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GEM Magnet Subsystem Independent Estimate Evaluation

Robert Hunt, Dr. Lydia Bock, David Davison,
Harold Rafuse, Donald Trapp
U.S. Cost, Inc. / Science Applications International Corp.

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Abstract:

An independent evaluation of the GEM Magnet Subsystem Cost Estimate as prepared by the SSCL.

GEM MAGNET SUBSYSTEM

INDEPENDENT ESTIMATE EVALUATION

June 1992

by:

Robert Hunt
Dr. Lydia Bock
David Davison
Harold Rafuse
Donald Trapp

U.S. Cost, Inc.
1499 Regal Row, Suite 509
Dallas, TX 75247

Science Applications International Corp.
1710 Goodridge Drive
McLean, VA 22102

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EXECUTIVE SUMMARY

An independent evaluation was conducted on the GEM magnet subsystem cost estimate prepared by the SSCL. The evaluation was the first in a series of such to be conducted on all six of the GEM subsystems.

SSCL GEM magnet cost estimate documentation was examined in detail, including technical, schedule, and cost rationale used in developing the estimate. Major cost drivers were identified and contingency schemes and factors used in the cost estimate were reviewed.

Two approaches were used in conducting the evaluation. The first centered on the principal categories of cost. Fabricated materials and associated labor and, separately, labor rates used throughout the SSCL estimate were analyzed for stability and for principal factors potentially affecting those estimates. Additionally, contingency costs and subcontractor adjustments used in the SSCL estimate were also examined. The second approach focused on the basis of costing on high cost/high risk WBS elements. Results of both approaches were linked in formulating evaluation conclusions.

Results of both approaches to the independent estimate evaluation indicated clearly that the SSCL estimate has been soundly prepared and thoroughly documented using appropriate cost estimating methodologies. All technical challenges and cost and schedule impacts have been fully considered and appropriate contingencies have been assigned. The SSCL estimate appears reasonable and consistent.

A few minor concerns were noted particularly from the detailed evaluations in the high cost/high risk WBS elements. The principal finding was in the area associated with rigging, movement, and positioning of the vacuum vessels in the Exhibition Hall. Confirmation of rigging equipment capabilities and availability is recommended and the sufficiency of access shaft clearance needs verification, particularly if vessel redesigns are necessary to accommodate proper placement and alignment.

An alternative approach to assessing risks was pursued in lieu of the SSCL cost risk methodology. A possible 3% to 5% reduction in the total magnet cost estimate was realized from application of the alternative scheme.

The area of subcontractor adjustments also should be examined further in order to fully clarify the expected subcontractor participation. Potential small total cost increases may arise with increased subcontractor activity.

I. INTRODUCTION

The work herein was performed under contract F08635-90-C-0382, Task Order 91-5, issued to U.S. Cost, Inc., Atlanta, Georgia.

A. BACKGROUND

U.S. Cost, Inc., has been directed to develop independent cost estimates for each of the six GEM subsystems. These estimates are to include backup information, assumptions, computer models, and collected data from subsystem leaders, as appropriate. Also, these estimates are to address:

- Work Breakdown Structure (WBS) modifications needed
- Issues not sufficiently defined to support a precise estimate
- Assumptions and ground rules
- Baseline documents and references used
- Estimating methodologies used
- Probable cost drivers

Science Applications International Corporation (SAIC),a subcontractor to U.S. Cost, Inc., was tasked to lead the independent cost estimate effort. After meetings with the SSCL, it was agreed that the effort should focus on reviews of the detailed, in-house GEM subsystem cost estimates. These reviews are to examine the reasonableness, completeness, and consistency of the detailed cost estimates. It was also agreed with SSCL that the GEM magnet subsystem be addressed first. This report is for the magnet only; future reports will address the other major GEM subsystems.

B. SCOPE OF WORK

This report reviews GEM magnet cost estimates developed in-house by SSCL based on the GEM Baseline 1 dated 23 April 1992. Two broad groups of cost -- fabricated materials and labor -- were examined for reasonableness based on price trends. Contingency cost and risk factors also were examined. In addition, seven high cost, high risk WBS elements (cost drivers) were examined as follows:

- Distribution of cost across estimating categories to clarify areas for further investigation.
- Comparison of planned manufacturing, assembly, and construction activities with generally accepted practices to provide insight into the degree of cost risk.
- Examination of vendor estimates to validate the in-house estimates.

- Determination of the stability of material and labor values used in the estimates.
- Examination of the contingency cost estimates for reasonableness and consistency.

C. SOURCES OF INFORMATION

The following documents were provided by SSCL for SAIC's review:

- GEM Magnet Subsystem Post-LOI Conceptual Design Cost Estimate, Rev E, 27 May 1992.
- GEM Magnet Subsystem Vendor Estimates, Rev A, April 2, 1992
- SSC Laboratory Magnet Systems presentation materials
- GEM Detector Second Level Summary and Magnet detailed estimating spreadsheets
- GEM Detector Systems, Chapter 2, Magnets
- GEM Solenoid Design from Peter Clee
- GEM Cost Estimating Plan, Rev D, April 13, 1992
- Statement of Work for the GEM Detector Super Conducting Magnet Subsystem, 1 June 1992, Section 5
- Selections from magnet design and performance requirements

Additional reference were:

- Geographic Reference 1991 Annual Report of Costs, Wages, Salaries, and Human Resource Statistics
- The Almanac of Jobs and Salaries 1990-91

II. METHODOLOGY

An intensive examination was made of all of the source documents. Efforts focused on:

- Understanding and correlating information among the various documents
- Assessing the technical, schedule, and cost rationale used in developing the magnet estimate
- Identifying major cost drivers
- Researching and compiling information related to factors possibly impacting the major cost drivers
- Reviewing the contingency scheme and risk factors utilized in the cost estimate

The combined impacts of cost, schedule, and technical factors were considered in analyzing the basis of forecasted costs.

Two different approaches were pursued. The first approach focused on the principal categories of costs. Fabricated materials with their associated labor and, separately, labor rates were specifically analyzed for the stability of their estimates and the principal drivers potentially affecting those estimates. Additionally, contingencies and subcontractor adjustments were addressed. The second approach focused on the basis of the SSCL estimates for high cost/high risk WBS elements. Results of both approaches were linked in preparing conclusions.

The following depicts the magnet cost estimate by summary level WBS element:

	$K	% of Total
• Construction	116,639	89.5
• R&D	5,576	4.3
• Con/Prelim Design	8,172	6.2
Total	130,387	100.0

Both analytical techniques concentrated on the construction activities since they account for 90% of the magnet costs.

Results of both approaches are contained in the following sections of this report.

III. ANALYSIS OF MATERIAL, LABOR, AND OTHER COSTS

A. FABRICATED MATERIALS

1. Magnet System Cost Drivers

The detailed cost breakdown by WBS, was examined to identify cost drivers for the magnet system.

Figures 1 and 2 are pie charts of the elements contributing to the magnet system cost (contingency costs are excluded) broken into materials and labor cost elements and SSC cost elements, respectively. As shown in Figure 1, procured fabricated material costs constitute approximately 68% of the total magnet system cost while labor constitutes 24% of total cost. The objective of this section is to further examine the cost of the procured fabricated materials and the associated labor costs. Specific focus is placed on identifying the various ways in which costs of fabricated materials procured for the SSC Magnet system may fluctuate, being affected by changes in variables such as supply and demand, labor rates, and energy costs.

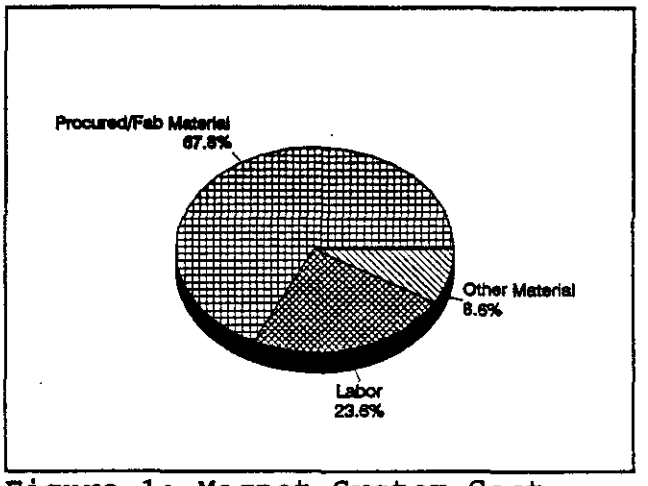


Figure 1: Magnet System Cost Breakdown by Materials and Labor Elements.

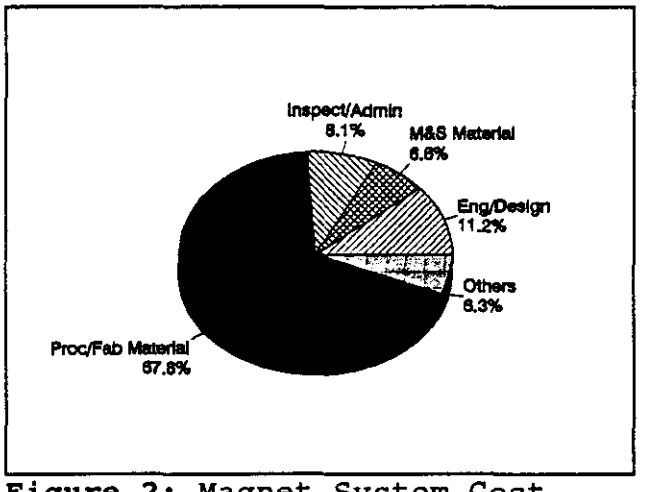


Figure 2: Magnet System Cost Breakdown by SSC Cost Elements.

2. Fabricated Materials as a Cost Driver

As mentioned before, the procured fabricated materials costs constitute approximately 68% of the total magnet system. Figure 3 shows a pie chart of the cost elements of the procured fabricated materials. As shown, the cost drivers are the fabricated metals procured for the magnet systems which constitute approximately 65% of the SSC procured fabricated material. This translates into 44% of the <u>total</u> magnet system cost.

Basically, the cost of fabricated steel and aluminum is a function of variable costs such as raw materials, labor, and energy and fixed costs such as capital, equipment, overheads, and other financial elements. Assuming that the supplier business base is large compared to the SSC procurement sizes, only the variable costs should cause a variation in the price of the fabricated metals. (This assumption is not correct for the super conducting wire and was addressed in the CDM Conductor presentation).

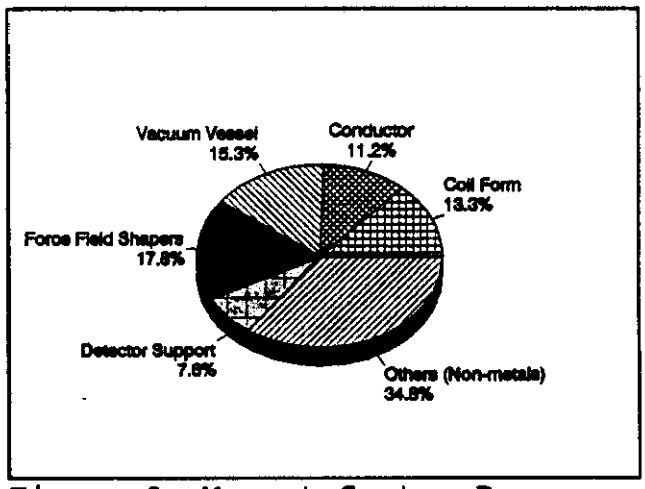


Figure 3: Magnet System Procured/Fabricated Materials Cost Breakdown.

Consequently, the focus in this section is on the investigation of the cost of metals which stems from the economics, as well as the manufacturing process labor costs involved.

3. Procured Fabricated Metals

The major metals procured for the SSC magnet subsystem include super conducting wire, steel, iron, and aluminum. Note that the super conducting wire cost was analyzed thoroughly by the SSC laboratory (CDM Conductor Costs presentation).

The cost of fabricated metals depend not only on the type of material, but also on its shape. The process flow for the fabricated metals procured by SSC begins with raw materials which are processed into raw metals (ingots, bars and billets), in turn into shaped metals (structural), and further into fabricated parts.

raw materials--> raw metals--> shaped metals--> fabricated metals

The raw metals are produced in shape by casting, extrusion, forging, rolling or drawing, with various tolerances and surface finishes. The fabricated parts are processed further to meet specific SSC requirements. The cost per unit weight depends on the type and form of the raw materials as well as the fabrication process necessary to meet SSC requirements.

Table 1 lists all the shaped metals to be procured by SSC for the magnet system, including 8,588 tons of ferrous material, 289,000 kg of AL 1100 used for the conductor and 6061-T6 aluminum coil forms materials estimated at $6.5-7.0M.

TABLE 1: SHAPED METALS PRODUCED FOR THE SUPER COLLIDER

Shaped Materials Procured - Magnet System (Major Items)										
Component	WBS no.	Materials								
		SC Wire	*Al 1100 ext*	*Stainless Steel*	*SA516 grade*	*Cast Steel*	*Low Carbon*	*Iron*	*Aluminum*	*Totals($)*
		(km)	*(kg)*	*(304 L) (tons)*	*Steel(tons)*	*(tons)*	*Steel(tons)*	*(tons)*	*6061-T6*	
		($.4478/km)	*($3.3/kg)*	*($2.00/lb)*	*($0.36/lb)*	*($1.10/lb)*	*($0.36/lb)*	*($1.50/kg)*		
Coil Sub - Conductor	1.1.3.1.1.1.2	12,848	289,000	cost $295K						7,002,034
Coil Sub - Coil Form	1.1.3.1.1.1.1								$6500-7000K	6,750,000
Vessel Shells	04.1.1.3.1				852					613,440
Vessel Stiffeners	04.1.1.3.2			146	794					1,155,680
Vessel Support Structure	04.1.1.3.3			342						1,368,000
Forward Field Shapers	04.1.2.1					2,400				5,280,000
FFS Support Structures	04.1.2.2			630			1,470			3,578,400
Central Detector Support	04.1.3.1			846			770			3,938,400
Return Field Mitigation	04.6.							338		460,356
Total Weight		n/a	289,000	1,964	1,646	2,400	2,240	338		
Total Cost ($)		5,753,334	953,700	8,151,000	1,185,120	5,280,000	1,612,800	460,356	6,750,000	30146310
% of Total Cost		19.08	3.16	27.04	3.93	17.51	5.35	1.53	22.39	100

4. Material Market Trends

In the metal industry, raw metals cost (ingot, billet or bars) typically constitute 20% to 60% of fabricated metal cost, depending on the complexity of the manufacturing process. The cost of ingots, billets, or bars varies with market prices for ores and scrap. The price of a particular ore or scrap material is subject to fluctuation due to supply and demand and, if the ore is imported, geopolitical factors. If scrap is produced during manufacturing, the value of the scrap is deducted from the material cost. This value, which may be 10% of the original material cost, depends on the type of scrap and the demand for it. Therefore, it is important to evaluate raw materials trends.

Steel. Figure 4 shows scrap steel prices. As shown the steel prices fell by approximately 25% in the last year. By June, 1991, the Bureau of Labor Statistics (BLS) price index for steel mill products had dropped about 2% since the beginning of the year and had declined by nearly 5% since its April, 1989, peak. However, spot prices for certain products such as hot-rolled and galvanized sheet, fell as much as 10% from the beginning of 1991.

Steel shipment demands are expected to increase about 4% in 1992, as the economy moves out of recession. However, this forecast would still be well below the demands recorded for the last economic cycle of 1988-90. By the mid-1990's, shipment of steel is projected to reach 1988-90 level. No extraordinary rise in imports and import penetration is expected.

Aluminum. A sharp reduction in price is shown in Figure 5 for aluminum. After peaking at $0.87 per lb. in September, 1990, Midwestern transaction ingot quotes fell to as low as $0.50 per pound by mid-October, 1991, due to the below average recovery in the U.S economy. On the London Metal Exchange, a flood of Soviet aluminum exports to Europe has raised aluminum inventories to record levels and forced prices down. Production curtailments and cuts made so far will probably be insufficient to eliminate the aluminum surplus. Therefore, the aluminum prices for 1992 may decline to levels slightly lower than those in 1991 before demand and supply will balance and the prices will rebound. Consequently, average ingot prices for 1992 could reach $0.70 per pound, which is higher than the 1991 average price of 0.58 but lower than the 1990 price of $0.75 per pound.

Fabricated aluminum products' prices typically lag ingot quotes by roughly six months. The persistent downtrend in aluminum ingot prices for most of 1991 will lead to deeper discounts in fabricated products by mid-1992. Therefore, average fabricated product quotes in 1992 should be moderately less than 1991's average prices which are also below those of 1990.

Figure 4

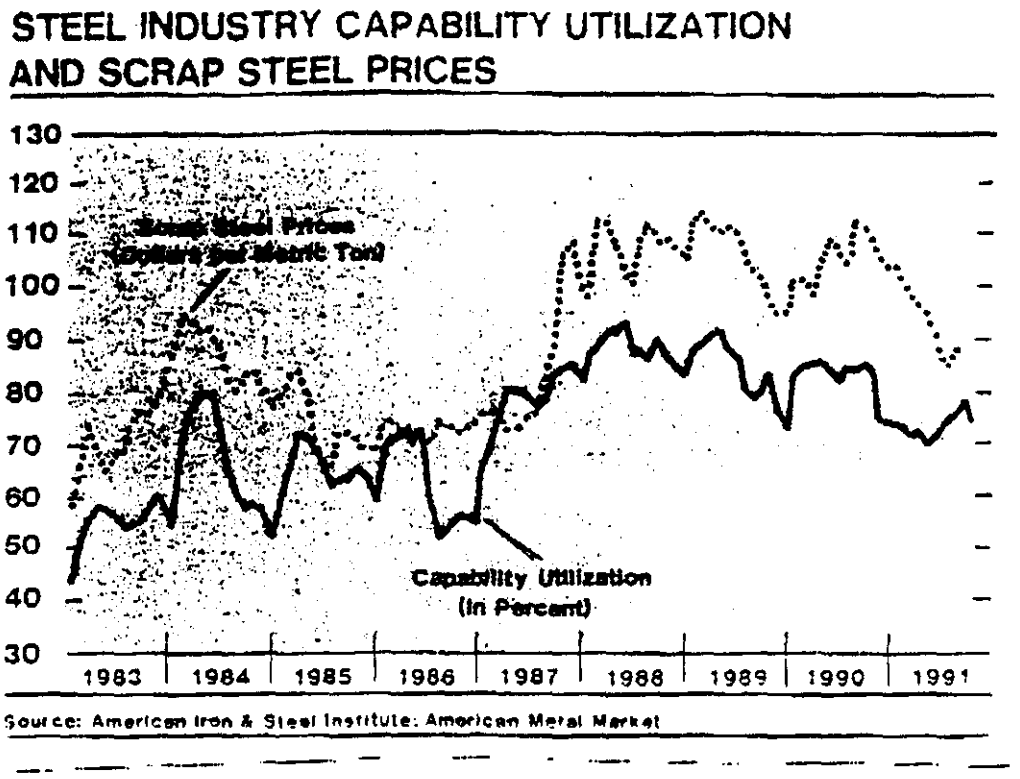
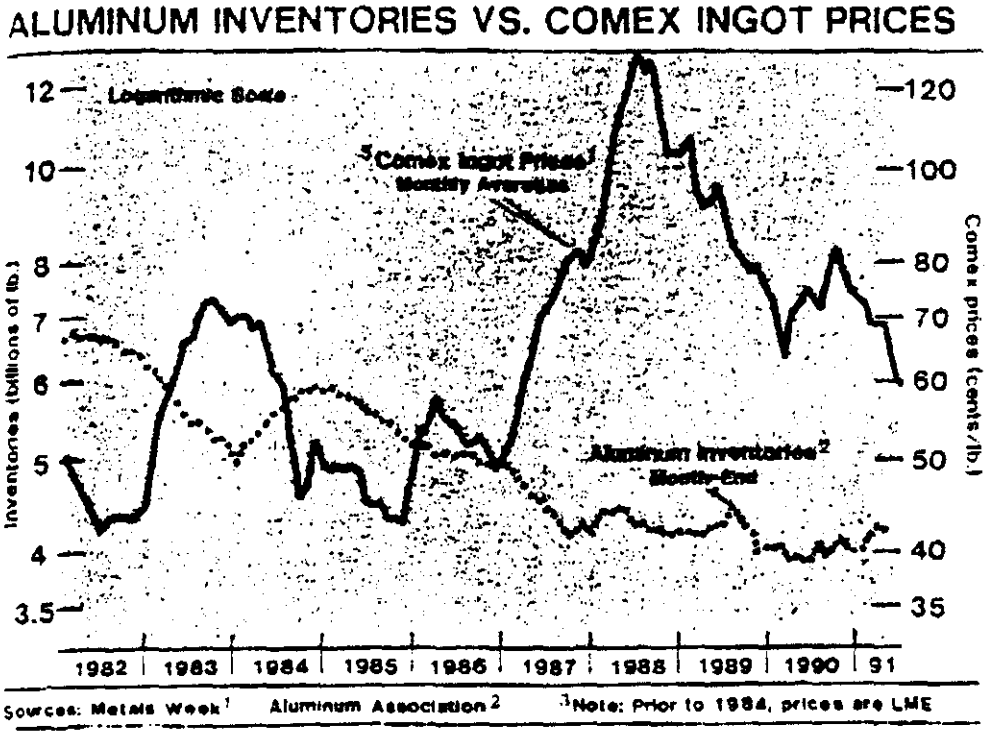


Figure 5



It is projected that the world aluminum capacity will grow at 2% to 3% a year and that consumption will grow at 3% to 4% a year. Assuming worldwide economic expansion, the aluminum industry will experience steady improvement in the next few years, and may see a tight supply situation by the middle of the decade.

Based on these forecasts, it is estimated that the raw materials price increases will drive the shaped metal cost by approximately 5% to 10% by the mid 1990's. The SSC vendor estimates were taken at 4th quarter, 1991, when prices of metal were at a low point. Therefore, the recommended contingencies to the procured shaped metal cost should be between 5% to 10%.

5. Material Labor Cost Trends

The integrated steel and aluminum industries generally employ union labor which is more expensive and less flexible than non-union labor. (Steel mini-mills employ non-union labor and therefore their product is slightly lower than the integrated companies products). Consequently, when examining trends in material labor rates, labor union pacts need to be considered.

In July, 1992, labor pacts between Alcoa, Reynolds Metals, and the major unions are coming up for negotiations. The current contracts provide profit sharing for each year from 1988 through 1991. This leads to the conversion of labor costs from fixed to semi-variable expense. Given the likelihood of no profit sharing for 1991, the unions might opt to return to fixed wage hikes in the next contract. This course will limit the ability of U.S. industry to reduce labor costs. Therefore, it is projected that material labor rates will stay flat or go up a few percent in the next couple of years, but will not decline.

6. Conclusions

The following are highlights from this section:

- Procured fabricated material cost is a major cost driver for the SSC magnet system ($66.7M).
- Metal procured fabricated material cost constitutes 65% ($46.7M) of total procured fabricated material cost.
- Aluminum and steel prices estimated by SSC in late 1991 are at a two year low point.
- An up-trend in metal prices, labor rates, and energy cost is projected for mid 1990's.

Assuming shaped metal prices increase 5% to 10% and labor rates increase of 0% to 3%, it can be inferred that by the mid 1990's the price of the procured fabricated metals may increase by 3% to 8%.

Contingencies as low as 5% and as high as 10% are recommended for the procured fabricated metals to offset projected increases in material, labor, energy, and other cost variables.

B. LABOR RATES COMPARISONS

1. Purpose

This section examines the distribution of labor for the SSC magnet system and compares the labor rates with industry standards.

2. Labor Cost Drivers

Table 2 lists the cost distribution by function for the SSC magnet system and Figure 6 depicts the information diagrammatically. As shown, Engineering/Design and Inspection/Administration are the two major cost drivers, representing 36% and 28% of the total, respectively. The following sections focus on a comparison of the labor rates in each of the functional areas.

Table 2
LABOR PERCENTAGES ACCORDING TO FUNCTION

Task	Labor Cost ($K)	% of Total
Eng/Design	4,118	36.19
Inspect/Admin	3,213	28.24
Assembly	2,499	21.96
Installation	1,548	13.61
Total	$11,378	100.00

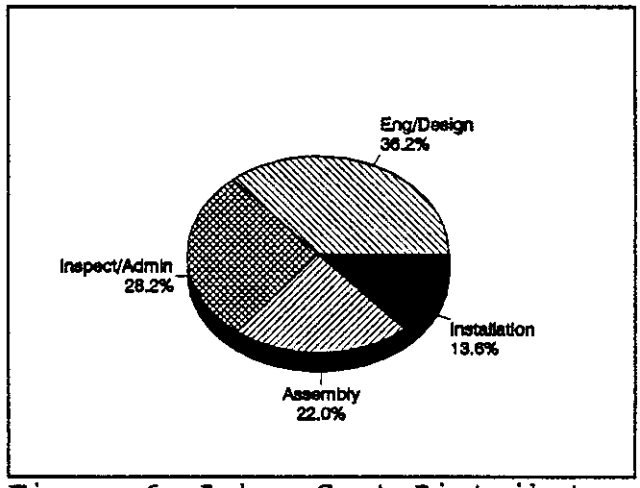


Figure 6: Labor Cost Distribution by Function.

3. Labor Rates Analysis

The labor rates reported in the magnet system cost estimate were compared to industry standards. For the crafts, the SSC labor rates were compared to national average labor rates, adjusted for Dallas, Texas. A burden rate of 1.8 was applied to reflect comparable fully burdened rates.

The result of the analysis is as follows:

CRAFT	SSCL	Nat'l [Adj]	DIFF %
Crane Operator	$24.52	$24.73	- 1
Electrician	27.40	23.81	15
Laborer	12.02	15.50	-22
Pipe fitter	19.71	23.94	-18
Rigger	22.12	23.49	- 6
Welder	22.12	23.58	- 6

There may be a need to further investigate the wage rates for electricians, laborers, and pipe fitters since they deviate by more than 20% from the national averages adjusted for the Dallas area.

SSCL combined the professional staff into teams and a composite team hourly rate was calculated for estimating purposes. The composition of teams and the resulting rates appeared reasonable.

4. Engineering Design Cost Analysis

On the next page is listed the number and cost of drawings for each part of the magnet system. The total number of drawings is 708. The total cost of engineering and design involved in these drawings was found to be $5,617K. The average cost of a drawing is approximately $7,930.

A cost of $7,930 per drawing is reasonable for the SSC work which involves new conceptual designs using mostly conventional materials with some exotic material applications. In space applications, for instance, the typical cost of a standard size drawing is approximately $10,000 and involves new conceptual designs on almost exclusively exotic materials. Therefore, for the super collider, the drawing costs appear reasonable as forecasted.

# of drawings?

5. Conclusions

In general, SSC labor cost estimates compared reasonably well with industry standards. The following summarizes findings:

- Engineering/design and Inspection/Administration tasks are the two cost drivers for the labor costs ($4.1 and

TABLE 3: LIST OF DRAWINGS AND COSTS

Engineering/Design Costs				
Component	Drawings	Rate($k/my)	Drawing Cost ($k)	Eng/Design Cost ($k)
Coil Sub - Coil Form	6	100	11.54	33
Coil Sub - Conductor	16	100	30.77	54
Coil Sub - Diagnostics	4	100	7.69	12
Coil Sub - Winding Tooling	40	100	76.92	125
LN Thermal Rad Shields	6	119	13.73	32.1
Superinsulation	4	119	9.15	10.7
Shield Supports/Thermal Intercepts	5	119	11.44	26.2
Vessel Shells	12	119	27.46	92.8
Vessel Stiffeners	16	119	36.62	111.9
Vessel Support Structures	38	119	86.96	130.9
Vessel Assembly	26	119	59.50	138
Cold Mass Supports - Radial Rods	6	119	13.73	26.2
Cold Mass Supports - Axial Rods	6	119	13.73	26.2
Internal Cryo Sys - LN Piping	4	119	9.15	21.4
Internal Cryo Sys - LHe Thermosyp	4	119	9.15	21.4
Internal Cryo Sys - LHe Forced-flow	4	119	9.15	21.4
Assembly & Testing Equip	18	100	34.62	62
On-Site Assembly	25	119	57.21	155
Testing	10	119	22.88	53.6
Forward Field Shapers	25	119	57.21	132.1
FFS Support Structures	90	119	205.96	380.8
*On Site Assembly	4	100	7.69	15
Central Detector Support	41	100	78.85	300
Power Supply	0	119	0.00	29.8
Buswork	11	119	25.17	40.5
Interrupters and Quench Resistors	8	119	18.31	30.9
Quench Detection and Diagnostics	0	119	0.00	29.8
Discharge Resistors and Switch	8	119	18.31	30.9
LN Storage Dewar	0	100	0.00	10
LN Subcooler	0	100	0.00	25
LN Piping and Distribution	25	100	48.08	77
Refrigerator	0	100	0.00	15
LHe Supply Sys Piping/Dist	14	100	26.92	50
Gas Bag & Assoc. Component	15	100	28.85	29

TABLE 3 (con't): LIST OF DRAWINGS AND COSTS

Recovery Compressor	0	100	0.00	25
Helium Purification	0	100	0.00	25
Gas Storage	0	100	0.00	25
LHe Mag Storage & Supply Dewar	0	100	0.00	10
LHe Thermosyphon Dist.	25	100	48.08	77
LHe Subcooler	0	100	0.00	12
Forced-Flow Dist	25	100	48.08	77
Vacuum Pumps	0	119	0.00	60
Vacuum Piping	0	100	0.00	100
Power Controls	5	119	11.44	16.7
Protection Controls	4	119	9.15	17.9
Cryogenics Controls	6	119	13.73	27.4
Vacuum Controls	3	119	6.87	11.9
Return Field Mitigation	10	100	19.23	77
Central Detector Support	32	100	25.00	50
Coil Assemblies	40	100	100.00	200
Pole Assemblies	40	100	100.00	200
Testing Equipment	20	119	45.77	114
Solenoid Magnet Installation	0	119	0.00	119
LN System Installation	2	100	3.85	39
LHe System Installation	2	100	3.85	69
Vacuum System Installation	0	119	0.00	59.5
Control System Installation	3	119	6.87	7.1
Tech Design Oversight/Mgmt	0	154	0.00	1848
Totals	708		1,498.67	5,617.10
Cost per Drawing	7.93			

$3.2 million, respectively).

- Labor rates for pipe fitters, technicians, and laborers used in the SSCL estimate are lower than the national averages. However, the impact of labor rate deviations in these few catagories on the total cost will probably not be significant.
- SSC Engineering/Design cost per drawing is reasonable for the type of work involved.

6. References

1) Standard & Poor's Industry Surveys Jan, 1992

- Steel and Heavy Machinery
- Metal, non-ferrous

2) US Industrial Outlook 1992 - Metals

3) Iron Age Jan, 1992, "Steel in the 90's".

C. CONTINGENCY

The initial examination of source documents focused on corroborating data among the various information sources. Efforts included assessing the following:

- Consistent identification, description, and uniformity of WBS elements used throughout the documents so that all facets of a particular element are clearly presented
- Reconciliation of technical, cost, and schedule data
- Sense of data values in both absolute and relative terms

Part of the evaluation was to fully understand the application of risk factors and how they relate to contingency. When the LOI Cost Estimate risk factors were used to calculate contingency the results did not match the spreadsheet values.

As an example a table of differences (Table 4) was prepared from the written material.[1] The contingencies were calculated from the spreadsheet, the top row of risk factors was taken from the cost estimate, and the bold, lower row of risk factors was taken from the spreadsheet.

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[1] Conceptual Design Cost Estimate, 27 May 1992, contained the risk factors: Estimating spreadsheets for magnet cost detail contained data for calculating contingency percentages.

TABLE 4: CONCEPTUAL DESIGN VERSUS SPREADSHEET RISK FACTORS				
WBS Element	% Contingency	Technical Risk Factor	Cost Risk Factor	Schedule Risk Factor
4.1.1.1.1 Coil Form	25%	10 4	10 4	8 5
4.1.1.1.2 Conductor	25%	8 5	6 3	8 4
4.1.1.1.4 Winding Tool	35%	10 7	10 5	8 4
4.1.1.1.5.2 On-Site Assembly	40%	10 6	8 6	8 10

Examination of the above information showed inconsistency between percent contingency and the LOI estimate risk factors.

Using the LOI risk factors, the first and third elements, Coil Form and Winding Tooling, have identical risk factors, but do not have similar contingencies. Further, the first element has a lower contingency and higher cost risk factor than does the fourth element, On-Site Assembly, their other risk factors being equal. The relationship between risk and cost is not clear in this circumstance.

From Section 8.2 of the GEM Cost Estimating Plan, the Risk Percentage Table[2], risk percentages were identified as:

Technical	Design or manufacturing concerns	2%
	Design and manufacturing concerns	4%
Cost	Material or labor cost	1%
	Material and labor cost	2%
Schedule		1%

Also from Section 8.2, Risk Factor Table, risk factors used in the Conceptual Design Cost Estimate were identified as:

TABLE 5: RISK FACTOR TABLE			
Risk Factor	Technical	Cost	Schedule
1	Existing design and off-the-shelf hardware	Off-the-shelf or catalog item	Not used
2	Minor modifications to an existing design	Vendor quote from established drawings	No schedule impact on any other item

[2] GEM Cost Estimating Plan, Rev D, April 13, 1992.

3	Extensive modifications to an existing design	Vendor quote with some design sketches	Not used
4	New design within established product line	In-house estimate for item within current product line	Delays completion of non-critical path subsystem item
6	New design different from established product line. Existing technology	In-house estimate for item with minimal company experience but related to existing capabilities	Not used
8	New design. Requires some R&D development but does not advance state-of-the-art	In-house estimate for item with minimal company experience and minimal in-house capability	Delays completion of critical path subsystem item
10	New design. Development of new technology which advances state-of-the-art	Top down estimate from analogous programs	Not used
15	New design way beyond state-of-the-art	Engineering judgement	Not used

Using the above definitions for each WBS element, the consistency of the spreadsheet values was verified with the result being compared to independent evaluation risk factor values, detailed in Section IV of this report.

The result of the comparison is shown below:

	LOI Estimate				Spreadsheet				Assessment			
Vessel Shells	4	4	4		4	3	4		4	3	8	
	12%	8%	4%	24%	12%	6%	4%	22%	12%	6%	8%	26%
Stiffeners	4	3	4		4	3	4		4	3	4	
	12%	6%	4%	22%	12%	6%	4%	22%	12%	6%	4%	22%
On-Site Assembly ✓	10	8	8		6	6	10		8	6	8	
	30%	16%	8%	54%	18%	12%	10%	40%	24%	12%	8%	44%
Winding Tooling ✓	10	10	8		7	5	4		7	5	4	
	30%	20%	8%	58%	21%	10%	4%	35%	21%	10%	4%	35%
Conductor	8	6	8		5	3	4		6	3	8	
	24%	12%	8%	44%	15%	6%	4%	25%	18%	6%	8%	32%
Coil Form ✓	10	10	8		4	4	5		4	4	6	
	30%	20%	8%	58%	12%	8%	5%	25%	12%	8%	6%	26%
Central Det Support	6	6	4		4	4	4		4	4	4	
	18%	12%	4%	34%	12%	8%	4%	24%	12%	8%	4%	24%
Labor	$18,927				$18,927				$18,927			
Material	75,598				75,598				75,598			
Contingency	28,581	[30%]			22,114	[23%]			23,106	[24%]		
Magnet Construction	$123,106				$116,639				$117,631			

The effect of risk factors from the spreadsheet is a 23% contingency. Independent evaluation of selected WBS elements came to the conclusion that, overall, the spreadsheet risk factors were of the correct order of magnitude. The distribution of risk was somewhat different but the result was a 24% contingency.

The SSCL cost risk methodology as discussed above assumes that the risk factors and percentage risk adjustments can be applied to a WBS line item cost estimate independent of how the cost estimate is distributed among materials, labor, and other cost categories.

Some of the WBS line items have a very high proportion of shaped material cost -- more than 67% for five line items. As discussed in Section III.A, the cost of shaped materials is primarily affected by market trends and could increase 5% - 10%.

It may be, then, more appropriate to apply a 5% to 10% contingency to the shaped materials rather than the substantially greater contingencies estimated using the SSCL cost risk methodology. Shaped materials costs for nine line items in the Shaped Materials Alternative Contingency Cost Calculations on Table 6 are compared to the total cost without contingency.

On average 67% of the cost is for shaped materials. The contingency for the same line items amounts to $11.1M or 23%. As an excursion, the contingency is adjusted, as shown in the last two columns, in the following manner:

- A contingency of 10% and 5% is applied to the shaped materials
- A contingency percentage as calculated by the SSCL cost risk methodology is applied only to that portion of the cost exclusive of shaped materials

The result is that the contingency for the nine line items reduces by 35% to 49%, or $3.9M to $5.4M. This would result in a reduction of the magnet construction cost of 3% to 5%.

D. SUBCONTRACTOR ADJUSTMENTS

The SSCL magnet cost estimate first assumed that all work would be performed by government organizations and later included an adjustment (as WBS Element 4.9.6) for the use of industrial contractors to perform a portion of the work. In total, the subcontractor cost corrections amounted to $12.3M, or 9.5%, of the total construction cost. The following summarizes the subcontractor cost corrections, including contingency:

	Proc/Fab Materials	Labor	Contingency	Total
		$ Millions		
Subcontractor				
Labor Rate Corrections	-	-0.1	-	-0.1
Cost of Money	0.7	0.15	0.2	1.1
Subcontract Charges	1.0	0.15	0.3	1.5
Material Handling Charges	0.6	-	0.1	0.7
Fee	2.7	0.9	0.9	4.5
Subtotal	4.9	1.1	1.5	7.7
Government				
Tech. Design, Oversight & Management	-	3.7	0.9	4.6
Total	4.9	4.8	2.4	12.3

(Numbers may not add due to some "Other Material" and rounding)

The subcontractor adjustments assume Procured/Fabricated Materials that 50% of all Procured/Fabricated Materials ($66.7M) are included in subcontracts (0.50 * $66.7M * 0.08 = $2.7M).

Also note that the labor subcontractor adjustment assures that 83% of all labor ($14.1M) is included in subcontracts (0.83 * $14.1M * 0.08 = $0.9M).

There is uncertainty as to the reasonableness of the 50% of Procured/Fabrication Material assumption. This percentage could be considerably higher - possibly more in line with the labor percentage of 83%. If, for example, the Procured/Fabricated Material subcontracted portion was 75%, then the construction cost estimate would increase approximately $2.5M.

TABLE 6: SHAPED MATERIALS ALTERNATE CONTINGENCY COST CALCULATIONS

SHAPED MATERIALS ALTERNATE CONTINGENCY COST CALCULATIONS

COMPONENT	Total Shaped Materials	Total w/o Cont.	% Material Cst.	Contingency	Contingency %	Contingency Adjusted 10%	Contingency Adjusted 5%
Coil Sub - Conductor	7,002	8,364	84%	2,091	25%	1,041	691
Coil Sub - Coil Form	6,750	9,714	69%	2,428	25%	1,416	1,078
Vessel Shells	613	4,761	13%	1,047	22%	973	943
Vessel Stiffeners	1,156	3,388	34%	745	22%	606	549
Vessel Support Structures	1,368	2,434	56%	414	17%	318	250
Forward Field Shapers	5,280	7,872	67%	1,574	20%	1,046	782
FFS Support Structures	3,578	5,969	60%	1,134	19%	812	633
Central Deflector Support	3,938	5,900	67%	1,416	24%	865	668
Return Field Mitigation	460	686	67%	220	32%	118	95
TOTAL COST (K$)	30,145	49,088	61%	11,069	23%	7,196	5,689

IV. ANALYSIS OF HIGH COST, HIGH RISK WBS ELEMENTS

Identification of high cost, high risk elements of the SSCL work breakdown structure helped prioritize the cost validation effort by focusing upon principal contributors to the SSC costs.

Selection criteria identified elements contributing 2% or more to the magnet's cost estimate. Within the 2% group WBS elements exhibited a wide range of contingencies. Only those in the group with a contingency percentage of 20% or more were retained for examination. Three elements were eliminated from the 2% group. The source of data was a spreadsheet obtained from the SSCL[3].

WBS elements retained for examination are shown below:

WBS	ELEMENT NAME	(A)	(B)	(C)	(D)
4	Magnet Sub-System Construction	$116,639	$22,114	23.4%	100.0%
4.1	Solenoid Magnet Sub-System	77,680	15,385	24.7%	65.9%
4.1.1	Coil Assemblies	53,646	11,230	26.5%	44.9%
4.1.1.1	Coil Sub-Assemblies	30,164	6,589	27.9%	24.9%
- 4.1.1.1.1	Coil Form	12,142	2,428	25.0%	10.3%
- 4.1.1.1.2	Conductor	10,455	2.091	25.0%	8.8%
- 4.1.1.1.4	Winding Tool	3,358	871	35.0%	2.6%
4.1.1.1.5	Assembly	4,149	1,185	40.0%	3.1%
4.1.1.1.5.2	On-Site Assembly	4,149	1,185	40.0%	3.1%
4.1.1.3	Vacuum Vessel Sub-Assemblies	14,911	2,617	21.3%	13.0%
- 4.1.1.3.1	Vessel Shells	5,808	1,047	22.0%	5.0%
- 4.1.1.3.2	Vessel Stiffeners	4,133	745	22.0%	3.6%
4.1.3	Detector Supports	7,316	1,416	24.0%	6.2%
- 4.1.3.1	Central Detector Support . .	7,316	1,416	24.0%	6.2%
4.7	Installation/Testing Tooling	2,641	545	26.0%	2.2%
4.8	Installation Testing	5,041	1,089	27.6%	4.2%
4.9	Sub-System Management and Integration	15,832	2,870	22.1%	13.7%
4.9.6	Sub-Contract Cost Corrections	12,343	2,389	24.0%	10.5%
- 4.9.6.5	Fee	4,552	881	24.0%	3.9%

Column definitions are:

A Total Estimated Cost
B Contingency Estimate
C (B)/(A-B) = % Contingency
D (A-B)i/(A-B)max: i = individual element

The WBS elements retained in the 2% group are identified by the dotted lines.

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[3] GEM Detector Second Level Summary, Magnet, dated 6/2/92.

A. Vessel Shells/Stiffeners [4.1.1.3.1/4.1.1.3.2]

Vessel shells and vessel stiffeners comprise 66% of the vacuum vessel sub-assemblies cost estimate. Their contingencies are twenty-two percent.

The vessel shell consists of an outer and concentric inner cylinder made of low carbon steel plate with ports provided for valves, piping, pumps, electrical and cryogenic penetrations, and coil splices. Plates are two and one inch thick, respectively.

The stiffeners are fourteen rings and four C section end rings of SA516 grade 70 steel and longerons of 304L stainless steel.

Associated with these two WBS elements is element 4.1.1.3.4.2, On-Site Vessel Assembly. Although On-Site Vessel Assembly did not meet the original selection criteria, upon investigation of the vessel shell and stiffener elements, it became obvious the assembly element had to be included to reconcile SSCL and vendor estimates.

1. Distribution of Cost

Costs are distributed as follows:

		SHELL		STIFF		ASSEMBLY	
(L)	Engr/Design	93		112		138	
(M)	M&S Material	105		105		79	
(L)	Insp/Admin	189		81		135	
(M)	Proc/Fab Matl	4,374	(92%)	3,090	(91%)	1,360	(79%)
	Assembly	0		0		0	
	Installation	0		0		0	
	TOTAL	4,761		3,388		1,712	
	Labor	282		193		273	
	Material	4,479	(94%)	3,195	(94%)	1,439	(84%)
	TOTAL	4,761		3,388		1,712	

It would appear the bulk of cost is in material. However, the classification of Procure/Fabricate Material is misleading. The estimate includes vendor costs other than material -- labor, overhead, profit, etc.

Raw material analysis indicates material for the shell and stiffeners consists of:

	304L Stainless ($2.00/lb)	SA516 Steel ($0.36/lb)	Cost
Shell	N/A	852T	$ 613,440
Stiffener	146T	794T	1,155,680

Therefore, the cost of shell material is (105 + 613)/4,761 = 15% of total cost; For stiffener material is (105 + 1,156)/3,388 = 37% of total cost.

The point is that if both stiffener materials, 304L and SA516, increase ten percent in cost, the impact on total price would be only an increase of only 3% as calculated below:

$$\frac{3,388+[0.10*1,156]}{3,388}=1.0342$$

2. Comparison With Existing Technologies

Technological requirements for tooling, forming, assembling, and welding are standard, proven, industrial technologies. Vessel size is not out of the ordinary for heavy industry applications and the material content is basic to construction industry standards.

3. Estimate Review

Three vendor estimates plus a summary from the Rutherford model were reviewed in evaluating estimated vessel costs. The review is as follows:

TABLE 7: COST ESTIMATE CORROBORATION AMONG SSCL, THREE SUPPLIERS, AND RUTHERFORD MODEL SUMMARY

SSCL ESTIMATE		SUPPLIER/VENDOR ESTIMATE	
4.1.1.3.1 Vessel Shell		Pitt-Des Moines, Inc.	
Outer Shell Weight	207T	Weight	1,600T
Inner Shell Weight	187T	Cost	$10,525
Half Shell	394T		
2 Sections	x 2	33 mon schedule reasonable	
Whole Vessel	788T	Increase on-site work by 50% [18 mon from 12 mon]	
Cost Estimate	$ 4,374		
4.1.1.3.2 Vessel Stiffener		CBI Services	
End Rings	268T	Weight	1,700T
Stiffener Rings	100T	Cost	$10,000
Longerons	68T		
Half Shell	436T	32 weeks fabrication delivery	
2 Sections	x 2		
Whole Vessel	872T	60 weeks field erection	
Cost Estimate	$ 3,090		

4.1.1.3.4 Vessel Assembly Cost Estimate	$ 1,360	Graver Tank Cost	$12,500
		40 weeks to start 36 weeks field erection	
TOTAL WEIGHT TOTAL COST EST	1,660T $8,824	Rutherford Model Cost	$ 7,603

Estimates from the LOI are 13% below the average of supplier estimates, their average being $10,157. Using a standard deviation calculation, the range of estimates would be $8.1 to $12.2.

4. Stability of Estimate Values

Over 90% of the cost of the vessel and stiffener price will be from negotiated contracts with fabricators and vendors. More than anything else, success in negotiations will affect the success in meeting element cost estimates.

In the current economy, labor costs are not likely to change dramatically in the time frame for completing vessel design, fabricating, and installing it. Fabricated material prices are expected to increase 5% - 10% baring a major political change in raw material source countries.

5. Risk/Contingency

There is concern that the alternative for vessel half reorientation is still unclear based upon the following items:

1. The physical characteristics described for the components[4] include a sequencing of the components for lowering and installing the magnet in the Hall. The sequence identifies the following:

   Forward Field Shaper - South
   Magnet Coil Assembly - South
   Central Membrane - Barrel Calorimeter
   Magnet Coil Assembly - North
   Forward Field Shaper - North

   WBS 4.1.1.8.2 states "... includes final assembly of coil assembly and radiation shields into the vacuum vessels, ..., and rotation of the assembly into final orientation."

[4] GEM Magnet System Specifications, section 3.6.6.2, pg 23, June 4, 1992.

The concept is to inset the coils into the vessel above ground, pick up the entire 1,600T assembly and rotate its axis from vertical to horizontal, then move it to the vertical access shaft of the Hall and lower the unit to the Hall.

2. According to an excerpt from an unknown SSCL document, Section 2.6.5, Magnet System Assembly, Sub-section 6, Uprighting the Magnet Assembly, Bigge Rigging Company, Fremont, CA, can upright the 1,500T [sic], 23m x 15m solenoid. Quality rigging specialists are quoted that this type of rotation is within their capability.

According to Pitt-Des Moines, the largest transi-lift crane capacity is 1,000 tons. Each vessel half shell with corresponding stiffeners weighs 800 tons. The coil subassembly for one section weighs 574T[5]. Some items add even more weight. Pitt-Des Moines is concerned about the weight.

Vessel weights and measures comparisons between Fermilab's Collide Detector Facility and the SSC's collide detector indicate care must be taken in extrapolating vessel handling capabilities from Fermilab's vessel handling techniques:

	SSC	Fermi
Weight	1,600T	11T
Length	30m	5m
Diameter	19m	3.4m

No documentation was provided supporting Bigge's claims so the two points of view were not reconciled herein.

3. Also, if additional rigging and fasteners are required to lower the assembled weight down the vertical access shaft, there must be abundant assurance of sufficient clearance to accommodate rigging and fasteners.

Overall assumptions for magnet cost estimating excluded installation crane and rigging requirement[6]. Even if the cost of the exclusions is chargeable outside the vessel WBS elements, there is a possibility that assembly procedural changes might effect cost changes within the magnet vessel elements.

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[5] Ibid, section 3.2.2.2, pg 9.

[6] Conceptual Design Cost Estimate, Chapter 7, Miscellaneous Assumptions.

Also, if, in fact, specific rigging procedures and equipment availabilities have not been specified and verified it would be prudent to do so now. Resequencing assembly of the magnet could be very costly if changes are made late in the schedule.

Reviewing the elements' factors leads to the following comments:

Vessel Shells: The technical risk factor of 4 is consistent with a new design within established product line and agrees with the new spreadsheet value. A cost factor of 3 would be more appropriate than a 4 when the consistency of vendor estimates is considered and this agrees with the spreadsheet values. A schedule factor of 8 would be more appropriate than a 4 when considering the critical path of the solenoid schedule. The vessel shells readiness is a prerequisite to the coil being inserted and the assembly placed in the Hall. The critical path is noted in the Conceptual Design Cost Estimate. This does not agree with the new spreadsheet value.

Vessel Stiffeners: The technical factors are consistent with the discussion under vessel shells and should not be changed. This agrees with the new spreadsheet values.

Risk factors seem correct even though the overall estimate is 13% below the average of supplier estimates. Material prices are expected to increase no more than 10%, increasing the estimates by about 3%. The basis for estimates before a contingency is applied should be reviewed.

WBS 4.1.1.3.4's twenty-four percent contingency seems too high if Bigge Rigging Company's capacity is validated. A fifteen percent contingency would be more in line with this labor intensive element distributed as technical two [6%], cost three [6%], and schedule 3 [3%].

B. On-Site Assembly [4.1.1.1.5.2]

On-Site Assembly comprises 13% of the construction cost estimate. Contingency, at forty percent, is the highest of the WBS elements being reviewed.

On-Site Assembly includes all activities required to prepare the coil form for winding, to transfer the conductor from its delivery drum to a final position within the bobbin, to install instrumentation, to complete electrical and fluid connections, and to perform appropriate tests.

Most of the large tooling fabrications will have been procured; however, in the field, additional tooling may be re-

quired due to breakage, unanticipated design modifications, etc.

Considerable testing will have been performed in resolving questions related to the coil placement, ie:

Wrinkling on the inside of the conductor diameter
Tearing on the outside of the conductor diameter
Maintaining the desired cross section profile
Connecting joints between bobbins

1. Distribution of Cost

Costs are distributed as follows:

(L)	Engineering/Design	0	
(M)	M&S Material	0	
(L)	Inspection/Admin	167	
(M)	Proc/Fab Material	300	
	Assembly	2,497*	(84%)
	Installation	0	
	TOTAL	2,964	

* $1,497 in labor; 1,000 in material.

Labor	1,664	(56%)
Material	1,300	
TOTAL	2,964	

The estimate, as would be expected from the WBS title, is more sensitive to labor cost. However, if material cost increases 10% across the board the total element cost would increase 4% as calculated below:

$$\frac{2,964+[0.10*1,300]}{2,964}=1.0439$$

2. Comparison With Existing Technologies

Technological requirements for tooling, forming, assembling, and fastening are standard field tasks or are the result of assembly techniques developed in WBS 4.1.1.1.4, Winding Tooling. See Subsection e, Risk/Contingency, for further discussion.

3. Estimate Review

No specific vendor estimates for this WBS were available for review. It is noted[7] that two vendor estimates of labor required to wind and assemble the magnet were received. The conceptual

[7] Conceptual Design Cost Estimate, May 27, 1992, WBS 4.1.1.1.5.2

design estimate for labor across four related WBS elements [WBS 4.1.1.1.5.2, Coil Winding; WBS 4.1.1.8.2, Coil Assembly; WBS 4.1.1.9, Coil Testing; WBS 4.8, Installing] is thirty-one percent [31%] higher than the vendor estimates.

4. Stability of Estimate Values

Material costs are primarily for supplies such as epoxy, insulation, fasteners, etc.. It is hard to expect a significant change in material price for these items but, if it did occur, the expected impact is still in the range of 3% or less.

Labor prices are the other major cost category. In the current economy, labor cost isn't likely to change dramatically.

5. Risk/Contingency

Reviewing the element's risk factors leads to the following comments:

The technical risk factor reflects a significant concern regarding the ability to properly place the coil inside its bobbin. That problem is being addressed in the laboratory at present. Contingency for high risk should be assigned to production of the conductor and its formation for use when delivered for field assembly. Field work should benefit from thorough R&D. It should not be a time of remedial discovery although there will be some necessary refinement at the site. It is suggested that eight is the appropriate risk factor based upon the expected success of laboratory work. This is higher than the current spreadsheet value of six, reflecting some uncertainty regarding the possible extent of field changes.

The cost risk factor should be a six, rather than eight, based upon the previous discussion. This agrees with the spreadsheet value.

By prior definition, the schedule risk factor is correct for this critical work element. The spreadsheet value of ten places schedule risk impact too late in the process.

Based upon prior procurement of large tooling fabrication [WBS 4.1.1.1.4, Winding Tooling], prior development of diagnostics and controls [WBS 4.1.1.1.3, Coil Subassemblies -- Diagnostics], and prior conductor and form research and development [WBS 4.1.1.1.2, Coil Subassemblies -- Conductor; WBS 4.1.1.1.1, Coil Subassemblies -- Coil Form], the contingency for this WBS is about one-third too high.

C. Winding Tooling [4.1.1.1.4]

Winding Tooling comprises 2.9% the magnet construction estimate. Contingency is 35%.

Winding Tooling includes conductor roller, rotating platforms, insulation taping machines, high-potential testing devices, compression force rollers, and fixtures and hardware for conductor positioning, for making conductor splices, for leak checking the completed assembly, for administering and curing the epoxy, etc.

Forty drawings will be required to express the final design.

1. Distribution of Cost

Costs distributed as follows:

(L)	Engineering/Design	155	
(M)	M&S Material	24	
(L)	Inspection/Admin	49	
(M)	Proc/Fab Material	2,260	(91%)
	Assembly	0	
	Installation	0	
	TOTAL	2,488	
	Labor	204	
	Material	2,284	(92%)
	TOTAL	2,488	

It appears the bulk of cost is in material. As with vessels the cost in Procure/Fabricate Material includes fabricator and vendor labor, overhead, etc. Unlike vessels, however, the ratio of labor cost to material cost is not known so a sensitivity analysis can not be performed on this WBS.

2. Comparison With Existing Technologies

Technology requirements for tooling, forming, assembling, and welding winding tools are standard, proven, industrial technologies. It is only the winding tooling itself which is not known in detail.

SSC's solenoid is significantly larger than any other world wide. Material handling, placement, and securing require new factory and field processes with potentially significant cost and schedule impact.

3. Estimates Review

No specific estimates for winding tooling were found in the

provided materials. Until laboratory tests regarding conductor bending properties are complete, designs can not be completed for placing conductor in the bobbin. Extrapolation from previous efforts of this nature, Fermi, CERN, etc., are expected to be too empirical in nature to be of value here and are not attempted.

4. Stability of Estimate Values

There is no apparent reason to believe the ratio of fabricated material to the WBS element's total cost without contingency will be different than experienced with the other elements. Material cost increases over the next few years would, therefore, not materially affect the total construction cost nor would labor costs.

5. Risk/Contingency

At the time of documenting winding tooling cost estimates, little, if anything, was known about specific performance or physical characteristics for the items included in the WBS description, placement procedures for the conductor were not clear cut, and mechanical properties of the coils relative to materials handling, placement, and securing the conductor to the bobbin inner surface, was relatively unknown at the scale of the undertaking. Specifics of splices between bobbin conductor ends and their cooling, testing requirements and instruments required to conduct the tests, and delivery dates for the tooling were also unknown.

Taken all together, this is the **key WBS element** for completing the solenoid within cost and schedule.

Recognition of this WBS element as the keystone in coil subassemblies and the magnitude of unknowns in its make-up supports the risk factors being near their maximum value. The contingency, thirty-five percent, is high and should remain at this level until more is known. Technical, cost, and schedule risk factors in the spreadsheet agree with this assessment.

D. Conductor [4.1.1.1.2]

Conductor comprises 8.8% the construction cost estimate. Contingency is 25%.

Conductor includes all activities required to provide the finished conductor in a form suitable for transfer into the bobbin.

Cost of this type of conductor is not well understood. A potential large risk is associated with welding the aluminum stabilizer to the stainless steel tube while assuring good surface contact between mating pieces as well as weld integrity

after the forming operation.

1. Distribution of Cost

Costs are distributed as follows:

(L)	Engineering/Design	60	
(M)	M&S Material	52	
(L)	Inspection/Admin	119	
(M)	Proc/Fab Material	8,001	(96%)
	Assembly	133	
	Installation	0	
	TOTAL	8,365	
	Labor	236	
	Material	8,128	(97%)
	TOTAL	8,364	

2. Comparison With Existing Technologies

Solenoid conductor cable is of a relatively complicated design, possibly requiring extensive modification to existing equipment and acquisition of a particular stranding machine to extend capabilities not in-house for one vendor[8]. General availability of such a stranding machine is unknown but the installed cost of a used one is in excess of a quarter million dollars.

Experience in winding coils on a 9.5 meter radius is non-existent. The forming process needs to be developed. Determination of the amount of reforming required to transfer the conductor from its four meter diameter shipping spool to its nineteen meter diameter bobbin without undue mechanical deformation is pending.

3. Estimates Review

Although supplier estimates do not clearly break out costs for specifics of this WBS element, material estimates for the cable appear to be about twenty-five to thirty percent of its total cost.

A breakdown of inner strand price per billet indicates a raw material contribution of thirty-nine percent[9]. Procured shaped materials from Subsection 6.4 of this report quote aluminum at $3.30 per kilogram while the estimated price from one of the suppliers is $5.50 per kilogram for 99.99% purity and $28.00 per

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[8] New England Electric Wire, Vendor Estimate comments.

[9] SSCL Magnet Systems presentation material.

kilogram for 99.999% purity. The price of stranded copper was also listed in the referenced subsection. From supplier estimates copper appeared to be consistent in drawn profile at about $2.67 - $3.40 per pound domestic and foreign, respectively.

In summary, from information supplied there isn't good corroboration among price bases for conductor components.

4. Stability of Estimate Values

It is the process itself which appears to drive cost in this WBS element. This is reflected in the largest part of cost not being material although, depending upon the suppliers' price at time of contract, an impact on the cost estimate is possible.

5. Risk/Contingency

Reviewing the element's risk factors leads to the following comments:

> Manufacturing the solenoid's conductor is within existing technology though it borders on state-of-the-art. and exceeds the usual production plant capacity. The technical risk factor is too high, a six being more appropriate.
>
> Although there appears to be considerable variance in per unit price for the conductor there is leeway in choice of purity and supplier, domestic or foreign, which will, in time, fix the price. With material and labor prices being reasonably stable and supplier estimates referring to design sketches, such sketches being in evidence, the cost risk factor should be three.
>
> Conductor is on the critical path. If its mechanical properties problems are not solved in time, or there is a problem in manufacturing and delivery ready for transfer to the bobbins, placement of the half shell will be delayed, a WBS element also on the critical path. Accordingly the schedule risk factor is correct at eight.

Risk factors should be 6, 3, and 8 rather the 8, 6, and 8. New values in the spreadsheet are 5, 3, and 4 -- a difference of about 5% - 6%.

E. Coil Form [4.1.1.1.1]

Coil Form comprises 41% of the construction cost estimate. Contingency is 25%.

Coil form includes manufacturing and assembling sections for

a bobbin of nominal nineteen meters inside diameter by 1.2 meters long by two inches thickness of 6061-T6 aluminum.

Possible machining requirements may significantly increase cost. Use of stainless steel may decrease the cost by $100K.

1. Distribution of Cost

Cost distribution analysis shows 98% of the coil form cost is in Procure/Fabricate Material as follows:

(L)	Engineering/Design	71	
(M)	M&S Material	16	
(L)	Inspection/Admin	81	
(M)	Proc/Fab Material	9,545	(98%)
	Assembly	0	
	Installation	0	
	TOTAL	9,713	
	Labor	153	
	Material	9,561	(98%)
	TOTAL	9,714	

2. Comparison With Existing Technologies

There is some question whether the bobbin will be of aluminum or stainless steel. In either case, technological requirements for manufacturing bobbin quarters and flanges and field assembling and welding of the quarters and flanges are standard, proven, industrial technologies.

Final decisions on internal diameter machining and the number of bolts required to secure flange interfaces are still a question.

3. Estimates Review

Three supplier estimates for the bobbin ranged from $6.5 million to $7.0 million. One supplier estimated their accuracy at -10% to +40%. At $9.8 million [$7.0 x 1.40] the highest estimate is very close to the SSCL estimate.

4. Stability of Estimate Values

Essentially all coil form cost is in procurement and fabrication. Remembering prior discussions regarding the make-up of estimates in this category, with the closeness of supplier estimates, the cost estimate should be reasonably accurate even though the question of aluminum versus stainless steel has not been answered.

Estimates were made at the low point in aluminum unit prices so there is expectation of a 5% - 10% increase in those prices by mid-1990's.

5. Risk/Contingency

Based upon definitions for risk factors it is recommended they be 4, 4, and 6 rather than 10, 10, 8. This is in line with the new spreadsheet values except the impact of possible lateness on the bobbins caused the recommended schedule risk factor to be six instead of five, a 1% difference.

F. Central Detector Support [4.1.3.1]

Central Detector Support comprises 6.2% of the construction cost estimate. Contingency is 24%.

Central Detector Support consists of two flat plates four inches thick, 71.5 feet in diameter, tied together with radial stiffeners. The structure is free standing and permanently supports the 3,000T central detector. It attaches the inner ends of the two solenoid vessel halves.

It is made of A36 low carbon steel and 304L stainless steel fabricated in the field.

1. Distribution of Cost

Costs are distributed as follows:

(L)	Engineering/Design	357	
(M)	M&S Material	0	
(L)	Inspection/Admin	116	
(M)	Proc/Fab Material	5,427	(92%)
	Assembly	0	
	Installation	0	
	TOTAL	5,900	
	Labor	473	
	Material	5,427	(92%)
	TOTAL	5,900	

2. Comparison With Existing Technologies

Technology requirements for assembling, welding, cleaning, and finishing the membrane are standard field assembly practices.

3. Estimates Review

No supplier estimates were found in the source documents.

4. Stability of Estimate Values

Estimates are based upon prices with well known fluctuations, basic to the construction industry. There should be no surprises here.

5. Risk/Contingency

Primarily, this is a field task based upon standard labor practices using well known fabrication processes. Risk factors should be 4, 4, and 4 rather than 6, 6, and 4 as shown in the cost estimate. This agrees with spreadsheet risk factors.

V. CONCLUSIONS

Review of the SSC estimate clearly indicates that it has been soundly prepared and thoroughly documented using appropriate cost estimating methodologies. All technical challenges and cost and schedule impacts have been fully considered and appropriate risk factors have been assigned to cover contingencies.

The following summarizes additional conclusions from the independent evaluation, as documented throughout this report:

- SSCL vendor estimates were taken at a low point in material costs. It is estimated shaped metal costs will rise 5% to 10% by the mid 1990's and material labor rates will increase 0% to 3% during the same period. A 5% to 10% contingency range for procured fabricated materials appears appropriate.

- Examination of labor rates validated those used in the SSCL estimate, with the exception of a small grouping of crafts which should have no significant impact on the total cost estimate.

- Drawing costs appear reasonable considering the level of technology involved.

- Independent assessment of the application of risk factors resulted in an overall contingency of 24% compared to SSCL's 23%. The difference is insignificant.

- Independent assessment of contingency resulted in a distribution different than SSCL's. The most significant difference was noted in processes associated with assembly of the coils. Risk should be more appropriately assigned to the winding tooling WBS rather than the on-site assembly WBS.

- Opposing capability statements from vendor estimates regarding rigging and moving the vacuum vessel halves for positioning in the Hall after its vertical assembly in the field were noted. Confirmation of rigging equipment capabilities and availability is recommended along with confirmation of sufficient access shaft clearance, especially if vessel redesigns are necessary for placement and alignment in the Hall.

- Overall, cost distribution analysis shows 68% of the magnet's cost is in Procure/Fabricate Material as follows:

	<- Magnet ->		Shell	Stiff-eners	Vessel Assy	On-Site Assy	Winding Tool	Cond	Form	Detector Support
Engineering/Design	11,807	11.2%	2%	4%	8%	0%	6%	1%	1%	6%
M&S Material	6,931	6.6%	2%	3%	5%	0%	1%	1%	0%	0%
Inspection/Admin	8,597	8.1%	4%	2%	8%	6%	2%	1%	1%	2%
Proc/Fab Material	71,655	67.8%	92%	91%	79%	10%	91%	96%	98%	92%
Assembly	4,083	3.9%	0%	0%	0%	84%	0%	1%	0%	0%
Installation	2,544	2.4%	0%	0%	0%	0%	0%	0%	0%	0%
TOTAL	105,618	100.0%	100%	100%	100%	100%	100%	100%	100%	100%
Labor	24,888	23.6%	6%	6%	16%	56%	8%	3%	2%	8%
Material	80,730	76.4%	94%	94%	84%	44%	92%	97%	98%	92%
TOTAL	105,618	100.0%	100%	100%	100%	100%	100%	100%	100%	100%

Cost for the Procure/Fabricate Materials category involve multiple factors (material, labor, other) which may have different impacts to the total cost given the economic situation at time of execution. Risk factors in the SSCL estimate attempting to cover such diverse contingencies should be reviewed.

- Alternative approaches to assessing risks were pursued in lieu of the SSCL cost risk methodology. A reduction of 3% to 5% is realized in the total magnet construction cost if expected material cost increases noted in the independent assessment (5% to 10%) are applied to material procurements and the nominal contingency factors are applied to the balance of the estimates.

- SSCL estimate subcontractor adjustments are assumed to be 50% for Procured/Fabricated Materials. If the subcontractor portion is increased, the construction cost estimate will increase accordingly. For instance, if the subcontractor portion is increased to 75% the construction cost estimate will increase approximately $2.5 million. The area of subcontractor adjustments also should be examined further in order to fully clarify the expected subcontractor participation. Potential small total cost increases may arise with increased subcontractor activity.