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GEM Magnet Subsystem Specification

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Abstract:

This document contains the top-level technical specification for the GEM Magnet Subsystem. These specifications define the required performance of the magnet and serve as the ultimate basis upon which the magnet is designed.

GEM MAGNET

SUBSYSTEM SPECIFICATION

REVISION D

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GEM DETECTOR MAGNET SUBSYSTEM SPECIFICATION

REVISION D, 23 NOVEMBER, 1992

TABLE OF CONTENTS

1 SCOPE 3
2 APPLICABLE DOCUMENTS 4
2.1 GENERAL 4
2.2 SSC LABORATORY DOCUMENTS 4
2.3 NON-SSC LABORATORY DOCUMENTS 4
3 REQUIREMENTS 5
3.1 SYSTEM DEFINITION 5
3.1.1 General Description 5
3.1.2 Subsystem Diagrams 6
3.1.3 Magnet Interfaces 6
3.1.4 Major Components 10
3.2 CHARACTERISTICS 11
3.2.1 Performance 11
3.2.2 Physical Characteristics 17
3.2.3 Reliability 18
3.2.4 Maintainability 18
3.2.5 Environmental Conditions 19
3.2.6 Transportability/Handling 20
3.2.7 Installation 20
3.2.8 Storage Protection and Airborne Pollutant 20
3.2.9 Vibration Environment 20
3.2.10 Shock Loads 20
3.2.11 Earthquake Loads 20
3.3 DESIGN AND CONSTRUCTION 20
3.3.1 Materials, Processes and Parts 20
3.3.2 Nameplates and Product Markings 21
3.3.3 Workmanship 21
3.3.4 Safety 22
3.3.5 Human Performance/Human Engineering 22
3.3.6 Structural Integrity 22
3.4 DOCUMENTATION 22
3.4.1 Specifications 22
3.4.2 Engineering Drawings and Associated Lists 23
3.4.3 Operating Manuals 23
3.4.4 Documentation Numbering 23
3.4.5 Acceptance Test Data Package/Report 23
3.5 MAINTENANCE 23
3.6 MAJOR COMPONENT CHARACTERISTICS 23
3.6.1 Cold Mass 23
3.6.2 Vacuum Vessel Assembly 27
3.6.3 Cryogenic System - Liquid Helium Supply 30
3.6.4 Forward Field Shapers/Support 31
3.6.5 Central Detector Support 31
3.6.6 Magnet Installation 31
3.7 PRECEDENCE 32
4 QUALITY ASSURANCE PROVISIONS 32
4.1 RESPONSIBILITY FOR INSPECTION 32
4.1.1 Witnessing of Tests 32
4.2 VERIFICATIONS 32
4.3 COMPLIANCE MATRIX 32

GEM DETECTOR MAGNET SUBSYSTEM SPECIFICATION

1 SCOPE

This specification establishes the technical requirements for the Super Conducting Super Collider GEM Detector Magnet Subsystem. Included in the specification are an outline of the magnet interfaces with other detector subsystems, magnet performance requirements and physical characteristics.

The GEM Detector, Figure 1, will observe gammas (photons) and electrons with a highly accurate electromagnetic calorimeter. The GEM design for muon measurement relies on tracking in a magnetic field outside of the calorimeter. High precision on the muon momentum is attained by measuring the curvature over a 5 m track length in a magnetic volume. This design philosophy leads to the need for a very large electromagnet.

The GEM Magnet subsystem must provide a stable, well-characterized, large-volume magnetic field to support the operation of the other detector subsystems. The central magnetic field strength, 0.8T, is modest in comparison with other large superconducting magnet systems. Because of its unusually large size, the magnet has a relatively high stored energy - 2.5GJ at full charge. Since this energy could cause significant damage if deposited in any component in an uncontrolled manner, excellent magnet stability and protection are required. In addition, the large size of the magnet necessitates field-fabrication and field-assembly of many large and heavy components, some of which need to be clean, well-aligned, and mobile.

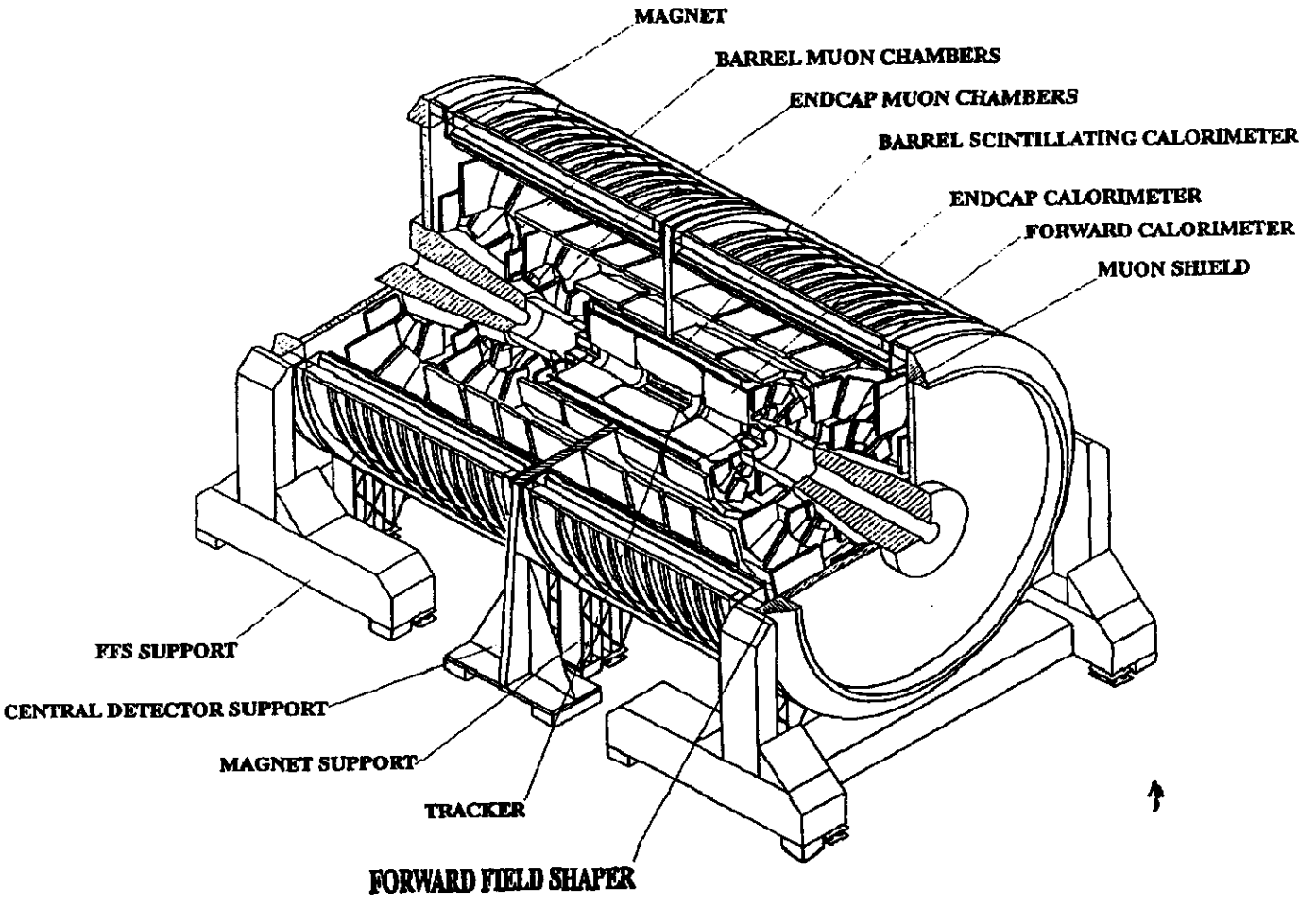

Figure 1. GEM Detector

2 APPLICABLE DOCUMENTS

2.1 GENERAL

The following documents form a part of this specification to the extent specified herein. If conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement. In those instances where a document is referenced for use as a guide, the Contractor must provide his own interpretation and verify proper applicability before use.

2.2 SSC LABORATORY DOCUMENTS

a.	TBD	GEM Detector Magnet Interface Control Document
b.	SSC-SR-1043	Field Measurements and Analysis of Underground Vibrations at the SSC Site
c.	P40-000003	SSCL Standard, Part Numbering System
d.	P40-000004	SSCL Standard, Engineering Drawing Format
e.	P40-000013	SSCL Guideline 4.4, Engineering Drawings
f.	P40-000017	SSCL Standard, Engineering Drawing Preparation
g.	P40-000030	SSCL Practice, Parts List Preparation
h.	P40-000001	SSCL Document Numbering Procedure
i.	P40-000070	Draft SSCL Guideline 3.21.1, Mechanical Engineering
j.	P40-000137	Identification marking of Parts & Assembly
k.	GEM TN-92-116	Magnet Technical Design Report

2.3 NON-SSC LABORATORY DOCUMENTS

a.	*American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code*	
b.	ASME B31.3	Chemical Plant and Petroleum Refinery Piping
c.	American Institute of Steel Construction (AISC); Codes of	
d.	MIL-STD-454	Standard General Requirements for Electronic Equipment
e.	ANSI C84.1	Electrical Power Systems and Equipment
f.	ANSI/IEEE 241-1983	Standard Specifications of Testing Concrete
g.	NFPA-70	National Electric Code
h.	DOE Order 5481.1B	Safety Analysis & Review System
i.	ANSI B30	Hoisting & Rigging of Critical Components

j.	IEEE	Large Rotating Electrical Apparatus Test
k.	ASME B31.1	Power Piping
l.	Section 3.7B Seismic Criteria,	Comanche Peak Steam Electric Station, Final Safety Analysis Report
m.	FED-STD-595	Colors
n.	MIL-Q-9858A	Quality Assurance
o.	LLNL-MEL-92-001810	SSCL GEM Vacuum Vessel

3 REQUIREMENTS

3.1 SYSTEM DEFINITION

3.1.1 General Description

The coil assemblies (magnet halves) consist of the cold mass subassemblies, the vacuum vessels and the internal cryostat components which include, the thermal radiation shields, the cold-mass supports, the cryogenic current leads, and the internal cryogenic systems. The two coil assemblies are stand-alone objects, capable of supporting themselves against gravity and seismic loads, holding vacuum, and moving in limited ways. With the addition of auxiliary systems (vacuum, cryogenics, and power), the coil assemblies can be operated as a magnet.

Since the magnet subsystem itself does not perform a physics measurement, as do most other subsystems, the overall physics performance requirement on it is to properly support the operation of the other subsystems. The primary physics requirement placed on the magnet subsystem is to provide the magnetic field for appropriate operation of the muon subsystem. It must also provide the field required by the central tracker, but this requirement does not drive the design in any significant way.

The general configuration of the GEM magnet will be a large solenoid, with magnetic-field shaping in the forward regions. All other GEM detector subsystems present at startup will be placed inside the magnet. The return field of the magnet is free in the sense that it does not have a local flux return, such as an iron barrel. Overall, the working inner volume of the magnet will be 18.0 m inner diameter, by 30.8 m length (measured between the ends of the magnet vacuum vessels).

The coil assembly, which includes the cold mass subassemblies, internal cryostat components, and vacuum vessels, will be split at the axial midplane, and the two halves will have the capability to be moved apart axially, to provide access to the internal detector hardware. The central detectors (calorimeters and tracker) will be supported by a structure which is physically independent of the coil assemblies and is capable of remaining in place and stable even when both coil assemblies are moved away axially for internal access. When the coil assemblies are in operating position, the (compressive) axial magnetic loads between the two assemblies will be reacted on separate structures, which penetrate through the central detector support. The compressive loads will not be transferred to the central detector support itself.

The magnet subsystem shall provide structural support for the muon subsystem. The muon subsystem will provide the space-frame structures necessary to support and align the detectors to the required accuracy, and the magnet subsystem shall provide discreet mounting points for these structures. The mounting points shall be structurally stable, and able to accept the loads applied by the muon subsystem.

As a design goal, the overall magnet configuration should allow for possible future upgrade of the muon subsystem. Specifically, an annular space around the outside of the magnet vessels shall be reserved for the addition of an external superlayer of muon detectors.

To facilitate maintenance and repair on the other detector subsystems, the magnet shall be charged or discharged (under normal circumstances) in a maximum of 8 hours; at the end of such a normal discharge cycle, the magnet will be ready for immediate re-charging. This allows field-free access to components outside the working volume of the magnet with two-

day turnaround. In an emergency situation, the magnet shall be capable of a 5 minute discharge without sustaining any damage. Following an emergency discharge, the magnet is not required to be capable of immediate recharge, and may require a longer period to cool down before charging.

3.1.2 Subsystem Diagrams

A functional schematic of the magnet subsystem is shown in Figure 2. The entire magnet system is designed around the superconducting coil, which operates at a temperature of approximately 4.5°K. When the design current is flowing in the coil, the required magnetic field is produced inside the central field region defined herein. All of the magnet subsystems are involved in establishing and maintaining this condition or in protecting the coil against damage in the event of a fault condition.

The coil is suspended inside an evacuated vessel, with heat shields and insulation designed to minimize heat flow to the coil and liquid helium. The GEM Detector layout, Figure 3, shows the major dimensions and the relationship between the magnet and other detector subsystems.

3.1.3 Magnet Interfaces

The magnet interfaces with various systems/components as summarized in the following paragraphs. The magnet interfaces are defined in the Magnet Technical Design Report (TDR).

3.1.3.1 Magnet/Central Tracker Interface

The main requirements imposed on the magnet by the interface with the central tracker involve magnetic field, physical support, and access for installation and maintenance. The tracker has modest magnetic-field requirements for proper operation; the field is required to be high as possible, and uniform throughout the tracker volume to 0.5%. The central membrane support subsystem must physically support the tracker's weight, but it does this through the calorimeter subsystem. The central detector support must provide the necessary stability for proper long-term operation of the tracker, and this requirement will drive the design of the support. The tracker will be the last detector subsystem to be available for installation, and the magnet subsystem design shall accommodate this installation. Furthermore, the magnet must allow some access for possible repair of the tracker, on a long, (3 month) turn-around basis. These requirements were key in developing the requirement for the split/mobile magnet halves.

3.1.3.2 Magnet/Calorimeter Interface

The calorimeter interface provides requirements which primarily affect the design of the central detector support. The weight of the calorimeter and the required stability are the key factors in this area. A potential fault mode for the LiAr calorimeter is a cryogenic spill, and this fault mode will affect the magnet inner vessel. The magnet shall withstand this calorimeter fault without significant damage.

3.1.3.3 Magnet/Muon Interface

This interface provides requirements on the magnetic field, most of which result from consideration of muon performance. The structural stability of the muon mounting points is required to meet the alignment requirements of the muon detector.

3.1.3.4 Magnet/Forward Field Shaper Interface

The magnetic force exerted on the Forward Field Shaper (FFS) is transferred to the vacuum vessel through the FFS support structure. There are eight points of load transfer from the support structure to the vacuum vessel. These interfaces at the vessel are landing pads located at each of the eight longeron stiffeners.

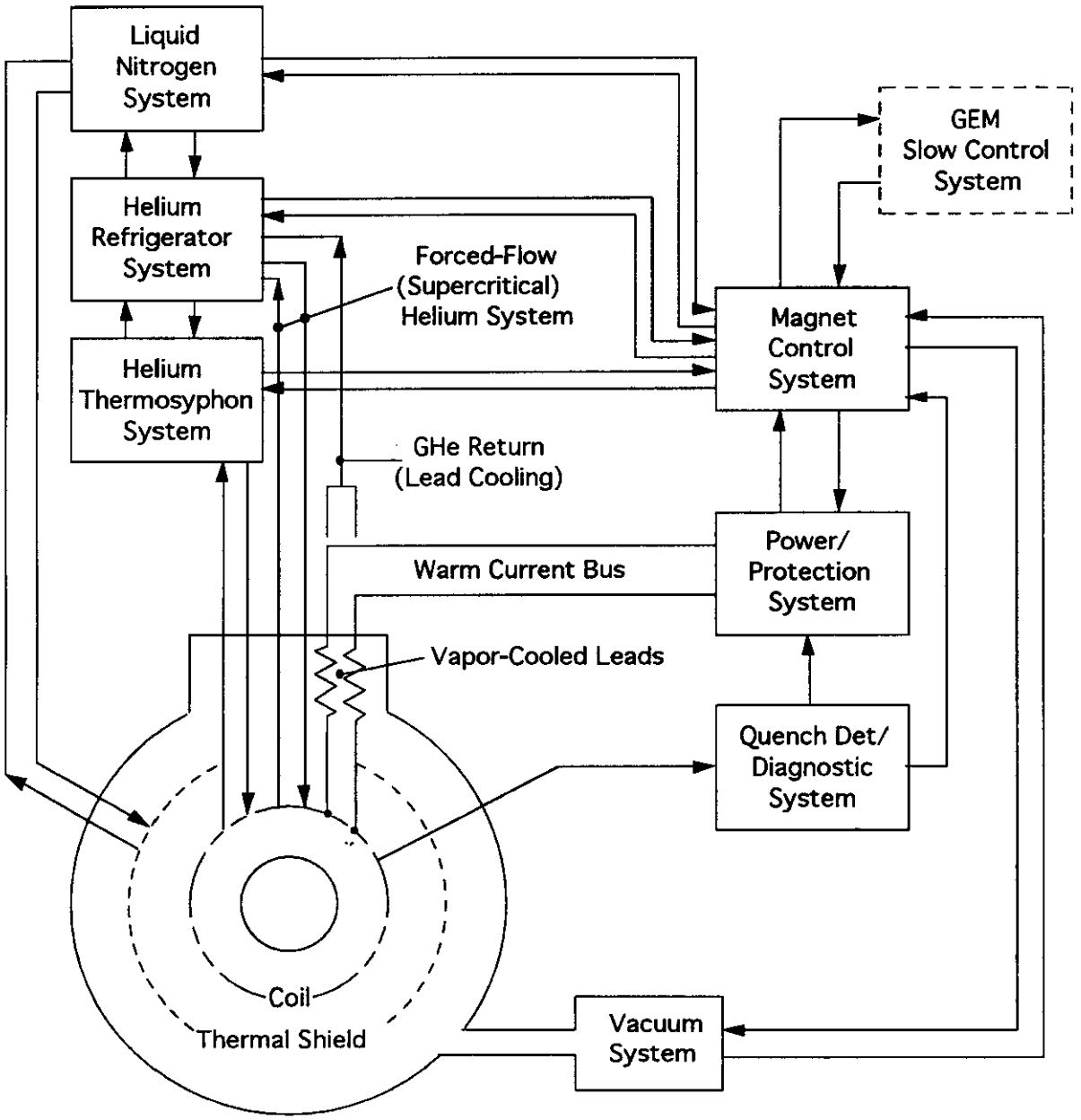

Figure 2. Magnet System Functional Schematic

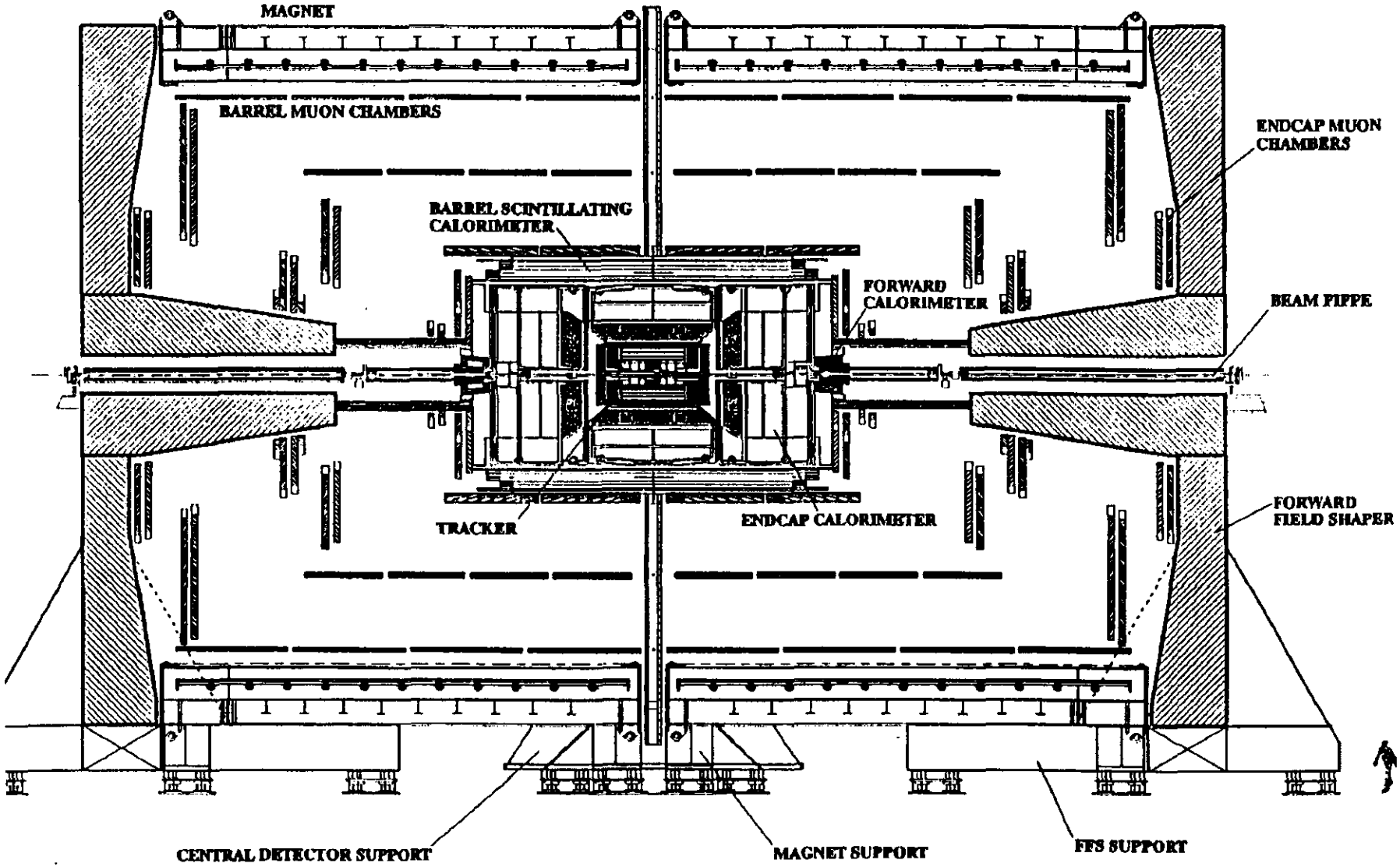

Figure 3 - GEM Detector Layout

3.1.3.5 Magnet/Facility Interface

The magnet interfaces extensively with the above-ground and underground facilities at SSCL. Since design of the facilities is in progress, the magnet subsystem must accept most of the requirements as imposed on it by the facilities design. This is the case particularly for the above ground assembly buildings. The magnet subsystem provided rough requirements to the facilities design. However, the overall requirement on the magnet subsystem is to fit into the facilities available to it.

3.1.3.6 Magnet/GEM Control System Interface

The magnet subsystem interfaces with the overall GEM Detector control system specifically in the "Slow Controls." GEM Detector Slow Control will provide overall control of the magnet during detector operations. The magnet subsystem will include local controls for the power/protection system and for the cryogenic systems, and these local controls will interface with detector-level slow control system.

3.1.4 Major Components

The GEM Magnet System consists of two identical magnet halves or coil assemblies. Each magnet half is composed the Coil Subassembly, the Vacuum Vessel, and the Forward Field Shaper (FFS). The Central Detector Support (CDS), the Cryogenic System and the Power/Protection System are common to the two magnet halves. Major elements of each component are defined in the following paragraphs.

3.1.4.1 Coil Subassembly

The superconducting coils of the GEM Coil Subassembly provide the magnetic field necessary for the high precision measurement of muon momentum. The GEM Coil Subassembly is composed of twelve identical coil modules that are joined together to become a monolithic structure. Each 19 m diameter coil module consists of the coil form , and approximately 1140 meters of cable-in-conduit (CIC) conductor. The coil modules will be mated electrically and mechanically with resistive, helium cooled joints. The coil form consists of an outer wall, end flanges, ground plain insulation, and liquid helium cooling tubes. Two identical Coil Subassemblies are required for the GEM magnet.

3.1.4.2 Vacuum Vessel

The vacuum vessels contains the following principal elements:

a Internal Cryogenic Piping (includes 4.35 K LHe, and 80 K LN)

b. 80 K Thermal Shields

c. Thermal Insulation

d. Coil Subassembly Suspension System

e. Annular Vacuum Shell

f. External Support/Transportation

It serves to support the coil subassembly accurately and reliably within the vacuum vessel, provides all required internal cryogenic piping, and insulates the cold mass from heat radiated and conducted from the environment. It must function reliably during magnet movement and handling, normal magnet operation, quenches, and other upset conditions. The external support saddles shall provide the transportation to separate the installed coil assemblies and to move them axially to their respective ends of the experimental hall to allow access to the internal detector components. The GEM Magnet System requires two identical vacuum vessels.

3.1.4.3 Cryogenic System

The GEM Magnet is cooled by liquid helium (LHe) which flows by natural convection in a thermosyphon loop which couples a large storage dewar located at the ground surface with the magnet about 50 m below. A second flow circuit supplies a small flow of supercritical helium, cooled to the temperature of the thermosyphon loop, to the conductor conduit for the purpose of enhancing the conductor stability, cooling the conductor splices and cooling the current leads. The interface between the cryogenic system and the rest of the magnet subsystem is defined to be the outer surface of the vacuum vessel.

3.1.4.4 Magnet Power Supply and Protection Systems

The Magnet Power Supply and Protection Systems supply a controlled DC current to the magnet, detect magnet quenches and dissipate the energy stored in the magnet during emergency dump situations. The Power Supply System consists of a 20 VDC, 55 KA power supply , high current buswork and local controls. The Protection System consists of 55 KA current interrupters, dump resistor, magnet quench detection and diagnostic monitors (sensors), and local controls. The interface between the power/protection system is defined to be at the connection of the warm current busses to the vapor-cooled leads at the vacuum vessel outer surface.

3.1.4.5 Forward Field Shaper/Support

The Forward Field Shapers (FFS's) are large steel cones used to shape the magnetic field inside the GEM detector. Field calculations determine the size and form of the forward field shaper, as well as its location relative to the vacuum vessel. The GEM detector has two identical Forward Field Shapers (FFS). Each FFS is held in space by a support structure which butts to the end of the vacuum vessel. Each FFS weighs approximately 900 mg tons. Each support structure weighs an additional 900 mg tons. The FFS is an approximately 8 meters long truncated solid cone varying in diameter from 3.1 to 5 meters. Each FFS assembly, including the support structure, is independently mounted to the experimental hall floor, at specially reinforced mounting locations. For initial installation, and ongoing maintenance and repair, each assembly can be lifted and translated to the ends of the experimental hall.

3.1.4.6 Central Detector Support

The Central Detector Support (CDS) provides dead load support and seismic stability for the central detectors. It is a free standing structure with a coil assembly (magnet half) on either side. The magnet axial loads are reacted via columns through holes in the CDS or on bearing pads between the coil assemblies. In the present design, the CDS is composed of two annular membranes, separated by radial gussets which connect them. Each membrane weighs about 360 mg tons, is 0.1 m thick, and 21.8 m in diameter. The total structure weighs approximately 1800 mg tons. The Central Detector Support with the detectors installed weighs approximately 4500 mg tons.

3.1.4.7 Magnet System Control

3.2 CHARACTERISTICS

3.2.1 Performance

3.2.1.1 Magnetic Field

Overall, the field shall be roughly solenoidal, with some shaping in the forward direction. The magnetic field shall be 0.8T and uniform to 0.5% in the Tracker volume (an area .7m in dia. and 2.8 m long centered on the interaction point). In the GEM Detector coordinate system, the z axis is aligned with the axis of the colliding beams; this is also the ideal axis of the Magnet Subsystem. The origin of the Detector coordinate system is at the Interaction Point, and the Magnet Subsystem is symmetrical about the z = 0 plane.

Since the field is provided by two axially-separated coil halves, some non-uniformity will occur at large radii near the z=0 midplane; this non-uniformity shall be less than that produced by a 1.5 m gap between the two coil subassemblies.

In the forward region, the required field shape is presently defined by the shape and location of the Forward Field Shaper iron which results in acceptable muon subsystem resolution. The required field shape is produced by a frustum of a cone extending from z=10 m to z=18 m, with an included angle of 17.4 degrees;

The magnetic field and its distribution shall be known at all times during operation to high accuracy to facilitate data reduction. The field magnitude and distribution shall be known at all times during operation to an accuracy of 0.1%. This accuracy may be attained by a combination of detailed field-mapping before interior detectors are installed and continuous monitoring at numerous locations within the working volume.

3.2.1.2 Superconducting Coil Stability

The cable-in-conduit (CIC) conductor is stable against sudden disturbances. Coils made with CIC conductors are distinguished by the lack of training often found in coils made with other conductor types. This high stability is due to a) the high heat capacity of the helium which is in intimate contact with the superconducting wires, and b) the very large heat transfer surface area from the wire to the helium. The most likely source of disturbance in the GEM Magnet is due to some mechanical event occurring external to the CIC. In this case, the superconducting strands are buffered from this disturbance energy by the helium in the conduit. The energy margin then is given by the enthalpy of the helium and the wire between the operating temperature of 4.5K and the current sharing temperature. This is dominated by the helium enthalpy which is 1-2 orders of magnitude greater than all the other conductor components. For such an external perturbation event, the time scale is practically irrelevant since all the helium must be brought up to the current sharing temperature before a quench will occur.

Other types of disturbances internal to the cable can also occur, although these are very much less likely in the GEM operation. One of these could be AC loss, but only during coil charge or discharge. Since the nominal charge time is 8 hours, the loss energy will be removed on a quasi-steady state basis by the thermal-siphon loop. Another possible disturbance source could be sudden wire motion within the cable. Measurements of the mechanical hysteresis have been performed at 4.2K on a large, similar cable. Those results indicate that, even if all this energy was deposited suddenly in the cable, the energy margin is at least one order of magnitude greater.

For internal disturbances the stability margin is defined as the largest sudden energy deposition to the conductor from which it can still recover the superconducting state. The stability margin is not necessarily equal to the enthalpy margin of the helium because the helium is only effective if the energy dissipated directly in the cable can be transferred effectively to the fluid. This depends on the power balance between heat generation, due primarily to Joule heating in the strand, and the convective heat flux to the supercritical helium. The GEM conductor is designed to insure that this energy balance is always satisfied, i.e. at normal operating conditions the helium enthalpy is used to maximum advantage. This is accomplished by insuring that the limiting current between being well-cooled or ill-cooled is above the operating current. The limiting current is defined as I_{lim} where,

$$I_{\lim} = \frac{hpA_{cu}(T_c - T_b)}{\rho_{cu}}$$

where,

h = heat transfer coefficient (W/m^2-K)

p = cooled perimeter (m)

A_{cu} = area of copper stabilizer in cable

ρ_{cu} = copper stabilizer resistivity (Ω-m)

T_c = critical temperature (K)

T_b = initial helium temperature (K).

The stability results for the main coil modules are summarized as follows:

Energy margin for external disturbances 315 J/m

Energy margin for internal disturbances 250 J/m

By comparison the energy margins of indirectly cooled, high purity aluminum conductors typical of those used for other large solenoidal detector magnets (e.g.., CDF, ALEPH, DELPHI) is between one and two orders of magnitude lower than that of the CIC. This implies that conductor motion of ~1 mm would quench the magnet.

The joints between the coil modules have been designed to be cryostable. This is done primarily by using large copper blocks with integral cooling channels to lower the Joule heating below the steady state heat flux. With a cryostable joint design, this normally resistive portion of the coil circuit is not a weak link, but actually more stable than the bulk of the coil. This can be achieved with a moderate flow of 0.5 g/s of supercritical helium at 4.5 K to independently remove the 1.25 W generated at each joint.

3.2.1.3 Coil Protection

The Magnet Assembly shall be protected against conductor overheating, voltage breakdown and structural damage during quenches, cryogenic system failures or other off-normal conditions.

3.2.1.4 Charging Time

The time required to charge the magnet central field from 0 to 0.8 Tesla shall be kept to a minimum and shall be no greater than 8 hours. This shall include the effects of eddy current heating during charging.

3.2.1.5 Discharge Time

The time required for normal (not emergency) discharge of the magnetic field from 0.8 to 0 Tesla shall be kept to a minimum and shall be no greater than 8 hours. The effects of eddy current heating during discharging shall be considered and included in the design. Following a normal discharge, the magnet shall be ready for immediate charging.

In an emergency situation, the time required to discharge the magnet from 0.8 to 0.04T shall be no more than 300 sec (implying a time constant, τ, of less than or equal to 100 sec for an exponential discharge). For this discharge, the maximum lead-to-lead voltage in the magnet DC circuit shall be $\leq$ 1kV. Following an emergency discharge, the magnet is not required to be capable of immediately initiating a charge.

3.2.1.6 System Shut Down

The magnet system shall be capable of controlled shutdown in the following modes:

a. Normal discharge of the coil, as defined in Paragraph 3.2.1.5.

b. The magnet system shall be capable of operating normally for 12 hours without an external supply of liquid helium, other than the storage dewar, to allow for shutdown of the Helium Refrigerator for maintenance or repair.

c. Automatic emergency discharge of the magnet, initiated by the Magnet Protection System, to protect the coil from damage (ref. Paragraph 3.2.1.3) or in response to some other critical system failure.

d. Operator initiated emergency discharge of the magnet, in response to off-normal conditions outside of the magnet subsystem which require the rapid removal of the magnetic field.

3.2.1.7 Duty Cycle

Under normal circumstances, the magnet shall operate at 100% capacity continuously, 24 hours per day, for 9 months, with 99% availability.

3.2.1.8 Lifetime

The design lifetime of the magnet subsystem shall be 20 years. During this time period, the magnet shall be capable of 100 thermal cycles and 200 vacuum cycles. It shall also be capable of 200 normal charge/discharge cycles, including 20 emergency discharge cycles. These requirements shall be incorporated into the component designs for fatigue and fracture-toughness. The operating cycles are defined as follows.

a. A vacuum cycle begins with the vacuum vessel at ambient pressure, and ends when the vessel is returned to ambient pressure after evacuation.

b. A thermal cycle begins with the magnet evacuated and at ambient temperature, and ends when the magnet is warmed from operating temperature to ambient. This may be in preparation for maintenance or repair of the accelerator system (not necessarily the magnet itself). The magnet may remain at 293 K for an extended time depending upon the nature of the maintenance.

c. A magnetic charge/discharge cycle occurs when the magnet is excited from a low field level (typically 0 Tesla) to the operating level (typically 0.8 Tesla). A magnetic cycle is completed when the excitation of the magnet is reduced to a low field level.

d. An emergency discharge cycle occurs when the magnet is discharged from the operating field level (approximately 0.8T) to zero field.

3.2.1.9 Alignment

The magnetic field must be aligned to the collider, and its position must be well-known and stable. Because magnet components also serve as mounting bases for the other detector subsystems, the physical positions of the vacuum vessels, FFS's, and CDS must also be well-known and stable. Separate requirements are specified for the placement accuracy, the stability, and the drift. These requirements will be frequently updated, and will be controlled through Interface Control Documents. The current specifications are listed below.

Magnet components shall be positioned in the underground hall by measuring the position of alignment fiducials on the magnet components with respect to the position of alignment fiducials mounted in the hall. Misalignment of the actual positions of alignment fiducials on coil halves, FFS's, and CDS shall be less than 10 mm (radially or axially) with respect to the ideal position as measured from the hall monuments. It shall be assumed that the actual position of any component can be measured with an accuracy of 1.0mm at best, and this measurement inaccuracy is not a part of the 10 mm misalignment allowance. The position of alignment fiducials on magnet components shall be known, with respect to the sensitive elements (coils) with a total error of less than 20mm radially or axially.

Coil halves and FFS's shall exhibit uncontrolled short-term motion relative to the beamline of less than 0.02mm radially, 0.01mm azimuthally, and 0.02mm axially. The CDS shall exhibit uncontrolled short-term motion relative to the beamline of less than 0.01mm radially, 0.01mm azimuthally, and 0.01mm axially. This requirement relates primarily to vibration and thermal motions which vary on a time scale of less than a minute..

Long-term motion (drift) of the coil halves and the FFS with respect to the hall fiducials shall be less than 1mm radially, azimuthally, and axially between realignments. Long-term motion (drift) of the CDS with respect to the hall fiducials shall be less than 1mm radially, 1mm azimuthally, and 5mm axially between realignments.

3.2.1.10 Eddy Current Effects

The Coil Assembly shall not be damaged electrically or structurally by a magnetic field collapse occurring during an emergency discharge. Internal heating due to a normal charge or discharge shall not cause the magnet to quench spontaneously.

3.2.1.11 Grounding Requirements

All metallic surfaces (excluding multilayer insulation) not requiring electrical isolation, shall be attached with low resistance techniques and be at the ground potential of the shell. The connections shall not create any undesired ground loops that may impact operation, testing or safety.

3.2.1.12 Cryogenic Piping

The coil assembly design shall be such that the heat load to the cold mass is less than 1200 W (total for both cold mass assemblies, not including VCL's). The design of the thermal radiation shields shall be such that the heat load to the thermal radiation shield shall be less than 4 w/m^2.

Design Pressure

All cryogenic piping will be designed to withstand a leak checking pressure of at least 2.0 MPa while at room temperature. Working pressures for magnet operation are tabulated in Table 1.

TABLE 1

CRYOGEN WORKING PRESSURE AT EXPERIMENTAL HALL FLOOR

	P, Atm., abs.
Liquid nitrogen	6.2[1]
Liquid helium thermosyphon	2.1[2]
Helium forced flow system	3.8 - 4.8
Quench pressure (all cryogenic piping)	15
Quench pressure (conductor)	340

Test Pressure

Test pressure will be 1.5 times the maximum operating pressure.

Flow Capacity

The flow capacity of the liquid helium thermosyphon system shall be such as to accommodate a heat load to the cold mass of 1600 W while maintaining the cold mass temperature within 0.3 K of the liquid helium storage temperature.

The flow capacity of the forced flow system shall be such as to accommodate a flow of 13 g/s current lead flow with warm return plus 24 g/s total flow for conductor stabilization and splice cooling, with cold return to the storage dewar.

The mass flow rate of the liquid nitrogen system shall be sufficient to accept the design heat loads, and maintain the shields between 77 k and 89 k.

Shielding and Insulation

The helium supply and cold returns for the thermosyphon and forced flow systems shall be shielded with liquid nitrogen temperature shields. Multilayer insulation will be used between the outer vacuum jacket and LN shield and between the LN shield and inner line. These lines shall not require continuous pumping to maintain insulating vacuum.

3.2.1.13 Changes in Parameters

The magnet shall be designed so that during its useful life for the operating cycles defined in 3.2.1.7, 3.2.1.8 and the expected transportation environments:

a. The magnet shall exhibit no damage or net shifting of component positions as the result of a thermal cycle.

b. The leakage current from coil to ground shall not exceed twice the original value while subjected to the specified environmental conditions.

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[1] Hydrostatic head plus 1.2 atm storage pressure. Increase for higher storage pressure and/or pump head

[2] Hydrostatic head plus 1.3 atm storage pressure

3.2.2 Physical Characteristics

3.2.2.1 Size

The size/envelope of the magnet system major components described in paragraph 3.1.4 are to be determined by the subcontractor and defined in his design. Approximate sizes are shown in the drawing package provided..

3.2.2.2 Weight

The approximate weight of the components described in paragraph 3.1.4 are shown below. The final weight of the magnet system major components shall be refined by the subcontractor and defined in the design.

COMPONENT	ESTIMATED WEIGHT (mg)
Coil Form Wall	15
Compression Flanges	14
Conductor	11
Turn Insulation	2
Ground Insulation	2
Subtotal Coil Subassy Module(1)	44
Subtotal Coil Subassembly (12)	528
Vacuum Vessel - Outer (per half)	544
Vacuum Vessel - Inner (per half)	363
Radiation Shields (per half)	23
Coil Subassembly Supports (per half)	9
Subtotal Magnet Half	1467
Total Magnet	2934

3.2.2.3 Helium Inventory

Liquid Helium	60,000 L
Gaseous Helium	2500 m^3 @ 18 Atmospheres

3.2.2.4 Power

Conventional power and technical power will conform to, ANSI C84.1 and ANSI/IEEE 241-1983.

120 volt power will be 1 phase, separate ground wire, 120VAC, 60 Hz.

208 volt power will be 3 phase,4 wire, 208VAC, 60 Hz.

277 volt power will be 1 phase, separate ground wire, 277VAC, 60 Hz.

480 volt power will be 3 phase,4 wire, 480VAC, 60 Hz.

4160 volt power will be 3 phase,3 or 4 wire, 4160VAC, 60 Hz.

3.2.3 Reliability

The magnet system shall have adequate design margins to ensure the capability to operate continuously or intermittently without failure or degradation of performance over the magnet useful life. The magnet shall exhibit no wear or fatigue type failures when exposed to the moving, storage, installation or maintenance, misalignments, pre-operating and operating environments and the specified number and types of cycles (paragraph 3.2.1.8). A total of 1130 hours of unscheduled maintenance and 3130 hours of scheduled maintenance and upgrades are planned per year for the SSC collider and accelerator systems. However, routine maintenance of the GEM magnet subsystem shall not require the magnet to be discharged for a period exceeding 14 hours at any one time, not including the charge and discharge time.

3.2.3.1 Electrical Connections and Cabling

All electrical connections and cabling shall be joined in a reliable and inspectable manner and secured and adequately protected from degradation due to radiation exposure, thermal, magnetic or quench hydraulic induced movements, and assembly or maintenance procedures. Cabling shall be routed to avoid the contact with rough surfaces and adequately protected against chafing. Termination of wires shall be in a manner to prevent loosening or degradation. Wires to be connected during magnet installation shall be provided with a permanent unique identification.

3.2.4 Maintainability

The magnet system shall provide for:

a. Roll back of each of the two coil assemblies (magnet halves) in 144 hours (after the collider quadrupoles and beam pipes have been removed) to allow access to the internal detector components. This time includes any time required to roll back the FFS assemblies.

b. Reinstallation of each of the two coil assemblies (magnet halves) in 264 hours (this includes floor settling and leveling but does not include external systems reconnection). This time includes any time required to roll back the FFS assemblies.

c. External systems reconnection in 72 hours.

d. Interchangeability of assemblies and equipment elements (if any) that are designed for removal and replacement as the normal corrective maintenance action .

e. Standardization and simplicity of test equipment and its use.

f. Accessibility for in-place maintenance and inspection consistent with the design constraints, and tools and test equipment.

g. Capability of being repaired by skilled/semi-skilled technicians possessing magnet specific training, working under an experienced supervisor.

h. Minor periodic realignment in 48 hours while cold and installed in the experimental hall.

3.2.5 Environmental Conditions

3.2.5.1 Natural Environments

The magnet shall meet the performance requirements of 3.2.1 during and after exposure to the following operating and pre-operating (moving/handling, storage and installation) environments. Some of these steps will be environmentally controlled, others will not.

3.2.5.1.1 Temperature

Operating Ambient Temperature: 23 ° ± 1 °C

Pre-Operating Temperatures: 12 ° C

3.2.5.1.2 Humidity

The relative humidity environments shall be as follows:

a. Operating: 45% ± 5%

b. Pre-Operating:10% to 98%

The superconducting coil subassemblies shall be protected during manufacturing, installation, pre-operating and operating conditions to prevent degradation due to humidity. Other oxidizing components shall be protected from rusting.

3.2.5.1.3 Foreign Debris

During all phases of assembly, test, and installation the magnet components shall be protected from contamination or damage from foreign debris.

3.2.5.1.4 Corrosive Atmosphere

The magnet shall not degrade when exposed to the expected operating and pre-operating environments.

3.2.5.2 Induced Environments

The magnet shall meet the operational requirements of 3.2.1 during or after exposure to the following induced environments.

3.2.5.2.1 Radiation

The magnet shall be designed to withstand a radiation dose of 10 Mrad at the coil minimum radius.

3.2.5.2.2 Operating Magnetic Environment

The magnet and external components and subsystems shall be able to withstand and function nominally without permanent or transient structural, mechanical, or electrical detrimental degradation during exposure to the operationally induced magnetic environments resulting from compliance with all operating conditions.

3.2.5.2.3 Operating Thermal Environment

The magnet shall be able to withstand and function nominally without permanent or transient structural, mechanical, or electrical detrimental degradation during exposure to the operationally induced thermal environments resulting from all conditions.

3.2.6 Transportability/Handling

For movement of components to the receiving site at SSCL and for movement/handling of the magnet and assemblies or lowering into the experimental hall, the items shall be transportable without detrimental degradation in alignment or performance. During movement and handling for assembly or installation of the magnet into the experimental hall, mechanical restraints may be used to prevent misalignment or damage. Provisions shall be made for measuring environmental conditions (temperature, moisture and vibration) during transport and handling to verify that the magnet has not exceeded the vibration environment shown in 3.2.9, the shock loads of 3.2.9, the temperature limits of 3.2.5.1.1, or the humidity levels of 3.2.5.1.2.

3.2.7 Installation

The magnet shall be installed in the experimental hall and acceptance tests, including field mapping, satisfactorily accomplished. The coil subassemblies shall then be separated and moved axially to the ends of the experimental hall to allow access for installation of internal detector components. The coil assemblies shall then be moved to their operating positions, re-connected to the auxiliary subsystems, and prepared for full operation with other detector subsystems.

3.2.8 Storage Protection and Airborne Pollutant

The magnet, and its components during assembly and installation, shall be protected from the temperature and humidity environments specified herein that may cause loss of prestress, creep, water absorption or other detrimental efforts.

3.2.9 Vibration Environment

The response of the magnet to vibrations present in the tunnel and experimental hall, as described in SSC-SR-1043, "Field Measurements and Analysis of Underground Vibrations at the SSC Site", shall not cause the alignment tolerances to be exceeded as specified herein. The suspension system shall be dampened where possible and shall not degrade or suffer fatigue that will reduce the capability of meeting the magnet life expectancy when subject to the tunnel vibrations over operating and non-operating temperature ranges, the vibrations during transportation, the vibrations due to cryogenic equipment operation and flow.

3.2.10 Shock Loads

Magnet assemblies and subassemblies shall be designed to handle static loads and seismic loads defined in section 3.2.11. Additional loads imposed by transportation and rigging shall be addressed by additional design enhancements and analysis to meet the factors of safety defined in section 3.3.6. Shock loads imposed by transportation and rigging shall be minimized and thoroughly analyzed in the design documentation.

3.2.11 Earthquake Loads

The magnet system shall be designed to earthquake criteria defined in section 3.7B, Seismic Criteria, of the Comanche Peak Steam Electric Station Final Safety Analysis Report. Comanche Peak is a power plant operated by Texas Utilities near the SSCL. This report defines design response spectra for both horizontal and vertical motion. Maximum ground accelerations are defined to be 0.08 vertical and 0.12 horizontal. Factors of safety under dynamic load for all systems shall be those defined in section 3.3.6.

3.3 DESIGN AND CONSTRUCTION

3.3.1 Materials, Processes and Parts

The magnet shall be designed and fabricated to the intent of the ASME Boiler and Pressure Vessel Code (B&PVC), section VIII and ANSI/ASME B31.1 (Power Piping) and B31.3 (Chemical Plant and Refinery Piping Code) as applicable. Full compliance with material and fabrication requirements are required for all components of the magnet assembly. Full material and manufacturing process documentation as required by the B&PVC and B31.3 shall be provided

by the manufacturer. Non pressure subsystems shall be designed in accordance with the AISC Structural Design Code. Design of vacuum components shall conform to (B&PVC) design requirements unless otherwise approved by SSCL.

3.3.1.1 Corrosion Prevention and Control

All materials subject to corrosion will be protected by paint or grease. Direct externally exposed surface-to-surface contact between dissimilar metals shall be controlled according to the best available practices for corrosion prevention and control, and leak tightness. Preventive maintenance may be used on external magnet components to control corrosion.

3.3.1.2 Colors

External magnet assembly surfaces requiring protection shall be painted **TBD blue with 27769 white** lettering per FED-STD-595, Colors.

3.3.1.3 Materials to be Avoided

Only materials consistent with the radiation environment shall be used in magnet design and construction. Radiation sensitive materials such as PTFE shall not be used in the coil subassembly.

3.3.1.4 Weldments

All manufacturing and field weldments of pressure components shall be performed by a qualified welder and conform to the requirements of ASME B&PVC, section VIII and ANSI/ASME B31.3 as applicable. In addition all other manufacturing and field weldments shall be in according to the SSCL Mechanical Engineering Guideline, section 4.3.5 and LLNL-MEL-92-001810. The design shall accommodate the use of standard welding machines to allow for conformance to this requirement. Welding, and weld test and acceptance, shall be accomplished according to Process Control Procedures that have been reviewed and accepted by the SSC Laboratory. Flanges provided for repair/maintenance activities shall not be degraded by up to 6 such activities.

3.3.1.5 Soldering and Brazing

All soldered connections shall be designed and constructed as part of the joint contractor/SSCL development effort. Any soldering flux used shall be approved by the SSCL before use.

3.3.1.6 Coating, Potting, and Molding

Coating, potting and molding shall conform to the subcontractor's specifications, standards and drawings. These shall be submitted to SSCL for review prior to use.

3.3.1.7 Selection of Parts

Maximum use shall be made of standard or commercial parts.

3.3.2 Nameplates and Product Markings

Nameplates, product marking, serial and lot number markings, and all other identifying informational and certifying marking shall be according to the SSC Laboratory's direction.

3.3.3 Workmanship

The magnets shall be fabricated with repeatable field quality and quench characteristics and finished in a thoroughly workmanlike manner. Particular attention shall be given to freedom from blemishes, defects, burrs, sharp edges and foreign materials; saturation induction of magnetic materials; accuracy of dimensions; application of insulating material; care during assembly; radii of fillets; marking of parts; thoroughness of cleaning; quality of brazing, welding, riveting,

painting and wiring; alignment of parts; and specification tightness, prestress and torquing of fasteners. MIL-STD-454, Requirement 9, shall be used as a guide in applying workmanship standards.

3.3.4 Safety

Performance under this contract shall be consistent with the DOE policy of providing employment and a place of employment free from recognized occupational safety and health hazards by complying with the DOE Order 5481.1B and DOE prescribed OSHA standards. The magnet system shall be designed to comply with the National Electric Code (NFPA-70). Specific personnel hazards and/or special instructional markings of hardware shall be identified by the subcontractor and noted on applicable drawings or procedures. The subcontractor shall also identify and advise SSCL of personnel safety considerations, e.g., helium gas venting duct size, liquid air runoff hazard, high voltage hazard, etc., which should be incorporated into the facility which will house the magnet system. A failure modes and effects analysis identifying all potential safety hazards is required.

3.3.5 Human Performance/Human Engineering

The magnet design shall be consistent and compatible with the human capabilities required to build, test, install and repair the magnet in a repeatable, consistent, effective and safe manner. This includes tasks, tools, equipment, environment, personnel-equipment interfaces and other items required of this design. Mature, performance proven, standard, commercially available equipment shall not be modified without due consideration of safety to personnel or equipment.

3.3.6 Structural Integrity

3.3.6.1 Handling Attach Points

Rings, shackles and lugs shall be designed for a minimum yield factor of safety of 3.0 based on dead load (weights).

3.3.6.2 Allowable Stresses

Stresses in piping shall comply with ASME B31.1, Power Piping, or ASME B31.3, Chemical Plant and Refinery Piping, as applicable. Design of vacuum vessel and pressure vessel components shall conform to ASME Boiler and Pressure Vessel Code Section VIII, Division 1. In cases of combined loads or geometries not explicitly covered in these codes, adequate supporting calculations shall be performed to insure that allowable Code stresses are not exceeded. Stresses in non-pressure boundary components, such as auxiliary equipment support structure and brackets, shall conform to the AISC Specification for the Design, Fabrication, and Erection of Structure Steel for Buildings.

Load conditions on magnet subsystem components shall include, but shall not necessarily be limited to gravity, static preload, steady-state and transient magnetic, steady-state and transient thermal, steady-state and transient cryogenic fluid pressure, magnet quench, transportation and handling, and environmental loadings.

3.4 DOCUMENTATION

Technical documentation shall be delivered, sufficient in level of detail, type and quality to allow evaluation of the magnet.

3.4.1 Specifications

The following specifications shall be developed by the Subcontractor:

a. Prime Item Development Specification establishing the performance, design, development and test requirements for the GEM Detector Magnet.

b. Prime Item Product Fabrication Specification establishing the requirements for manufacture, rigging, and acceptance of the GEM Detector Magnet.

c. Process Specifications defining specific processes involved in manufacturing techniques.

3.4.2 Engineering Drawings and Associated Lists

Level three drawings and associated lists shall be provided. P40-000001, P40-000004, P40-000013, P40-000017, P40-000030, and P40-000034 shall be used in the preparation of these documents.

3.4.3 Operating Manuals

Operating manual and procedures describing all aspects of operating the GEM Detector Magnet in all operating modes shall be developed.

3.4.4 Documentation Numbering

Documentation numbering schemes shall be according to the SSCL Document Numbering Procedure.

3.4.5 Acceptance Test Data Package/Report

After completion of the acceptance tests, the Subcontractor shall prepare an Acceptance Test Data package/report.

3.5 MAINTENANCE

The design shall be such that scheduled maintenance and repair shall not be required. Minimal preventive and corrective maintenance shall be required.

3.5.1.1 Preventive Maintenance

Requirements for preventive maintenance shall be limited to visual inspection, cleaning surfaces, and similar tasks necessary to ensure that the magnet does not deteriorate with age or use. Preventive maintenance shall not be required at intervals less than ten operating years. No preventive maintenance to protect the magnet against degradation during extended periods of non-use shall be required. Preventive maintenance shall include tasks such as external rust removal or corrosion prevention etc.

3.5.1.2 Corrective Maintenance

Corrective maintenance shall be restricted to repair of leaks or electrical connections that can be accomplished without degradation of the magnet integrity. The design shall allow access to the cold mass subassembly conductor splices and LHe manifold connections.

3.6 MAJOR COMPONENT CHARACTERISTICS

The GEM Detector Magnet will consist of two halves (coil assemblies) which when installed in the experimental hall will be separated by the central detector support. Characteristics of the coil subassembly, cryostat, cryogenic system, forward field shapers central detector support, and installation are provided below.

3.6.1 Cold Mass

Two cold mass subassemblies are required. Each consists of 12 coil modules. Each coil module is comprised of 19 turns of cable-in-conduit superconductor (approximately 1140 m) and its supporting structure which includes the coil form wall and compression end flanges. The coil shall operate with stagnant supercritical helium at a nominal temperature of 4.5 K and a pressure of 3.5 atm. Since the coil is operated DC the only heat loads are expected to be thermal radiation and conduction. These heat loads are removed continuously by conduction to the aluminum coil form which is in turn cooled by the thermosyphon loop. An internal bus connects the coil to the external power bus. Magnet detection and diagnostic monitors provide magnet health information to the protection system.

The superconductor is enclosed in an aluminum sheath. The conductor and sheath are internally wound into the coil form, which may have a hoop compression adjustment. The end flanges are bolted to the coil form wall and provide axial compression.

3.6.1.1 Cold Mass Performance

The magnet shall not be degraded at operating and installation temperatures when subjected to the cool down and warm-up modes defined herein.

3.6.1.1.1 Conductor

The 50,200 amp operating current superconductor/aluminum sheath will be supplied in lengths adequate to wind one full coil module with no splices (1.134 km).

3.6.1.1.2 Conductor Insulation

The conductor insulation shall assure that no turn-to-turn shorts or shorts to ground occur when subjected to the environments described herein over the useful life of the magnet. The design shall satisfy the intent of IEEE Large Rotating Electrical Apparatus Test.

3.6.1.1.3 Conductor Splices

Conductor splices shall be designed and fabricated such that no magnet quenches are initiated at the splice. The splices shall be adequately secured against movements. All conductor splices shall be located at the flange between coil modules. The maximum splice resistance shall be less than 4.7×10^{-10} Ohms at the operating field.

3.6.1.1.4 Magnet Detection and Diagnostic Monitors

Detection and Diagnostic Monitors (sensors) shall provide magnet status and system health information adequate to initiate, (automatically and/or manually) corrective action prior to any permanent damage to the magnet components during any normal or failure modes.

The Detection and Diagnostic Monitor wiring shall accommodate all movements due to thermal and magnetic cycling without causing turn-to-turn or turn to ground shorts.

3.6.1.1.5 Internal Bus

The magnet internal power lead buses shall consist of the insulated cable-in-conduit superconductor/aluminum sheath. The buses shall be capable of operating at 50,200 A at operating temperature and survive a credible fault.

The bus shall be designed to handle the maximum currents and voltages for all operating or magnet failure modes. These modes shall include quench and emergency dump modes.

The bus shall accommodate all movements due to thermal and magnetic cycling without performance or lifetime degradation.

3.6.1.1.5.1 Paschen Breakdown

The internal bus shall not breakdown to ground at 1500 V during all operating and fault scenarios.

3.6.1.1.5.2 Internal Bus Mounting

The bus shall be secured and thermally isolated such that it will perform in accordance with 3.6.1.1.5.

3.6.1.1.6 Ground Plane Insulation

The ground plane insulation (insulation between the bobbin and coil) shall be designed and tested to withstand the calculated peak voltages at ambient temperature, pressure and in a helium environment without arcing, tracking or breakdown. The design margin shall be 300%.

3.6.1.2 Physical Characteristics

3.6.1.2.1 Coil Geometry

The coil geometry shall be selected to meet the requirements contained herein and maintain its integrity over the life of the magnet.

3.6.1.2.2 Conductor

The conductor is a classical cable-in-conduit (CIC) design using strands of multifilamentary NbTi-copper composite wires in a multistage cable enclosed by a stainless steel conduit. This circular CIC is surrounded by a rectangular sheath of aluminum. In this design the stabilizer function for fast transient stability is provided by the local copper in the multifilamentary strand, while the aluminum sheath provides the low resistance current shunt for hotspot protection during a quench. The conductor parameters are shown in Table IV.

Table IV. Conductor Parameters

Sheath Material	Aluminum Alloy 1100
RRR (Residual Resistivity Ratio)	>14
Hole Diameter (mm)	25.0
Width Wo (mm)	45.10
Height Ho (mm)	68.50
Corner Radii Ro (mm)	3.0
Conduit Material	Type 304 SS
Outer Diameter (mm)	25.0
Inner Diameter (mm)	20.0
Cable	
Cable Pattern	3x5x5x6
Strand Diameter Ds (mm)	0.73
Cu:Non-Cu	3
Number strands	450
Cabling Factor	1.05
Iop (Amperes)	50,200
Strand Area (mm2)*	188.3
Copper Area (mm2)*	141.3
Superconductor Area (mm2)*	47.1
Wetted Perimeter (mm)	860.0
Cabling Factor*Strand Area (mm2)	197.8
Helium Area (mm2)	116.4
Cable Space Area (mm2)	314.2
Void Fraction	0.371
Overall Conductor. Area (mm2)	3081.6
Al Sheath Area (mm2)	2590.8
SS Conduit Area (mm2)	176.7
Hydraulic Diameter (mm)	0.541
Fraction of Al - Fal	0.841
Fraction of SS - Fss	0.057
Fraction of Helium - Fhe	0.038
Fraction of Cable - Fcable	0.064
Fraction of Copper - Fcu	0.046
Fraction of NbTi - Fsc	0.015
Jsuperconductor(A/mm2)	1066
Jcopper (A/mm2)	355
Jstrand (A/mm2)	267
Jaluminum (A/mm2)	19.38
Jcable space (A/mm2)	159.8
Jconductor (A/mm2)	16.3

* Area normal to strand cross section

3.6.1.2.3 Conductor Insulation

The conductor insulation shall not be degraded during production and usage. Repairs shall be done using SSCL approved procedure.

3.6.1.2.4 Conductor Splices

Conductor splices located at the flange between coil modules shall be mechanically supported , adequately cooled, and shall not degrade the performance of the magnet. The splices between the coil modules shall be cryostable. This is done primarily by using large copper blocks with integral cooling channels to lower the Joule heating below the steady state heat flux. With a cryostable joint design, this normally resistive portion of the coil circuit is actually more stable than the bulk of the coil. This shall be achieved with a moderate flow of 0.5 g/s of supercritical helium at 4.5 K to independently remove the 1.25 W generated at each joint.

3.6.1.2.5 Magnet Detector and Diagnostic Monitors

The magnet shall contain a variety of sensor elements to monitor temperatures, voltages and stresses at various points on the coil. The sensors will be thermocouples, resistive temperature devices (RTD's), voltage taps and strain gauges. Outputs from these sensors will form the core of the data used to detect quenches and other off normal magnet operation. Approximately 200 of each type may be used. Commercial instrumentation modules shall be used to monitor the sensors and provide readout capability. The sensor design shall minimize the potential for voltage breakdown, work in a radiation environment, and shall be reliable for 20 years without replacement.

3.6.1.2.6 Internal Bus

The bus shall be adequately supported to prevent Lorentz forces, eddy currents, and temperature cycling from degrading magnet operation. The connection shall be capable of operating over the magnet useful life without magnet assembly performance or lifetime degradation.

3.6.2 Vacuum Vessel Assembly

The vacuum vessel assembly is made up of the following major sub-elements.

a. Cryogenic Piping: Cryogenic piping shall provide conduits for moving liquid and gaseous helium and liquid nitrogen necessary for cooling the magnet. The piping ends shall provide for demountable joints.

b. Thermal Shields: The cold mass shall be surrounded by thermal shields to reduce the radiant heat load on the cryogenics system.

c. Thermal Insulation: Thermal insulation blankets shall be employed with the thermal shields. These blankets consist of multiple layers of aluminized reflective plastic film separated by plastic mesh.

d. Cold Mass Supports: The coil subassemblies and thermal shields shall be supported relative to the vacuum vessel by the CMS system. This system shall function properly under all conditions of cryostat assembly, shipment, installation, operation and fault conditions.

e. Vacuum Vessel: The annular vacuum vessel consists of the outer shell, inner shell, and end plates. The coil subassembly, thermal shields and suspension system shall be contained in, and supported relative to, the outer vacuum vessel. The primary functions of the vacuum vessel include the provision of a thermal insulating vacuum and mechanical support for the muon detector and Forward Field Shapers. The magnet mount to the floor is attached to the vacuum vessel end rings.

3.6.2.1 Performance

3.6.2.1.1 Heat Leak

The vacuum vessel assembly shall provide low heat leak support to the cold mass. The allowable heat flows to the 4.35 K, and 80 K heat sinks are defined in paragraph 3.2.1.12.

3.6.2.1.2 Vacuum

The evacuated space between the inner and outer vessel shells shall be able to be pumped to a pressure of 10^{-5} torr in 72 hours or less. The leak rate shall not exceed 10^{-4} atm-cc/sec.

Mechanical roughing pumps shall be isolated with refrigerated or liquid nitrogen traps. Roughing pumps shall be valved so that connections can be made with any roughing pump to either vacuum vessel. A nitrogen gas purge capability shall be provided to reduce vessel contamination. Mechanical pumps and roots blowers shall be mounted on vibration isolation pads.

All high vacuum pumps shall be independently valved from the vacuum vessel for repair and maintenance. The vacuum system shall be sized so that any one pump may be rendered inoperable without resulting in a degraded vacuum as defined in section 3.6.2.1.3. High vacuum pumps shall be chosen to minimize contamination of the vacuum vessel, minimize vibration, and operate in a high magnetic field environment.

3.6.2.1.3 Vacuum Vessel Operating Environment

Magnet thermal design shall be such that the allowable heat flows found in paragraph 3.2.1.12 are met when operating in "normal operation".

The normal operating pressure of the vacuum vessel before magnet cooldown shall be 10^{-5} torr. Composition of outgassing sources within the vessel shall be measured and characterized. Residual gas analyzers and pressure gauges shall be a permanent parts of the vacuum system.

"Degraded vacuum" is defined as a pressure level greater than 10^{-5} torr, caused by excessive internal or external leaks, degraded pump performance, contamination of the vacuum environment, or other sources.

3.6.2.1.4 Suspension/Support System

The function of the Suspension/Support System is three fold: to support the static weight of a coil subassembly (520 metric tonnes), to maintain the magnetic alignment of the coil to the beam axis and to counteract the axial magnetic force exerted by the coil when energized (52 MN per magnet half). In performing these functions the supports shall minimize the heat load to any LHe cooled surfaces and also allow for thermal contraction of the coil subassembly without inducing any additional stresses and consequently distortion to the assembly. Each coil subassembly will contract approximately 8.1 cm on the diameter and 6.1 cm axially during cooldown.

3.6.2.1.5 External Support

The external supports shall support the dead weight of the coil assembly, provide adjustment for magnet alignment with the SSC beam, and provide transportation to move the coil assembly axially to the end of the assembly hall to allow access to the internal detector components.

3.6.2.2 Physical Characteristics

3.6.2.2.1 *Cryogenic Piping*

The vacuum vessel shall incorporate cryogenic bulkhead feed throughs for the piping which service the liquid helium (LHe) thermosyphon (supply and return); the supercritical, high pressure, low flow LHe supply and return for conductor cooling; the low pressure LHe supply and return for conductor splice and current lead cooling; and the 80 K liquid nitrogen supply and return for radiation shield cooling. The forced flow and splice LHe pipes shall contain non-conductive segments for voltage isolation. Positioning of the cooling pipe ends shall be according to the GEM Magnet Interface Document. The LHe pipes shall be supported from the coil subassembly.

3.6.2.2.2 *Thermal Shields*

The thermal shield, operating in the temperature range 77 to 89 K shall be used in the vacuum vessel and surround the coil assembly (cold mass) . The shield shall absorb the radiant heat flux and provide heat sink stations for the suspension and anchor system. The shields shall be supported by and thermally connected to the vacuum vessel. The shield may be divided into segments to facilitate assembly, and to minimize stresses and bowing during transient temperature conditions. Panel to panel tube joints shall be made utilizing an automatic tube welder. In addition, two areas of the shield assembly shall be designed such that the potential maintenance areas of the magnet, namely the superconducting splices and the cooling tube manifold weld joints in the LHe plumbing system can easily be accessed.

3.6.2.2.3 Thermal Insulation

Superinsulation will be used to minimize the heat load to the LHe cooled surfaces. It will consist of 0.00635mm thick polyester film with one side having a high purity aluminum deposit of 250 angstroms. Approximately 20-60 layers of superinsulation will be applied separately to both sides of the thermal radiation shields. They will be installed in blankets with each blanket having between 5 and 10 layers of superinsulation each.

3.6.2.2.4 Suspension/Support System

The suspension/support system shall provide the required lateral and vertical structural stiffness. The coil subassembly support rods are divided into two types; radial rods and axial rods. The radial rods support the static weight of the coil subassembly and allow the coil to contract symmetrically about the beam axis so that the magnetic centerline of the coil remains constant. The radial rods are oriented in pairs about the circumference of the coil, spaced at 45 degree increments and aligned tangent to the circumference. Eight pairs of rods are required for each coil end, making a total of 32 pairs or 64 individual rods required for the entire magnet. One end of the rod is attached to the stiffening rings on the inside of the vacuum vessel and the other end is attached to the end flange on the coil subassembly.

The axial support rods' function is to counteract the load on the coil due to the magnetic forces generated when energized and during moving/handling and installation. The rods are attached in pairs to large bosses which are welded to the outside of the coil subassembly coil form. The other end of the rod is attached to a stiffening member welded to the outer vacuum vessel. Eight pairs of axial rods which are spaced at 45 degree intervals about the circumference of the coil are used to counteract this magnetic load. The rods are placed so that they transfer their load to the eight large longitudinal support members that are welded to the outside of the vacuum vessel.

3.6.2.2.5 External Support/Transport System

Four semi-permanent mounts shall be located on each coil assembly to provide adjustable but stable support during magnet operation. The mounts shall accommodate a transportation mechanism to lift the coil assembly and move it axially in the assembly hall to provide access to internal detector components. The magnet shall be designed such that this movement can be accomplished during a normal SSC maintenance shutdown of 3-6 months. These mounts may need to be non-magnetic to accommodate the magnetic field uniformity requirements.

3.6.2.2.6 Outer Vacuum Shell

The outer vacuum shell is 15 m long and 21.8 m outside diameter with a stiffened 25.4mm thick wall. Two of these vacuum shells are required, one for each coil assembly.

3.6.2.2.6.1 Dimensional Stability

The outer vacuum vessel shell shall be designed and fabricated to maintain lifetime alignment by minimizing deformations due to stress relaxation of welds or other material yielding. Changes in the relationship of the fiducials to the cold mass magnetic axis, due to changes in the cryostat structure resulting from transport and handling loads, shall be included with the alignment requirements.

3.6.2.2.6.2 Service Penetrations

Various vessel wall penetrations will be required for vacuum pump lines, electric power, diagnostics and instrumentation, alignment sight glasses, coil supports, cryogenics, and access. All such penetrations shall be designed in accordance with ASME Boiler and Pressure Vessel Code, Section VIII. In addition, special care shall be taken in design to account for disruption of other load paths through the vessel, such as magnetic loads. Other precautions shall be taken which are specifically applicable to each type of penetration. Man access ports shall comply with all OSHA and other safety regulations. Cryogenic feedthroughs shall be designed so that the adjacent base material temperature of the vacuum vessel does not decrease more than 5 degrees Celsius. Each penetration, if individually tested off line, shall have a maximum allowable leak rate of 10^{-8} atm-cc/second.

3.6.2.2.6.3 Pressure Relief Device

A pressure relief device shall be provided on the outer vacuum shell. The pressure relief setting and inner diameter shall be set consistent with a maximum vacuum vessel pressure of 6.9kPa (gage) during faulted conditions. Flow capacity shall exceed choke flow conditions under maximum postulated load by 200%.

3.6.2.2.7 Inner Vacuum Shell

The inner vacuum shell is 15 m long and 18.25 m outside diameter with a 25.4 mm thick wall. Two of these vacuum shells are required, one for each coil assembly.

3.6.2.2.7.1 Service Penetrations

There shall be no service penetrations in the inner vacuum vessel shell.

3.6.3 Cryogenic System - Liquid Helium Supply

3.6.3.1 Performance

The cryogenic system shall satisfy the requirements of paragraph 3.2.1.12.

3.6.3.2 Physical Characteristics

The GEM magnet is cooled by liquid helium which flows by natural convection in a thermosyphon loop which couples a large storage dewar located at the ground surface with the magnet about 50 m below. A second flow circuit supplies a small flow of supercritical helium, cooled to the temperature of the thermosyphon loop, to the conductor conduit for the purpose of enhancing the conductor stability, cooling the conductor splices and for current lead cooling. The helium refrigerator will be the same as that specified for the SSC magnet test stand which is rated at 2 kW plus 20 g/s liquefaction. Two of these refrigerators may ultimately be utilized in the circuit. The second refrigerator besides providing additional refrigeration capacity which could be useful on cool down or perhaps required for steady state cooling would also greatly enhance the system reliability. The refrigerator(s) will supply cold two phase helium to a ground level helium storage dewar of 60,000 liquid liter capacity.

3.6.4 Forward Field Shapers/Support

3.6.4.1 Performance

In the forward region, the required magnetic field shape is defined by the shape and location of the iron which results in acceptable muon subsystem resolution. The required field shape is produced by a frustum of a cone extending from z=10 m to z=18 m, with an included angle of 17.4 degrees. The internal induction at saturation shall be >1.7T and shall not vary more than 0.03T in any region.

The FFS structure shall be independently mounted to the floor, but shall be mobile, and will move axially away from the central detector support to the end of the detector hall. Movement of the FFS shall be accomplished with the same devices used for moving the coil assemblies.

The FFS structure shall support the dead load of 16 muon sectors weighing approximately 9 mg tons each. Bearing pads between the FFS and the vacuum vessel shall allow the forward field shaper to deflect under magnetic load without imposing moments into the end of the vacuum vessel

Any non-axisymmetric structures may need to be non magnetic to meet the magnetic field requirements.

3.6.4.2 Physical Characteristics

The forward field shapers (FFS) are large conical steel masses used to shape the magnetic field inside the GEM detector. Each FFS weighs approximately 900 mg tons. Each support structure weighs an additional 900 mg tons. The FFS is an approximately 8-9 meters long truncated solid cone varying in diameter from 3.1 to 5 meters.

The FFS support structure is a large steel weldment which supports static, magnetic, and seismic loads. The 900 mg ton field shaper is cantilevered into the vacuum vessel, putting large moments into the support structure. When retracted from the vessel during maintenance or repair, the field shaper structure is free standing,

3.6.5 Central Detector Support

3.6.5.1 Performance

The Central Detector Support (CDS) shall provide dead load support and seismic stability for the central detector while minimizing space conflicts with the muon detectors. Provisions shall be made for CDS alignment. The central detector support shall be free standing with provisions to react the magnetic loads from the coil assemblies. It shall not unduly affect magnetic field uniformity. Regions within the solenoid volume shall have intrinsic induction at saturation of less than 0.05T.

3.6.5.2 Physical Characteristics

In the present design, the CDS is composed of two annular membranes, separated by radial gussets which connect them. Each membrane weighs about 320 mg, is 0.1 m thick, and 21.8 m in diameter. The total structure weighs approximately 1800 mg. The Central Detector Support with the detectors installed weighs approximately 4500 mg.

3.6.6 Magnet Installation

3.6.6.1 Performance

The magnet installation shall meet the requirements of paragraph 3.2.7.

3.6.6.2 Physical Characteristics

The magnet components will be lowered to the experimental hall using the north assembly shaft. Components will be moved to the assembly shaft, lowered approximately 50 meters to the experimental hall, moved southward to their proper position, and installed.

The magnet components shall be aligned as required by paragraph 3.2.1.9.

3.7 PRECEDENCE

If conflict between the provisions of this specification and other documents, the following precedence shall apply:

a. The GEM Detector Magnet Statement of Work

b. This Specification

c. Documents Referenced herein

4 QUALITY ASSURANCE PROVISIONS

The ability of the magnet system defined by this specification to meet the requirements specified in Section 3.0 shall be verified by the performance of inspections, analyses and tests as set forth herein.

4.1 RESPONSIBILITY FOR INSPECTION

Unless otherwise specified in this specification or in the contract the subcontractor is responsible for all inspections, analyses and tests specified herein.

4.1.1 Witnessing of Tests

Representatives of SSCL, and DOE shall have the right to witness all inspections and tests and shall be notified sufficiently in advance of the test so that a representative may be designated for this purpose.

4.2 VERIFICATIONS

a. Inspections and analysis

b. Development/verification tests

c. *Acceptance tests*

4.3 COMPLIANCE MATRIX

This section provides a correlation between the requirements of Section 3 and the types of tests listed in Section 4.2. The verification compliance matrix is TBD.