

Technical Specification

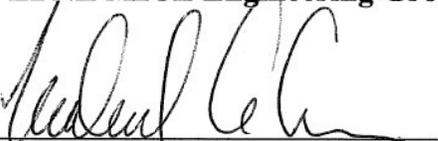
MICE Spectrometer Solenoid Magnets Fabrication, Assembly, Test and Shipping

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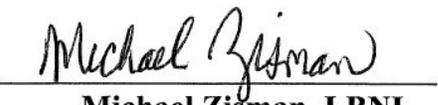
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1/23/08	Modified Section 3.8.10 to include support base plates Added Section 3.10.7 regarding diffuser mechanism mount Added Section 3.13 regarding magnet discharge circuits Updated Figure 2 to incorporate changes Updated Figure 5 to incorporate support stand changes Added Figure 10 regarding diffuser mechanism mount

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ATTACHMENTS

Attachment 1: Magnet chapter from the MICE Technical Reference Document

Attachment 2: Nb-Ti Superconducting Wire for the MICE Solenoids – Spec LBNL-10153

Attachment 3: MICE Cleaning and Welding Procedure – Note LBNL-10150

Attachment 4: MICE Vacuum Leak Check Procedure – Note LBNL-10151

Attachment 5: Specification for MLI for the MICE Magnets and Absorbers – Spec LBNL-10152

1. General Information

The subcontractor shall fabricate for the Lawrence Berkeley National Laboratory (LBNL) two (2) superconducting spectrometer solenoids that are described within this specification. Please refer to the magnet chapter from the MICE Technical Reference Document for background information (Attachment 1). Each spectrometer solenoid includes: the coil cold mass, the helium cryostat, intermediate temperature shields and cold mass intercepts, the magnet vacuum vessel and support stand, 4 K cryo-coolers for cooling the magnet, magnet leads, magnet instrumentation, testing of the magnet at the subcontractor's fabrication facility, and the packing and shipping of the magnets to the Rutherford Appleton Laboratory, Chilton-Didcot, United Kingdom.

The magnet coil shall be wound with conductor supplied to the subcontractor by the Lawrence Berkeley National Laboratory. The conductor is being purchased in accordance with the attached superconductor specification (Attachment 2). The actual conductor will have an insulated cross section that is 1.65 mm wide and 1.00 mm thick. The insulating material is Formvar, and the superconductor alloy is standard grade. The conductor will consist of 222 filaments of 41 μm diameter having a copper-to-superconductor ratio of 4.0. Cooling for each magnet will be provided by three cryo-coolers.

One detector magnet assembly consists of five coils that fit into a cryostat that is approximately 2735 mm long assembled together to give a single cold mass. There are two matching coils that will be tuned to match the muon beam between the spectrometer coil set and the focusing coil set. The three spectrometer solenoid coils generate a uniform magnetic field (good to better than 1 percent) in a detector volume that is 1000 mm long and 300 mm in diameter. The matching coils and the spectrometer magnet coils are designed to operate using three 350 A, 10 V power supplies. The three coils in the spectrometer part of the magnet (the two end coils and the center coil) are connected in series and are powered from one of the 350 A power supplies. The two match coils each have their own 350 A power supply. Two 50 A, 5 V power supplies are connected across end coil #1 and end coil #2, respectively, to permit fine tuning of those coils with respect to the center coil. The longitudinal forces that are to be carried by the detector magnet cold-mass support system are less than 0.50 MN during the anticipated operating and failure modes of the experiment.

2. Applicable Codes and Standards

The following is a list of various codes to be applied to the design, fabrication, assembly and testing of the MICE Spectrometer Solenoid magnets. Where applicable, the use of equivalent international codes and standards is acceptable. The magnets will be operated as part of an experimental system located in the United Kingdom.

- 1) ASME – American Society of Mechanical Engineers
 - Boiler & Pressure Vessel Code - Section VIII
 - Properties of Material, Design – Section IID
- 2) ASME Y14.5M-1994 Dimensioning Tolerance Code
- 3) ASTM International – American Society for Testing and Materials
 - Material Specification for Stainless Steel
 - ASTM E-498 Standard Test Methods for Leaks Using the Mass Spectrometer Leak Detector or Residual Gas Analyzer in the Tracer Probe Mode
- 4) AWS – American Welding Society, Section D1.1
 - Welding technique, testing, welder qualification and weld rod specification
- 5) AVS – American Vacuum Society
 - Vacuum Leak Check Standard 2.1
- 6) ISO – International Organization for Standardization
 - For metric fasteners, threads and flange specification
- 7) LBNL Publication 3000
 - LBNL Health and Safety Manual available at the following URL:
<http://www.lbl.gov/ehs/pub3000/>
- 8) ASA – American Standard Association
 - Material, flange, elbow and reducer specification

3. Fabrication Requirements

3.1. General Requirements

The MICE Spectrometer Solenoid magnets shall be designed, fabricated and assembled according to the dimensions and instructions detailed in this specification. The subcontractor shall develop the design and the fabrication and assembly processes using accepted engineering practices that meet the LBNL design requirements.

3.2. Spectrometer Solenoid Magnet Coil Positions and System Design

3.2.1. Spectrometer Solenoid Magnet Description

Table 1 provides many of the basic parameters of the spectrometer solenoid. Tolerances are provided on many parameters where appropriate. The tolerances are reflected in Table 1, the attached drawings and in the text of this specification.

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The solenoid shall consist of five independent coils; match coil 1, match coil 2, end coil 1, the center coil, and end coil 2. End coil 1, the center coil and end coil 2 shall be connected in series so that the field polarity of each of the three coils is the same direction when current flows through the coils. The three coils in series form the spectrometer solenoid. Match coil 1, match coil 2, and the spectrometer solenoid shall be connected to leads A-B, leads C-D, and leads E-F respectively. Leads shall be connected to the ends of the center coil so that the two end coil currents can be adjusted for matching to the rest of the MICE channel and for ensuring the field uniformity within a 1-meter long region that is 0.3-meter diameter in the warm bore of the solenoid at the center of the center coil.

3.2.2. Inner Coil Radius

The warm inner radius of all of the superconducting coils is shown in Table 1 and Figure 1 as 258 mm. The inner radius of the coils may be adjusted by the subcontractor by up to +5 mm provided the total amount of superconductor used in the coils does not increase by more than 3 percent over the calculated value given in Table 1. *The subcontractor must provide a measurement of the inner radii of all of the as-built magnet coils.*

3.2.3. Longitudinal Current Center Position

The relative longitudinal position of the coil current centers must be the same as is shown in Table 1 within ± 1 mm. The subcontractor must provide a measurement of the current centers for all of the magnet coils.

3.2.4. Number of Layers, Number of Turns and Coil Thickness

The number of layers in each coil must be an even number. The number of turns per layer must be the same as shown in Table 1. The thickness of the coils may be larger or smaller than shown in Table 1 depending on the layer-to-layer insulation chosen, and provided the amount of superconductor in the coils does not change more than ± 3 percent. The subcontractor must provide a log of the number of turns wound on each layer of the magnet coils.

3.2.5. Axial Dimensions and Locations

The length of the cryostat vacuum vessel from the match coil end of the vacuum vessel wall to the spectrometer coil end of the vacuum wall is 2735 ± 1 mm (see Figure 2). The distance from the spectrometer solenoid magnet cryostat vacuum vessel end wall to the vacuum vessel flange (on the match coil end) is 259 ± 1 mm. The space allocated for the radiation shutter at the match coil end of the spectrometer solenoid magnet is 189 mm. The thickest portion of the end walls of the cryostat is shown as being 20 mm thick. This portion is used for mounting the radiation shutter (at the match coil end) and the patch panel (at the spectrometer coil end). The distance from the iron shield to the end wall of the cryostat is

nominally 250 mm. The nominal distance from the end of the final spectrometer solenoid coil (end coil 2) to the iron shield is 400 mm.

3.2.6. Subcontractor's Winding Facility

The superconducting coils must be wound in a part of the subcontractor's facility that is clean and free from metallic chips. Machine tools must not be in the same enclosure as the coil winding operation.

3.2.7. Magnet Coil Impregnation

The subcontractor may wind the coil using a wet lay up or the coil may be wound and vacuum impregnated. The winding and potting method must be approved by the Lawrence Berkeley National Laboratory before the magnet coils are fabricated by the subcontractor.

3.2.8. The Coil Mandrel

The coils in Figure 1 are shown as being wound on a 6061-aluminum mandrel. A primary purpose of the mandrel is to provide passive magnet quench protection through quench back. The subcontractor may propose to use an alternative material (such as copper) for the mandrel, or no mandrel at all. The subcontractor must show how the magnet can be passively protected during a quench if there is no mandrel.

3.2.9. Coil Banding and Helium Space

The subcontractor may use banding on the outside of the coils to control stress. If there is to be helium outside of the coils, there must be a minimum space of 5 mm for liquid helium on the outside of the spectrometer solenoid coils. The liquid helium may be in tubes attached to the outside of the coils, provided the surface area is large enough to provide good heat transfer. The thickness of the coil cold mass shown in Figure 1 may be changed to allow for coil banding and liquid helium tubes.

3.2.10. Helium Temperature Cooling of the Coils

Helium cooling may be outside the coils as shown in Figure 1, or it may be in tubes attached to the outside of the coils or to banding on the outside of the coils (see Section 3.2.9). If the helium cooling is in tubes, Sections 3.3.1 and 3.3.2 do not apply. The cooling tubes must be arranged as a thermal siphon cooling system with condensed liquid entering the cooling tubes at the bottom of the magnet. Boil off gas generated in the tubes must be returned to the condenser pot from the top of the magnet cooling tubes in a separate pipe. Details of the condenser configuration are dependent on the final selection of a cooler by LBNL. Other indirect cooling methods will be considered by LBNL provided the subcontractor can demonstrate that the temperature uniformity within the magnet is within 0.2 K of the coldest temperature of the cold mass.

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3.2.11. Ground Insulation

The thickness of the ground insulation between the coils and the winding mandrel must be greater than 1.0 mm (0.040 inches). There must be no gaps in the ground insulation in regions where the conductor is present. The minimum allowable clear path between the coil and ground (the mandrel) is 10 mm. A high voltage check of each coil must be done after the coil is wound and potted. The minimum voltage between the coil and ground must be 8.4 kV. The maximum leakage current shall be 200 microamps.

3.2.12. Magnet Coil Leads and Voltage Taps

The leads for the five coils shall be brought to a single location on the outside of the center coil so that they can be connected to the magnet current leads. Voltage taps are to be connected to the coil leads at a point where the coil leads connect to the magnet current leads. The purpose of these voltage taps is to provide coil resistance data during the magnet cool down (with a small current run through the coils) and to provide voltage data when the magnet coil is charged and during a quench.

3.2.13. Spectrometer Magnet Polarity

The three coils that make up the spectrometer magnet (end coil 1, the center coil, and end coil 2) must be connected in series such that the magnetic polarity of the three coils is the same when the spectrometer magnet is powered with the E lead positive and the F lead negative. The lead between end coil 1 and the center coil shall be marked as the G lead. The lead between the center coil and end coil 2 shall be marked as the H lead. (See Figure 3.)

3.2.14. Match Coil 1 Leads

Match coil 1 must have the same magnetic polarity as the spectrometer solenoid powered in the manner described in Section 3.2.13, when the A lead is positive and the B lead is negative. (See Figure 3.)

3.2.15. Match Coil 2 Leads

Match coil 2 must have the same magnetic polarity as the spectrometer solenoid powered in the manner described in Section 3.2.13, when the C lead is positive and the D lead is negative. (See Figure 3.)

3.2.16. Lead Polarity Check and Lead Labels

All of the magnet leads shall be properly marked once the field polarity checks have been done. LBNL reserves the right to perform independent polarity checks.

3.3. Spectrometer Solenoid Magnet Cryostat Helium Vessel

3.3.1. Cryostat Helium Vessel Description

The helium vessel may either be a single vessel for all of the coils or there may be separate helium vessels for each coil in the spectrometer solenoid magnet. If the helium vessels are separated, the bottoms and tops of the vessels around the coils must be connected together to form a common helium vessel. The entrance pipe for cryogenics entering the magnet during the cool down must be at the bottom at one end of the magnet. The exit or vent pipe used during the cool down of the magnet must exit at the top of the magnet at the opposite end of the magnet from the entrance port.

3.3.2. Cryostat Helium Vessel Design Concept

The helium vessel in Figure 1 is shown as a vessel formed from the magnet mandrel and rolled cover plates. A single rolled cover plate may cover all of the coils and not be connected to the spacers between the coils. Alternatively each coil may have its own rolled cover plate, as shown in Figure 1. A completely separate helium vessel for the magnet is permitted but its design must be approved by the Lawrence Berkeley National Laboratory.

3.3.3. Cryostat Helium Vessel Pressure Rating and the Pressure Vessel Code

The helium vessel or cooling tube system for the spectrometer solenoid must be designed in accordance with the ASME Pressure Vessel Code or equivalent. Suitable documentation must be provided to show that the helium vessel or cooling tube system was manufactured to the standards of the pressure vessel code. The cryostat helium vessel welds must be made by qualified welders in accordance with the MICE Cleaning and Welding Procedure (Attachment 3) and the pressure vessel code. The welds must be inspected in accordance with the pressure vessel code. The design internal working pressure for the helium vessel shall be 4 bars (44 psig). If the magnet is cooled with helium in tubes, the tubes must have a pressure rating of 20 bar (290 psig). The design external working pressure must be 1 bar (15 psig) for vacuum leak checking. The helium vessel relief valve shall be set at 3 bars (29 psig) or lower. The helium vessel rupture disc relief pressure shall be greater than 3.3 bars (32 psig) and less than 4 bars (44 psig).

3.3.4. Magnet Lead Connections

The magnet leads may be connected to the combined HTS and copper leads in the vacuum space of the cryostat provided a feedthrough from the helium vessel into the cryostat vacuum meets the vacuum leak tightness standards set by Section 3.3.7 of this specification. The magnet leads may be connected to the combined HTS and copper leads within a neck where the leads are bathed with helium gas. Either option is allowed provided the HTS leads can operate in a helium

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atmosphere (subject to discussion with the subcontractor) and the 4.2 K heat leak requirements in Section 3.9.1 are met.

3.3.5. Cold Mass Instrumentation within the Cryostat

Within the helium vessel is a curved liquid helium level gauge and the voltage taps for the five coils. These leads may be brought out through a neck with helium around them. The voltage taps must be well insulated from the level sensor leads. Alternatively the instrumentation leads may be brought out through a feedthrough into the cryostat vacuum, provided the feedthrough meets the vacuum leak tightness standards set by this specification in Section 3.3.7. The voltage taps should come through a separate feedthrough from the level sensor leads.

3.3.6. Cryostat Necks and Relief Devices

The helium vessel must have two 25-mm-diameter necks with a thermal intercept that is connected to the first stage of the cooler. The neck that connects to the bottom of the helium vessel will contain a rupture disc as a relief device (see Section 3.3.3). The neck that goes to the top of the helium vessel is connected to the helium vessel relief valve. The necks may be bent in order to reduce the heat leak to 4 K due to thermal radiation from room temperature.

3.3.7. Required Helium Vessel Vacuum Leak Tightness

The piping subassemblies for the cryostat helium vessel must be leak tight to helium at 1 atmosphere at room temperature at the rate of $10^{-10} \text{ Pa}\cdot\text{m}^3\cdot\text{s}^{-1}$ ($10^{-9} \text{ mbar}\cdot\text{liters}\cdot\text{s}^{-1}$). The whole cold mass assembly must be vacuum leak tight to helium at room temperature at 1 atmosphere at the rate of $10^{-9} \text{ Pa}\cdot\text{m}^3\cdot\text{s}^{-1}$ ($10^{-8} \text{ mbar}\cdot\text{liters}\cdot\text{s}^{-1}$). See the attached MICE Vacuum Leak Check Procedure (Attachment 4).

3.3.8. Heater and Temperature Sensors Mounted on the Cold Mass

There shall five (5) Cernox 4 K temperature sensors mounted on the outside (vacuum side) of the helium temperature cold mass assembly. Two temperature sensors shall be mounted on the mandrel at each end of the cold mass. A single temperature sensor shall be mounted in the magnet center on the cover plate. A DC heater capable of putting up to 6 W into the cold mass shall be attached to the mandrel on the outside of the cold mass.

3.3.9. Magnet Hi-Pot

A high voltage check of the cold mass assembly must be performed between the coils and ground with the coils connected to each other. The minimum voltage between the coils and ground must be 5.0 kV. The maximum leakage current shall be 200 microamps.

3.4. Spectrometer Solenoid Magnet Cold Mass Supports and Connections

3.4.1. Spectrometer Solenoid Magnet Heater Instrumentation Wires from the Cold Mass

The wires from these sensors will be fed through a room temperature feedthrough on the vacuum vessel. The instrumentation wires that come through the cryostat vacuum vessel shall have a thermal intercept to the first stage of the coolers that are used to cool the magnet.

3.4.2. Spectrometer Solenoid Magnet Cold Mass Thermal Insulation

The 4 K cold mass shall be insulated with multilayer insulation (MLI) in accordance with the Specification for Multilayer Insulation for the MICE Magnets and Absorbers (Attachment 5).

3.4.3. Spectrometer Solenoid Magnet Cold Mass Supports

The magnet cold mass supports must have low heat leak at 4 K (<0.25 W). The cold mass supports must have thermal intercepts that connect to the first stage of the coolers used to cool the magnet. The cold mass support must carry up to 50,000 N in the radial direction and up 500,000 N in *either* longitudinal direction. The longitudinal and radial spring constants for the cold mass supports shall be greater than $2 \times 10^8 \text{ N} \cdot \text{m}^{-1}$. A cold mass support system where the position of the center of the magnet does not change as the magnet is cooled down is preferred, but LBNL will consider another type of support system. Each of the cold mass support assemblies shall be tested to 1.25 times its design force.

3.4.4. Cold Mass Position Accuracy

The spectrometer solenoid cold mass central axis shall be co-axial with the cryostat vacuum vessel axis within $\pm 0.3 \text{ mm}$. The maximum allowable tilt of the cold mass axis (the magnetic axis) with respect to the axis of the warm bore tube shall be less than $\pm 0.001 \text{ radian}$ ($\pm 0.057 \text{ degree}$)

3.4.5. Spectrometer Solenoid Magnet Cryostat Piping

The piping connecting the spectrometer solenoid cold mass to the coolers and to the spectrometer solenoid magnet vacuum vessel must be designed to withstand loads of 3 g in any direction. The piping must be tied down to prevent it from moving when the spectrometer solenoid magnet helium vessel is pressurized to its full design working pressure. All bellows in the piping system must be designed for pressurization to the helium vessel design working pressure.

3.5. Spectrometer Solenoid Magnet Shields and Intercepts

3.5.1. Shield and Intercept Purpose and Description

The intermediate temperature shields and intercepts will be cooled by the first stage of the magnet coolers in the temperature range from 40 to 60 K. The radiation heat load that passes through the multi-layer insulation (MLI) located

between the room temperature cryostat vacuum vessel and the cold mass will be intercepted by a shield placed around the MLI-insulated magnet cold mass. The cold mass supports from room temperature to 4 K have intercepts that carry the heat from room temperature to the first stage of the coolers. All cryostat necks between room temperature and 4 K will have thermal intercepts to the first stage of the coolers. In addition, all instrumentation wires from room temperature will be tied to the first stage of the coolers through thermal intercepts.

3.5.2. The Magnet Thermal Shields

The magnet shield shall be conduction cooled. The thickness of the shield and the material in the shield shall be such that the temperature of the shield furthest from the coolers does not exceed 80 K.

3.5.3. The Cold Mass Support Intercepts

The cold mass support system and the intercept system shall be designed so that the design temperature of the cold mass support intercepts does not exceed 70 K.

3.5.4. Cryostat Neck Intercepts

The intercepts on the cryostat necks shall have a design temperature that does not exceed 70 K.

3.5.5. Instrumentation and Heater Lead Intercepts

The design temperature of the instrumentation leads at the intercept point shall not exceed 70 K.

3.5.6. Current Lead Intercepts

The design temperature of the intercept between the copper lead that comes from room temperature and the HTS superconducting lead that goes to 4 K shall not exceed 70 K (subject to discussion with the subcontractor).

3.5.7. Closed Loop Circuits

The radiation shield and intercepts shall be designed so that no closed current loops are formed around the solenoid during a magnet quench. The shield shall be slit and the slits covered by non-conductive (electrically) aluminized tape so that radiation from room temperature does not pass through the slits in the shield. The intercept cooling paths must have at least one break so that closed loops are not formed during a magnet quench.

3.5.8. Thermal Insulation between the Shield and the Vacuum Vessel

The shields and intercepts shall be insulated with multilayer insulation (MLI) in accordance with the Specification for Multilayer Insulation for the MICE Magnets and Absorbers (Attachment 5).

3.5.9. Shield and Intercept Workmanship

The minimum allowable distance from the 4 K surface to the shield is 5 mm. The minimum allowable distance between the shield and a room temperature surface is 20 mm. Care must be taken to avoid holes in the shield that can expose a 4 K surface or the MLI covering a 4 K surface to a radiation source at room temperature. The shields and intercepts shall be fabricated so that the MLI under them is not compressed unduly. The shields and intercepts must be mounted so that normal shipping loads can be taken up without damage to the shields and intercepts or the MLI on either side of the shields.

3.5.10. Shield Temperature Sensors

Four Cernox temperature sensors shall be attached to the far ends of the shield and to a point on the shield near the cold mass support intercepts. The leads from the temperature sensors shall have thermal intercepts to the first stage of the cooler.

3.6. Spectrometer Solenoid Magnet Current Leads

3.6.1. Spectrometer Solenoid Magnet Current Lead Requirements

The spectrometer solenoid has two sizes of leads. There are six leads (labeled A through F) that carry a nominal current of 300 A. There are two leads (labeled G and H) that carry a nominal current of 50 A. It is proposed that the leads be clustered together and exit the magnet cryostat through a lead neck. The leads may either be in a helium atmosphere or in the cryostat vacuum, depending on the design of the HTS leads.

3.6.2. Spectrometer Solenoid Magnet 300 A Leads

A 300 A lead shall consist of a conduction-cooled copper lead that carries current from room temperature to the intercept temperature (at 70 K nominal) and a high temperature superconductor (HTS) lead that carries current from the intercept (at 70 K nominal) to the niobium titanium pigtail lead from the coil, which is at 4 K. The copper lead shall be optimized for a current of 280 A, but must be capable of carrying a current up to 350 A. In order to provide additional margin, the HTS lead must be capable of carrying 500 A when the high-temperature end of the lead is nominally at 60 K (subject to discussion with the subcontractor).

3.6.3. Spectrometer Solenoid Magnet 50 A Leads

A 50 A lead shall consist of a conduction-cooled copper lead that carries current from room temperature to the intercept temperature (at nominal 70 K) and a high temperature superconductor (HTS) lead that carries current from the intercept (at nominal 70 K) to the niobium-titanium pigtail lead from the coil, which is at 4 K. The copper lead shall be optimized for a current of 30 A, but must be capable of carrying a current up to 50 A. In order to provide additional margin, the HTS lead

must be capable of carrying 100 A when the high-temperature end of the lead is nominally at 60 K (subject to discussion with the subcontractor).

3.7. Spectrometer Solenoid Magnet 4 K Coolers

3.7.1. Operating Conditions for the Spectrometer Solenoid Magnet Coolers

The coolers for cooling the spectrometer solenoid will operate with the cold end of the cold heads down. Liquid cryogenics will be used to cool down the magnet. The second stage of the coolers will be connected to condensers that re-liquefy the helium in the magnet cryostat after the spectrometer solenoid has been filled with liquid helium. Details of the condenser configuration are dependent on the final selection of a cooler by LBNL.

3.7.2. Electric Power to the Compressors

The cooler compressors will operate on electric power with a frequency of either 50 or 60 Hz at a minimum voltage of 230 V.

3.7.3. Magnetic Field at the Coolers

The axial component of magnetic induction in the region of the cold heads will be from 0.09 T to 0.16 T (900 to 1600 G). The radial component of magnetic induction in the cold head will be about 0.03 T (300 G). The warm part of the cooler attached to the cold head assembly will operate in an axial magnetic induction range of 0.05 to 0.09 T (500 to 900 G). The radial component of magnetic induction in the warm part of the cooler attached to the cold head will be about 0.03 T (300 G).

3.7.4. Cooler Temperature Sensors

A Cernox temperature sensor must be mounted on the copper ring that connects to the first stage of each cooler. These temperature sensors will be mounted on the cryostat vacuum side of the copper ring. A Cernox temperature sensor must be mounted on each helium condenser that is attached to the second stage of each cooler. The lead for the condenser temperature sensors may pass through the same feedthrough as the leads for the helium liquid-level gauge.

3.7.5. The Magnet Coolers

The Lawrence Berkeley National Laboratory will provide to the subcontractor the cryo-coolers that will be used to cool the spectrometer solenoid. The coolers must operate with the cold heads down. (The cold head direction is perpendicular to the magnet axis.)

3.8. Spectrometer Solenoid Magnet Cryostat Vacuum Vessel

3.8.1. Cryostat Vacuum Vessel Description

The spectrometer solenoid magnet vacuum vessel will be 1404 mm \pm 5 mm in outer diameter with a length of 2735 mm \pm 3 mm from end plate to end plate along the warm bore tube. The cryostat vacuum vessel has a free room-temperature bore with an inside diameter of 401 mm \pm 3 mm. At the match coil end of the spectrometer solenoid magnet is a vacuum volume for the radiation shutter for MICE. This vacuum volume is separate from the cryostat vacuum. The match coil end of the spectrometer solenoid magnet cryostat is terminated by a flange that allows the spectrometer solenoid magnet to be attached to the MICE AFC module through a bellows assembly. The flange weld to the vacuum vessel must be strong enough to carry a 500,000 N longitudinal force. (See Figures 2 and 4.)

3.8.2. Vacuum Vessel Design Concept

The vacuum vessel in Figures 2 and 4 is shown as a single vessel with welded end plates. Alternatively the subcontractor may choose to split the spectrometer solenoid magnet vacuum vessel at other locations along the cylindrical portion of the vacuum vessel.

3.8.3. Cryostat Vacuum Vessel Pressure Rating and the Pressure Vessel Code

The vacuum vessel for the spectrometer solenoid must be designed in accordance with the ASME Pressure Vessel Code or equivalent. Suitable documentation must be provided to show that the vacuum vessel was designed and manufactured to the standards of the pressure vessel code. The welds must be inspected in accordance with the pressure vessel code. The external design working pressure for the helium vessel shall be 1 bar (15 psig). The design internal working pressure shall be 0.3 bar (4.4 psig). The relief valve setting will be 0.14 bar (2 psig). The rupture disc relief pressure shall be 0.3 bar (4.4 psig).

3.8.4. Magnet Lead Connections

The magnet current leads must be brought out of the spectrometer solenoid magnet cryostat on the top of the cryostat vacuum vessel.

3.8.5. Instrumentation Wires from within the Helium Vessel

If the instrumentation wires from inside the helium vessel are brought out through a neck that has helium within it, these leads must be brought out at the top of the spectrometer solenoid magnet vacuum vessel. If the instrumentation wires from inside the helium vessel are brought out through the cryostat vacuum, these leads may be brought out at the top or the side of the spectrometer solenoid magnet vacuum vessel through the same port as the wires in Section 3.8.6.

3.8.6. Instrumentation Wires from the outside of the Cold Mass

Instrumentation wires from inside the helium vessel may be brought out at the top or the side of spectrometer solenoid magnet vacuum vessel.

3.8.7. Necks for Liquid Cryogen Feed and Venting

The neck for the rupture disc and the tube that feeds liquid cryogens into the helium vessel during a magnet cool down must be brought out of the top of the vacuum vessel. The neck for the relief valve and the tube that vents the helium vessel during the magnet cool down must also be brought out of the top of the vacuum vessel.

3.8.8. Required Vacuum Vessel Vacuum Leak Tightness

The whole vacuum vessel assembly must be vacuum leak tight to helium at room temperature at 1 atmosphere at the rate of $3 \times 10^{-8} \text{ Pa} \cdot \text{m}^3 \cdot \text{s}^{-1}$ ($3 \cdot 10^{-7} \text{ mbar} \cdot \text{liters} \cdot \text{s}^{-1}$). See the LBNL specification on vacuum leak checking and vacuum leak tightness.

3.8.9. Spectrometer Solenoid Magnet Cold Mass Supports

The room-temperature end of the cold mass supports must be brought through the vacuum vessel. The room temperature end of the support and the cryostat vacuum vessel wall must support the forces from the magnet cold mass supports when they carry the design forces of 50,000 N in the radial direction and up 500,000 N in *either* longitudinal direction.

3.8.10. The Spectrometer Solenoid Magnet Support Stand

The vacuum vessel must be attached to a support stand as shown in Figures 2 and 5. The stand carries the gravity forces (the magnet, its cryostat, the iron shield, the radiation shutter, the VLPC boxes and any other object that is attached to the spectrometer solenoid magnet vacuum vessel), the vacuum forces, and the magnetic forces to the six base plates that attach to the MICE channel supports on the floor. The stand must carry all of the forces simultaneously, with none of the loads being passed on to the adjacent AFC module, with a maximum displacement of 1 mm in the longitudinal direction.

3.8.11. Vacuum Pumping Ports

A 25-mm diameter vacuum pumpout port for the cryostat vacuum shall be provided. The pumpout port has a flange to allow a pumpout valve and relief valve to be attached for the vacuum cryostat space. A second vacuum pumpout port for the vacuum space between the AFC module and the detector window shall also be provided. The vacuum pumping ports are not included in the vacuum vessel drawing (Figure 4). The port has a 50-mm-diameter flange located near the radiation shutter to allow a pump out valve and a relief valve to be attached for this vacuum system. A vacuum gauge can also be attached here to measure the vacuum between the AFC and the spectrometer solenoid volume.

3.8.12. Vacuum Gauges

Thermocouple type vacuum gauges that can operate in a magnetic field of 0.5 T must be attached to the cryostat vacuum and the vacuum between the AFC module and the spectrometer solenoid module. The vacuum gauges must measure vacuum in the range from 0.1 Pa to 1000 Pa (10^{-3} to 10 torr).

3.9. Spectrometer Solenoid Magnet Maximum Allowable Heat Load Requirements

3.9.1. Allowable Heat Loads at 4 K

The maximum allowable heat load at the second stage of the coolers is 4.5 W total with three coolers being used to cool the spectrometer solenoid magnet.

3.9.2. Allowable Heat Loads at 60 K

The maximum allowable heat load at the first stage of the coolers is 150 W total with three coolers being used to cool the spectrometer solenoid magnet.

3.10. Mechanical Interfaces for Attached Devices on the Magnet Cryostat

3.10.1. Attachment of the Iron Shield for the PMT

An iron shield (1.5 m in diameter with a 0.5 m hole and a mass of 1240 kg) with its support clamps will be connected to the end of the spectrometer solenoid magnet cryostat. The attachment brackets will carry a longitudinal force of 100,000 N in addition to the gravity load. The required mounting pads (“saddle plates”) to be included on the vacuum vessel outer diameter are shown in Figures 2 and 6.

3.10.2. Patch Panel Seal and Support

The patch panel shell with its seal will be bolted to the end of the spectrometer solenoid magnet cryostat at the spectrometer coil end. (See Figure 7.) The seal surface shall be free of scratches and have a machined surface finish of 32 microinches or better.

3.10.3. Tracker Module Support to the Magnet

The tracker module attachment point at the spectrometer coil end of the magnet cryostat vacuum vessel will be integrated with the patch panel design. The other end of the tracker module will be supported by resting on the warm bore tube of the magnet. The warm bore tube ID of 402 mm must be round within ± 3 mm to accommodate the tracker module (See Figure 8.)

3.10.4. Radiation Shutter Attachment to the Spectrometer Solenoid Magnet Cryostat

There shall be attachment points and feed-throughs for the radiation shutter at the match coil end of the cryostat. (See Figure 9.)

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3.10.5. Attachment of the Spectrometer Solenoid Magnet to the AFC Module

A flange with bolt holes shall be provided for attachment of the spectrometer solenoid module to the AFC module. The interface flange details are included in Figure 4. The flange surface shall be free of scratches and have a machined surface finish of 32 microinches or better. Also, the flange weld to the vacuum vessel must be strong enough to carry a 500,000 N longitudinal force.

3.10.6. Window between Tracker Volume and AFC-to-Spectrometer Solenoid Vacuum

A place for the attachment of a vacuum window in the spectrometer solenoid magnet warm bore between the tracker volume and the vacuum space between the AFC module and spectrometer solenoid module shall be provided. (See Figure 8.)

3.10.7. Diffuser Mechanism Attachment to the Spectrometer Solenoid Magnet Cryostat

The diffuser mechanism will be attached to the Center Coil end of the magnet. The mounting surface will be a half ring with tapped holes welded to the upper portion of the end of the vacuum vessel (Figure X).

3.11. Lifting Fixtures for the Finished Spectrometer Solenoid

3.11.1. Lifting and Tie-down Devices

All lifting and tie-down devices on the container must be designed in accordance with the Department of Labor's OSHA standard 29 CFR 1910, Subpart N for materials handling and storage or the equivalent Rutherford Appleton Laboratory standard.

3.12. Electrical Interfaces between the Magnet and Outside World

3.12.1. Current Leads for the Spectrometer Solenoid

Three pairs of 300-A leads (conduction-cooled to first stage of the cooler) are attached to the 500 A HTS leads (from the cooler first stage to the magnet) that are attached to match coil 1, match coil 2 and the spectrometer magnet. These leads are connected to the magnet pigtails A through F as described in Sections 3.2.13 through 3.2.15. (See Figure 3.)

3.12.2. Correction Leads for the Spectrometer Solenoid

A pair of 50-A leads (conduction-cooled to the first stage of the cooler) is attached to the 100 A HTS leads (from the cooler first stage to the magnet) that are attached to the ends of the center coil. These leads permit adjustment of the current in the two end coils with respect to the current in the center coil by the use of 50 A power supplies. These leads are connected to the magnet pigtails G and H as described in Section 3.2.13. (See Figure 3.)

3.12.3. Magnet Coil Voltage Taps

Voltage taps for the ends of each of the five coils in the spectrometer solenoid magnet (ten voltage tap leads in all) are to be provided. (Note: these leads carry almost no current.) These leads should pass through a feedthrough to the outside that is separate from the magnet instrumentation leads.

3.12.4. The Helium Level Gauge Leads

The leads for a helium liquid-level sensor for the magnet helium space (four leads in all) should be physically separated from the voltage taps.

3.12.5. Heater and Temperature Sensor Leads

All of the temperature sensor leads may be brought out of the cryostat vacuum vessel through the same connector that is used for the liquid-level gauge leads. These leads must not be put through the same feedthrough as the coil voltage taps.

3.12.6. Pressure Transducer Leads

The leads to the pressure transducer used to measure the pressure in the cryostat helium vessel come directly off the transducer, which is located at the room temperature end of the cryostat necks.

3.12.7. Vacuum Gauge Leads

The leads to vacuum gauges attached to the cryostat vacuum port and the vacuum between the spectrometer solenoid and the AFC module come out of the gauges into room temperature air.

3.13. Magnet Discharge System

3.13.1. Discharge Circuits

A series of circuits will be required in order to protect the power supplies and Hi-Tc leads in the event of a power failure. Separate systems are needed for the Center and End Coil groups as well as for each of the two Match Coils. The specifications for these circuits are provided in Sections 3.13.2 and 3.13.3.

3.13.2. Center and End Coils

The required current decay time constant for a rapid discharge for the three-coil tracker solenoid should be about 1800 seconds. If a varistor is used to discharge the coil, the voltage across the varistor should be about 11.6 V. Since the quench protection system has four diodes in series. The voltage drop per diode during a rapid discharge is 3 V. Per your request, we enclosed the cost estimation for power supplies and Hi-Tc Lead Protection against power failure.

3.13.3. Match Coils

The required current decay time constant for a rapid discharge for the M1 and M2 coils is determined by the cold diodes in the quench protection system. This means that the coil charge and discharge voltage can be no larger than about 3

volts. For the M1 coil the L over R time constant should be greater than 1250 seconds. For the M2 coil the L over R time constant should be greater than 550 seconds.

4. Inspection, Testing and Acceptance Requirements

Unless otherwise noted, the inspections and tests described below are to take place at the subcontractor's facility, during and after the completion of fabrication. Successful completion of these requirements will be sufficient to allow LBNL to receive the magnets at the time of delivery without an additional acceptance period, other than to inspect for shipping damage.

4.1. Travelers

The subcontractor shall develop appropriate travelers for the documentation of various fabrication processes. Information to be recorded on the travelers should include but not be limited to the documentation requirements set forth in Sections 4 and 5. All traveler entries must be signed and dated by the appropriate personnel. It is the responsibility of the subcontractor to control and update all travelers. Any failure to do so which will entail extra activities and a corresponding extra cost will be at the expense of the subcontractor. Prior to implementing the travelers, the subcontractor will submit the traveler forms to LBNL for review and approval. All travelers will be provided to LBNL at the completion of the procurement.

4.2. Material Certification

The subcontractor shall provide material certification documents for all of the materials that go into the cold mass vessel and the magnet vacuum vessel in accordance with the pressure vessel code that governs the design and construction of such components.

4.3. Magnet Winding and Potting Records

The subcontractor shall provide to the buyer records of the number of turns applied to each layer of each coil in the magnet as well as a record of the materials and procedures used for impregnation of the coils. The subcontractor shall also provide the buyer with the following measurements: the OD of the insulated mandrel prior to coil winding, the OD of the wound coils, and the wound widths of each of the five coils (see Sections 3.2.2 through 3.2.4 and Table 1).

4.4. Magnet Coil Polarity Checks

The subcontractor shall provide the buyer records of the magnet polarity checks in accordance with Sections 3.2.13 through 3.2.16.

4.5. Magnet Voltage Checks

The subcontractor shall provide LBNL with records showing that high voltage checks of the magnets were performed in accordance with Sections 3.2.11 and 3.3.9.

4.6. Wire and Pin Checks on the Helium Vessel

The subcontractor shall provide the buyer certification that continuity checks have been made on the voltage taps and the liquid-level gauge within the cryostat. The subcontractor shall provide a map as to which wire is attached to which pin on a feedthrough from the cryostat helium space to the vacuum space.

4.7. Cold Shock, Pressure and Vacuum Leak Checks

Piping subassemblies attached to the cold mass shall be cold shocked by dipping the part in liquid nitrogen. The subassembly shall be pressure tested to 1.25 times the working pressure (see Section 3.3.3) of the cryostat helium vessel with dry nitrogen and vacuum leak checked in accordance with Section 3.3.7. The subcontractor shall certify that these tests were done in accordance with this specification. LBNL representatives shall be given the option of witnessing these tests.

4.8. Helium Vessel Weld Inspection

The welds on the cryostat cold mass vessel and the magnet vacuum vessel shall be inspected in accordance with the provisions in the pressure vessel code.

4.9. Cold Mass Vessel Pressure and Vacuum Leak Checks

The cryostat helium vessel shall be pressure tested at room temperature to 1.5 times the working pressure of that vessel (see Section 3.3.3) with dry nitrogen before vacuum leak checking in accordance with Section 3.3.7. The subcontractor shall certify that these tests were done in accordance with this specification.

4.10. Cold Mass Assembly Force Check

The subcontractor shall provide LBNL with a record of the force checks on the cold mass support assemblies in accordance with Section 3.4.3.

4.11. Warm Magnetic-Field Check of the Coils

The subcontractor shall power the spectrometer magnet (end coil 1, the center coil, and end coil 2) to a current in the 1 to 2 A range. The subcontractor shall measure the magnetic field along the axis of the magnet when the spectrometer magnet is powered. The subcontractor shall power match coil 1 to a current in the 1 to 2 A range and measure the magnetic field generated by the coil along the axis of the magnet. The subcontractor shall power match coil 2 to a current in the 1 to 2 A range and measure the magnetic field generated by the coil along the axis of the magnet. The subcontractor shall power end coil 1 to a current in the 1 to 2 A range and measure the magnetic field generated by the coil along the axis of the magnet. The subcontractor shall power end coil 2 to a current in the

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1 to 2 A range and measure the magnetic field generated by the coil along the axis of the magnet. The buyer must be allowed to view the warm magnetic field tests.

4.12. Cold Mass Surveying

The subcontractor shall allow an LBNL representative to be present when the magnet cold mass is surveyed into the cryostat vacuum vessel so that the cold mass positional and tilt tolerances can be met as shown in Section 3.4.4.

4.13. Insulation Inspection

The subcontractor shall allow the buyer to observe the process of insulating and shielding the magnet. The subcontractor shall provide the buyer a record of the number of layers of MLI applied in accordance to Section 3.5.8.

4.14. Wire and Pin Checks on the Vacuum Vessel

The subcontractor shall provide the buyer certification that continuity checks have been made on the thermometry and heater leads within the cryostat vacuum vessel. The subcontractor shall provide a map as to which wire is attached to which pin on a feedthrough from the vacuum space to the outside.

4.15. Vacuum Vessel Weld Inspection

The welds on the cryostat cold mass vessel and the magnet vacuum vessel shall be inspected in accordance with the provisions in the pressure vessel code.

4.16. Vacuum Vessel Pressure and Vacuum Leak Checks

The cryostat vacuum vessel shall be pressure tested to 1.5 times its design internal working pressure (see Section 3.8.3) with dry nitrogen before it is vacuum leak checked in accordance with Section 3.8.8. The subcontractor shall certify that these tests were done in accordance with this specification.

4.17. Magnet Cryogenic Test

The magnet shall be cooled down using liquid cryogenics. After the helium portion of the cool-down has started, the coolers will be turned on to cool the shields and intercepts. A long-term test of the cryogenic performance of the magnet shall be made with the coolers running. The cooler performance and the temperature in the magnet shall be monitored over a period of one-week before the magnet current tests commence.

4.18. Magnet Quench Test and Training

Magnet circuits in the spectrometer solenoid magnet (match coil 1, match coil 2, and the spectrometer coils) shall be trained to an operating current that is 15% greater than the design current shown in Table 1 or the current limit set by the power supply to be provided by LBNL, whichever is lower.

4.19. Magnetic Check of the Spectrometer Solenoid Magnet

Once the individual magnet circuits have been powered to their maximum currents, given in Section 4.18, the whole spectrometer solenoid shall be powered to the currents shown in Table 1. LBNL will have a technical representative present during each of the magnet tests described. The magnetic field shall be measured with a hall probe that travels down the center of the magnet bore. Detailed MICE spectrometer solenoid magnetic field mapping measurements will not be done at the subcontractor's facility.

5. Packing, Shipping and Handling Requirements

5.1. Shipping Loads and Packaging Performance Requirements

During handling and transport, the shipping crate and enclosed magnet will be subject to both shock and vibratory accelerations. An analysis has been performed to determine the magnitude of acceleration in each coordinate direction that the magnets can tolerate. The following requirements are based on the results of the analyses along with appropriate factors of safety: a) the transmitted loads from the shipping container exterior to the magnet must be less than 2g along the beam-line (z), lateral (x), and vertical (y) axes for the NCT and normal handling, b) the transmitted shock load to the magnet during an HAC event must be limited to 3g. The specified limits are the net maximum allowable accelerations measured on the magnets during transport. The shipping crate must isolate the magnets from the actual external shipping accelerations which could be considerably higher. The magnet shall be supported and tied down within the crate using the support stand base mounting locations.

5.2. Normal Handling Loads

Normal handling loads consist of incidental loads from forklift transport and lifting operations. Accidental loads occur as a result of mishandling and can be severe. Specifically, the worst hypothetical accident condition (HAC) is anticipated to be a 0.3 m (1-foot) drop onto an essentially unyielding surface.

5.3. Instrumentation

The subcontractor shall provide four RD298 Shocklog Tri-axial Recorders made by Lamerholm Fleming Ltd. (or equivalent) for shock and vibration monitoring during transport of each crate. Two units are to be mounted on the vacuum vessel inside the shipping crate for redundancy. A second pair of redundant accelerometer systems will be located on the exterior of the shipping crates such that they are clearly visible and protected from damage during handling of the crate. Accelerometers may be reused if the magnets are shipped separately. The subcontractor shall provide LBNL with the accelerometer data records after each package has been delivered to CCLRC Rutherford Appleton Laboratory.

5.4. Other Shipping Requirements

Each magnet assembly (see Figure 2) shall have its own shipping container and, specifically, the packaging design must satisfy the following:

- 5.4.1. An acceptable “margin of safety” must be maintained against buckling and/or yielding of the container under static or NCT compressive loading, e.g. stacking of containers during transport.
- 5.4.2. All welds used in the construction of the shipping container must conform to AWS code as determined by an AWS certified weld inspector.
- 5.4.3. The magnet helium vessel and the magnet cryostat vacuum vessel shall be filled with dry nitrogen gas and sealed before shipping.
- 5.4.4. The shipping container should include supports and tie-downs for the spectrometer solenoid magnet, as well as space and restraints for additional spectrometer solenoid magnet hardware.
- 5.4.5. The package should be able to withstand outside environmental conditions, without corrosion or other damage to the spectrometer solenoid magnet, for an indefinite period.

5.5. Shipping Destination

The magnet assemblies are to be shipped to the following person and address:

Dr. Paul Drumm
CCLRC Rutherford Appleton Laboratory
Chilton, Didcot
Oxon, United Kingdom
OX11 0QX
Phone: +44 1235 445000
Fax: +44 1235 445808

The subcontractor shall provide LBNL with a minimum of 4 weeks notice prior to shipping the assemblies to allow for coordination with customs in the UK.

6. Notification Requirements

- 6.1. In the event that the subcontractor detects a mistake in the drawing, machining or fabrication of the parts listed herein, the subcontractor shall notify LBNL within 24 hours. LBNL will have 72 hours, excluding weekends and official holidays, to respond to such notification without incurring any costs due to idle equipment, manpower, or temporary storage space.
- 6.2. The subcontractor must notify LBNL at least 10 working days ahead of the dates when the following activities will be performed:
 - 6.2.1. Start of coil winding on the mandrel

6.2.2. Completion of coil winding

6.2.3. Installation of coil package on cold mass support

6.2.4. Warm magnetic-field check of the coils (Section 4.11)

6.2.5. Magnet cryogenic test (Section 4.17)

6.2.6. Magnet quench test and training (Section 4.18)

6.2.7. Magnetic check of the spectrometer solenoid magnet (Section 4.19)

7. List of Government Furnished Property (GFP)

7.1. Superconductor Material

The conductor is being purchased in accordance with the attached superconductor specification. The actual conductor will have an insulated cross section that is 1.65 mm wide and 1.00 mm thick. The insulating material is Formvar, and the superconductor alloy is standard grade. The conductor will consist of 222 filaments of 41 μm diameter and with a copper-to-superconductor ratio of 4.0.

7.2. Cryo-coolers

The cryo-coolers described in this specification for cooling the magnets will be supplied by LBNL. The specific manufacturer and model information will be made available to the subcontractor at the time of contract award. Drawings showing the cryo-cooler interface requirements will be provided as well.

7.3. Power Supply for Magnet Quench Testing and Training

An appropriate power supply will be specified and purchased by LBNL and shipped to the subcontractor's location to be used for the magnet testing and verification. LBNL will consult with the subcontractor during the process of specification of this power supply.

7.4. Bonded Storage

The subcontractor shall store all special materials (such as but not limited to: government supplied superconductor, cryo-coolers, HTS lead assemblies, high strength bolts and other special materials) used for the construction in accordance with the subcontract requirements.

8. Quality Assurance

8.1. LBNL Technical Representative

Correspondence between the subcontractor and LBNL shall be conducted through the LBNL technical representative identified below. A secondary contact is listed in case the LBNL technical representative is not immediately available.

LBNL Technical Rep.: Steve Virostek Lawrence Berkeley National Lab
 510-486-6271 1 Cyclotron Road, M/S 71-259
 spvirostek@lbl.gov Berkeley, CA 94720

LBNL Secondary Contact: Michael Zisman Lawrence Berkeley National Lab
 510-486-5765 1 Cyclotron Road, M/S 71-259
 mszisman@lbl.gov Berkeley, CA 94720

8.2. General Requirements

The subcontractor must be ISO 9000 or equivalent national standard registered. The subcontractor shall prepare and implement a Quality Assurance Manual (QAM), complying with ISO 9000 or an equivalent national quality standard, covering the procurement, fabrication, testing and inspection of all components. The manual must be submitted to LBNL for approval no later than three months after placing the contract. Furthermore, the subcontractor shall prepare and present a design review to LBNL and collaboration personnel at the completion of the magnet engineering design phase. Timing of the review is to be consistent with the subcontractor's proposed design and fabrication schedule.

8.3. Process Control, Inspection and Testing

Each process proposed and assessed by the subcontractor must be such as to guarantee that the design, construction and tests of the solenoid magnets comply with the requirements set forth in this specification. Quality requirements for manufacturing functions and associated material handling and control, inspection and testing activities, and process equipment identification shall be planned and performed according to written procedures and documented.

8.4. Process Documentation

The subcontractor shall submit the following to LBNL for approval at or before the time of the design review (prior to fabrication):

- 8.4.1. Detailed fabrication and inspection plan
- 8.4.2. Vacuum leak checking procedures
- 8.4.3. Welding procedures
- 8.4.4. Cleaning procedures
- 8.4.5. Cold shock procedures

8.4.6. Any other non-destructive test methods applicable to the subcontractor's QA program

For some specific processes, Special Process Qualification must be written and followed by the subcontractor. In all cases, the following processes shall be carried out by qualified personnel, and the certificates of qualification shall be enclosed in the Final Dossier: i) welds, ii) geometric surveys, iii) vacuum tests, iv) electric breakdown tests, v) X-ray and UT inspections, vi) crane operation, vii) non-destructive tests.

8.5. Document and Data Control

The subcontractor shall supply all documents as required in this specification. All documents and correspondence shall be written in English. Every document must be numbered according to the Quality Assurance Manual and must contain the names of the author(s), the person(s) who checked the document, and the person who approved the document. Every revision of a document must be justified with the reasons for the change(s) clearly spelled out in the cover page of the document. Any revision shall be accepted by the LBNL technical representative. All drawings to be submitted to LBNL shall be transmitted in hard copy as well as soft copy in both dxf and pdf formats. A full set of drawings, revised as necessary to include all "as built" modifications, shall be forwarded to the LBNL technical representative before the contract is completed. All significant documentation relating to the magnets' manufacturing (like computation notes, fabrication drawings, material certificates, welding processes, welder certificates, inspection reports, control records, test results and specifications for proposed subcontracts, etc.) must be sent to the LBNL technical representative in duplicate. This procedure is foreseen to protect both parties against obvious mistakes in design and planning but, as such, it does not relieve the subcontractor of any of its contractual responsibilities.

8.6. Purchasing, Sub-contracting and Product Traceability

The subcontractor is free to choose suppliers within the budget limits granted in the contract; however, any primary sub-contractors must be agreed upon by the LBNL technical representative. The subcontractor shall be responsible for ensuring the traceability of the various components during the entire fabrication phase.

8.7. Management Responsibility

At the time of contract placement, the subcontractor shall supply a functional organization chart where the stakeholders for each activity are clearly identified. These stakeholders will be responsible for interfacing with the LBNL technical representative as necessitated by the requirements of this specification. The subcontractor shall notify the LBNL representative in real time of any changes to the functional organization chart.

8.8. Project Planning

The subcontractor shall present, as part of the QAM, a detailed Work Breakdown Structure (WBS) for all the activities covered by this specification. The subcontractor shall clearly indicate for each individual activity, the stakeholder, the duration of the activity, the required facilities and/or instrumentation required, the number of people involved in each activity and their qualification. Periodic progress meetings shall be agreed upon with the responsible LBNL person at the time of contract placement. The subcontractor must strictly follow the construction and test planning schedule. On a monthly basis, the subcontractor shall send to the LBNL technical representative a chart showing the status and the provisional dates for the future activities. The subcontractor shall notify LBNL in the event that a planning deviation exceeding two weeks is anticipated. Any proposed significant schedule change must be negotiated with LBNL technical representative before being effective. For its schedules, the subcontractor shall use planning software that is compatible with MS-Project.

8.9. Deviation and Nonconformance

The QAM shall also provide for disposition and resolution of departure from approved drawings, specifications, data, procedures and standards. No work shall proceed on the proposed deviation until approved in writing by LBNL. Nonconformance and Deviation request forms will be provided by LBNL for this purpose. The subcontractor shall insure proper description, documentation and response in requesting a deviation.

In case of non-conformity during production, the LBNL technical representative must be informed of the problem and corrective actions must be taken. These corrective actions will be the object of detailed procedures to be agreed upon with the subcontractor. The subcontractor must supply to LBNL a copy of every Non-conformance Report (NCR) as well as an updated copy of the NCR Logbook. In the logbook, the subcontractor will spell out clearly the NCR Title Number and the status (open or closed). All NCR's must be closed prior to requesting a Provisional Acceptance Certificate for the concerned item.

The Contractor will be in charge of the maintenance and management of all concerned items in all aspects. Any extra costs due to non-conformities caused by poor maintenance or poor management shall be at the expense of the subcontractor.

LBNL's response time for an action initiated by the subcontractor will be as follows:

1. Routine: Response within 7 working days required
2. Urgent: Response within 3 working days required
3. Emergency: Response within 24 hours required (next working day)

8.10. Monitoring by LBNL

LBNL reserves the right to have its technical or procurement representatives witness any or all manufacturing steps, tests and inspections established under the subcontractor's

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Quality Assurance program to demonstrate compliance with this Technical Specification. LBNL's representative shall have visitation access to the subcontractor's plant and personnel during normal operating hours with 24-hour notice for the purpose of conducting Quality Assurance and Audits. The subcontractor shall provide a reasonable office space and office supplies for use by LBNL's representative during the visits to the subcontractor's plant.

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Table 1. The Basic Parameters of the Spectrometer Solenoid

Parameter	Match 1	Match 2	End 1	Center	End 2
Inner Coil Radius (mm)+	258	258	258	258	258
Coil Thickness (mm)	46.2	30.8	61.6	22.0	68.2
Coil Length (mm)	198	197	110	1294	110
Current Centre Axial Position* (mm)	124 ±1	564 ±1	964 ±1	1714 ±1	2464 ±1
Current Centre Radial Position# (mm)+	281.1	273.4	288.8	269.0	292.1
Coil Average J (A mm ⁻²)	118.04	138.28	136.80	146.90	142.49
Number of layers per Coil	48	28	56	20	62
Number of Turns per Layer	120 ±2	119 ±2	66 ±1	784 ±10	66 ±1
Design Current (A)**	223.3	271.2	249.5	265.9	265.2
Coil Self Inductance (H)^	17.1	5.0	9.6	41.6	11.4
Coil Stored Energy (MJ)**	0.47	0.20	0.30	1.49	0.40
Peak Field in Coil (T)**	4.7	2.42	5.61	4.02	5.62
Temperature Margin at 4.2 K (K)**	~2.0	~2.5	~1.9	~2.3	~1.7
Conductor Length (m)	8910	5730	7220	25720	7910
Coil Mass (kg)	133	67	89	347	98
Total Conductor Length for Magnet (m)	55,490				
Cold Mass Inner Diameter (mm)	490				
Cold Mass Outer Diameter (mm)	690				
Cold Mass Length (mm)	2544				
Insulation Thickness, Coil-Mandrel (mm)	>0.75				
Min. Coil-to-Ground Clear Path (mm)	5				
Minimum Coil OD-to-Cryostat Gap (mm)	5				
Vacuum Vessel Outer Diameter (mm)	1404 ±3				
Magnet Warm Bore (mm)	401 ±3				
Magnet Cryostat Length (mm)	2735 ±1				
Cryostat End Wall-to-Vessel Flange (mm)	259 ±1				
Total Spect. Magnet Cold Mass (kg)	~1390				
Copper Shield and Intercepts Mass (kg)	~290				
Vacuum Vessel and Cooler Mass (kg)	~1990				
PMT Iron Shield Mass (kg)	~1240				
Total Spectrometer Solenoid Mass (kg)	~4910 (with iron shield)				
Peak Cold Inter Coil Force (MN)**	~1.47				
Peak Cold to Warm Force (MN)**	~0.23 (with iron shield)				

+ The coil radius may be adjusted by the subcontractor by up to +5 mm

* Axial dimensions are from the match coil end of the cold mass cryostat (Figure 1)

Radial dimensions are from the magnet axis

** For the standard (Case 1) with $p = 200$ MeV/c and $\beta = 42$ cm based on the 300 K dimensions of the coils

^ The self-inductance of the two end coils and the centre coil in series = 78 H

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Figure 1. MICE Spectrometer Solenoid Magnet Cold Mass Sub-assembly with Supports

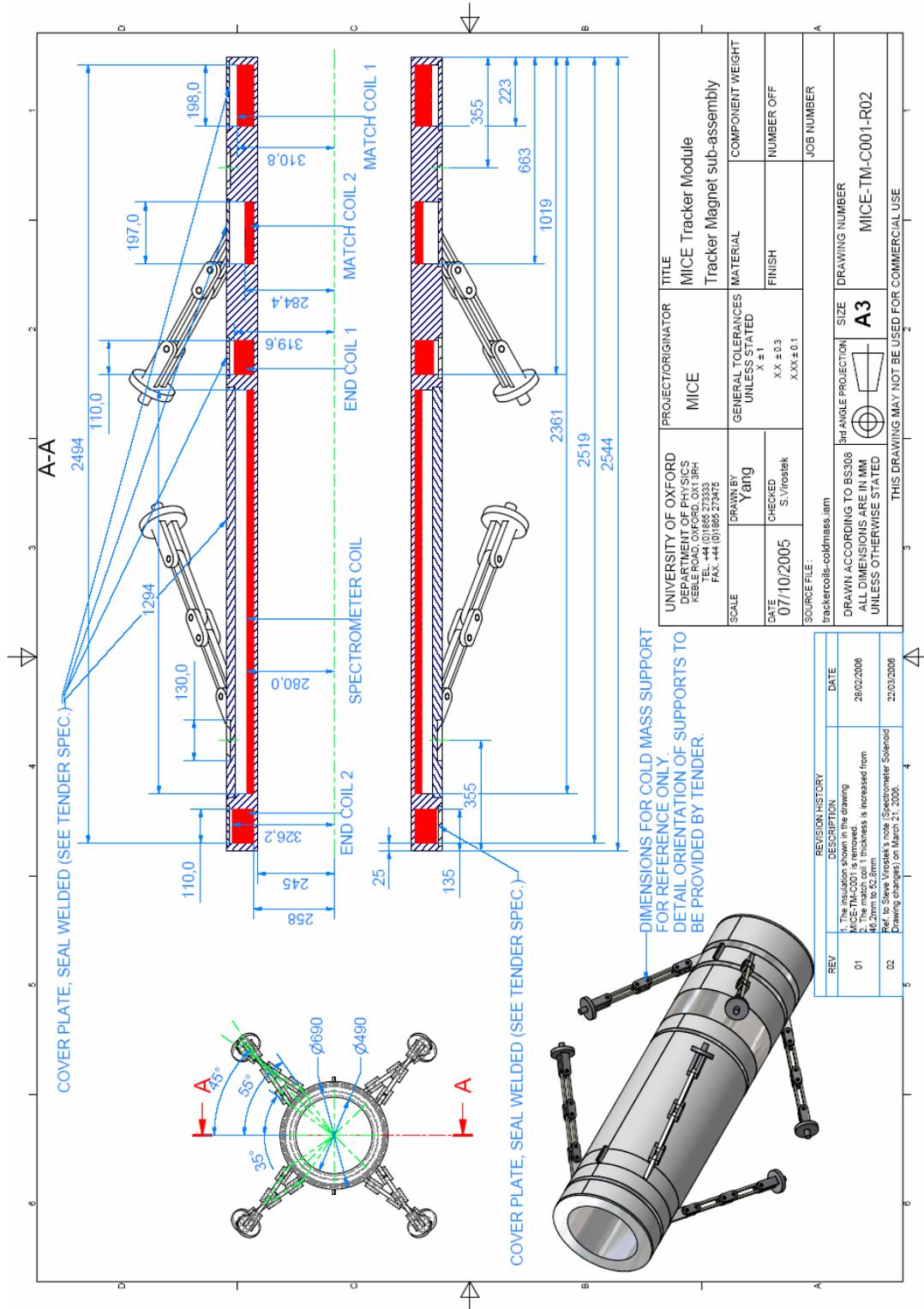
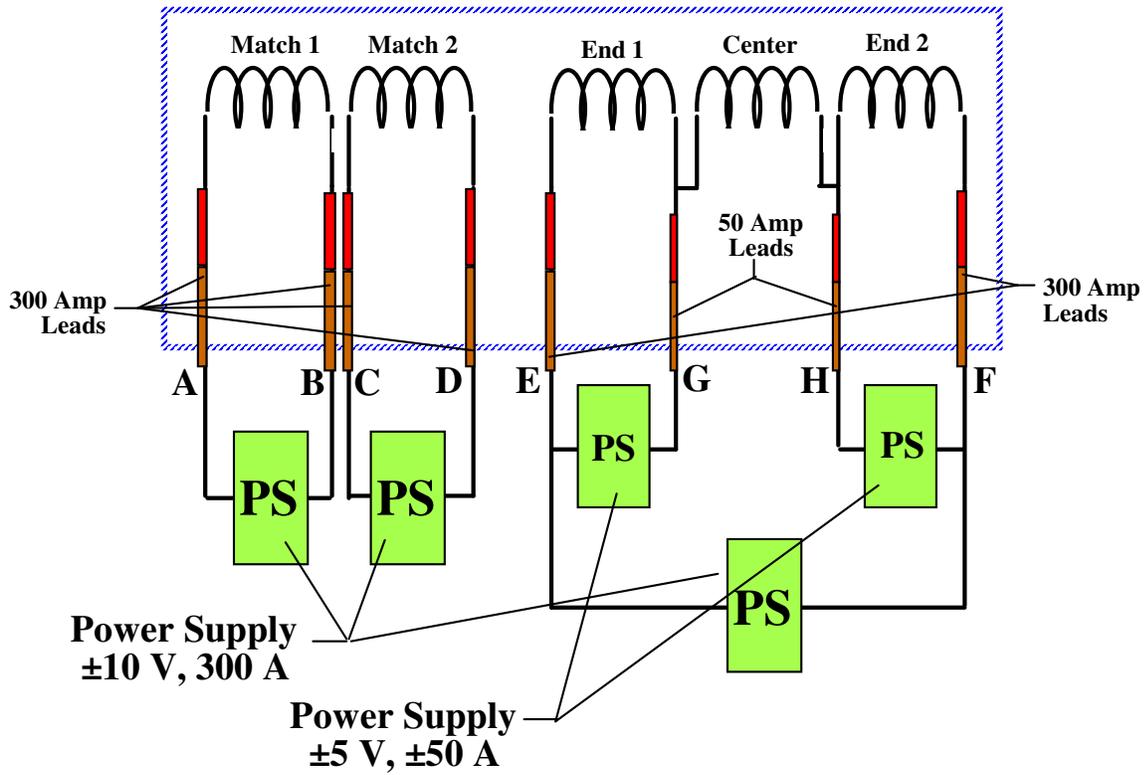


Figure 3. Magnet Coil, Magnet Leads, and Magnet Power Supply Circuit Diagram

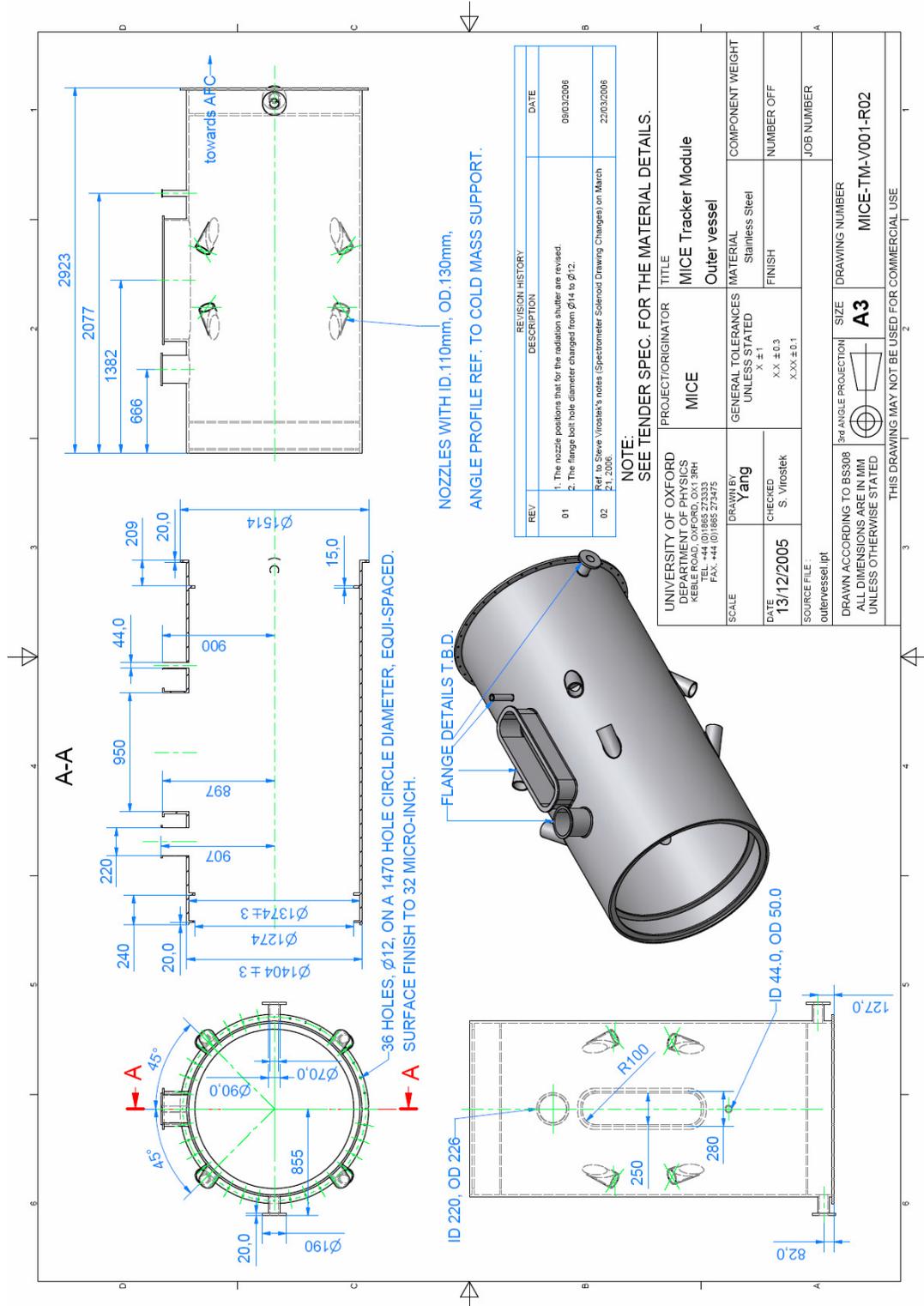


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Figure 4. Spectrometer Solenoid Magnet Outer Vacuum Vessel Details

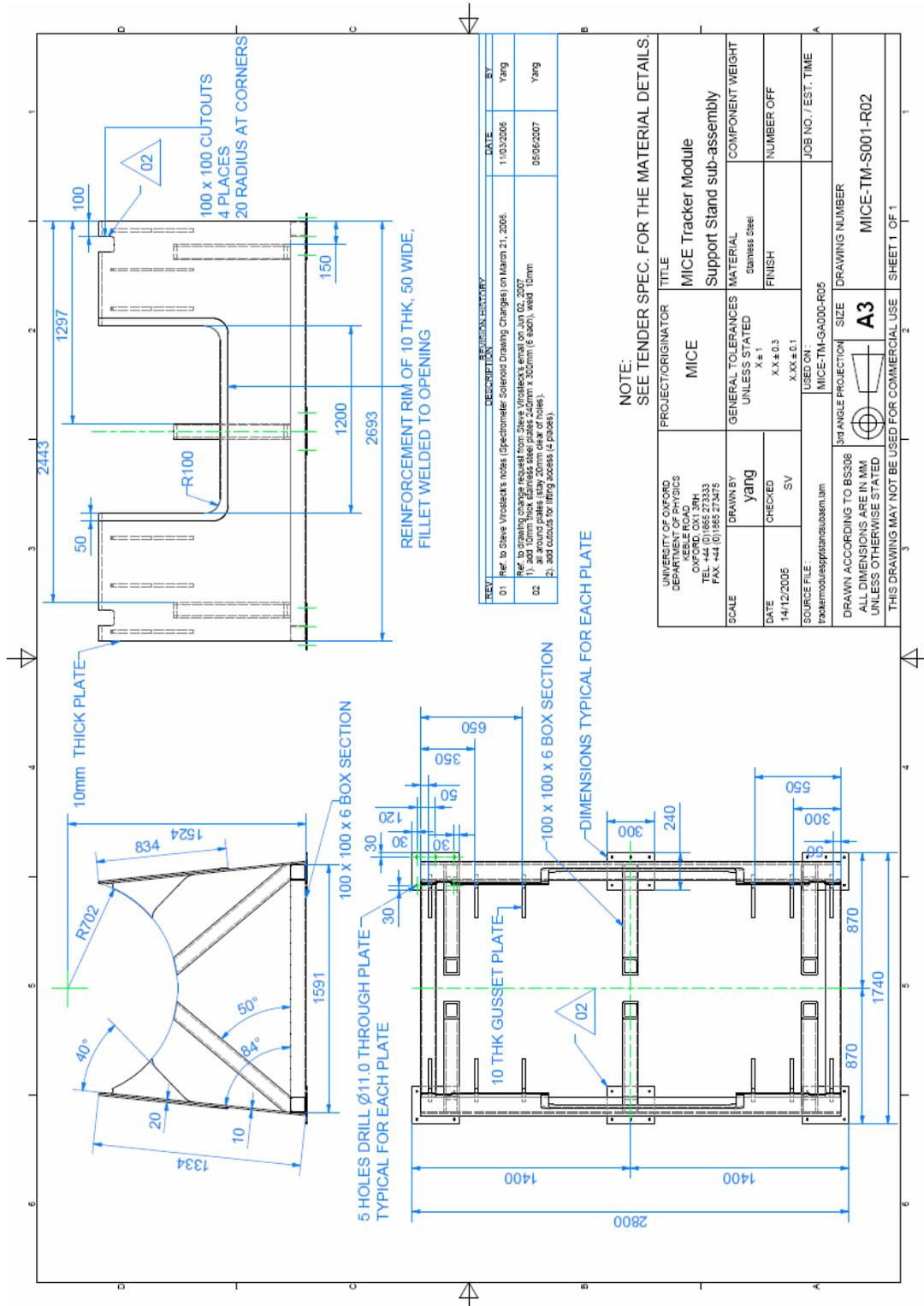


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Figure 5. The MICE Spectrometer Solenoid Magnet Support Stand



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Figure 6. Iron Shield Mounting Pad Details

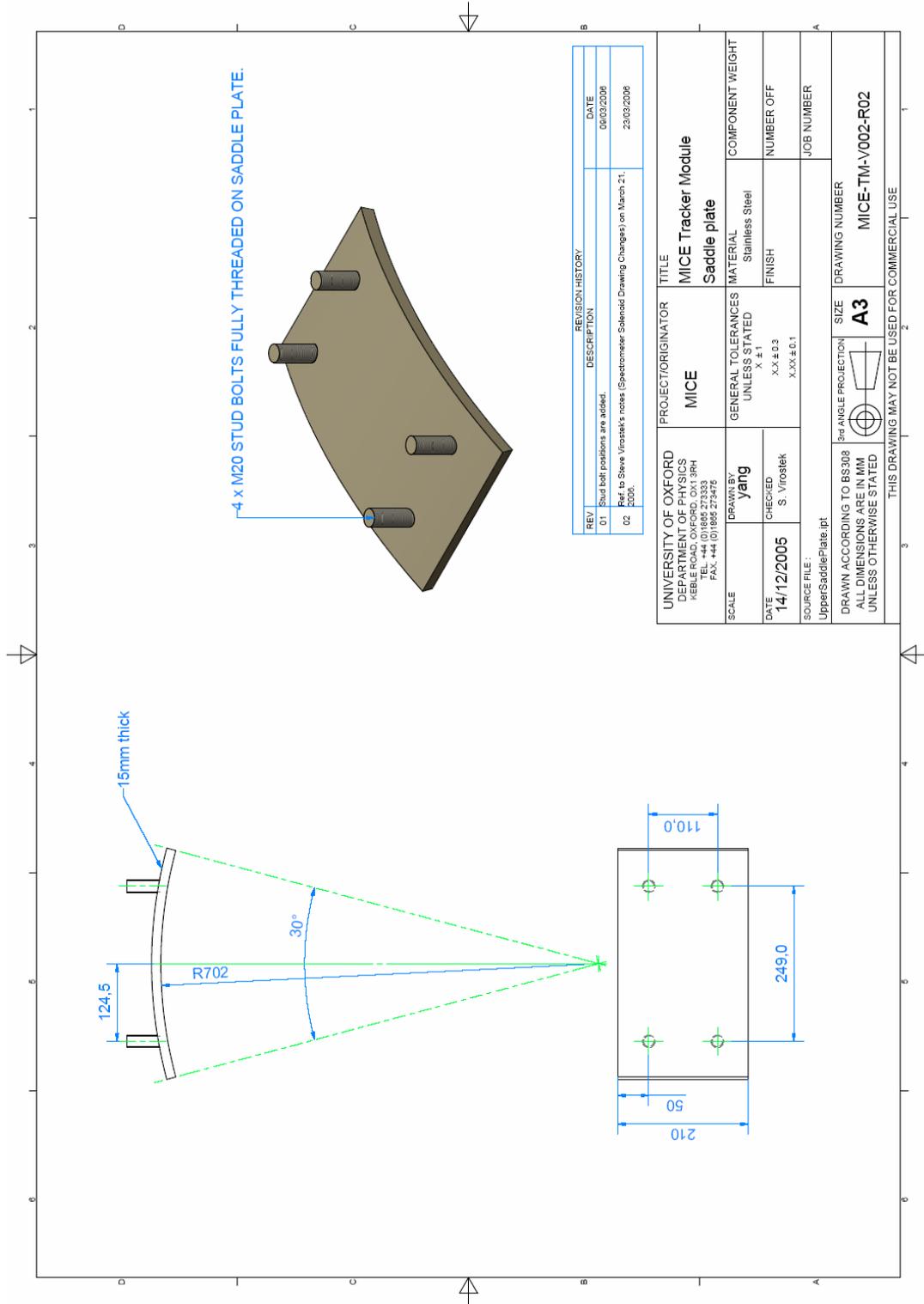
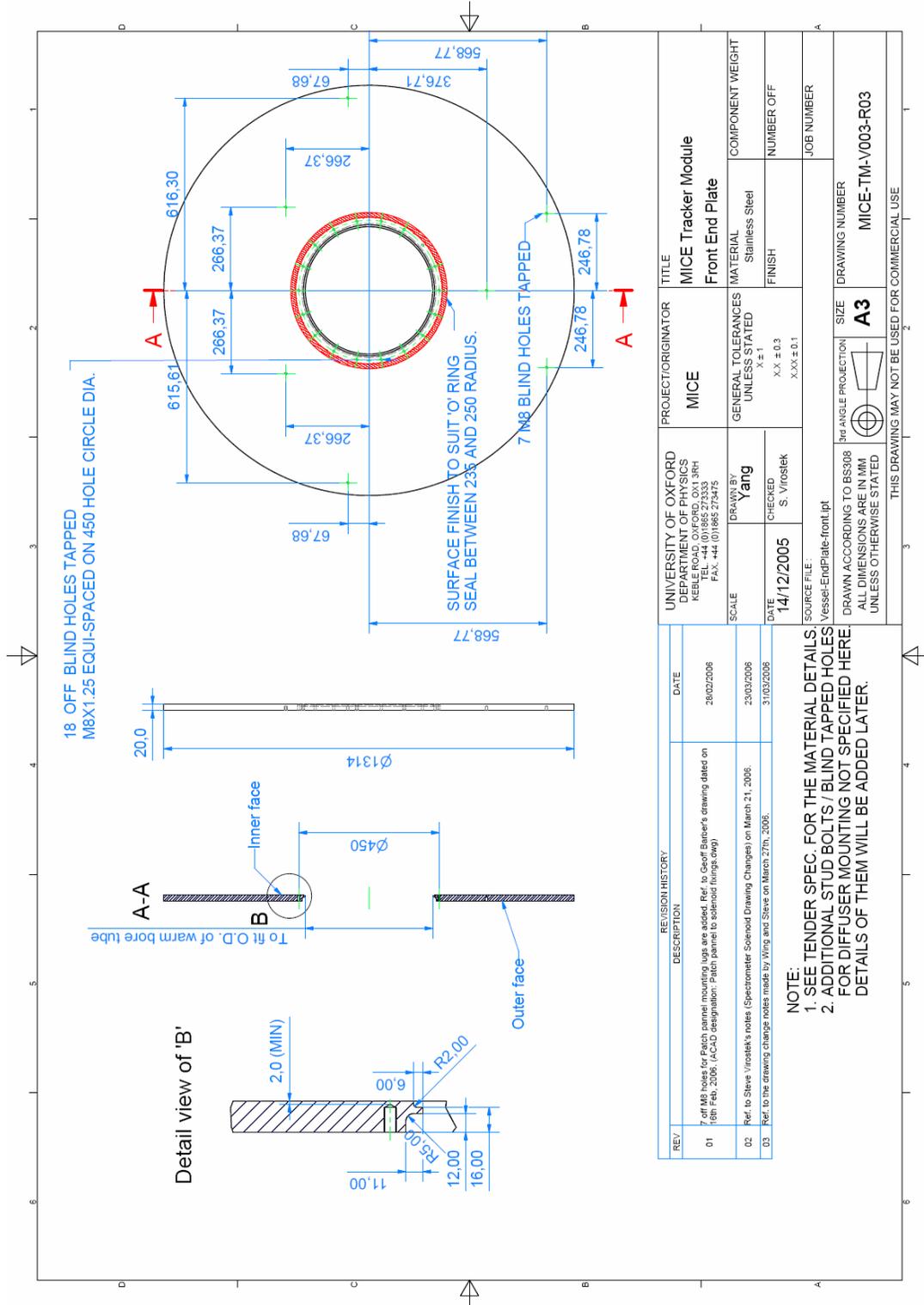


Figure 7. Patch Panel Interface Details

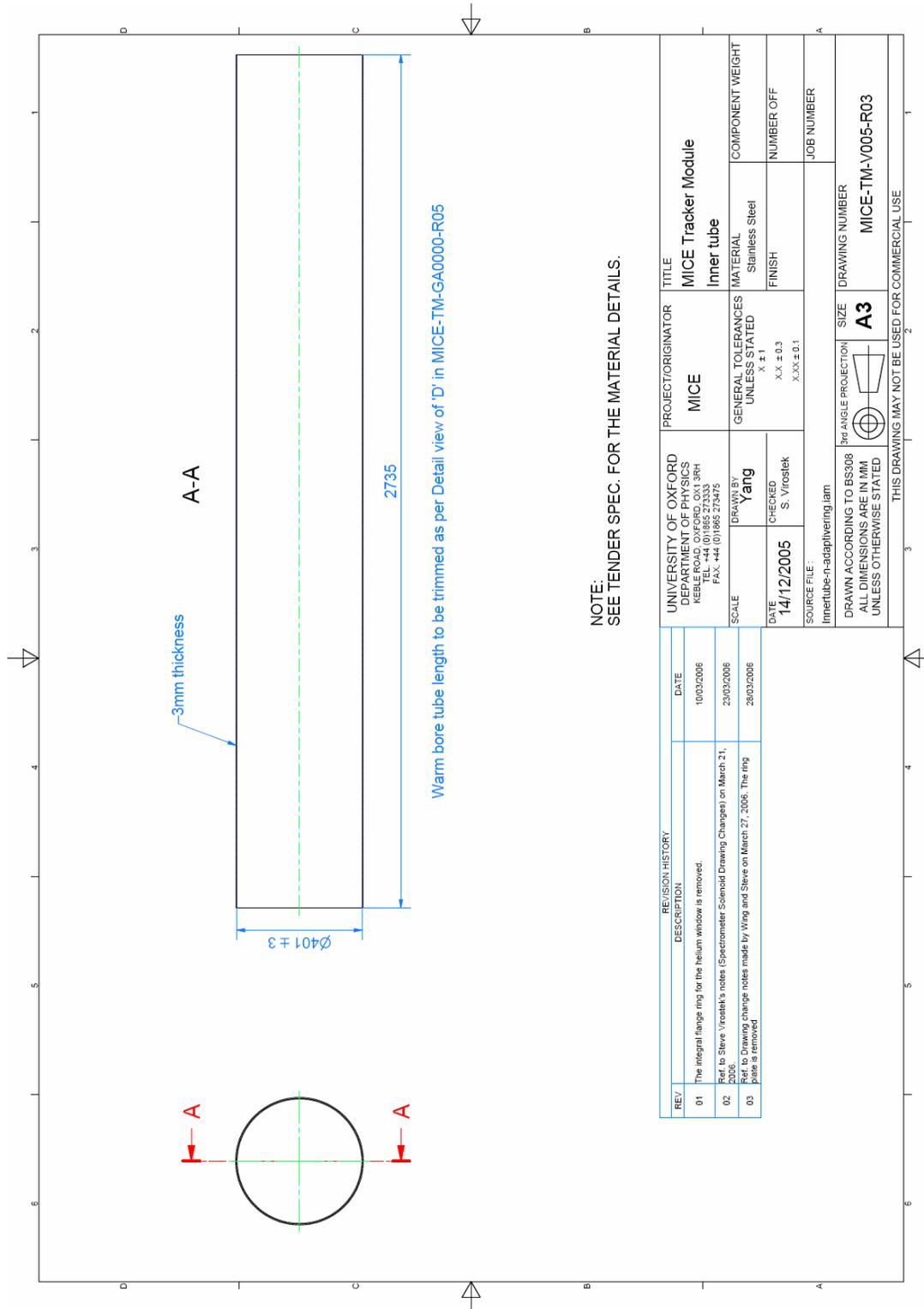


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Figure 8. Spectrometer Solenoid Warm Bore Details

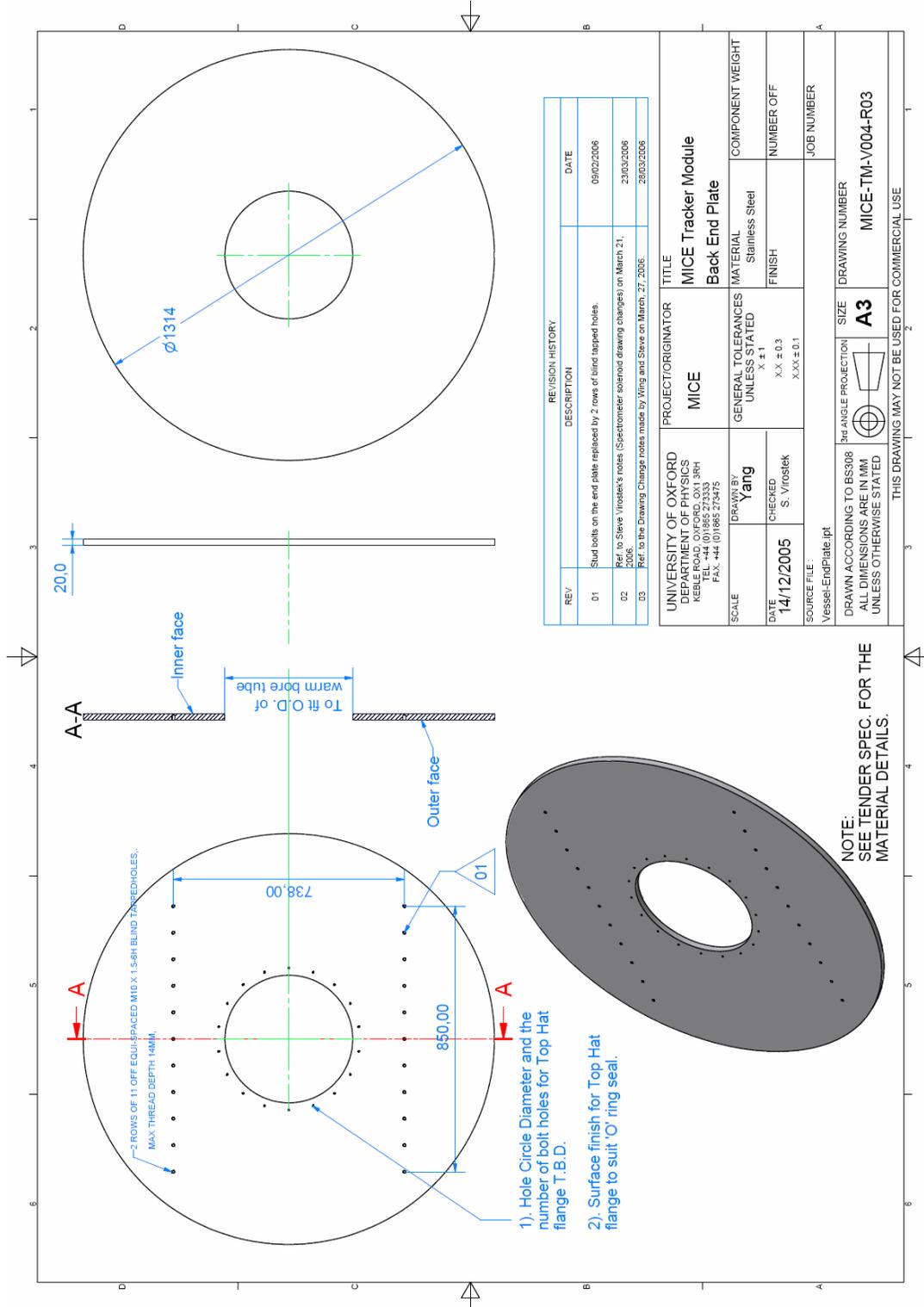


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Figure 9. Radiation Shutter Interface Details



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Figure 10. Diffuser Mechanism Mounting Ring

