The Superconducting Super Collider

Cost Comparisons for SSC Magnet Dependent Systems

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SSC Magnet Dependent Systems Cost Comparison Report

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SSC Magnet Dependent Systems

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I. INTRODUCTION

A. Objective

An SSC Cost Estimating Task Force was appointed by the SSC Director in May, 1985. The charge to the task force was to perform a detailed review of costs for all superconducting magnet design styles that are under consideration for the SSC. Cost information on five magnet styles was reviewed in detail by the task force members. The basic cost information was developed by participating laboratories and by industry. Details of the procedure and analysis are presented in Chapter III.

The purpose of this report is to provide a comparison of all SSC construction project cost information that is dependent on the various magnet styles. It is emphasized that the costs displayed in the tables of this report are not the total costs for an SSC construction project. Only those systems for which costs vary with magnet style are included. In Appendix E, current results are compared with the relevant parts of the 1984 SSC Reference Designs Study (RDS) cost estimate.

Following the method used in the RDS, the costs that are developed here are non-site specific. The labor rates utilized are based on a national average for the various labor categories. The Conventional Systems costs for underground structures are derived from an extension of the "median-site" model as described in the RDS.

The results of the 1984 RDS indicate that the superconducting magnet system of the SSC collider ring is a dominant part of the projected technical systems construction costs. This system is also a vital element influencing the size (and hence total project costs) and operating costs for an accelerator project in the SSC energy region. It is therefore important to understand the cost and operational implications of each of the candidate superconducting magnet systems.

There have been numerous developments in the magnet R&D program over the past year. The conceptual designs for the magnet styles of the RDS have been greatly improved and two additional design styles are under consideration. A number of magnet models have been fabricated and tested for these designs. In addition there have been impressive improvements in the development of superconducting cable. The costs of the various magnet styles have been evaluated in light of the improved designs and associated R&D programs.

B. Background

In the 1984 RDS, a detailed Work Breakdown Structure (WBS) was established for the complete SSC project (see Table II-1). The WBS was developed in consultation with HEP construction project managers and experienced accelerator designers. The cost of each WBS element was determined from known or estimated materials and labor costs. Total Project Costs were estimated for three different magnet styles which, for reference, we shall label A(84), B(84), and C(84).

The general philosophy of the RDS approach was to include all construction costs incurred after project approval to bring a 20-TeV colliding beam proton accelerator to a state of operational readiness and to create a laboratory environment suitable for conducting high-energy experiments at the facility. To accomplish this goal and to insure completeness and uniform procedures in cost estimating, a set of guidelines and assumptions were established. These are listed in Table I-1.

Table I-1
RDS Cost Estimating Guidelines and Assumptions

1. All primary technical components are developed to a state of engineering design readiness.
2. A significant number of main ring production prototype magnets have been produced and tested successfully.
3. The facility is constructed at a median* site within the U.S.
4. Materials costs and labor rates are based on a national average.
5. Past escalation rates, as required for estimating, are determined from DOE records (DOE-HEP-81402).
6. The SSC laboratory administration will manage the construction contracts.
7. Conventional construction contracts will be subcontracted by AE/CM firms.
8. Engineering Design and Inspections (EDI) for technical components will be performed by the laboratory staff.
9. Final assembly and testing of major technical components and systems will be done at the SSC site.
10. The responsibility for risk and quality assurance of major components and systems will be borne by the SSC.
11. The construction period is six years.

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*See 1984 SSC Reference Design Study Report, page 53.

In addition to the above guidelines, the RDS established that the following items were excluded from the SSC Project Cost Estimate:

- o R&D on accelerator systems and components.
- o Costs incurred prior to project approval to ensure an orderly and efficient start.
- o Site acquisition costs.
- o Pre-operation Costs
- o Power distribution beyond the site boundary.
- o Physics research equipment (e.g. detectors and associated computers).

C. Progress Since the RDS

In this section we list a number of items which represent changes in technical parameters and associated costs from that determined in the RDS.

1. Superconductor Development. At the time of the RDS, superconducting cable of approximately 1900 A/mm^2 was available, and it was assumed that the development program could achieve approximately 2400 A/mm^2 at the time of construction. The developments have occurred much faster than anticipated. As cable up to 2500 A/mm^2 is presently produced and samples to 3000 A/mm^2 have been achieved, 2750 A/mm^2 is now assumed to be available at the time of construction.

2. Design Changes in Previous Magnets. Magnet styles A(84), B(84), and C(84) have evolved over the past year, and the improved designs are labeled A, B, and C in this report. In brief, a collared coil system and an intermediate heat shield have been incorporated into Design A. Design B has an improved cryostat design and magnet support system. Design C has a significant change in magnet length, additional trim coils have been added, and fabrication techniques have been developed further.

3. New Design Styles. Magnet Designs D and C* have been added for consideration. Basically Style D is a "1-in-1" version of Design A, i.e. magnetically and cryogenically decoupled. The latest improvements in

cryostat design have also been incorporated. C* is a "1-in-1" version of Style C which is cryogenically decoupled.

4. Peak Operating Fields. Practical peak operating fields have been evaluated in view of the design changes and the improvements in superconductor. These are as follows for the current designs:

<u>Style</u>	<u>Field (T)</u>
A	6.4
B	5.75
D	6.4
C	3.0
C*	3.0

Prior to this determination, slightly different peak fields were considered for design styles A, B, and D. These are given in the parameter comparison (Section II-C) and carried in the estimating process through Section III-A. In Section III-A-4, an adjustment is made to normalize the cost factors to the currently projected peak operating fields as listed above.

5. Model Tests. All of the magnet designs reflect a high degree of confidence that peak fields and overall field quality can be achieved as a result of actual models tests over the past year.

Five one-meter models have been fabricated and tested at LBL to verify design features of the Design A and D collared coil systems. Four 4.5 m magnets (3 cm bore) of the Design A style were fabricated and tested at BNL. In addition, two 4.5 m models (4.0 cm bore) have been successfully tested at BNL for the D design. At FNAL a number of one-meter models have been fabricated to explore the effects of construction details such as the Cu/SC ratio, helium ventilation, collar stiffness, etc. Also, a 12 m cryostat model was successfully tested to verify the achievement of the projected peak leaks. The TAC program has produced four one-meter models (two "1-in-1" and two "2-in-1") of Design C which have been tested as well as a seven-meter model. A 28-meter unit is currently being assembled by industry from components and subassemblies furnished by TAC.

6. Magnet System Apertures. An SSC aperture task force was created to determine the required aperture for each magnet style. The results are incorporated in Section III A-4 with appropriate cost adjustments.
7. Conventional Facilities. The tunnel unit cost data, as determined in the RDS, have been supplemented by additional information from the current A/E consortium (Raymond Kaiser - Tudor - Keller Gannon & Knight). In particular, case histories of the final costs of 84 tunnels tabulated by the U.S. National Committee on Tunneling Technology serve to confirm the currently projected unit costs.
8. Other Technical Systems. In the RDS the major cost difference for the magnet styles considered was estimated to be in the category of cryogenic systems. With current designs the variation in the costs of cryogenic systems has narrowed. The costs for other systems have been estimated and are presented in Section III-B.
9. Contingency Factors. The contingency analysis of the RDS has been extended in light of the current data. In particular, a more detailed analysis has been used for magnet systems in view of the additional information from the magnet development program noted above.

D. The Current Cost Estimating Model.

The methods used in this report follow closely that of the RDS. The same WBS structure is utilized and the same guideline assumptions apply as listed in Section B above. The current costs reflect the impact of the R&D program of the past year, resulting design improvements, and other factors as summarized in the previous section. The basic information, procedures, and methods of this report are described in Chapter II.

The magnet style costs, as described in Section III-A, were developed from basic cost data provided by the laboratories and, for some magnet styles, by two industrial firms. The basic data was reviewed by the Cost Estimating Task Force (CETF) and its consultants to arrive at a CDG estimate. The CDG estimate reflected corrections and/or additions to the basic cost information to insure an appropriate normalization to the same design goals and cost estimating guidelines.

Finally, in Section III A-4, the CDG estimates are adjusted to the currently prescribed apertures and fields. In order to facilitate

comparisons with previous data, the current costs are converted to FY84 dollars.

The costs for other Technical Systems are estimated for each magnet design style in Section III-B. Such systems include cryogenics, vacuum, power supplies, rf, instrumentation, controls, and safety. Costs for these items are evaluated from the basic information developed in the RDS.

Conventional Systems costs are updated in Section III-C to adjust to the conditions required by the current designs. The largest cost item is the collider tunnel for which the circumference (and cost) is scaled to reflect the current design and prescribed peak operating field of each magnet style. Other factors such as roads, tunnel access, and utilities are also evaluated.

In Section III-D and III-E, the EDI and contingency for the elements of this cost estimate are determined. The resulting total costs of the magnet dependent systems for each of the given magnet styles are summarized in Chapter IV.

II. ESTIMATING METHOD AND PROCEDURE

The following sections in Chapter II are brief summary descriptions of the information and materials used in developing, assembling, and analyzing the magnet dependent system cost estimates. The estimating models and background information is described in Section II-A and B; a brief parameter comparison is tabulated in Section II-C. The five magnet designs described as types A, B, C, C*, and D are grouped for convenience into major categories of "Cosine Theta Magnet Styles" and "Superferric Magnet Styles." Within each of these major categories the 2-in-1 designs and 1-in-1 designs are described. The following nomenclature is used:

Cosine Theta Styles:	2-in-1	Design A
	1-in-1	Designs B and D
Superferric Styles:	2-in-1	Design C
	1-in-1	Design C*

A. Estimating Formats

The material is arranged to display all of the appropriate SSC cost elements that are dependent on a particular magnet style. An attempt has been made to estimate explicitly the elements that are "uniquely" required to incorporate each magnet style in the SSC Total Facility. All cost elements have been defined in terms of a WBS element or task. The same seven major WBS categories used for the SSC Cost Estimate in the RDS are considered. This structure is shown in Table II.1 for the detail elements as defined to the third WBS level. For this magnet-dependent systems cost comparison report it is assumed that cost factors are affected only in the Collider Facilities, Systems Engineering, and Contingency categories (1.4, 1.6, and 1.7). These WBS categories are expanded to lower levels in Table II.2.

To clarify the cost estimate comparisons, all cost elements presented in this report adhere to this WBS structure. The detailed "bottoms up" cost estimates that were done for each of the magnet styles were based on a "Level 9" WBS table that described the magnet Collider Accelerator System

Magnets in great detail. These magnet elements fit into the above structure within category 1.4.2.1 (Collider Accelerator Systems - Magnets) in Table II.1.

Table II.1
Work Breakdown Structure for SSC

- 1. SSC Laboratory
  - 1.1 Project Management and Administration
    - 1.1.1 Construction Project Management
    - 1.1.2 Laboratory Support Services
  - 1.2 Central Laboratory Facilities
    - 1.2.1 Conventional Construction
    - 1.2.2 Equipment
  - 1.3 Injector Facilities
    - 1.3.1 Conventional Construction
    - 1.3.2 Injector Systems
  - 1.4 Collider Facilities
    - 1.4.1 Conventional Construction
    - 1.4.2 Collider Accelerator Systems
  - 1.5 Experimental Facilities
  - 1.6 Systems Engineering and Design
    - 1.6.1 AE/CM Services
    - 1.6.2 Engineering, Design, & Inspection
  - 1.7 Contingency
    - 1.7.1 Conventional Construction
    - 1.7.2 Technical Components

Table II-2
Magnet Dependent Systems Work Breakdown Structure for SSC

1.4 Collider Facilities

1.4.1 Conventional Construction

1.4.1.1 Land Improvements

1.4.1.2 Tunnel Enclosure

1.4.1.2.1 Tunnel Type I

1.4.1.2.2 Tunnel Type II

1.4.1.2.3 Tunnel Type III

1.4.1.2.4 Tunnel Other Common Elements

1.4.1.3 Cryogenic Facilities

1.4.1.4 Support Buildings

1.4.1.5 Utility Distribution Systems

1.4.1.6 Special Access Shafts

1.4.2 Collider Ring Systems

1.4.2.1 Magnet Systems

1.4.2.1.1 Tooling

1.4.2.1.2 Dipole Magnets

1.4.2.1.3 Quadrupole Magnets

1.4.2.1.4 Special Devices/Spool Pieces

1.4.2.1.5 Special Magnets/Insertions

1.4.2.1.6 Installation and Survey

1.4.2.2 Cryogenic Systems

1.4.2.3 Vacuum Systems

1.4.2.4 Main Power Supplies

1.4.2.5 Correction Element Power Supplies

1.4.2.6 RF System

1.4.2.7 Injection System

1.4.2.8 Abort System

1.4.2.9 Beam Instrumentation

1.4.2.10 Controls

1.4.2.11 Personnel Protection/Safety

1.6 Systems Engineering and Design

1.6.1 Conventional Systems

1.6.2 Collider Facilities

1.6.2.1 Magnet Systems

1.6.2.2 Other Technical Systems

1.7 Contingency

1.7.1 Conventional Systems

1.7.2 Collider Facilities

1.7.2.1 Magnet Systems

1.7.2.1 Other Technical Systems

The detailed costs for the magnet-dependent conventional facilities (e.g., tunnel, cryogenic facilities, etc.) comparisons also follow the WBS format and are described according to an expansion of the 1.4.1 (Collider Facilities - Conventional Construction) section shown in Table II-2. The appropriate AE/CM and Contingency estimates are also described for the Conventional Systems within sections 1.6 and 1.7 accordingly.

All magnet costs that are presented in Section III-A were developed for this study in FY1985 dollars and reflect the nominal apertures, field levels, and lengths as described in the text. For the final machine specific cost comparisons required, certain CDG adjustments to the initially developed magnet costs are made to convert to Reference Designs Report "Cost Comparison Units" (essentially FY84 dollars for simplified RDS comparisons) as well as to address several physical adjustment factors, such as field level, aperture scaling variations, etc. The "Other Technical Components" described in Section III-B are estimated in FY84 dollars for the specific magnet styles, and the Conventional Construction (Section III-C) estimates are normalized to first quarter 1984 costs.

B. Basis for the Estimates

1. Technical Systems

The technical component cost estimates for the various magnet styles were developed in the following manner. The SSC Central Design Group provided a set of "cost estimating guidelines", estimating data sheets, and a detailed WBS to each participating group. All costs for the technical components were separated into "materials" (including not only the price of raw materials but also the complete purchase cost for all "vendor supplied components" for finished machined, fabricated, or purchased units) and "labor" (which included machining and/or fabrication if appropriate, and all assembly, test, inspection, and installation labor). Considerable attention was given to ensure that each group was using the same criteria for costing; standard craft code designators were specified for describing the type of labor required, and standard labor rates were developed to represent an "average" labor market. Labor rates were normalized to a national average to minimize any geographical dependence of the estimate.

The various magnet system detailed costs were estimated both by participating magnet development groups and by industrial manufacturing firms; they were assembled, reviewed, and analyzed by the Central Design Group Cost Estimating Task Force for uniformity, consistency, and completeness. All of the estimates are presented as they were received; the CDG estimates represent the best Task Force projections after a thorough review and analysis.

The basis for the estimate follows the assumptions listed in Table I-1. All primary technical components are assumed to be in an advanced state of development at the start of the construction phase. In particular, the dipole magnet design is presumed to have been fully developed and a significant number of production prototype magnets have been produced and thoroughly tested.

For the technical components, we assume that overall contract management and all administrative functions would be carried out by the SSC laboratory. The technical engineering, design, and inspection (EDI) would be carried out predominantly by laboratory staff. Also it is assumed for this cost comparison model that the major final assembly and testing of the technical components and systems would be carried out at or near the site and that the primary technical risk and quality assurance responsibility will be borne by the laboratory. For the magnet production schedule, a period of five years has been assumed for magnet fabrication (of any style).

The magnet styles being considered and the lead groups responsible for initially developing and providing the primary cost detail materials are indicated below:

Cosine Theta Style Magnets:

Magnet Style A - Tooling and Dipole Magnets, BNL

Magnet Style B - Tooling and Dipole Magnets, FNAL

Magnet Style D - Tooling and Dipole Magnets, BNL & FNAL, GD*, W**

(* General Dynamics, ** Westinghouse)

Superferric Style Magnets:

Magnet Style C - Tooling and Dipole Magnets, TAC, GD, W

Magnet Style C*- Tooling and Dipole Magnets, TAC

Cryogenics A, D - BNL

Cryogenics B - FNAL

Cryogenics C - TAC, CCI (Cryogenic Consultants Inc.)

Conventional Facilities - PB*, RTK**, CDG

(*Parsons Brinckerhoff, ** Raymond Kaiser, Tudor,
Keller & Gannon-Knight)

Note that two industrial firms, General Dynamics and Westinghouse, both provided independent manufacturing plans and cost estimates for tooling and dipole magnets for the two particular styles C and D. For the magnet manufacturing tasks, these studies followed the same outline format, utilized the same WBS elements, and cast their estimates in the same style as the laboratory estimates. The specific "material dollars" and "direct labor hours" were explicitly described. This allows a direct comparison of each of the magnet assembly elements made by each of the estimators. In the industrial estimates, the various methods of addressing certain overall project managing and contracting forms (that each specific industry uses to develop their specific "bottom line" cost elements) are treated as "contract factors" (e.g., purchasing expenses, QA, documentation and reporting, fee or profit, "cost of money" allowances, etc.). These elements from the industrial estimates don't align directly with the SSC WBS factors and cost model that includes Project Management, EDI (Engineering, Design, and Inspection), Contingency, etc.

General Dynamics extends their "material" and "factory labor hours" estimate to provide a model corresponding to a single industrial subcontract (e.g., with GD Convair Division in San Diego) under which they would manufacture all the tooling and dipole magnets required. They would assume certain project risk by contracting for more project responsibility by providing all necessary project management, QA, purchasing, material handling, testing, etc. This, of course, is not the model that we follow here for the cost comparison study. However, for such a manufacturing model we present a correlation (as shown in the detail analysis sections below and in the Appendix) between the laboratory, industry, and CDG estimates that allow direct comparisons of the "bottom line" costs as well as just the magnet fabrication cost.

The original model that was assumed for the Reference Designs Study remains a common basis for this comparison analysis. Although the costs of the various magnet dependent systems were developed and presented by the technical teams from the participating laboratories and industry; all data have been reviewed and analyzed by the CDG task force before a CDG assessment estimate was made. The overall responsibility for the SSC cost estimates presented in this report rests with the SSC Central Design Group.

2. Conventional Systems

In the RDS, the SSC collider ring, which determines the size of the required site, had a circumference of 56 to 100 miles depending upon the magnetic field used. The collider ring components are confined to an underground tunnel and to the surface buildings placed near the tunnel.

Buildings next to (or straddling) the tunnel roughly every 5-8 miles contain power supplies, helium refrigeration systems, and points of access to the tunnel. At six locations around the ring, other buildings intersect the tunnel and house the facilities for experiments in the interaction regions where the two circulating beams collide. The Injector and Central Laboratory were located in a campus-like configuration adjacent to the position of the collider.

The conventional system designs for the RDS were developed by an architectural/engineering firm, Parsons Brinckerhoff (PB). At a preconceptual

level they prepared a technical design such that it was possible to generate a cost estimate. Following guidance from the technical groups, the PB engineers produced fifty drawings, numerous tables, outline schedules, and several reports covering the following topics:

- WBS 1.2.1 Central Laboratory Facilities
- 1.3.1 Injector Facilities
- 1.4.1 Collider Facilities
- 1.5.1 Experimental Facilities
- 1.6.1 Estimates for AE/CM Services
- 1.7.1 Contingency Estimate

The objective of the current effort, as in the RDS, is to provide a cost estimate that is appropriate prior to the selection of a specific SSC site. In this regard national data bases were used for labor costs, materials, average tunnel costs, etc. Local geotechnical condition appropriate to specific sites represent variances about these average numbers. As noted in the previous section, the Collider Facilities are affected by the magnet style together with the estimated AE/CM Services and Contingency. The ring circumference in the current estimates is appropriately updated to reflect the projected peak operating fields of the present designs.

C. Magnet Parameter Comparison

The five basic dipole magnet styles are described briefly below. A parameter summary comparison table is shown in Table II-3.

COSINE THETA STYLES:

Type A is a High Field (6T) superconducting magnet utilizing a two layer collared cosine-theta coil (stainless-steel collars), cold iron for the flux return, and arranged with two bores in one single yoke (e.g. 2-in-1) all contained in a single cryostat. The coil i.d. is 4 cm and the bore tube i.d. is 3.28 cm. The magnet has an effective magnetic length of 16.6 m and an overall length of 17.6 m. For a 20-TeV SSC, 4200 such magnets would be required if the central field is 6T. The Type A design has been developed by LBL and BNL.

Type B is a high field (5.5T) magnet utilizing a two-layer collared cosine-theta coil (with aluminum collars) and no "cold iron." The outer vacuum vessel is a "warm iron" shell that provides magnetic shielding; the magnets

TABLE II - 3

MAGNET STYLE PHYSICAL PARAMETERS

(Nominal Design Values, Not reflecting CDG cost scaling adjustments for Field, aperture, length, etc.)

	COSINE THETA STYLES			SUPERFERRIC STYLES	
	A	B	D	C	C ^m
CENTRAL FIELD, T	6.0	5.5	6.0	3.0	3.0
MAGNETIC LENGTH, M	16.6	11.25	16.6	35.0	35.0
2-IN-1 OR 1-IN-1	2-IN-1	1-IN-1	1-IN-1	2-IN-1	1-IN-1
NO. REQD FOR SSC	4200	13392	8400	4000	8000
BORE ID, CM	3.28		3.28	2.5 X 3.2	2.5 X 3.2
BORE TUBE MATERIAL	NITRONIC 40	ALUMINUM	NITRONIC 40	STAINLESS	STAINLESS
COIL ID, CM	4.0	5.2	4.0	width: 4.5	width: 4.5
NO. COIL TURNS; INNER, OUTER	2X(32, 40)	48, 37	32, 40	2X(2(trin), 4, 4)	2(trin), 4, 4
CONDUCTOR LENGTH/MAGNET, ft	2X(3664, 4648)	3670, 2830	3664, 4648	2X(472(trin), 1890)	472(trin), 1890
COIL COLLARS, MAT'L	NITRONIC 40	ALUMINUM	NITRONIC-40	NA	NA
NO. COLLARS/MAGNET, STAMPINGS	2X20300		20300	NA	NA
NO. YOKE LAMINATIONS, PIECES	2x21150	NA	21150	3X22920	2X22920
LAMINATION THICKNESS, IN.	.060	NA	.060	.060	.060
LAMINATION CROSS SECTION, IN.	14.0 DIA	NA	10.5 DIA	5.5X9.27 EQUIV	5.5X4.45 EQUIV
WT. LAMINATION MAT'L REQD/MAGNET, LBS.	39400	NA	22900	24900	12600
CRYOSTAT/VACUUM VESSEL OD, IN.	27.5	26.0	24.0	16.75	12.5
VACUUM VESSEL MATERIAL	STEEL	STEEL	STEEL	ALUMINUM	ALUMINUM
HEAT SHIELDS AT TEMPERATURES, K	20, 80	10, 80	20, 80	10, 80	10, 80
NUMBER LAYERS MULTI-LAYER INSULATION	40	40	40	65	65
INTERNAL COLD MASS SUPPORTS, NUMBER	5	5	5	5	5
SUPPORT POST TYPE,	PEDESTAL	PEDESTAL	PEDESTAL	PEDESTAL	PEDESTAL

are all single bores (1-in-1). The coil i.d. is 5 cm; the overall length is 12 m (magnetic length 11.25 m), and approximately 13400 such magnets are required for 5.5T operation. Style B was developed by FNAL.

Type D represents a magnetically and cryogenically decoupled version of style A. Magnetic parameters are similar. Approximately 8400 units at 6T central field operation are required for the SSC. Style D is being developed by a collaboration of BNL, FNAL, and LBL.

SUPERFERRIC STYLES:

Type C is a low field (3T) superferric magnet developed by TAC. This magnet has cold iron, and is arranged for 2-in-1 magnetically decoupled units to be mounted vertically in a single cryostat. The iron gap is 2.5 cm high and 3.2 cm wide for the useful aperture. Each bore of the magnet has three separately energized coils that are adjusted to tune out unwanted multipoles, and each coil set must follow a prescribed ramping program sequence. These magnets are fabricated in 35 m elements, three each of which are preassembled or joined together at the laboratory site to form 105 m long dipole units. A total of 1333 of these long units (or 4000 of the fabricated 35 m units) are required for the SSC.

Type C* is the same style as C with the same magnetic geometry and parameters, but utilizes two independent 1-in-1 magnets contained in separate cryostats. Hence for C*, 2666 each of the long units (or 8000 fabricated 35 m units) would be required for the SSC. Style C* is also being developed by TAC.

III. COST ESTIMATES AND ANALYSIS

This chapter presents the detail cost estimate materials for comparison and discussion. Section III-A contains costs for all of the five magnet system styles; Section III-B contains the "Other Technical Components" costs, and III-C discusses the Conventional Facilities Costs. Sections III-D and III-E contain the CDG analysis for EDI and Contingency.

A. Magnet Systems

1. Summary and Overall Magnet Comparisons

The cost summary material is arranged to display the cost estimate totals for all of the magnet systems in this section (Section 1), and to provide detail comparisons and analysis for the cosine theta and superferric magnet styles in the next two sections (Section 2 and Section 3) respectively. The CDG adjustments to the costs are discussed in Section 4. The construction model assumed for the magnet fabrication has been discussed in the "basis for the estimate" in Section II-A.

The collider ring magnet system as defined by the total WBS 1.4.1 category comprises not only the ring dipole magnet elements, but also the corresponding quadrupole magnets, spool piece elements, "special" insertion region magnets, and the final installation and ring survey. During the RDS, all of these various components were defined and costed explicitly as described in Appendix C of the RDS Report. For this cost comparison study, certain of these magnet-dependent specific systems were re-examined and costed in detail (e.g., styles D and C quadrupoles and spools, installation), and certain systems received only a rather brief re-examination (e.g., style A and B quads, spools, etc.). Additional new elements for style C* have not been considered or designed in any detail; cost values for C* estimates are developed largely by extension from style C. In areas where "new data" are not developed explicitly for this cost comparison report, the earlier RDS data are used. Where these data are used, they were carefully updated to current fiscal year conditions (escalated), and scaled for quantity, aperture conformance, etc.

Also, in order to represent the total magnet system costs, it is necessary to consider appropriate portions of the Engineering, Design, and Inspection

and Contingency costs. A discussion of the "EDI" factors and the Contingency to be applied to the estimates is included in Section III-D and III-E.

With these comments in mind, the summary data presented in Table III-1 may be studied. These costs are the CDG "adjusted" values that were developed in Section III-A-4, and represent figures for the total magnet system for each magnet style after adjustments for field level, aperture, and FY1984 costs are made. A comparison and discussion of the cost data for the magnet systems follow in the next sections. The dipole magnet cost data are fully developed and compared in detail. (Additional cost comparison discussion appear in the Appendix.) The other special magnet elements and other related systems are discussed, but the material is generally at a more summary level.

TABLE III - 1
MAGNET SYSTEM COST COMPARISON SUMMARY
ADJUSTED MAGNET SYSTEM COSTS
FY1984 K\$

STYLE:	A	B	D	C	C*
1 TOOLING	41,497	23,738	41,497	21,810	21,810
2 DIPOLE MAGNETS	573,837	642,937	646,421	278,358	384,744
3 QUADRUPOLE MAGNETS	38,341	54,346	42,397	19,048	24,762
4 SPEC. DEVICES/SPOOLS	37,543	75,818	67,874	84,667	110,067
5 SPEC. MAGNETS/INSERTIONS	14,286	14,286	14,286	14,286	14,286
6 INSTALLATION & SURVEY	26,750	58,765	40,833	23,306	34,286
TOTAL ADJUSTED MAG SYS	732,254	869,890	853,309	441,473	589,953

2. Cosine Theta Magnet Styles; A, B, and D

a. Dipoles. All costs presented in this section (and section 3 for superferric styles) represent the "unadjusted" parameter costs. Some of the statements and descriptions below as they pertain in general to the WBS element descriptions and to the evaluation and analysis of the industrial participant cost estimates will also apply generally to the superferric styles as well. The material that is presented as the CDG estimate is based on a careful review and analysis of the cost estimate details that were developed by the laboratory and industrial participants. The first part of Table III-2 (dipole unit costs) shows the CDG compilation of the WBS "level 7" summary of detail elements for the three cosine theta dipole magnets. In general the cost estimates were developed by the participants at WBS "level 9" detail, and then summed to various higher levels for comparisons.

Each of the cost tables will show four columns as indicated for a) Material Dollars, b) Labor Hours, c) Labor Dollars, and d) Total Dollars. The subtotal represents a "per magnet" cost according to the manufacturing production model, and the labor rate (\$/hr) conversion as developed by the CDG and supplied to all the cost estimating participants for common use.

The lower portion of Table III-2 shows the total costs estimated for all of the dipole magnets. The tooling cost corresponds to the manufacturing cost to replicate the rate-tooling necessary to meet the magnet production schedule, and the total dipole cost is simply the product of the number of magnets times the "per magnet" price.

A brief definition of the WBS "level 7" elements will aid in the comparisons. In general there is a direct "row by row" correspondence for all of the magnet styles, but in some cases the absolute boundary or interface between certain tasks or materials becomes "fuzzy" and certain items may be interpreted and collected by various estimators under different low level categories. This is not a problem for the major and well-defined systems that are clearly common to all systems (e.g., bore tube, coils, coil collaring, yoke and components, and the "cold mass" helium containment vessel.) However, due to the differences in the specific designs, certain of the cryostat elements were not as "common" and some decision had to be made in terms of which WBS category was most appropriate for cost groupings. For example, the WBS listing has separate "level 7 collections" for upper, lower, and ends of the vacuum vessel. This was appropriate for the Designs A and D where the vacuum vessel was

TABLE III-2
COSINE THETA STYLE DIPOLE MAGNET COMPARISONS

COSINE THETA STYLE MAGNET COMPARISONS
UNIT COSTS PER DIPOLE MAGNET

ITEM: (WBS)	COS THETA STYLE A CENTRAL DESIGN GROUP ESTIMATE				COS THETA STYLE B CENTRAL DESIGN GROUP ESTIMATE				COS THETA STYLE D CENTRAL DESIGN GROUP ESTIMATE			
	MATL \$	LBR HRS	LABOR \$	TOTAL \$	MATL \$	LBR HRS	LABOR \$	TOTAL \$	MATL \$	LBR HRS	LABOR \$	LABOR \$
C MAGNETS - DIRECT MATLS AND LABOR, (FACTORY)												
14212. 1.1 COLD BORE TUBE	5273.0	68.5	1575.5	6848.5	410.0	30.0	690.0	1100.0	2636.0	34.3	788.9	3424.9
1.2 COILS	65750.0	292.9	6736.7	72486.7	23488.0	120.0	2760.0	26248.0	32875.0	146.5	3369.5	36244.5
1.3 COIL COLLARING	12282.0	69.6	1600.8	13883.6	3941.0	30.0	690.0	4631.0	6141.0	34.8	800.4	6941.4
2.1 YOKE AND COMPONENTS	15870.0	43.6	1002.8	16872.8	0.0	0.0	0.0	0.0	9341.0	38.7	890.1	10231.1
2.2 HELIUM CONTAINMENT VESSEL	5444.6	16.6	981.8	5826.4	2186.0	44.0	1012.0	3198.0	3196.0	14.4	331.2	3527.2
3.1 COLD MASS SUBASSEMBLY PREP	832.2	15.3	351.9	1184.1	7534.0	0.0	0.0	7534.0	803.0	15.0	345.0	1148.0
3.2 20K HEAT SHIELD	912.9	18.9	434.7	1347.6	2342.0	0.0	0.0	2342.0	913.0	18.9	434.7	1347.7
3.3 BOK HEAT SHIELD	2558.4	18.7	430.1	2988.5	1064.2	42.8	984.4	2048.7	2173.0	18.7	430.1	2603.1
3.4 UPPER VACUUM VESSEL	3562.8	14.5	333.5	3896.3	0.0	31.4	722.2	722.2	2883.0	14.5	333.5	3216.5
3.5 LOWER VACUUM VESSEL	1744.6	19.6	450.8	2195.4	0.0	0.0	0.0	0.0	1471.0	19.6	450.8	1921.8
3.6 VESSEL ENDS	475.5	13.0	299.0	774.5	61.2	1407.6	1407.6	1407.6	415.0	13.0	299.0	714.0
4.1 INTERNAL BUS WORK	3553.7	103.0	2369.0	5922.7	560.0	5.0	115.0	675.0	1776.9	51.5	1184.5	2961.4
5.1 INTERCONNECTION REGION PARTS	5000.0	22.0	506.0	5506.0	2700.0	20.0	460.0	3160.0	3600.0	22.0	506.0	4106.0
5.2 SHIPPING/STORAGE/HANDLING	30.0			30.0	30.0			30.0	30.0			30.0
6.1 TESTING		8.0	184.0	184.0		8.0	184.0	184.0		8.0	184.0	184.0
6.2 WARM MAGNETIC MEASUREMENTS		16.0	368.0	368.0		8.0	184.0	184.0		8.0	184.0	184.0
6.3 COLD MAGNETIC MEASUREMENTS	150.0	8.0	184.0	334.0	150.0	4.0	92.0	242.0	150.0	4.0	92.0	242.0
6.4 CRYOGENIC TESTING FACILITY OPERNS.		4.0	92.0	92.0		4.0	92.0	92.0		4.0	92.0	92.0
8.1 DIRECT SHOP SUPPORT				0.0				0.0				0.0
8.2 MISCEL. AND INDIRECT SHOP SUPPORT	200.0	180.0	5760.0	5960.0		100.0	3200.0	3200.0	200.0	110.0	3520.0	3720.0
MATERIAL FACTORS & ALLOWANCES	4000.0			4000.0	1380.0			1380.0	2000.0			2000.0
ALLOWANCE FOR REJECTS	2000.0	14.0	322.0	2322.0	675.0	7.0	161.0	836.0	1120.0	10.0	230.0	1350.0
SUBTOTAL	129640.5	946.2	23382.6	153023.1	46460.2	515.4	12754.2	59214.4	71723.9	585.9	14465.7	86189.6

FOR TOTAL DIPOLE MAGNET PRODUCTION.

NUMBER OF DIPOLE MAGNETS TO BE PRODUCED:	4200.0	13392.0	8400.0
TOOLING REQ'D:	46,477 K\$	26,058 K\$	46,477 K\$
TOTAL COST FOR DIPOLE MAGNETS:	642,697 K\$	793,000 K\$	723,992 K\$
TOTAL DIPOLE MAGNET PRODUCTION:	689,174 K\$	819,058 K\$	770,469 K\$

constructed in this manner, but is not directly appropriate for Design B that has a single vacuum vessel. (Style C and C* have "upper" and "lower" components, but no separate "ends".) The shields, cryogenic tubing, and super-insulation also were occasionally collected together by the estimators for convenience. We have made an attempt to separate and keep the WBS levels as common and as well defined as possible; however, the direct comparison between each of the magnets at each "row" level should not be considered exact in each case, and occasionally it is necessary and more proper to compare groups of rows. For example, usually the entire cryostat system can accurately be compared for all magnets, but the individual supports, alignment, and various assembly tasks might not be as easily compared.

The entry for "Interconnection Region Parts" collects the costs of the materials (and any preparation labor) for connecting the dipole magnets in the ring. These are the dipole interconnections only and are not to be confused with the "Special Devices/Spools" that are associated with groups of dipoles (e.g., at each half cell) and are discussed separately. The labor of assembling/installing the interconnection region is covered with the installation costs.

The WBS category entry for a "shipping/storage/handling" allowance provides nominal material and labor for preparing the elements for movement, transport, or storage.

The categories for "Testing", "Warm and Cold Measurements", and "Cryogenic Testing Facility Support" cover the technician and factory/shop personnel required to perform the inspection and testing of the final magnet assembly. Typically this will cover the final electrical, mechanical, vacuum, and cryogenic checks, as well as the magnetic measurement support. The magnet measurement model assumes that every magnet will have complete "warm" measurement tests, and that 10% of the final production magnets will have complete "cold" measurements made. Additional program management and magnet QA, inspection, and test functions are covered in the CDG model as a part of EDI. (In addition to the EDI and the "final magnet assembly" checkout functions above, there is some direct labor called out at the manufacturing and subassembly steps for progress checkout and tests.)

The categories for "Direct" and "Indirect" Shop Support cover the additional personnel in the magnet factory that are not covered in the labor

"overhead" burden, and are not costed directly as a task/labor direct operation. Such elements as supervision, materials transport, parts handlers, machine loaders, rigging, and many other "indirect" personnel must be accounted for here. The model used after analysis of the BNL production evaluations and from the TAC projections indicates that approximately 23-25% of the direct labor must be added in this way to cover these necessary functions.

The "Materials Factors and Allowances" are allowances to project material use variances, damaged or unusable materials, excess purchases, etc. We use an allowance of 5% for all of the superconducting materials, (to cover such items as short cable lengths at the ends of reels, damaged and unusable materials, "short-sample" testing materials, etc.) and 1% of all other materials.

The "Reject Allowance" factor uses a production model that assumes 1% of the final magnets are not acceptable and are rejected as unusable, and an additional 1% of all the coils that have been fabricated are unusable. This model assumes that all of the materials and labor are completely lost. In reality, some larger portion of the magnets will undergo some "rework" labor to be saved, and a smaller portion may actually be totally lost. This allowance model is an attempt to project a production capability that must reach this loss level.

b. Total Magnet Systems. The complete magnet system includes the tooling, dipole, quadrupoles, special devices/spool pieces, special magnets for insertions, installation, etc. These elements and their unadjusted costs are shown at the summary level in the table below in FY85 dollars.

In general, all of the "Total Magnet Systems" cost elements for Design A are projections from the new Design D data base. There has been no new direct design effort or separate detailed cost estimate for any of these Design A or B system elements by either the laboratories or industry. All of the A and B estimates were extended and projected by prorating certain major elements of the Design D totals or by extending the RDS work.

Table III-3
Cosine Theta Style Magnet System
 (Unadjusted Costs - FY85 K\$)

<u>WBS Element</u>	<u>Style A</u>	<u>Style B</u>	<u>Style D</u>
Tooling	46,477	26,058	46,477
Dipole Magnets	642,697	793,000	723,992
Quadrupole Magnets	42,942	67,030	47,485
Special Devices/ Spools	42,084	83,228	76,019
Special Magnets/Insertions	15,000	15,000	15,000
Installation and Survey	29,960	64,508	45,733
 TOTAL MAGNET SYSTEMS:	 819,124	 1,048,824	 954,706

For the Design D system, a review of the earlier RDS estimate for the Design A(84) quadrupoles combined with a current estimate for the required length and strength required for Type D resulted in an overall estimate of 28,265\$ (each magnet) being arrived at by the CDG study. This was the value used above (for each of the 1680 Design D quads required - 47485K\$ total). The quadrupole estimate for styles A and B was updated from the RDS data.

The "Special Device/Spool" category includes not only the correction element windings and spool pieces and half-cell interconnection region hardware, but also an assortment of cryogenic, mechanical, and electrical apparatus. No recent design or cost effort has been included in this study; the RDS data is still the most appropriate basis for projection. We use the same relative scaling factors (0.065 and 0.105 times the dipole cost respectively) for Styles A and B as used in the RDS, and rely on the "B" scaling factor (0.105) to be the most appropriate factor to be assumed for Style D.

The "Special Magnet" category includes the quadrupoles and other apparatus for the insertion regions. These items have not been re-examined, and the CDG estimate simply relies on an average allowance of 15,000K\$ to be adequate for all magnet systems. (This is approximately the RDS value adjusted for all systems.)

The "Installation and Survey" cost estimate for Design D was studied separately by the CDG. The results of this study show a cost estimate of 8,976K\$ for special installation/survey/checkout tooling and equipment, 9,207K\$ for final pre-assembly and test, 4,904K\$ for overall installation, and 22,646K\$ for final checkout. The total for all these tasks is 45,733K\$. This is the estimate we project for the final magnet systems installation for Style D. Styles A and B receive the same installation costs as used in the RDS.

3. Superferric Magnet Styles; C and C*

a. Dipoles. All costs presented in this section (as in section 2 above for cosine theta styles) represent the "unadjusted" parameter costs. The statements and descriptions presented before for the cosine theta style as they pertain in general to the WBS element descriptions and the evaluation and analysis of the industrial participant cost estimates also apply to the superferric styles as well. The material that is presented as the CDG estimate is based on a careful review and analysis of the cost estimate details that were developed by the laboratory and industrial participants. The upper portion of Table III-4 (dipole unit costs) shows the CDG compilation of the WBS "level 7" summary of detail elements for the two superferric dipole magnets.

The lower portion of Table III-4 shows the total costs estimated for all of the dipole magnets. The tooling cost corresponds to the manufacturing cost to replicate the rate-tooling necessary to meet the magnet production schedule, and the total dipole cost is simply the product of the number of magnets times the "per magnet" price.

b. Total Magnet Systems. The complete magnet system costs (unadjusted) for the tooling, dipoles, quadrupoles, spool pieces, special magnets, installation, etc. are shown at the summary level in Table III-5.

TABLE III-4
SUPEFERRIC STYLE DIPOLE MAGNET COMPARISONS

SUPERFERRIC STYLE MAGNET COMPARISONS
UNIT COSTS PER DIPOLE MAGNET

(WBS)	ITEM:	SUPERFERRIC STYLE C CENTRAL DESIGN GROUP ESTIMATE				SUPERFERRIC STYLE C* CENTRAL DESIGN GROUP ESTIMATE			
		MATL \$	LBR HRS	LABOR \$	TOTAL \$	MATL \$	LBR HRS	LABOR \$	TOTAL \$
C	MAGNETS - DIRECT MATLS AND LABOR, (FACTORY)								
14212.	1.1 COLD BORE TUBE	4735.0	42.1	968.3	5703.3	2367.5	21.0	483.0	2850.5
	1.2 COILS	15935.8	80.2	1843.7	17779.5	7968.0	40.1	922.3	8890.3
	1.3				0.0				0.0
	2.1 YOKE AND COMPONENTS	12453.0	106.9	2458.7	14911.7	7353.0	81.0	1863.0	9216.0
	2.2 HELIUM CONTAINMENT VESSEL	1760.0	33.3	765.9	2525.9	2760.0	30.0	690.0	3450.0
	3.1 COLD MASS SUBASSEMBLY PREP (6 CRYOSUP)	2264.6	33.0	759.0	3023.6	1900.2	30.0	690.0	2590.2
	3.2 10K HEAT SHIELD	2457.2	56.0	1288.0	3745.2	2400.0	50.0	1150.0	3550.0
	3.3 80K HEAT SHIELD	3632.4	10.0	230.0	3862.4	3600.0	8.0	184.0	3784.0
	3.4 VACUUM VESSEL	3855.2	61.0	1403.0	5258.2	5345.4	61.0	1403.0	6748.4
	3.5				0.0				0.0
	3.6				0.0				0.0
	4.1 INTERNAL BUS WORK	7380.0	40.0	920.0	8300.0	3690.0	20.0	460.0	4150.0
	5.1 INTERCONNECTION REGION PARTS	200.0			200.0	200.0			200.0
	5.2 SHIPPING/STORAGE/HANDLING	61.2	6.0	138.0	199.2	61.2	6.0	138.0	199.2
	6.1 TESTING		8.0	184.0	184.0		6.0	138.0	138.0
	6.2 WARM MAGNETIC MEASUREMENTS		16.0	368.0	368.0		8.0	184.0	184.0
	6.3 COLD MAGNETIC MEASUREMENTS		8.0	184.0	184.0		4.0	92.0	92.0
	6.4 CRYOGENIC TESTING FACILITY OPENS.	150.0	8.0	184.0	334.0	150.0	4.0	92.0	242.0
	8.1 DIRECT SHOP SUPPORT				0.0				0.0
	8.2 MISCEL. AND INDIRECT SHOP SUPPORT	200.0	120.0	3840.0	4040.0	100.0	84.0	2688.0	2788.0
	MATERIAL FACTORS & ALLOWANCES	1200.0			1200.0	800.0			800.0
	ALLOWANCE FOR REJECTS	1020.0	10.0	230.0	1250.0	510.0	5.0	115.0	625.0
	SUBTOTAL	57304.4	638.5	15764.6	73069.0	39205.3	458.1	11292.3	50497.6

FOR TOTAL DIPOLE MAGNET PRODUCTION,

NUMBER OF DIPOLE MAGNETS TO BE PRODUCED:	4000.0	8000.0
TOOLING REQ'D:	22,900 K\$	22,900 K\$
TOTAL COST FOR DIPOLE MAGNETS:	292,276 K\$	403,981 K\$
TOTAL DIPOLE MAGNET PRODUCTION:	315,176 K\$	426,881 K\$

Table III-5
Superferric Style Magnet System
 (Unadjusted Costs - FY85 K\$)

<u>WBS Element</u>	<u>Style C</u>	<u>Style C*</u>
Tooling	22,900	22,900
Dipole Magnets	292,276	403,981
Quadrupole Magnets	20,000	26,000
Special Devices/ Spools	88,900	115,570
Special Magnets/Insertions	15,000	15,000
Installation and Survey	<u>24,471</u>	<u>36,000</u>
TOTAL MAGNET SYSTEMS:	463,547	619,451

In general, all of the "Other Magnet Systems" cost elements for Design C* are projections from the Design C data base. There has been no new design effort or separate detailed cost assessment for any of the Design C* elements by either the laboratories or industry. All of the C* estimates were extended and projected by prorating certain major elements of the Design C totals or by extrapolation from the RDS work.

For Design C, a review of the earlier RDS estimate for the quadrupoles and a new readjustment/projection scaling for the required length and strength estimates resulted in an overall estimate of 20000K\$ being arrived at by the CDG study. This was the value selected above and assumed appropriate for Style C. For Style C* a value of 26000K\$ was estimated.

The "Special Device/Spool" category includes not only the correction element windings and spool pieces and half-cell interconnection region hardware, but also an assortment of cryogenic, mechanical, and electrical apparatus. A current design and cost estimate (\$56700 each) has been presented by CCI (Cryogenic Consultants, Inc.), and forms the basis for the estimate that is projected by the CDG. In order to add an allowance for the superconducting correction coils for the two bore tubes, and to allow for the complex diode package for the several electrical circuits and the interconnections necessary within the "spool piece," an additional allowance of \$10,000 per spool was assumed (the same allowance as was used in the RDS C(84) cost estimate). The overall CDG estimate is for a unit cost of \$66,700 each for the 1333 half-cell interconnections, or an overall total of approximately 88,900K\$. The

interconnection boxes for design C* were taken to cost approximately 30% more, 115,570K\$ total, in accordance with the 30% ratio for the overall difference between C and C*.

The "Installation and Survey" cost estimate for Design C was studied separately by the CDG. The results of this study show a cost estimate of 6,056K\$ for special installation/survey/checkout tooling and equipment, 9,838K\$ for final pre-assembly and test (pre-joining and tests for three each 35 m long dipoles into one 105 m long assembly unit for installation in the tunnel), 2,944K for overall installation, and 5,633K\$ for final checkout. The total for all these tasks is 24,471K\$. This is the estimate we project for the final magnet systems installation. Design C* is projected at 36,000K\$.

4. CDG Adjustments

Section 4 describes the adjustments to be factored into the magnet systems estimates to account for the SSC machine specific parameters to be used in the cost comparison study. The adjustments are made in three steps, and a separate table is shown below after each adjustment has been made. The adjustments are made to reflect peak operating field level, magnet aperture conformance, and FY1984 dollars. Table III-6 repeats the cost estimates for the "unadjusted" magnet system values below (repeated from Sections 2 and 3).

Peak Operating Field. Based upon magnet model results and recently improved superconductor we believe that the operating field level of the cosine theta magnets should be adjusted upward accordingly: 5.75T for Design B; 6.4T for Designs D and A (SSC-N-23). The adjustment for field level results in an effective change in the number of dipole elements since we assume that the total product of field level times the effective bending magnet system length must remain constant. We assume that the individual magnet length remains constant and that therefore the total number of magnets required scales as the ratio of field levels. The tooling for production also scales approximately with the number of elements required, and the number of quadrupoles, spool pieces, and the installation and survey requirements also vary nearly directly with the number of dipole elements. The special magnets are required for the insertion regions and remain constant with main ring dipole field level. The operating field level projected and resulting number of dipole magnets for the various magnet styles is shown in Table III-7.

Table III-6
Magnet System Cost Comparison Summary
Unadjusted Parameters
(FY85 K\$)

	A	B	D	C	C*
UNADJUSTED PARAMETER VALUES:					
FIELD LEVEL, T	6.00	5.50	6.00	3.00	3.00
NUMBER OF DIPOLES:	4,200	13,392	8,400	4,000	8,000
APERTURE, (DIA: A,B,D; GAP: C,C*),CM:	4.00	5.00	4.00	2.54	2.54
MAGNET SYSTEMS, WBS 1.4.2					
TOOLING	46,477	26,058	46,477	22,900	22,900
DIPOLE MAGNETS	642,697	793,000	723,992	292,276	403,981
QUADRUPOLE MAGNETS	42,942	67,030	47,485	20,000	26,000
SPEC. DEVICES/SPOOLS	42,048	83,228	76,019	88,900	115,570
SPECIAL MAGNETS/INSERTIONS	15,000	15,000	15,000	15,000	15,000
INSTALLATION & SURVEY	29,960	64,508	45,733	24,471	36,000
TOTAL MAGNET SYSTEMS:	819,124	1,048,824	954,706	463,547	619,451

Table III-7
Magnet System Cost Comparison Summary
Adjusted Field Level
(unadjusted aperture)
(FY85 K\$)

	A	B	D	C	C*
ADJUSTED PARAMETER VALUES:					
ADJUSTED FIELD LEVEL, T	6.40	5.75	6.40	3.00	3.00
ADJUSTED NUMBER OF DIPOLES:	3,938	12,810	7,875	4,000	8,000
APERTURE, (DIA: A,B,D; GAP: C,C*), CM:	4.00	5.00	4.00	2.54	2.54
FIELD LEVEL/QUANTITY SCALING FACTOR:	.938	.957	.938	1.000	1.000
(* INDICATES ITEMS ADJUSTED)					
MAGNET SYSTEMS, WBS 1.4.2					
* TOOLING	43,572	24,925	43,572	22,900	22,900
* DIPOLE MAGNETS	602,528	758,522	678,742	292,276	403,981
* QUADRUPOLE MAGNETS	40,258	64,116	44,517	20,000	26,000
* SPEC. DEVICES/SPOOLS	39,420	79,609	71,268	88,900	115,570
SPECIAL MAGNETS/INSERTIONS	15,000	15,000	15,000	15,000	15,000
* INSTALLATION & SURVEY	28,088	61,703	42,875	24,471	36,000
TOTAL MAGNET SYSTEMS:	768,866	1,003,875	895,974	463,547	619,451

Aperture. In order to make the adjustment for required aperture, a study was made to examine the cost effect for a 1.0 cm aperture or gap perturbation for each of the magnet styles (Appendix C). An appropriate scaling factor at each "level 7" cost table entry was applied separately for materials and labor. The resulting total cost was then derived and used to determine normalized overall aperture scaling factors; in this case we project a factor for a 1.0 cm decrease for Style B. The resulting overall aperture scaling factor of 0.890 was developed to scale from a Style B 5.0 cm bore to a 4.0 cm bore.

Table III-8 shows the magnet system costs after the aperture scaling factor has been applied. We assume that the tooling, special devices (cryogenic interconnections and spool pieces), and installation and survey are independent of aperture, and that dipoles and quadrupoles are both scaled directly with the aperture factor.

The resulting apertures used here for the various designs are consistent with those values determined by the Aperture Task Force through a detailed calculation analysis (SSC-SR-1013).

FY 1984 Cost. The final adjustment we make is to convert from current FY1985 to RDS-FY1984 dollars to allow a summation with the other Technical Systems costs and Conventional Systems costs and to permit direct comparisons to be made with the RDS data. We assume an overall escalation/inflation rate of 5% for FY1984; therefore the adjustment is made by dividing all FY85 costs by 1.05 to approximate equivalent FY84 costs. Using this overall factor, then, the final adjusted table for the Magnet System costs is shown in Table III-9.

Table III-8
Magnet System Cost Comparison Summary
Adjusted Field Level
Adjusted Aperture
(FY85 K\$)

	A	B	D	C	C*
ADJUSTED PARAMETER VALUES:					
ADJUSTED FIELD LEVEL, T	6.40	5.75	6.40	3.00	3.00
ADJUSTED NUMBER OF DIPOLES:	3,938	12,810	7,875	4,000	8,000
APERTURE, (DIA: A,B,D; GAP: C,C*),CM:	4.00	4.00	4.00	2.54	2.54
FIELD LEVEL/QUANTITY SCALING FACTOR:	.938	.957	.938	1.000	1.000
APERTURE SCALING FACTOR:	1.000	.890	1.000	1.000	1.000
(* INDICATES ITEMS ADJUSTED)					
MAGNET SYSTEMS, WBS 1.4.2					
TOOLING	43,572	24,925	43,572	22,900	22,900
* DIPOLE MAGNETS	602,528	675,084	678,742	292,276	403,981
* QUADRUPOLE MAGNETS	40,258	57,063	44,517	20,000	26,000
SPEC. DEVICES/SPOOLS	39,420	79,609	71,268	88,900	115,570
SPECIAL MAGNETS/INSERTIONS	15,000	15,000	15,000	15,000	15,000
INSTALLATION & SURVEY	28,088	61,703	42,875	24,471	36,000
TOTAL MAGNET SYSTEMS:	768,866	913,385	895,974	463,547	619,451

Table III-9
Magnet System Cost Comparison Summary
Adjusted Field Level
Adjusted Aperture
FY84 K\$

	A	B	D	C	C*
ADJUSTED PARAMETER VALUES:					
ADJUSTED FIELD LEVEL, T	6.40	5.75	6.40	3.00	3.00
ADJUSTED NUMBER OF DIPOLES:	3,938	12,810	7,875	4,000	8,000
APERTURE, (DIA: A,B,D; GAP: C,C*),CM:	4.00	4.00	4.00	2.54	2.54
FIELD LEVEL/QUANTITY SCALING FACTOR:	.938	.957	.938	1.000	1.000
APERTURE SCALING FACTOR:	1.000	.890	1.000	1.000	1.000
ESCALATION SCALING FACTOR:	1.050	1.050	1.050	1.050	1.050
(* INDICATES ITEMS ADJUSTED)					

MAGNET SYSTEMS, WBS 1.4.2

* TOOLING	41,497	23,738	41,497	21,810	21,810
* DIPOLE MAGNETS	573,837	642,937	646,421	278,358	384,744
* QUADRUPOLE MAGNETS	38,341	54,346	42,397	19,048	24,762
* SPEC. DEVICES/SPOOLS	37,543	75,818	67,874	84,667	110,067
* SPECIAL MAGNETS/INSERTIONS	14,286	14,286	14,286	14,286	14,286
* INSTALLATION & SURVEY	26,750	58,765	40,833	23,306	34,286
TOTAL MAGNET SYSTEMS:	732,254	869,890	853,309	441,473	589,953

B. OTHER TECHNICAL SYSTEMS

"Other Technical Systems" is the nomenclature for all other technical components of the SSC main ring apart from the superconducting magnet systems. The same definitions of these systems apply as described in the RDS. These systems with their associated WBS identification (See Table II-2) are as follows:

- 1.4.2.2 Cryogenics
- 1.4.2.3 Vacuum
- 1.4.2.4 Main Power Supplies
- 1.4.2.5 Correction Element Power Supplies
- 1.4.2.6 RF System
- 1.4.2.7 Injection System
- 1.4.2.8 Abort System
- 1.4.2.9 Beam Instrumentation
- 1.4.2.10 Controls
- 1.4.2.11 Safety Systems

1. The RDS Model

In the RDS there were significant differences in the conceptual design considerations for the category of cryogenics. In particular there were 24 refrigerator stations for Design C(84) and 12 stations for Designs A(84) and B(84). This amounted to a variation in the costs of these systems (~\$50M) as indicated in the details of the RDS cost summaries.

Apart from the category of cryogenics, the costs of all other systems listed above (i.e., 1.4.2.3 vacuum through 1.4.2.11 safety systems) were estimated at \$97M for Design A(84). This total amount was less than 5% of the total costs of the RDS estimate.

Approximate estimates of the cost variations of these systems were investigated for each magnet style A(84), B(84), and C(84); however since detailed designs did not exist and the cost variations among the three magnet styles appeared relatively small, it was decided to utilize the costs as determined for Design A(84) for the three RDS magnet systems. This decision was consistent with the purpose of the RDS which was to determine the overall technical and economic feasibility of the SSC for the potential magnet systems under consideration at that time. The results are summarized below.

Table III-10
Reference Design Study
Other Technical Systems Costs (FY84 M\$)

	<u>A (84)</u>	<u>B (84)</u>	<u>C (84)</u>
1.4.2.2 Cryogenics	123.9	115.9	158.2
1.4.2.3 Vacuum Through } 1.4.2.11 Safety Systems }	96.8	96.8	96.8
	_____	_____	_____
Total Costs	220.7	212.7	255.0

2. The Current Cost Evaluation

The purpose of this report is to specifically evaluate all systems costs that vary with magnet style. In concert with this purpose, the cost of other technical systems has been reviewed for each design style.

A detailed bottoms-up estimate was not done for each design style. In general, the RDS costs for Design A(84) were used as the cost baseline and appropriate components were scaled according to ring size or half-cell length.

For cryogenics, a new detailed estimate was made for Design Style C and D. The cryogenics design for Style C has changed significantly and now also utilizes 12 refrigeration stations.

A brief description of the scaling method is given for each technical system in the next sections. Table III-11 will be used in subsequent sections for systems that scale by the number of half-cells. Table III-11.2 through Table III-11.11 show the adjusted costs for the other technical systems elements. The last decimal digit of the table identification, (Table III-11."xx") corresponds to the last decimal digit of the WBS (1.4.2."xx") identifier for reference. The results are tabulated in Table III-12.

Table III-11
Scaling Factors for Other Technical Systems
(FY84 M\$)

	<u>RDS A(84)</u>	<u>A</u>	<u>B</u>	<u>D</u>	<u>C</u>	<u>C*</u>
Field B(T)	6.5	6.4	5.75	6.4	3.0	3.0
Circumference(km)	90	92	100	92	172	172
No. Half Cells	783	792	792	792	1332	1332
Half Cell						
Scaling Factor	1.0	1.01	1.01	1.01	1.70	1.70
Circumference						
Scaling Factor	1.0	1.02	1.11	1.02	1.90	1.90

1.4.2.2 Cryogenics Systems

The major components of the cryogenics systems are the refrigerator compressor systems and their associated liquid and gas storage systems, cryogenic piping, and controls. Cryosystems for production magnet testing and special equipment for tunnel magnet testing are also included. The overall costs for these systems for Design D is currently estimated at \$136M (FY84\$).

As noted above, all magnet design styles now specify systems that utilize the same number of refrigerator stations. Assuming that Design C incorporates an additional 20K pipe for shield cooling and the standard 150% multiplier is applied to all of the designs uniformly, the A.C. power consumption for the various designs will be as follows:

<u>Design Style</u>	<u>A</u>	<u>B</u>	<u>D</u>	<u>C</u>	<u>C*</u>
A.C. Power (MW)	26.2	29.6	32.3	25.1	33.0

Each of the cryogenic systems designs for the above magnet systems are different in conception. For example they have different amounts of liquid storage relative to the total inventory; some have liquid air plants.

The costs for Designs A and B are taken from the RDS. The costs for Designs D and C result from new estimates submitted by the laboratories with adjustments to rectify omissions. The costs for C* is on the same basis as C with compressors and refrigerators scaled according to A.C. power.

The overall costs for each system are presented in Table III-11.2 below. Within this summary, Design C includes a warm gas return header and controls. A production test facility is also included for each system.

Table III-11.2
Cryogenics Systems Cost (FY84 M\$)

	RDS A(84)	A	B	D	C	C*
Total	123.9	129	121	136	137	150

1.4.2.3 Vacuum System

The main ring vacuum system costs are in three main subsystems:

- a) the warm bore system for the six straight sections
- b) the cold beam tube system within the main ring magnets
- c) the cryostat insulating vacuum system

The warm bore system is the same for all designs. The cold beam tube system is dominated with equipment that resides at the spool pieces and the costs are proportional to the number of half cells in the main ring. The insulating vacuum category includes a large number of turbo-carts for installation and emergency pumping and valves and gauges proportional to the number of half cells. Thus the insulating vacuum costs will scale as the number of half cells for 2-in-1 designs and 1-in-1 designs will have an additional factor of 2.

Table III-11.3
Vacuum System Cost (FY84 M\$)

	RDS A(84)	A	B	D	C	C*
Warm Bore	3.40	3.40	3.40	3.40	3.40	3.40
Cold Bore (scaling)	4.24	4.28 (1.01)	4.28 (1.01)	4.28 (1.01)	7.20 (1.70)	7.20 (1.70)
Cryostat (scaling)	4.58	4.62 (1.01)	9.25 (2.02)	9.25 (2.02)	7.80 (1.70)	15.60 (3.40)
	—	—	—	—	—	—
Total	12.22	12.30	16.93	16.93	18.40	26.20

1.4.2.4 Main Power Supplies

The power supply systems for the various magnet types are not directly comparable. Designs A, B, and D have the same design that is similar to the design described in the RDS. Design C is considerably more complicated, with four main supplies per aperture, and per sector. The additional cost is somewhat compensated for by a reduction to four power supply sectors in Design C and C*. This appears feasible due to the lower inductance of the type C magnet, although voltages during quench or dump and ramp rate limitations must be considered carefully.

The power supply systems have been analyzed in four subsystems:

1. Power Supplies
2. Energy Extraction: Dump resistors and switches.
3. Quench protection: An analysis for the RDS indicated that a passive scheme with one diode per magnet would cost about the same as an active scheme with one heater per half cell. The type C design has four diode packs per half cell, which is equivalent. We believe this subsystem is comparable in cost to the system evaluated in the RDS.
4. Software.

The results of the analysis are provided in the following table.

Table III-11.4
Main Power Supply Cost
(FY84 M\$)

	<u>RDS A(84)</u>	<u>A</u>	<u>B</u>	<u>D</u>	<u>C</u>	<u>C*</u>
Power Supplies	9.9	9.9	9.9	9.9	11.1	11.1
Energy Extr.	3.4	3.4	3.4	3.4	3.4	3.4
Quench Prot.	6.4	6.4	6.4	6.4	6.4	6.4
Software	<u>1.3</u>	<u>1.3</u>	<u>1.3</u>	<u>1.3</u>	<u>1.3</u>	<u>1.3</u>
Total	21.0	21.0	21.0	21.0	22.2	22.2

The overall difference of \$1.2M is considered smaller than the uncertainty in the estimate. The RDS total estimate of \$21.0M is therefore used for all magnet design styles in the summary Table III-12.

1.4.2.5 Correction Element Power Supplies and Quench Protection

The power supply sub-systems of this category include the following:

1. Correction Dipole Elements
2. Higher Order Elements
3. Matching Sextupole Corrections
4. Persistent Current Correction

In the RDS, 900 dipole corrector power supplies were assumed for 783 half cells. The difference, i.e., 117 units, were used at special locations such as straight sections. The 783 units will scale as the number of half cells.

For higher order elements, the RDS assumed 24 circuits per aperture per correction type. These are the same for all designs.

The matching section sextupoles are no longer needed. The persistent current correctors are not required for C or C*; the same costs should apply for A, B, and D as described in the RDS.

Table III-11.5
Correction Element Power Supply Costs
(FY84 M\$)

	RDS <u>A(84)</u>	<u>A</u>	<u>B</u>	<u>D</u>	<u>C</u>	<u>C*</u>
Dipole half-cell corr. (scaling)	7.40	7.50 (1.01)	7.50 (1.01)	7.50 (1.01)	12.60 (1.70)	12.60 (1.70)
Misc. Dipole corr.	1.10	1.10	1.10	1.10	1.10	1.10
High Order Elements	2.06	2.06	2.06	2.06	2.06	2.06
Matching Sextupoles	2.24	0	0	0	0	0
Persistent Current	.58	.58	.58	.58	0	0
Total	13.37	11.24	11.24	11.24	15.76	15.76

1.4.2.6. Radio Frequency System

The voltage required for the rf system is determined by the following:

1. The amount of voltage required to accelerate to full energy in 1,000 seconds. This implies a factor of ~2 more voltage for the Design C ring by the reduced revolution frequency (20 MV for A and D and 40 MV for C and C*).
2. The stability of the beam against coupled bunch oscillation modes. Preliminary studies from the SSC Task Force on Operations and Commissioning indicate that Design C will require 80 MV at injection to provide the larger momentum spread required for stability. This is eight times the required voltage for the higher field Designs A, B, and D.

Since Designs A and D require 20 MV for acceleration, the 80 MV required for stability will increase the rf costs by a factor of 4 for the Designs C and C*.

Table III-11.6
Radiofrequency Costs
(FY84 M\$)

	<u>RDS</u> <u>A(84)</u>	<u>A</u>	<u>B</u>	<u>D</u>	<u>C</u>	<u>C*</u>
Total	7.73	7.7	9.3	7.7	30.9	30.9

1.4.2.7 Injection System

There is no significant difference in the injection costs for the various designs. The estimated cost is \$2.94 M.

It should be pointed out the the bending magnets in the injection straight sections are for two purposes:

- a. to reduce accidental losses in the superconducting magnets.
- b. to separate the beams sufficiently to insert kicker magnets.

If the protection against accidental loss is not necessary, then there would be a cost difference between 1-in-1 and 2-in-1 designs.

1.4.2.8 The Abort System

The main considerations for the abort system are the increased beam levels and slower revolution frequency of the low field designs. This will increase the cost of the beam dump and the kicker magnets and their associated power supplies as follows:

Table III-11.8
Abort System Costs
(FY84 M\$)

	<u>RDS</u> <u>A(84)</u>	<u>A</u>	<u>B</u>	<u>D</u>	<u>C</u>	<u>C*</u>
Beam Dump and Pulsed Magnet (scaling)	3.35	3.38 (1.01)	3.38 (1.01)	3.38 (1.01)	5.69 (1.70)	5.69 (1.70)
Other Components	<u>4.67</u>	<u>4.67</u>	<u>4.67</u>	<u>4.67</u>	<u>4.67</u>	<u>4.67</u>
Total	8.02	8.10	8.10	8.10	10.40	10.40

1.4.2.9 Beam Instrumentation

Most of the cost of beam instrumentation is in the beam position detectors. All of the costs of these units except for the software and electronics development will scale as the number of half cells.

The radiation detectors will also scale as the number of half cells except for those required for special locations (~20%). We assume that wire scanners and other special devices do not scale with the number of cells. The results are summarized below.

Table III-11.9
Beam Instrumentation Costs
(FY84 M\$)

	<u>RDS</u> <u>A(84)</u>	<u>A</u>	<u>B</u>	<u>D</u>	<u>C</u>	<u>C*</u>
Scaled elements	4.74	4.79	4.79	4.79	8.06	8.06
(scaling factor)		(1.01)	(1.01)	(1.01)	(1.70)	(1.70)
Other elements	<u>2.26</u>	<u>2.26</u>	<u>2.26</u>	<u>2.26</u>	<u>2.26</u>	<u>2.26</u>
Total	7.0	7.05	7.05	7.05	10.32	10.32

1.4.2.10 Controls

The control system is composed of the following elements:

1. Host computer
2. Control consoles
3. Sector computers
4. Microprocessors
5. Interface crates and controllers
6. Software
7. Ring information network

The host computer, consoles, sector computers and software do not scale with magnet design. The micro-processor units, interface crates and controllers will scale by the number of half cells. The ring information network will scale as the ring circumference. The results are tabulated below.

Table III-11.10
Controls
(FY84 M\$)

	<u>RDS A(84)</u>	<u>A</u>	<u>B</u>	<u>D</u>	<u>C</u>	<u>C*</u>
Micro-pro, crates, controllers (scale)	4.89	4.94 (1.01)	4.94 (1.01)	4.94 (1.01)	8.31 (1.70)	8.31 (1.70)
Ring information network (scale)	1.29	1.32 (1.02)	1.43 (1.11)	1.32 (1.02)	2.45 (1.90)	2.45 (1.90)
All other systems	<u>13.10</u>	<u>13.10</u>	<u>13.10</u>	<u>13.10</u>	<u>13.10</u>	<u>13.10</u>
Total	19.28	19.36	19.47	19.36	23.86	23.86

1.4.2.11 Personnel Protection System

This personnel protection system consists of monitors, controls, and equipment that are associated with the various entrance and access points around the main ring. While the precise rules for access spacing are not well established, we have assumed that the number of access regions will scale as the size of the ring mainly due to safety considerations.

Table III-11.11
Personnel Protection System Costs
(FY84 M\$)

	<u>RDS A(84)</u>	<u>A</u>	<u>B</u>	<u>D</u>	<u>C</u>	<u>C*</u>
Personnel Protection (scaling)	5.32	5.43 (1.02)	5.90 (1.11)	5.43 (1.02)	10.11 (1.90)	10.11 (1.90)

1.4.2.2 through 1.4.2.11 Cost Summary of Other Technical Systems

The results of the previous ten subsections are summarized below in Table III-12. The first column shows the 1984 RDS estimate for comparison. All costs are expressed in FY1984M\$.

Table III-12
Other Technical Systems Cost Summary
(FY84 M\$)

STYLE:	RDS A(84)	A	B	D	C	C*
2 CRYOGENICS	123.9	129.0	121.0	136.0	137.0	150.0
3 VACUUM SYSTEMS	12.2	12.3	16.9	16.9	18.4	26.2
4 MAIN POWER SUPPLIES	21.0	21.0	21.0	21.0	21.0	21.0
5 CORRECTION POWER SUPPLIES	13.4	11.2	11.2	11.2	15.8	15.8
6 RF SYSTEM	7.7	7.7	9.3	7.7	30.9	30.9
7 INJECTION SYSTEM	2.9	2.9	2.9	2.9	2.9	2.9
8 ABORT SYSTEM	8.0	8.1	8.1	8.1	10.4	10.4
9 INSTRUMENTATION	7.0	7.0	7.0	7.0	10.3	10.3
10 CONTROLS	19.3	19.4	19.5	19.4	23.9	23.9
11 SAFETY SYSTEMS	5.3	5.4	5.9	5.4	10.1	10.1
TOTAL "OTHER" TECH SYS COST	220.7	224.1	222.9	235.7	280.6	301.4

C. Conventional Systems Costs and Analysis

In order to provide a reasonable basis for conventional systems costs in the RDS, a median site was created by utilizing main ring sectors taken from four differing geological regions (see Fig. 1). This method allowed for the development of representative cost estimates for tunneling in the absence of a specific site, and served to illustrate tunneling techniques customarily employed for each of the various types of conditions. It was envisioned that segments of the tunnels were cut through hard rock (igneous, limestone, or hard sandstone), through soft clayey silt with sand and gravel, and through areas where the land had first been excavated, the tunnel constructed and then covered with soil. Precast concrete pipe, cast-in-place concrete liners, or segmented precast concrete liners were used, as appropriate. Figure 2 illustrates the variation in surface elevation of the various geological sectors of the median site. The median site was developed for the 6.5T RDS-A(84) magnet design. The method of extending the median site to other sizes is described in Section C-2.

1. "Median Site" in the Reference Designs Study

The north geological sector in the 56 mile ring in the RDS extends for 17 miles and varies from an elevation of 922 ft at mile 11.6 to 831 ft at mile 22. The beam dump is at mile 18.6, at depth of 30 ft, and collision hall 2 is at the eastern end of this sector at a depth of 17 ft. Surface deposits in this sector are sandy, silty clay to a depth of 10 ft, with some boulders up to 1.5 ft diameter. Layers of soft and hard rock can be found in this sector. Rock tunneling (Type I) is needed for the first 12 miles. This is bored with a machine and lined with shotcrete reinforced with welded wire fabric. Cut-and-cover tunneling in soft shale is needed in the last 5 miles of this sector and precast concrete pipe is used for this portion of tunnel.

The east sector extends for 13 miles and consists of sand and clayey silt near the surface, with sand and gravel increasing with depth. Surface elevation varies from 900 to 832 ft and, at collision hall 4, the surface elevation is 880 ft. Soft ground tunneling (type II) is assumed for this area, and the tunnel is formed from a precast segmented concrete lining.

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Fig. 1. The SSC main ring tunnel types in relation to the four hypothetical geological sectors and their composition. Mileage around the perimeter, clock position and the position of each collision hall are also indicated for a ring of 56 miles circumference.

Fig. 2. Profile of assumed surface topography around the circumference of the main ring tunnel indicating the relationship between circumferential distance in miles and clock position and their joint relationship to main geological features and tunnel construction methods. Positions of the collision halls, rf acceleration section, injection to the SSC main ring, and beam dump are given to illustrate the nature of the overlying strata at these points (and thus assumed elevations). These features impact on construction costs and methods.

The southern and western sectors extend 25 miles through hard clay and glacial till to a depth of 50 ft; the trenches in soil are stable, with near-vertical cut slopes, at depths up to 60 ft. Cut-and-cover tunneling (type III) is used for these sectors and precast concrete pipe is used for the tunnel.

The ring is interrupted at six locations by interaction regions (where the beams collide for physics experiments) and by three utility straight sections. Two of the former areas are left undeveloped to allow for future expansion of experimental opportunities, while the other four are sites of the experimental halls and associated facilities. The complex of buildings at each interaction region is designed to allow the transport and assembly of experimental equipment, and to provide for the undertaking of long-term experiments. The utility straight sections contain the rf accelerating cavities, the injection system for the incoming beam, and the beam abort apparatus. Appropriate buildings are associated with each of these functions, and equipment access to the tunnel is provided.

2. Extension of the "Median Site"

The Median Site concept was developed to provide a technical baseline for conventional systems in the RDS. The A/E firm, Parsons Brinckerhoff, prepared this model so that civil, structural, electrical and mechanical engineers could do a design study under "almost realistic" conditions. As described earlier, the model was done for a 56 mile ring, employing 6.5T magnets, and extended to larger circumferences as required by the utilization of lower field magnets.

In order to illustrate how the median site can be extended, another illustration has been created. Assuming that the same proportions of geological conditions prevail, Figure 3 shows how the varying segments might appear. The length of such segments are shown as in Table III-13.

CONDITIONS:

GEOLOGICAL SECTOR		MATERIAL	METHOD
North	Type I	Hard Rock Igneous, Limestone Hard Sandstone	Shotcrete Lining (10 ft. I.D.)
North	Type III	Soft Shale	Cut & Cover Precast Pipe (9 ft. I.D.)
East	Type II	Clayey Silt with Sand & Gravel	Precast Segmental Lining, Softground Tunneling (10 ft. I.D.)
South	Type III	Stiff to Hard Clay	Cut & Cover Precast Pipe (9 ft. I.D.)
West	Type III	Glacial Till	Cut & Cover Precast Pipe (9 ft. I.D.)

Fig. 3. Extension of Median Site Concept to Three Ring Sizes.

Table III-13
Length of Typical Tunnel Segments
 (feet)

<u>-Design Style</u>	<u>A, D</u>	<u>B</u>	<u>C, C*</u>
Type I	64,806	70,442	121,160
Type II	70,722	76,872	132,220
Type III	<u>166,317</u>	<u>180,779</u>	<u>310,940</u>
	301,845	328,093	564,320
Circumference (miles)	57	62	107

3. Technical Considerations

In the RDS, a 9 or 10 ft internal diameter tunnel is assumed to lie in a horizontal plane at an average depth of 40 ft below the surface. The superconducting magnets and other beam handling devices are positioned and aligned in the tunnel. Vacuum pipes, cryogenic systems, power supplies, and instrumentation services must be provided. Space in the tunnel must also be allowed for suitable personnel and equipment transporters. In addition, adequate aisle space must be provided for the people who will work on technical components in the tunnel.

Recent work at the CDG has examined two tunnel cross sections. The arrangement of equipment, piping, magnets, transporters and working space can be seen in Figs. 4 and 5. The tunnel shell in the example is shotcrete lined, with welded wire fabric reinforcement, typical of hard-rock tunneling construction. A poured concrete floor results in a level, 8.3 ft wide working surface within a 9-10 foot circular cross section. Floor drainage is installed. Lighting fixtures and a cable tray are anchored in the roof and conduit racks are fixed to the wall on the magnet side of the tunnel. These last items support lines for compressed gas, 480 V electrical cable, water supply and return lines, and a warm-helium gas return line. Periodically a signal area containing a telephone, signaling system, fire pull alarm, and space for monitoring instrumentation is located on the wall.

Normal and purging ventilation are provided, complete with the necessary fans, ducts, outlets and controls. Ventilation is an important feature in the tunnel due both to its length and because of the large numbers of people working at a variety of activities during the construction phase. An

Fig. 4. Tunnel Cross Section Magnet Design D

Fig. 5. Tunnel Cross Section Magnet Design C

additional need for the ventilation is to replenish the atmosphere quickly if a large volume of helium were accidentally vented into a section of the tunnel during tests or operations. Matters of tunnel access for installation, and servicing coupled with safety consideration lead to using tunnel cross sections for this study similar to those used in the RDS.

4. Unit Costs

A) Tunnel

The A/E firm developed unit costs for the three different tunnel types by a careful evaluation of the appropriate method of construction in each case. By assembling information on materials and labor requirements, rate of advance, etc., Parsons Brinckerhoff provided a basis for a cost estimate of the tunnels. This information was combined with the costs for access shafts, exits, auxiliary buildings, etc., to form an overall cost for the collider ring.

Recently, another A/E firm, RTK (Raymond Kaiser Engineers, Tudor Engineering, Keller & Gannon-Knight), has been engaged. One of their first tasks was to consider the cost of tunnels such as those used in the RDS. RTK chose to examine the data from a variety of completed tunnels. For the analysis, case histories and data on 84 tunnels used by the U.S. National Committee on Tunneling Technology (USNCTT) were used. The raw USNCTT data were originally analyzed for the USNCTT by Don Rose, a member of the RTK team. The USNCTT data are drawn nationwide and represent a recent study published in June, 1985. The USNCTT cost data have been normalized and are the final as-built cost including all paid claims and change orders.

- a. Hard Rock Tunnels (Type I). The USNCTT weighted average cost for hard rock tunnels excavated by tunnel boring machines (TBM's) is \$323/CY. The USNCTT costs are all normalized to July, 1982, costs and have been increased by 3.7% to compare to 1984 costs used in the RDS. This USNCTT cost is given in \$/CY and must be converted to \$/LF for comparison with the RDS. For an 11-foot outside diameter hard rock TMB tunnel, the USNCTT weighted average cost, updated to the first quarter of 1984, is \$1180/LF.

- b. Soft Ground Tunnels (Type II) The USNCTT weighted average cost for soft ground tunnels is \$300/CY. The USNCTT costs are all normalized to July, 1982, costs and have been increased by 3.7% to compare to the RDS. This USNCTT cost is given in \$/CY and must be converted to \$/LF for comparison with the RDS. For an 11-foot outside diameter soft ground tunnel, the USNCTT weighted average cost updated to the first quarter of 1984, is \$1,095/LF.
- c. Cut and Cover Costs (Type III) The scheme considered an open cut about 45 feet deep with steep side slopes open for a relatively short time. These slopes are assumed stable in all weather conditions the year around, provided no groundwater problems exist. An unusually wide bottom width is provided to allow special vehicles to carry precast pipe alongside the finished work. The precast pipe would be carried from the plant to a point near to the excavation, a distance of up to several tens of miles. The excavation work lends itself to mass production work using innovative excavators, or conventional scrapers and tractors. Different bidders will no doubt select different methods and equipment. For this report, the cut/cover scheme shown in the RDS has been evaluated by an RTK study with reference to federal, state and private agencies for costs comparable of work done using conventional equipment. RTK believes the cut/cover tunnel will cost \$873/LF (first quarter 1984 prices) for the example studied. The average cost for all cut and cover costs (Type III) described is estimated as \$780/LF.
- d. Summary The recent evaluation by RTK can be conveniently compared to the earlier work by looking at Table III-14. There is excellent agreement between these independent estimates by experienced A/E firms.

Table III-14
Unit Cost Estimates for Tunnel Types
(\$ Per Linear Foot)

	<u>RDS</u>	<u>RTK</u>	<u>CDG</u> <u>Value</u>
Main Ring Tunnel - Type I	1,150	1,167; 1,180	1,160
Main Ring Tunnel - Type II	1,100	1,095	1,100
Main Ring Tunnel - Type III, avg	<u>755</u>	<u>780</u>	<u>770</u>
Weighted Avg., Types I, II, III	920	-	930

The total Conventional Facility costs for the Collider Ring WBS 1.4.1 are shown for the five designs in Table III-15.

B) Ramps/Slots

There are several differences that arise from the choice of magnetic field and corresponding style of magnet. The different circumferences have been addressed earlier, although there are additional items that must be considered. First of all, the allowance for site infrastructure (such as roads, utilities) must scale with the circumference. In addition, the number of exits will be increased in proportion to the increased tunnel length, thereby keeping fixed the distance between exits within the tunnel.

In contrast to the position taken during the RDS, the same number of refrigerator/compressors stations (12) will be used in all the configurations. This will change the distance between stations from 5 miles in Design A to almost 9 miles in Design C.

Because it is envisioned that the very long superferric magnets will be assembled at four places adjacent to the collider ring, a number of adjustments must be made to the plan for a campus works area, and to the approach used for getting the 380 ft magnets into the ring. One might expect to need more works building space due to the assembly areas being dispersed.

The predominant effect of the long magnets is to require access ramps or slots at four locations to move assembled magnets down into

Table III-15
Conventional Facility Cost Comparison Summary
(FY 84K\$)

MAGNET STYLE:	A	B	D	C	C*
PARAMETER VALUES:					
FIELD LEVEL, T	6.40	5.75	6.40	3.00	3.00
CIRCUMFERENCE, MI	57.17	62.14	57.17	106.88	106.88
(CIRCUMFERENCE, KM)	92.00	100.00	92.00	172.00	172.00
CONVENTIONAL FACIL. SYSTEMS,					
.1 LAND IMPROVEMENTS	15,300	16,631	15,300	28,605	28,605
2.1 TUNNEL TYPE I	88,038	95,693	88,038	164,592	164,592
2.2 TUNNEL TYPE II	90,249	98,097	90,249	168,726	168,726
2.3 TUNNEL TYPE III	154,292	167,709	154,292	288,459	288,459
2.4 TUNNEL (OTHER ELEMENTS) (CRYO, BM DUMP, RF, ETC)	13,927	13,927	13,927	13,927	13,927
.3 CRYOGENIC FACILITIES	7,998	7,998	7,998	7,998	7,998
.4 SUPPORT BUILDINGS	1,750	1,902	1,750	3,272	3,272
.5 UTILITIES	38,822	42,198	38,822	72,581	72,581
.6 ACCESS SHAFTS	0	0	0	13,540	13,540
TOTAL CONVEN. FACILITIES	410,376	444,154	410,376	761,700	761,700

the tunnel. RTK has done a study of this approach using a depth appropriate for soft ground tunnels. In FY84 dollars they have established a cost of \$5.7M each for a ramp scheme and \$3.4M each for a vertical slot scheme.

D. Systems Engineering

The Systems Engineering (EDI for Technical Systems and AE/CM for the Conventional Facilities) are described below for the Magnet Systems, Other Technical Systems, and Conventional Facilities.

1. Magnet Systems

During the RDS cost estimate analysis, a very thorough and careful development of the Engineering, Design, and Inspection tasks and costs was done for the dipole magnet systems. Although a special case, the main ring magnet system - by far the largest technical subsystem - is not without precedent. The Tevatron magnet design and fabrication is a useful model for this undertaking; in fact, the basic principles and mechanical structure of the SSC designs closely follow those of the Tevatron magnet system. The number of units - about 4,000 in the SSC Reference Design A case - is not vastly different than that for the Tevatron, which had approximately 1,000 dipole magnets. Furthermore, an adequate R&D program prior to the SSC construction phase is assumed. One result of this R&D phase will be the production of a significant number of magnets made with full-scale tooling, i.e., the same tooling as will be used in the first production. Thus, it is assumed herein that, at the start of construction, the bulk of the tooling and manufacturing methods will be well worked out and needs for inspection manpower will be minimized by careful planning and use of specialized tooling and analysis equipment. These assumed conditions applied in many ways to the construction stage of the Tevatron, so the magnet production, testing and installation phase of the Tevatron can be used as a model for estimating the design costs.

In the RDS, a manpower analysis was made for the Tevatron experience according to the following tasks:

- Engineering

- Design and Drafting

- Liaison (shops, manufacturers, vendors, etc.)

Inspection, testing and monitoring
Quality assurance
Documentation
Office and staff support

Appropriate improvements or modifications were made to the Tevatron manpower levels as suggested by their experience. These manpower levels were then extrapolated to the scale of the SSC project. The resulting total level of effort was then represented as a percentage of the total dipole magnet construction cost (10% for EDI resulted). For the current comparison study, the same EDI value (10%) is used for the dipole and quadrupole construction, and values of 15, 20, 25, and 20% are used respectively for magnet tooling, special devices/spools, special magnets/insertions, and installation respectively.

The overall percentage values used for each of the various magnet designs, and the resulting EDI costs for the construction program are tabulated in Table III-16. The net effective weighted average EDI percentage for Magnet Systems is indicated at the last line of the table.

Table III-16
Magnet Systems EDI
(FY84 K\$)

(WBS) 1.4.2.1.	STYLE: EDI	A PCT		B PCT		D PCT		C PCT		C* PCT	
1 TOOLING		41,497	15	23,738	15	41,497	15	21,810	15	21,810	15
2 DIPOLE MAGNETS		573,837	10	642,937	10	646,421	10	278,358	10	384,744	10
3 QUADRUPOLE MAGNETS		38,341	10	54,346	10	42,397	10	19,048	10	24,762	10
4 SPEC. DEVICES/SPOOLS		37,543	20	75,818	20	67,874	20	84,667	20	110,067	20
5 SPEC. MAGNETS/INSERTIONS		14,286	25	14,286	25	14,286	25	14,286	25	14,286	25
6 INSTALLATION & SURVEY		26,750	20	58,765	20	40,833	20	23,306	20	34,286	20
TOTAL ADJUSTED MAG SYS		732,254		869,890		853,309		441,473		589,953	

1.4.2.1. EDI COSTS

1 TOOLING	6224.6	3560.7	6224.6	3271.4	3271.4
2 DIPOLE MAGNETS	57383.7	64293.7	64642.1	27835.8	38474.4
3 QUADRUPOLE MAGNETS	3834.1	5434.6	4239.7	1904.8	2476.2
4 SPEC. DEVICES/SPOOLS	7508.6	15163.7	13574.8	16933.3	22013.3
5 SPEC. MAGNETS/INSERTIONS	3571.4	3571.4	3571.4	3571.4	3571.4
6 INSTALLATION & SURVEY	5350.0	11753.0	8166.6	4661.1	6857.1
TOTAL EDI COST:	83872.4	103777.2	100419.3	58177.9	76663.9
OVERALL EDI PERCENTAGE:	11.5	11.9	11.8	13.2	13.0

2. Other Technical Systems

The general design of the SSC closely resembles large accelerator systems now in existence. Many of the components and subsystems required for the SSC are very similar to existing components and subsystems. For example, the radio-frequency system for the SSC main ring is currently visualized as the same system used for the PEP collider ring except that only about 2/3 of the rf cavities are required for most of the SSC designs under consideration. Apart from magnets and cryogenics, the specifications for most systems are sufficiently understood that the EDI can be estimated with confidence based on past experience.

Experience from other relatively large accelerator projects (PEP & Tevatron) indicates that the EDI for technical components is ~25% of construction costs. This should be compared with EDI rates of all SSC systems (except magnets and cryogenics) which average 24% for the SSC. Because of their considerably larger cost scale, the magnet systems EDI are expected to have a lower percentage of construction cost as shown by the analysis in the preceding section. The cryogenics EDI of 15% reflects an average of two components: a large refrigerator purchase (~\$60M) for which designs exist and associated cryogenic systems which have an estimated EDI of ~25%.

A summary of the resulting estimated EDI for other technical systems of the SSC is provided in Table III-17.

Table III-17
Other Technical Systems EDI
(FY84 M\$)

(WBS)	STYLE: EDI	A PCT	B PCT	D PCT	C PCT	C* PCT
1.4.2. CONSTRUCTION COSTS:						
2 CRYOGENICS		129.0 15	121.0 15	136.0 15	137.0 15	150.0 15
3 VACUUM SYSTEMS		12.3 25	16.9 25	16.9 25	18.4 25	26.2 25
4 MAIN POWER SUPPLIES		21.0 20	21.0 20	21.0 20	21.0 20	21.0 20
5 CORRECTION POWER SUPPLIES		11.2 20	11.2 20	11.2 20	15.8 20	15.8 20
6 RF SYSTEM		7.7 25	9.3 25	7.7 25	30.9 25	30.9 25
7 INJECTION SYSTEM		2.9 25	2.9 25	2.9 25	2.9 25	2.9 25
8 ABORT SYSTEM		8.1 25	8.1 25	8.1 25	10.4 25	10.4 25
9 INSTRUMENTATION		7.0 25	7.0 25	7.0 25	10.3 25	10.3 25
10 CONTROLS		19.4 30	19.5 30	19.4 30	23.9 30	23.9 30
11 SAFETY SYSTEMS		5.4 25	5.9 25	5.4 25	10.1 25	10.1 25
TOTAL "OTHER" TECH SYSTEMS COSTS:		224.1	222.9	235.7	280.6	301.4
1.4.2. EDI COSTS:						
2 CRYOGENICS		19.4	18.1	20.4	20.6	22.5
3 VACUUM SYSTEMS		3.1	4.2	4.2	4.6	6.5
4 MAIN POWER SUPPLIES		4.2	4.2	4.2	4.2	4.2
5 CORRECTION POWER SUPPLIES		2.2	2.2	2.2	3.2	3.2
6 RF SYSTEM		1.9	2.3	1.9	7.7	7.7
7 INJECTION SYSTEM		.7	.7	.7	.7	.7
8 ABORT SYSTEM		2.0	2.0	2.0	2.6	2.6
9 INSTRUMENTATION		1.8	1.8	1.8	2.6	2.6
10 CONTROLS		5.8	5.8	5.8	7.2	7.2
11 SAFETY SYSTEMS		1.4	1.5	1.4	2.5	2.5
TOTAL "OTHER" TECH SYS		42.5	43.0	44.7	55.8	59.7
OVERALL EDI PERCENTAGE:		19.0	19.3	19.0	19.9	19.8

3. Conventional Systems

The AE/CM services for the SSC Conventional Systems in the Reference Designs Study were estimated by the AE/CM firm of Parsons Brinckerhoff (PB). Specifically the AE/CM services included:

- Project Management and coordination
- Quality Assurance/Control
- Site Manager
- Project Administration
- Reporting
- Cost and Schedule Control
- Contract Administration
- Title I Design and Report
- Title II Design
- Coordination with Technical Facilities Interface
- Inspection and Record Keeping
- Construction Management and Administration
- Construction Safety and Security
- Systems Operational Manuals

In the RDS, an across-the-board estimate of 16.0% of construction was developed to cover the AE/CM services listed above independent of ring size.

Discussions were held concerning the possible variation of the AE/CM percentage with ring size in view of the repetitive nature of the design elements for the collider tunnel. An alternative perspective is that there are many nuances in underground construction that require continuous design attention. In particular without detailed site specific information it would not be prudent to assume a reduced AE percentage.

For this study the AE/CM estimate is determined by the same percentage of construction (16%) as developed for the RDS. Table III-18 shows the AE/CM costs for each of the major systems of the conventional facilities.

Table III-18
Conventional Systems AE/CM (EDIA)
(FY84 K\$)

STYLE:		A		B		D		C		C*	
AE/CM PERCENT:		PCT		PCT		PCT		PCT		PCT	
PARAMETER VALUES:											
FIELD LEVEL, T		6.40		5.75		6.40		3.00		3.00	
CIRCUMFERENCE, MI		57.17		62.14		57.17		106.88		106.88	
(CIRCUMFERENCE, KM)		92.00		100.00		92.00		172.00		172.00	
(WBS)											
1.4.1 CONVENTIONAL FACIL. SYSTEMS, COSTS:											
.1 LAND IMPROVEMENTS		15,300	16	16,631	16	15,300	16	28,605	16	28,605	16
.2.1 TUNNEL TYPE I		88,038	16	95,693	16	88,038	16	164,592	16	164,592	16
.2.2 TUNNEL TYPE II		90,249	16	98,097	16	90,249	16	168,726	16	168,726	16
.2.3 TUNNEL TYPE III		154,292	16	167,709	16	154,292	16	288,459	16	288,459	16
.2.4 TUNNEL (OTHER ELEMENTS) (CRYO, BM DUMP, RF, ETC)		13,927	16	13,927	16	13,927	16	13,927	16	13,927	16
.3 CRYOGENIC FACILITIES		7,998	16	7,998	16	7,998	16	7,998	16	7,998	16
.4 SUPPORT BUILDINGS		1,750	16	1,902	16	1,750	16	3,272	16	3,272	16
.5 UTILITIES		38,822	16	42,198	16	38,822	16	72,581	16	72,581	16
.6 ACCESS SHAFTS		0	16	0	16	0	16	13,540	16	13,540	16
TOTAL CONVEN. FACILITIES		410,376		444,154		410,376		761,700		761,700	
AE/CM COSTS:											
.1 LAND IMPROVEMENTS		2,448		2,661		2,448		4,577		4,577	
.2.1 TUNNEL TYPE I		14,086		15,311		14,086		26,335		26,335	
.2.2 TUNNEL TYPE II		14,440		15,695		14,440		26,996		26,996	
.2.3 TUNNEL TYPE III		24,687		26,833		24,687		46,153		46,153	
.2.4 TUNNEL (OTHER ELEMENTS) (CRYO, BM DUMP, RF, ETC)		2,228		2,228		2,228		2,228		2,228	
.3 CRYOGENIC FACILITIES		1,280		1,280		1,280		1,280		1,280	
.4 SUPPORT BUILDINGS		280		304		280		524		524	
.5 UTILITIES		6,212		6,752		6,212		11,613		11,613	
.6 ACCESS SHAFTS		0		0		0		2,166		2,166	
TOTAL AE/CM COSTS		65,660		71,065		65,660		121,872		121,872	
OVERALL AE/CM PERCENTAGE:		16.0		16.0		16.0		16.0		16.0	

E. Contingency Analysis

1. Magnet Systems

The following contingencies were estimated for the magnet Design Styles in the RDS.

<u>Magnet Style</u>	<u>Contingency</u>
A (84)	30%
B (84)	25%
C (84)	35%

These contingencies were applied to the total cost of each magnet system. The differences in contingency rate were based on the relative complexity of the systems and the knowledge of the design features at the time of the RDS.

Since the RDS, considerably more details of the designs have been developed and, in particular, a number of dipole models have been constructed and tested for each design. These model tests have served to verify design features and, in some cases, confirm performance projections.

A large part of the magnet costs is due to the superconducting cable. Experience in cable procurement in the U.S. over the past year, as well as, the cable costs for the HERA project in Hamburg have served to confirm the unit costs projected in the RDS.

In view of the above information a more detailed contingency analysis is provided in this report. The contingency has been estimated for each WBS level 7 element of the dipole magnets. The details are shown in Tables D-1 through D-5 of Appendix D. For example, the contingency for materials costs is estimated at 10% for Superconductor and 15% for Yoke laminations and Helium and Vacuum containment systems. Most other material costs are estimated at 25%. The labor estimates in all level 7 components have a 35% contingency. These same contingency percentages are applied uniformly to each of the five magnet design styles of this report. Because of the different costs of components for each level 7 subsystem, this results in an average dipole contingency that varies from 18.1% for Design A to 20.6% for Design C.

The other components of the magnet systems have higher contingencies. While quadrupole designs should be relatively straight forward, no development

models have been produced. A 25% contingency is applied to the quadrupoles. Spool pieces are extremely complex units and a higher contingency of 35% is applied.

Table III-19 provides a level 5 summary of the Magnet Systems Contingency. The top half of the Table shows the construction cost and contingency factor (%) for each of the magnet system components and for each of the 5 Design Styles. The lower half of the Table shows the resulting contingencies (K\$) for each element, as well as, an overall average contingency factor for each design style.

2. Other Technical Systems

The conceptual details of the subsystems included under this category have not changed substantially since the RDS. The same contingency factor percentages that were developed for the RDS are applied here. The results are summarized in Table III-20 for each subsystem in each of the five design styles. The construction cost and the contingency factor (%) are shown in the top half of the Table. The resulting contingency (in K\$) is provided in the lower half of the Table. The last line shows the average contingency for all subsystems.

3. Conventional Systems

In the RDS the contingency increased slightly with the collider ring circumference. This was done in part to provide a partial allowance for construction uncertainties associated with the access and installation concerns for using the long type C magnets. For example, the requirements for constructing and assembling the very long magnets is tied to tunnel access points and additional technical and assembly work space may be needed.

Another reason for the larger contingency used in conjunction with the larger circumference ring concerns an allowance to be made for design variations arising from the larger site. As the ring circumference increases, it is likely that additional support services facilities may need to be distributed around the collider ring.

Table III-19
Magnet Systems Contingency
(FY84 K\$)

	STYLE: CONTINGENCY:	A PCT	B PCT	D PCT	C PCT	C* PCT
1 TOOLING		41,497 30	23,738 30	41,497 30	21,810 30	21,810 30
2 DIPOLE MAGNETS		573,837 18.1	642,937 20.3	646,421 18.6	278,358 20.6	384,744 20.6
3 QUADRUPOLE MAGNETS		38,341 25	54,346 25	42,397 25	19,048 25	24,762 25
4 SPEC. DEVICES/SPOOLS		37,543 35	75,818 35	67,874 35	84,667 35	110,067 35
5 SPEC. MAGNETS/INSERTIONS		14,286 30	14,286 30	14,286 30	14,286 30	14,286 30
6 INSTALLATION & SURVEY		26,750 30	58,765 30	40,833 30	23,306 30	34,286 30
TOTAL ADJUSTED MAG SYS		732,254	869,890	853,309	441,473	589,953

2.1. CONTINGENCY COSTS

1 TOOLING	12449.2	7121.4	12449.2	6542.9	6542.9
2 DIPOLE MAGNETS	103864.4	130516.3	120234.4	57341.8	79257.2
3 QUADRUPOLE MAGNETS	9585.3	13586.4	10599.3	4761.9	6190.5
4 SPEC. DEVICES/SPOOLS	13140.0	26536.5	23755.9	29633.3	38523.3
5 SPEC. MAGNETS/INSERTIONS	4285.7	4285.7	4285.7	4285.7	4285.7
6 INSTALLATION & SURVEY	8025.0	17629.5	12249.9	6991.7	10285.7
TOTAL CONTINGENCY COST:	151349.6	199675.9	183574.5	109557.3	145085.3
OVERALL CONTING PERCENTAGE:	20.7	23.0	21.5	24.8	24.6

Table III-20
"Other" Technical Systems Contingency
(FY84 M\$)

(WBS)	STYLE: CONTING:	AGENCY:	A PCT	B PCT	D PCT	C PCT	C" PCT
1.4.2.	<u>CONSTRUCTION COSTS:</u>						
2	CRYOGENICS		129.0 20	121.0 20	136.0 20	137.0 20	150.0 20
3	VACUUM SYSTEMS		12.3 25	16.9 25	16.9 25	18.4 25	26.2 25
4	MAIN POWER SUPPLIES		21.0 20	21.0 20	21.0 20	21.0 20	21.0 20
5	CORRECTION POWER SUPPLIES		11.2 20	11.2 20	11.2 20	15.8 20	15.8 20
6	RF SYSTEM		7.7 20	9.3 20	7.7 20	30.9 20	30.9 20
7	INJECTION SYSTEM		2.9 30	2.9 30	2.9 30	2.9 30	2.9 30
8	ABORT SYSTEM		8.1 30	8.1 30	8.1 30	10.4 30	10.4 30
9	INSTRUMENTATION		7.0 30	7.0 30	7.0 30	10.3 30	10.3 30
10	CONTROLS		19.4 30	19.5 30	19.4 30	23.9 30	23.9 30
11	SAFETY SYSTEMS		5.4 30	5.9 30	5.4 30	10.1 30	10.1 30
	TOTAL "OTHER" TECH SYSTEMS COSTS:		224.1	222.9	235.7	280.6	301.4
1.4.2.	<u>CONTINGENCY COSTS:</u>						
2	CRYOGENICS		25.8	24.2	27.2	27.4	30.0
3	VACUUM SYSTEMS		3.1	4.2	4.2	4.6	6.5
4	MAIN POWER SUPPLIES		4.2	4.2	4.2	4.2	4.2
5	CORRECTION POWER SUPPLIES		2.2	2.2	2.2	3.2	3.2
6	RF SYSTEM		1.5	1.9	1.5	6.2	6.2
7	INJECTION SYSTEM		.9	.9	.9	.9	.9
8	ABORT SYSTEM		2.4	2.4	2.4	3.1	3.1
9	INSTRUMENTATION		2.1	2.1	2.1	3.1	3.1
10	CONTROLS		5.8	5.8	5.8	7.2	7.2
11	SAFETY SYSTEMS		1.6	1.8	1.6	3.0	3.0
	TOTAL "OTHER" TECH SYS		49.7	49.8	52.3	62.8	67.4
	OVERALL CONTING PERCENTAGE:		22.2	22.3	22.2	22.4	22.3

It will, in general, be more difficult to find a site for the larger ring. Overcoming some of the site limitations could require that the collider tunnels be constructed deeper in the ground. Such a result would very quickly increase the cost of constructing the experimental halls and access shafts.

As a result of the above RDS analysis the contingency allowance (25%) was constant for all elements of the conventional systems except the main ring. For the main ring a variance in the contingency rates was recommended by PB because of the increased probability of unanticipated problems in the larger sized ring.

Approximately the same procedure is followed in this report as in the RDS. The contingency allowances for the main ring structures are 25% for Designs A and D, 25.5% for Design B, and 30% for Designs C and C*. A constant allowance of 20% is used for certain cryogenic facilities and support building structures. The results for each of the current Design Styles are indicated in Table III-21.

4. Systems Engineering

An average design contingency of 25% is applied to the EDI for Technical Systems. The rate was developed in the RDS from a detailed analysis of the various components. For conventional systems the contingency on the EDIA (AE/CM) varies from 25% for Designs A and D to 30% for Designs C and C* in view of the probability of additional design problems that may occur for the larger rings. The results are summarized in Table IV-1 of the next section.

Table III-21
Conventional Construction Contingency
(FY84 K\$)

STYLE:		A		B		D		C		C*	
CONTINGENCY PERCENT:		PCT		PCT		PCT		PCT		PCT	
PARAMETER VALUES:											
FIELD LEVEL, T		6.40		5.75		6.40		3.00		3.00	
CIRCUMFERENCE, MI		57.17		62.14		57.17		106.88		106.88	
(CIRCUMFERENCE, KM)		92.00		100.00		92.00		172.00		172.00	
(WBS)											
1.4.1		<u>CONVENTIONAL FACIL. SYSTEMS, COSTS:</u>									
.1 LAND IMPROVEMENTS		15,300	25	16,631	25.5	15,300	25	28,605	30	28,605	30
.2.1 TUNNEL TYPE I		88,038	25	95,693	25.5	88,038	25	164,592	30	164,592	30
.2.2 TUNNEL TYPE II		90,249	25	98,097	25.5	90,249	25	168,726	30	168,726	30
.2.3 TUNNEL TYPE III		154,292	25	167,709	25.5	154,292	25	288,459	30	288,459	30
.2.4 TUNNEL (OTHER ELEMENTS) (CRYO, BM DUMP, RF, ETC)		13,927	20	13,927	20	13,927	20	13,927	20	13,927	20
.3 CRYOGENIC FACILITIES		7,998	20	7,998	20	7,998	20	7,998	20	7,998	20
.4 SUPPORT BUILDINGS		1,750	20	1,902	20	1,750	20	3,272	20	3,272	20
.5 UTILITIES		38,822	25	42,198	25.5	38,822	25	72,581	30	72,581	30
.6 ACCESS SHAFTS		0	25	0	25.5	0	25	13,540	30	13,540	30
TOTAL CONVEN. FACILITIES		410,376		444,154		410,376		761,700		761,700	
 <u>CONTINGENCY COSTS:</u>											
.1 LAND IMPROVEMENTS		3,825		4,241		3,825		8,581		8,581	
.2.1 TUNNEL TYPE I		22,009		24,402		22,009		49,378		49,378	
.2.2 TUNNEL TYPE II		22,562		25,015		22,562		50,618		50,618	
.2.3 TUNNEL TYPE III		38,573		42,766		38,573		86,538		86,538	
.2.4 TUNNEL (OTHER ELEMENTS) (CRYO, BM DUMP, RF, ETC)		2,785		2,785		2,785		2,785		2,785	
.3 CRYOGENIC FACILITIES		1,600		1,600		1,600		1,600		1,600	
.4 SUPPORT BUILDINGS		350		380		350		654		654	
.5 UTILITIES		9,706		10,761		9,706		21,774		21,774	
.6 ACCESS SHAFTS		0		0		0		4,062		4,062	
TOTAL CONSTR. CONTING. COSTS		101,410		111,949		101,410		225,990		225,990	
OVERALL CONTINGENCY PERCENTAGE:		24.7		25.2		24.7		29.7		29.7	

IV. COST ROLLUP OF SSC MAGNET DEPENDENT SYSTEMS

The following table, Table IV-1, presents the complete tabulation of all of the Magnet Dependent System costs for the five magnet designs. The individual elements have all been presented in earlier sections of this report; they are combined here for the final summation. Again it should be re-emphasized, this "Total Cost" is for the SSC "magnet dependent systems" only, and should not be misinterpreted as a "Total SSC Construction Cost" for the entire project. In order to develop the "Total SSC Construction Cost" the costs for project management, injection accelerators, and other "common" technical and conventional systems must be included as shown in the 1984 RDS Report.

In the summation of Table IV-1, the Magnet Systems costs are those "CDG adjusted" values that were described in Section III-A-4. The Other Technical Systems costs were discussed in Section III-B, and the Conventional Systems costs are from Section III-C. The EDI and contingency costs were discussed in Sections III-D and III-E. Comparisons between the costs in Table IV-1 and the Reference Designs Study cost estimate are shown in Appendix E.

Table IV-1
Summary Cost Estimate
Magnet Dependent Systems
(FY84 K\$)

SUMMARY COST ROLLUP
MAGNET DEPENDENT SYSTEMS ONLY

	STYLE A	STYLE B	STYLE D	STYLE C	STYLE C*
<u>CONSTRUCTION COSTS:</u>					
ADJUSTED MAGNET SYSTEMS	732.25	869.89	853.31	441.47	589.95
OTHER TECHNICAL SYSTEMS	224.10	222.90	235.70	280.60	301.40
CONVENTIONAL SYSTEMS	410.38	444.15	410.38	761.70	761.70
SUBTOTAL: CONSTRUCTION	1,366.73	1,536.94	1,499.38	1,483.77	1,653.05
<u>SYSTEMS ENGINEERING COSTS:</u>					
MAGNET SYSTEMS	83.87	103.78	100.42	58.18	76.66
OTHER TECHNICAL SYSTEMS	42.50	43.00	44.70	55.80	59.70
CONVENTIONAL SYSTEMS	65.66	71.06	65.66	121.87	121.87
SUBTOTAL: SYS. ENGIN.	192.03	217.84	210.78	235.85	258.24
<u>CONTINGENCY COSTS:</u>					
MAGNET SYSTEMS	151.35	199.68	183.57	109.56	145.09
OTHER TECHNICAL SYSTEMS	49.70	49.80	52.30	62.80	67.40
CONVENTIONAL SYSTEMS	101.41	111.95	101.41	225.99	225.99
SYSTEMS ENGINEERING	48.01	54.82	52.69	65.06	70.65
SUBTOTAL: CONTINGENCY	350.47	416.24	389.98	463.40	509.13
<u>TOTAL MAGNET SYS. DEPEND. COSTS</u>	1,909.23	2,171.03	2,100.14	2,183.02	2,420.42

APPENDIX A
COST ESTIMATING PARTICIPANTS AND
DIPOLE MAGNET TASK FORCE MEMBERS

As stated earlier, many individuals and groups participated in the development of the particular cost estimating data presented in this report. The report was prepared with three major cost sections for the Magnet Dependent Costs (Magnet Systems, Other Technical Systems, and Conventional Systems). The major styles being considered and the lead groups responsible for initially developing and providing the primary cost detail materials are indicated below:

MAGNET SYSTEMS:

    Cosine Theta Style Dipole Magnets:

        Magnet Style A - Tooling and Dipole Magnets, BNL

        Magnet Style B - Tooling and Dipole Magnets, FNAL

        Magnet Style D - Tooling and Dipole Magnets, BNL & FNAL, GD, W
                            (General Dynamics, Westinghouse)

    Superferric Style Magnets:

        Magnet Style C - Tooling and Dipole Magnets, TAC, GD, W

        Magnet Style C*- Tooling and Dipole Magnets, TAC

OTHER TECHNICAL SYSTEMS:

    Cryogenics A, D - BNL; B - FNAL; C - TAC, CCI

    All other systems - CDG

CONVENTIONAL FACILITIES:

    Conventional Facilities - PB, RTK, CDG

        (Parsons Brinckerhoff, Raymond Kaiser, Tudor, Keller &
        Gannon-Knight)

In addition to the laboratory, university groups, and industrial participants, the SSC Central Design Group reviewed, analyzed, and prepared cost estimates as well. The CDG groups also prepared the estimates for EDI and Contingency. The primary CDG personnel responsible for each of the above categories are listed below:

Magnet Systems: T. Elloff, R. Yourd, K. Mirk, P. Limon

Other Technical Systems: T. Elloff, P. Limon

Conventional Systems: J. Sanford, T. Toohig

For a detailed review of the dipole magnet costs, a Dipole Magnet Cost Estimating Task Force was assembled and met with the CDG during July, 1985. Various cost consultants also participated in these meetings. A list of the Task Force Members and Consultants, and a schedule of the meetings at the CDG is shown in Table A-1.

Table A-1
SSC-CDG DIPOLE MAGNET COST ESTIMATING TASK FORCE
JULY 18-24, 1985

Participants:

Task Force: Tom Elioﬀ, Ron Yourd, Ken Mirk, Carl Goodzeit
Laboratory Consultants: Norb Engler, Greg Kobliska, Russ Huson,
Industrial Estimates: General Dynamics (Bob Baldi),
Westinghouse (Andy Jarabak)

Agenda:

July 18, 1985

9 - 10am Introduction: describe scope of our work, the procedures we will use to assemble report, the materials available, and how we will arrive at a CDG table of costs for overall comparisons.

10am - 4pm Review Design Style D: laboratory estimates, GD materials, and Westinghouse materials; review material quotes and unit costs;

July 19, 1985

9 - 12am Review Design Style A: laboratory estimates, BNL scaling factors, extrapolation of style D data base, etc.

1 - 4pm Review Design Style B: laboratory estimate, FNAL data extrapolation from style D data base, etc.

July 22, 1985

9am - 4pm Complete Style D Package: review Carl's aperture scaling factors, length factors, Quadrupoles, Spool Pieces, Installation, Cryogenic Systems, etc.

July 23, 1985

9am - 4pm Review Style C and C* Materials: review laboratory estimates, review GD and Westinghouse estimates, assemble CDG estimate, evaluate scaling factors, etc.

July 24, 1985

1 - 4pm Review Complete Style C and C* Packages

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A-4

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APPENDIX B MAGNET COST DATA COMPARISONS

The following tables (Tables B-1, B-2, and B-3) present the individual cost comparisons from the cost estimating participants for the Style A, B, and D design respectively. They show the laboratory and CDG detail comparisons and for Design D shows the industrial estimates from General Dynamics and Westinghouse for comparison.

Tables (Tables B-4 and B-5) present the individual cost comparisons from the cost estimating participants for the Style C, and C* designs respectively. They also show the laboratory and CDG detail comparisons and for Design C shows the Industrial estimates from General Dynamics and Westinghouse.

The CDG projection is the estimate that is carried forward throughout the cost comparison report. It is apparent from the comparisons that some of the estimators did not address all of the detail elements in the same manner (for example, often the shop support functions, testing, and allowance factor areas were incomplete). The CDG estimate is presented as the most complete and thoroughly integrated package, appropriate for the cost comparison study.

1. General Discussion of the Estimating Methods

In comparing the estimates in Tables B-1 through B-3, and in particular to explain how certain CDG assessments were developed, the following discussion will describe particular features of the laboratory and industrial estimates in detail. The general comments will focus on the estimates for style D since most of the new detail analysis was done on that system and because that is the cosine theta style that the industrial participants reviewed. Table B-3.1 presents the "per magnet" cost for materials and labor hours for the laboratory, the CDG, GD, and Westinghouse.

An overall assessment at the bottom line showing total labor of 561, 585, 616, and 703 hours respectively for the Labs, CDG, GD, and W indicate surprisingly good agreement and a common understanding of the overall direct labor effort necessary for the Style D dipole magnet assembly. Common labor rates, \$/hr, were developed and prescribed by the CDG to describe a national

average; a range of labor classifications was indicated to allow for differing skill level requirements. The common CDG labor rates were not used by the industrial estimators. Although the GD estimate does not reveal the specific labor rate they use for each of the labor groups represented in the estimate (because of their proprietary individual labor rate structure), their total "labor-to-dollar" conversion for all of their project labor would indicate an overall net rate of approximately \$45/hr (probably representative of the overall GD-Convair San Diego facilities). While this is not the particular rate for each specific shop or factory labor task in their estimate, this net rate serves to indicate that the GD labor base is substantially higher than the CDG analysis for a national average labor rate ranging from \$21-\$42/hr for technician and shop skill levels. The Westinghouse estimate assumes a relatively high skill level (if it is correlated to the CDG rates), and their net effective labor rate indicates an overall labor average of \$35/hr. The laboratory estimates use the specific CDG rates as prescribed, and generally indicate that even the "lower skill level" technician rates would be adequate for most of their labor tasks. The CDG estimate reflects the overall rates also, but we assume a mix of skill levels for all labor that reflects an overall rate blend of \$23/hr for direct labor; \$32/hr for supervision and support. The resulting effect of these labor rate differences for each of the estimators results in higher labor costs indicated by the GD and Westinghouse estimates than for the laboratory and CDG estimates, even though the total labor "hours" are nearly identical.

An overall assessment at the bottom line (Table B-3.1) showing a total cost for materials of \$66,973, \$71,723, \$89,262, and \$82,014 respectively for the Labs, CDG, GD, and W would indicate generally good agreement with the exception of the high GD value. The GD value includes an overall general allowance of \$11,210 that accounts for a large portion of the difference; this overall allowance factor is GD's method for handling miscellaneous allowances for "low dollar allocations," "material usage variance," "damaged materials," etc. This value appears to be extraordinarily large in our analysis since we find that most of the parts were itemized materials from drawings and parts lists and were costed explicitly from the low level WBS categories. We feel that the CDG suggested allowance factor of 5% for the overall superconductor

purchase quantity and 1% excess for all other materials is adequate for a materials variance, and that higher values for breakage and damage, design "growth" and vendor "Class II" changes should be treated as a contingency and not a direct cost.

GD has added a factor for fee and cost of money which we have not included in the CDG estimates, its inclusion being inconsistent with the management and risk assumption model used for this estimate. Inclusion of these items in a self-consistent way requires knowledge of the particular contracting vehicle being used and to be useful would have to be obtained through competitive bidding procedures.

In noting certain of the other "row-by row" comparisons for the WBS elements in the tables for Design D, we should comment that the CDG estimate largely reflects the cost estimate detail from the laboratory estimate columns, and that the industrial estimates were used primarily for overall consistency checks, particular vendor quotation sources, task and labor estimate confirmation, etc.

2. Cosine Theta Styles

Design D: All of the cost estimates for the cold bore tube rely on the BNL estimate for the copper coated bore tube with a Multiwire correction coil package applied. The CDG provided this base cost information to both GD and Westinghouse for their use, since we felt that in this case considerable R&D had been done by BNL, that the actual design was specific to a "Multiwire" process, and that it would not be as efficient for them to individually deal with the same "Multiwire" personnel. However, GD did adjust the material and labor costs slightly to add additional cleaning, testing, and inspection steps.

The coil costs are largely dominated by the superconductor material unit cost; this unit cost was also developed by the CDG and supplied to all the estimators as a common cost base for all to use. The coil collaring costs depend on certain specification requirements; the GD and Westinghouse estimates are based on a cost for "Nitronic-40" material, a specific Armco product. This specific material was prescribed by BNL in the basic collar designs and has subsequently been adjusted to a "more generic" stainless steel

of a type 304-N or equivalent. The material cost differences account for most of the differences between the estimate details. The CDG costs assume the lower cost stainless alloy will be incorporated into the design.

For the "yoke and components," again most of the cost difference in materials depends on particular "anticipated assumptions" in the lamination material requirements or stamping tolerance requirements. The CDG estimate selected for the cost comparison a nominal material cost of 0.34 \$/lb and a stamping cost ranging from 0.05 to 0.08 \$/each depending on the size and tolerance requirement. It was felt that these were representative current costs based on the large experience base for other similar magnet lamination costs and did not necessarily reflect any one particular vendor quote or cost source. The range of vendor quotations in the various estimates was surprisingly wide considering our expectation that the "lamination cost" would be one of the most well-established and consistent cost packages. In fact, the vendors hesitated to bid on such very large and future projections since the "anticipated requirements" for stamping acceptance (burr requirement, precision and uniformity, relative tolerances between corresponding lamination sections) and the particular material requirements that are "anticipated" (test and certification data, permeability range selection, surface conditions, packaging, etc.) were not clearly delineated in these R&D design packages.

It is apparent in reviewing all of the estimates that the "R&D model" drawing packages that were developed by the laboratories (and were sent to the estimators) and that were subsequently sent out for vendor quotations were obviously not representative of what will be eventually developed into "magnet production" drawings. Since the drawings have not received a "manufacturing analysis" and/or a "value engineering review," the vendors were asked to present estimates that often required certain ranges of assumptions; therefore, the particular estimates were not always comparable and required some interpretation.

The comparison of the remaining "material" elements for design D, however, appear to be fairly consistent with the exception of the Westinghouse estimate for the vacuum vessel components. Their value is several thousand dollars higher than the others with no apparent explanation, other than perhaps individual vendor "quotation" interpretations as described above.

The labor estimates for direct and indirect shop support are developed by each group in a different manner. The CDG estimate assumes an overall percentage of 23% of the "direct labor" is required for additional shop support. The industrial estimates reflect other equivalent percentages, and some inconsistencies occur here in trying to define adequately which shop services are covered by the labor "overhead factors" on the direct labor rates, and which supporting services are covered directly by Project Management or EDI (including QA) categories.

In examining the overall estimates for the full magnet system production, it should be remembered that for the CDG estimate, in addition to the entries shown for the "Total Cost for Tooling and Dipole Magnets" the complete cost includes additional costs developed and collected within the overall "SSC Project Management" and "Systems Engineering and Design" (EDI) WBS elements.

Design A: The CDG cost estimate summation for Design A utilizes the base information for the Design D estimate, and the yoke and cryostat costs are scaled for a size adjustment.

Design B: The CDG estimate for Design B utilizes the laboratory (FNAL) base information with the following exceptions. For the material estimate, we adjust the interconnection material to be consistent with the Design D interconnection base, and add a cost for a single internal bypass bus to the electrical package. In addition we add the same factors for Material Allowances and Reject Allowances as in the other designs. Other material cost factors result from specific design differences described for style B. One notable overall difference is in the cold bore tube; FNAL design B proposes an aluminum bore tube with "transition metal ends" to be connected to stainless steel bellows in the interconnection regions. The bore tube is proposed to have separate correction coil windings incorporated as opposed to the "Multiwire" concept described for Designs D and A. The estimated cost of such a system was developed by FNAL and also was used directly in the CDG estimate. The bore tube estimate used here appears to be considerably less expensive than the estimates for Designs D and A and we have not made a detail analysis of the differences for this study; a similar design concept should

conceivably work for all cosine theta type systems, and similar costs should be reflected in all the estimates. Another difference between the designs is in the coil collars; Design B proposes aluminum collars, Design D (and A) uses stainless steel. Again, we have used the costs as proposed by FNAL for their system, but point out this difference in design concept.

For the labor estimate, the CDG estimate follows the same format as in the other systems whereby we describe an allowance for additional overall shop support (factor of 23%) based on the direct labor. We also assume a difference in the coil fabrication concept for this study: the CDG estimate is based on the "wet winding" coil fabrication concept that is consistent with that described for Designs D and A, (and in fact the actual Design D labor cost base was used after proper length scaling for Design B); the FNAL estimate is based on a "dry winding" method that is under development and consideration. Once again, if the dry winding method is successful and is adopted for the cosine theta style production, its cost savings should be reflected in all of the cosine theta designs accordingly.

3. Superferric Styles.

The cost estimates for Designs C and C* are shown in Tables B-4 and B-5. There is considerably more disparity between the estimates presented by the Laboratory group (TAC), CDG, GD and Westinghouse in the case of Design C than was evident in Design D (Table B-3 above). As evident in examining the first section of Table B-3.1, the laboratory estimate does not address the particular sections for internal bus work, magnet interconnections, and the various testing and measurement operations, as well as the allowances for material factors and rejects. The CDG estimate treats all of these elements in a comparable manner as was described for the cosine theta styles; i.e. we assume the same model holds for rejects, material factors, cold and warm magnetic measurements, and for shop support.

Design C: The apparent large discrepancy in treating the interconnection region parts hardware (materials) (CDG: \$200, GD: \$10630, and W: \$2350.) occurs due to the different way of describing the expansion joints. The CDG estimate counts only the few dipole to dipole interconnection components with

the dipole magnet costs; the CDG counts the dipole to spool piece connection as part of the "Special Devices/Spools" costs. The actual dipole-to-dipole hardware for design C is very small (essentially a "hard" magnet to magnet connection with no expansion joint) compared to the corresponding area for designs D, A, and B (where all of the bellows, buss connections, and cryogenic contractions are allowed). All of the equivalent bellows, bus flex joints, and contraction regions for design C were costed by the industrial firms, but were "pro-rated" to show a somewhat equivalent "per-dipole" allowance and were collected with the dipole cost as being equivalent to the interconnection area for Design D. This discrepancy distorts the dipole costs, and the CDG estimate more appropriately costs the large interconnection Design C box with the "Special Devices" category in the overall "Magnet Systems" table.

Another large discrepancy occurs in the "Internal Bus Work" category. The laboratory package does not include an estimate for this area, and the design was very ill-defined at the time that the industrial groups were asked to estimate. Subsequently, a design for the bus links and connections has been defined by TAC, and a careful attempt to cost the components on a basis comparable to the estimates developed for the cosine theta styles leads to the total cost reflected by the CDG. This package appears to be a high cost item, but it should be remembered that there are many high current connection legs for each bore (e.g., two separate dipole windings at 12,000 A, 1 dipole winding at 3000A, quadrupoles, correctors, etc.) and long magnet lengths that need to be properly counted.

The labor hours for the Design C estimate were examined in considerable detail by the CDG and the values shown represent a composite CDG assessment after separate review of each task and work package. They appear to be somewhat intermediate between the laboratory and industrial estimates overall; they appear to be nearly the same as the laboratory estimates for coil and yoke fabrication, but they are considerably higher than the laboratory estimates in the areas of cryostat and vacuum vessel assembly. In addition, separate labor estimates are shown for the testing, measurement and support tasks, as well as the shop support categories.

Design C*: Design C* was developed by direct extrapolation and scaling of the Design C costs. No additional review or comparison checks were made.

8/07/85

Table B-1.1
Design A Magnet Comparisons
Cost Per Each Dipole Magnet

PER EACH DIPOLE MAGNET - STYLE A
ITEM

		LABORATORY ESTIMATE (BNL & FNAL)				CENTRAL DESIGN GROUP ESTIMATE			
(WBS)		MATL \$	LBR HRS	LABOR \$	TOTAL \$	MATL \$	LBR ¹ HRS	LABOR \$	TOTAL \$
B	MAGNETS - DIRECT MATLS AND LABOR,								23.0
14212.	1.1 COLD BORE TUBE	5273.0	68.5	1494.6	6767.6	5273.0	68.5	1575.5	6848.5
	1.2 COILS	63333.3	292.9	7292.5	70625.8	65750.0	292.9	6736.7	72486.7
	1.3 COIL COLLARING	12282.0	69.6	1465.8	13748.6	12282.0	69.6	1600.8	13883.6
	2.1 YOKE AND COMPONENTS	15416.8	43.6	1240.3	16657.1	15870.0	43.6	1002.8	16872.8
	2.2 HELIUM CONTAINMENT VESSEL	5444.6	16.6	401.2	5845.8	5444.6	16.6	381.0	5826.4
	3.1 COLD MASS SUBASSEMBLY PREP	832.2	15.3	358.7	1190.9	832.2	15.3	351.9	1184.1
	3.2 20K HEAT SHIELD	912.9	18.9	440.9	1353.8	912.9	18.9	434.7	1347.6
	3.3 80K HEAT SHIELD	2558.4	18.7	436.7	2995.1	2558.4	18.7	430.1	2988.5
	3.4 UPPER VACUUM VESSEL	3562.8	14.5	412.3	3975.1	3562.8	14.5	333.5	3896.3
	3.5 LOWER VACUUM VESSEL	1744.6	19.6	508.4	2253.0	1744.6	19.6	450.8	2195.4
	3.6 VESSEL ENDS	475.5	13.0	416.0	891.5	475.5	13.0	299.0	774.5
	4.1 INTERNAL BUS WORK	3553.7	103.0	2163.0	5716.7	3553.7	103.0	2369.0	5922.7
	5.1 INTERCONNECTION REGION PARTS	2569.0	22.0	704.0	3273.0	5000.0	22.0	506.0	5506.0
	5.2 SHIPPING/STORAGE/HANDLING				0.0	30.0			30.0
	6.1 TESTING				0.0		8.0	184.0	184.0
	6.2 WARM MAGNETIC MEASUREMENTS		2.5	80.0	80.0		16.0	368.0	368.0
	6.3 COLD MAGNETIC MEASUREMENTS	150.0	5.0	160.0	310.0	150.0	8.0	184.0	334.0
	6.4 CRYOGENIC TESTING FACILITY OPERNS.				0.0		4.0	92.0	92.0
	8.1 DIRECT SHOP SUPPORT				0.0				0.0
	8.2 MISCEL. AND INDIRECT SHOP SUPPORT		180.0	5760.0	5760.0	200.0	180.0	5760.0	5960.0
	MATERIAL FACTORS & ALLOWANCES	3634.0			3634.0	4000.0			4000.0
	ALLOWANCE FOR REJECTS	2000.0	14.0	294.0	2294.0	2000.0	14.0	322.0	2322.0
	SUBTOTAL	123743.6	917.7	23628.4	147372.0	129640.5	946.2	23382.6	153023.1

Total Dipole Magnet Costs for Tooling and Full Production

8/07/85

PER 4200 DIPOLE MAGNETS - STYLE A
ITEM

(WBS)

LABORATORY ESTIMATE: (BNL + FNAL)

CENTRAL DESIGN GROUP ESTIMATE

MATL K\$ LDR KHRS LABOR K\$ TOTAL K\$

MATL K\$ LDR KHRS LABOR K\$ TOTAL K\$

A TOOLING - DIRECT

14211.	1.1	COIL PRODUCTION	17,269	289	10,340	27,608	17,269	289	10,340	27,609
	1.2	YOKES, COLLARS, HE CONTN.	6,957	15	571	7,528	6,957	15	571	7,528
	1.3	ELECTRICAL SYSTEMS	198	2	71	269	198	2	71	269
	1.4	FINAL ASSEMBLY - CRYOSTAT	10,239		0	10,239	10,239		0	10,239
	1.5	TESTING AND MEASUREMENTS	341	14	491	832	341	14	491	832
		SUBTOTAL (MAGNET 'TOOLING' DIRECT)	4.2 35,004	320	11,472	46,476	35,004	320	11,473	46,477

B MAGNETS - DIRECT MATLS AND LABOR,

14212. 1.1	COLD BORE TUBE	22,147	288	6,277	28,424	22,147	288	6,617	28,764
1.2	COILS	266,000	1,230	30,628	296,628	276,150	1,230	28,294	304,444
1.3	COIL COLLARING	51,588	292	6,156	57,744	51,588	292	6,723	58,311
2.1	YOKE AND COMPONENTS	64,751	183	5,209	69,960	66,654	183	4,212	70,866
2.2	HELIUM CONTAINMENT VESSEL	22,867	70	1,685	24,552	22,867	70	1,604	24,471
3.1	COLD MASS SUBASSEMBLY PREP	3,495	64	1,507	5,002	3,495	64	1,478	4,973
3.2	20K HEAT SHIELD	3,834	79	1,852	5,686	3,834	79	1,826	5,660
3.3	80K HEAT SHIELD	10,745	79	1,834	12,579	10,745	79	1,806	12,552
3.4	UPPER VACUUM VESSEL	14,964	61	1,732	16,695	14,964	61	1,401	16,364
3.5	LOWER VACUUM VESSEL	7,327	82	2,135	9,463	7,327	82	1,893	9,221
3.6	VESSEL ENDS	1,997	55	1,747	3,744	1,997	55	1,256	3,253
4.1	INTERNAL BUS WORK	14,926	433	9,085	24,010	14,926	433	9,950	24,875
5.1	INTERCONNECTION REGION PARTS	10,790	92	2,957	13,747	21,000	92	2,125	23,125
5.2	SHIPPING/STORAGE/HANDLING	0	0	0	0	126	0	0	126
6.1	TESTING	0	0	0	0	0	34	773	773
6.2	WARM MAGNETIC MEASUREMENTS	0	10	336	336	0	67	1,546	1,546
6.3	COLD MAGNETIC MEASUREMENTS	630	21	672	1,302	630	34	773	1,403
6.4	CRYOGENIC TESTING FACILITY OPERNS.	0	0	0	0	0	17	386	386
8.1	DIRECT SHOP SUPPORT	0	0	0	0	0	0	0	0
8.2	MISCEL. AND INDIRECT SHOP SUPPORT	0	756	24,192	24,192	840	756	24,192	25,032
	MATERIAL FACTORS & ALLOWANCES	15,263	0	0	15,263	16,800	0	0	16,800
	ALLOWANCE FOR REJECTS	8,400	59	1,235	9,635	8,400	59	1,352	9,752
	SUBTOTAL	519,723	3,854	99,239	618,962	544,490	3,974	98,207	642,697
	TOTAL COST FOR TOOLING + DIPOLE MAGNETS	554,727	4,174	110,712	665,439	579,494	4,294	109,680	689,174

Table B-2.1

Design B Magnet Comparisons

Cost Per Each Dipole Magnet

8/07/85

PER EACH DIPOLE MAGNET - STYLE B
ITEM

(WBS)	LABORATORY ESTIMATE (FNAL)				CENTRAL DESIGN GROUP ESTIMATE			
	MATL \$	LBR HRS	LABOR \$	TOTAL \$	MATL \$	LBR HRS	LABOR \$	TOTAL \$
B							23.0	
14212. 1.1 COLD BORE TUBE	410.0	30.0	790.0	1200.0	410.0	30.0	690.0	1100.0
1.2 COILS	23488.0	36.0	767.0	24255.0	23488.0	120.0	2760.0	26248.0
1.3 COIL COLLARING	3941.0	162.0	3578.0	7519.0	3941.0	30.0	690.0	4631.0
2.1 YOKE AND COMPONENTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.2 HELIUM CONTAINMENT VESSEL	2186.0	44.0	1148.0	3334.0	2186.0	44.0	1012.0	3198.0
3.1 VACUUM VESSEL	7534.0	0.0	0.0	7534.0	7534.0	0.0	0.0	7534.0
3.2 HEAT SHIELDS	2342.0	0.0	0.0	2342.0	2342.0	0.0	0.0	2342.0
3.3.1 SUPPORTS (PARTS AND SUBASSY)	1064.2	42.8	898.8	1963.0	1064.2	42.8	984.4	2048.7
3.3.2 SUPPORTS (INSTALL)	0.0	31.4	659.4	659.4	0.0	31.4	722.2	722.2
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.1 FINAL ASSEMBLY LABOR		61.2	1205.2	1285.2		61.2	1407.6	1407.6
4.1 INTERNAL BUS WORK	0.0	0.0	0.0	0.0	560.0	5.0	115.0	675.0
6.1 INTERCONNECTION REGION PARTS	1414.0	20.0	640.0	2054.0	2700.0	20.0	460.0	3160.0
6.2 SHIPPING/STORAGE/HANDLING				0.0	30.0			30.0
6.1 TESTING				0.0		8.0	184.0	184.0
6.2 WARM MAGNETIC MEASUREMENTS				0.0		8.0	184.0	184.0
6.3 COLD MAGNETIC MEASUREMENTS	784.0			784.0	150.0	4.0	92.0	242.0
6.4 CRYOGENIC TESTING FACILITY OPERNS.				0.0		4.0	92.0	92.0
0.1 DIRECT SHOP SUPPORT				0.0				0.0
0.2 MISCEL. AND INDIRECT SHOP SUPPORT				0.0		100.0	3200.0	3200.0
MATERIAL FACTORS & ALLOWANCES				0.0	1380.0			1380.0
ALLOWANCE FOR REJECTS	250.2	6.7	141.4	391.6	675.0	7.0	161.0	836.0
SUBTOTAL	43413.5	434.1	9907.8	53321.3	46460.2	515.4	12754.2	59214.4

Design B Magnet Comparisons

Total Dipole Magnet Costs for Tooling and Full Production

8/07/85

PER 13392 DIPOLE MAGNETS - STYLE B
ITEM

FNAL COST ESTIMATE

CENTRAL DESIGN GROUP ESTIMATE

MATL K\$ LBR KHRS LABOR K\$ TOTAL K\$

MATL K\$ LBR KHRS LABOR K\$ TOTAL K\$

(WBS)

A TOOLING - DIRECT

14211.	1.1	COIL PRODUCTION	13,111	12	250	13,361	13,111	12	250	13,361
	1.2	YOKES, COLLARS, HE CONTN.	8,202	12	253	8,455	8,202	12	253	8,455
	1.3	ELECTRICAL SYSTEMS	216			216	216			216
	1.4	FINAL ASSEMBLY - CRYOSTAT (INCL ABOVE)				0				0
	1.5	TESTING AND MEASUREMENTS	2,669	65	1,357	4,026	2,669	65	1,357	4,026
		SUBTOTAL (MAGNET 'TOOLING' DIRECT)	13.39 24,198	89	1,860	26,058	24,198	89	1,860	26,058

B MAGNETS - DIRECT MATLS AND LABOR,

14212. 1.1	COLD BORE TUBE	5,491	402	10,580	16,070	5,491	402	9,240	14,731
1.2	COILS	314,551	482	10,272	324,823	314,551	1,607	36,962	351,513
1.3	COIL COLLARING	52,778	2,170	47,917	100,694	52,778	402	9,240	62,018
2.1	YOKE AND COMPONENTS	0	0	0	0	0	0	0	0
2.2	HELIUM CONTAINMENT VESSEL	29,275	589	15,374	44,649	29,275	589	13,553	42,828
3.1	VACUUM VESSEL	100,895	0	0	100,895	100,895	0	0	100,895
3.2	HEAT SHIELDS	31,364	0	0	31,364	31,364	0	0	31,364
3.3.1	SUPPORTS (PARTS AND SUBASSY)	14,252	573	12,037	26,289	14,252	573	13,183	27,436
3.3.2	SUPPORTS (INSTALL)	0	421	8,831	8,831	0	421	9,672	9,672
		0	0	0	0	0	0	0	0
5.1	FINAL ASSEMBLY LABOR	0	820	17,211	17,211	0	820	18,851	18,851
4.1	INTERNAL BUS WORK	0	0	0	0	7,500	67	1,540	9,040
6.1	INTERCONNECTION REGION PARTS	18,936	268	8,571	27,507	36,158	268	6,160	42,319
6.2	SHIPPING/STORAGE/HANDLING	0	0	0	0	402	0	0	402
6.1	TESTING	0	0	0	0	0	107	2,464	2,464
6.2	WARM MAGNETIC MEASUREMENTS	0	0	0	0	0	107	2,464	2,464
6.3	COLD MAGNETIC MEASUREMENTS	10,500	0	0	10,500	2,009	54	1,232	3,241
6.4	CRYOGENIC TESTING FACILITY OPERNS.	0	0	0	0	0	54	1,232	1,232
8.1	DIRECT SHOP SUPPORT	0	0	0	0	0	0	0	0
8.2	MISCEL. AND INDIRECT SHOP SUPPORT	0	0	0	0	0	1,339	42,854	42,854
	MATERIAL FACTORS & ALLOWANCES	0	0	0	0	18,481	0	0	18,481
	ALLOWANCE FOR REJECTS	3,351	90	1,894	5,245	9,040	94	2,156	11,196
	SUBTOTAL	581,394	5,814	132,686	714,080	622,196	6,902	170,804	793,000
	TOTAL COST FOR TOOLING + DIPOLE MAGNETS	605,592	5,902	134,546	740,138	646,394	6,991	172,664	819,058

Table B-3.1
Design D Magnet Comparisons
Cost Per Each Dipole Magnet

/07/85

PER EACH DIPOLE MAGNET - STYLE D
ITEM

(VBS)	LABORATORY ESTIMATE (BNL & FNAL)				CENTRAL DESIGN GROUP ESTIMATE				GENERAL DYNAMICS ESTIMATE				WESTINGHOUSE ESTIMATE			
	MATL \$	LDR HRS	LABOR \$	TOTAL \$	MATL \$	LDR HRS	LABOR \$	TOTAL \$	MATL \$	LDR HRS	LABOR \$	TOTAL \$	MATL \$	LDR HRS	LABOR \$	TOTAL \$
MAGNETS - DIRECT MATLS AND LABOR,																
1212. 1.1 COLD BORE TUBE	2636.5	34.3	747.3	3383.8	2636.0	34.3	788.9	3424.9	3137.2	41.0			3384.0	6.7	212.0	3596.0
1.2 COILS	31666.6	146.5	3646.3	35312.9	32875.0	146.5	3369.5	36244.5	31486.0	133.9			35650.4	46.5	1395.0	37045.4
1.3 COIL COLLARING	6141.4	34.0	732.9	6874.3	6141.0	34.8	800.4	6941.4	9021.0	55.9			6904.7	36.3	794.0	7698.7
2.1 YOKE AND COMPONENTS	0941.5	38.7	1083.2	10024.7	9341.0	38.7	890.1	10231.1	11356.0	40.1			12409.8	66.0	2062.0	14471.8
2.2 HELIUM CONTAINMENT VESSEL	3196.1	14.4	353.0	3549.9	3196.0	14.4	331.2	3527.2	3100.5	15.6			970.8	71.8	2963.0	3933.8
3.1 COLD MASS SUBASSEMBLY PREP	803.0	15.0	340.0	1151.0	803.0	15.0	345.0	1148.0	2959.7	72.8			768.2	35.1	1444.0	2212.2
3.2 20K HEAT SHIELD	912.9	18.9	440.9	1353.8	913.0	18.9	434.7	1347.7	2232.9	14.3			956.7	19.2	774.0	1730.7
3.3 BOK HEAT SHIELD	2173.1	18.7	436.7	2609.8	2173.0	18.7	430.1	2603.1	1185.3	14.3			1967.0	29.6	1207.0	3174.0
3.4 UPPER VACUUM VESSEL	2082.9	14.5	412.3	3295.2	2083.0	14.5	333.5	3216.5	4420.9	44.2			11545.3	62.4	2621.0	14166.3
3.5 LOWER VACUUM VESSEL	1470.7	19.6	508.4	1979.1	1471.0	19.6	450.8	1921.8	1631.1	44.2			912.0	37.5	1577.0	2489.0
3.6 VESSEL ENDS	415.0	13.0	416.0	831.0	415.0	13.0	299.0	714.0	0.0				230.1	43.8	1773.0	2003.1
4.1 INTERNAL BUS WORK	3313.2	51.5	1081.5	4394.7	1776.9	51.5	1104.5	2961.4	684.7	10.4			1419.2	44.6	1827.0	3246.2
5.1 INTERCONNECTION REGION PARTS	2342.0	22.0	704.0	3046.0	3600.0	22.0	506.0	4106.0	5092.8				3254.4			3254.4
5.2 SHIPPING/STORAGE/HANDLING				0.0	30.0			30.0	32.1	2.5			80.0	5.0	185.0	265.0
6.1 TESTING				0.0		8.0	184.0	184.0	0.0	54.9						0.0
6.2 WARM MAGNETIC MEASUREMENTS		2.5	80.0	80.0		8.0	184.0	184.0	0.0					10.0	298.0	298.0
6.3 COLD MAGNETIC MEASUREMENTS	150.0	5.0	160.0	310.0	150.0	4.0	92.0	242.0	0.0					.8	20.0	20.0
6.4 CRYOGENIC TESTING FACILITY OPERNS.				0.0		4.0	92.0	92.0	0.0							0.0
8.1 DIRECT SHOP SUPPORT				0.0				0.0	0.0	30.8						1561.5
8.2 MISCEL. AND INDIRECT SHOP SUPPORT		103.7	3318.0	3318.0	200.0	110.0	3520.0	3720.0	656.2	25.6				175.2	5916.0	5916.0
MATERIAL FACTORS & ALLOWANCES	1817.0			1817.0	2000.0			2000.0	11210.7				0.0			0.0
ALLOWANCE FOR REJECTS	1112.0	8.3	222.0	1334.0	1120.0	10.0	230.0	1350.0	1055.2	7.5			1561.5	9.6	360.0	1921.5
SUBTOTAL	69973.9	561.4	14691.3	84665.2	71723.9	585.9	14465.7	86189.6	89262.4	616.0			82014.1	700.2	25428.0	107442.1

Design D Magnet Comparisons

Total Dipole Magnet Costs for Tooling and Full Production

3" BNL-CDG-GD-W comparisons 4

3/07/85

PER 8400 DIPOLE MAGNETS - STYLE D
ITEM
(VBS)

LABORATORY ESTIMATE (DNL & FINAL)

MATL K\$ LDR KHRS LABOR K\$ TOTAL K\$

CENTRAL DESIGN GROUP ESTIMATE

MATL K\$ LDR KHRS LABOR K\$ TOTAL K\$

GENERAL DYNAMICS ESTIMATE

MATL K\$ LDR KHRS LABOR K\$ TOTAL K\$

WESTINGHOUSE ESTIMATE

MATL K\$ LDR KHRS LABOR K\$ TOTAL K\$

TOOLING - DIRECT

4211. 1.1 COIL PRODUCTION	17,269	209	10,340	27,608	17,269	209	10,340	27,609		9,575	19	608	0	
1.2 YOKES, COLLARS, HE CONTN.	6,957	15	571	7,520	6,957	15	571	7,520		17,176	64	2,043	19,219	
1.3 ELECTRICAL SYSTEMS	198	2	71	269	198	2	71	269					0	
1.4 FINAL ASSEMBLY - CRYOSTAT	10,239		0	10,239	10,239		0	10,239		4,215			4,215	
1.5 TESTING AND MEASUREMENTS	341	14	491	832	341	14	491	832		724			724	
SUBTOTAL (MAGNET 'TOOLING' DIRECT)	35,004	320	11,472	46,476	35,004	320	11,473	46,477	15,740	258	31,691	83	2,651	34,341

MAGNETS - DIRECT MATLS AND LABOR

4212. 1.1 COLD BORE TUBE	22,147	288	6,277	28,424	22,142	288	6,627	28,769	26,352	344	28,426	57	1,701	30,206
1.2 COILS	265,999	1,231	30,629	296,628	276,150	1,231	28,304	304,454	264,482	1,125	299,463	390	11,718	311,181
1.3 COIL COLLARING	51,580	292	6,156	57,744	51,584	292	6,723	58,300	75,776	470	57,999	305	6,670	64,669
2.1 YOKE AND COMPONENTS	75,109	325	9,099	84,207	78,464	325	7,477	85,941	95,390	404	104,242	554	17,321	121,563
2.2 HELIUM CONTAINMENT VESSEL	26,847	121	2,972	29,819	26,846	121	2,782	29,628	26,044	131	8,155	603	24,889	33,044
3.1 COLD MASS SUBASSEMBLY PREP	6,745	126	2,923	9,668	6,745	126	2,890	9,643	24,861	612	6,453	295	12,130	18,582
3.2 20K HEAT SHIELD	7,668	159	3,704	11,372	7,669	159	3,651	11,321	10,756	120	8,036	161	6,502	14,538
3.3 80K HEAT SHIELD	18,254	157	3,668	21,922	18,253	157	3,613	21,066	9,957	120	16,523	249	10,139	26,662
3.4 UPPER VACUUM VESSEL	24,216	122	3,463	27,680	24,217	122	2,801	27,019	37,136	371	96,901	524	22,016	118,997
3.5 LOWER VACUUM VESSEL	12,354	165	4,271	16,624	12,356	165	3,787	16,143	13,701	371	7,661	315	13,247	20,908
3.6 VESSEL ENDS	3,486	109	3,494	6,980	3,486	109	2,512	5,998	0	0	1,933	368	14,893	16,826
4.1 INTERNAL BUS WORK	27,831	433	9,085	36,915	14,926	433	9,950	24,875	5,751	87	11,921	375	15,347	27,260
5.1 INTERCONNECTION REGION PARTS	19,673	185	5,914	25,586	30,240	185	4,250	34,490	42,780	0	27,337	0	0	27,337
5.2 SHIPPING/STORAGE/HANDLING	0	0	0	0	252	0	0	252	270	21	672	42	1,554	2,226
6.1 TESTING	0	0	0	0	0	67	1,546	1,546	0	461	0	0	0	0
6.2 WARM MAGNETIC MEASUREMENTS	0	21	672	672	0	67	1,546	1,546	0	0	0	84	2,503	2,503
6.3 COLD MAGNETIC MEASUREMENTS	1,260	42	1,344	2,604	1,260	34	773	2,033	0	0	0	7	168	168
6.4 CRYOGENIC TESTING FACILITY OPERMS.	0	0	0	0	0	34	773	773	0	0	0	0	0	0
8.1 DIRECT SHOP SUPPORT	0	0	0	0	0	0	0	0	0	259	13,117	0	0	13,117
8.2 MISCEL. AND INDIRECT SHOP SUPPORT	0	871	27,871	27,871	1,600	924	29,568	31,248	5,512	215	0	1,472	49,694	49,694
MATERIAL FACTORS & ALLOWANCES	15,263	0	0	15,263	16,800	0	0	16,800	94,170	0	0	0	0	0
ALLOWANCE FOR REJECTS	9,341	70	1,065	11,206	9,400	84	1,932	11,340	8,864	63	13,117	81	3,024	16,141
SUBTOTAL	587,781	4,716	123,407	711,180	602,400	4,922	121,512	723,992	749,804	5,174	702,035	5,881	213,595	915,630
TOTAL COST FOR TOOLING + DIPOLE MAGNETS	622,785	5,036	134,879	757,664	637,484	5,242	132,985	770,469	765,544	5,433	733,726	5,964	216,246	949,971

- ADDITIONAL FACTORS INCLUDED IN GD EST:
OTHER COSTS - MAGNET FAB. RELATED (GD EST)
PROJECT MANAGEMENT - DIRECT+ENGIN SUPPORT
QUALITY ASSURANCE PROGRAM
TOOLING MAINT., MATL + LABOR
SUBTOTAL (OTHER FAB RELATED)

TOTAL - A + B + C

OTHER 'FACTORS AND ALLOWANCES' (GD EST)
MATERIAL PROCUREMENT EXPENSES (ALLOWANCE)
GRAPHICS/OVERTIME/TRAVEL ALLOWANCE
FEE + COST OF MONEY ALLOWANCE
SUBTOTAL (FACTORS/ALLOWANCES)

440
1,296
1,040
1,840
2,159
767,384 7,591 335,432 1,102,846

59,390
16,760
177,540
253,690

TOTAL COSTS- CONSTR: 1,356,536

Table B-4.1
Design C Magnet Comparisons
Cost Per Each Dipole Magnet

TAC-COG-GD-W comparisons 4

07/85

PER EACH DIPOLE MAGNET - STYLE C
ITEM

WBS)	LABORATORY ESTIMATE (TAC)				CENTRAL DESIGN GROUP ESTIMATE				GENERAL DYNAMICS ESTIMATE				WESTINGHOUSE ESTIMATE			
	MATL \$	LBR HRS	LABOR \$	TOTAL \$	MATL \$	LBR HRS	LABOR \$	TOTAL \$	MATL \$	LBR HRS	LABOR \$	TOTAL \$	MATL \$	LBR HRS	LABOR \$	TOTAL \$
MAGNETS - DIRECT MATLS AND LABOR,																
12. 1.1 COLD BORE TUBE	2171.2	22.0	462.0	2633.2	4735.0	42.1	968.3	5703.3	5391.9	44.2			3450.0	51.1	1390.0	4840.0
1.2 COILS	17403.0	84.0	1764.0	19167.0	15935.8	80.2	1043.7	17779.5	15935.8	80.6			17170.0	39.5	1060.8	18250.8
1.3				0.0				0.0							0.0	0.0
2.1 YOKE AND COMPONENTS	11458.8	105.5	2215.0	13673.8	12453.0	106.9	2450.7	14911.7	12509.2	127.4			13383.0	128.1	4091.6	18274.6
2.2 HELIUM CONTAINMENT VESSEL	2408.0	45.0	960.8	3368.8	1760.0	33.3	765.9	2525.9	1760.0	54.6			3460.0	23.0	946.1	4406.1
3.1 COLD MASS SUBASSEMBLY PREP (6 CRYOSUP)	2264.6	4.5	95.6	2360.2	2264.6	33.0	759.0	3023.6	2719.2	6.5			1740.0	26.9	1029.1	2769.1
3.2 10K HEAT SHIELD	4697.5	3.5	73.5	4771.0	2457.2	56.0	1288.0	3745.2	2457.2	28.6			1320.0	17.5	643.6	1963.6
3.3 80K HEAT SHIELD		54.0	1134.0	1134.0	3632.4	10.0	230.0	3862.4	3632.4	20.6			1290.0	17.5	727.0	2017.0
3.4 VACUUM VESSEL	5931.2	15.2	318.5	6249.7	3855.2	61.0	1403.0	5258.2	6351.0	05.0			10462.0	92.1	3791.0	14253.0
3.5				0.0				0.0							0.0	0.0
3.6				0.0				0.0							0.0	0.0
4.1 INTERNAL BUS WORK				0.0	7300.0	40.0	920.0	8300.0	952.3	22.1			1556.0	45.3	1849.6	3405.6
5.1 INTERCONNECTION REGION PARTS				0.0	200.0			200.0	10630.0				2350.0		0.0	2350.0
5.2 SHIPPING/STORAGE/HANDLING				0.0	61.2	6.0	130.0	199.2	61.2	4.4			160.0	8.0	296.0	456.0
6.1 TESTING				0.0		8.0	184.0	184.0	0.0	128.0					0.0	0.0
6.2 WARM MAGNETIC MEASUREMENTS				0.0		16.0	368.0	368.0	0.0					16.6	489.4	409.4
6.3 COLD MAGNETIC MEASUREMENTS				0.0		8.0	184.0	184.0	0.0					1.2	30.7	30.7
6.4 CRYOGENIC TESTING FACILITY OPERNS.				0.0	150.0	8.0	184.0	334.0	0.0						0.0	0.0
0.1 DIRECT SHOP SUPPORT				0.0				0.0	0.0	31.8				225.5	7566.0	7566.0
0.2 MISCEL. AND INDIRECT SHOP SUPPORT	84.0		2608.0	2608.0	200.0	120.0	3040.0	4040.0	3406.8						0.0	0.0
MATERIAL FACTORS & ALLOWANCES				0.0	1200.0			1200.0	11947.5						0.0	0.0
ALLOWANCE FOR REJECTS				0.0	1020.0	10.0	230.0	1250.0	1020.0	8.1			1090.0	8.6	317.5	1407.5
SUBTOTAL	46334.3	410.5	9711.4	56045.7	57304.4	638.5	15764.6	73069.0	78774.5	650.7			57431.0	701.1	25048.4	82479.4

Design C Magnet Comparisons

Total Dipole Magnet Costs for Tooling and Full Production

TAC-CDG-GD-W comparisons 4

1/07/05 PER 4000 DIPOLE MAGNETS - STYLE C ITEM (WBS)	TAC COST ESTIMATE				CENTRAL DESIGN GROUP ESTIMATE				GENERAL DYNAMICS ESTIMATE				WESTINGHOUSE ESTIMATE			
	HATL K\$	LDR KHRS	LADOR K\$	TOTAL K\$	HATL K\$	LDR KHRS	LADOR K\$	TOTAL K\$	HATL K\$	LDR KHRS	LADOR K\$	TOTAL K\$	HATL K\$	LDR KHRS	LADOR K\$	TOTAL K\$
TOOLING - DIRECT																
1211. 1.1 COIL PRODUCTION	15,000			15,000				0					2,721	11	365	0
1.2 YOKES, COLLARS, HE CONTN.				0				0					9,450	10	592	10,042
1.3 ELECTRICAL SYSTEMS				0				0								0
1.4 FINAL ASSEMBLY - CRYOSTAT				0				0					3,261			3,261
1.5 TESTING AND MEASUREMENTS				0				0					706			706
SUBTOTAL (MAGNET 'TOOLING' DIRECT)	4 15,000	0	0	15,000	14,560	417	8,340	22,900	14,560	169			16,130	30	957	17,095
MAGNETS - DIRECT HATLS AND LABOR.																
1212. 1.1 COLD BORE TUBE	8,605	80	1,040	10,533	10,940	160	3,873	22,013	21,560	177			13,800	205	5,560	19,360
1.2 COILS	69,612	336	7,056	76,668	63,743	321	7,375	71,110	63,743	322			60,600	150	4,323	73,003
1.3	0	0	0	0	0	0	0	0	0	0			0	0	0	0
2.1 YOKE AND COMPONENTS	45,835	422	8,860	54,695	49,812	420	9,835	59,647	50,037	510			53,532	512	19,566	73,098
2.2 HELIUM CONTAINMENT VESSEL	9,632	183	3,843	13,475	7,040	133	3,064	10,104	7,040	218			13,840	92	3,784	17,624
3.1 COLD MASS SUBASSEMBLY PREP (S CRYOSUP)	9,058	18	382	9,441	9,058	132	3,036	12,094	10,877	26			6,960	100	4,116	11,076
3.2 10K HEAT SHIELD	18,790	14	294	19,084	9,029	224	5,152	14,981	9,029	114			5,200	70	2,574	7,854
3.3 80K HEAT SHIELD	0	216	4,536	4,536	14,530	40	920	15,450	14,530	114			5,160	70	2,908	8,068
3.4 VACUUM VESSEL	23,725	61	1,274	24,999	15,421	244	5,612	21,033	25,404	343			41,040	369	15,164	57,012
3.5	0	0	0	0	0	0	0	0	0	0			0	0	0	0
3.6	0	0	0	0	0	0	0	0	0	0			0	0	0	0
4.1 INTERNAL BUS WORK	0	0	0	0	29,520	160	3,600	33,200	3,809	80			6,224	181	7,390	13,622
5.1 INTERCONNECTION REGION PARTS	0	0	0	0	800	0	0	800	42,520	0			9,400	0	0	9,400
5.2 SHIPPING/STORAGE/HANDLING	0	0	0	0	245	24	552	797	245	18			640	32	1,104	1,024
6.1 TESTING	0	0	0	0	0	32	736	736	0	512			0	0	0	0
6.2 WARM MAGNETIC MEASUREMENTS	0	0	0	0	0	64	1,472	1,472	0	0			0	66	1,950	1,950
6.3 COLD MAGNETIC MEASUREMENTS	0	0	0	0	0	32	736	736	0	0			0	5	123	123
6.4 CRYOGENIC TESTING FACILITY OPERNS.	0	0	0	0	600	32	736	1,336	0	0			0	0	0	0
8.1 DIRECT SHOP SUPPORT	0	0	0	0	0	0	0	0	0	127			0	902	30,264	30,264
8.2 MISCEL. AND INDIRECT SHOP SUPPORT	0	336	10,752	10,752	800	400	15,360	16,160	13,627	0			0	0	0	0
MATERIAL FACTORS & ALLOWANCES	0	0	0	0	4,000	0	0	4,000	47,790	0			0	0	0	0
ALLOWANCE FOR REJECTS	0	0	0	0	4,000	40	920	5,000	4,000	32			4,360	35	1,270	5,630
SUBTOTAL	185,337	1,674	30,846	224,183	229,218	2,554	63,058	292,276	315,098	2,603			229,724	2,804	100,194	329,911
TOTAL COST FOR TOOLING + DIPOLE MAGNETS	200,337	1,674	30,846	239,183	243,778	2,971	71,390	315,176	329,658	2,772			245,062	2,834	101,150	347,011
- ADDITIONAL FACTORS INCLUDED IN GD EST:																
OTHER COSTS - MAGNET FAB. RELATED (GD EST)																
PROJECT MANAGEMENT - DIRECT+ENGIN SUPPORT																
QUALITY ASSURANCE PROGRAM																
TOOLING MAINT., HATL + LABOR																
SUBTOTAL (OTHER FAB RELATED)																
TOTAL - A + B + C																
OTHER 'FACTORS AND ALLOWANCES' (GD EST)																
MATERIAL PROCUREMENT EXPENSES (ALLOWANCE)																
GRAPHICS/OVERTIME/TRAVEL ALLOWANCE																
FEE + COST OF MONEY ALLOWANCE																
SUBTOTAL (FACTORS/ALLOWANCES)																
TOTAL COSTS - CONSTR:																
628,939																

8/07/85

Table B-5.1
Design C* Magnet Comparisons
Cost Per Each Dipole Magnet

PER EACH DIPOLE MAGNET - STYLE C* (1-IN-1)
ITEM

		LABORATORY ESTIMATE				(TAC)	CENTRAL DESIGN GROUP ESTIMATE			
(WBS)		MATL \$	LBR HRS	LABOR \$	TOTAL \$		MATL \$	LBR HRS	LABOR \$	TOTAL \$
B	MAGNETS - DIRECT MATLS AND LABOR,								23.0	
14212.1.1	COLD BORE TUBE	1085.6	11.0	231.0	1316.6		2367.5	21.0	483.0	2850.5
1.2	COILS	8701.5	42.0	882.0	9583.5		7968.0	40.1	922.3	8890.3
1.3					0.0					0.0
2.1	YOKE AND COMPONENTS	6997.2	79.5	1669.5	8666.7		7353.0	81.0	1863.0	9216.0
2.2	HELIUM CONTAINMENT VESSEL	3547.2	36.0	756.0	4303.2		2760.0	30.0	690.0	3450.0
3.1	COLD MASS SUBASSEMBLY PREP (6 CRYOSUP)	1900.2	4.5	95.6	1995.8		1900.2	30.0	690.0	2590.2
3.2	10K HEAT SHIELD	4318.0	3.0	63.0	4381.0		2400.0	50.0	1150.0	3550.0
3.3	80K HEAT SHIELD		56.2	1180.6	1180.6		3600.0	8.0	184.0	3784.0
3.4	VACUUM VESSEL	4421.4	15.2	318.6	4740.0		5345.4	61.0	1403.0	6748.4
3.5					0.0					0.0
3.6					0.0					0.0
4.1	INTERNAL BUS WORK				0.0		3690.0	20.0	460.0	4150.0
5.1	INTERCONNECTION REGION PARTS				0.0		200.0			200.0
5.2	SHIPPING/STORAGE/HANDLING				0.0		61.2	6.0	138.0	199.2
6.1	TESTING				0.0			6.0	138.0	138.0
6.2	WARM MAGNETIC MEASUREMENTS				0.0			8.0	184.0	184.0
6.3	COLD MAGNETIC MEASUREMENTS				0.0			4.0	92.0	92.0
6.4	CRYOGENIC TESTING FACILITY OPERNS.				0.0		150.0	4.0	92.0	242.0
8.1	DIRECT SHOP SUPPORT				0.0					0.0
8.2	MISC. AND INDIRECT SHOP SUPPORT		61.0	1952.0	1952.0		100.0	84.0	2688.0	2788.0
	MATERIAL FACTORS & ALLOWANCES				0.0		800.0			800.0
	ALLOWANCE FOR REJECTS				0.0		510.0	5.0	115.0	625.0
	SUBTOTAL	30971.1	308.4	7148.3	38119.4		39205.3	458.1	11292.3	50497.6

Design C* Magnet Comparisons

Total Dipole Magnet Costs for Tooling and Full Production

8/07/85		TAC COST ESTIMATE				CENTRAL DESIGN GROUP ESTIMATE			
(WBS)	ITEM	MATL K\$	LBR KHRS	LABOR K\$	TOTAL K\$	MATL K\$	LBR KHRS	LABOR K\$	TOTAL K\$
A	TOOLING - DIRECT								
14211.	1.1 COIL PRODUCTION	15,000			15,000				0
	1.2 YOKES, COLLARS, HE CONTN.				0				0
	1.3 ELECTRICAL SYSTEMS				0				0
	1.4 FINAL ASSEMBLY - CRYOSTAT				0				0
	1.5 TESTING AND MEASUREMENTS				0				0
	SUBTOTAL (MAGNET 'TOOLING' DIRECT)	15,000	0	0	15,000	14,560	417	8,340	22,900
B	MAGNETS - DIRECT MATLS AND LABOR,								
14212.	1.1 COLD BORE TUBE	8,685	88	1,840	10,533	18,940	168	3,864	22,804
	1.2 COILS	69,612	336	7,056	76,668	63,744	321	7,378	71,122
	1.3	0	0	0	0	0	0	0	0
	2.1 YOKE AND COMPONENTS	55,978	636	13,356	69,334	58,824	640	14,904	73,728
	2.2 HELIUM CONTAINMENT VESSEL	28,378	288	6,048	34,426	22,080	240	5,520	27,600
	3.1 COLD MASS SUBASSEMBLY PREP (6 CRYOSUP)	15,202	36	765	15,966	15,202	240	5,520	20,722
	3.2 10K HEAT SHIELD	34,544	24	504	35,048	19,200	400	9,200	28,400
	3.3 80K HEAT SHIELD	0	450	9,445	9,445	28,800	64	1,472	30,272
	3.4 VACUUM VESSEL	35,371	122	2,549	37,920	42,763	488	11,224	53,987
	3.5	0	0	0	0	0	0	0	0
	3.6	0	0	0	0	0	0	0	0
	4.1 INTERNAL BUS WORK	0	0	0	0	29,520	160	3,680	33,200
	5.1 INTERCONNECTION REGION PARTS	0	0	0	0	1,600	0	0	1,600
	5.2 SHIPPING/STORAGE/HANDLING	0	0	0	0	490	48	1,104	1,594
	6.1 TESTING	0	0	0	0	0	48	1,104	1,104
	6.2 WARM MAGNETIC MEASUREMENTS	0	0	0	0	0	64	1,472	1,472
	6.3 COLD MAGNETIC MEASUREMENTS	0	0	0	0	0	32	736	736
	6.4 CRYOGENIC TESTING FACILITY OPERNS.	0	0	0	0	1,200	32	736	1,936
	8.1 DIRECT SHOP SUPPORT	0	0	0	0	0	0	0	0
	8.2 MISCEL. AND INDIRECT SHOP SUPPORT	0	488	15,616	15,616	800	672	21,504	22,304
	MATERIAL FACTORS & ALLOWANCES	0	0	0	0	6,400	0	0	6,400
	ALLOWANCE FOR REJECTS	0	0	0	0	4,080	40	920	5,000
	SUBTOTAL	247,769	2,467	57,186	304,955	313,642	3,665	90,338	403,981
	TOTAL COST FOR TOOLING + DIPOLE MAGNETS	262,769	2,467	57,186	319,955	328,202	4,082	98,678	426,881

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APPENDIX C
MAGNET APERTURE SCALING FACTORS

In order to make the adjustment for required aperture, a study was made to examine the cost effect for a 1 cm aperture or gap perturbation for each of the magnet styles. An appropriate scaling factor at each "level 7" cost table entry was applied separately for materials and labor. Tables C-1 through C-5 show the individual scaling factors applied for each of the magnet styles. These individual factors for the cosine theta styles were obtained from a BNL program that was used to develop cosine theta costs for various magnet apertures. For the superferric styles, we used a geometric scaling relationship and approximated the various entries accordingly.

The resulting total cost was then derived and used to determine a normalized overall aperture scaling factor for a 1.0 cm increase/decrease for each of the styles. The resulting overall aperture scaling factors are shown below for the dipoles.

Table C-6
Dipole Magnet Scaling Factors for a 1 cm Aperture Perturbation

Magnet Style:	A	B	D	C	C*
unadjusted aperture (cm)	4	5	4	2.54	2.54
perturbed aperture (cm)	5	4	5	3.54	3.54
Dipole Cost (unperturbed)	153023	59214	86190	73069	50498
Dipole Cost (perturbed)	179241	52672	100123	99030	67885
Dipole aperture cost factor	1.171	0.890	1.162	1.355	1.344

Table C-1
Style A - Magnet Aperture Scaling Factors
(FY85 \$)

UNIT COSTS PER DIPOLE MAGNET		APERTURE SCALING FACTORS:				MAT'L FACT	LABOR FACT
ITEM:		COS THETA STYLE A (4 CM REF) CENTRAL DESIGN GROUP ESTIMATE					(5 CM)
(WBS)		MATL \$	LBR HRS	LABOR \$	TOTAL \$		TOTAL \$
C	MAGNETS - DIRECT MATLS AND LABOR						
14212.	1.1 COLD BORE TUBE	5273.0	68.5	1575.5	6848.5	1.25	1.00 8166.8
	1.2 COILS	65750.0	292.9	6736.7	72486.7	1.16	1.10 83516.8
	1.3 COIL COLLARING	12282.8	69.6	1600.8	13883.6	1.51	1.00 20111.0
	2.1 YOKE AND COMPONENTS	15870.0	43.6	1002.8	16872.8	1.27	1.06 21247.6
	2.2 HELIUM CONTAINMENT VESSEL	5444.6	16.6	381.8	5826.4	1.26	1.07 7262.5
	3.1 COLD MASS SUBASSEMBLY PREP	832.2	15.3	351.9	1184.1	1.02	1.02 1204.7
	3.2 20K HEAT SHIELD	912.9	18.9	434.7	1347.6	1.00	1.00 1347.6
	3.3 80K HEAT SHIELD	2558.4	18.7	430.1	2988.5	1.07	1.00 3172.7
	3.4 UPPER VACUUM VESSEL	3562.8	14.5	333.5	3896.3	1.09	1.00 4217.0
	3.5 LOWER VACUUM VESSEL	1744.6	19.6	450.8	2195.4	1.07	1.00 2317.5
	3.6 VESSEL ENDS	475.5	13.0	299.0	774.5	1.06	1.00 803.0
	4.1 INTERNAL BUS WORK	3553.7	103.0	2369.0	5922.7	1.00	1.00 5922.7
	5.1 INTERCONNECTION REGION PARTS	5000.0	22.0	506.0	5506.0	1.04	1.00 5701.0
	5.2 SHIPPING/STORAGE/HANDLING	30.0	0.0	0.0	30.0	1.00	1.00 30.0
	6.1 TESTING	0.0	8.0	184.0	184.0	1.00	1.00 184.0
	6.2 WARM MAGNETIC MEASUREMENTS	0.0	16.0	368.0	368.0	1.00	1.00 368.0
	6.3 COLD MAGNETIC MEASUREMENTS	150.0	8.0	184.0	334.0	1.00	1.00 334.0
	6.4 CRYOGENIC TESTING FACILITY OPERNS.	0.0	4.0	92.0	92.0	1.00	1.00 92.0
	8.1 DIRECT SHOP SUPPORT	0.0	0.0	0.0	0.0	1.00	1.00 0.0
	8.2 MISCEL. AND INDIRECT SHOP SUPPORT	200.0	180.0	5760.0	5960.0	1.00	1.00 5960.0
	MATERIAL FACTORS & ALLOWANCES	4000.0	0.0	0.0	4000.0	1.16	1.00 4640.0
	ALLOWANCE FOR REJECTS	2000.0	14.0	322.0	2322.0	1.16	1.00 2642.0
	TOTALS	129640.5	946.2	23382.6	153023.1		179240.9
						5 CM/4 CM RATIO:	1.171

Table C-2
Style B - Magnet Aperture Scaling Factors
(FY85 \$)

UNIT COSTS PER DIPOLE MAGNET		APERTURE SCALING FACTORS:				MAT'L	LABOR
ITEM:		COS THETA STYLE B (5 CM REF)				FACT	FACT
		CENTRAL DESIGN GROUP ESTIMATE					(4 CM)
		MATL \$	LBR HRS	LABOR \$	TOTAL \$		TOTAL \$
MAGNETS - DIRECT MATLS AND LABOR							
1.1	COLD BORE TUBE	410.0	30.0	690.0	1100.0	.80	1.00 1018.8
1.2	COILS	23488.0	120.0	2760.0	26248.0	.86	.91 22791.4
1.3	COIL COLLARING	3941.0	30.0	690.0	4631.0	.66	1.00 3306.8
2.1	YOKE AND COMPONENTS	0.0	0.0	0.0	0.0	1.00	1.00 0.0
2.2	HELIUM CONTAINMENT VESSEL	2186.0	44.0	1012.0	3198.0	.79	.94 2683.9
3.1	COLD MASS SUBASSEMBLY PREP	7534.0	0.0	0.0	7534.0	.90	1.00 6780.6
3.2	20K HEAT SHIELD	2342.0	0.0	0.0	2342.0	.95	1.00 2224.9
3.3	80K HEAT SHIELD	1064.2	42.8	984.4	2048.7	1.00	1.00 2048.7
3.4	UPPER VACUUM VESSEL	0.0	31.4	722.2	722.2	1.00	1.00 722.2
3.5	LOWER VACUUM VESSEL	0.0	0.0	0.0	0.0	1.00	1.00 0.0
3.6	VESSEL ENDS	0.0	61.2	1407.6	1407.6	1.00	1.00 1407.6
4.1	INTERNAL BUS WORK	560.0	5.0	115.0	675.0	1.00	1.00 675.0
5.1	INTERCONNECTION REGION PARTS	2700.0	20.0	460.0	3160.0	.96	1.00 3057.4
5.2	SHIPPING/STORAGE/HANDLING	30.0	0.0	0.0	30.0	1.00	1.00 30.0
6.1	TESTING	0.0	8.0	184.0	184.0	1.00	1.00 184.0
6.2	WARM MAGNETIC MEASUREMENTS	0.0	8.0	184.0	184.0	1.00	1.00 184.0
6.3	COLD MAGNETIC MEASUREMENTS	150.0	4.0	92.0	242.0	1.00	1.00 242.0
6.4	CRYOGENIC TESTING FACILITY OPERNS.	0.0	4.0	92.0	92.0	1.00	1.00 92.0
8.1	DIRECT SHOP SUPPORT	0.0	0.0	0.0	0.0	1.00	1.00 0.0
8.2	MISCEL. AND INDIRECT SHOP SUPPORT	0.0	100.0	3200.0	3200.0	1.00	1.00 3200.0
MATERIAL FACTORS & ALLOWANCES		1380.0	0.0	0.0	1380.0	.86	1.00 1186.8
ALLOWANCE FOR REJECTS		675.0	7.0	161.0	836.0	1.00	1.00 836.0
TOTALS		46460.2	515.4	12754.2	59214.4		52672.2
4 CM/5 CM RATIO:							.890

Table C-3
Style D - Magnet Aperture Scaling Factors
(FY85 \$)

UNIT COSTS PER DIPOLE MAGNET		APERTURE SCALING FACTORS:				MAT'L FACT	LABOR FACT
ITEM:		COS THETA STYLE D (4 CM REF) CENTRAL DESIGN GROUP ESTIMATE					(5 CM)
(WBS)		MATL \$	LBR HRS	LABOR \$	TOTAL \$		TOTAL \$
C	MAGNETS - DIRECT MATLS AND LABOR						
14212.	1.1 COLD BORE TUBE	2636.0	34.3	788.9	3424.9	1.25	1.00 4083.9
	1.2 COILS	32875.0	146.5	3369.5	36244.5	1.16	1.10 41759.7
	1.3 COIL COLLARING	6141.0	34.8	800.4	6941.4	1.51	1.00 10054.9
	2.1 YOKE AND COMPONENTS	9341.0	38.7	890.1	10231.1	1.27	1.06 12823.5
	2.2 HELIUM CONTAINMENT VESSEL	3196.0	14.4	331.2	3527.2	1.26	1.07 4377.5
	3.1 COLD MASS SUBASSEMBLY PREP	803.0	15.0	345.0	1148.0	1.02	1.02 1168.0
	3.2 20K HEAT SHIELD	913.0	18.9	434.7	1347.7	1.00	1.00 1347.7
	3.3 80K HEAT SHIELD	2173.0	18.7	430.1	2603.1	1.07	1.00 2759.6
	3.4 UPPER VACUUM VESSEL	2883.0	14.5	333.5	3216.5	1.09	1.00 3476.0
	3.5 LOWER VACUUM VESSEL	1471.0	19.6	450.8	1921.8	1.07	1.00 2024.8
	3.6 VESSEL ENDS	415.0	13.0	299.0	714.0	1.06	1.00 738.9
	4.1 INTERNAL BUS WORK	1776.9	51.5	1184.5	2961.4	1.00	1.00 2961.4
	5.1 INTERCONNECTION REGION PARTS	3600.0	22.0	506.0	4106.0	1.04	1.00 4246.4
	5.2 SHIPPING/STORAGE/HANDLING	30.0	0.0	0.0	30.0	1.00	1.00 30.0
	6.1 TESTING	0.0	8.0	184.0	184.0	1.00	1.00 184.0
	6.2 WARM MAGNETIC MEASUREMENTS	0.0	8.0	184.0	184.0	1.00	1.00 184.0
	6.3 COLD MAGNETIC MEASUREMENTS	150.0	4.0	92.0	242.0	1.00	1.00 242.0
	6.4 CRYOGENIC TESTING FACILITY OPERNS.	0.0	4.0	92.0	92.0	1.00	1.00 92.0
	8.1 DIRECT SHOP SUPPORT	0.0	0.0	0.0	0.0	1.00	1.00 0.0
	8.2 MISCEL. AND INDIRECT SHOP SUPPORT	200.0	110.0	3520.0	3720.0	1.00	1.00 3720.0
	MATERIAL FACTORS & ALLOWANCES	2000.0	0.0	0.0	2000.0	1.16	1.00 2320.0
	ALLOWANCE FOR REJECTS	1120.0	10.0	230.0	1350.0	1.16	1.00 1529.2
	TOTALS	71723.9	585.9	14465.7	86189.6		100123.3
						5 CM/4 CM RATIO:	1.162

Table C-4
Style C - Magnet Aperture Scaling Factors
(FY85 \$)

UNIT COSTS PER DIPOLE MAGNET		APERTURE SCALING FACTORS:				MAT'L	LABOR
ITEM:		SUPERFERRIC STYLE C (2.54 CM GAP)				FACT	FACT
		CENTRAL DESIGN GROUP ESTIMATE					(3.54CM GAP)
		MATL \$	LEB HRS	LABOR \$	TOTAL \$		TOTAL \$
MAGNETS - DIRECT MATLS AND LABOR							
2. 1.1	COLD BORE TUBE	4735.0	42.1	968.3	5703.3	1.40	1.20 7791.0
1.2	COILS	15935.8	80.2	1843.7	17779.5	1.40	1.00 24153.8
1.3		0.0	0.0	0.0	0.0	1.00	1.00 0.0
2.1	YOKE AND COMPONENTS	12453.0	106.9	2458.7	14911.7	2.00	1.20 27856.4
2.2	HELIUM CONTAINMENT VESSEL	1760.0	33.3	765.9	2525.9	1.40	1.20 3383.1
3.1	COLD MASS SUBASSEMBLY PREP (6 CRYOSUP)	2264.6	33.0	759.0	3023.6	1.20	1.20 3628.3
3.2	10K HEAT SHIELD	2457.2	56.0	1288.0	3745.2	1.20	1.00 4236.6
3.3	80K HEAT SHIELD	3632.4	10.0	230.0	3862.4	1.20	1.00 4588.9
3.4	VACUUM VESSEL	3855.2	61.0	1403.0	5258.2	1.40	1.20 7080.9
3.5		0.0	0.0	0.0	0.0	1.00	1.00 0.0
3.6		0.0	0.0	0.0	0.0	1.00	1.00 0.0
4.1	INTERNAL BUS WORK	7380.0	40.0	920.0	8300.0	1.00	1.00 8300.0
5.1	INTERCONNECTION REGION PARTS	200.0	0.0	0.0	200.0	1.20	1.00 240.0
5.2	SHIPPING/STORAGE/HANDLING	61.2	6.0	138.0	199.2	1.20	1.00 211.4
6.1	TESTING	0.0	8.0	184.0	184.0	1.00	1.00 184.0
6.2	WARM MAGNETIC MEASUREMENTS	0.0	16.0	368.0	368.0	1.00	1.00 368.0
6.3	COLD MAGNETIC MEASUREMENTS	0.0	8.0	184.0	184.0	1.00	1.00 184.0
6.4	CRYOGENIC TESTING FACILITY OPERNS.	150.0	8.0	184.0	334.0	1.00	1.00 334.0
8.1	DIRECT SHOP SUPPORT	0.0	0.0	0.0	0.0	1.00	1.00 0.0
8.2	MISCEL. AND INDIRECT SHOP SUPPORT	200.0	120.0	3840.0	4040.0	1.00	1.00 4040.0
	MATERIAL FACTORS & ALLOWANCES	1200.0	0.0	0.0	1200.0	1.00	1.00 1200.0
	ALLOWANCE FOR REJECTS	1020.0	10.0	230.0	1250.0	1.00	1.00 1250.0
TOTALS		57304.4	638.5	15764.6	73069.0		99030.4
						3.54 CM GAP/2.54 CM GAP: 1.355	

Table C-5
Style C* - Magnet Aperture Scaling Factors
(FY85 \$)

UNIT COSTS PER DIPOLE MAGNET		APERTURE SCALING FACTORS:				MAT'L	LABOR
ITEM:		SUPERFERRIC STYLE C*(2.54 CM GAP)				FACT	FACT
		CENTRAL DESIGN GROUP ESTIMATE				(3.54CM GAP)	
(WBS)		MATL \$	LBR HRS	LABOR \$	TOTAL \$		TOTAL \$
C	MAGNETS - DIRECT MATLS AND LABOR						
14212.	1.1 COLD BORE TUBE	2367.5	21.0	483.0	2850.5	1.40	1.20 3894.1
	1.2 COILS	7968.0	40.1	922.3	8890.3	1.40	1.00 12077.5
	1.3	0.0	0.0	0.0	0.0	1.00	1.00 0.0
	2.1 YOKE AND COMPONENTS	7353.0	81.0	1863.0	9216.0	2.00	1.20 16941.6
	2.2 HELIUM CONTAINMENT VESSEL	2760.0	30.0	690.0	3450.0	1.40	1.20 4692.0
	3.1 COLD MASS SUBASSEMBLY PREP (6 CRYOSUP)	1900.2	30.0	690.0	2590.2	1.20	1.20 3108.2
	3.2 10K HEAT SHIELD	2400.0	50.0	1150.0	3550.0	1.20	1.00 4030.0
	3.3 80K HEAT SHIELD	3600.0	8.0	184.0	3784.0	1.20	1.00 4504.0
	3.4 VACUUM VESSEL	5345.4	61.0	1403.0	6748.4	1.40	1.20 9167.2
	3.5	0.0	0.0	0.0	0.0	1.00	1.00 0.0
	3.6	0.0	0.0	0.0	0.0	1.00	1.00 0.0
	4.1 INTERNAL BUS WORK	3690.0	20.0	460.0	4150.0	1.00	1.00 4150.0
	5.1 INTERCONNECTION REGION PARTS	200.0	0.0	0.0	200.0	1.20	1.00 240.0
	5.2 SHIPPING/STORAGE/HANDLING	61.2	6.0	138.0	199.2	1.20	1.00 211.4
	6.1 TESTING	0.0	6.0	138.0	138.0	1.00	1.00 138.0
	6.2 WARM MAGNETIC MEASUREMENTS	0.0	8.0	184.0	184.0	1.00	1.00 184.0
	6.3 COLD MAGNETIC MEASUREMENTS	0.0	4.0	92.0	92.0	1.00	1.00 92.0
	6.4 CRYOGENIC TESTING FACILITY OPERNS.	150.0	4.0	92.0	242.0	1.00	1.00 242.0
	8.1 DIRECT SHOP SUPPORT	0.0	0.0	0.0	0.0	1.00	1.00 0.0
	8.2 MISCEL. AND INDIRECT SHOP SUPPORT	100.0	84.0	2688.0	2788.0	1.00	1.00 2788.0
	MATERIAL FACTORS & ALLOWANCES	800.0	0.0	0.0	800.0	1.00	1.00 800.0
	ALLOWANCE FOR REJECTS	510.0	5.0	115.0	625.0	1.00	1.00 625.0
	TOTALS	39205.3	458.1	11292.3	50497.6		67885.0
						3.54 CM GAP/2.54 CM GAP: 1.344	

APPENDIX D DIPOLE MAGNET CONTINGENCIES

The following tables show the contingency factors that were developed for the various styles of the dipole magnets. Magnet Styles A, B, D, C, and C* are represented on Tables D-1 through D-5 respectively. The method used is to apply a separate contingency factor percentage to each detail "level 7" WBS category; individual factors were applied to material costs and labor costs. As will be noted in the tables, the percentage values ranged from 10% to 35%.

An individual assessment was made of the general design status and level of detail cost information available for each WBS entry. The lowest contingency values were assigned to the items fairly well developed and costed: superconducting cable unit costs (10%), lamination costs on a dollar per pound of steel and a per piece stamping cost basis, cryostat shield components, and vacuum vessel materials (15%). The highest costs were assigned to the overall labor (35% used for all of the labor in this study) to account for uncertainties in not only the direct labor quantities (hours) but also such variable factors as productivity factors, labor rate variations, etc. The tables show total contingency dollars calculated for each of the various magnet styles. At the bottom of each table a net effective contingency percentage is shown; this value is treated as an overall dipole magnet contingency factor and represents the weighted average of the individual factors applied directly.

Table D-1
Style A - Magnet Contingency Factors
(FY85 \$)

UNIT COSTS PER DIPOLE MAGNET		CONTINGENCY ANALYSIS				MAT'L	LABOR
ITEM:		COS THETA STYLE A CENTRAL DESIGN GROUP ESTIMATE				\$	\$
(WBS)		MAT'L \$	LBR HRS	LABOR \$	TOTAL \$	CS	CONTING\$
C	MAGNETS - DIRECT MATLS AND LABOR,						
14212.	1.1 COLD BORE TUBE	5273.0	68.5	1575.5	6848.5	25	35 1869.7
	1.2 COILS	65750.0	292.9	6736.7	72486.7	10	35 8932.8
	1.3 COIL COLLARING	12282.8	69.6	1600.8	13883.6	25	35 3631.0
	2.1 YOKE AND COMPONENTS	15870.0	43.6	1002.8	16872.8	15	35 2731.5
	2.2 HELIUM CONTAINMENT VESSEL	5444.6	16.6	381.8	5826.4	15	35 950.3
	3.1 COLD MASS SUBASSEMBLY PREP	832.2	15.3	351.9	1184.1	25	35 331.2
	3.2 20K HEAT SHIELD	912.9	18.9	434.7	1347.6	15	35 289.1
	3.3 80K HEAT SHIELD	2558.4	18.7	430.1	2988.5	15	35 534.3
	3.4 UPPER VACUUM VESSEL	3562.8	14.5	333.5	3896.3	15	35 651.1
	3.5 LOWER VACUUM VESSEL	1744.6	19.6	450.8	2195.4	15	35 419.5
	3.6 VESSEL ENDS	475.5	13.0	299.0	774.5	15	35 176.0
	4.1 INTERNAL BUS WORK	3553.7	103.0	2369.0	5922.7	25	35 1717.6
	5.1 INTERCONNECTION REGION PARTS	5000.0	22.0	506.0	5506.0	25	35 1427.1
	5.2 SHIPPING/STORAGE/HANDLING	30.0	0.0	0.0	30.0	25	35 7.5
	6.1 TESTING	0.0	8.0	184.0	184.0	25	35 64.4
	6.2 WARM MAGNETIC MEASUREMENTS	0.0	16.0	368.0	368.0	25	35 128.8
	6.3 COLD MAGNETIC MEASUREMENTS	150.0	8.0	184.0	334.0	25	35 101.9
	6.4 CRYOGENIC TESTING FACILITY OPERNS.	0.0	4.0	92.0	92.0	25	35 32.2
	8.1 DIRECT SHOP SUPPORT	0.0	0.0	0.0	0.0	25	35 0.0
	8.2 MISCEL. AND INDIRECT SHOP SUPPORT	200.0	180.0	5760.0	5960.0	25	35 2066.0
	MATERIAL FACTORS & ALLOWANCES	4000.0	0.0	0.0	4000.0	25	35 1000.0
	ALLOWANCE FOR REJECTS	2000.0	14.0	322.0	2322.0	25	35 612.7
	TOTALS	129640.5	946.2	23382.6	153023.1		27674.7
						CONTING. %:	18.1

Table D-2
Style B - Magnet Contingency Factors
(FY85 \$)

UNIT COSTS PER DIPOLE MAGNET		CONTINGENCY ANALYSIS				MAT'L	LABOR	CONTING\$
ITEM:		COS THETA STYLE B CENTRAL DESIGN GROUP ESTIMATE				\$	\$	
		MATL \$	LBR HRS	LABOR \$	TOTAL \$			
MAGNETS - DIRECT MATLS AND LABOR,								
2. 1.1	COLD BORE TUBE	410.0	30.0	690.0	1100.0	25	35	344.0
1.2	COILS	23488.0	120.0	2760.0	26248.0	10	35	3314.8
1.3	COIL COLLARING	3941.0	30.0	690.0	4631.0	25	35	1226.8
2.1	YOKE AND COMPONENTS	0.0	0.0	0.0	0.0	15	35	0.0
2.2	HELIUM CONTAINMENT VESSEL	2186.0	44.0	1012.0	3198.0	15	35	682.1
3.1	COLD MASS SUBASSEMBLY PREP	7534.0	0.0	0.0	7534.0	25	35	1883.5
3.2	20K HEAT SHIELD	2342.0	0.0	0.0	2342.0	15	35	351.3
3.3	80K HEAT SHIELD	1064.2	42.8	984.4	2048.7	15	35	504.2
3.4	UPPER VACUUM VESSEL	0.0	31.4	722.2	722.2	15	35	252.8
3.5	LOWER VACUUM VESSEL	0.0	0.0	0.0	0.0	15	35	0.0
3.6	VESSEL ENDS	0.0	61.2	1407.6	1407.6	15	35	492.7
4.1	INTERNAL BUS WORK	560.0	5.0	115.0	675.0	25	35	180.2
5.1	INTERCONNECTION REGION PARTS	2700.0	20.0	460.0	3160.0	25	35	836.0
5.2	SHIPPING/STORAGE/HANDLING	30.0	0.0	0.0	30.0	25	35	7.5
6.1	TESTING	0.0	8.0	184.0	184.0	25	35	64.4
6.2	WARM MAGNETIC MEASUREMENTS	0.0	8.0	184.0	184.0	25	35	64.4
6.3	COLD MAGNETIC MEASUREMENTS	150.0	4.0	92.0	242.0	25	35	69.7
6.4	CRYOGENIC TESTING FACILITY OPERNS.	0.0	4.0	92.0	92.0	25	35	32.2
8.1	DIRECT SHOP SUPPORT	0.0	0.0	0.0	0.0	25	35	0.0
8.2	MISCEL. AND INDIRECT SHOP SUPPORT	0.0	100.0	3200.0	3200.0	25	35	1120.0
	MATERIAL FACTORS & ALLOWANCES	1380.0	0.0	0.0	1380.0	25	35	345.0
	ALLOWANCE FOR REJECTS	675.0	7.0	161.0	836.0	25	35	225.1
TOTALS		46460.2	515.4	12754.2	59214.4			11996.6
CONTING. \$:								20.3

Table D-3
Style D - Magnet Contingency Factors
(FY85 \$)

UNIT COSTS PER DIPOLE MAGNET		CONTINGENCY ANALYSIS				MAT'L	LABOR
ITEM:		COS THETA STYLE D CENTRAL DESIGN GROUP ESTIMATE				\$	\$
(WBS)		MATL \$	LEB HRS	LABOR \$	TOTAL \$		CONTING\$
C	MAGNETS - DIRECT MATLS AND LABOR,						
14212.	1.1 COLD BORE TUBE	2636.0	34.3	788.9	3424.9	25	35 935.1
	1.2 COILS	32875.0	146.5	3369.5	36244.5	10	35 4466.8
	1.3 COIL COLLARING	6141.0	34.8	800.4	6941.4	25	35 1815.4
	2.1 YOKE AND COMPONENTS	9341.0	38.7	890.1	10231.1	15	35 1712.7
	2.2 HELIUM CONTAINMENT VESSEL	3196.0	14.4	331.2	3527.2	15	35 595.3
	3.1 COLD MASS SUBASSEMBLY PREP	803.0	15.0	345.0	1148.0	25	35 321.5
	3.2 20K HEAT SHIELD	913.0	18.9	434.7	1347.7	15	35 289.1
	3.3 BOK HEAT SHIELD	2173.0	18.7	430.1	2603.1	15	35 476.5
	3.4 UPPER VACUUM VESSEL	2883.0	14.5	333.5	3216.5	15	35 549.2
	3.5 LOWER VACUUM VESSEL	1471.0	19.6	450.8	1921.8	15	35 378.4
	3.6 VESSEL ENDS	415.0	13.0	299.0	714.0	15	35 166.9
	4.1 INTERNAL BUS WORK	1776.9	51.5	1184.5	2961.4	25	35 858.8
	5.1 INTERCONNECTION REGION PARTS	3600.0	22.0	506.0	4106.0	25	35 1077.1
	5.2 SHIPPING/STORAGE/HANDLING	30.0	0.0	0.0	30.0	25	35 7.5
	6.1 TESTING	0.0	8.0	184.0	184.0	25	35 64.4
	6.2 WARM MAGNETIC MEASUREMENTS	0.0	8.0	184.0	184.0	25	35 64.4
	6.3 COLD MAGNETIC MEASUREMENTS	150.0	4.0	92.0	242.0	25	35 69.7
	6.4 CRYOGENIC TESTING FACILITY OPERNS.	0.0	4.0	92.0	92.0	25	35 32.2
	8.1 DIRECT SHOP SUPPORT	0.0	0.0	0.0	0.0	25	35 0.0
	8.2 MISCEL. AND INDIRECT SHOP SUPPORT	200.0	110.0	3520.0	3720.0	25	35 1282.0
	MATERIAL FACTORS & ALLOWANCES	2000.0	0.0	0.0	2000.0	25	35 500.0
	ALLOWANCE FOR REJECTS	1120.0	10.0	230.0	1350.0	25	35 360.5
	TOTALS	71723.9	585.9	14465.7	86189.6		16023.5
						CONTING. %:	18.6

Table D-4
Style C - Magnet Contingency Factors
(FY85 \$)

UNIT COSTS PER DIPOLE MAGNET		CONTINGENCY ANALYSIS				MAT'L	LABOR	CONTING\$
ITEM:		SUPERFERRIC STYLE C CENTRAL DESIGN GROUP ESTIMATE				\$	\$	
		MATL \$	LBR HRS	LABOR \$	TOTAL \$			
MAGNETS - DIRECT MATLS AND LABOR,								
1.1	COLD BORE TUBE	4735.0	42.1	968.3	5703.3	25	35	1522.7
1.2	COILS	15935.8	80.2	1843.7	17779.5	10	35	2238.9
1.3		0.0	0.0	0.0	0.0	25	35	0.0
2.1	YOKE AND COMPONENTS	12453.0	106.9	2458.7	14911.7	15	35	2728.5
2.2	HELIUM CONTAINMENT VESSEL	1760.0	33.3	765.9	2525.9	15	35	532.1
3.1	COLD MASS SUBASSEMBLY PREP (6 CRYOSUP)	2264.6	33.0	759.0	3023.6	25	35	831.8
3.2	10K HEAT SHIELD	2457.2	56.0	1288.0	3745.2	15	35	819.4
3.3	80K HEAT SHIELD	3632.4	10.0	230.0	3862.4	15	35	625.4
3.4	VACUUM VESSEL	3855.2	61.0	1403.0	5258.2	15	35	1069.3
3.5		0.0	0.0	0.0	0.0	15	35	0.0
3.6		0.0	0.0	0.0	0.0	15	35	0.0
4.1	INTERNAL BUS WORK	7380.0	40.0	920.0	8300.0	25	35	2167.0
5.1	INTERCONNECTION REGION PARTS	200.0	0.0	0.0	200.0	25	35	50.0
5.2	SHIPPING/STORAGE/HANDLING	61.2	6.0	138.0	199.2	25	35	63.6
6.1	TESTING	0.0	8.0	184.0	184.0	25	35	64.4
6.2	WARM MAGNETIC MEASUREMENTS	0.0	16.0	368.0	368.0	25	35	128.8
6.3	COLD MAGNETIC MEASUREMENTS	0.0	8.0	184.0	184.0	25	35	64.4
6.4	CRYOGENIC TESTING FACILITY OPERNS.	150.0	8.0	184.0	334.0	25	35	101.9
8.1	DIRECT SHOP SUPPORT	0.0	0.0	0.0	0.0	25	35	0.0
8.2	MISCEL. AND INDIRECT SHOP SUPPORT	200.0	120.0	3840.0	4040.0	25	35	1394.0
	MATERIAL FACTORS & ALLOWANCES	1200.0	0.0	0.0	1200.0	25	35	300.0
	ALLOWANCE FOR REJECTS	1020.0	10.0	230.0	1250.0	25	35	335.5
TOTALS		57304.4	638.5	15764.6	73069.0			15037.6
CONTING. %:								20.6

Table D-5
Style C* - Magnet Contingency Factors
(FY85 \$)

UNIT COSTS PER DIPOLE MAGNET		CONTINGENCY ANALYSIS				MAT'L	LABOR	
ITEM:		SUPERFERRIC STYLE C*						
		CENTRAL DESIGN GROUP ESTIMATE						
(WBS)		MATL \$	LBR HRS	LABOR \$	TOTAL \$			CONTING\$
C	MAGNETS - DIRECT MATLS AND LABOR,							
14212.	1.1 COLD BORE TUBE	2367.5	21.0	483.0	2850.5	25	35	760.9
	1.2 COILS	7968.0	40.1	922.3	8890.3	10	35	1119.6
	1.3	0.0	0.0	0.0	0.0	25	35	0.0
	2.1 YOKE AND COMPONENTS	7353.0	81.0	1863.0	9216.0	15	35	1755.0
	2.2 HELIUM CONTAINMENT VESSEL	2760.0	30.0	690.0	3450.0	15	35	655.5
	3.1 COLD MASS SUBASSEMBLY PREP (& CRYOSUP)	1900.2	30.0	690.0	2590.2	25	35	716.5
	3.2 10K HEAT SHIELD	2400.0	50.0	1150.0	3550.0	15	35	762.5
	3.3 80K HEAT SHIELD	3600.0	8.0	184.0	3784.0	15	35	604.4
	3.4 VACUUM VESSEL	5345.4	61.0	1403.0	6748.4	15	35	1292.9
	3.5	0.0	0.0	0.0	0.0	15	35	0.0
	3.6	0.0	0.0	0.0	0.0	15	35	0.0
	4.1 INTERNAL BUS WORK	3690.0	20.0	460.0	4150.0	25	35	1083.5
	5.1 INTERCONNECTION REGION PARTS	200.0	0.0	0.0	200.0	25	35	50.0
	5.2 SHIPPING/STORAGE/HANDLING	61.2	6.0	138.0	199.2	25	35	63.6
	6.1 TESTING	0.0	6.0	138.0	138.0	25	35	48.3
	6.2 WARM MAGNETIC MEASUREMENTS	0.0	8.0	184.0	184.0	25	35	64.4
	6.3 COLD MAGNETIC MEASUREMENTS	0.0	4.0	92.0	92.0	25	35	32.2
	6.4 CRYOGENIC TESTING FACILITY OPERNS.	150.0	4.0	92.0	242.0	25	35	69.7
	8.1 DIRECT SHOP SUPPORT	0.0	0.0	0.0	0.0	25	35	0.0
	8.2 MISCEL. AND INDIRECT SHOP SUPPORT	100.0	84.0	2688.0	2788.0	25	35	965.8
	MATERIAL FACTORS & ALLOWANCES	800.0	0.0	0.0	800.0	25	35	200.0
	ALLOWANCE FOR REJECTS	510.0	5.0	115.0	625.0	25	35	167.8
	TOTALS	39205.3	458.1	11292.3	50497.6			10412.6
						CONTING. \$:		20.6

APPENDIX E
REFERENCE DESIGNS STUDY COST COMPARISONS

The following tables show the cost comparisons for the magnet dependent systems for the various styles that are presented and compared in this report and the corresponding elements from the Reference Designs Study Cost Estimate (RDS Appendix C, May 1984).

Table E-1 shows the comparisons for the Magnet Systems Costs. It should be noted, however, that although both cost sections have been adjusted to FY1984 dollars for the comparison, the field level and aperture adjustments made for the present designs A, B, C, C*, and D do not correspond exactly to the same values in the RDS. The numbers of the dipole elements are slightly different, and in particular, the aperture for design B has been adjusted to 4.0 cm for the present cost comparisons, and it was formerly 5.0 cm in the RDS.

Table E-2 shows the Total Magnet Dependent Systems costs from the present study; Table E-3 shows the corresponding RDS values.

Table E-1
RDS Comparisons with Collider Magnet Systems
Adjusted Field Level
Adjusted Aperture
(FY84 K\$)

	A	B	D	C	C*
<u>ADJUSTED PARAMETER VALUES:</u>					
ADJUSTED FIELD LEVEL, T	6.40	5.75	6.40	3.00	3.00
ADJUSTED NUMBER OF DIPOLES:	3,938	12,810	7,875	4,000	8,000
APERTURE, (DIA: A,B,D; GAP: C,C*),CM:	4.00	4.00	4.00	2.54	2.54
FIELD LEVEL/QUANTITY SCALING FACTOR:	.94	.96	.94	1.00	1.00
APERTURE SCALING FACTOR:	1.00	.89	1.00	1.00	1.00
ESCALATION SCALING FACTOR:	1.05	1.05	1.05	1.05	1.05
(* INDICATES ITEMS ADJUSTED)					

MAGNET SYSTEMS, WBS 1.4.2

* TOOLING	41,497	23,738	41,497	21,810	21,810
* DIPOLE MAGNETS	573,837	642,937	646,421	278,358	384,744
* QUADRUPOLE MAGNETS	38,341	54,346	42,397	19,048	24,762
* SPEC. DEVICES/SPOOLS	37,543	75,818	67,874	84,667	110,067
* SPECIAL MAGNETS/INSERTIONS	14,286	14,286	14,286	14,286	14,286
* INSTALLATION & SURVEY	26,750	58,765	40,833	23,306	34,286
TOTAL MAGNET SYSTEMS:	732,254	869,890	853,309	441,473	589,953

REFERENCE DESIGNS STUDY COST COMPARISON:

FY1984 K\$

RDS	RDS	RDS
A(84)	B(84)	C(84)

REFERENCE DESIGNS STUDY PARAMETER VALUES:

FIELD LEVEL, T	6.50	5.00	3.00
NUMBER OF DIPOLES:	3,870	14,880	990*
APERTURE, (DIA: A,B; GAP: C),CM:	4.00	5.00 *	2.54

MAGNET SYSTEMS, WBS 1.4.2

TOOLING	38,504	21,290	14,979
DIPOLE MAGNETS	590,899	719,205	244,111
QUADRUPOLE MAGNETS	39,481	60,792	11,014
SPEC. DEVICES/SPOOLS	38,692	75,483	58,133
SPECIAL MAGNETS/INSERTIONS	11,241	20,000	6,430
INSTALLATION & SURVEY	35,673	58,505	7,825
GENERAL FACTORY SUPPORT (RDS A & C ONLY)	28,463	0	15,000
TOTAL MAGNET SYSTEMS:	782,953	955,275	357,492

Table E-2
Summary Cost Estimate
Magnet Dependent Systems
(FY84 K\$)

	STYLE A	STYLE B	STYLE D	STYLE C	STYLE C*
<u>CONSTRUCTION COSTS:</u>					
ADJUSTED MAGNET SYSTEMS	732.25	869.89	853.31	441.47	589.95
OTHER TECHNICAL SYSTEMS	224.10	222.90	235.70	280.60	301.40
CONVENTIONAL SYSTEMS	410.38	444.15	410.38	761.70	761.70
SUBTOTAL: CONSTRUCTION	1,366.73	1,536.94	1,499.38	1,483.77	1,653.05
<u>SYSTEMS ENGINEERING COSTS:</u>					
MAGNET SYSTEMS	83.87	103.78	100.42	58.18	76.66
OTHER TECHNICAL SYSTEMS	42.50	43.00	44.70	55.80	59.70
CONVENTIONAL SYSTEMS	65.66	71.06	65.66	121.87	121.87
SUBTOTAL: SYS. ENGIN.	192.03	217.84	210.78	235.85	258.24
<u>CONTINGENCY COSTS:</u>					
MAGNET SYSTEMS	151.35	199.68	183.57	109.56	145.09
OTHER TECHNICAL SYSTEMS	49.70	49.80	52.30	62.80	67.40
CONVENTIONAL SYSTEMS	101.41	111.95	101.41	225.99	225.99
SYSTEMS ENGINEERING	48.01	54.82	52.69	65.06	70.65
SUBTOTAL: CONTINGENCY	350.47	416.24	389.98	463.40	509.13
<u>TOTAL MAGNET SYS. DEPEND. COSTS</u>	1,909.23	2,171.03	2,100.14	2,183.02	2,420.42

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Table E-3
Summary Cost Estimate
Reference Designs Study
(FY84 K\$)

	RDS A(84)	RDS B(84)	RDS C(84)
<u>CONSTRUCTION COSTS:</u>			
MAGNET SYSTEMS	782.95	955.27	357.49
OTHER TECHNICAL SYSTEMS	220.78	212.69	255.03
CONVENTIONAL SYSTEMS	398.65	496.11	733.48
SUBTOTAL: CONSTRUCTION	1,402.39	1,664.07	1,346.01
<u>SYSTEMS ENGINEERING COSTS:</u>			
MAGNET SYSTEMS	78.30	95.51	35.75
OTHER TECHNICAL SYSTEMS	42.21	40.98	47.43
CONVENTIONAL SYSTEMS	63.78	79.38	117.36
SUBTOTAL: SYS. ENGIN.	184.29	215.86	200.54
<u>CONTINGENCY COSTS:</u>			
MAGNET SYSTEMS	234.90	238.80	125.10
OTHER TECHNICAL SYSTEMS	48.00	47.10	55.70
CONVENTIONAL SYSTEMS	98.09	124.03	220.04
SYSTEMS ENGINEERING	90.46	98.76	83.39
SUBTOTAL: CONTINGENCY	471.44	508.69	484.24
<u>TOTAL MAGNET SYS. DEPEND. COSTS</u>	2,058.12	2,388.62	2,030.79