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Technical Specification for the 1.5 Tesla Superconducting Solenoid for the BaBar Detector

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For the BABAR Detector

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1.0 Introduction

This document sets forth the specification of the BABAR superconducting solenoid and power supply which is being supplied to the BABAR collaboration by INSTITUTO NAZIONALE DI FISICA NUCLEARE (INFN). The solenoid will be installed in the BABAR detector which will be located at Interaction Region 2 (IR2) of the PEP II machine, a positron electron collider, presently under construction at the Stanford Linear Accelerator Center (SLAC) located in Menlo Park, California. The solenoid will become part of the BABAR detector which will be used in SLAC's high energy physics program.

Intense beams of electrons and positrons are made to collide inside the solenoid magnet. High field uniformity quality, precise mechanical alignment and long term stability are essential characteristics of the solenoid.

INFN will set up a committee that will provide contractual and technical oversight throughout the design, fabrication and installation phases of the BABAR solenoid construction. That committee will be the final authority to resolve any differences between these specifications and the INFN supplied drawings, in addition to any differences between these specifications or the INFN supplied drawings and the proposals from the vendor. All submissions for approval to INFN whether for design changes, material approval, design submissions or others as required by this specification shall be acted upon INFN within two (2) weeks of receipt of the submission. If no answer is given the vendor may assume approval and proceed.

2.0 Statement of Work

The vendor shall furnish all labor, equipment, materials, facilities and services to engineer, design, fabricate, inspect, test, and ship to SLAC the superconducting solenoid and power supply system defined herein. The superconducting solenoid system shall consist of the integrated coil and cryostat, service chimney, control dewar, and all ancillary instrumentation, safety relief valves, etc. as specified and/or deemed necessary by the vendor.

The vendor shall guide, and approve the installation and commissioning of the system in the SLAC BABAR assembly hall. The vendor shall also supply all documentation as required in this specification.

This specification, including the drawings listed in Appendix A and the list of codes and standards and materials properties references in Appendix B defines the requirements for the design, fabrication, testing, delivery, installation and commissioning of the superconducting solenoid system required by INFN for the BABAR detector in IR2 of the PEP-II machine presently under construction at SLAC.

3.0 Items furnished by INFN

Two vacuum pumps are available for use, however, their suitability for this application must be determined by the vendor. If the vacuum pumps are determined to be unsuitable for this application the vendor will then supply vacuum pumps appropriate for the BABAR solenoid. In either event the vendor must assume full responsibility for the vacuum pumps operation and to interface into the solenoid control system. The specifications of the vacuum pumps available at SLAC are listed in Appendix C

4.0 Associated Documents

In Appendix A are listed the specification drawings which are part of this specification. In Appendix B are listed the standards and codes which are part of this specification insofar as they are applicable.

5.0 Requirements

5.1 General Requirements

5.1.1 The solenoid system shall be fully contained within the "stay clear" zone as defined in Figure 1. This drawing indicates the volume allowed for the solenoid cryostat, the allowed pathway for the service chimney, and the relative location and allowed volume for the control dewar. Figure 2 specifies the required mounting/support holes that shall be provided on the end flanges of the solenoid cryostat outer vacuum vessel. No exception to this specification without prior INFN approval shall be permitted.

5.1.2 Figure 3 enumerates the cryogenic, mechanical, electrical instrumentation, and control interfaces for the system in Interaction Region 2 (IR2, the location of the BABAR detector).

5.1.3 The solenoid overall radial thickness in interaction lengths shall be 0.25 (98.5 mm aluminum equivalent), but if this is not feasible then the interaction length should not exceed 0.40 (158 mm aluminum equivalent), excluding the cold mass supports and the portions of the cryostat beyond the ends of the outer support cylinder.

5.1.4 The cold mass supports shall be designed to minimize the heat leak to the helium system, while meeting all of the mechanical requirements specified in 5.1.5 and 5.5

5.1.5 The solenoid axis of the coil shall align to the axis of the outer vacuum vessel to within +/- 1.0 milliradians angular deviation, and the coil position with respect to the vacuum vessel shall be known and fixed to within +/- 2.0 mm in any transverse or axial direction, when the solenoid is cold and energized. The maximum relative motion of the coil with respect to the vacuum vessel shall be limited to +/- 2.0 mm in any radial or axial direction upon energization of the solenoid accompanied by the decentering forces specified in 5.5.1.3. No exception to this specification without prior INFN approval shall be permitted.

5.1.6 The service chimney which connects the solenoid cryostat with the control dewar shall be designed to permit it to be disconnected from the solenoid and the control dewar as specified in Figure 1, during the shipping of the system to SLAC. This will also allow the solenoid and control dewar to be installed separately into the flux return

5.1.7 The control dewar shall serve as the primary vacuum relief manifold of the cryostat and control dewar as specified in 5.6.4. INFN will provide bayonet fittings which interface all solenoid system cryogenic lines to the BABAR cryogenics supply and return lines as shown in Figure 4. The service vacuum vessel shall be made of a material suitable for low temperature use in addition to being non-magnetic as described in 5.9.7, and it shall be relieved as specified in 5.5.2 and 5.9.4.

5.1.8 The vendor shall deliver to INFN two conductor samples each 3 m in length from each finished conductor used in the solenoid prior to the start of coil winding. The samples shall be taken not less than 2 m from each end of the conductor length and be identified unambiguously as specified in 5.14.2 to permit correlation with specified sample testing of 5.14.5.1, 5.14.5.2 and 5.14.5.3 and usage in the finished coil per 5.14.5.4. The vendor shall deliver to INFN two samples each 3 m long of finished cable. The samples be shall taken not less than 3 m from each end of the cable length and to be identified as described above.

5.1.9 The vendor shall review the documents provided by INFN as specified in 4. 0. This review shall take place prior to the preliminary design review and the vendor shall certify in writing to INFN that this review has been conducted.

5.1.10 The solenoid shall be delivered FOB to the Port of San Francisco, CA.

5.1.11 The vendor shall guide, and approve the installation of the solenoid system into the BABAR flux return at SLAC. Following notification by INFN of the scheduled beginning of installation, the vendor shall guide and approve the rigging and installation of the system at SLAC, and shall guide and approve the closure of the field joint in the service chimney as specified in 5.1.6 following the procedure specified in 5.13.2 supplied by the vendor. After the system has been connected to the SLAC electrical, cryogenic, electronic systems in the BABAR assembly hall, the vendor shall guide and approve the testing of the system as specified in 5.14.9. At this point all technical elements of the subcontract will have been fulfilled.

5.1.12 The vendor shall submit to INFN all design drawings, calculations and engineering notes, material specifications, etc., of the solenoid system engineering design, and the design of fixtures specified in 5.12, for approval. The engineering design may be divided into subunits convenient to the vendor and the necessary design drawings, calculations etc. be submitted accordingly , for INFN approval. No procurement or fabrication shall be initiated by the vendor until the appropriate design approval has been granted.

5.1.13 The vendor shall prepare and submit to INFN for approval the test plans and fabrication procedure plans specified in 5.13. INFN approval shall be granted in writing, with allowances made for any needed clarification or modification.

5.1.14 INFN shall approve the final engineering design of the solenoid system, the design of the fixtures as specified in 5.12, and the testing and fabrication plans specified in 5.13, prepared by the vendor. However, the vendor shall remain solely responsible.

5.1.15 Should it appear advantageous or necessary that any element of the vendor's design, testing or fabrication plan be changed after it has been approved by INFN, this change shall be proposed by the vendor and made only if approved by INFN.

5.1.16 All approval drawings specified in 5.1.12 and fixture drawings specified in 5.12 shall be transmitted to INFN in hardcopy form, plus in electronic IGES format in a manner to be agreed upon between INFN and the vendor. A full set of the system drawings, revised as necessary to include all "as built", shall be forwarded to INFN in both hardcopy and electronic format prior to the completion of the contract.

5.2 Magnetic Field Requirements

5.2.1 The vendor shall produce a solenoid field at the center of the solenoid clear bore (R = 0.0, Z = 0.0) defined as B_o to not less than 1.5 tesla at the operating current.

5.2.2 The final steel reference geometry will be supplied to the vendor by INFN at the time the order is placed. A representative steel design is described in Appendix D along with the B-H curve for 1020 steel. The vendor shall design the solenoid using the reference geometry to produce a uniform field ($\Delta B_o / B_o$) of 2% over the volume defined as $-1500 < z < 1600$ mm and $0.0 \leq r \leq 800$ mm.

5.3 Coil Winding Requirements

5.3.1 The solenoid superconductor shall be a Rutherford cable of strands of copper-stabilized multifilament niobium-titanium composite. The cable is stabilized by high-purity aluminum metallurgically bounded to it. The bond between the pure aluminum and the cable must be able to support a shear stress of 30 MPa or greater to ensure quench safety and operating stability. The use of other cable configurations shall require INFN approval.

5.3.2 The conductor design current divided by the short sample critical current I_{op} / I_{crit}, shall not exceed 0.40 at peak field. The short sample critical current I_{crit} shall be as defined along the load line of the solenoid at operating temperature expected during chargeup of the solenoid.

5.3.3 The conductor turn-to-turn insulation shall not be less than 0.5 mm total thickness. The thermal transmittance defined as thermal conductivity divided by thickness of this material shall not be less than $8 \times 10^{-3} W / cm^2 K$. The ground-plane insulation shall withstand the test voltages as described in Section 5.4.4 and shall not be less than 1 mm thick. The thermal transmittance for this material shall not be less than $4 \times 10^{-3} W / cm^2 K$. The specified thickness minimum and thermal transmittance minimum are those that apply when the coil is cold and fully energized.

5.3.4 The coil shall be supported by an aluminum alloy outer support cylinder which provides axial integrity and radial hoop support.

5.4 Electrical Requirements

5.4.1 The design current shall not exceed 7500 amperes. The design current shall be equal to greater than 105% of the operating current.

5.4.2 The solenoid shall operate at any current equal to or less than design current, at either polarity. During operation the solenoid coil and current leads in the service chimney shall carry the design current or any fraction thereof stably in the fully superconducting state.

5.4.3 The solenoid's adiabatic peak temperature during a quench shall not exceed 100 K and the solenoid shall not sustain damage of any kind when quenched (either spontaneously or during tests specified in 5.14.8) from design current or any fraction thereof without an external protection resistor.

5.4.4 The solenoid (or other current-carrying member of the system as specified in 5.14) shall sustain high potential tests at +500 and -500 volts DC to appropriate ground as specified in 5.14 at room temperature. The maximum leakage current recorded after stable current levels have been achieved at each voltage polarity shall be the basis for defining compliance or noncompliance with this specification as described 5.14.3.2 with the maximum leakage current for the individual test are listed in the test specification in 5.14.

5.4.5 The solenoid shall discharge without quenching when discharged from design current or any fraction thereof into the IR2 energization circuit buswork which has a resistance of 1×10^{-4} ohms plus a voltage drop of approximately 1 volt across "free-wheel" diodes and switchgear in the circuit (the "slow discharge" mode).

5.4.6 The solenoid shall discharge safely from design current using an external protection resistor which in parallel with the IR2 energization circuit buswork specified in 5.4.5 generates a discharge voltage between the cold ends of the vapor cooled leads and to ground not greater than 250 V. The protection resistor shall have a grounded center tap to limit the discharge voltage of any element of the system to ground to one-half of the voltage between the vapor cooled leads.

5.4.7 The solenoid shall permit charging at either polarity to design current within one half hour, or to any fraction of design current in proportionately less time.

5.4.8 The vapor cooled current leads shall operate without damage at design current of the solenoid for a period of not less than 4 minutes, after cooling gas flow is interrupted.

5.4.9 The solenoid system shall be tested to 30% of the design current as specified in 5.14.8 at the vendor's facility prior to shipping to SLAC. Once the solenoid system is installed inside the flux return the solenoid shall be tested to design current as specified in 5.14.8.

5.4.10 Electronics Subsystem Characteristics

The Electronics Subsystem shall consist of the high current power supply, high current contractor, dump resistor, and four instrumentation and control cabinets. The major purpose of the electronics subsystem is to control, power and protect the solenoid. Protection is accomplished by monitoring instrumentation and effecting either a dump or a slow discharge in the event of a detected unacceptable condition.

5.4.10.1 Subsystem Operating Requirements

The Electronics Subsystem has four distinct operating modes in addition to shutdown

Charging: Charging the solenoid will be accomplished by adjusting the Current Controller to the desired current. The Power Supply *will then slowly ramp the current to the desired operating level.* Time to charge to 1.5 Tesla shall not be greater than 30 minutes.

Steady State: The Power Supply shall be adjusted to obtain any steady state field between zero and 1.65 Tesla (10% over the operating field of 1.5 Tesla). In addition, for fields between 0.5 and 1.5 Tesla the Power Supply current must be regulated to +/- 0.1% in any 24 hour period. The Subsystem must function continuously for field up to 1.5 Tesla and for a minimum of one hour at any field between 1.5 and 1.65 Tesla.

Slow Discharge: The subsystem must be capable of slowly discharging the solenoid. When the solenoid is full charged to 1.5 Tesla the discharge time shall be less than 30 minutes. Discharge is to be accomplished automatically when conditions indicate a dangerous condition, or manually, when a shutdown or lower current operating level is desired. Slow discharge is to be accomplished by a gentle reversal of Power Supply voltage, rather than a resistive load discharge.

Fast Discharge: A fast discharge will be initiated under the emergency conditions or when manually requested. The fast discharge is an emergency operating mode and will be completed in less than three minutes. Discharge will begin when the High Current Contractor is commanded to open. The solenoid energy will then be released into the air-cooled passive dump resistor. Discharge voltage shall not exceed 550 V and the dump resistor temperature shall not exceed 121 C. The dump resistor will be fenced to reduce the personal hazards that exist from the high voltage and temperature

5.5 Mechanical Requirements

5.5.1 The solenoid system shall be designed to sustain all loadings generated by cooldown, charging to and operation at the design current or any fraction thereof, during quenching, during cooldown recovery from a quench, and warmup to room temperature, as well as the loadings generated by its support and the detector elements (Inner RPC see 5.5.1.1) it supports.

5.5.1.1 As indicated in Figure 2 the solenoid cryostat is supported by the flux return. The solenoid cryostat in turn shall be designed to serve as the support for the inner Resistive Plate Counter (RPC). The inner cylindrical RPC will be installed on the inside diameter of the solenoid cryostat which consists of 9 quarter circular components. The total thickness of the inner RPC is 30 mm and the total mass is very small compared to weight of the solenoid.

5.5.1.2 The solenoid control dewar cold mass structure, cold mass support system, radiation shields and vacuum vessels, piping, conductor buses, and instrumentation leads shall sustain all thermal strains, displacements and stresses generated during cooldown warmup , and the thermal conditions generated by charging and discharging the solenoid, in addition to the loadings specified in 5.5.1.1.

5.5.1.3 The solenoid cold mass structure, cold mass support system, radiation shields and vacuum vessels, piping and conductor buses, and instrumentation leads shall be designed to sustain all magnetic loadings and displacements generated by the coil when operated at the design current or any fraction thereof, including the decentering forces (which are to be taken as simultaneous) generated by the differences in the forward and backward flux return doors and all forces due to eddy currents generated by charging and discharging the solenoid. In addition to the loadings and displacements of 5.5.1.1 and 5.5.1.2. The magnetic decentering forces which scale proportionately with the operating current in the solenoid are:

5.5.1.3.a The maximum of either an axial force of 20t or the magnetic decentering force from an axial alignment error of 2 cm in either direction at the design current;

5.5.1.3.b The maximum of either a radial force of 20t or the magnetic decentering force from a radial alignment error of 2 cm at the design current;

5.5.1.4 The solenoid, control dewar, cold mass structure, cold mass support system, radiation shields, vacuum vessels, piping, conductor buses, and instrumented leads shall be designed to sustain all loadings and displacements generated by quenching, or undergoing discharge as defined in 5.4.5 and 5.4.6 from design current or any fraction thereof, in addition to the simultaneous loadings and displacements of 5.5.1.1, 5.5.1.2, and 5.5.1.3.

5.5.1.5 The solenoid system shall be designed to sustain all loadings and displacements generated by the following seismic conditions in addition to the simultaneous loadings and displacements of 5.5.1.1, 5.5.1.2, 5.5.1.3 and 5.5.1.4. The entire detector will be built on seismic isolators which greatly reduces the horizontal and axial seismic loads in these directions. :

5.5.1.5.a An axial force in either direction equivalent 0.2 times gravity dead weight of the cold mass;

5.5.1.5.b A force in any transverse horizontal direction equivalent to 0.2 times the gravity dead weight of the cold mass;

5.5.1.5.c The vertical force in either direction equivalent to 1.6 times gravity dead weight of the cold mass;

5.5.2 The solenoid shall sustain the following abnormal loadings in addition to the simultaneous loadings and displacements of 5.5.1.1, 5.5.1.2, 5.5.1.3 and 5.5.1.4 with no subsequent structural or electrical degradation or failure.

5.5.2.1 Abnormal loadings of internal vessels from loss of vacuum conditions defined by CGA S-1.3, paragraph 4.9.1.1;

5.5.2.2 Abnormal pressure loadings on internal vessels from the fire condition defined by CGA S-1.3, paragraph 5.3.5;

5.5.2.3 Abnormal loadings from rupture of internal piping;

5.5.2.4 Abnormal loadings of vacuum vessels from release of pressure by internal vessels as specified in CGA 341, paragraph 6.4.2;

5.5.2.5 Other loadings - the vendor shall identify all other credible fault conditions and loadings specific to his design and accommodate them in his mechanical design.

5.5.3 The solenoid system shall sustain all shipping and handling loadings during shipment as defined by the vendor from the vendor's facility to IR2 at SLAC, and installation of the system into the BABAR apparatus

5.5.3.2 Removable shipping supports for the cold mass are permissible.

5.5.4 The inner and outer cylindrical shell of the solenoid cryostat vacuum vessel shall be free of access port coverings, O-ring seals, fasteners, or protruding features

5.5.5 O-ring seals, if used on any vacuum vessel, shall be double with a pump-out port between the two.

5.5.6 Stiff members ("bumpers") shall be provided on the interior of the solenoid cryostat end bulkheads which can support an outward axial loading from the solenoid coil. These members shall not contact the solenoid coil nor radiation shield during normal solenoid operation but serve to constrain it within the cryostat in the event of a cold mass support system failure.

5.6 Vacuum Requirements

5.6.1 The magnet vacuum system vessel in its entirety, including exterior and interior vessels, piping, valves and fittings shall be free of leaks to the following specified limits. The maximum helium leak rate from any part of the cryogenic magnet system which is enclosed in a vacuum shell or vacuum piping, which also includes current leads and instrumentation feed-throughs, shall not exceed 1×10^{-8} mbar l s^{-1} for all temperatures from ambient to operating temperature. The maximum helium leak rate for any part of the solenoid system shall not enclosed within the vacuum vessel shall not exceed 1×10^{-6} mbar l s^{-1} for all operating temperatures.

5.6.2 During fabrication the vendor shall perform helium leak checks, as appropriate, to all component parts, assemblies, and sub-assemblies using a helium mass spectrometer leak detector with a sensitivity not less than 1×10^{-10} mbar l s^{-1}.

5.6.3 The service chimney shall be no larger than 360 mm OD with the inner cryogenic plumbing occupying equivalent cross sectional area of 210 mm OD Cryogenic standoffs shall be designed to minimize the impact on vacuum pumping conductance. Two CS 150 vacuum pump out ports as located in SLAC Figure 1, shall be provided for the two Varian V450 turbo molecular pumps which will provide by SLAC.

5.6.4 A pressure relief valve shall be provided in the chimney for safety of both the magnet and control dewar vacuum specs. This relief valve shall be sized to safely vent a catastrophic rupture of the control dewar and magnet cooling loops or to safety vent a steady state helium released from the liquefier.

5.7 Cryogenic Requirements

5.7.1 The magnet system shall be designed to permit it to be cooled from room temperature to its operating temperature of 4.5K in 170 hours. Initial cooldown to ~40K will be accomplished by using helium gas or liquid nitrogen in a controlled manner. The remainder of the cooldown will be carried out with liquid helium from the cryoplant supply dewar.

5.7.2 SLAC Liquefier/Refrigerator

SLAC is planning to acquire a helium liquefier refrigerator which may eventually be used to supply liquid helium and gas to the BABAR solenoid. The helium liquefier/refrigerator is a modified Linde TCF-200. The anticipated capacity of the plant is given in Table 5.7.

MODE	100 g/s @ 1.8MPa (235 psig)	
	With LN2	Without LN2
As a Liquefier @ 4.5K	280 l/h	130 l/h
As a Refrigerator @ 4.5 K	870 W	710 W
In Mixed Mode		
• Liquefaction @ 4.5K and	265 l/h	115 l/h
• Refrigeration @ 40K	350 W	350 W

Table 5.7
Liquefier/Refrigerator Capacity

5.7.3 The valving, piping cooling circuits, instrumentation and control systems, where employed, must be of adequate design for the safe and stable cooldown and normal operation of the magnet coil and its heat shields. The configuration must be compatible with the operation of the liquefier / refrigerator described in 5.7.2

5.7.4 Coil Cooldown

Initial cooldown can be with LN_2 or cold N_2 or He gas. The vessel is then purged and the cooldown continued with helium. Liquid helium or cold helium gas from the liquefier/refrigerator, is supplied to the service vessel, where it is mixed with ambient temperature gas from the helium compressor to obtain the appropriate gas temperature for that point of the cooldown. The gas then passes through the coil cooling loops and returns to the refrigerator. Gas mixing is done by proportional control valves and a process control system, using appropriate logic loops and temperature sensors.

Helium will be available for gas mixing, as liquid, from the liquefier storage dewar at 39 kPa (5 psig); or as cold gas directly from the liquefier/refrigerator at ~9K, and 0.4 MPa (50 psig).

Purified ambient temperature helium gas from the compressor will be available for gas mixing, at 1.8 MPa (235 psig).

A simplified schematic of the service vessel valving, is shown in

Figure 3.

5.7.5 The vendor will be responsible for the safe and controlled cooldown of the magnet coil and its shields.

5.7.6 The radiation shield will be cooled progressively and simultaneously with the coil, using refrigerated helium or nitrogen gas, to its operating temperature.

5.7.7 The same cryogen supply used for radiation shield cooling, or a fraction thereof, will also be used to intercept heat flow down the cold mass support links and instrumentation leads.

5.7.8 The radiation shield shall be designed to permit cooling and continuous operation independent of the temperature of the magnet coil.

5.7.9 The control valve for the supply and flow control of liquid helium to the coil liquid helium reservoir shall be located in the control dewar of the of the solenoid. The vendor shall install three identical (one active, two spare) superconducting, liquid helium level gauges in the coil liquid helium reservoir. The vendor shall furnish the manufacturer's recommended control units for these level gauges. The control unit must be incorporated into the vendor supplied control system.

5.7.10 The vendor, shall establish all process control requirements. These requirements together with the proposed process control system shall be submitted to INFN for approval

5.7.10.1 The vendor supplied process control system shall be capable of meeting all cryogenic operating requirements including cool down and warm up of the solenoid coil, operation during quench conditions and other operating requirements specified by the vendor in 5.7.10. The type of process controller must be approved by INFN. The processor will include an asynchronous serial interface (digital) i.e. an RS232 data port for command and data exchange with other BABAR systems. It shall also have the operating status of the coil cryogenic system available via the data port.

5.7.10.2 The vendor shall be responsible for supplying a system to control all valves, switches, etc. to accomplish the requested operation.

5.7.10.3 The vendor shall deliver all coding documentation which shall include address comments and rung comments. Comments shall fully explain functionality of the address and/or rung.

5.7.10.4 The vendor shall provide all system source codes and one set of programming hardware.

5.7.10.5 The vendor shall provide a complete set of reproducible electrical diagrams and control drawings with I/O numbering.

5.7.10.6 The vendor shall provide operating status data from the processor via the data port. Status data shall include liquid level, pressure, temperature and any information required to safely and efficiently operate the coil cryogenic system in all modes. The vendor shall provide all pertinent data for the BABAR supplied operator interface.

5.7.10.7 Controls shall be configured in a manner that minimizes the impact of all upset conditions on the coil and the SLAC cryogenic plant.

5.7.10.8 All control valves shall be provided with the capability of manual override and adjustment.

5.7.10.9 The vendor shall only use operational control valves which feature removable plugs and seats, to permit adjustment of the valve trim and control parameters over a reasonable range.

5.7.11 Cryogenic Heat Loads

5.7.11.1 The total conduction and radiation heat load from the cold (4.5K) magnet system, inclusive of the power leads, during steady state operation of the magnet at design current or any fraction thereof, shall not exceed 70 watts for shields operating at 77 K.

5.7.11.2 The total conduction and radiation heat load from the thermal shields and heat load intercepts of the magnet system, during steady state operation of the magnet at design current or any fraction thereof, shall not exceed 350 watts.

5.7.12 The total heat load to the liquid helium supply stream of the transfer line is less than 3W.

5.7.13 The design pressures in the following parts of the solenoid cryo-magnet system under normal operating conditions with the magnet powered will be:

1) liter supply dewar. 0.04 MPa (5 psig)
2) Solenoid coil control dewar. 0.03 MPa (3.5 psig)
3) Compressor return, at the coldbox. 0.01 MPa (1.5 psig)

The pressure drop between the coil control dewar and the compressor return pressure at the coldbox will be 0.015 MPa (2.0 psig)

5.7.14 No external surface of any part of the solenoid system, shall have a temperature lower than 5°C below ambient (where ambient temperature range is 4 - 32 C and the relative humidity range is 20 - 80%) when warmed solely by free convection of ambient air, during all normal operations, inclusive of coil and shield cool down and at design current. If the vapor cooled current leads cannot be designed to prevent icing or condensation on their external surfaces or supports, then provision must be made for these to be maintained at no less than 5°C below ambient temperature by an electrical heating system.

5.7.15 The magnet coil and its shields and their associated low temperature ancillaries, shall be designed to permit forced warmup in a safe and controlled manner, similar to magnet cooldown.

5.7.16 BABAR will supply the mating female bayonet fittings, which will be incorporated in the solenoid control dewar, to accept the, coil and radiation shield helium transfer line bayonet fittings.

5.7.17 Pressure and vacuum sensing lines shall be provided with isolation valves external to the vacuum vessel and differential pressure sensing lines shall be provided with external balance manifolds.

5.7.18 The pressure drop across the vapor cooled current leads shall be such that it will permit adequate lead cooling and proper flow regulation at the design current of the magnet, or any fraction thereof.

5.7.19 Helium Leak Rates

a) Vacuum enclosed.

The maximum helium leak rate from any part of the cryogenic magnet system enclosed within the vacuum vessel, including the coil cooling loops, helium reservoir, shields, pipings, valves, current lead feed-throughs and instrumentation feed-throughs shall not exceed 1×10^{-8} mbar l s^{-1}, under all ranges of temperature from ambient to operating when pressurized to 1.5 times their standard operating pressure.

b) Non Vacuum Enclosed.

The maximum helium leak rate from any part of the cryogenic magnet system ,including the vacuum vessel and any parts not enclosed within the vacuum vessel, shall not exceed 1×10^{-6} mbar l s^{-1}, under all ranges of their operating temperature.

5.7.20 During fabrication, the vendor shall perform helium leak checks, when and where appropriate, to all component parts, assemblies and sub-assemblies, using a helium mass spectrometer leak detector with a sensitivity not less than 1×10^{-10} mbar l s^{-1}

5.7.21 The vendor shall thermally shock all welds and whenever feasible, the vendor will thermally shock, all applicable cryogenic component parts, assemblies and sub-assemblies, by submerging or spraying with liquid nitrogen and then repeat the helium mass spectrometer leak test.

5.8 Lifetime and Operational Cycle Requirements

5.8.1 Design Life - the solenoid system shall be capable of operation as defined herein for a period of 10 years.

5.8.2 Thermal Cycles - the solenoid system shall permit 150 cooldown cycles from room temperature to operating temperature and back to room temperature. The system vacuum may be repressurized to atmospheric at each thermal cycle.

5.8.3 Energization Cycles - the solenoid system shall permit 2500 energization cycles to design current or any fraction thereof, plus the cycles generated by the testing specified in 5.14. The normal method of discharge shall be via the slow discharge as specified in 5.4.5.

5.8.4 Although the solenoid shall be designed to be charged to and operate at design current or any fraction thereof without quenching, the solenoid shall be designed to withstand up to 20 quenches without the use of the fast discharge protection resistor specified in 5.4.6.

5.8.5 The solenoid shall be designed to withstand up to 400 quenches from design current or any fraction thereof when discharge into the fast discharge resistor specified in 5.4.6.

5.8.6 The solenoid system shall be designed for fitness to the intended experimental environment:

Following successful completion of the installation and tests at SLAC as specified in 5.1.12 and 5.14.9, the detector components that go in the solenoid bore will be installed and the entire apparatus will be moved into the beam line region so that physics data taking can begin. While the apparatus is being moved between the assembly location in IR2 and the beam line location, the solenoid system will be isolated from the IR2 cryogenic, energization, and vacuum systems.

Once accelerator operation begins, the beam line region becomes a radiation hazard area and the entire apparatus becomes inaccessible. All aspects of the solenoid system operation shall be accomplished remotely, and any access to the control dewar requires undesirable down time. Access to the service chimney or the solenoid cryostat would constitute a major upset to the experiment and the SLAC operating schedule and is highly undesirable.

A normal experiment run will require that the solenoid remain cold and energized for up to a year, with deliberate discharges from time to time for field reversal. The solenoid may be discharged occasionally to permit access to certain parts of the BABAR apparatus, and unexpected discharge of the solenoid may occur due to loss of power or other unforeseen system upset. Short periods of 5-60 days may elapse wherein the solenoid is discharged and allowed to warm by means of the interruption of the flow of cryogens to the system from the refrigerator. For longer standby periods, which may extend to a year or more, the system will be allowed to warm to room temperature, and optionally the vacuum space may be repressurized to atmospheric with dry nitrogen

5.9 Design Methodology and Code Requirements

5.9.1 Basic Analysis Approach - The vendor shall utilize finite element codes such as NASTRAN, ANSYS, TOSCA, or the equivalent as primary tools for structural, magnetostatics and thermal analysis. A time dependent quench analysis code such as QUENCH shall be used to predict quench behavior. INFN shall approve and if it deems necessary require validation any code selected by the vendor. Analytic analysis where appropriate and adequate is acceptable.

5.9.2 Structural Analysis Methodology - Structural analysis shall be based on linear elastic behavior of all elements of the system throughout all loadings as specified in Section 5.5. Detailed plastic analysis may be employed in specific instances to show that stress are within the specified limits.

5.9.3 The stress Intensity Criteria shall be used for combined stresses.

5.9.4 The ASME Boiler and Pressure Vessel Code Section VIII, Division 1, shall be the basis for design of all vacuum vessels. Vacuum vessels need not be Code stamped, and shall be designed for full vacuum (0.10 MPa, 15 psid) and internal relieving pressure of at least 0.09 MPa (12 psig) and not greater than 0.20 MPa (15 psig).

5.9.5 The vendor shall provide design analysis documentation sufficient to certify that all vacuum vessels have been designed as specified in 5.9.4. They shall provide relief for all vessels and piping as required by the ASME Boiler and Pressure Vessel Code, Section VIII, and ANSI B31.3 piping standards under the abnormal loadings specified in 5.5.2 and provide analysis for all relieving conditions and subsequent sizing of relief orifices.

5.9.6 Structural materials shall be selected to have acceptable properties over the entire range of temperatures to which they will be exposed. The design allowables for any material shall be the minimum material properties given over the entire operating temperature range. Materials properties shall be based on NBS data or equivalent for low temperature application when the ASME Boiler and Pressure Vessel Code does not address the material. All materials used in the solenoid coil and cryostat and service chimney shall be selected to meet the specified performance criteria after a dose of 1.0×10^6 Rads.

If in the opinion of INFN insufficient data exists to verify the acceptability of a selected material, tests shall be conducted by the vendor to verify such material and its subsequent use shall be approved by INFN

5.9.7 No ferromagnetic or other magnetically active material shall be utilized in the construction of the coil or cryostat.

5.9.8 Material Certification data sheets shall be provided for all standard metal shapes (plates, rounds, tubings, etc.) used in fabricating the elements of the system. Omitted from this requirement are standard parts, fittings, etc., which are supplied in such a manner that precludes this specification. Welding specifications, welder qualifications, and coupons shall be delivered to INFN.

5.10 Factors of Safety and Analysis Limits Requirements

5.10.1 The design allowable stresses for the loading conditions specified in 5.5, where not otherwise covered by the ASME Boiler and Pressure Vessel Code, Section VIII, are presented in Table 5.10:

ITEM	Normal Load	Abnormal Load
Membrane σ_m	$\sigma_m \le 2/3\ \sigma_{yield}$ and $\sigma_m \le 1/4\ \sigma_{ult}$	$\sigma_m \le \sigma_{yield}$ and $\sigma_m \le 3/8\ \sigma_{ult}$
Bending σ_b	$\sigma_b \le \sigma_{yield}$ and $\sigma_b \le 3/8\ \sigma_{ult}$	$\sigma_m \le \sigma_{yield}$ and $\sigma_m \le \sigma_{ult}$
Membrane + Bending	$\sigma_m + \sigma_b \le \sigma_{yield}$ and $\sigma_m + \sigma_b \le 3/8\ \sigma_{ult}$	$\sigma_m + \sigma_b \le \sigma_{yield}$ and $\sigma_m + \sigma_b \le 3/8\ \sigma_{ult}$
Tensile	$\sigma_t \le 1/4\ \sigma_{ult}$	$\sigma_t \le 3/8\ \sigma_{ult}$

Table 5.10 Stress Analysis Limits

5.10.2 For buckling analysis, a factor of safety of 5.0 shall be applied if end conditions, etc., are not precisely defined. Otherwise a buckling factor of safety of 4.0 shall be applied.

5.10.3 In cases where non-metallic composite materials are utilized, principal stresses shall be limited to 20% of the material ultimate strength to prevent conditions of creep/flow

5.10.4 In cases where non-reinforced non-metallic materials are utilized, principal stresses shall be limited to 10% of the material ultimate strength to prevent conditions of creep/flow.

5.10.5 For finite element modeling and safety margin calculations, the nominal thickness of plate and tube material shall be used.

5.10.6 Cyclic stress shall be considered following the lifetime loading requirements *specified in* 5.8, where a given cyclic loading lifetime shall be multiplied by a factor of four in counting the total number of cycles to be applied in particular stress analysis.

5.11 System Instrumentation and Valving Requirements

5.11.1 The vendor shall provide all necessary instrumentation required for safe and reliable operation of the solenoid system. Cabling and connectors shall be selected to be suitable to the use intended in the applicable cryogenic, vacuum, high voltage, radiation, and limitation of accessibility, environments of the solenoid system. The minimum instrumentation is enumerated in 5.11.2, 5.11.3, 5.11.5, 5.11.6, and 5.11.7 as specified therein. The minimum valving is enumerated in 5.11.9.

5.11.2 The potential taps shall be not be located at the coil center, but rather at the ends of the coil. The taps specified shall be separately connected to the coil so that they are physically as well electrically redundant.

5.11.3 The minimum temperature measurement instrumentation shall be:

1. Temperature of each radial and each axial support at the coil support cylinder: For example: Lake Shore carbon glass resistor, approx. 500 ohm at 4.2 K, Model CGR-1-500-4B, 4-wire, factory calibrated for 4-40K:
2. Temperature of each radial and each axial support at the intermediate temperature intercept: For example: Lake Shore Platinum resistor, approx. 100 ohms @ 0C, Model PT-102-77Lm 3 or 4 wire, factory calibrated for 75-325K;
3. Temperature of supply helium at the control dewar: For example: Lake Shore carbon glass resistor. approx. 500 ohm at 4.2 K, Model CGR-1-500-4B, 4 wire, factory calibrated for 4-40K;
4. Temperature of return helium at the solenoid control dewar: as specified in [3.];
5. Temperature of inlet helium at solenoid: as specified in [3.];
6. Temperature of outlet helium at the solenoid: as specified in [3.];
7. Temperature of solenoid support cylinder at the service chimney end, at the coil center, and at the end opposite the service chimney, top and bottom at each axial location: For example: Lake Shore carbon glass resistor. approx. 500 ohm at 4.2K, Model CGR-1-500-4L, 4 wire, factory calibrated for 4-325 K.
8. Temperature of the inner surface of the coil at the service chimney end, at the coil center, and at the end opposite the service the chimney, top and bottom of the coil at each axial location: For example: Lake Shore carbon glass resistor. approx. 500 ohm at 4.2 K, Model CGR-1-500-4L, 4 wire, factory calibrated for 4-325 K;
9. Temperature of the magnet inner and outer radiation shield at the service chimney end, and at the opposite end top and bottom (8 total): As specified in [2.];
10. Temperature of the magnet inner radiation shield at the top and bottom center: As specified in [2.];
11. Temperature of the magnet outer radiation shield at the top and bottom center: As specified in [2.];

12. Temperature of the shield nitrogen flow at the control dewar, supply and return: As specified in [2.];
13. Temperature of the support nitrogen flow at the control dewar, supply and return: As specified in [2.];
14. Temperature of warm ends of the vapor cooled leads: As specified in [2.];
15. Temperature of the cold ends of the vapor cooled leads: As specified in [1.];
16. Temperature of the vacuum vessel outer shell, inner shell, and one end bulkhead: As specified in [2.];

5.11.4 The minimum pressure measurements instrumentation shall be:

1. Pressure of helium supply at the solenoid control dewar: For example Rosemount Inc. Model 1151GP6E1215, Calibrated to 0-100 PSIG, (or equivalent model calibrated to exceed expected quench pressure maximum), Proof pressure = 2000 psig, overall accuracy = 0.25%, output 4-20 ma;
2. Pressure of the helium supply at the magnet inlet and outlet For example Rosemount Inc. Model 1151GP6E1215, Calibrated to 0-20 PSIG, Proof pressure = 2000 psig, overall accuracy = 0.25%, output 4-20 ma;
3. Pressure of nitrogen supply at the control dewar: For example Rosemount Inc. Model 1151GP6E1215, Calibrated to 0-100 PSIG, Proof pressure = 2000 psig, overall accuracy = 0.25%, output 4-20 ma;

5.11.5 The minimum flowrate measurement instrumentation shall be:

1. Helium flowrate measurement at the control dewar supply and return: For example venturi plus Rosemount Inc. Model 1151DP4E1215, calibrated to 0-100 inches H_2O (calibration depends on venturi design), Proof pressure = 2000 psig, overall accuracy = 0.25%, output 4-20 ma;
2. Helium flowrate measurement at the positive and negative vapor cooled leads: For example Brooks High Mass Flow Controller Readout, Model 5853I, calibrated for 0-280 SLPM helium, Input 4-20 ma, Output 4-20 ma, D-type connector;

5.11.6 The minimum liquid level measurement instrumentation shall be:

1. Helium liquid level (2 redundant probes) in control dewar subcooler: For example American Magnetics superconducting liquid helium level probe and power supply and readout, for selected probe length;

5.11.7 The minimum vacuum pressure measurement instrumentation shall be:

1. Vacuum pressure at the control dewar, and for the guard vacuum (if such is provided) of the vapor cooled current lead dielectric breaks: For example: Granville Phillips Nude Gage, Model 6PC274028, and Granville Phillips Vacuum Gage Controller, Model 340004-1, Range: $1x10^{-10}$ Torr, 120 VAC, Scale: Torr, and Granville Phillips Convectron gage tube, Model 275 071;

5.11.8 The vendor shall provide at a minimum the following valves in the control dewar, and actuators and transducers as specified which interface to the selected valves. All valves shall have replaceable trims.

1. Helium supply to solenoid control valve: For example: Valtek Mark One Model 25 linear actuator, standard spring air to open, stem = 0.88 inch, thread = 3/4-16, 2.00 inch spud, standard stem clamp and bolting; and Beta pneumatic positioner, Model TA6000-41, input 4-20ma, output 3-15 psig;
2. Magnet helium return control valve: As specified in [1.];
3. Helium cooldown line control valve: As specified in [1.];
4. Cold mass support nitrogen flow control valve: As specified in [1.];
5. Radiation shield nitrogen flow control valve: As specified in [1.];

5.11.9 The vendors of the instrumentation specified are:

1. Lake Shore Cryotronics, 64 East Walnut St., Westerville, Ohio 43081-2339, (614) 891-2243
2. Rosemount Inc., 2505 S. Finley Rd., Suite 110, Lombard, IL 60148, (708) 495-8383
3. Valtek, 1350 N. Mountain Springs Parkway, Springville, Utah 84663-0903, (801) 489-8611
4. Brooks, Control Plus, 257 N. West Ave., Suite 204, Elmhurst, IL, (708) 279-9025

5. Fairchild, 3920 West Point Blvd., Winston-Salem, NC 27103, (919) 659-3400
6. Granville-Phillips, 7115 Virginia Rd, Crystal Lake, IL 60014, (815) 477-5478
7. American Magnetics, P.O. Box R, 461 Laboratory Rd., Oak Ridge, TN 37830, (615) 482-1056

If equivalent instrumentation from vendors other than those specified is proposed, INFN must approve of such selection.

5.12 Fixtures, Apparatus and Tooling

5.12.1 The vendor shall provide engineering designs of the following fixtures, apparatus and tooling for review and approval by INFN. No fabrication, procurement, or use of these fixtures may be initiated until this approval is granted.

1. Winding line tensioning apparatus
2. Conductor cleaning and insulating apparatus
3. Coil winding clamps
4. Curing or impregnating fixturing
5. End flange installation fixturing and apparatus
6. Radiation shield and vacuum shell installation apparatus
7. Coil cold mass support system installation fixturing
8. Liquid helium cooling pipes attached to the support cylinder and connection to cryogenic circuit

5.12.2 Should it appear advantageous or necessary that any fixture, apparatus, or tooling be substantively modified after its design has been approved by INFN, this modification shall be brought to the attention of INFN in a timely fashion.

5.13 Procedures and Plans

5.13.1 Preparation and approval of written plans and procedures:

1. All procedures and plans specified in 5.13.2 shall be described in writing by the vendor.
2. All written correspondence and reviews shall be in English.

3. The written description of a fabrication procedure shall contain at a minimum a description of special tooling or fixturing required, an outline of processes or steps involved, all tests, measurements, and inspections required to demonstrate suitability of function and compliance to specification of the corresponding fabricated element, and statements of working tension, pressure, strain, temperature, voltage, etc. as required by the fabrication.
4. INFN shall review and approve all procedures specified as part of the conceptual and final design approval process and no fabrication relating to use of any specified procedures may be initiated until this approval is granted.
5. If at any time during the execution of the contract it may appear advantageous or necessary that any procedure or plan approved by INFN be revised, this revision shall be described and approved by INFN and the vendor before it is implemented.

5.13.2 Procedures and Plans that shall be described by the vendor:

1. Finished Conductor Shipping and Handling
2. Coil Winding Line Testing and Operation
3. Conductor Joint Fabrication
4. Coil Axial Preload Generation
5. Coil Winding and Impregnation
6. End Flange Installation
7. Instrumentation Lead and Potential Tap Installation
8. Radiation Shield Installation
9. Cold Mass Support Installation
10. Vacuum Shell Installation
11. Coil Alignment Fiducial Installation and survey
12. Cryogenic and Current Bus Connections at Magnet Cryostat / Chimney interface
13. Liquid helium cooling pipes attached to the support cylinder and connection to cryogenic circuit
14. Service chimney field joint and vacuum closeout
15. Control Dewar Assembly
16. Service Chimney and Magnet Cryostat Integration
17. Shipping plan
18. Inspection plan after receipt at SLAC
19. DC powering system, quench detection system and controls

20. Cryogenic control system

5.14 Measurements, Tests and Inspections

5.14.1 Preparation and approval of written test plans

1. All tests, measurement, and inspections specified in 5.14.5 shall be described in writing by the vendor.
2. The written description of a test, measurement, or inspection specified in 1 above shall contain at a minimum a list of special test instrumentation and or facilities required, an outline of the procedures involved, and any analysis, extrapolation, or other manipulation of data that is required to render the test results suitable for demonstration of compliance to specification on the part of the item tested, measured, or inspected.
3. INFN shall review and approve the descriptions of all tests, measurements, and inspections, specified in 1 above, as part of the conceptual and final design approval process as specified in section 6 and before and such test, measurements, or inspection is conducted by the vendor.
4. If at any time during the execution of the contract it should appear advantageous that inspection approved by INFN be revised, this revision shall be described and approved jointly by INFN and the vendor before it is implemented.

5.14.2 Documentation of Measurements, Tests, and Inspections

1. All measurements, tests, and inspections made by the vendor or his agents shall be documented at the time of the performance. Components shall be identified uniquely and testing documentation designed so that traceability to the vendors records of all measurements, tests, and inspections is complete and unambiguous. The date of the test, inspection, or measurement, and the signature of the person making it as well as that of the person certifying it, shall be part of each record. The final compliance or non-compliance of the tested item to specification shall be clearly indicated on the record as described in 5.14.3. In the case of testing documentation prepared by agents of the vendor, all such documentation shall be dated and certified by the issuing agent and once again by the vendor when

such documentation is submitted to INFN and filed by the vendor as specified in 3 and 4 below.

2. A sequential photographic record shall be made during the assembly of all complex elements. This record shall consist of annotated photographs fixed in a suitable binder with dates and legends sufficient to identify the subassembly or process being documented. Photographs shall be made using 35 mm color film with good lighting and a quality camera and printed to 13 x 18 cm (5 x 7 inch) size or larger. A (P) symbol next to any test or inspection specified below indicates that a photographic record of the associated fabrication step, test or inspection is required. This indication denotes the minimum instances in which such photographic records shall be made.
3. Originals or legible copies of all documentation prepared under this specification shall be forwarded to INFN within two (2) weeks after the performance of the measurement, test, or inspection.
4. The vendor shall file and retain for a period of not less than 5 years copies of all documentation prepared under this specification.

5.14.3 Approval of Tests, Measurements, and Inspections, and Compliance and Noncompliance

1. INFN shall approve the results of the tests specified in 5.14.5.1, 5.14.5.2, and 5.14.5.3 as part of the project checkpoint "approval to begin coil winding". INFN shall approve the results of the tests specified in 5.14.5.4, 15.14.5.5, 15.14.5.6, 15.14.5.7, and 5.14.5.8 as part of the project checkpoint "assemble the magnet in the cryostat". INFN shall approve the results of the tests specified in 5.14.5.9 and 5.14.5.10 as part of the project checkpoint "approval to begin assembly of the control dewar". INFN shall approve the results of the tests specified in 5.14.5.11 and 5.14.5.12 as part of the project checkpoint "approval to begin control dewar tests". INFN shall approve there results of the tests specified in 5.14.6 and 5.14.7 as part of the project checkpoint "approval to begin integrated system tests"
2. The vendor shall notify INFN of any element of the fabrication deemed by vendor not to be in compliance with the specification, inspection, measurement, or any other reason. The rework, repair, or replacement of the element shall be proposed by the vendor and approved by INFN before repair is effected. Any approved repair, rework, or replacement shall be fully documented by the subcontractor. No exception to this specification shall be permitted.

5.14.4 Witness of measurements, tests, and inspections

1. INFN shall be notified well in advance of the tests specified in 5.14.6 and 5.14.8 conducted at the vendor's facilities and INFN may witness them.

5.14.5 At a minimum the vendor shall perform the following measurements, tests, and inspections of specified components and subassemblies, or supply information on:

5.14.5.1 Superconductor Strand

1. Short sample critical current measurement of ten representative strands in high field at design current, and measured both in a transverse and longitudinal field;
2. Filament quality index measurement or acid etch and inspection of ten representative strands (P);
3. Filament diameter measurement of representative strands (P);
4. Filament twist pitch of representative strands;
5. Number of filaments in representative strand;
6. Representative filament alloy composition;
7. Representative strand copper/NbTi ratio;
8. Representative strand final copper residual resistivity ratio;
9. Representative strand final diameter;

5.14.5.2 Superconducting Cable

1. Cable transposition length;
2. Dimensions after final compaction (P);
3. Short sample critical current measurement of each finished cable;

5.14.5.3 Stabilized Finished Conductor

1. Aluminum billet chemical analysis;
2. Aluminum – superconducting metallurgical bond measured for each finished conductor;
3. Continuous monitoring and recording of critical aluminum-cable coextrusion process variables such as temperature, etc., including an ultrasonic inspection of the cable-aluminum interface (a video camera is suggested as a recording device);

4. Location of superconductor in aluminum matrix cross-section measured at beginning and end of each finished conductor (P);
5. Short sample critical current measured at beginning and end of each finished conductor;
6. Final overall cross-section measured at beginning and end of each finished conductor;
7. Final aluminum Residual Resistivity Ratio and yield strength measured at beginning and end of each finished conductor in as-delivered condition;
8. Cable ID, Aluminum billet ID in each finished piece;

5.14.5.4 Cable Winding – note a certain winding/assembly technique is assumed; if alternates are selected, an equivalent set of measurements, inspections, and tests must be performed.

1. Diameter, straightness and roundness of winding mandrel before use;
2. Diameter, straightness and roundness of insulated winding surface;
3. Inspection of dielectric insulation at the conductor inlet to coil (P);
4. Measurement of alignment of end flanges;
5. Measurement of conductor cross-section every 100 m during winding, and recording of ID of conductor length in use;
6. Continuous inspection of conductor surface finish and corner radius during winding as documented by signature of inspector;
7. Continuous inspection of conductor insulation during winding as documented by signature of inspector;
8. Continuous monitoring of winding tension as documented in winding logbook and signature of inspector; (not sure we need this if we are winding on the inside of the support cylinder)
9. Continuous monitoring of winding preloading as documented in winding logbook an signature of inspector; (not sure we need this if we are winding on the inside of the support cylinder)
10. Measurement of axial location of every tenth turn with respect to beginning end flange at phi corresponding to conductor length;

11. Axial and angular location of all finished conductor joints (P);
12. Inspection of dielectric wedges, insulation, etc., at all joints (P);
13. Make sample joints and test two (2) or more in a magnetic field prior to proceeding with the real joints;
14. Inspection/tests of all joints (P);
15. Measure the RRR of all joints;
16. Measurement of alignment, axial position of second end flange (P);
17. High potential test as specified in 5.4.4 of the conductor to second end flange, with leakage current not to exceed 1 mA;
18. Clamping and curing/impregnation history of first layer if applicable;
19. Coil electrical resistance at room temperature;

5.14.5.5 Coil Outer Support Cylinder – note a certain assembly technique is assumed; if alternates are selected, an equivalent set of measurements, inspections, and tests must be performed:

1. Diameter and roundness of outer support cylinder an straightness taken every 45 degrees of arc before and after the conductor is wound on the inside ID of the support cylinder.
2. Pressure test of cooling tubing ASME B31.3
3. Vacuum leak test of cooling tubing;

5.14.5.6 Magnet Cryostat Radiation Shields

1. Measurement of circumference of shields at center and ends;
2. Measurement of electrical resistance across dielectric break in shield;
3. Pressure test of cooling tubing following ASME B31.3;
4. Leak test of cooling tubing;

5.14.5.7 Magnet Cryostat Vacuum vessel

1. Measurement of circumference of inner and outer vessels at center and ends before assembly;
2. Measurement of end bulkheads before assembly;
3. Measurement of inner diameter of outer shield and diameter of inner shields after installation to vacuum shells;

4. Measure location of coil with respect to vacuum vessel and end flange after coil and cold mass supports are installed;
5. Vacuum leak check vacuum vessel after vessel has been welded closed up to and including the service chimney;

5.14.5.8 Magnet Cryostat Cold Mass Supports

1. Room temperature test to failure of at least one (1) extra production support (P);
2. Room temperature proof test of each support to be used in magnet to 125% of design load;
3. Vacuum leak check of nitrogen intercept (if applicable);

5.14.5.9 Vapor Cooled Current Leads

1. Radiograph inspection of any soldered or welded current-carrying joints;
2. Proof test the leads at temperature and at the design current;
3. Operate dump switch and energize dump at 30% of maximum operating current of the solenoid. Can we operate the dump switch at maximum current capability of the power supply independent of the solenoid which can only reach 30% at the vendor
4. High potential test the high current carrying members to ground as specified in 5.4.4, with leakage current not to exceed 1mA;
5. Demonstrate operation of data logger installed as required by 5.14.8, item 9;

5.14.5.10 Magnet instrumentation

1. Measure room temperature of 80 K resistance of RTD's.
2. Measure room temperature and 80 K resistance of carbon resistors;
3. Check calibration of pressure transducers;
4. Check calibration of flow meters;
5. Check calibration of vacuum transducers

5.14.5.11 Service Chimney Assembly

1. Leak check all internal piping the requirements described in 5.6;

2. Pressure test all internal piping;
3. Leak test vacuum jacket;
4. DC resistance measurement of current buses;

5.14.5.12 Control Dewar Assembly

1. Leak check internal vessel following the requirements described in 5.6;
2. Verify that internal vessel is code stamped;
3. Leak check all internal piping follow the requirements described in 5.6;
4. Pressure test all internal piping;
5. Check operation of high pressure reliefs;
6. Leak test vacuum jacket following the requirements described in 5.6;
7. Test operation of vacuum relief;

5.14.6 Integrated Control Dewar and Service Chimney Tests - Note it is assumed that the far end of the magnet high current bus are shorted and enclosed in a temporary vacuum enclosure with cryogenic turn-arounds as appropriate.

1. Pressure test of the helium and nitrogen systems;
2. Leak test of the helium, nitrogen, and vacuum systems following ASME V, Article 10, Appendix V;
3. Room temperature flow test of the helium and nitrogen systems;
4. Test operation of all reliefs on the helium and nitrogen systems;
5. Cool the system to operating temperature, logging temperatures of the cold ends of the vapor cooled current leads and the DC resistance of the combined leads and buses vs. time;
6. Test operation of all reliefs on the helium and nitrogen systems;
7. Measure heat leak to the helium and nitrogen systems at zero current;
8. Measure the heat leak to the helium and nitrogen systems at 30% of the design current of the magnet;
9. High potential test between one current lead and the control dewar "ground" as specified in 5.4.4, with leakage current not to exceed 0.1 mA with full vacuum in the service chimney and all internal components at full operating temperatures, pressures and flow rates;

5.14.7 Test of vendor's energization and quench detection system
These tests have been combined with the tests done in 4.14.5.9.

5.14.8 Operational test of the fully integrated solenoid, service chimney, control dewar system, power supply, and vacuums system;

1. Pressure test of the Helium and Nitrogen systems;
2. Leak test of the helium, nitrogen, and vacuum systems;
3. Room temperature flow test of the helium and nitrogen systems;
4. High potential test between one current lead and the control dewar "ground" as specified in 5.4.4, with leakage current not to exceed 0.1 mA with full vacuum in the service chimney at room temperature;
5. Cool the system to operating temperature, logging coil temperatures vs. time; note that in this and all subsequent tests thru 15 below, the helium supply to the solenoid shall be at the temperature and flowrate as specified in Table 5.7.
6. Measure heat leak to the helium nitrogen systems at zero current;
7. Operate power supply to small current and verify proper connection and operation of all potential taps and temperature instruments;
8. Charge the incrementally to at least six increasingly larger current values of 5%, 10%, 15%, 20%, 25% and 30% of the design current at the specified charge rate appropriate to the current level with fast and slow discharges at the end of each current plateau. Operate dump switch and energize dump at 30% of maximum operating current of the solenoid. Log versus time the solenoid current and solenoid terminal voltages, coil and shield temperatures, and helium flow rate, temperature, and pressure in the coil , and temperature, voltage drop and helium flow rates in the vapor cooled current leads, and the temperature of the protective resistor, during this and all tests specified in 10, 11, 12, 13, 14, and 16 below. Logging rates for quantities recorded shall be sufficiently rapid to display he useful time-dependent detail in each parameter, especially during quenching;
9. Verify that the solenoid can be charged to 30% of the design current in the time specified in 5.4.7, and measure inductance of the solenoid;

10. Repeat items 9 and 10 with the solenoid current polarity reversed, selecting fewer intermediate current plateaus if desired;
11. Operate the solenoid at 30% of the design current for a period of not less than 12 hours;
12. Charge magnet at a rate charge sufficient to reach design current in 15 minutes with out exceeding the 30% of the design current.
13. Measure the coil temperature, current, and terminal voltage vs. time following initiation of a quench from 15% design current with the protection resistor shorted;
14. Repeat items 13 quenching the solenoid from 20% and 30% of the design current with the protection resistor shorted;
15. Measure the solenoid field during steps 10, 11, and 12, at locations to be determined by INFN using a Hall probe.

5.14.9 System Tests at SLAC of the fully integrated solenoid, service chimney, control dewar steel flux return, and plugs.

1. Pressure test of the Helium and Nitrogen systems;
2. Leak test of the helium, nitrogen, and vacuum systems;
3. Room temperature flow test of the helium and nitrogen systems;
4. High potential test between one current lead and the control dewar "ground" as specified in 5.4.4, with leakage current not to exceed 0.1 mA with full vacuum in the service chimney at room temperature;
5. Cool the system to operating temperature, logging coil temperatures vs. time; note that in this and all subsequent tests thru 16 below, the helium supply to the solenoid shall be at the temperature and flowrate as specified in Table 5.7.
6. Measure heat leak to the helium nitrogen systems at zero current;
7. Operate power supply to small current and verify proper connection and operation of all potential taps and temperature instruments;
8. Charge the incrementally to at least six increasingly larger current values of 32%, 44%, 63%, 78%, 90%, and 100% of the design current at the specified charge rate appropriate to the current level with fast and slow discharges at he end of each current plateau. Operate dump switch and energize dump at 30% of maximum operating current of the solenoid. Log versus time the solenoid current and solenoid terminal voltages, coil

and shield temperatures, and helium flow rate, temperature, and pressure in the coil , and temperature, voltage drop and helium flow rates in the vapor cooled current leads, and the temperature of the protective resistor, during this and all tests specified in 9, 10, 11, 12, 13, and 14 below. Logging rates for quantities recorded shall be sufficiently rapid to display he useful time-dependent detail in each parameter, especially during quenching;

9. Verify that the solenoid can be charged to the design current in the time specified in 5.4.7, and measure inductance of the solenoid;
10. Repeat items 8 and 9 with the solenoid current polarity reversed, selecting fewer intermediate current plateaus if desired;
11. Operate the solenoid at the design current for a period of not less than 12 hours;
12. Charge magnet at a rate charge sufficient to reach design current in 15 minutes;
13. Measure the coil temperature, current, and terminal voltage vs. time following initiation of a quench from 71% design current with the protection resistor shorted;
14. Repeat items 13 quenching from 87%, and 100% design current with the protection resistor shorted;
15. Operated the solenoid at the design current for a period of not less than 8 hours.
16. Measure the solenoid field during steps 9, 10, and 11, at locations to be determined by INFN using a Hall probe.

6 Project Checkpoints

Approval by INFN of all elements of the vendor's design for the solenoid system as specified 5.1, for procedures and tests in specified in 5.13 and 5.14, and for fixtures as specified in 5.12. This approval process creates the basis for critical checkpoints as enumerated in Table 6, items 3, 5, and 19 Approval for corresponding check points

(a) Preliminary Design

(b) Final Design and Assembly

(c) Vendor testing of 5.14.8

shall be preceded by formal oral presentations by the vendor to INFN at a date, time, and location to be agreed upon by INFN and the vendor. The

ordering of the elements in Table 6 are not intended to indicated preferred sequence of work.

Table 6. Project Checkpoints

ITEM	Check Point
1	Approval of Project Management Plan
2	Approval of Quality Assurance Plan
3	Approval of Preliminary Design (Formal Meeting)
4	Approval of Quench Safety Analysis
5	Approval of Final Design (Formal Meeting)
6	Approval of Procurement of Superconductor
7	Approval to Begin cold Mass Support Fabrication
8	Approval to Begin Winding/Curing Tooling Fabrication
9	Approval to Begin Magnet Cryostat Fabrication
10	Approval to Begin Assembly Tooling Fabrication
11	Approval to Procure Instrumentation
12	Approval to Begin Control Dewar Fabrication
13	Approval to Begin Service Chimney Fabrication
14	Approval to Begin Coil Winding
15	Approval to Procure/Fabricate Vapor Cooled Leads
16	Approval of Control Dewar Tests
17	Approval to Begin Control Dewar Tests
18	Approval to Assemble Magnet in Cryostat
19	Approval if Integrated System Test Plan
20	Approval to Begin Integrated System Tests
21	Approval to Begin System Shipment

Appendix A: SLAC Drawings

The SLAC drawings that are part of this specification are:

Figure 1: Solenoid System "stay clear" layout

Figure 2: Solenoid Mounting & Lifting Hole Locations

Figure 3: Cryogenic Interface Drawing

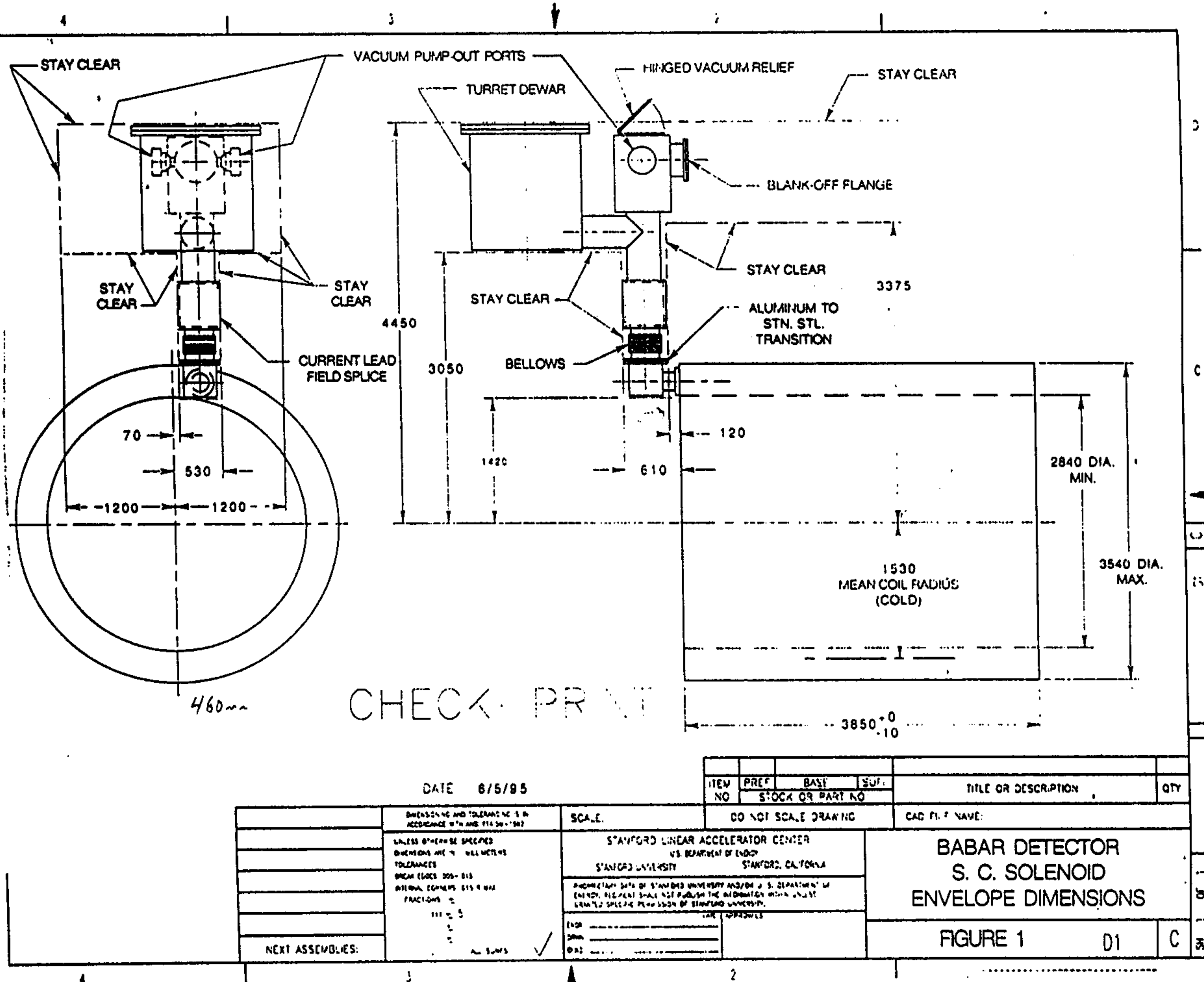
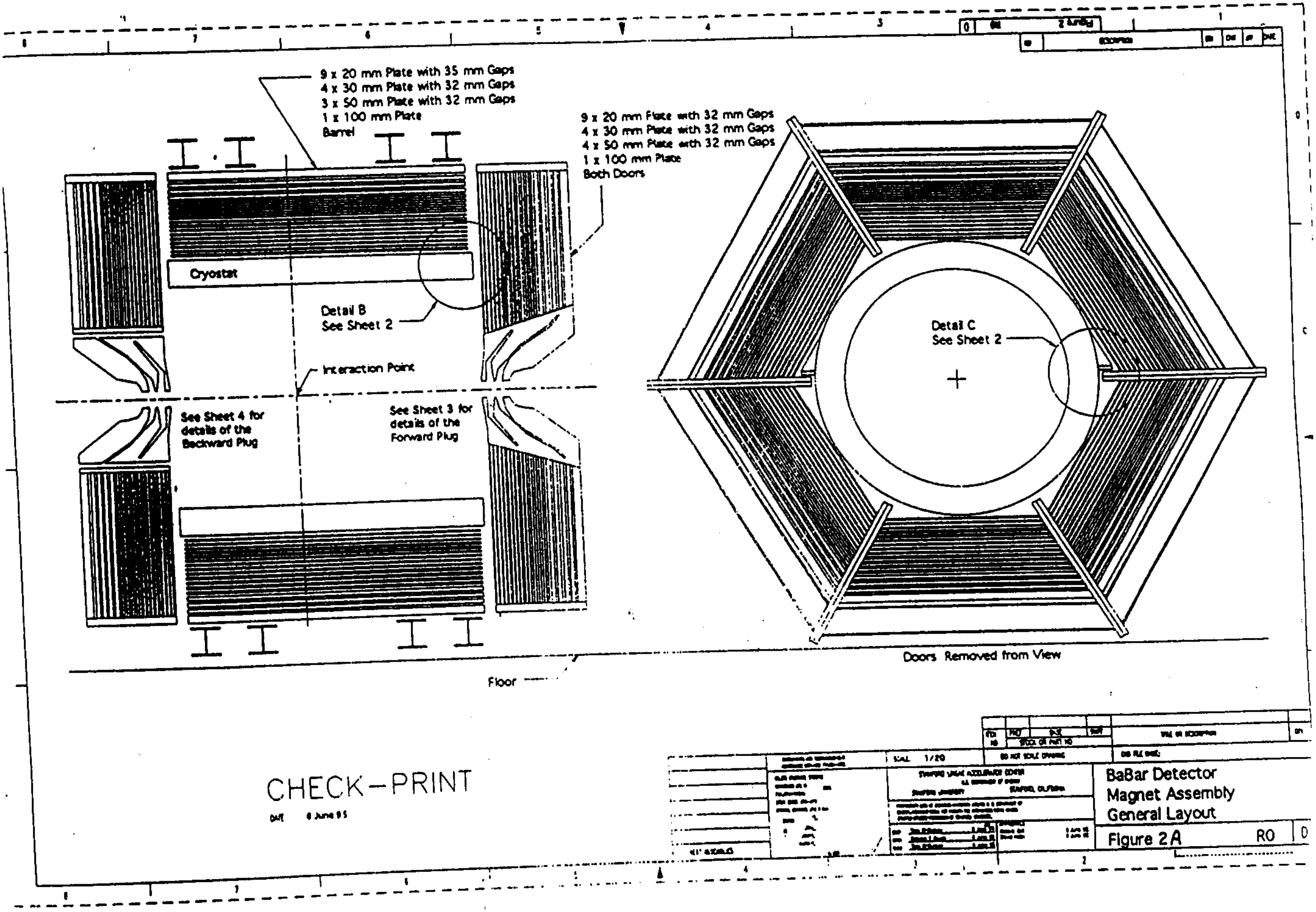
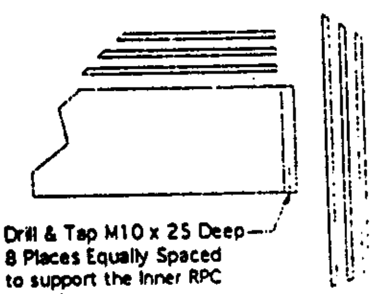
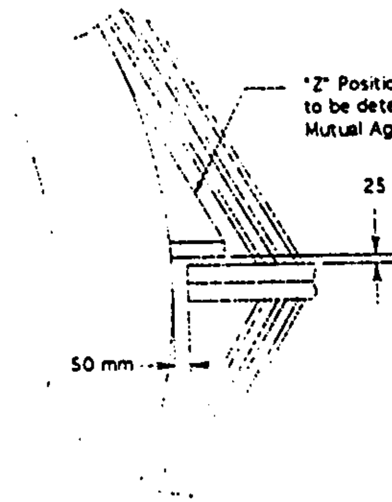


Figure 1: Solenoid System "stay clear" layout


9 x 20 mm Plate with 35 mm Gaps
4 x 30 mm Plate with 32 mm Gaps
3 x 50 mm Plate with 32 mm Gaps
1 x 100 mm Plate
Barrel
9 x 20 mm Plate with 32 mm Gaps
4 x 30 mm Plate with 32 mm Gaps
4 x 50 mm Plate with 32 mm Gaps
1 x 100 mm Plate
Both Doors
Cryostat
Detail B
See Sheet 2
Detail C
See Sheet 2
Interaction Point
See Sheet 4 for details of the Backward Plug
See Sheet 3 for details of the Forward Plug
Doors Removed from View
Floor
CHECK–PRINT
DATE 8 June 95
SCALE 1/20
BaBar Detector
Magnet Assembly
General Layout
Figure 2A
R0
D



Detail B
Scale: 1/8



Detail C
Scale: 1/8

CHECK – PRINT

6 June 95

BaBar Detector
Magnet Assembly
General Layout

Figure 2B

R0

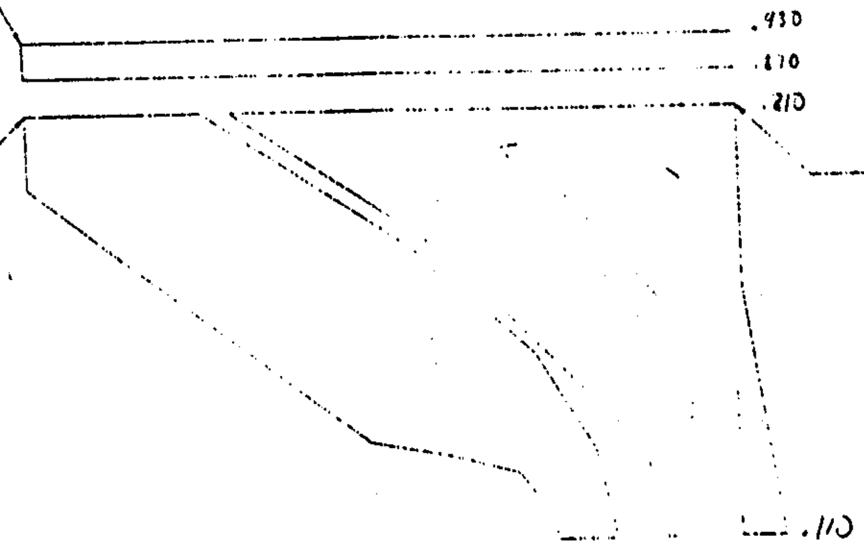
D

X,Y Coordinates from the magnet center starting at this point and going counter-clock-wise around

(-3.169,0.930)
(-3.169,0.870)
(-2.025,0.870)
(-2.025,0.930)
(-3.169,0.930)

X,Y Coordinates from the magnet center starting at this point and going counter-clock-wise around

(-3.169,0.810)
(-3.169,0.691)
(-2.630,0.273)
(-2.499,0.250)
(-2.391,0.221)
(-2.342,0.150)
(-2.331,0.110)
(-2.237,0.110)
(-2.267,0.255)
(-2.361,0.415)
(-2.521,0.564)
(-2.869,0.797)
(-2.883,0.810)
(-3.169,0.810)



Backward Plug
Scale: 1/5

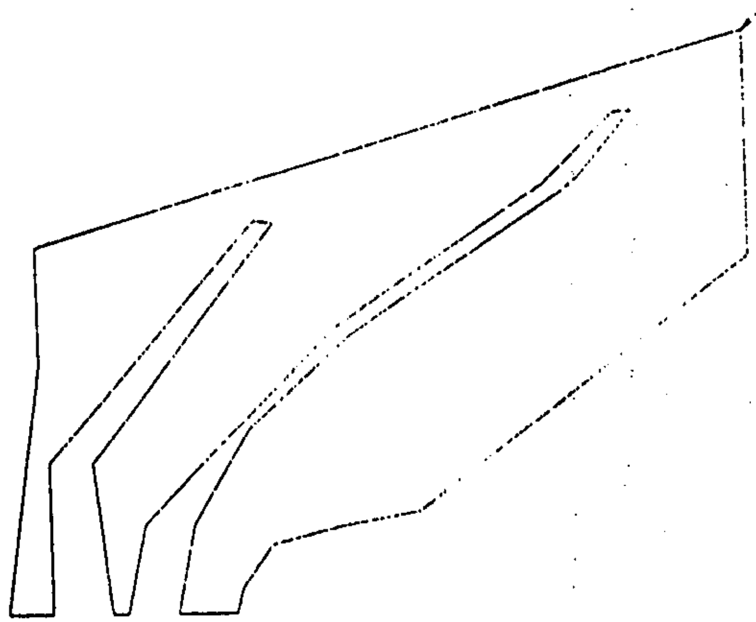
X,Y Coordinates from the magnet center starting at this point and going counter-clock-wise around

(-2.025,0.810)
(-2.840,0.810)
(-2.499,0.578)
(-2.187,0.255)
(-2.157,0.110)
(-2.132,0.110)
(-2.107,0.355)
(-2.405,0.748)
(-2.374,0.751)
(-2.037,0.355)
(-2.037,0.110)
(-1.967,0.110)
(-2.025,0.517)
(-2.025,0.810)

CHECK-PRINT

BaBar Detector
Magnet Assembly
General Layout

Figure 2C R0



Forward Plug
Scale: 1/5

X,Y Coordinates from the magnet center starting at this point and going clock-wise around

(3.169,1.065)
(3.169,0.691)
(2.630,0.273)
(2.499,0.250)
(2.391,0.221)
(2.342,0.150)
(2.331,0.110)
(2.237,0.110)
(2.267,0.255)
(2.361,0.415)
(2.521,0.564)
(2.869,0.797)
(2.900,0.825)
(2.987,0.931)
(2.955,0.927)
(2.843,0.812)
(2.499,0.578)
(2.187,0.255)
(2.157,0.110)
(2.132,0.110)
(2.107,0.355)
(2.405,0.748)
(2.374,0.751)
(2.037,0.355)
(2.037,0.110)
(1.967,0.110)
(2.025,0.517)
(2.025,0.711)
(3.169,1.065)

CHECK-PRINT
DATE 8 June 95

BaBar Detector
Magnet Assembly
General Layout
Figure 2D
R0
0

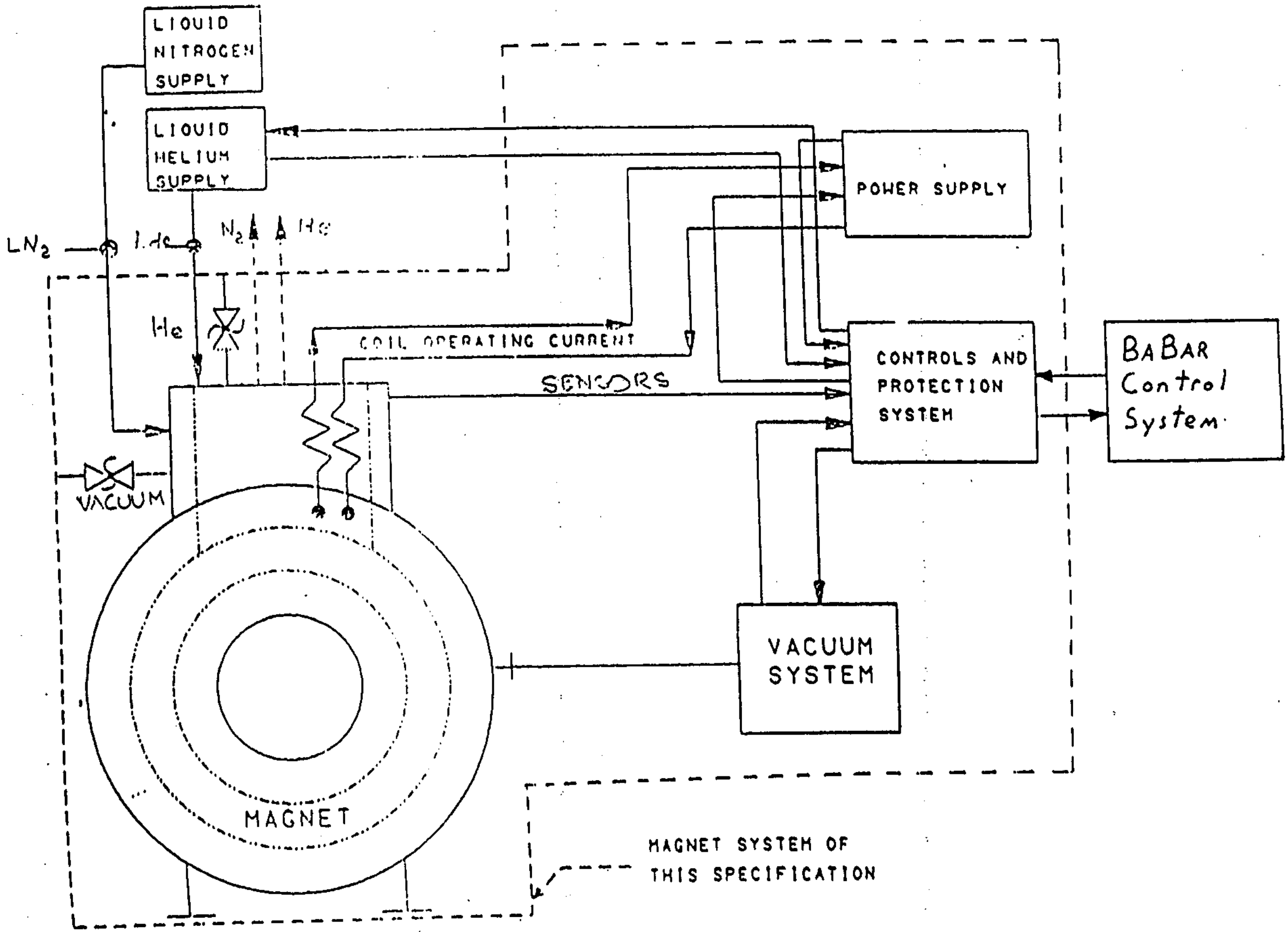


Figure 3: Interface Drawing

Appendix B: Codes and Standards

Standard Codes and Standards which shall be applied where applicable and which are part of this Specification. The latest published version at the time of order shall apply.

B.1 ANSI Codes

ANSI Y14.5M Dimensioning and Tolerancing

ANSI B31.3 Chemical Plant and Petroleum Refinery Piping

B.2 ASME Codes, American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10017

a) ASME Boiler and Pressure Vessel Code – Pressure Vessels, Section VIII

B.3ASTM

B714-82 Standard Test Method for DC Critical Current Composite Superconductors (10^{-14} Ohm meter);

B.4 Compressed Gas Association, 1235 Jefferson Davis Hwy, Arlington, VA 22202

a) CGA S-1.3 Pressure Relief Device Standards, Compressed Gas Storage Containers;
b) CGA 341 Standard for Insulated Cargo Tank Specifications for Cryogenic Liquids;

B.5 Physical Properties

NBS TN 631 Thermophysical Properties of Helium-4 from 2 to 1500 K with pressures to 1000 atmospheres, NTIS, US Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161;

NBS N 129 Thermophysical Properties of Nitrogen from 64 to 300 K between 0.1 and 200 atmospheres;

Brookhaven National Laboratory Selected Cryogenic Data Notebook, 1980, NTIS

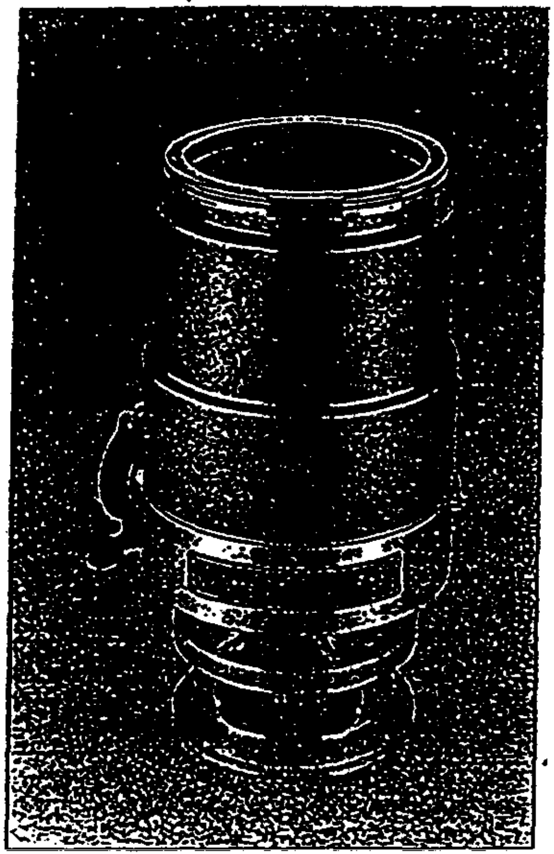
Materials at Low Temperatures, NBS, Reed & Clark eds., American Society of Metals, 1983, NTIS

Reviews of Particle Properties, Physical Review D45, Part 2, June 1992

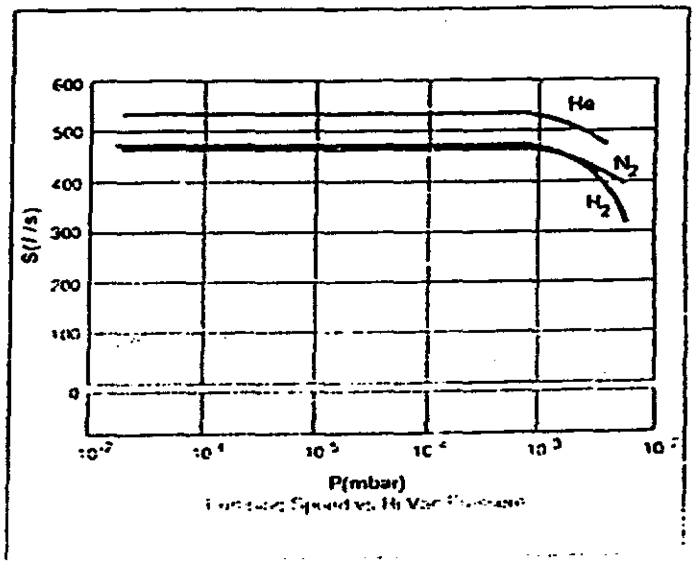
Handbook of Materials of Superconducting Machinery MCIC-HB-04, ARPA-BS-Battelle

Appendix C: Vacuum Specification.

Turbo-V450™ Turbomolecular Pump



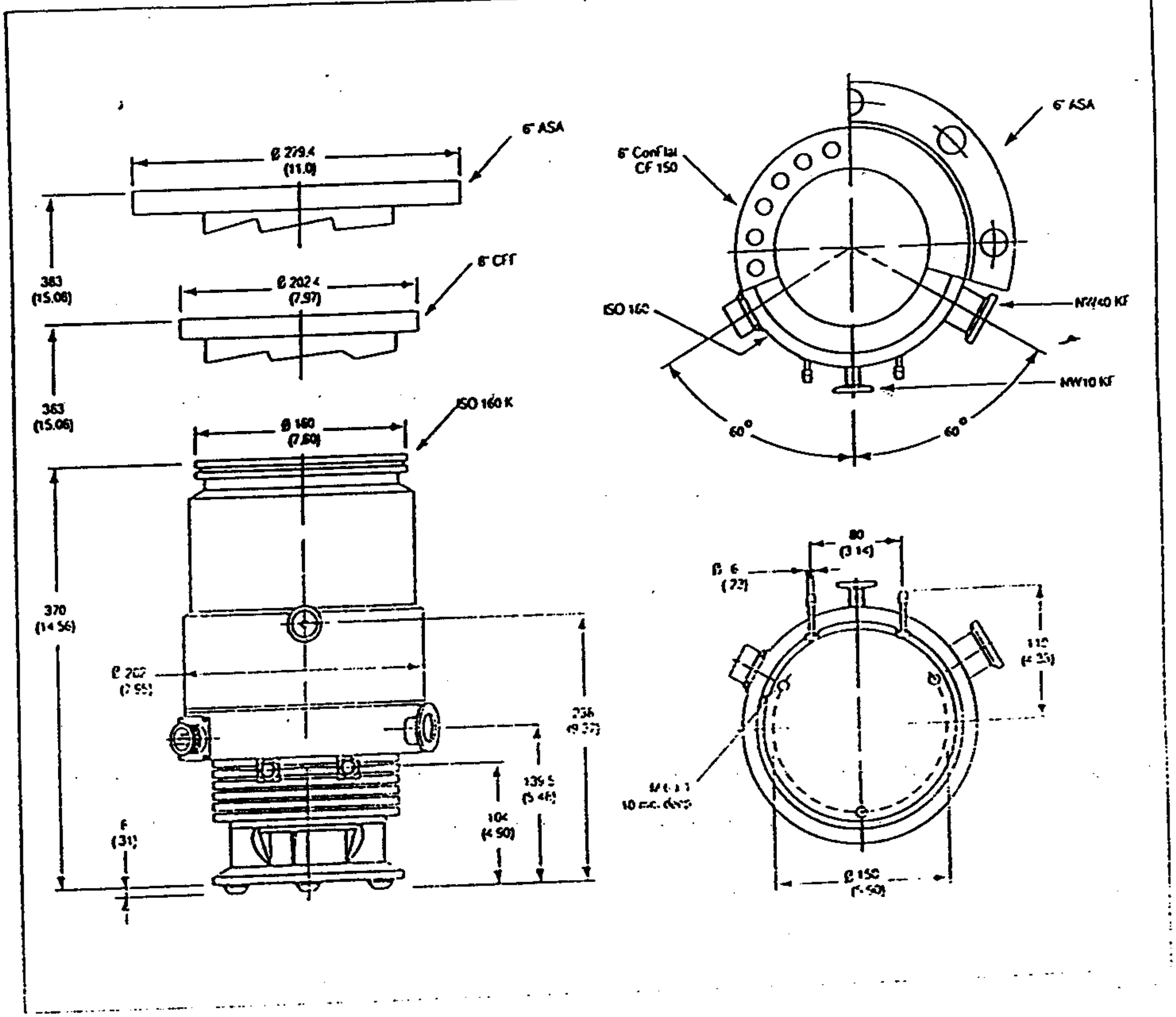
speed curve



specifications

	[illegible]	[illegible]	[illegible]
Pumping Speed l/s	[illegible]	[illegible]	[illegible]
Compression Ratio	[illegible]	[illegible]	[illegible]
Base Pressure	[illegible]		
Rotational Speed	[illegible]		
Recommended Forepump	[illegible]		
Start-up Time	[illegible]		
Operating Position	Vertical, [illegible]		
Interstage Vent Port	[illegible] KF		
Maximum Bakeout Temperature	120°C at Inlet Flange		
Water Flow Rate	[illegible] (0.13 gpm)		
Pressure:	2 - 4 bar (30 - 60 PSI)		
Temperature:	10° - 25°C		
Noise Level	< 50 dB (A) at 1 M		
Operating Ambient Temperature:	5° - 35°C		
Weight:	25 Kg		
Vibration Level:	<0.02 microns		
Lubricant	Varian T.A. oil, 80cm³		

outline drawing mm(inches)



ordering information

	Order Number**	Shipping Wt (lb/kg)
Turbo-V450 Pump with 8" O.D. ConFlat Inlet	969-9042	62/28
Turbo-V450 Pump with ISO 160 Inlet	969-9041	62/26
Turbo-V450 Pump with 6" ASA Inlet	969-9043	62/26
Turbo-V450 Controller and Cables, Factory Set for 120V	969-9547	29/13
Turbo-V450 Controller and Cables, 220V	969-9442	29/13
Inlet Screen for Turbo-V450 *	969-9303	1/0.5
accessories		
V450 Air Cooling Kit	969-9324	6/3
Heater Band 120V	969-9608	3/1.5
220V	969-9807	3/1.5
Rack Adapter for Controller	969-9191	4/2
Vent Device	969-9631	5/2.2
Vent Valve with fixed time delay	969-9833	4/2
Emergency Vent Valve	969-9832	1/0.5
Rotary converter 60 Hz	969-9741	
50 Hz	969-9641	
spares		
Varian T.A. oil, 100 cm^3	969-9901	1/0.5
Varian T.A. oil, 1000 cm^3	969-9902	3/1.5

* *Optional inlet screen is highly recommended.*

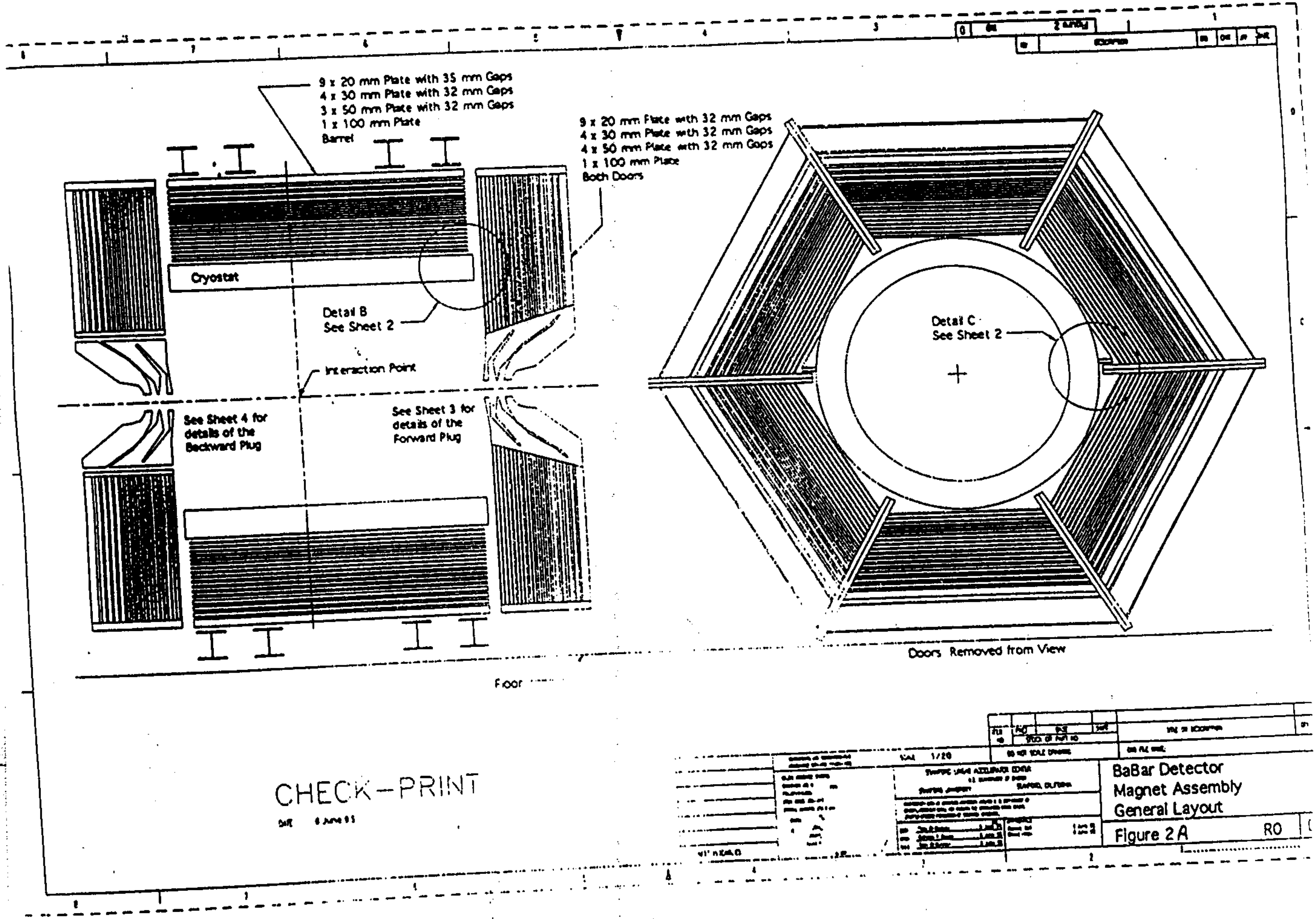
** *Order controller and inlet screen separately. For controller description see, pages 115 and 119.*

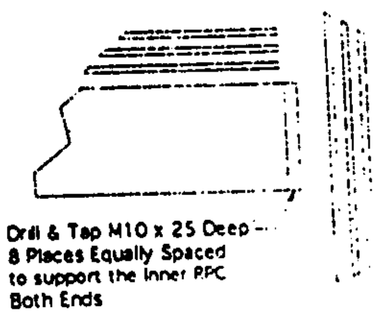
Appendix D: Reference Steel Design

1 oersted = 796 A/m

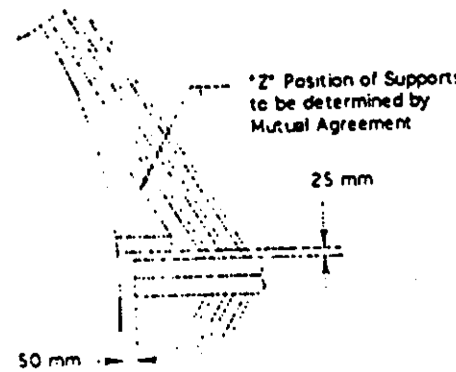
1020 Steel
7/1/83

B (Kg)	H (oersted)	H (A/m)	B^2 (T^2)	H $\left(\frac{\text{Amp-Turn}}{\text{meter}}, \times 10^2\right)$	$\gamma = \frac{1}{\mu} = \frac{H}{B}$ $\left(\frac{\text{Amp-Turn}}{\text{T}\cdot\text{m}} \times 10^{-2}\right)$
0	0		0	0.00	-
0.5	0.1	7.96	.0025	.08	2.
1	0.2	15.92	.01	.16	2.
2	0.4	31.9	.04	.32	2.
3	0.6	47.76	.09	.48	2.
4	0.8	63.7	.16	.64	2.
5	1.1	87.6	.25	.88	2.2
6	1.5	119.4	.36	1.19	2.5
7	2.0	159.2	.49	1.59	2.857
8	2.6	207	.64	2.07	3.25
9	3.6	286	.81	2.86	4.00
10	4.6	366	1.00	3.66	4.6
11	6.2	493	1.21	4.93	5.636
12	8.2	653	1.44	6.53	6.833
[illegible]	11.5	915	1.69	9.15	8.846
14	17.0	1353.2	1.96	13.53	12.143
15	28.8	2292	2.25	22.92	19.2
16	47.0	3741	2.56	37.40	29.375
17	86.0	6845	2.89	68.44	50.588
18	138.0	10985	3.24	109.85	76.667
19	215.0	17114	3.61	171.09	113.158


9 x 20 mm Plate with 35 mm Gaps
4 x 30 mm Plate with 32 mm Gaps
3 x 50 mm Plate with 32 mm Gaps
1 x 100 mm Plate
Barrel
9 x 20 mm Plate with 32 mm Gaps
4 x 30 mm Plate with 32 mm Gaps
4 x 50 mm Plate with 32 mm Gaps
1 x 100 mm Plate
Both Doors
Cryostat
Detail B
See Sheet 2
Interaction Point
See Sheet 4 for
details of the
Backward Plug
See Sheet 3 for
details of the
Forward Plug
Detail C
See Sheet 2
Doors Removed from View
Floor
CHECK-PRINT
1/20
BaBar Detector
Magnet Assembly
General Layout
Figure 2A
R0



Detail B
Scale: 1/8



Detail C
Scale: 1/2

BaBar Detector
Magnet Assembly
General Layout

Figure 2B

R0

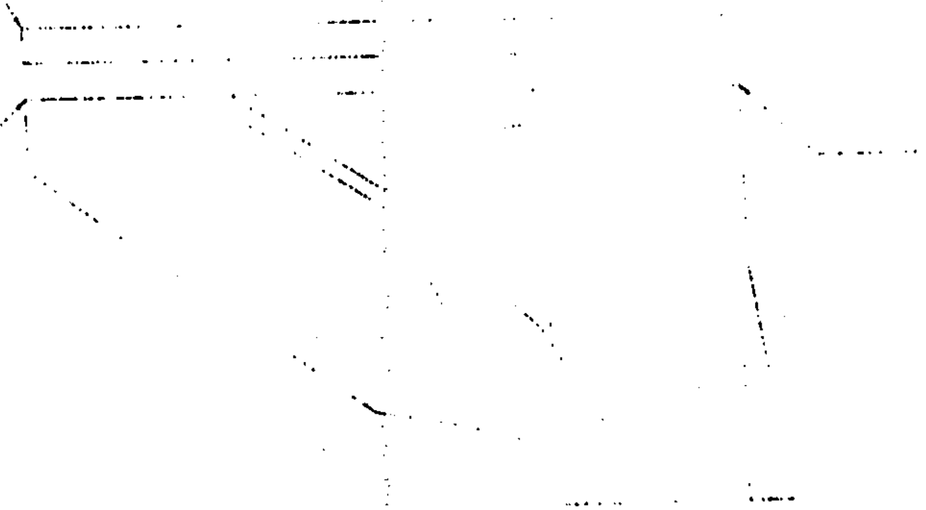
D

X,Y Coordinates from the magnet center starting at this point and going counter-clock-wise around

(-3.169,0.930)
(-3.169,0.870)
(-2.025,0.870)
(-2.025,0.930)
(-3.169,0.930)

X,Y Coordinates from the magnet center starting at this point and going counter-clock-wise around

(-3.169,0.810)
(-3.169,0.691)
(-2.630,0.273)
(-2.499,0.250)
(-2.391,0.221)
(-2.342,0.150)
(-2.331,0.110)
(-2.237,0.110)
(-2.267,0.255)
(-2.361,0.415)
(-2.521,0.564)
(-2.869,0.797)
(-2.883,0.810)
(-3.169,0.810)



Backward Plug
Scale: 1/5

X,Y Coordinates from the magnet center starting at this point and going counter-clock-wise around

(-2.025,0.810)
(-2.840,0.810)
(-2.499,0.578)
(-2.187,0.255)
(-2.157,0.110)
(-2.132,0.110)
(-2.107,0.355)
(-2.405,0.748)
(-2.374,0.751)
(-2.037,0.355)
(-2.037,0.110)
(-1.967,0.110)
(-2.025,0.517)
(-2.025,0.810)

BaBar Detector
Magnet Assembly
General Layout

Figure 2C R0 D

Forward Plug
Scale: 1/5

X,Y Coordinates from the magnet center starting at this point and going clock-wise around

(3.169,1.065)
(3.169,0.691)
(2.630,0.273)
(2.499,0.250)
(2.391,0.221)
(2.342,0.150)
(2.331,0.110)
(2.237,0.110)
(2.267,0.255)
(2.361,0.415)
(2.521,0.564)
(2.869,0.797)
(2.900,0.825)
(2.987,0.931)
(2.955,0.927)
(2.843,0.812)
(2.499,0.578)
(2.187,0.255)
(2.157,0.110)
(2.132,0.110)
(2.107,0.355)
(2.405,0.748)
(2.374,0.751)
(2.037,0.355)
(2.037,0.110)
(1.967,0.110)
(2.025,0.517)
(2.025,0.711)
(3.169,1.065)

BaBar Detector
Magnet Assembly
General Layout

Figure 2D R0 0

Technical Information Department • **Lawrence Livermore National Laboratory**
University of California • Livermore, California 94551