nonconformance is defined as any deviation from the Drawing or this specification, which has already occurred. Any nonconformance in material, workmanship, dimensional tolerances, procedures, records, or qualifications shall require written approval by the Purchaser or his Agent. The Seller shall insure proper description, documentation, and response in requesting a Nonconformance, as follows:

1) Complete the information of the type of deviation, the quantity of items involved, and other identification information.

2) Identify the requirements which would be affected by the nonconformance, such as a deviation of manufacturing drawing dimensions, specifications, codes, and standards, process procedures, QA verification, etc.

3) Describe the nonconformance
4) Propose a disposition of the item, and detail remedial actions or facts to validate such disposition.

5) Report the cause of the nonconformance and the corrective action to be applied to prevent the reoccurrence of this event.

6) Estimate the cost or schedule impact based on the recommended disposition.

7) Use the following terms to initiate response to the Deviation Report:
   - **Routine:** Seven days response required
   - **Urgent:** Three day response required
   - **Emergency:** 24 Hour response required

**QA Audits (External)**

The Purchaser or his Agent shall have the right to conduct an unannounced audit of the Seller’s QA program at any time during the project. Such an audit might include, but not be limited to the following:

- Welder Qualification Records
- Weld Inspector Qualifications
- Material Certifications

**1.1.13 Correspondence**

All correspondence regarding technical issues shall be directed to:

**Street/Mail Address:**

**Email Address:**

All correspondence regarding contractual issues shall be directed to:

**Street/Mail Address:**

**Email Address:**
1.1.14 Documentation

The minimum documentation required by this specification, and supplied by the Bidder and Seller is listed in the following table. All documents may be submitted by mail or electronically to those listed in the Correspondence section.

<table>
<thead>
<tr>
<th>Title</th>
<th>Submitted with the Bid</th>
<th>Submitted to Purchaser or Agent for Resolution, Acknowledgement or Approval</th>
<th>Available to the Purchaser or Agent at the Shop</th>
<th>Addended to Section 3 of this Specification</th>
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<td>Final As-Built Drawings</td>
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<td>Conductor Witness Samples</td>
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### Deviation Request Form

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<td>(24 hour)</td>
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**Date:**

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<th>From:</th>
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**Type:** material, part, subassy, final assy, procedure, design conflict, spec conflict

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<th>Requirements violated</th>
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<table>
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<tr>
<th>Remedial Action/ justification</th>
<th>see attached</th>
<th>Cause and corrective action</th>
<th>see attached</th>
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### Seller Approvals

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### Purchaser Approvals

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<th>Purchaser Disposition: accept request</th>
<th>deny request</th>
<th>see attached</th>
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</table>

<table>
<thead>
<tr>
<th>Purchaser or His Agent Signature</th>
<th>date</th>
<th>BNL Project Leader</th>
<th>date</th>
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## Nonconformance Report

<table>
<thead>
<tr>
<th>Routine</th>
<th>Urgent</th>
<th>Emergency</th>
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<tbody>
<tr>
<td>(7 day)</td>
<td>(3 day)</td>
<td>(24 hour)</td>
</tr>
</tbody>
</table>

### Date:

### To:  

### From:  

### Type:  
- material  
- part  
- subassy  
- final assy  
- procedure  
- design conflict  
- spec conflict  

### Item Name and serial number

### Dwg # or Spec#

### QTY nonconforming items

### Description of nonconformance  

### Requirements violated  

### Remedial Action/ justification  

### Cause and corrective action  

### Seller Approvals

<table>
<thead>
<tr>
<th>Recommended Disposition</th>
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</thead>
<tbody>
<tr>
<td>Accept redesign reject repair</td>
<td>date date</td>
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### Purchaser Approvals

| Purchaser Disposition: accept request deny request | see attached |

| Purchaser or his Agent Signature | date | BNL Project Leader date |

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1.2.0 Technical Requirements

1.2.1 Conductor Requirements

The conductor shall be CDA No. 10200 oxygen-free copper. The Required physical properties are enumerated in the following section on cold work and allowable stresses. The conductor shall have a room temperature conductivity of >100% IACS. The conductor shall be subjected to the electrical resistivity test prescribed in ASTM B193. The Conductor shall have a RRR value of: 35 after cold work as measured by ASTM.

1.2.1.1 Conductor Cold Work Specification and Allowable

The inner skin of the bore of the solenoid is allowed to reach the yield stress. - Treating this stress as a bending stress with a 1.5*Sm allowable with Sm based on 2/3 Yield.

Interpolated values: Work hardened copper-, OFHC c10100 60% red

<table>
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<th>temp deg k</th>
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<th>90</th>
<th>100</th>
<th>125</th>
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</table>

The maximum stress in the three segment coil is 166 MPa. Half hard copper should satisfy this requirement at liquid nitrogen temperatures. In order to minimize the difficulties of winding the first layers of the inner solenoid, it is intended that the conductor physical properties and degree of cold work be selected to just satisfy a 166 MPa yield stress. A winding test is required to verify feasibility of the winding process.

Prior to the purchase of the conductor, the Seller shall perform a test bend of a sample length of conductor, over a mandrel or bend fixture which has minimum radius required for winding the coil segments. The conductor sample shall have the same physical properties, - yield strength ultimate and % elongation, as the specified conductor, and shall have the same anti-keystone cross section specified for the inner coil segment. The test sample of the conductor shall be wrapped with glass tape, and the mandrel surface shall have a Kapton sheet applied. Cuts in the Kapton, or tears in the fiberglass tape shall be reported to Purchaser for resolution. Keystone dimensional changes shall be reported to the Purchaser and shall form the basis for final anti-keystoning dimensions. The selection of the conductor corner radius, and specification of degree of cold work in the conductor are to be confirmed by this test.

Witness samples of the conductor shall be taken from the beginning of the coil segment winding and at the end of the coil segment winding. Hardness checks shall be performed on these witness samples to verify the uniformity of the properties of the conductor lengths. Conductor Samples shall be available to the Purchaser’s shop inspector, and shall be shipped with the completed pulsed magnet assembly.
1.2.1.2 Conductor Joints

There shall be no joints in the more highly stressed inner coil segment. If required conductor lengths are not available for the second and third coil segments, silver solder scarf joints may be employed. An acceptable braze is Handy and Harmon SILFOS-5. A test joint shall be prepared and a pull test conducted. Results of the pull test shall be available to the Purchaser’s Shop Inspector. The pull test shall test to failure. Shear failure of the scarf joint is cause for rejection of the braze procedure. An acceptable braze procedure will produce tensile failure of the conductor net section. The Seller shall include sketches of the proposed scarf joint, and it’s position within the winding pack in his winding procedure submittal.

1.2.1.3 Keystoning and Conductor Dimensional Requirements:

At the first turn of the inner coil segment, the bending strain is $H/(2*r) = .012/1.2 = 6\%$ (elastic strain). For Plastic bending, (poisson=.5) the Keystoning contraction is 3%.

The Seller may choose to form the anti-keystone conductor cross section with rollers as a part of the winding process, or purchase conductor preformed with an appropriate anti-keystone cross section. If the keystone is formed at the time of winding, the keystone cross section shall be adjusted to that required for each layer.

If conductor is purchased with anti-keystone dimensions, It is judged impractical to specify keystone corrections for every layer. Three Keystone specs are chosen. The keystone geometry for the first coil segment should be .012/.15/2*.5 = 2%. Keystone allowances in outer two segments are 1.2%, and .86%.

1.2.1.4 Conductor Cleaning

The conductor shall be cleaned prior to winding. The Seller shall include his cleaning procedures and the chemicals in his winding procedure. As a minimum the conductor shall be degreased with a suitable solvent, washed with soap and water, dried, and finally wiped down with isopropl alcohohl.

1.2.1.5 Insulation Requirements
A good grade of fiberglass tape shall be utilized. Tape weave shall be specified to maximize wetting, and mechanical resistance during winding. The tape finish shall include silane, and shall be compatible with the epoxy system chosen. The insulation system is designed to minimize the radial inventory of Kapton layers to improve thermal conductivity to the cooling channels. This is the basis for omitting the turn to turn Kapton tape. The conductor is wound with only a half lap of 3 mil glass tape applied. At the surfaces that face the cooling channels, and between each layer, an interleaved layer of Kapton and fiberglass is applied. At the layers next to cooling channels (the first and eighth layer of each of the three magnet segments) Kapton arcs are to be added to the turn to turn insulation, every eighth turn. This is intended to create reliable mechanical separation with insulation to allow the expected axial contraction of the layers closest to the cooling channels.

Manufacturers, and manufacturer’s designations for the fiberglass tape, and Kapton tape shall be included in the Seller’s winding procedures, and are subject to the approval by the Purchaser or his agent.

1.2.1.6 Winding Requirements

The seller is responsible for selecting the winding process that will best achieve the required coil geometry, insulation configuration, and impregnation quality. The high packing fraction requirement, and sequential assembly of the three magnet segments, require a tightly controlled radial build-up of the layers. Meeting the required number of turns in the axial direction requires a tight tolerance on axial build-up. Details of the winding geometry are included in the drawings included in Section 2.

<table>
<thead>
<tr>
<th>Winding Data (Applicable to Sections 1, 2 and 3 of the Magnet)</th>
<th>Section 1</th>
<th>Section 2</th>
<th>Section 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of turns per segment</td>
<td>624</td>
<td>624</td>
<td>624</td>
</tr>
<tr>
<td>Layers in each coil segment</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Turns per layer</td>
<td>78</td>
<td>78</td>
<td>78</td>
</tr>
<tr>
<td>Conductor radial dimension</td>
<td>.0116698 m</td>
<td>.0116698 m</td>
<td>.0116698 m</td>
</tr>
<tr>
<td></td>
<td>.45944 in</td>
<td>.45944 in</td>
<td>.45944 in</td>
</tr>
<tr>
<td>Conductor Axial dimension</td>
<td>.012516 m</td>
<td>.012516 m</td>
<td>.012516 m</td>
</tr>
<tr>
<td></td>
<td>.49274359 in</td>
<td>.49274359 in</td>
<td>.49274359 in</td>
</tr>
</tbody>
</table>

A possible winding method is described in section 1.3. The bidder shall describe his proposed winding procedure, and any change to the purchaser’s suggested procedure as a part of bid proposal. The Seller’s winding procedure shall be submitted to the purchaser for review and approval.

Layout of the winding spools, rollers, and tensioning rollers (if used) should be such that the insulation is applied after contact with the rollers, and the feed and roller layout
should be such that the conductor bend curvature (whether from the supply spool winding or imposed by a set of feed rollers), prior to the tensioning stage, is as close to its final wound radius of curvature as possible. This is intended to reduce spring-back and locked in strain energy that must be resisted by clamps and blocking. The taping head (if used) should be designed such that a tape jam automatically stops the taping process before the tape is torn or the conductor is damaged. To the extent possible sufficient fiberglass tape shall be spooled to minimize tape end/start laps. If needed, these should be applied in the end transition region of the layer winding.

1.2.1.7 Epoxy System Selection

The Epoxy system shall use a good cryogenic grade of epoxy such as CTD 101K. The Seller shall propose an epoxy system which the Seller has used successfully with prior magnet impregnations. If a system is proposed with which there is not adequate prior experience, the Seller shall demonstrate the acceptability of the epoxy and impregnation procedures with a mock-up that includes similar conductor and insulation details, and similar percolation path lengths. The impregnated sample shall be cut as needed to demonstrate that no voids developed. As a minimum, the epoxy cure characteristics shall be tested as described below:

Cure test

Acceptable cure behavior of the epoxy system shall be demonstrated prior to impregnation with a test cure. Exothermic behavior is affected by chemistry, the thickness of the sections, and thermal mass of the conductor. For the pulsed magnet, approximately a quart container filled with epoxy, and scrap copper shall be cured. Viscosity, and exothermal behavior of the cure shall be tested. Exothermic behavior that might cause regions of the coil to go above the epoxy glass transition temperature during the cure must be reduced with appropriate adjustments in the epoxy system.

The Seller shall submit the manufacturer and manufacturer’s designation of the resin, hardener, and accelerator in his winding procedures. The selection of the epoxy system is subject to the Approval of the Purchaser, or his Agent.

1.2.1.8 Vacuum Pressure Impregnation (VPI) Requirements

An impregnation and cure in the same autoclave is preferred. The pressure and temperature control of the autoclave alleviates some of the concerns with the coil mold design.

Vacuum fill in a tank with subsequent transfer to a cure oven is also acceptable.

Flow Logic and Fill Direction

Epox fill shall be from bottom to top, with an ample reservoir provided at the top of epoxy exit sprue. Fill paths shall be laid out to minimize short circuiting the flow between inlet and outlet around the windings. Dams, or baffles shall be provided in any free space to force flow into the winding. The pulsed magnet segments have terminal break-outs at
one end. They shall be included in the pressure boundary or sealed against the pressure boundary. If sealed to the pressure boundary, the coil shall be impregnated vertically with the break-outs at the top.

The Seller shall submit sketches of the fill logic to the Purchaser or his agent for review and approval. These shall show coil orientation, pressure boundary components and sealing mechanisms, locations of dams, and baffles, filler pieces, peal-ply – Tedlar or Teflon sheet locations.

The mold pressure boundary may be made up from the winding mandrel and added external shells or rubber bags. Care should be taken to seal the area around the conductor break-outs. Insulation and epoxy application beginning three inches after the break-out and on the lead stems may be done after the impregnation by hand lay-up. Prior to impregnation, the high pressure capability of the impregnation pressure boundary shall be demonstrated by maintaining a 50% over pressure for 1 hour. The vacuum integrity shall be demonstrated prior to the VPI by drawing a vacuum and holding it for a minimum of 12 hrs with less than ___ loss in vacuum.

After the initial vacuum epoxy fill, the pressure shall be cycled between one atmosphere and vacuum multiple times. Provision should be made for addition of epoxy to the top reservoir during pressure cycling.

A pressure of ___ atmospheres shall be applied to the epoxy volume during the cure process to reduce the size of any residual voids in the impregnation.

Application of cure temperature, shall be monitored adequately to ensure uniform temperature. Exothermic properties of the epoxy cure shall be considered when setting the target cure temperature. If steam or oil heat is used, measurement of inlet temperature shall be made along with thermocouples in the coil at those regions where thermal conduction would produce the lowest temperature. If autoclave cure is used, a forced convection feature should be included in the autoclave, along with adequate temperature sensors within the autoclave and magnet to demonstrate full penetration of the cure temperature. If electric strip heaters are used, the coil and mold/mandrel shall be generously instrumented to ensure there are no hot spots. Multiple heater zones with independent controls shall be employed.

1.2.1.9 Electrical Testing

The Seller shall assign a trained personnel and provide all necessary test equipment including digital multimeters for resistance measurement and DC hipot testers for ground insulation testing, during assembly process and at the completion of the pulsed magnet. Electrical testing of the electrical connection and component, including pulsed coil and bus connection, sensors, and diagnostic wiring, shall be performed at the point in the assembly when a component will become inaccessible for service.
The checkpoints and the type of electrical testing during assembly stage shall be defined by the Seller in the fabrication plan and approved by the Purchaser’s Representative. The Purchaser or his Agent shall be notified a minimum of ten working days prior to this test to allow the Purchaser’s Inspector to witness the tests.

1.2.1.10 Flow equalization tests, and application of flow corrections.
The Seller shall perform a flow test of the assembled magnet by blowing air in the Helium outlet connection, and with the flat cover of the cryostat removed, flow velocity of each channel shall be measured with HVAC flow Anemometer, a Pitot tube. Restrictions on the channels will be applied until uniform flow is achieved. Restrictions can be in the form of g-10 strips bonded into portions of the channel opening. Flow variations of less than 20% from the average are acceptable. The Purchaser or his Agent shall be notified a minimum of ten working days prior to this test to allow the Purchaser’s Inspector to witness the tests.

1.2.2 Vessel Requirements

Vessel components including the cryostat and vacuum jacket, shall be manufactured, inspected and tested in accordance with ASME VIII. In recognition of the non-standard design features of the pulsed magnet vessels, a code stamp need not be applied.

Base materials for the vessels shall conform to the Purchaser’s Drawings, and shall be procured under an ASTM or ASME specification.

The design pressure of the vacuum jacket is +/- 1.0 atmospheres
The design pressure of the Helium cryostat is 20.0 atmospheres gauge. (21 to the vacuum jacket)

1.2.2.1 Vessel Welding Requirements

Weld joints shall blend into the adjacent base metal in gradual smooth curves, using acceptance criteria consistent with ASME Boiler and Pressure Vessel Code Section VIII. All welds shall be visually inspected by AWS Certified Weld Inspectors (CWI), Certified Associate Weld Inspectors (CAWI) under the supervision of a CWI, or in-house NDE inspectors trained in accordance with the ASME Code. All final weld inspection shall take place after straightening, realignment, or stress relieving of welded assemblies.

Weld Design

Unless otherwise specified in the Purchaser’s Drawings, or approved by the Purchaser or his Agent, the design of pressure boundary welds shall conform to the general design philosophy of the ASME Boiler and Pressure Vessel Code, Section VIII, Division I, part UW, as required for structural soundness. Non vacuum boundary structural welds on low carbon steel (where applicable) shall conform to AWS D1.1.
Weld procedures and welder qualifications

Seller shall fabricate this vessel only at a facility that has an established weld quality assurance program that establishes written procedures and qualification records as described below.

**Weld Procedure Specification (WPS)**
A WPS is required for each weld process, combination of wire filler and base metal type and size to be used in the construction of this vessel. The format of this procedure shall be equivalent to AWS D1.1 Appendix E.

**Procedure Qualification Record (PQR)**
A PQR is required for each Weld Procedure Specification. Each PQR shall be prepared in accordance with ASME Boiler and Pressure Vessel Code or AWS D1.1, and signed by a Certified Welding Inspector, NDE inspector, or qualified QC inspector.

**Welder Qualification Test Record**
A Welder Qualification Test Record is required for each welder or welding operator covering each welding process, and shall be prepared in accordance with ASME Boiler and Pressure Vessel Code or AWS D1.1, and signed by a Certified Welding Inspector. Certifications shall indicate that the welder has demonstrated the ability to make sound welds of the same type and position, for the same process and materials, using the same equipment as specifically required for fabrication.

**Weld Inspector Certification**
Weld inspectors shall be certified in accordance with ASME Section VIII or AWS QC1-88, as appropriate, for the specific type of testing or inspection being accomplished.

**Filler Metal Storage**
All welding wire and flux (if applicable) shall be stored in accordance with AWS D1.1 or ASME Boiler and Pressure Vessel Code, as applicable.

**Weld Symbols**
Weld symbols on sketches and drawings shall be interpreted in accordance with AWS

**Weld Identification**
The Seller shall maintain records identifying the welders associated with each weldment. Each welder shall be assigned a unique symbol or identification number that cannot be transferred.

**Weld Filler Metal**
Electrodes and filler wire for vacuum boundary welds shall conform to ASME Boiler and Pressure Vessel Code, Section II, Part C.
1.2.2.2 Tests

**NDE Examination and Certification**

Non-Destructive Evaluation (NDE) personnel shall be qualified in accordance with ASNT-TC-1A.

**Proof Pressure Test.**

The vessels shall be tested at a pressure not less than 1.5 times the difference between the design pressure and normal atmospheric pressure[ASME B&PVC Sec. VIII –Div. 1 UG-99 (f)]. A standard hydrostatic pressure test is required at $1.5P_{\text{design}}$ [ASME B&PVC Sec. VIII –Div. 1 UG-99 (f)] to validate the design. The Helium cryostat shall be tested first, prior to the addition of the vacuum jacket. This will allow inspection of the vessel welds. A hydro test is not desirable due to the use of the cryogenic mechanical seal on the closure head, and a hydro test is not practical for the vacuum jacket due to the inclusion of MLI insulation. A pneumatic test is permitted [ASME B&PVC Sec. VIII –Div. 1 UG-100]. The vessel pressure is raised gradually in step-wise fashion [ASME B&PVC Sec. VIII –Div. 1 UG-100 (d)] until the test pressure is reached. The pressure is then reduced to 4/5ths of the test pressure and held there only for a time sufficient to permit inspection. The Purchaser or his Agent shall be notified a minimum of ten working days prior to this test to allow the Purchaser’s Inspector to witness the tests.

1.2.2.3 Inspection and Testing

The Seller shall perform inspections and tests to assure conformance to this specification.

**Visual Inspection**

The minimum inspection requirement for all welds in this specification shall be a visual inspection in accordance with ASME Section VIII or AWS D1.1, as appropriate. Visual inspection shall include a pre-weld check of joint preparation and fit-up, as well as for straightness, alignment and perpendicularity, as specified in the drawing.

**Leak Testing with a Helium Leak Detector**

Seller shall assign trained personnel and provide all equipment necessary to perform helium leak testing, which includes helium leak detectors with a dry pump or a diffusion pump with a LN cold trap, calibrated leaks, calibrated sniffer, roughing pump with cold trap, traps, port covers, valves, piping, bellows, connection hardware, gauges, bottled helium, and liquid nitrogen.

Vacuum leak test will be the only acceptable leak checking procedure in the present project. The sniffing method will be used as rough screening when the targeted boundary cannot support a negative pressure in the contained volume. Any inspection with sniffing method shall be re-inspected with vacuum leak test in the later assembly stage.
Alternate leak checking procedures proposed by the Seller shall not be substituted unless specifically approved in writing by The Purchaser or his Agent. The checkpoints and the type of helium leak checking during assembly stage shall be defined by Seller in the fabrication plan and approved by MIT Technical Representative.

**Vacuum Tests**
The following shall be performed in the prescribed order:

1) Evacuate vessel to maximum pressure of $10^{-3}$ torr using a dry pump or a LN trapped roughing pump.

2) Leak testing shall be performed with a mass spectrometer leak detector in accordance with ASTM E493, ASTM E 498, or ASTM E 499. Two standard calibrated leak devices are required for this test. Both shall have been calibrated within two years, and both shall be used to calibrate the leak detector immediately prior to the leak test. After leak detector calibration, one calibrated leak shall be connected directly to the vessel through an isolation valve, and the other shall be connected directly to the leak detector through an isolation valve. Appropriate valving shall be provided so that the roughing pump and the leak detector can be individually isolated from the vessel.

3) Spot leak checking shall be performed using an external helium source while the leak detector is pumping the vessel.

4) Final leak checking shall be performed by enveloping (bag) the entire vessel in a helium filled enclosure for a minimum of 10 minutes while the leak detector is pumping the vessel.

5) The maximum allowable leak rate shall be $10^{-8}$ std atm-cc/second (helium) with all pump effluent to a residual gas analyzer or mass spectrometer leak detector.

**Sniffing Tests**
The following shall be performed in the prescribed order:

1) Confirm the sensitivity of sniffer is better than $5 \times 10^{-5}$ std atm-cc/second helium with a calibrated helium source.

2) Use an appropriate temporary cover to close the vessel / volume, and introduce helium gas into the test volume without cracking the temporary seal.

3) Confirm the background helium reading is below the sensitivity of the sniffer.

4) Spot leak checking shall be performed by inserting the sniffer in the envelop, which covers the outer surface of the joint area.

5) At high background helium count, consider isolating the first envelop from the background with a second envelope, which is flushed with nitrogen gas.

6) Remove leak checking attachments and clean up the surface. Flush out helium gas if necessary.

**1.2.2.3 Vacuum Vessel Requirements**
The Vacuum jacket/vessel shall be constructed in accordance with the Purchaser’s Drawings in Section 2, and the following additional requirements.
Vacuum Boundary Welds
Weld joints shall be welded so that there are no cracks, crevices or incomplete fusion remaining on the vacuum side of the joint. Within the joint, there shall be no trapped volumes that could act as a virtual leak. There shall be no welds that consist of continuous partial penetration welds on both sides of a vacuum boundary joint. For partial penetration joint designs, the vacuum side shall be continuous and the outside weld shall be intermittent. The skin surface of the vacuum side of the joint shall not be broken or machined.
Weld smoothness shall be sufficient to facilitate cleaning by hand with clean room quality wipe cloth to Mil-Std-1246C level 500 without snagging or tearing the wipe material.

Vacuum vessel fabrication Requirements

Cutting Fluids
The following cutting fluids have been tested for low residual outgassing after high pressure, hot water washing with surfactants. No other cutting fluids shall be used unless specifically approved by the Purchaser or his agent.

<table>
<thead>
<tr>
<th>Cutting Fluid</th>
<th>Manufacturer</th>
<th>Address</th>
<th>Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synspar GP</td>
<td>IPG Industrial Products Group</td>
<td>A Division of Spartan Chemical Company, IN 110 N. Westwood Ave, Toledo, OH 43607</td>
<td>(604) 526-0551</td>
</tr>
<tr>
<td>Blaser 4000 Strong</td>
<td>Swiss Instrument/Belmag Machinery</td>
<td>71A Clipper St Coquitlam, B. C.</td>
<td>1-800-537-8990</td>
</tr>
<tr>
<td>Dascool #2227 &amp; #2227B</td>
<td>D.A. Stuart Company</td>
<td>4580 Weaver Parkway Warrentville, IL 60555</td>
<td>630-393-0833</td>
</tr>
<tr>
<td>Trim-Sol</td>
<td>Master Chemical Corp.</td>
<td>501 W. Boundary Perrysburg, Ohio 43551-1263</td>
<td>1-800-537-3365</td>
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<tr>
<td>Dascool #2227 &amp; #2227B</td>
<td>D.A. Stuart Company</td>
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<td>630-393-0833</td>
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<td>Trim-Sol</td>
<td>Master Chemical Corp.</td>
<td>501 W. Boundary Perrysburg, Ohio 43551-1263</td>
<td>1-800-537-3365</td>
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<tr>
<td>Cimtech #410</td>
<td>Cincinnati Milacron Corp.</td>
<td>Cincinnati, Ohio 45209</td>
<td>513-841-8978</td>
</tr>
<tr>
<td>Ecosyn #00SND</td>
<td>Fuchs Lubricants Co.</td>
<td>Harvey, Ill. 60426</td>
<td>(709) 333-8900</td>
</tr>
<tr>
<td>Cimtech #3700</td>
<td>Cincinnati Milacron Corp.</td>
<td>Cincinnati, Ohio 45209</td>
<td>513-841-8978</td>
</tr>
<tr>
<td>Orion Synthetic #7397-2</td>
<td>Vulcan Oil &amp; Chemical Products</td>
<td>5353 Spring Grove Ave Cincinnati, Ohio 45217</td>
<td>(513) 242-2672</td>
</tr>
<tr>
<td>WOCO WS-6500</td>
<td>Wallover Oil Company</td>
<td>1032 Pennsylvania Ave. East Liverpool, Ohio 43920</td>
<td>(330) 385-9336</td>
</tr>
<tr>
<td>WISCO #4776\</td>
<td>Wisco</td>
<td>P.O. Box 20893 Indianapolis, Indiana 46220</td>
<td>(317) 784-4689</td>
</tr>
</tbody>
</table>
Tool Materials
If any stainless steel weld slag requires removal, it shall be done with a clean stainless steel brush, file, burr, or chisel. Abrasive cutting and grinding wheels are acceptable for use on stainless steel only if they are used exclusively on stainless steel and not contaminated with other material. Abrasive polishing compounds shall not be used.

Vacuum Sealing Surfaces
All surfaces which interface with a vacuum seal shall have a 0.80 micrometer RMS (32 microinch) finish. All o-ring seal surfaces shall be free of dirt, grit, dust and any other contaminants that would prevent a seal or compromise a high vacuum system. Machining or polishing marks shall run parallel to the o-ring seal.

O-Ring Surface Protection
O-ring surfaces shall be protected during subsequent assembly, packaging, or shipping operations to prevent contamination or scoring. Type of protection selected shall not leave residues that could contaminate a vacuum system.

Vacuum Vessel Interior Wall
Final surface finish of all vessel walls exposed to vacuum shall be sufficient to facilitate cleaning by hand with clean room quality wipe cloth to Mil-Std-1246C level 500. This can be accomplished by prepolishing the construction material prior to fabrication. Leak check acceptance testing shall be accomplished only after any internal polishing or finishing is complete.

Exterior Painted Surfaces
If low carbon steel is used in a part of the fabricated assembly (such as a support stand), these surfaces shall require preparation, priming, and painting. Paint shall be Sherwin Williams designated Polane paint #63EXL609-4394 (Emeryville, CA 510-658-0877) or Purchaser-approved equivalent.
Painting preparation shall remove mill scale, dirt, rust, grease, oil and foreign matter. Sandblasting, bead blasting, or wire brushing is recommended for surface preparation. Prime with E65A71 Polane Plus Sealer available from Sherwin Williams, lightly sand with #220 wet dry paper, and apply designated polane paint.
The Purchaser reserves the right to approve surface preparation before all painting.

Exterior Unpainted Surfaces
Exterior stainless steel surfaces that are not vacuum sealing surfaces shall be bead blasted to a matte finish or electro polished.
Forming
If brake forming is selected as a fabrication process by the seller, it shall be followed by a visual inspection of bend points to verify that cracking has not occurred.

1.2.3 Magnet/Vessel Assembly Acceptance Testing

The Purchaser or Purchaser’s Agent shall be notified at least 10 working days in advance of acceptance testing at the Seller’s facility so that Purchaser or his Agent can be sent to witness the tests.

1) Upon completion of the vacuum vessel close-out welding, the Seller shall perform vacuum leak testing of the vacuum jacket in accordance with Section 3.2.2.1 under the following conditions:
   a. Close all openings of the LHe compartment and LN jacket. Evacuate the vacuum jacket and perform vacuum helium leak checking of the outer surface of the vacuum jacket.
   b. Evacuate, back fill, and pressurize the LHe compartment with helium gas up to 15 psig and hold for 10 minutes while the helium leak detector is leak checking the vacuum jacket.
   c. Evacuate, back fill, and pressurize the LN jacket with helium gas up to 30 psig and hold for 10 minutes while the helium leak detector is leak checking the vacuum jacket.

2) Demonstrate that all sensors and diagnostic wires are properly connected to the pin connectors on the joint flange without unwanted shorting in accordance with Section 3.2.3.1.

Demonstrate that the pulsed magnet coil are electrically connected with acceptable ground insulation in accordance with Section 3.2.3.

1.2.4 Preparation for Shipment

The Pulsed Magnet shall be shipped completely assembled in it’s cryostat/vacuum jacket. The interior of all equipment shall be free from all foreign material such as welding rod, waste, mill scale, oil, grease or other deleterious material. The Pulsed magnet shall be suitably crated or boxed to protect against damage during handling and shipping. All ports blanked off with bolted covers. Bellows Extensions shall be wrapped with foam packing material, and taped. The box/crate shall be sealed against the weather, and have handling and rigging instructions and precautions printed on the outside.
1.3. Purchaser Design Basis Winding procedure.

The Coil is layer wound on mandrels. Mandrels maintain a precise bore geometry to facilitate later assembly of the segments. The coil is fabricated in three segments. At assembly of the magnet, the outer two segments are slipped over the inner segments. Phased manufacture is allowed, with the possibility of the outer one or two coil segments being added at Brookhaven.

The insulation system is designed to minimize the radial inventory of Kapton layers to improve thermal conductivity to the cooling channels. This is the basis for omitting the turn to turn Kapton tape. The conductor is wound with only a half lap of 3 mil glass tape applied. The winding begins with a preparation of the mandrel surface. It will be a part of the impregnation mold, and release agents are applied at this time. The annular cooling channel insulation is applied next. This is an interleaved layer of Kapton and glass tape similar to that used subsequently between layers. The conductor that forms the terminal break-out is fitted through slots provided in the mandrel flange. At the completion of a layer, an interleaved layer of Kapton and fiberglass is applied. This will have to be done manually, assuming the pay-out rolls of the conductor can’t be rotated with the mandrel. In the first and last layers of the coil segment, Kapton arcs are to be added to the turn to turn insulation, every eighth turn. This is intended to create reliable mechanical separation with insulation to allow the expected axial contraction of the layers closest to the cooling channels.
**Mandrel and Impregnation Mold Design**

Three separate mandrels are planned, each of these forms part of the vacuum impregnation boundary. The precision of the inner bore of the impregnated coil relies on the precision of the mandrel design. The mandrel will need to be capable of disassembly so that it can be removed from the bore. A four piece split mandrel design is suggested. A keystone segment is included that can be pressed out after impregnation. The mandrel segments must be sealed for the VPI process, and an outer shell added and sealed against the mandrel flanges. Terminal extensions will have to be encased, and sealed. The mandrel winding surface will have four sets of two grooves machined in it that will form “stops” to engage the ribs on the outer surface of inner coil segment, and provide twisting registration of the assembled coil segments.

**Formation of Outer Radial Support Ribs.**

Ribs in the form of fiberglass strips are bonded to outer surface of the wound and impregnated coil. It is not recommended that these be formed in the impregnation process because the insulation thickness of the outer layer of the winding needs to be minimized to ensure adequate thermal conduction to the cooling channel that is formed by the ribs. This can be done with a vacuum bag on the OD which is tightly wound. The coil geometry is specified to allow a tolerance of -0+2mm on the OD of the winding. That is the target dimension of the coil would produce a 4mm channel gap, but a 2mm gap is allowed. The radial accumulation of tolerance as the eight layers are applied cannot exceed the 2mm allowance, or there will be insufficient coolant flow.

Ribs are machined to match the ID of the next coil segment. Coils are slipped on to one another. – with a temperature difference if needed. Two methods of obtaining a thermal difference between coil segments are acceptable. The inner assembly can be cooled with liquid nitrogen, and/or the outer segment may be resistively heated. If the later method is employed, the temperature of the magnet shall not be heated beyond 20 deg. C below the epoxy glass transition temperature.
Section 2
Drawings, Sketches, and Data

<table>
<thead>
<tr>
<th>MIT Drawing #</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
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Section 3
Data by Bidder/Seller

Names of subsuppliers not identified in the Purchaser’s technical documents.

Proposed winding procedures (if different from the Purchaser’s proposed winding procedure).

Deviation Request Forms

Non Conformance Forms