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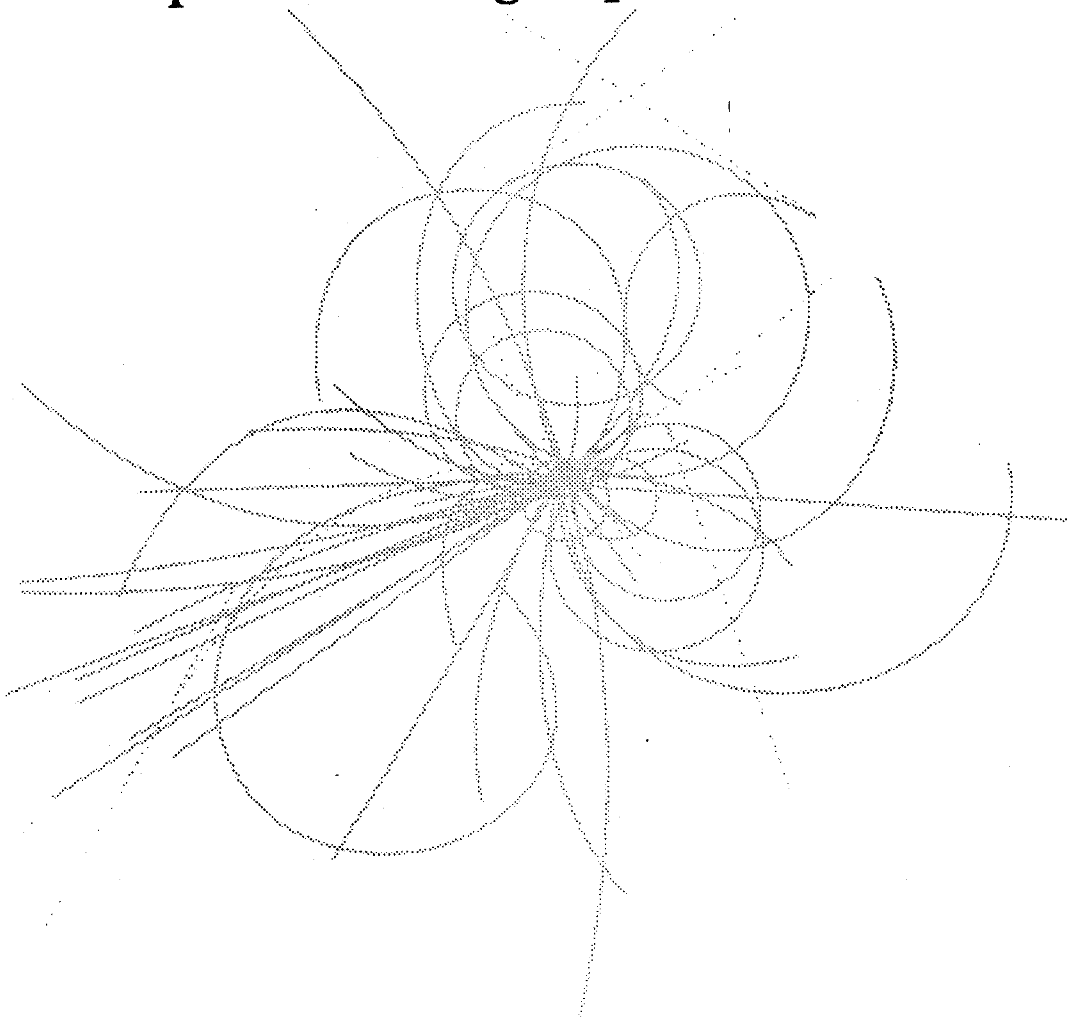
Superconducting Super Collider Laboratory



Superconducting Super Collider Reference Design Magnets Style "D" Cost Design Contents

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April 1985

SSC-SR-1004

SUPERCONDUCTING SUPER COLLIDER
REFERENCE DESIGN MAGNETS
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April 1, 1985

SUPERCONDUCTING SUPER COLLIDER

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SSC-CDG
April 1, 1985

REFERENCE DESIGN MAGNETS

STYLE "D" COST DESIGN DESCRIPTION

1. Reference Design D, Introduction

This note describes a 'Design D' style superconducting dipole magnet being studied for the SSC. This particular version of the design is being developed for initial manufacturing studies and reference cost estimate comparison. The main bending magnets are being considered in detail because they are the most costly elements of the machine and, therefore, require considerable R&D to verify performance and to develop the most economical design. Also to be described (but not in this note) are the quadrupole magnets, field correction magnets, and certain special magnets. Sections of this note draw heavily from the text presented as Appendix A for the SSC Reference Designs Study (May 8, 1984). The "Type Specific" characteristics are updated and revised as required to describe the Style D Cost Design specifically.

For Reference Design D, the main ring dipole magnet has a 6.0 T central field (nominal) at 20TeV, and is a 1-in-1 magnet style. (This terminology refers to the fact that each magnet coil, beam tube, etc is independently contained within each iron yoke and cryostat as opposed to the 'Reference Design A', for example, a 2-in-1 design for a 6.5 T magnetically and cryogenically coupled concept.) Overall the Design D style might be characterized as a high field, coil-dominated superconducting magnet utilizing a two-layered cosine theta coil, with a cold bore tube and cold iron flux return path, all contained in a cryostat and vacuum vessel designed for low heat leak and high magnetic and cryogenic efficiency. Due to the large production quantities required for the SSC (approximately 8,400 individual elements of this style), the magnets must be designed for efficient mass production fabrication and assembly processes, with considerable emphasis on manufacturability and cost efficiency while maintaining high field quality and precision.

For the superconducting dipole magnets, liquid-helium coolant is pumped around the ring, passing through cooling channels in the yoke of each magnet; the coils and beam tube are surrounded by supercritical single phase helium at approximately 4.5 K and 4 atmospheres pressure. The helium refrigeration system is an integral part of the overall magnet system design; the complete system being considered for this SSC Reference Design utilizes twelve refrigerators (each having approximately 7.5 kW maximum capacity), equally spaced around the ring, to maintain the magnet temperature at or below 4.5 K with a forced-flow of pressurized helium. The refrigeration system is designed to accommodate quenches, staged installation, and a relatively rapid magnet replacement when required during debugging or accelerator operation

A system for quench protection is provided to limit temperature increases when an individual magnet quenches. Quenches can occur when a section of the magnet undergoes a superconducting-to-normal transition leading to a rapid resistance and temperature increase. The amount of copper in the cable is chosen to limit the temperature increase to a safe value.

The Appendix A for the SSC Reference Designs Study (referenced above) describes the overall superconductor and cable design parameters, critical current density relationships, magnet load line, field quality, persistent current error fields, saturation behavior, multipole error terms, etc. and will not be repeated in this note.

The remainder of this report will present a brief technical description of the specific Design D characteristics; it will describe the physical parameters and will consider certain aspects of the overall manufacturing plan and magnet testing requirements.

2. Magnet and Cryostat Assembly

The Design D SSC dipole magnet is shown in cross section in Figure 2-1. A technical description parameter list is presented in Table 2-1. The magnetic effective length is 16.6m; the physical overall length including the magnet interconnections is 17.5 m. The cold mass consists of the bore tube and collared coil subassembly that is contained in a yoke structure and helium containment shell, all operating at 4.5K. It is cooled to this temperature by a flow of supercritical helium through holes in the yoke structure and through channels in the coil insulators and collars. The helium permeates the superconducting cable and the electrical insulation. The helium film on the conductor makes an important contribution to the stability of the superconducting state.

The cold mass of the magnet is supported in vacuum by low-heat-leak tension loop supports made of fiberglass-epoxy composite straps. Additional thermal insulation is provided by aluminum radiation shields, the outermost cooled by a liquid nitrogen circuit, and an intermediate shield cooled by a 10-20K He line. Blankets of multi-layer aluminized Mylar sheets ("superinsulation") fill spaces on both sides of the thermal shields. The outer vacuum vessel is made of low-carbon steel.

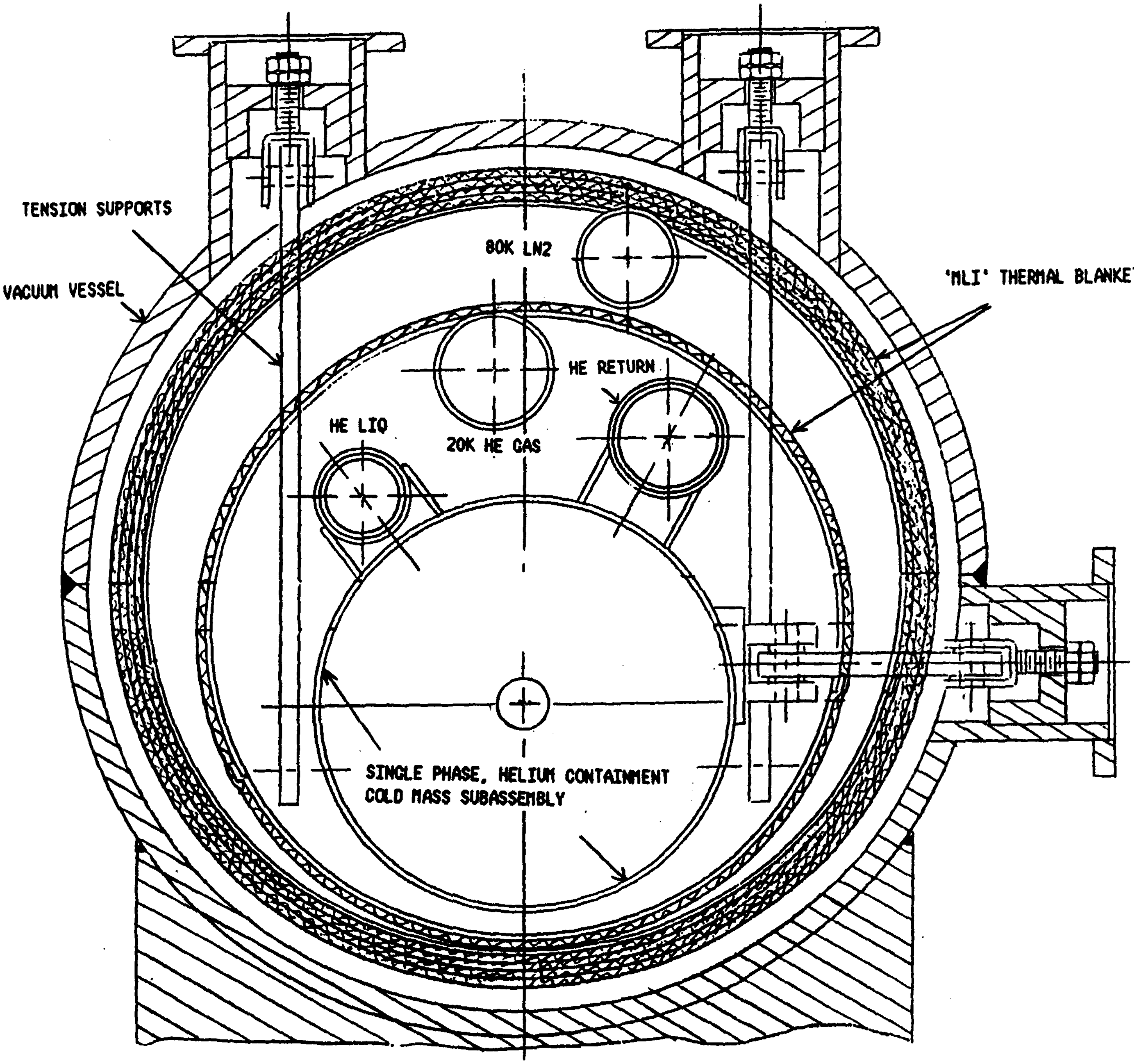

Figure 2-1 Style D Cost Design SSC Dipole Cross Section

Table 2-1

SSC MAGNET DESIGN STUDY
REFERENCE DESIGN D
TECHNICAL DESCRIPTION
3/20/1985

ITEM NUMBER	MAIN TOPIC	SUB-TOPIC	SSC. REF. DESIGN D
0.0	GENERAL AND MAGNETIC PARAMETERS	ENERGY PER RING, TEV	20
		CIRCUMFERENCE, KM	
		BEAM CURRENT, AMP	
		BEAM TUBE ID OR WIDTH, CM	3.280
		BEAM TUBE HEIGHT, CM	--
		MAGNETIC FIELD, T	6.0
		OPERATING CURRENT, AMP	
		SYNCHROTRON RADIATION PER BEAM, KW	
		DIPOLE MAGNETIC LENGTH, METERS	16.600
		BORES PER DIPOLE	1
		NUMBER OF DIPOLES PER SSC	8400
0.2	CONDUCTOR, INNER	BARE CABLE WIDTH, IN	.366
		AVERAGE THICKNESS, IN	.0574
		STRAND DIAMETER, IN	.0318
		NUMBER OF STRANDS	23
		STRAND Ic AT 4.2 DEG AND 5T, AMP	535
		Jc (non-Cu) AT 4.2 DEG AND 5T, A/SQ-MM	2400
		CABLE Ic AT 4.2 DEG AND 5T, AMP	10460
		Cu:SC, IN STRAND	1.3
		EXTRA STABILIZING Cu AREA, SQ-MM	--
		KEYSTONE, DEG	1.7
		FILAMENT DIAMETER, MICRONS	approx 5
		ALLOY	NbTi
0.3	CONDUCTOR, OUTER COIL OR SECONDARY COIL	BARE CABLE WIDTH, IN	.383
		AVERAGE THICKNESS, IN	.0459
		STRAND DIAMETER, IN	.0255
		NUMBER OF STRANDS	30
		STRAND Ic AT 4.2 DEG AND 5T, AMP	282
		Jc (non-Cu) AT 4.2 DEG AND 5T, A/SQ-MM	2400
		CABLE Ic AT 4.2 DEG AND 5T, AMP	7190
		Cu:SC, IN STRAND	1.8
		EXTRA STABILIZING Cu AREA, SQ-MM	
		KEYSTONE, DEG	1.24
		FILAMENT DIAMETER, MICRONS	approx 5
		ALLOY	NbTi

Table 2-1
Continuted

ITEM NUMBER	MAIN TOPIC	SUB-TOPIC [PAGE 2]	SSC. REF. DESIGN D
0.4	BORE TUBE	BORE TUBE, MATERIAL	NITRONIC 40*
		DIAMETER, OUTER, IN	1.360
		WALL THICKNESS, IN	.035
		COPPER COATING, IN	
		TRIM COIL & INSULATION THICKNESS, IN	
		BUMPERS, NUMBER	4
		BUMBERS, THICKNESS	.055
		RADIAL CLEARANCE TO COIL, IN	.055
0.5	INNER COIL	INSIDE DIAMETER, CM	4.000
		OUTSIDE DIAMETER, CM	5.923
		# OF TURNS, 1ST BLOCK	6
		START ANGLE, 1ST BLOCK, DEG AVG.	.088
		END ANGLE, 1ST BLOCK, DEG AVG.	23.190
		WEDGE, DEG	26.660
		# OF TURNS, 2ND BLOCK	7
		START ANGLE, 2ND BLOCK, DEG AVG.	28.690
		END ANGLE, 2ND BLOCK, DEG. AVG.	55.360
		WEDGE, DEG	21.180
		# OF TURNS, 3RD BLOCK	3
		START ANGLE, 3RD BLOCK, DEG AVG	65.590
		END ANGLE, 3RD BLOCK, DEG. AVG.	76.990
0.6	OUTER OR SECONDARY COIL	INSIDE DIAMETER, CM	5.974
		OUTSIDE DIAMETER, CM	7.986
		# OF TURNS, 1ST BLOCK	8
		START ANGLE, 1ST BLOCK, DEG AVG.	.062
		END ANGLE, 1ST BLOCK, DEG. AVG.	17.650
		WEDGE, DEG	17.430
		# OF TURNS, 2ND BLOCK	12
		START ANGLE, 2ND BLOCK, DEG AVG.	21.120
		END ANGLE, 2ND BLOCK, DEG AVG.	47.350

* Nitronic 40 is one manufacturer's trade name for this particular stainless steel. The generic name/composition is CR 21%, Ni 6%, Mn 9%.

Table 2-1
Continued

ITEM NUMBER	MAIN TOPIC	SUB-TOPIC [PAGE 3]	SSC. REF. DESIGN D
0.7	COLLARS	MATERIAL	NITONIC 40*
		THICKNESS, IN	.060
		OUTER DIAMETER, IN	4.366
		OUTER COIL DIAMETER, IN	1.598
		INNER COIL DIAMETER, IN	1.174
		OUTER COIL ANGLE, DEG	41.44
		INNER COIL ANGLE, DEG	73.71
		COIL ASSEMBLY PRESTRESS @ ROOM TEMP, PSI	12000
		NO. OF COLLAR PAIRS PER STRAIGHT SECTION	10766
0.8	COIL INSULATION	DIELECTRIC STRENGTH TO GROUND, KV	5.0
		COLLAR INSULATION TYPE	KAPTON SHEET
		COLLAR INSULATION THICKNESS, CM	.038
		INNER/OUTER KAPTON, CM	.015
		INNER/OUTER TEFLON, CM	.008
		MIDPLANE KAPTON, CM	.015
		ASSEMBLY SHIMS, CM	
		QUNCH HEATER THICKNESS, CM	
0.9	COIL CROSS SECTION AT ENDS	MINIMUM BEND RADIUS OF CABLE IN.	.625
		INNER COIL OD, IN	2.326
		INNER COIL ID, IN	1.582
		OUTER COIL OD, IN	3.138
		OUTER COIL ID, IN	2.360
		OVERALL COIL LENGTH, IN	646.900
		STRAIGHT SECTION LENGTH, IN	634.000
		DOG BONE LENGTH, IN	6.480
		DOGBONE TAPER, DEG (HALF ANGLE)	4.5
		COLLAR OD, IN	6.280
		COLLAR ID, IN	5.100
		# OF COLLAR PAIRS PER END	100
1.0	DIPOLE YOKE PAIRS	COILS PER YOKE PAIR	4
		LAMINATION SHAPE	CIRCULAR
		LAMINATION WIDTH OR DIA., IN	10.500
		LAMINATION HEIGHT, IN	--
		LAMINATION THICKNESS, IN	.197
		# OF STRAIGHT SECTION LAMINATION PAIRS	3279
		WEIGHT OF IRON IN YOKE, LBS.	11578
		BUS CAVITY WIDTH OR DIA, IN	1.700
		BUS CAVITY HEIGHT, IN	1.070
		# OF BYPASS HOLES	4
		DIA. OF BYPASS HOLES, IN	1.150
		COIL SUPPORT MATERIAL AT YOKE ENDS	RX630 DISKS

Table 2-1
Continued

ITEM NUMBER	MAIN TOPIC	SUB-TOPIC [PAGE 4]	SSC. REF. DESIGN D
1.1	He CONTAINMENT VESSEL	MATERIAL	304 SS
		WALL THICKNESS, IN	.187
		# OF WELDS TO ASSEMBLE	2
		TYPE OF YOKE SURVEY MARKERS	INSERTS
		LOCATION OF MARKERS	45 DEG.
		NUMBER OF MARKERS PER MAGNET	20
		WARM-UP HEATER TYPE	
		WARM-UP HEATER, WATTS	
		WEIGHT OF VESSEL, LBS.	1245
1.2	CRYOSTAT	VACUUM VESSEL MATERIAL	STEEL
		VACUUM VESSEL OD, IN	24
		WALL THICKNESS, IN	.25
		80 DEG SHIELD OD, IN	20
		80 DEG SHIELD THICKNESS, IN	.125
		80 DEG SHIELD PIPE OD, IN	2.5
		10-20 DEG SHIELD OD, IN	16.25
		10-20 DEG SHIELD THICKNESS, IN	.125
		10-20 DEG SHIELD PIPE OD, IN	3.25
		He SUPPLY PIPE OD, IN	1.66
		He RETURN PIPE OD, IN	2.875
		MLI LAYERS OUTSIDE 80 DEG	52
		MLI LAYERS OUTSIDE 10-20 DEG	13
		MLI LAYERS OUTSIDE 4.5 DEG	0
		COLD MASS SUPPORT TYPE	TENSION MEMBERS
		SUPPORT MATERIAL	F.R.P. UNIDIRECTIONAL
		SUPPORT INTERVEL, METERS	3.461
		LOAD PER SUPPORT, LBS	3160
1.3	ELECTRICAL SYSTEM	MAIN BUS STABILIZATION Cu, SQ-IN	.169
		BYPASS BUS STABILIZATION Cu, SQ-IN	.188
		MAX AMPS PER SQ-CM IN MAIN BUS Cu	
		MAX AMPS PER SQ-CM IN BYPASS BUS Cu	
		MINIMUM BUS BURN OUT TIME, SEC.	
		BUS EXPANSION JOINT MOTION, IN	
		QUENCH HEATER TYPE	FOIL
		QUENCH HEATER INPUT, JOULES	
		# OF CORRECTION COIL LEADS PER BORE	
		# OF INSTRUMENTATION LEADS PER BORE	
		CORRECTION COIL LEAD SIZE, GAUGE	
		INSTRUMENATION LEAD SIZE, GAUGE	

Table 2-1
Continued

ITEM NUMBER	MAIN TOPIC	SUB-TOPIC [PAGE 5]	SSC. REF. DESIGN D
1.4	CRYOGENIC SYSTEM	TOTAL He MASS FLOW PER DIPOLE, G/SEC	100
		COIL He MASS FLOW PER DIPOLE, G/SEC	1
		MAX LONGITUDINAL COIL DELTA T, DEG.	.09
		PRESSURE DROP PER MAGNET, ATM	.0014
		COLD MASS SUPPORT LOAD, WATTS	.058
		4.5 DEG RADIATION, WATTS	.05
		4.5 DEG INTERCONNECTIONS LOAD, WATTS	.05
		4.5 DEG INSTRUMENTATION LEADS, WATTS	.01
		SYNCHROTRON LOAD PER DIPOLE, WATTS	18.97
		TOTAL 4.5 DEG LOAD PER DIPOLE, WATTS	.3
		10-20 DEG SHIELD SUPPORTS, WATTS	.4
		10-20 DEG RADIATION PER DIPOLE, WATTS	1.72
		10-20 DEG INTERCONNECTIONS, WATTS	.05
		10-20 DEG INSTRUMENTATION, WATTS	.01
		TOTAL 10-20 DEG LOAD, WATTS	2.5
		80 DEG SHIELD SUPPORTS, WATTS	5.0
		80 DEG SHIELD RADIATION, WATTS	17.2
		80 DEG INTERCONNECTIONS, WATTS	1.0
		80 DEG INSTRUMENTATION, WATTS	.1
		TOTAL 80 DEG LOAD, WATTS	25

(0223c)

2.1 Beam Tubes

The cold beam tubes separate the helium magnet coolant from the beam vacuum chamber. They are made of 0.76 mm (0.035 in.) wall stainless steel tubing that is copper coated inside to limit the electrical resistance of the wall to image currents. The inside diameter of each beam tube is 33 mm. On their outside diameter the tubes support the distributed sextupole/decapole correction coils; they are keyed to the pole spacers to maintain orientation of the sextupole vertical axis. The correction coil is supported and electrically insulated from the main coil by plastic spacers 1.4 mm thick in the radial direction.

2.2 Coils

Figure 2-2 shows a cross section of the two-layer dipole windings. The cable is partially keystoned; that is, the cable cross section has a wedge shape that permits it to be stacked around the bore without gaps between adjacent turns. However, with the small bore and wide cable chosen for the Reference Design A and D magnets, it is not possible to keystone the cable enough to permit each turn to be aligned with the coil radius as was done in previous magnet designs (CBA, Tevatron, HERA). To minimize the departure from radial stacking, and to shape the winding for maximum field uniformity, insulated copper wedges are inserted in each layer. The 30-strand outer cable has less superconductor than the 23-strand inner cable because the maximum field in the outer layer is lower; the two layers are connected in series and carry the same current.

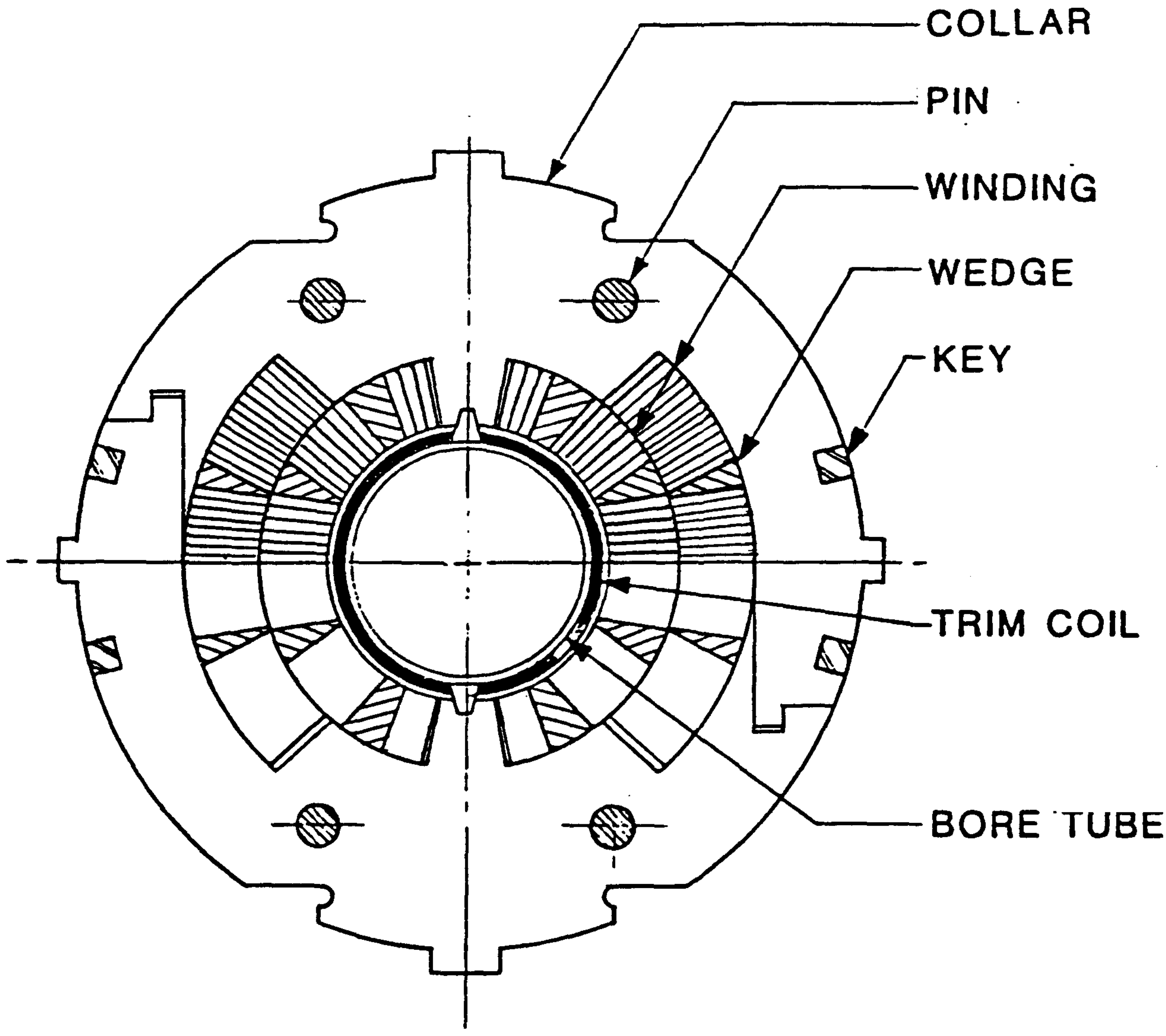

Figure 2-2 Collared Coil Subassembly

The cable is insulated with two layers of Kapton tape, each .15 mm thick and one layer of .10mm fiberglass with B-stage epoxy to hold the coil together during handling. After winding, the coil is compressed in a mold and then follows a heating cycle that assists the compaction of the windings to final dimensions and cures the epoxy. The inner and outer coils are assembled with insulation at the slip-plane and a strip heater between them. The heater is powered with a capacititave discharge circuit and is fired during a quench to ensure that enough of the coil goes normal to prevent a localized hot spot that could damage the conductor or insulation.

In order to have the advantages of two-layer coil construction and low inductance in a long magnet, it is necessary to use a high-current (and correspondingly large) cable. It is difficult to use this cable for the magnet ends with the usual saddle-shaped winding and maintain a 4 cm inner coil aperture; the wide cable, when bent around the required small radius at the ends of the usual saddle-shaped coil, becomes distorted, the insulation is easily damaged, and the end turns cannot be tightly packed. Therefore, in the proposed design, the diameter of the coil is enlarged conically at the ends (before the end turn is started) as shown in Fig 2-3. This flare-end technique has been successfully tested at LBL and BNL with model magnets. The end-support pieces are more complex in shape than for cylindrical ends, but these will be mass produced at low cost by injection molding. An advantage to this technique is that the increase in coil radius reduces the magnitude of the maximum field at the ends without requiring turn-to-turn spaces. Another advantage is that the leads can be brought out the end of the magnet inside the bulged end of the coil.

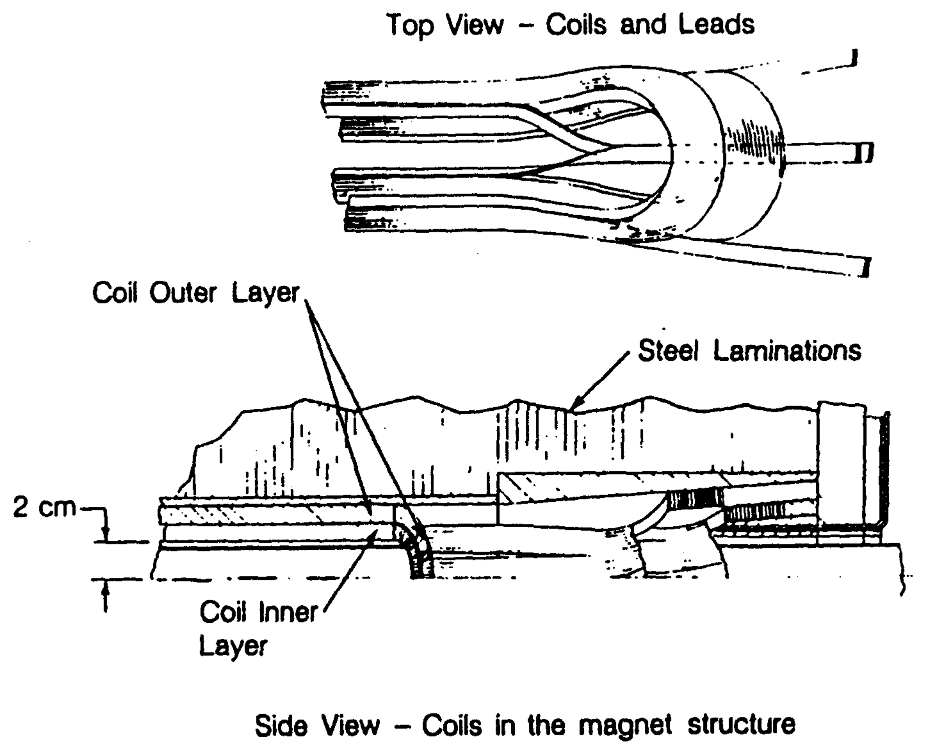

Figure 2-3 Top view and side view cross section of the flared ends of the SSC Reference Design A and D dipole coils. The flared region is required to increase the radius of curvature of the first layer, in particular the innermost turn. The lead and coil connection geometry is also shown.

2.3 Collaring of Coils

Prior to assembly in the yoke, the coils are assembled in collars as shown in Fig. 2-3. These collars provide the necessary radial restraint to keep the coils under a compressive stress of about 9000 psi at operating temperature. This preload is necessary in order to maintain the positional tolerances required for the conductor under the influence of the Lorentz forces when the magnet is energized. The collar laminations are punched from a fully austenitic stainless steel (Nitronic 40 or Cr 21%, Ni 6%, Mn 9% equivalent) that undergoes virtually no magnetic transformations at low temperature in order to preserve the necessary field quality. It is also required that the collars be made of a material with sufficiently high yield strength in order to contain the assembled coils at the proper assembly pre-stress with a collar having a radial width of 15 mm. This relatively thin radial width is needed to obtain the required contribution to the magnetic field from the iron yoke. The coils are insulated from the collars with several interleaved layers of Kapton sheet in order to provide the necessary dielectric strength to resist 5 KV.

2.4 Forced-Flow Cooling

Supercritical helium at 4.5K and 4 atm is passed through the magnets to remove heat and keep the coil temperature at or below 4.5 K. The static heat load from conduction and radiation is estimated to be 0.2 W/m and that due to synchrotron radiation is 0.12 W/m. The synchrotron radiation load is seen by the helium between the beam tube in the inner coil. The annular aperture for this helium is rather small; however, the load can be easily taken by the 1 gm/sec flow that passes through the region. Approximately 100 gm/sec total flow is required to limit the temperature increase to less than 0.2 K between recoolers spaced every 200 m. This larger flow passes through the four 1.15 inch diameter holes punched in the yoke laminations.

2.5 Yoke and Helium Containment

The magnet yoke consists of stacked iron laminations mounted in the helium containment shell as shown in Fig. 2-4. The laminations are 10.5 inches in diameter and at a 6T operating field contribute about 1.7T to the central field. The stampings are punched with keyways to provide accurate positioning on the collared coil assembly which is mounted in the yoke. Two rectangular slots are provided in the laminations for the main and diode bypass bus at the top and the correction coil leads at the bottom. The present concept calls for the use of 5mm thick ultra low carbon (less than .005%) plate. This material has been obtained in Europe for use in the DESY HERA magnets and is used in that thickness primarily to reduce the labor required for stacking the laminations since fewer laminations have to be handled with the thicker material. However, this should be weighed against the availability and cost of this material. It may be advisable to construct the yoke with .060 - .090 inch thick decarburized strip which may be more readily obtained. The yoke laminations would be stacked using manipulators to place them in position on stacking tables. Longitudinal rods are inserted through the stacked laminations which are accurately weighed to achieve a weight uniformity of 0.1% from yoke to yoke. The rods are tensioned to compress the yoke slightly to maintain an accurate longitudinal dimension with the appropriate number of laminations required for meeting the weight tolerance.

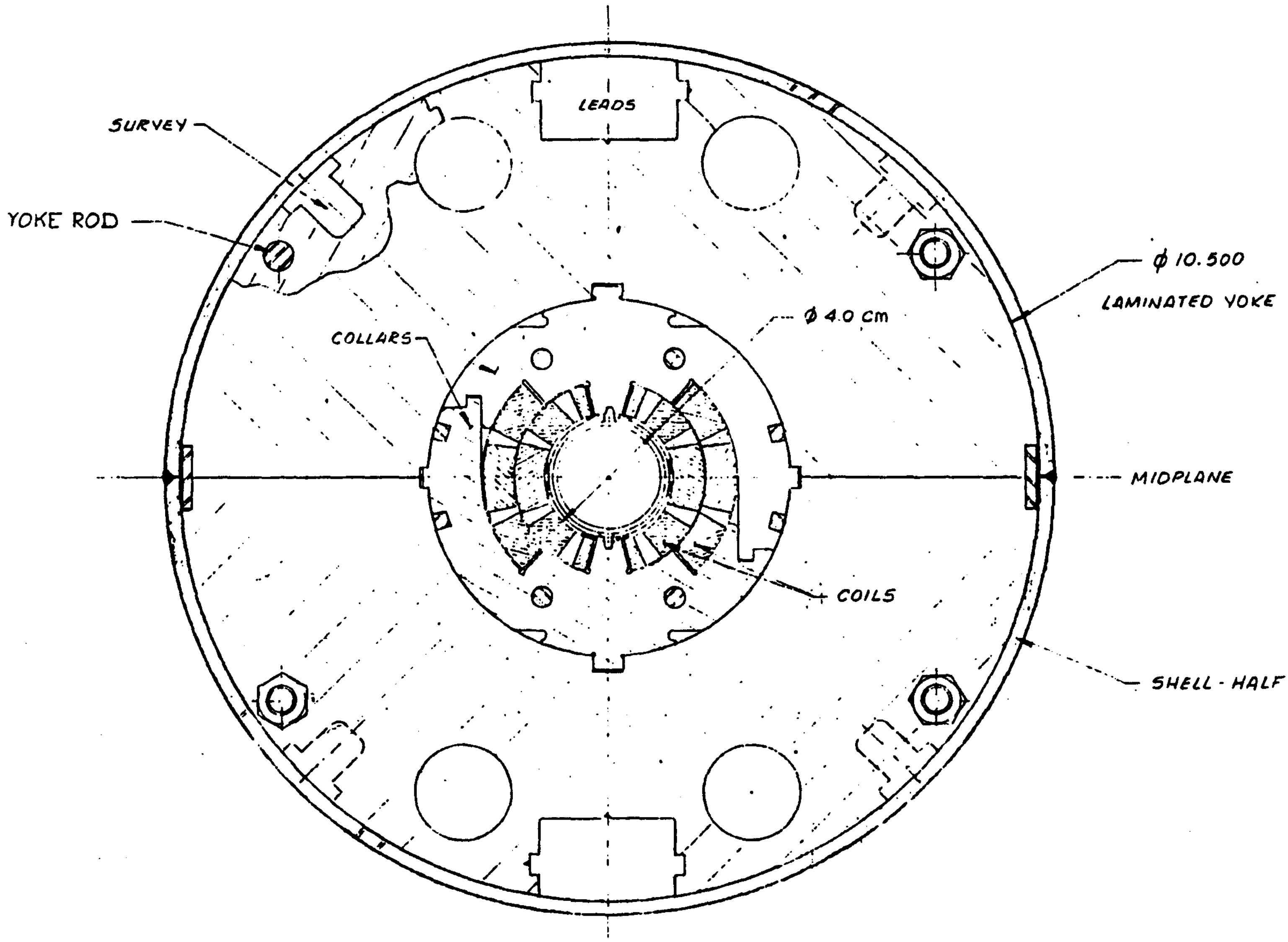

Figure 2-4 Collared Coil and Yoke Cold Mass Subassembly

The helium containment vessel is fabricated from .187 inch stainless steel plate that is formed as two half shells. After the collared coil is assembled into the yoke halves, the two halves are secured with the two backing strips at the midplane which are welded to the yoke to keep the assembly together. A press is then used to hold the two half shells in tight contact with the laminations while the two seams are simultaneously welded with automatic equipment to produce the finished yoke. Sets of holes are provided in the helium containment shells for the insertion of a series of fiducial marking plugs into recessed slots in the yoke. These plugs are sealed by final closure welding to the shells and are used as survey markers or indexing points for the magnet position.

2.6 Cryogenic Piping

The magnet and cryostat assembly contains all of the pipes to interconnect the magnet refrigeration system through the ring circumference.

The first "pipe" is the complete single phase liquid helium containment subassembly which delivers the supply cryogen which flows around the beam pipe and through the collared coil magnet assembly.

The second pipe is a 1.66 inch OD stainless steel liquid helium return pipe.

The third pipe is a 2.875 inch OD stainless steel 5K helium gas return pipe.

The fourth pipe is a 3.25 inch OD aluminum extrusion which is welded to the 20K aluminum heat shield. This pipe connects to the helium relief header during system cooldown, or to the return or supply headers during operation.

The fifth pipe is a 2.5 inch OD aluminum extrusion which is welded to the 80K heat shield. This pipe connects to the liquid nitrogen return or supply header.

2.7 Heat Shields, Insulation, and Vacuum Vessel

The 4.5 K assembly is surrounded by concentric thermal shields, operating at 20 K and 80 K, to reduce the radiant heat load of the cryogenic system. Shields are fabricated from aluminum flow channels and rolled shapes. Aluminum has desirable thermal properties and easily lends itself to normal manufacturing operations such as extruding, welding, brazing and machining at overall low cost. Aluminum does not exhibit a brittle low temperature transition and remains strong and ductile at cryogenic temperatures.

Thermal insulation will be employed between the 300 K vacuum vesel, 80 K shield and 20 K shield. The insulation blankets consist of multiple layers of aluminumized reflective plastic film (superinsulation) separated by random mat fiberglass.

The 4.5 K assembly and thermal shields with their distributed static, dynamic and magnetic loads are supported relative to the vacuum vessel by a suspension system. This system must function under conditions that include cryostat assembly, magnet shipping and installation, cooldown and warmup, steady-state operation and upset (i.e., magnet quench, cyrogenic fluid leakage, loss of insulating vacuum) situations. Desirable attributes of the suspension system are: low cost; installation and adjustment ease; high reliability; elastic and creep diminsional stability; and low heat leak. The suspension system employs tension suppport members at four locations and an independent support-anchor at the cryostat mid-length. To provide the necessary controlled motion to compensate for the thermal contraction/expansion of the 4.5 K assembly and the supports, the supports will be pivoted at each end. Sufficient transverse and rotational constraints are provided by the support assembly.

The sagitta and constraint of the 4.5 K assembly in the horizontal direction is controlled by four tension horizontal supports.

The 4.5 K assembly, thermal shields and suspension system are contained within, and supported relative to, the outer vacuum vessel. Vacuum vessel functions include the provision of thermal insulating vacuum and mechanical support. The vessel material is steel to contain any existing fringe fields. The basic vessel cross section is cylindrical and is made of parts that permit its assembly around the internal cryostat components.

2.8 Interconnections

The ends of the SSC magnet utilize straight pipe connections between the magnets. Interconnections between magnets include: beam tube, mechanical and electrical; 4.5 K helium pipe; 20 K and 80 K shields; and insulating vacuum. The connections incorporate bellows for magnet installation and thermal contraction. Machine welding is employed for all final closure welds to ensure high reliability. Because of the simple end geometry, thermal insulation is continuous across the end, thereby minimizing heat leak.

2.9 Magnet Stands

The magnet stands will be steel pedestals designed as a simple frame of bent structured shape requiring a minimum amount of welding.

The adjustment screw plate will be mounted on top of the stand. The assembled height will provide the vertical clearance between the bottom of the cylindrical vacuum vessel and the floor, to allow space for automatic welding equipment.

Stands will be located by survey and then bolted and grouted to the floor of the tunnel. The adjustment screws have deep threaded sockets to provide height and angular alignment. Clearance holes around the screws allow for lateral and longitudinal alignment as well. Survey for the initial alignment will be accomplished using fiducial marks (provided during the magnet manufacturing operation) on the outside of the cryostat that are available at each support location.

3.0 Manufacturing Plan

It is expected that initial development of prototype magnet designs will occur at a Research Center during the R&D phase. As the R&D phase matures, the technology will be transferred to an industrial environment by initiating industrial fabrication of the pre-production magnets. Pre-production dipoles and pre-production quadrupoles will be jointly produced by industry and the Research Center, using actual production tooling designs, methods, and procedures. During this period of technology transfer, production tooling will be developed jointly between the Research Center and industry to ensure a smooth transition from the development and prototype design (and tooling) phase to the production manufacturing phase. A total of approximately 8400 production magnets will be required. Peak production, which may occur in the third year after production starts, may amount to approximately 600 dipoles (and 120 quadrupoles) per quarter, with the factory running on a 2-shift, 5-day-per-week schedule. The schedule calls for completion of the manufacture and installation of the magnets in a 5-year period.

In the technical description of the magnet it was mentioned that the magnets are being designed with the objective of keeping materials and fabrication costs to a minimum. To aid in the latter objective, a production method has to be developed to utilize highly automated operations. Using these procedures, the labor costs for fabrication, assembly, and testing of a magnet should be reduced to a minimum fraction of the total magnet cost, without sacrificing the goal of consistent unit-to-unit quality. For example, this might be achieved by:

- employing automated, computer-controlled tooling for winding coils;
- using relatively thick (5 mm) yoke laminations to reduce the handling and assembly time of the yoke;
- using large assembly presses and automatic welding equipment to assemble the coils, yoke and helium containment shell;
- using automated testing equipment; and
- making sample tests of all components and assemblies according to recognized quality-assurance procedures.

The tooling built for these automated procedures can be amortized over a large production run, leading to a rather low unit tooling cost. It is estimated that this tooling cost might be approximately 5% of the total magnet fabrication cost, and will be necessary to produce magnets accurately and consistently, at the lowest possible total cost.

An example manufacturing plan concept has been developed to meet these production requirements and was described in the SSC Reference Designs Report for Designs A, B, and C.

To reach the peak rates for magnet production several acres of factory assembly space will be required. Due to physical construction restraints on sizes of buildings or constraints on land usage, it is likely that the factory buildings will actually be divided into smaller sizes. The factory layout eventually developed will include planned access for movement of parts and subassemblies between plants. A large number of interchangeable machined parts will be fabricated by vendors. These parts, upon entering the factory complex, must be quality inspected and warehoused, and they must subsequently enter the production process in a timely and organized fashion. A "Production and Materials Control" system will be developed to handle the task of maintaining an orderly flow of materials, parts, and subassemblies to the magnet assembly complex. Inventory control will require data processing techniques. From warehouses, stored parts and materials will be transported to the various factories to be assembled into the magnets as dictated by production demands. For efficiency, the factory complex must be planned to minimize material handling between factories.

The quality assurance plan that is developed must be integrated into every aspect of the factory complex, from incoming inspection to the installation of magnets in the tunnel. For the manufacture of magnets, guidelines and specifications will have to be set up to define each aspect of the production process. This, coupled with a uniform inspection procedure, can maintain a production record of each magnet. All procurement must be subject to acceptance by a receiving inspection group. Age-and/or environment-sensitive materials must be subject to strict control, and the assembly flow will be subject to periodic inspection by quality-control personnel.

Detail manufacturing plans, factory layouts, and tooling designs must be developed to describe the sequence of production steps needed to fabricate the SSC Reference Design D magnets. Conceptual Flow Plans and Charts were described in the Reference Designs Appendix A, and may be used a guide or for background material in considering the Design D production.