GEM IN-91-1

GEM MAGNET SUBSYSTEM LOI CONCEPTUAL DESIGN COST ESTIMATE

December 12, 1991

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Abstract:

This document details and supports Revision C (December 12, 1991) of the Gem Magnet LOI Cost Estimate. It contains a description of the scope, system parameter, work breakdown structure and labor rate assumptions. It also includes a complete cost/risk/schedule matrix, the existing subsystem drawings and a complete description of the basis of the magnet construction cost estimate.

GEM-LLNL-91-001

GEM—Magnet Subsystem LOI Conceptual Design Cost Estimate

Rev C

December 12, 1991

Lawrence Livermore National Laboratory
&
MIT Plasma Fusion Center

Contents

1.0 Introduction

The GEM collaboration has submitted to the SSCL a Letter-of-Intent (LoI) to construct a second large detector. This detector emphasizes precision measurement of gammas, electrons, and muons, and employs a large magnetic volume for precision tracking of these particles. As discussed in the LOI, we propose to create this large magnetic volume by using a large superconducting solenoid, with field-shaping iron end poles. The overall dimensions of this magnet are roughly 20m OD x 32m long, with a fairly uniform internal field of 0.8T.

To facilitate management of the detector construction, the detector has been broken into a 8 subsystems, one of which consists of the superconducting magnet itself. This document provides detailed information on the cost estimate of the magnet subsystem, as support to the summary information included in the LOI. It is intended that this document fully explain all assumptions made in developing the cost estimate, to facilitate reviews, as well as to form a basis for future design-to-cost effort within the magnet subsystem.

This document is organized with summary information at the front in Section 3.0. This section is intended to give the casual reviewer summaries at relatively high levels, with relatively few details. It also gives breakdowns by types of activities, as well as cost breakdowns for several of the more interesting components and assemblies.

Section 4.0 provides a detailed list of parameters associated with the magnet design concept which was used as the basis of the estimate. This section is intended to be a reasonably complete description of the design, which should facilitiate cost comparisons with other magnet systems.

Sections 5.0 and 6.0 show the Work Breakdown Structure, and the dictionary to accompany it. The dictionary is essentially a listing of the detailed content of each individual WBS element. This is useful for understanding the cost estimate at each level.

Section 7.0 discusses the labor rates assumed for this cost estimate.

The complete speadsheet-based cost/risk/schedule table is included as Section 8.0. Each of the entries in this table is either a sum of other elements, or it is supported by information in Section 9.0. The Basis of Estimate sheets in Section 9.0 are indexed by WBS number, to facilitate the review of any entries in the overall matrix. These sheets also refer to vendor estimates, which are outlined in Section 10.0; however, in order to protect vendors' proprietary information, their estimate details are bound separately and are available for review only upon request. Section 11.0 contains the design drawings which were used as the basis of estimate. Finally, any references outside this document are listed in Section 12.0.

2.0 Scope

This document supports the GEM LOI cost estimate of the Magnet Subsystem. This subsystem consists of the magnet coils, vacuum vessels, supports, power/protection systems, controls, cryogenics, end poles, vacuum system, tooling, etc. It includes all of the components and assemblies required to provide the magnetic field within the measurement volume of the GEM detector. It also includes the supports for the central detector subsystems (calorimeter(s) and central tracker), since these supports interface heavily with the magnet subsystem.

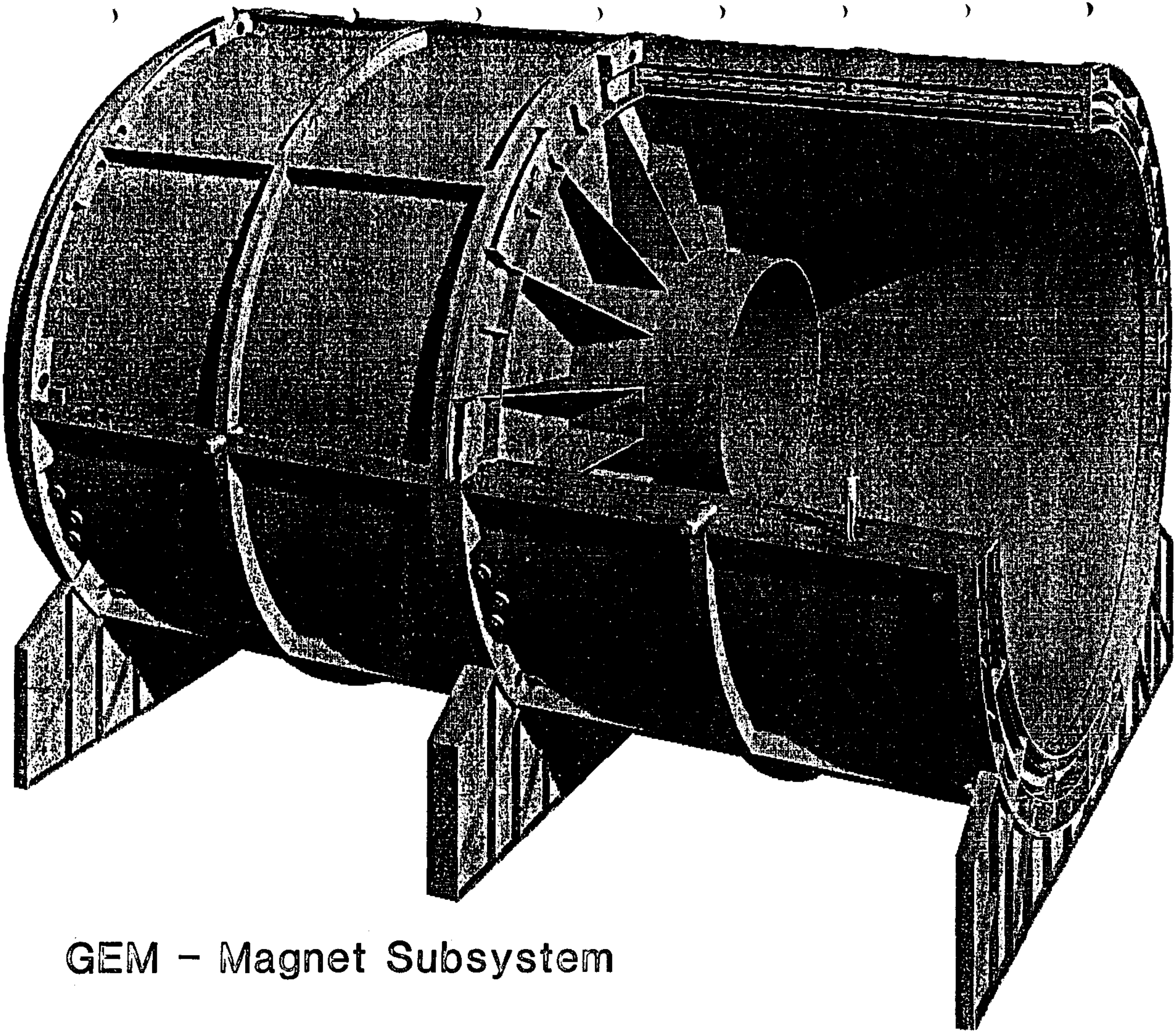
This estimate does not include any conventional facilities (above-ground or underground), or technical facilities, such as cooling water, etc. Interfaces have been informally defined with the Muon Subsystem, and mounts for muon sectors are included in the magnet subsystem.

This estimate is based on a specific design that is at the conceptual level, with both design and cost-estimating having been completed in less than 4 months. Although most design features still require a great deal of engineering, we have attempted to identify a specific design for the purpose of cost-estimating; we assert that the final product should not deviate significantly from this estimate, which includes appropriate contingency to cover the uncertainty in the design. Significant effort is required to develop this design to the preliminary-design level, and that effort is one of the major items estimated.

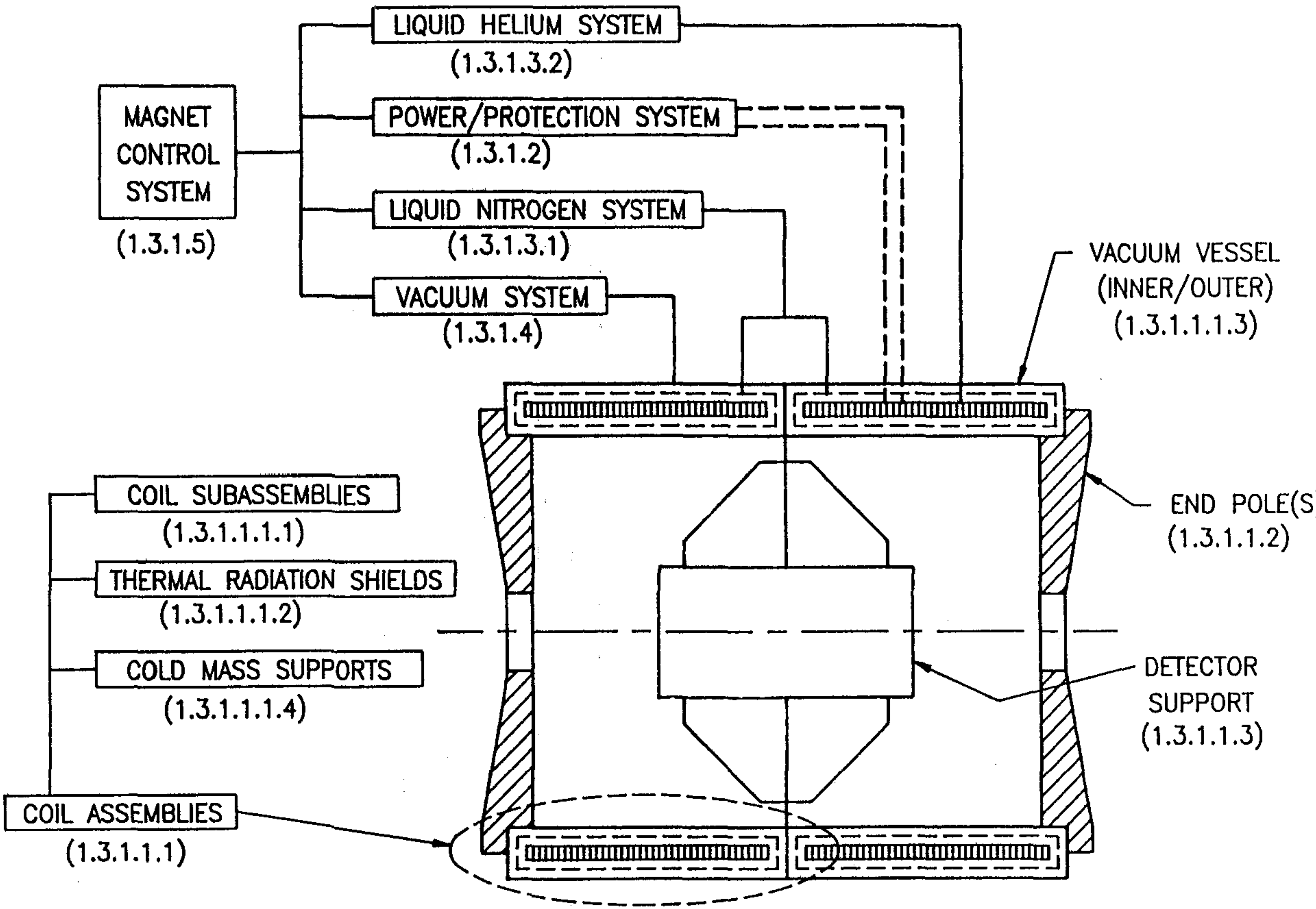
Figure 2-1 shows a computer generated solids model depicting the GEM Magnet Subsystem. Included is the vacuum vessel, support saddles, central detector support, coil subassembly and cold mass supports. A figure of a man is shown as a scale reference.

Figure 2-2 is a schematic of the Magnet Subsystem showing the major WBS items. Major subsystems are grouped together to show how they relate to the overall magnet subsystem.

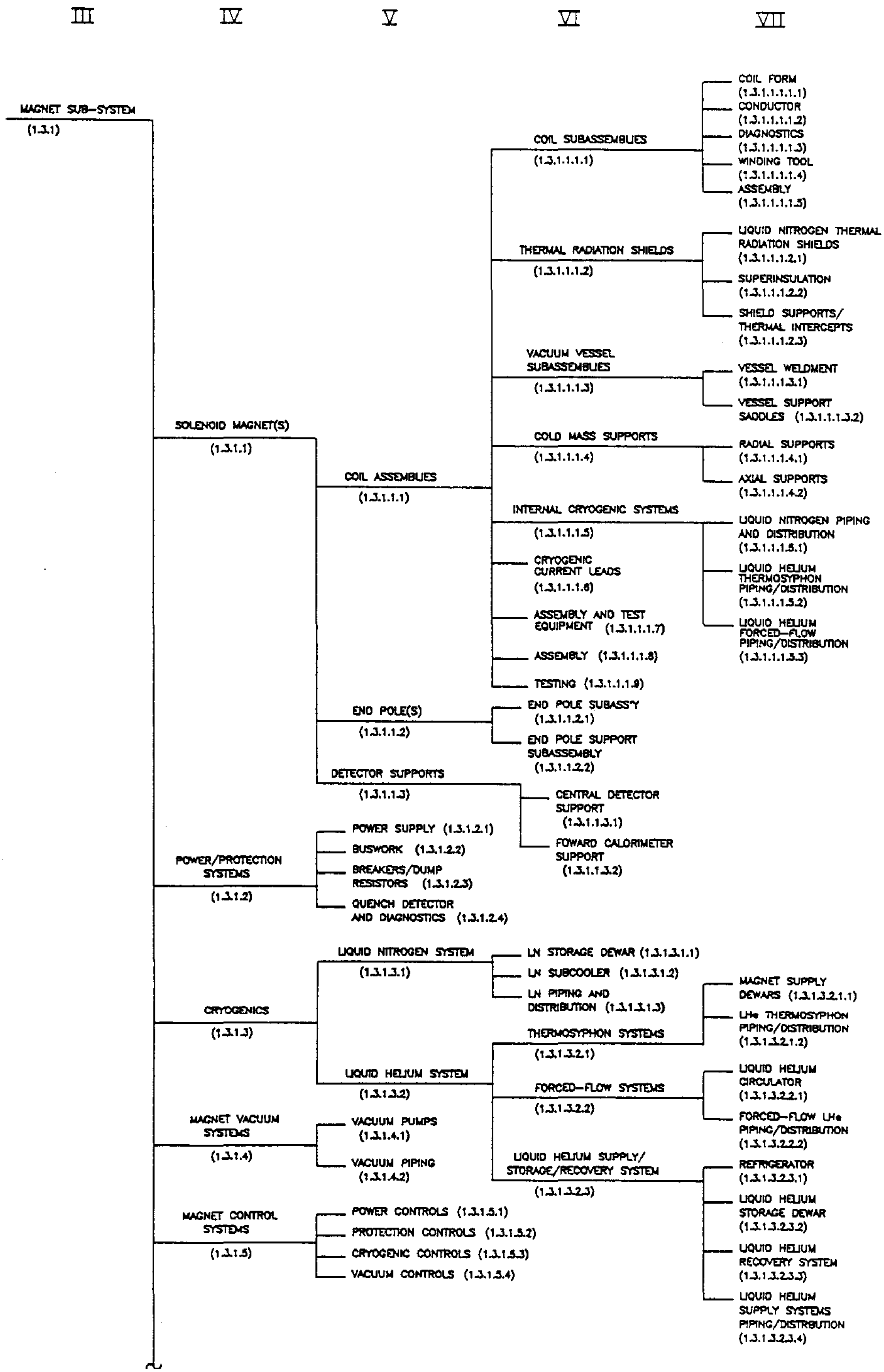
The next two pages, Figure 2-3(a) and (b) shows the entire 1.3.1 Magnet Subsystem WBS broken down to the bottom level at which cost-estimating was performed. This correlates directly to the cost matrix shown in section 8.0 of this cost estimate. It is shown in tree form to help clarify how the different subsystems interrelate with one another.



GEM - Magnet Subsystem



MAGNET SUBSYSTEM SCHEMATIC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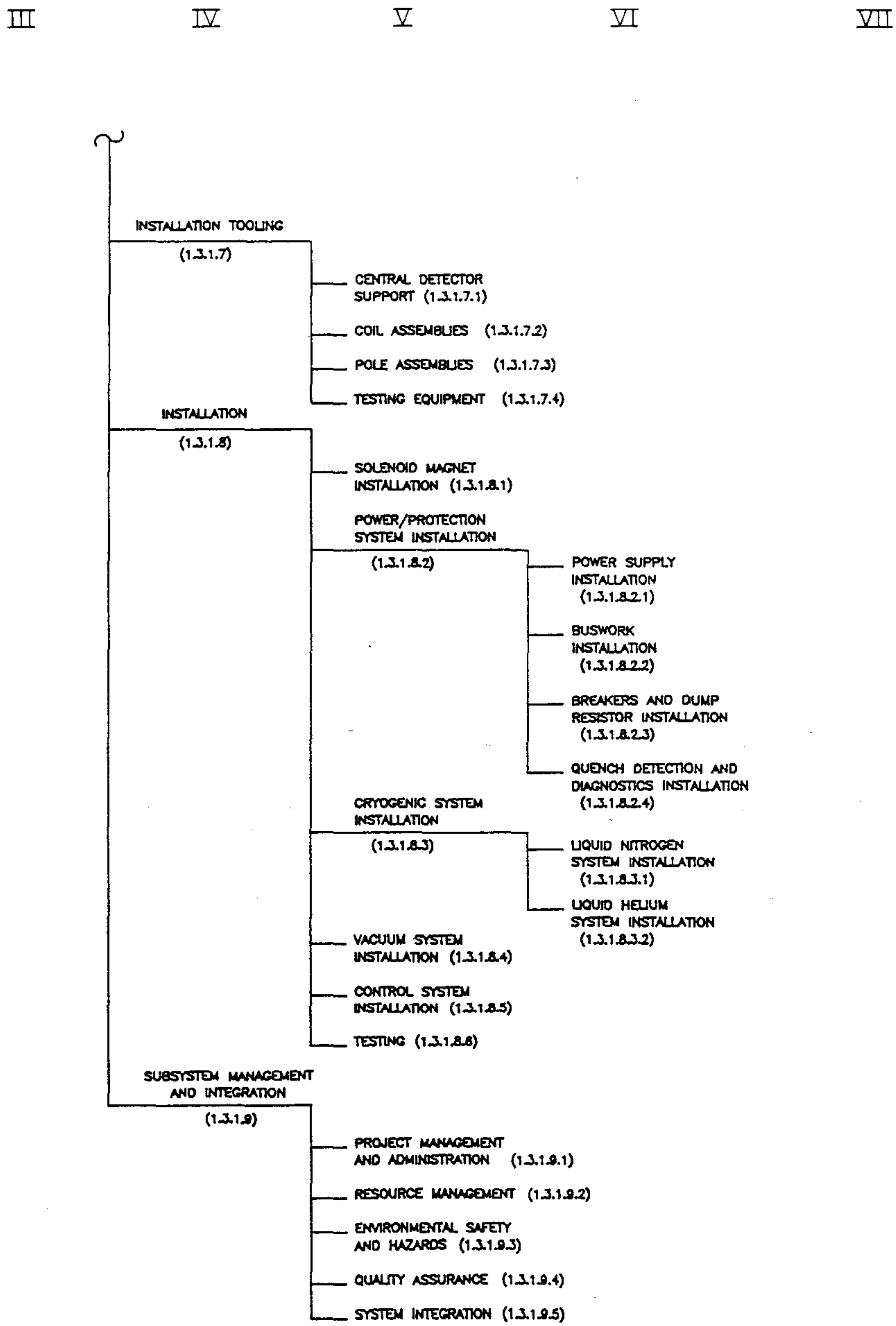
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3.0 Cost Estimate

Overview & Summary

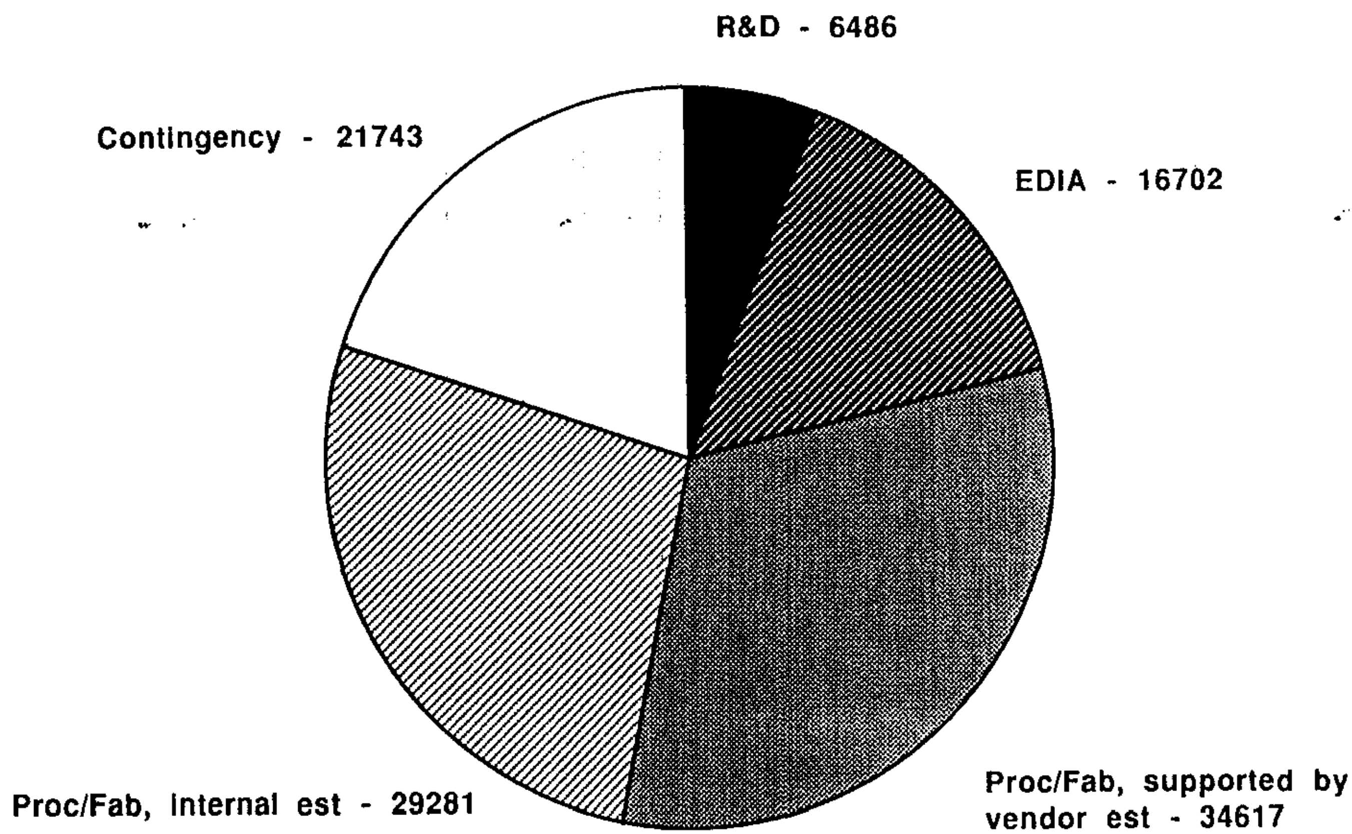
"Theriot-style" magnet cost analysis

	$k	
Labor (WBS 1.3 Inst/assy labor)	5481	
Materials (WBS 1.3 Proc/fab + Inst/Assy mat'l)	60032	
Subtotal (material+labor)	65513	
EDIA (1.2 EDIA + 1.3 EDIA)	16702	(25%)*1
Direct costs	82215	
Contingency	21743	(26%)*2
Subtotal	103958	
R&D (WBS 1.1)	4871	(6%)*1
Total	108829	

*1 - % of Subtotal, material+labor

*2 - % of Direct costs

32% of the total estimate is supported by vendor estimates



Total - 108829

gdcostrev2-18
12/12/91

Vendor estimates constitute a major fraction of the magnet estimate

Costs supported by vendor estimates*	34617	
Compare this cost to:		
Total magnet cost (incl R&D, cont, EDIA)	108829	(32%)
Total magnet cost, w/o R&D or contingency	82215	(42%)
Magnet labor and materials (no EDIA)	65513	(53%)

* Vendor estimates are considered proprietary but are available for inspection by collaboration members. They are bound as a separate document, GEM-LLNL-91-0002, for internal use only.

GEM—% Vendor Estimate

12/11/91

WBS Number	Item	Actual Estimate From Vendor in "1992 $'s"	in "1991 $'s"[c]	Cost Used in Basis of Est. in "1992 $'s"	in "1991 $'s"	delta $'s
1.3.1.1.1.1.1	Coil Form	$ 6500k	$ 6270k	$ 7475k	$ 7211k	$ 264k
1.3.1.1.1.1.2	Conductor	$ 7200	$ 6946	$ 7200	$ 6946	$ 254
1.3.1.1.1.1.5.2	Coil Winding Assembly	$ 1429[a]	$ 1429[d]	$ 3902	$ 3902	-
1.3.1.1.1.2.1	LN Thermal Radiation Shields	$ 3000	$ 2894	$ 2000	$ 2000	-
1.3.1.1.1.2.2	Superinsulatn	$ 116	$ 112	$ 116	$ 112	$ 4
1.3.1.1.1.3.1	Vesl. Weldmnt	$10000	$ 9647	$ 8556	$ 8556	-
1.3.1.1.1.4	Radial & Axial Supports Systems	$ 1534	$ 1480	$ 1534	$ 1480	$ 54
1.3.1.1.1.5	Internal Cryo Systems	$ 23	$ 23	$ 23	$ 23	-
1.3.1.1.1.8	Assembly	$ 1031[a]	$ 1031[d]	$ 761	$ 761	-
1.3.1.1.1.9	Testing	$ 257[a]	$ 257[d]	$ 518	$ 518	-
1.3.1.8.6	Testing			$ 471	$ 471	-
1.3.1.8.1	Installation	$ 281[b]	$ 281[d]	$ 2638	$ 2638	-
	Total:	**$31371k**	**$30369k**	**$35194k**	**$34617k**	**$ 577k**
Total prelim des & const cost: (WBS 1.2 & 1.3: includes EDIA but no contingency)		$82215	$82215	$82215	$82215	
	% of Total:	**38%**	**37%**	**43%**	**42%**	

[a] vendor estimate is calculated by averaging the two estimates received and using $45k/yr as the labor rate @ 1760 hrs/yr.

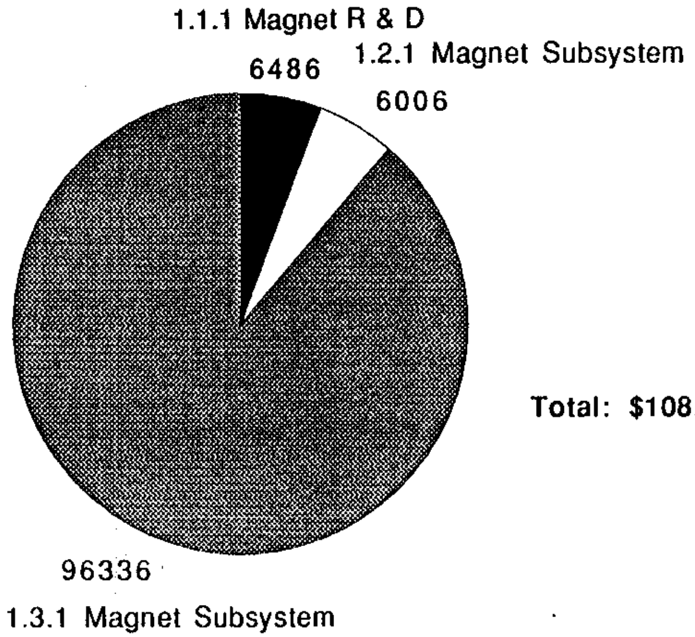
[b] vendor estimate is calculated by averaging the two estimates received and using $43k/yr as the labor rate @ 1760 hrs/yr.

[c] assumed escalation FY91-92 = 1.0366

[d] vendor estimates reported in labor hours; FY91 labor rates used to derive dollar cost estimates.

90% of the cost is in the "Construction" WBS (R&D/Prelim Des are approximately 5% each)

Subsystem cost breakdown



Total: $108.8 M

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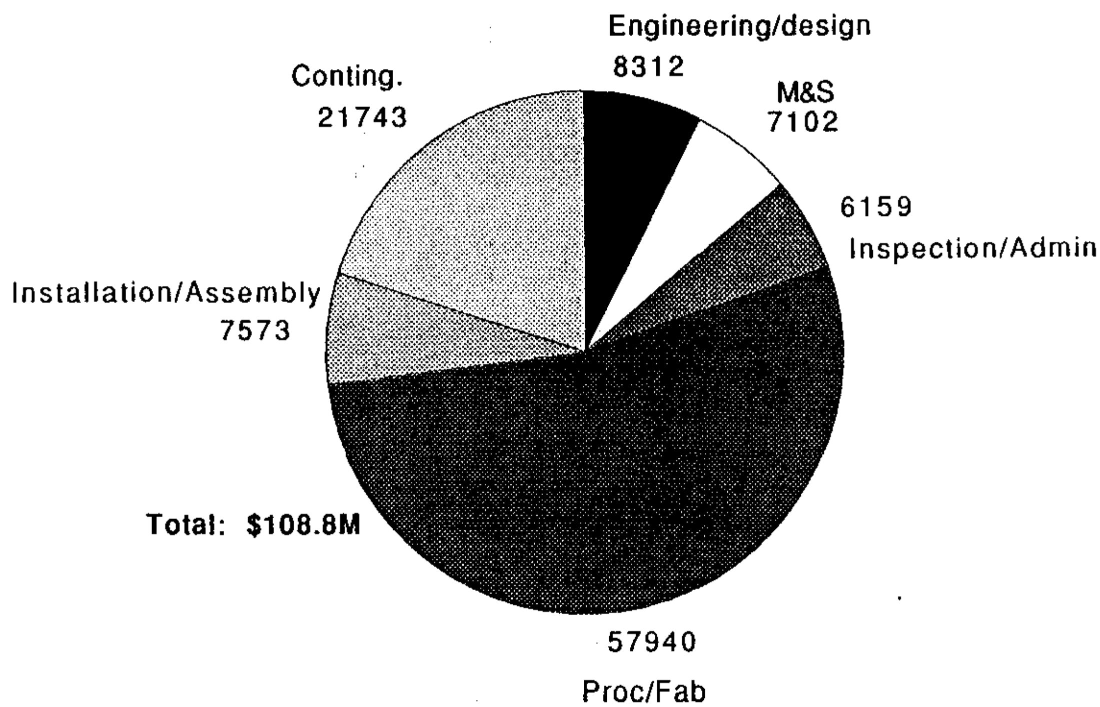
Of total costs, EDIA+R&D is 20%, and contingency is 20%*

Breakdown by major headings



* percentages of total magnet cost ($108.8M)

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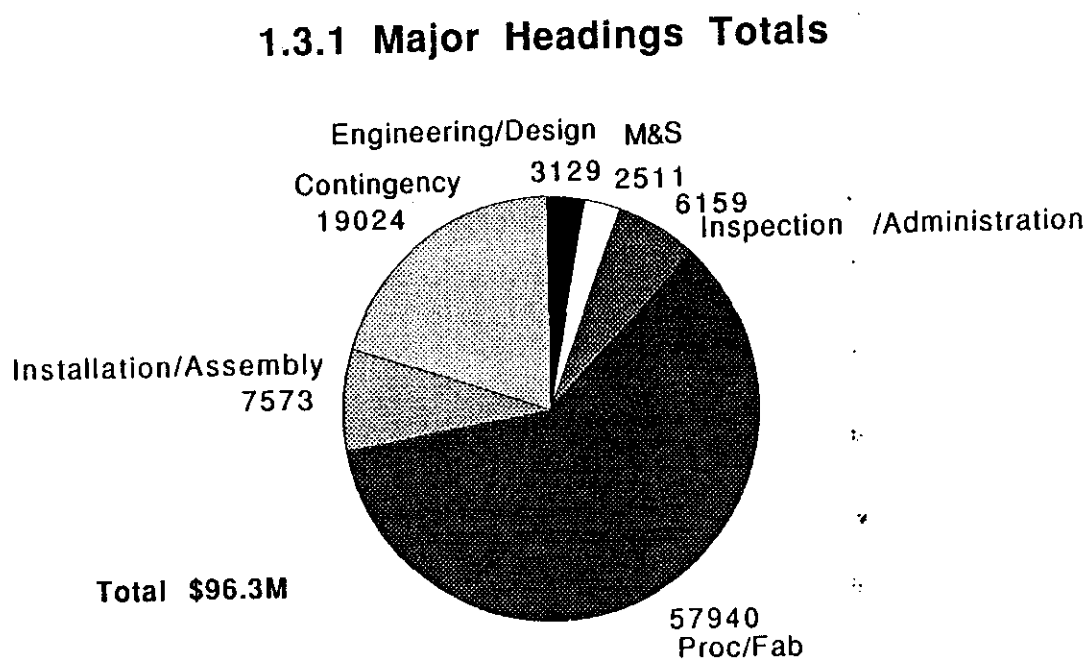
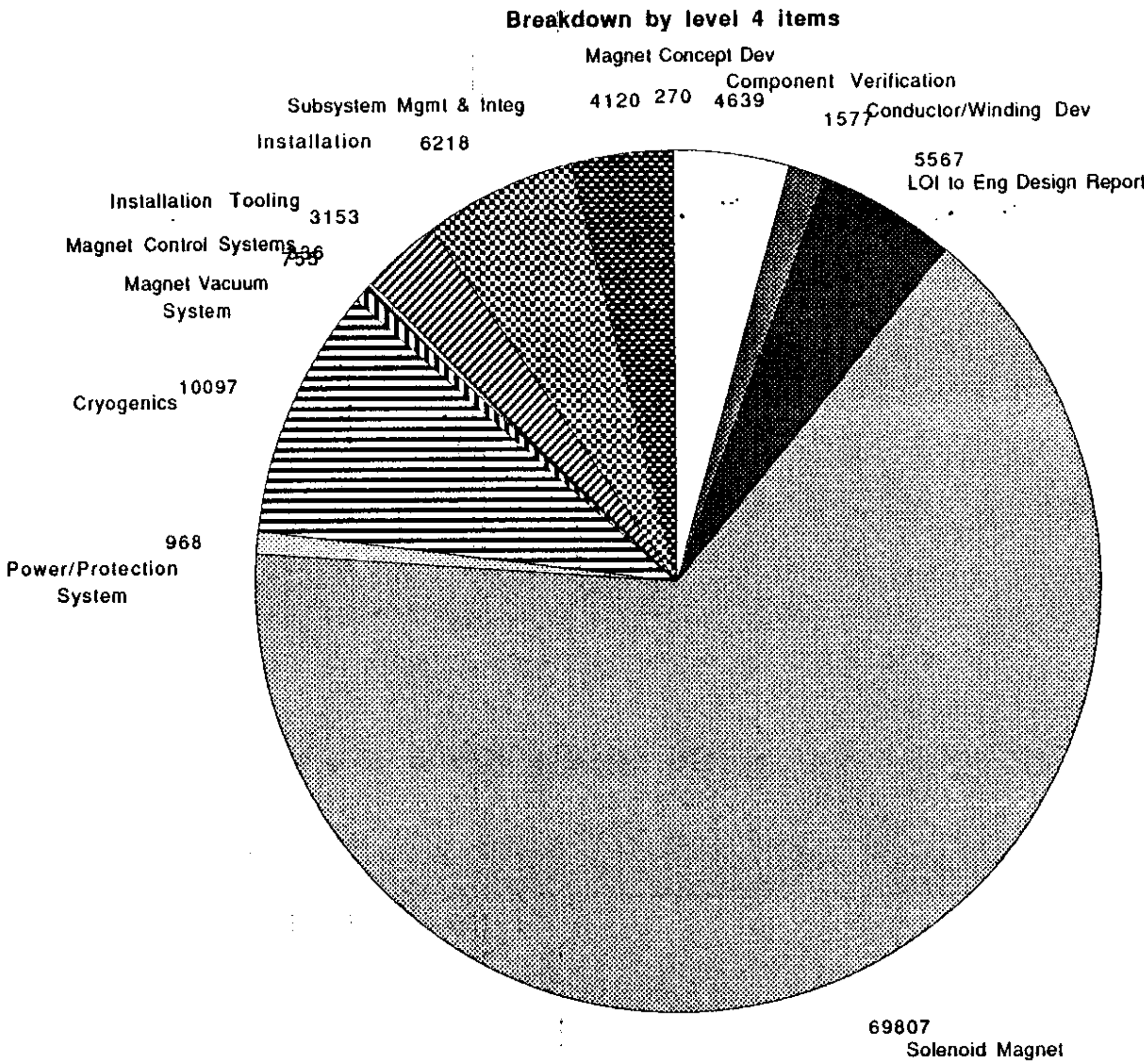
Within "construction", EDIA is 15%*, and contingency is 23%*



*** percentages of total magnet construction (WBS 1.3.1) cost - $96.3M**

The cost is completely dominated by the coils+vessels+poles



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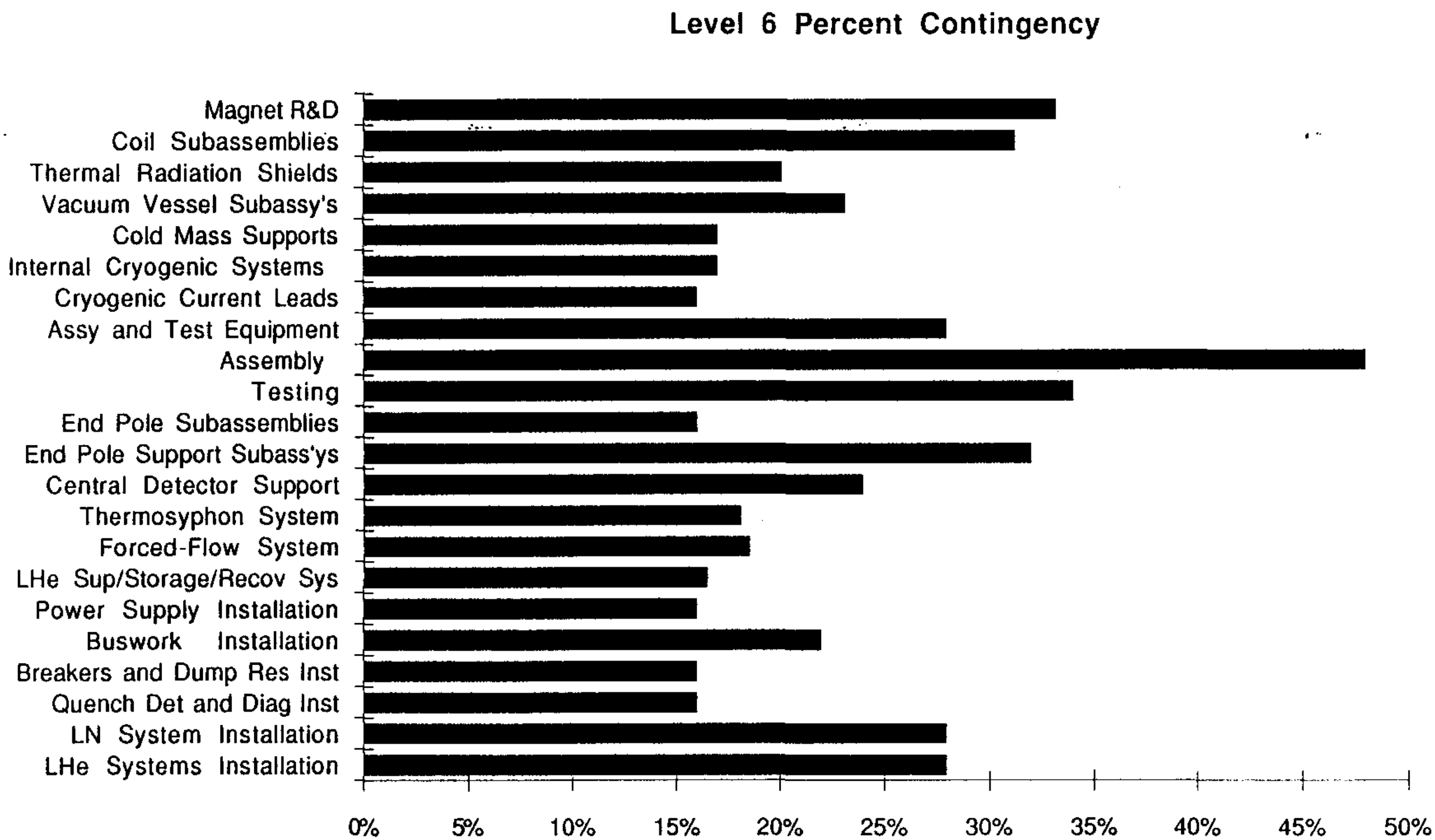
12/12/91

Contingencies ranged between 0 and 48%*



*** percentages of total direct costs (material, labor, EDIA) for each line item**

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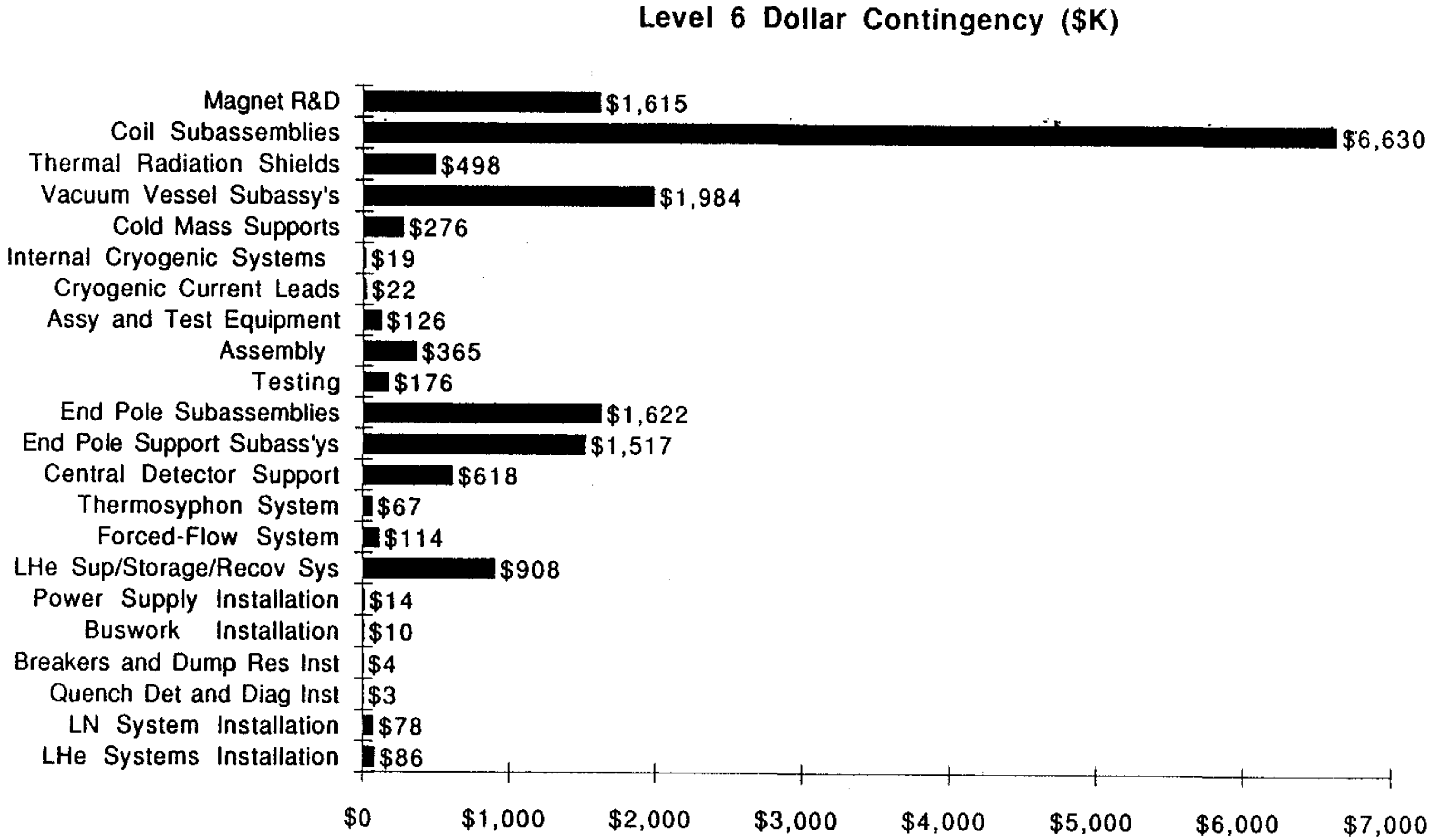
12/12/91

But most of the contingency dollars apply to the coil subassemblies (conductor, bobbin, winding)



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4.0 System Parameters

Single Coil Design

GEM Magnet Subsystem

Single-coil Design

Major Parameters List
Rev. 4
12/06/91

	Parameter	Symbol	Unit	Value	Ref.	Note	Rev
1.	Central Induction	Bi	T	0.80	-	1	1
2.	Mean radius of windings	Rw	m	8.9	6	2	1
3.	Outer Radius of outer cryostat vessel	Rv,o	m	9.4508	10	4	3
4.	Inner Radius of inner cryostat vessel	Rv,i	m	8.4	6	2	1
5.	Inner Radius, magnet subsystem		m	8.3	1	2	1
6.	Coil length, end-to-end (per half)	Li	m	14.438	10	4	3
7.	Pole-to-pole inside length	L	m	29.0	1	-	1
8.	Cryostat vessel length (end-to-end)	Lv	m	30.0	1	2	1
9.	Conductor Length	Lc	km	24	1	2	1
10.	Total mass of coil windings (per half)	Mw	t	238	10	4	3
11.	Total mass cold 4°K struct. (per half)	Mcs	t	383	10	4	3
12.	Total mass cryostat vessel(each half)	Mv	t	717	10	4	3
13.	Total mass iron end poles (each pole)	Mp	t	2950	1	2	1
14.	Radial pressure on windings	Pr	kPa	255	1	2	1
15.	Operating current	I	kA	52.5	9	3	2
16.	Stored Energy	Es	GJ	2.04	10	4	3
17.	Inductance	H	H	1.47	1	2	1
18.	Number of turns	Nt	#	408	9	3	2
19.	Thickness, inner thermal shield		m	0.0048	10	4	3
20.	Thickness, inner cryostat	tv,i	m	0.019	6	-	1
21.	Outer radius, inner cryostat vessel	Rvi,o	m	8.419	6	-	1
22.	Inner radius, inner LN shield		m	8.723	10	4	3
23.	Outer radius, inner LN shield		m	8.727	10	4	3
24.	Inner radius, conductor		m	8.8777	10	4	3
25.	Mean radius, conductor		m	8.900	6	-	1
26.	Outer radius, conductor		m	8.9222	10	4	3
27.	Inner radius, bobbin		m	8.9222	10	4	3
28.	Outer radius, bobbin		m	8.9730	10	4	3
29.	Inner radius, outer LN shield		m	9.3557	10	4	3
30.	Outer radius, outer LN shield		m	9.3605	10	4	3
31.	Thickness, outer cryostat vessel	tv,o	m	0.0508	10	4	3
32.	Inner radius, outer cryostat vessel	Rvo,i	m	9.400	6	-	1
33.	Overall outer radius (outside ribs)	Ro	m	10.2135	10	4	3
34.	Depth of outer ribs		m	0.7627	10	4	3
35.	Number of coil/cryostat assemblies		#	2	-	-	1
36.	Number of ribs per coil assembly		#	3	10	4	3
37.	Thickness of cryostat vessel ends		m	0.0381	10	4	3
38.	Actual axial winding length per assembly		m	14.25	6	-	1
39.	Central membrane maximum z		m	0.025	6	-	1
40.	Cryostat inner end minimum z		m	0.000	10	4	4
41.	Cryostat inner end maximum z		m	0.025	10	4	4

	Parameter	Symbol	Unit	Value	Ref.	Note	Rev
42.	LN shield minimum z		m	0.047	10	4	4
43.	Bobbin minimum z		m	0.285	10	4	4
44.	Winding minimum z		m	0.352	10	4	4
45.	Winding maximum z		m	14.648	10	4	4
46.	Bobbin maximum z		m	14.714	10	4	4
47.	LN shield maximum z		m	14.953	10	4	4
48.	Cryostat outer end minimum z		m	14.962	10	4	4
49.	Cryostat outer end maximum z		m	15.000	6	-	1
50.	Pole face minimum z		m	14.500	1	-	1
51.	Same as line 18				10	4	3
52.	Axial force on poles		N	63.5e6	3	-	1
53.	Axial force on conductor		N	27.9e6	7	-	1
54.	Mass of one muon sector		t	11.4	5	-	1
55.	Number of central muon sectors per half		#	16	5	-	1
56.	Radius of CG of central muon sectors		m	6.22	5	-	1
57.	Z-location of CG of central muon sectors		m	3.89	5	-	1
57.	Magnet axis height above hall floor		m	13.0	8	-	2

References

10. J. Bowers/A. Posey/R. Yamamoto: revised layouts & calculations, 10/24/91
9. P Martson calculation 8/27/91
8. GCD - 000002 (7/25/91 version)
7. G. Deis notes, "Axial Force on Coil" 8/13/91
6. P Marston notes, 8/12/91
5. F. Nimblett estimates, 8/9/91
4. Obsolete
3. P. Marston calculation, per G. Deis
2. Obsolete
1. Second Detector EOI

Notes

4. 10/24/91 - Values revised to reflect latest conceptual design for GEM cost estimate review to be held on 10/29/91.
3. 8/28/91 - Values revised from Ref1 values, based on more detailed design and calc's by P Martson.
2. 8/8/91 - Value revised from Ref1 value, based on more detailed design and calc's.
1. 8/8/91 - Ref 1 actually shows 0.823T, and historical number is 0.83T.

5.0 Work Breakdown Structure

GEM Magnet
Work Breakdown Structure
Rev 2g - 12/11/91

1.0 GEM
1.1 GEM Research and Development

- 1.1.1 Magnet R&D
  - 1.1.1.1 Magnet Concept Development
    - 1.1.1.1.1 Magnetic Field Analysis
    - 1.1.1.1.2 Future Detector Options
  - 1.1.1.2 Conductor/Winding Development
    - 1.1.1.2.1 Conductor Development and Testing
    - 1.1.1.2.2 Joint Development and Testing
    - 1.1.1.2.3 Conductor Tooling Development
    - 1.1.1.2.4 Winding Tooling Development
  - 1.1.1.3 Component Verification
    - 1.1.1.3.1 Materials Verification Testing
    - 1.1.1.3.2 Component Verification Testing
    - 1.1.1.3.3 Model Coil Test

1.2 GEM Conceptual/Preliminary Design

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  - 1.2.1.1 Pre-LOI Engineering/Design
  - 1.2.1.2 LOI to Engineering Design Report (EDR)
    - 1.2.1.2.1 Preliminary Design
      - 1.2.1.2.1.1 Solenoid Magnet
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          - 1.2.1.2.1.1.1.1 Coil Subassemblies
            - 1.2.1.2.1.1.1.1.1 Coil form
            - 1.2.1.2.1.1.1.1.2 Conductor
            - 1.2.1.2.1.1.1.1.3 Diagnostics
            - 1.2.1.2.1.1.1.1.4 Winding Tooling
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6.0 WBS Dictionary

GEM Magnet
WBS Dictionary
Rev 2G - 12/11/91

1.0 GEM

1.1 GEM Research and Development

1.1.1 Magnet R&D - This element covers research and development activities associated with the GEM magnet subsystem. This includes two types of activities: first, studies which contribute to defining the overall configuration and performance goals of the magnet subsystem, and second, efforts to develop the capabilities required to complete the design and fabrication of subsystem components. This element does not include efforts to perform preliminary or detailed design of the magnet subsystem. It does include effort to develop tooling for conductor production, as well to conduct tests of proposed component concepts.

1.1.1.1 Magnet Concept Development - This element provides for effort to establish the overall design concpet of the GEM magnet subsystem. In particular, it covers efforts to develop concepts for improving the physics performance of the magnet, primarily in the forward region. It includes studies of near-term options, which may be included in the baseline design in the near future, as well as future options, which can be added after GEM has been installed and operated. Efforts within this element will be limited to pre-conceptual studies; any further design will be included under other elements, if approved.

1.1.1.1.1 Magnetic Field Analysis - This element covers pre-conceptual magnetic-field analysis of all concepts which are proposed the baseline design. These concepts will be analyzed for physics performance, fringe fields, and at a coarse level, for feasibility. Options presently being considered focus on improvement of resolution in the forward direction by use of shaped iron poles or additional coils.

1.1.1.1.2 Future Detector Options - This element covers studies of possible future upgrades of the magnet subsystem; these options, if adopted, would be implemented after the GEM detector has been installed and operated. The bjective of this element is to define possible options for upgrade and identify any additional requirements which might apply to the current baseline design. In addition, this element provides for effort to determine the potential physics performance improvement, and the rough cost.and schedule associated with each concept.

1.1.1.2 Conductor/Winding Development - This element provides for R&D work needed to ensure an acceptable conductor design. This element does not cover design/analysis of stability or protection aspects; these are covered in preliminary and final design. This element does cover development and design verification testing on the conductor and joints, as well as development and testing of the tooling required to produce and wind the conductor.

1.1.1.2.1 Conductor Development and Testing - This element provides for the verification of the conductor design. It covers development, working with vendors, to produce sample lengths of the proposed conductor design, and then testing of these sample lengths to confirm acceptable performance. It also includes effort to define acceptable methods for fabrication of the conductor.

1.1.1.2.2 Joint Development and Testing - This element covers efforts aimed at the verification of the design of the joints in the conductor. It includes all efforts involved with producing sample joints and testing them to verify adequate performance. In addition, the development of any tooling required for making joints is included here. Actual design of the joints is included in preliminary and final design elements, elsewhere.

1.1.1.2.3 Conductor Tooling Development - This element includes all efforts to develop and test the tooling required for manufacturing the conductor. This includes all unique tooling required for fabricating the cable-in-conduit, and stabilizer, as well as for the actual joining of the cable-in-conduit with the stabilizer. Conductor is complete when it is on a storage drum, ready for winding into the bobbin.

1.1.1.2.4 Winding Tooling Development - This element covers the development of all tooling required to take the conductor+stabilizer, and complete individual (1-2m tall) coil assemblies. Tooling will be required for straightening conductor and stabilizer and winding them into bobbin sections. This element covers development required for all tooling needed in this step.

1.1.1.3 Component Verification - This element covers all efforts to verify specific designs by testing. It covers all tests of designed magnet components, as well as some materials tests.

1.1.1.3.1 Materials Verification Testing - This element covers all tests required to verify materials properties. These tests will include electrical, mechanical, and thermal tests on stabilizer and bobbin materials.

1.1.1.3.2 Component Verification Testing - This element covers testing of component designs, to verify their predicted performance. This includes items such as current breaks and cold-mass supports. This element does not cover tests of the conductor or of joints in the conductor.

1.1.1.3.3 Model Coil Test - This element covers the production and testing of a model coil. The objective of this effort will be to verify the designs of all the winding and joint-making tooling in a single test article. The model coil may not be superconducting, but its diameter will be comparable to the actual diameter of the coils for GEM.

1.2 GEM Conceptual/Preliminary Design

1.2.1 Magnet subsystem - This element consists of all GEM magnet design activities prior to approval as an official project; after project approval, final design will begin, under WBS 1.3. This element consists of all engineering and design required for preparation of the LOI, and all engineering and design required for preparation of the Engineering Design Report(EDR), assumed to be submitted in 11/92. R&D activities associated with this engineering work is included in WBS 1.1 (above). Activities covered here include engineering analysis to define and support the design, preparation of preliminary drawings, preparation of specifications, integration with other subsystems, documenting the design, preparing the LOI and EDR documents, cost estimating, etc. This element does not include final design. Most elements in this WBS element are directly related to elements in WBS 1.3.

1.2.1.1 Pre-LOI Engineering/Design - This element covers all engineering activity within the magnet subsystem, starting with approval of the GEM EOI, and ending with submission and defense of the GEM LOI. This includes all design and cost-estimating work, as well as attendance at meetings, preparation of presentations, etc.

1.2.1.2 LOI to Engineering Design Report (EDR) - This element covers all magnet engineering and design activities after the LOI preparation and defense, and through preparation and defense of the EDR. This includes analysis, preliminary design, and preparation of specifications for procurement of the major components. The technical scope of this design effort is all of the assemblies and elements required to provide the magnetic field in the interior of the detector. It includes the coils, coil forms, radiation shields, cold mass supports, vacuum vessels, end poles, current leads, cryogenic (LN and LHe) systems, and power and protection systems. It also includes components required to support the solenoid and end poles from the ground, the support for the central detectors, the attachment points for the muon and calorimeter subsystems, and any special tooling necessary to install any of these components. This subsystem does not include the building cranes, assembly buildings, or any concrete support features below the detector. Major interfaces are with: underground hall, above-ground facilities, muon subsystem, calorimeter subsystem, and the ring magnet system.

1.2.1.2.1 Preliminary Design - This element covers preliminary design activities for the magnet subsystem. It does not include actual preparation of the EDR, or the analysis tasks which are common to most assemblies (defined in 1.2.1.2.2 Analysis). The technical scopes of these tasks are directly related to 1.3.1 Magnet Subsystem (Construction). This element does include preparation of specifications for use in procurement.

1.2.1.2.1.1 Solenoid Magnet - This element covers preliminary design work on all the magnet-subsystem components which are to be installed within the underground hall, except for parts of the cryogenic systems. This includes the coil assemblies(consisting of conductor wound on coil forms, plus the radiation shields, the cold-mass supports, and the vacuum vessels), the components which support this system from the ground, the poles and pole supports, and the support for the central detectors. This does not include the thermosyphon supply dewars, cryogenic piping external to the vessels, or current leads external to the vessel. Physical attachment points for the central-region muon subsystem and calorimeter are included. Major interfaces are with the underground hall, above-ground facilities, the calorimeter subsystem, the muon subsystem, and the ring magnet system.

1.2.1.2.1.1.1 Coil Assemblies - This element covers preliminary design of all the components which are physically a part of the completed coil assemblies; these assemblies are the parts which will be assembled above-ground and delivered for installation in the underground hall. This includes the coils, the thermal radiation shields, the vacuum vessels, the cold-mass supports, and all cryogenic piping and distribution and current bussing which are within the vacuum-vessel boundary. This does not include the components required to physically support the coil assemblies, the end poles/pole supports, or the central detector supports. It also does not include the local thermosyphon supply dewars or any cryogenic piping external to the vacuum vessel boundary. Major interfaces are with the underground hall, the above-ground facilities, the poles/pole supports, the muon subsystem, and the central detector support.

1.2.1.2.1.1.1.1 Coil Subassemblies - This element consists of preliminary design of the magnet coils only, which are made up of conductor wound on coil forms, with any required diagnostics installed. It includes all activities, parts, and tooling required to produce the coils. This does not include the LHe thermosyphon or LHe forced-flow cryogenic piping/distribution. Major interfaces are with the cold-mass supports, the vacuum vessels, the radiation shields, and the internal cryogenic systems.

1.2.1.2.1.1.1.1.1 Coil form - This element comprises preliminary design of, and specification preparation for, the coil form within which the coil is wound. The coil form includes ribs to accept axial conductor loads, and attachment points for the cold-mass supports.

1.2.1.2.1.1.1.1.2 Conductor - This element includes all activities required to perform preliminary design of the conductor which makes up the coil. The conductor includes the SC wire, the stabilizer, and the passage for the forced-flow LHe. This element includes all of these parts, even if they are designed to be physically separate. The conductor is to be delivered on large spools, ready for winding into the coil forms. This does not include development work, to verify the design or to develop tooling. The preliminary design of the tooling is included.

1.2.1.2.1.1.1.1.3 Diagnostics - This element includes the design and specification of all controls or diagnostics which are actually installed on the coil subassembly. This includes voltage taps, temperature sensors, etc. This element does not include the electronics necessary to read out these sensor or to effect control.

1.2.1.2.1.1.1.1.4 Winding Tooling - This element covers design of all the winding tooling, which includes all of the tooling required to remove the conductor from the storage drums and wind it into final position in the coil form. Any tooling or hardware required for gluing or otherwise affixing the conductor in place is included in this element.

1.2.1.2.1.1.1.2 Thermal Radiation Shields - This element covers all preliminary design and speciification preparation required to produce the LN-cooled thermal radiation shields and all other heat-shielding parts. Included in this element are the inner, outer, and end shields, the thermal-intercept hardware for the cold-mass supports, the multilayer insulation, attachment points for mechanical supports, and the supports themselves if they are different from the main cold-mass supports. This does not include standard piping and manifolding for LN distribution within the vacuum vessel. Any tooling required to assemble the radiation shields is included. This element does not include the global thermal analysis of the entire system, which is covered under 1.2.1.2.2.2.

1.2.1.2.1.1.1.3 Vacuum Vessel Subassemblies - This element includes the preliminary design and specification of all of the parts required to establish a vacuum boundary around the coil: the inner and outer cylindrical vessels, the end plates, and any parts which are required to physically support the vessels. This does not include vacuum pumps or vacuum piping. It does include attachment points for the central muon subsystem and any tooling required for fabricating the vessels. Also included are any components attached to the outer vessel to withstand operational loads. This effort does not include the global structural analysis of the magnet subsystem (see 1.2.1.2.2.3)

1.2.1.2.1.1.1.4 Cold Mass Supports - This element includes the preliminary design and specification all of the mechanical supports for the 4K cold mass. Support for the LN radiation shields is included here, unless separate supports are found to be necessary. This element includes all of the rods, fasteners, etc required.

1.2.1.2.1.1.1.5 Internal Cryogenic Systems - This element includes the preliminary design and specification of all cryogenic piping and distribution which is enclosed in the vacuum vessel. This does not include any systems which are installed after coil assembly has been installed in the underground hall. It does include all

LHe and LN bayonets, manifolding, and piping which is installed separately from the coil subassembly and radiation shields.

1.2.1.2.1.1.1.6 Cryogenic Current Leads - This element covers the preliminary design and specification of the current leads which are installed after the coil is assembled into the vacuum vessels, and which are at cryogenic temperature. It does not include the warm current busses which are external to the vacuum vessel.

1.2.1.2.1.1.1.7 Assembly and Testing Equipment - This element covers preliminary design and specification of all of the hardware required to assemble the wound coil subassembly into the radiation shields and vacuum vessels, make up all internal electrical and fluids connections, verify all connections, rotate the assembly into its final orientation, and perform all checks prior to installation in the underground hall. It does not include provision for testing the coil assemblies at LHe temperature, or under significant current. It does include provision of leak hunting equipment and LN as required for thermal-shock testing. It also includes any temporary supports for the assemblies (other than those to be used for permanent installation in the unnderground hall).

1.2.1.2.1.1.2 End Poles/Supports - This element covers the prelimminary design and specification of the magnetic steel end poles for the solenoid, along with their supports. This includes attachment points for the muon endcap subsystem, as well as the transporter required for moving the poles for installation and maintenance. It does not include the fixtures required for installing the poles in the underground hall.

1.2.1.2.1.1.3 Detector Supports - This element covers the preliminary design and specification of any separate hardware required to support other subsystems within the magnet. It does not include simple attachment points on magnet components (such as those required for central-region muon sector support). This element includes the central detector support and the forward calorimeter support at this time.

1.2.1.2.1.2 Power/Protection System -

1.2.1.2.1.3 Cryogenics - This element covers preliminary design and specification of all of the cryogenics hardware (LN and LHe) which is installed external to the coil assemblies; this includes the cryogenics plants, storage dewars, and all of the distribution and transfer lines.

1.2.1.2.1.5.1 Liquid Nitrogen System - This element covers preliminary design and specification of all of the LN hardware external to the coil vacuum vessel. This includes the storage dewar, subcooler, circulator, and all piping and distribution.

1.2.1.2.1.5.2 Liquid Helium Systems - This element covers preliminary design and specification of all of the LHe hardware external to the coil vacuum vessel. This includes both the forced and thermosyphon systems, as well as the helium plant above ground, including all piping and distribution.

1.2.1.2.1.4 Vacuum System - This element covers preliminary design and specification of the vacuum system required to pump down and maintain the magnet system under vacuum. It does not include vaccum hardware associated with the main ring or any other systems.

1.2.1.2.1.5 Magnet Control Systems - This element covers preliminary design and specification of all of the local controls and diagnostic readouts required to operate the magnet subsystem. These controls will be brought together in a local control room, from which all magnet operations can be conducted. Controls in the main operations center are not included in this estimate. It is assumed that safety interlocks are monitored by the main control system, and the local system is responsible only for magnet subsystem operational interlocks, such as "poles closed", LCW on, etc.

1.2.1.2.1.7 Installation Tooling - This element covers preliminary design and specification of all of the hardware temporarily required for installation of magnet subsystem components into their final positions. It does not include any hardware which will be a permanent part of the installation.

1.2.1.2.1.8 Conventional/Technical Facilities - This element covers all activities associated with defining requirements for conventional facilities at SSCL, including both the underground hall and the surface facilities. Also included is effort associated with defining and maintaining the magnet/technical facilities/conventional facilities interface.

1.2.1.2.2 Analysis - This element covers analysis effort which supports the preliminary design, but in tasks which are common to many component design efforts. These analyses will be essentially stand-alone tasks, which will interface continually with the ongoing design efforts.

1.2.1.2.2.1 Magnetic Field/Force Analysis - This element provides for analysis to determine the magnetic field at any interesting points in space, to predict the resulting performance, and to predict magnetic forces on any concerned components.

1.2.1.2.2.2 System Thermal Analysis - This element covers a comprehensive thermal analysis of the magnet subsystem, focussing on the Solenoid Magnet Assembly. This analysis will determine heat loads to the various cryogenic systems, and operating temperatures for critical parts (such as cold-mass supports).

1.2.1.2.2.3 System Structural Analysis - This element includes a complete structural analysis of the Solenoid Magnet Assembly, including cold-mass, cold-mass supports, shields, vessels, saddles, poles, etc. This analysis will support the mechanical design of most of these componenets.

1.2.1.2.2.4 Magnetic Shielding Analysis - This element covers continued analysis of fringe fields, outside the bounds of the magnet volume. This includes both fields at the surface and fields inside the u/g hall but outside the detector. This analysis will support the design of any magnetic-field shields.

1.2.1.2.2.5 Safety/reliability analysis - This element covers an initial safety and reliability analysis, which will identify the most failure modes and effects, and indicate approaches for reducing the impact of failures. This effort will be followed by a more formal analysis ddduring final design.

1.2.1.2.8 EDR Preparation - This element covers actual preparation and defense of the EDR. This includes writing the magnet subsystem chapter, preparing graphics for the report, reviewing other subsystems, contributing to the cost volume, and making oral presentations.

<u>1.2.1.2.9 Magnet Subsystem Management/Integration</u> - This element covers management of both the preliminary design and the R&D efforts through the approval of the EDR. This element includes intergation activities with other subsystems and with SSCL, though it does not include facility interfaces. It includes project tracking, monitoring, and reporting, as well as attendance at collaboration meetings, engineering meetings, technical reviews, etc.

1.3 GEM Construction

1.3.1 Magnet subsystem - This subsystem consists of all of the assemblies and elements required to provide the magnetic field in the interior of the detector. It includes the coils, coil forms, radiation shields, cold mass supports, vacuum vessels, end poles, current leads, cryogenic (LN and LHe) systems, and power and protection systems. It also includes components required to support the solenoid and end poles from the ground, the support for the central detectors, the attachment points for the muon and calorimeter subsystems, and any special tooling necessary to install any of these components. This subsystem does not include the building cranes, assembly buildings, or any concrete support features below the detector. Major interfaces are with: underground hall, above-ground facilities, muon subsystem, calorimeter subsystem, and the ring magnet system.

1.3.1.1 Solenoid Magnet - This assembly consists of all the magnet-subsystem components which are to be installed within the underground hall, except for parts of the cryogenic systems. This includes the coil assemblies(consisting of conductor wound on coil forms, plus the radiation shields, the cold-mass supports, and the vacuum vessels), the components which support this system from the ground, the poles and pole supports, and the support for the central detectors. This does not include the thermosyphon supply dewars, cryogenic piping external to the vessels, or current leads external to the vessel. Physical attachment points for the central-region muon subsystem and calorimeter are included. Major interfaces are with the underground hall, above-ground facilities, the calorimeter subsystem, the muon subsystem, and the ring magnet system.

1.3.1.1.1 Coil Assemblies - This element consists of all the components which are physically a part of the completed coil assemblies; these assemblies are the parts which will be assembled above-ground and delivered for installation in the underground hall. This includes the coils, the thermal radiation shields, the vacuum vessels, the cold-mass supports, and all cryogenic piping and distribution and current bussing which are within the vacuum-vessel boundary. This does not include the components required to physically support the coil assemblies, the end poles/pole supports, or the central detector supports. It also does not include the local thermosyphon supply dewars or any cryogenic piping external to the vacuum vessel boundary. Major interfaces are with the underground hall, the above-ground facilities, the poles/pole supports, the muon subsystem, and the central detector support.

1.3.1.1.1.1 Coil Subassemblies - This element consists of the two (approx) 15m long magnet coils only, which are made up of conductor wound on coil forms, with any required diagnostics installed. It includes all activities, parts, and tooling required to produce the coils, as well as assembly of short coil pieces, if the coil is designed in that manner. This does not include the LHe thermosyphon or LHe forced-flow cryogenic piping/distribution. Major interfaces are with the cold-mass supports, the vacuum vessels, the radiation shields, and the internal cryogenic systems.

1.3.1.1.1.1.1 Coil form - This element comprises the coil form within which the coil is wound. The coil form includes ribs to accept axial conductor loads, and attachment points for the cold-mass supports.

1.3.1.1.1.1.2 Conductor - This element includes all activities required to provide the conductor which makes up the coil. The conductor includes the SC wire, the stabilizer, and the passage for the forced-flow LHe. This element includes all of these parts, even if they are designed to be physically separate. The conductor is to be delivered on large spools, ready for winding into the coil forms. This does not include the cost of facilities in which the work will be performed. It does include raw materials, conductor processing, storage drums, tooling, etc.

1.3.1.1.1.1.3 Diagnostics - This element includes all hardware and activities associated with any controls or diagnostics which are actually installed on the coil subassembly. This includes voltage taps, temperature sensors, etc. This element does not include the electronics necessary to read out these sensor or to effect control.

1.3.1.1.1.1.4 Winding Tooling - This element includes all of the tooling required to remove the conductor from the storage drums and wind it into final position in the coil form. Any tooling or hardware required for gluing or otherwise affixing the conductor in place is included in this element.

1.3.1.1.1.1.5 Assembly - This element covers all of the activity required to complete two 15m long coil subassemblies, starting from the basic parts identified in 1.3.1.1.1.1.1-4. This includes all activities required to prepare the coil form for winding, to actually remove the conductor from the storage drum and wind it into final position in the coil form, to install any diagnostics, sensors, or controls, to complete the electrical and fluid connections within the coil subassemblies, and to perform tests as required to verify proper function at this level.. This does not include any activity required to install the radiation shields, cold mass supports, or vacuum vessels. Because of the size of the completed coil subassemblies, all assembly effort take place on-site at SSCL.

1.3.1.1.1.1.5.1 Off-Site Assembly - None required

1.3.1.1.1.1.5.2 On-Site Assembly - This element covers all of the activity required to complete two 15m long coil subassemblies, starting from the basic parts identified in 1.3.1.1.1.1.1-4. This includes all activities required to prepare the coil form for winding, to actually remove the conductor from the storage drum and wind it into final position in the coil form, to install any diagnostics, sensors, or controls, to complete the electrical and fluid connections within the coil subassemblies, and to perform tests as required to verify proper function at this level.. This does not include any activity required to install the radiation shields, cold mass supports, or vacuum vessels. Because of the size of the completed coil subassemblies, all assembly effort take place on-site at SSCL.

1.3.1.1.1.2 Thermal Radiation Shields - This element covers all hardware and activities required to produce the LN-cooled thermal radiation shields and all other heat-shielding parts. Included in this element are the inner, outer, and end shields, the thermal-intercept hardware for the cold-mass supports, the multilayer insulation, attachment points for mechanical supports, and the supports themselves if they are different from the main cold-mass supports. This does not include standard piping and manifolding for LN distribution within the vacuum vessel. Any tooling required to assemble the radiation shields is included.

1.3.1.1.1.2.1 LN Thermal Radiation Shields - This element covers the LN radiation shields at the inner diameter, outer diameter and axial ends of the coil assemblies.

1.3.1.1.1.2.2 Super Insulation - This element covers all of the super insulation within the coil assemblies, and any tooling required to prepare it for installation or to install it.

1.3.1.1.1.2.3 Shield Supports/Thermal Intercepts - This element covers all LN shield support hardware, not including the cold-mass supports. Also included is the hardware required for 80K thermal intercepts on the cold-mass supports.

1.3.1.1.1.3 Vacuum Vessel Subassemblies - This element includes all of the parts required to establish a vacuum boundary around the coil: the inner and outer cylindrical vessels, the end plates, and any parts which are required to physically support the vessels. This does not include vacuum pumps or vacuum piping. It does include attachment points for the central muon subsystem and any tooling required for fabricating the vessels. Also included are any components attached to the outer vessel to withstand operational loads.

1.3.1.1.1.3.1 Vessel Weldment - This element includes the inner and outer vacuum vessel as well as any stiffening hardware required to withstand vacuum and magnetic loads. It also includes attachment points for the cold-mass supports and muon detectors.

1.3.1.1.1.3.2 Vessel Support Saddles - This element includes all of the hardware required to physically support the coil assemblies in the underground hall. This will include the saddles to support the outer vessel as well as any jacking hardware provided to align the magnet or to compensate for ground motion. This does not include any concrete structures, such as piers or support beams, which are assumed to be parts of the hall facility.

1.3.1.1.1.4 Cold Mass Supports - This element includes all of the mechanical supports for the 4K cold mass. Support for the LN radiation shields is included here, unless separate supports are found to be necessary. This element includes all of the rods, fasteners, etc required.

1.3.1.1.1.4.1 Radial Supports - This element includes all of the cold-mass supports which will support the weight of the cold mass in final position in the underground hall. This element does not include the attachment points on the cold mass, LN shields, or vacuum vessels; it also does not include thermal intercept hardware.

1.3.1.1.1.4.2 Axial Supports- This element includes all of the cold-mass supports which will support the axial magnetic forces on the cold mass in final position in the underground hall. This element does not include the attachment points on the cold mass, LN shields, or vacuum vessels; it also does not include thermal intercept hardware.

1.3.1.1.1.5 Internal Cryogenic Systems - This element includes all cryogenic piping and distribution which is enclosed in the vacuum vessel. This does not include any systems which are installed after coil assembly has been installed in the underground hall. It does include all LHe and LN bayonets, manifolding, and piping which is installed separately from the coil subassembly and radiation shields.

1.3.1.1.1.5.1 LN Piping and Distribution - This includes all of the in-vessel LN distribution piping which is not actually mounted on the radiation shields. It also includes the LN feedthroughs through the vacuum vessel wall. It does not include any external LN piping.

1.3.1.1.1.5.2 LHe Thermosyphon Piping and Distribution - This includes all of the in-vessel piping and manifolding required for the LHe thermosyphon system which cools the coil form. It includes only the hardware which is not mounted physically on the coil form. Feed-throughs through the vacuum vessel are included.

1.3.1.1.1.5.3 LHe Forced-Flow Piping and Distribution - This element covers all of the in-vessel piping and manifolding required for the forced-flow LHe loop, including vacuum feed-throughs.

1.3.1.1.1.6 Cryogenic Current Leads - This element covers the current leads which are installed after the coil is assembled into the vacuum vessels, and which are at cryogenic temperature. It does not include the warm current busses which are external to the vacuum vessel.

1.3.1.1.1.7 Assembly and Testing Equipment - This element covers all of the hardware required to assemble the wound coil subassembly into the radiation shields and vacuum vessels, make up all internal electrical and fluids connections, verify all connections, rotate the assembly into its final orientation, and perform all checks prior to installation in the underground hall. It does not include provision for testing the coil assemblies at LHe temperature, or under significant current. It does include provision of leak hunting equipment and LN as required for thermal-shock testing. It also includes any temporary supports for the assemblies (other than those to be used for permanent installation in the unnderground hall).

1.3.1.1.1.8 Assembly - This element covers all of the activities necessary to assemble complete coil assemblies, ready for installation into the underground hall. It includes final assembly of the coil subassembly into the radiation shields and vacuum vessels, installation of the cold-mass supports, installation of all in-vessel cryogenic distribution hardware, final make-up of all diagnostic, control, and current connections within the vacuum vessel, closure of the vacuum vessel, vacuum and helium leak hunting, and rotation of the assembly into final orientation. It does not include any testing activities under cryogenic conditions or to significant current. Due to the sizes involved, all assembly will be on-site at SSCL.

1.3.1.1.1.8.1 Off-site assembly - none

1.3.1.1.1.8.2 On-site assembly - All assembly activities outline in 3.1.1.1.8 are included in this element.

1.3.1.1.1.9 Testing - This element covers all "acceptance" testing of the coil assemblies in the above-ground area, prior to their installation in the underground hall. At present, this element includes only a cool-down test to LN temperature for all cryogenics lines in the coil assemblies (including radiation shields). No testing under superconducting conditions or with LHe is planned, and no significant current will be used in these tests.

1.3.1.1.2 End Poles/Supports - This element covers all activity and hardware required to provide the magnetic steel end poles for the solenoid, along with their supports. This includes attachment points for the muon endcap subsystem, as well as the transporter required for moving the poles for installation and maintenance. It does not include the fixtures required for installing the poles in the underground hall.

1.3.1.1.2.1 End Pole Subassemblies - This element include the magnetic steel end poles themselves, and does not include the structure required to support their weight or move them in the underground hall.

1.3.1.1.2.2 End Pole Support Subassemblies - This element covers the structures which support the weight of the end poles, and move the end poles axially to allow access inside the detector.

1.3.1.1.2.3 End Pole Field Shaper - This element covers any additional parts on the poles which are used for shaping the magnetic field at low angles. This does not include the pole itself, but it does include any magnetic hardware which hangs from it.

1.3.1.1.3 Detector Supports - This element covers any separate hardware required to support other subsystems within the magnet. It does not include simple attachment points on magnet components (such as those required for central-region muon sector support). This element includes only the central detector support at this time.

1.3.1.1.3.1 Central Detector Support - This element covers the structure which permanently supports the central detectors (formerly the "central membrane")

1.3.1.1.3.2 Forward Calorimeter Support - This element covers the structure which supports the two forward calorimeters off of the end poles.

1.3.1.2 Power/Protection System - This element covers all of the hardware required to provide current to the solenoid magnet assembly, and also to control and protect it in the event of unusual occurrences such as trips and quenches. Also included in this elemnt are the busses (normally-conducting) which connect the power supply, dump resistor, breaker, and coil. This element does not include any hardware within the vacuum boundary, or any of the conventional or technical facilities required to support power and protection.

1.3.1.2.1 Power Supply - This element covers the magnet power supply only. It includes all the hardware and controls between the AC power grid and the terminals of the warm bus. Only local controls on the power supply itself are included here.

1.3.1.2.2 Buswork - This element comprises all of the warm (normally-conducting) buswork which is connects the high-current components together. Major connections are with the power supply, the dump resistor, the breaker, and the coil.

1.3.1.2.3 Breakers and Dump Resistors - This element includes only the breaker and dump resistor required for discharging the magnet.

1.3.1.2.4 Quench Detection and Diagnostics - This element includes hardware required for quench detection, excpet that which is mounted within the vacuum envelope. This includes voltage taps and other items.

1.3.1.3 Cryogenics - This element covers all of the cryogenics hardware (LN and LHe) which is installed external to the coil assemblies; this includes the cryogenics plants, storage dewars, and all of the distribution and transfer lines.

1.3.1.3.1 Liquid Nitrogen System - This element covers all of the external LN system, including all LN storage, pumping, and transfer/distribution piping up to the vacuum vessel boundary. It is assumed that LN will not be produced on-site, but rather delivered to a local storage dewar.

1.3.1.3.1.1 LN Storage Dewar - This element covers the cost of the LN stroage dewar itself, without piping.

1.3.1.3.1.2 LN Subcooler - This element covers the cost of the LN subcooler only, without piping.

1.3.1.3.1.3 LN Piping and Distribution - This element covers all of the piping required to complete the LN system, above and below ground, up to the coil vacuum vessel. It includes all of the LN piping within the cryogenics building, and the transfer lines to the coil vessel.

1.3.1.3.2 Liquid Helium System - This element covers all of the LHe hardware external to the coil vacuum vessel. This includes both the forced and thermosyphon systems, as well as the helium plant above ground, including all piping and distribution.

1.3.1.3.2.1 Thermosyphon System - This element includes the hardware and piping required just for the thermosyphon loop. It includes mainly a local dewar, and tranfer line from the helium plant to the dewar. It does not include any of the systems to actually produce LHe, or any hardware within the coil vacuum vessel boundary.

1.3.1.3.2.1.1 Magnet Supply Dewars - This element covers the local dewars required for the LHe thermosyphon system.

1.3.1.3.2.1.2 LHe Thermosyphon Piping/Distribution - This element covers the piping required to connect the magnet supply dewar to the main helium plant, and to connect the magnet supply dewars to the coil assemblies..

1.3.1.3.2.2 Forced-Flow System - This element covers the hardware required for the forced-flow helium loop. It includes only hardware external to the vacuum vessel, and not within the helium plant itself.

1.3.1.3.2.2.1 LHe Circulator - This element includes the pump which forces the heium flow, as well as any associated hardware other than piping.

1.3.1.3.2.2.2 Forced-Flow LHe Piping/Distribution - This element includes all of the piping which is required to connect the forced-flow loop, external to the vacuum vessel.

1.3.1.3.2.3 LHe Supply/Storage/Recovery System - This element covers the main helium plant, which supplies LHe to both the forced-flow and thermosyphon systems. It includes all of the plumbing required to make and store LHe above-ground. It does not include the transfer lines to any below-ground systems.

1.3.1.3.2.3.1 Refrigerator - This element covers the Helium refrigerator only.

1.3.1.3.2.3.2 LHe Storage Dewar - This element covers the main, large-capacity abover-ground helium storage dewar.

1.3.1.3.2.3.3 LHe Recovery System - This element covers all the hardware required to handle returned He gas and liquid from the magnet, except for the piping itself.

1.3.1.3.2.3.4 LHe Supply System Piping and Distribution - This element includes all of the piping within the above-ground helium plant. It does not include any transfer lines to below-ground systems.

1.3.1.4 Magnet Vacuum System - This element covers all of the vacuum system required to pump down and maintain the magnet system under vacuum. It does not include vaccum hardware associated with the main ring or any other systems.

1.3.1.4.1 Vacuum Pumps - This element covers all the vacuum pumps for the magnet vessels, including any foreline pumps, roughing pumps, or booster pumps. Installation is not included here.

1.3.1.5.2 Vacuum Piping - This element covers all of the piping, valves, flanges, etc, required for the magnet vacuum system.

1.3.1.5 Magnet Control Systems - This element covers all of the local controls for the magnet subsystem. Any control computers or controls in the main operations center are not included in this estimate. It is assumed that safety interlocks are monitored by the main control system, and the local system is responsible only for magnet subsystem operational interlocks, such as "poles closed", LCW on, etc. This control system extends as far as local programmable controllers, but does not include control computers, which are are included under slow controls in the electronics subsystem.

1.3.1.5.1 Power controls - This element includes only the controls, operational interlocks, and monitor readouts for the magnet power supply. This element includes all of the magnet-system interlock logic required to permit operation of the magnet power supply; individual permissives for each part of the system are included in each element.

1.3.1.5.2 Protection controls - This element includes the controls, operational interlocks, and readouts for the magnet protection system, which includes quench detection, breaker control, dump resistor status, etc.

1.3.1.5.3 Cryogenics controls - This element includes all of the controls, operational interlocks, and readouts for the LN and LHe systems. This includes controls for the refrigerators and all cryogenic valves.

1.3.1.5.4 Vacuum controls - This element covers all of the controls required to operate the magnet vacuum system, which includes pump controls, pressure readouts, valve controllers, etc.

1.3.1.6 Return Field Mitigation - This element covers all of the hardware required to shield individual components or small volumes from the return field of the magnet, or alternatively, the additional cost of over-specifying components so that they will work properly in the field. This includes shielding for vacuum pumps, gages, etc, as well as shielding of local counting rooms and electronic racks below ground. It does not include hardware to shield the above-ground field.

1.3.1.7 Installation Tooling - This element covers all of the hardware temporarily required for installation of magnet subsystem components into their final positions. It does not include any hardware which will be a permanent part of the installation.

1.3.1.7.1 Central Detector Support - This element covers the tooling required to handle, align, and install the central detector support.

1.3.1.7.2 Coil Assemblies - This element includes all of the tooling required to handle the coil assemblies from the location at which they were tested above ground to their final position in the underground hall. It als includes any tooling required to anchor them and their support hardware in place and align them.

1.3.1.7.3 Pole Assemblies - This element includes all of the tooling required to move the pole assemblies from the surface to the underground hall and place them in position. If they are to be assembled in the underground hall, the tooling required for assembly is included here as well. This also covers tooling required to mount the supports.transporters, and align the poles.

1.3.1.7.4 Testing Equipment - This element covers all of the equipment required for testing the magnet system after installation. The primary testing equipment will be a system for mapping the magnetic field inside the magnet.

1.3.1.8 Installation - This element covers all of the actual installation of magnet subsystem hardware on-site at SSCL. It includes installation of the magnet assemblies in the underground hall, as well as the power and cryogenics systems above-ground. It does not include the assembly of any hardware, except if it occurs during the process of installation.

1.3.1.8.1 Solenoid Magnet Installation - This element covers the installation of the solenoid magnet assembly in the underground hall. It includes installation of the coil assemblies, coil supports, the pole/pole support assemblies, and the central detector support in the hall. It does not include installation of the power or cryogenics systems.

1.3.1.8.2 Power/Protection System Installation - This element covers only installation of the power and protection systems. Design and procurement of all major parts is included in 1.3.1.2, and the control system for power/protection is included in 1.3.1.5 and 1.2.1.8.5. This element does not include controls or the control computer.

1.3.1.8.2.1 Power Supply Installation - This element covers the physical installation of the power supply, connection to the AC line, and connection to all facilities systems (such as LCW). This also covers installation of local power supply interlocks. This does not include any interfacing to the control system.

1.3.1.8.2.2 Buswork Installation - This element covers the installation of all the high-current buswork for the magnet, from the terminals on the power supply/breakers to the terminals on the magnet coils. It does not include connection of the dump resistor.

1.3.1.8.2.3 Breakers and Dump Resistor Installation - This element includes the physical installation of the breakers and dump resistor, connection to lcw, connection to the high-current bus, and installation of local controls on the physical devices.

1.3.1.8.2.4 Quench Detection and Diagnostic Installation - This element consists of installation of all systems required to diagnose the magnet or to signal a magnet quench. This includes all systems external to the magnet vacuum vessel, and before the control system.

1.3.1.8.3 Cryogenic System Installation - This element covers the installation of all of the cryogenics for the magnet subsystem. It includes installation of the major components in the cryogenics building, as well as installation of the piping and distribution lines within the building and to the underground hall.

1.3.1.8.3.1 LN System Installation - This element covers the installation of all of the LN system for the magnet subsystem. It includes installation of the major components in the cryogenics building, as well as installation of the piping and distribution lines within the building and to the underground hall.

1.3.1.8.3.2 LHe Systems Installation - This element covers the installation of all of the LHe system for the magnet subsystem. It includes installation of the major components in the cryogenics building, as well as installation of the piping and distribution lines within the building and to the underground hall.

1.3.1.8.4 Vacuum System Installation - This element covers installation of all the pumps, valves, piping, traps, pressure sensors, etc required for the magnet vacuum system. Installation and wiring of controls is not included here (see 3.1.8.5).

1.3.1.8.5 Control System Installation - This element covers the installation of all the magnet local controls, including readouts and controls for power/protection, cryogenics, and vacuum system. It also covers the installation of a local control room, but not the connection to the main operations center.

1.3.1.8.6 Testing - This element covers all testing of the magnet subsystem after installation. This includes initial system checkout testing and extends through magnetic-field mapping. This element includes only testing performed prior to installation of the internal detector subsystems; testing of the detector as a whole is included in operations.

1.3.1.9 Subsystem Management & Integration - This element covers all management and oversight activities within the magnet subsystem. It includes conventional project management activities (cost/progress tracking), integration with other subsystems, safety/environmental control, and reporting to detector management. It does not include any management activities for the detector as a whole.

1.3.1.9.1 Project Management and Administration - This element covers subsystem-level management, including periodic reviews and reporting upward to GEM management.

1.3.1.9.2 Resource Management - This element includes the effort required to maintain magnet subsyste cost/schedule projectiuons, and to monitor actual progress and spending, in order to identify trends and provide information for subsystem and detector management.

1.3.1.9.3 ES&H - This element covers all activities required to ensure that magnet subsystem activities are conducted in the safest possible manner, with minimal impact on the environment and the health of the workers and public. It includes safety reviews of subsystem designs, as well as adequate tracking to ensure ES&H requirments are identified and met.

1.3.1.9.4 Quality Assurance - This element includes the development and maintenance of a magnet subsystem quality assurance plan (QAP), consistant with the overall GEM QAP. It includes the neccessary oversight and documentation.

1.3.1.9.5 System Integration - This element covers activities required to ensure proper integration of the various subsystems within GEM, as well as between GEM and the physical facilities on-site.

7.0 Labor Rates

General Assumptions

The basic unit used for reporting labor in this cost estimate is the Full-Time-Equivalent-Year (FTE-yr).

We have adopted the labor rates defined in the GEM Cost Estimate Plan (Ref. 1) for all manpower estimates. These labor rates are costs per FTE-yr, and include proper consideration of the actual number of man-hours per FTE-yr for each type of labor.

For most of the effort to be applied to the implementation of the GEM magnet subsystem, we have adopted labor rates based on team averages. For each type of activity, we have defined the mix of job categories which we plan to use, and the simply calculate the average labor rate for that mix. These standard team rates are defined below.

Unless otherwise noted, estimates done in hours or days are assumed to be in man-units (ie, not including vacation, sick leave, etc), and estimates done in weeks, months, or years are in FTE-units. Therefore, for conversion to FTE-years (the basic unit for reporting labor), 1 FTE-yr = 12 FTE-mo = 52 man-weeks = 222 man-days = 1776 man-hours.

Conceptual/Preliminary Design Team - This team will be responsible for all conceptual and preliminary design activities, as well as the R&D efforts. This team will consist of LLNL and MIT scientists, engineers, and designers. The estimate division of labor hours between LLNL and MIT is approximately 2.6:1. For the individuals who will be involved at MIT, a loaded labor rate of $150k/yr is appropriate. For the LLNL portion of the team, the mix will be

Type	Mix	Rate
Engineer, Nat'l lab	1.0	154
Designer, Nat'l lab	1.0	93
Coordinator, Nat'l Lab	0.5	93

This mix reflects a heavy emphasis on top-level design and analysis and contacts with vendors. Secretarial effort and management are included at no cost, since they are covered by burden which is included in the labor rates shown. The average rate for this mix is $117k/yr, and for the total LLNL/MIT team, the average is therfor $126k/yr.

Engineering/Design Team - This team will be used for writing the final specification, performing the final design, and monitoring the design process. We assume that final design will be performed by commercial vendors at national average rates, and the specification and oversight functions will be performed by national laboratory personnel. The team composition is as follows:

Type	Mix	Rate
Engineer, Nat'l lab	0.1	154
Designer, Nat'l lab	0.1	103
Coordinator, Nat'l Lab	0.1	103
Engineer, nat'l avg	0.9	133
Sr. Designer*, nat'l avg	1.8	107
Jr. Designer*, nat'l avg	2.7	82

(*designer rates were assumed to be the same as technician rates.) For this team, the average labor rate is 100k$/yr. Note that when estimates are in

Inspection/Administration Team - This team will be used for technical administration of design/fabrication contracts, and inspection of the resulting hardware. It will also be employed for supervision of assembly and installation activities. We assume that this team mix is appropriate for monitoring fabrication activities, answerng questions/problems during fabrication by vendors, inspecting delivered parts, and accepting/rejecting them. This effort is assumed to be entirely national laboratory personnel.

Type	Mix	Rate
Engineer, Nat'l lab	0.25	154
Coordinator, Nat'l Lab	0.25	103
Sr. Technician, Nat'l Lab	2.0	103
Jr. Technician, Nat'l Lab	2.0	77

The average labor rate for this team is 94k$/yr.

Assembly Team - This team will be used for assembly of magnet components, particularly the coils themselves.

Type	Mix	Rate
Engineer, Nat'l lab	1.0	154
Sr. Technician, Nat'l Lab	1.0	103
Sr. Technician, SSC	2.0	50
Technician, SSC	2.0	37
Sr. Technician, job shop	5.0	54
Jr. Technician, job shop	10.0	39
Welder	2.0	52

The average labor rate for this team is 52k$/yr. However, the supervision labor (performed by the Nat'l Lab employees) is an EDIA cost, and must therfore be reported under "Inspection/Administration"; note that, based on the assembly team mix described above, 8.7% of the team is supervision, and the remaining 91.3% is actual assembly labor. In recording the estimates, the total team labor will be estimated, and then 8.7% of it will be entered under Inspection/Adminstration, and the remaining 91.3% will be recorded under Installation/Assembly. The net labor rate (without supervision) for assembly will then be $45k/yr (derived from the above mix, without the Nat'l lab employees).

Installation Team - This team will be used for installation of magnet components into their final positions. This includes installation of the magnet halves, poles, cryogenics, power supplies, bus bars, etc.

Type	Mix	Rate
Engineer, Nat'l lab	1.0	154
Sr. Technician, Nat'l Lab	1.0	103
Engineer, SSC	1.0	154
Sr. Technician, SSC	1.0	50
Sr. Technician, job shop	5.0	54
Jr. Technician, job shop	5.0	39
Crane operator	1.0	58
Rigger	5.0	52
Welder	2.0	52
Pipefitter	2.0	47
Electrician	5.0	43
Laborer	10.0	29

The average labor rate for this team is 48k$/yr. However, the supervision labor (performed by the Nat'l Lab employees) is an EDIA cost, and must therfore be reported under "Inspection/Administration"; note that, based on the assembly team mix described above, 10% of the team is supervision, and the remaining 90% is actual assembly labor. In recording the estimates, the total team labor will be estimated, and then 10% of it will be entered under Inspection/Adminstration, and the remaining 90% will be recorded under Installation/Assembly. The net labor rate (without supervision) for assembly will then be $43k/yr (derived from the above mix, without the Nat'l lab employees).

8.0 Complete Cost/Risk/Schedule Matrix

The following pages contain the complete matrixes which give the cost estimate, contingency estimate, and shedule estimate (for escalation purposes only). Lines shown in bold are derived from other lines in the matrix. Normal-type lines are all original estimates, and each line is supported by a Basis of Estimate sheet in Section 9.0.

			Engineering/design			M&S	Inspection/Admin			Proc/Fab	Installation/Assembly					Totals				
			Labor	Rate	Total	Material	Labor	Rate	Total	Material	Labor	Rate	Subtotal	Material	Total	Labor	Material	Subtotal	Conting	Total
	WBS no.	Item	my	k$/my	k$	k$	my	k$/my	k$	k$	my	k$/my	k$	k$	k$	k$	k$	k$	k$	k$
		Magnet total	72.42	115	8312	7102	59.18	104	6159	57940	117.37	47	5481	2092	7573	19952	67134	87086	21743	108829
2	1.1	GEM Research and Dev																		
3	1.1.1	**Magnet R&D**	7.56	126	952	3919	0.00	0	0	0	0.00	0	0	0	0	952	3919	4871	1615	6486
4	1.1.1.1	**Magnet Concept Dev**	1.35	126	170	30	0.00	0	0	0	0.00	0	0	0	0	170	30	200	70	270
5	1.1.1.1.1	Magnetic Field Analysis	0.51	126	64	11	0.00	0	0	0	0.00	0	0	0	0	64	11	75	22	97
5	1.1.1.1.2	Future Detector Options	0.84	126	106	19	0.00	0	0	0	0.00	0	0	0	0	106	19	125	48	173
4	1.1.1.2	**Conductor/Winding Dev**	5.40	126	680	2821	0.00	0	0	0	0.00	0	0	0	0	680	2821	3501	1138	4639
5	1.1.1.2.1	Conductor Dev and Testing	1.01	126	128	1023	0.00	0	0	0	0.00	0	0	0	0	128	1023	1151	368	1519
5	1.1.1.2.2	Joint Dev and Testing	1.35	126	170	530	0.00	0	0	0	0.00	0	0	0	0	170	530	700	224	924
5	1.1.1.2.3	Conductor Tooling Dev	1.01	126	128	623	0.00	0	0	0	0.00	0	0	0	0	128	623	751	240	991
5	1.1.1.2.4	Winding Tooling Dev	2.02	126	255	645	0.00	0	0	0	0.00	0	0	0	0	255	645	900	306	1206
4	1.1.1.3	**Component Verification**	0.81	126	102	1068	0.00	0	0	0	0.00	0	0	0	0	102	1068	1170	407	1577
5	1.1.1.3.1	Materials Verification Testin	0.27	126	34	256	0.00	0	0	0	0.00	0	0	0	0	34	256	290	93	383
5	1.1.1.3.2	Component Verification Test	0.27	126	34	306	0.00	0	0	0	0.00	0	0	0	0	34	306	340	109	449
5	1.1.1.3.3	Model Coil Test	0.27	126	34	506	0.00	0	0	0	0.00	0	0	0	0	34	506	540	205	745
2	1.2	GEM Conceptual/Prelim Design																		
3	1.2.1	**Magnet subsystem**	33.58	126	4231	672	0.00	0	0	0	0.00	0	0	0	0	4231	672	4903	1104	6006
4	1.2.1.1	Pre-LOI Engineering/Design	3.49	126	440		0.00	0			0.00	0				440	0	440	0	440
4	1.2.1.2	**LOI to Eng Design Report (E**	30.09	126	3791	672	0.00	0	0	0	0.00	0	0	0	0	3791	672	4463	1104	5567
5	1.2.1.2.1	**Preliminary Design**	19.39	126	2444	434	0.00	0	0	0	0.00	0	0	0	0	2444	434	2878	716	3594
6	1.2.1.2.1.1	**Solenoid Magnet**	14.74	126	1857	330	0.00	0	0	0	0.00	0	0	0	0	1857	330	2187	578	2765
7	1.2.1.2.1.1.1	**Coil Assemblies**	12.58	126	1585	281	0.00	0	0	0	0.00	0	0	0	0	1585	281	1866	501	2367
8	1.2.1.2.1.1.1.1	**Coil Subassemblies**	6.78	126	854	152	0.00	0	0	0	0.00	0	0	0	0	854	152	1006	319	1325
9	1.2.1.2.1.1.1.1.1	Coil form	1.28	126	162	29	0.00	0	0	0	0.00	0	0	0	0	162	29	191	50	240
9	1.2.1.2.1.1.1.1.2	Conductor	3.51	126	442	78	0.00	0	0	0	0.00	0	0	0	0	442	78	520	166	686
9	1.2.1.2.1.1.1.1.3	Diagnostics	0.20	126	26	5	0.00	0	0	0	0.00	0	0	0	0	26	5	31	2	33
9	1.2.1.2.1.1.1.1.4	Winding Tooling	1.79	126	225	40	0.00	0	0	0	0.00	0	0	0	0	225	40	265	101	366
8	1.2.1.2.1.1.1.2	Thermal Radiation Shields	0.67	126	85	15	0.00	0	0	0	0.00	0	0	0	0	85	15	100	22	122
8	1.2.1.2.1.1.1.3	Vacuum Vessel Subassemblie	1.89	126	238	42	0.00	0	0	0	0.00	0	0	0	0	238	42	280	67	347
8	1.2.1.2.1.1.1.4	Cold Mass Supports	1.35	126	170	30	0.00	0	0	0	0.00	0	0	0	0	170	30	200	34	234
8	1.2.1.2.1.1.1.5	Internal Cryogenic Systems	0.40	126	51	9	0.00	0	0	0	0.00	0	0	0	0	51	9	60	11	71
8	1.2.1.2.1.1.1.6	Cryogenic Current Leads	0.81	126	102	18	0.00	0	0	0	0.00	0	0	0	0	102	18	120	19	139
8	1.2.1.2.1.1.1.7	Assy/Testing Equipment	0.67	126	85	15	0.00	0	0	0	0.00	0	0	0	0	85	15	100	28	128
7	1.2.1.2.1.1.2	End Poles/Supports	1.28	126	162	29	0.00	0	0	0	0.00	0	0	0	0	162	29	191	46	236
7	1.2.1.2.1.1.3	Detector Supports	0.88	126	111	20	0.00	0	0	0	0.00	0	0	0	0	111	20	131	31	162
6	1.2.1.2.1.2	Power/Protection System	1.18	126	149	26	0.00	0	0	0	0.00	0	0	0	0	149	26	175	28	203
6	1.2.1.2.1.3	Cryogenics	0.51	126	64	11	0.00	0	0	0	0.00	0	0	0	0	64	11	75	12	87
6	1.2.1.2.1.4	Vacuum System	0.40	126	51	9	0.00	0	0	0	0.00	0	0	0	0	51	9	60	8	68
6	1.2.1.2.1.5	Magnet Control Systems	0.54	126	68	12	0.00	0	0	0	0.00	0	0	0	0	68	12	80	13	93
6	1.2.1.2.1.7	Installation Tooling	0.47	126	60	11	0.00	0	0	0	0.00	0	0	0	0	60	11	71	18	89
6	1.2.1.2.1.8	Conv/Technical Facilities	1.55	126	196	35	0.00	0	0	0	0.00	0	0	0	0	196	35	231	60	290

5	1.2.1.2.2	**Analysis**	7.18	126	905	160	0.00	0	0	0	0.00	0	0	0	0	905	160	1065	276	1341
6	1.2.1.2.2.1	Magnetic Field/Force Anal	0.91	126	115	20	0.00	0	0	0	0.00	0	0	0	0	115	20	135	40	175
6	1.2.1.2.2.2	System Thermal Anal	1.35	126	170	30	0.00	0	0	0	0.00	0	0	0	0	170	30	200	32	232
6	1.2.1.2.2.3	System Structural Anal	1.25	126	157	28	0.00	0	0	0	0.00	0	0	0	0	157	28	185	44	230
6	1.2.1.2.2.4	Magnetic Shielding Anal	1.48	126	187	33	0.00	0	0	0	0.00	0	0	0	0	187	33	220	62	282
6	1.2.1.2.2.5	Safety/reliability analy	2.19	126	276	49	0.00	0	0	0	0.00	0	0	0	0	276	49	325	98	423
5	1.2.1.2.8	EDR Preparation	1.35	126	170	30	0.00	0	0	0	0.00	0	0	0	0	170	30	200	60	260
5	1.2.1.2.9	Magnet Subsys Mgmt/Int	2.16	126	272	48	0.00	0	0	0	0.00	0	0	0	0	272	48	320	51	371
2	1.3	GEM Construction																		
3	**1.3.1**	**Magnet subsystem**	**31.29**	**100**	**3129**	**2511**	**59.18**	**104**	**6159**	**57940**	**117.37**	**47**	**5481**	**2092**	**7573**	**14769**	**62543**	**77312**	**19024**	**96336**
4	**1.3.1.1**	**Solenoid Magnet**	**14.74**	**100**	**1474**	**1068**	**16.43**	**94**	**1544**	**46439**	**74.42**	**45**	**3344**	**1307**	**4651**	**6362**	**48814**	**55176**	**14630**	**69807**
5	**1.3.1.1.1**	**Coil Assemblies**	**8.67**	**100**	**867**	**665**	**11.58**	**94**	**1089**	**28893**	**70.09**	**45**	**3149**	**1207**	**4356**	**5104**	**30765**	**35869**	**10095**	**45965**
6	**1.3.1.1.1.1**	**Coil Subassemblies**	**2.24**	**100**	**224**	**154**	**5.58**	**94**	**525**	**16682**	**57.35**	**45**	**2581**	**1075**	**3656**	**3329**	**17911**	**21240**	**6630**	**27870**
7	1.3.1.1.1.1.1	Coil form	0.33	100	33	48	0.83	94	78	7211	0.00	0	0	0	0	111	7259	7370	1916	9286
7	1.3.1.1.1.1.2	Conductor	0.54	100	54	78	1.21	94	114	6946	1.35	45	61	75	136	228	7099	7327	2345	9672
7	1.3.1.1.1.1.3	Diagnostics	0.12	100	12	4	0.04	94	4	25	0.00	0	0	0	0	16	29	45	3	48
7	1.3.1.1.1.1.4	Winding Tooling	1.25	100	125	24	0.50	94	47	2400	0.00	0	0	0	0	172	2424	2596	883	3479
7	**1.3.1.1.1.1.5**	**Assembly**	**0.00**	**100**	**0**	**0**	**3.00**	**94**	**282**	**100**	**56.00**	**45**	**2520**	**1000**	**3520**	**2802**	**1100**	**3902**	**1483**	**5385**
8	1.3.1.1.1.1.5.1	Off-Site Assembly	0.00	100	·0	0	0.00	0	0	0	0.00	0	0	0	0	0	0	0	0	0
8	1.3.1.1.1.1.5.2	On-Site Assembly	0.00	100	0	0	3.00	94	282	100	56.00	45	2520	1000	3520	2802	1100	3902	1483	5385
6	**1.3.1.1.1.2**	**Thermal Radiation Shields**	**0.50**	**100**	**50**	**64**	**0.80**	**94**	**75**	**2284**	**0.00**	**0**	**0**	**0**	**0**	**125**	**2348**	**2473**	**498**	**2971**
7	1.3.1.1.1.2.1	LN Thermal Rad Shields	0.23	100	23	44	0.58	94	55	2000	0.00	0	0	0	0	78	2044	2122	467	2588
7	1.3.1.1.1.2.2	Superinsulation	0.08	100	8	8	0.04	94	4	112	0.00	0	0	0	0	12	120	132	9	141
7	1.3.1.1.1.2.3	Shield supports/thermal inte	0.19	100	19	12	0.18	94	17	172	0.00	0	0	0	0	36	184	220	22	242
6	**1.3.1.1.1.3**	**Vacuum Vessel Subassy's**	**2.75**	**100**	**275**	**311**	**3.15**	**94**	**296**	**7674**	**0.00**	**0**	**0**	**0**	**0**	**571**	**7985**	**8556**	**1984**	**10540**
7	1.3.1.1.1.3.1	Vessel Weldment	1.75	100	175	204	1.90	94	179	7006	0.00	0	0	0	0	354	7210	7564	1815	9379
7	1.3.1.1.1.3.2	Vessel Support Saddles	1.00	100	100	107	1.25	94	118	668	0.00	0	0	0	0	218	775	993	169	1161
6	**1.3.1.1.1.4**	**Cold Mass Supports**	**0.38**	**100**	**38**	**40**	**0.71**	**94**	**67**	**1480**	**0.00**	**0**	**0**	**0**	**0**	**105**	**1520**	**1625**	**276**	**1901**
7	1.3.1.1.1.4.1	Radial Supports	0.19	100	19	20	0.42	94	39	849	0.00	0	0	0	0	58	869	927	158	1085
7	1.3.1.1.1.4.2	Axial Supports	0.19	100	19	20	0.29	94	27	631	0.00	0	0	0	0	46	651	697	119	816
6	**1.3.1.1.1.5**	**Internal Cryogenic Systems**	**0.45**	**100**	**45**	**24**	**0.21**	**94**	**20**	**23**	**0.00**	**0**	**0**	**0**	**0**	**65**	**47**	**112**	**19**	**131**
7	1.3.1.1.1.5.1	LN Piping and Distribution	0.15	100	15	8	0.07	94	7	7	0.00	0	0	0	0	22	15	37	6	43
7	1.3.1.1.1.5.2	LHe Thermosyphon Piping/Dis	0.15	100	15	8	0.07	94	7	8	0.00	0	0	0	0	22	16	38	6	44
7	1.3.1.1.1.5.3	LHe Forced-Flow Piping/Dist	0.15	100	15	8	0.07	94	7	8	0.00	0	0	0	0	22	16	38	7	45
6	1.3.1.1.1.6	Cryogenic Current Leads	0.25	100	25	4	0.07	94	7	100	0.00	0	0	0	0	32	104	136	22	157
6	1.3.1.1.1.7	Assy and Test Equipment	0.62	100	62	20	0.18	94	17	350	0.00	0	0	0	0	79	370	449	126	575
6	**1.3.1.1.1.8**	**Assembly**	**1.10**	**100**	**110**	**40**	**0.63**	**94**	**59**	**0**	**10.04**	**45**	**452**	**100**	**552**	**621**	**140**	**761**	**365**	**1126**
7	1.3.1.1.1.8.1	Off-site assembly	0.00	100	0	0	0.00	94	0	0	0.00	0	0	0	0	0	0	0	0	0
7	1.3.1.1.1.8.2	On-site assembly	1.10	100	110	40	0.63	94	59	0	10.04	45	452	100	552	621	140	761	365	1126
6	1.3.1.1.1.9	Testing	0.38	100	38	8	0.25	94	24	300	2.70	43	116	32	148	178	340	518	176	694
5	**1.3.1.1.2**	**End Poles/Supports**	**5.07**	**100**	**507**	**403**	**3.55**	**94**	**334**	**15192**	**4.33**	**45**	**195**	**100**	**295**	**1036**	**15695**	**16731**	**3917**	**20647**

6	1.3.1.1.2.1	End Pole Subassemblies	0.80	100	80	109	0.90	94	85	9865		45	0		0	165	9974	10139	1622	11761
6	1.3.1.1.2.2	End Pole Support Subass'ys	3.50	100	350	218	1.90	94	179	3809	3.00	45	135	50	185	664	4077	4741	1517	6258
6	1.3.1.1.2.3	End Pole Field Shaper	0.77	100	77	76	0.75	94	71	1518	1.33	45	60	50	110	207	1644	1851	778	2629
5	**1.3.1.1.3**	**Detector Supports**	**1.00**	**100**	**100**	**0**	**1.30**	**94**	**122**	**2354**	**0.00**	**45**	**0**	**0**	**0**	**222**	**2354**	**2576**	**618**	**3194**
6	1.3.1.1.3.1	Central Detector Support	1.00	100	100	0	1.30	94	122	2354	0.00	45	0	0	0	222	2354	2576	618	3194
6	1.3.1.1.3.2	Forward Calorimeter Support	0.00	100	0	0	0.00	94	0	0	0.00	45	0	0	0	0	0	0	0	0
4	**1.3.1.2**	**Power/Protection System**	**1.43**	**100**	**143**	**20**	**0.40**	**94**	**37**	**632**	**0.00**	**0**	**0**	**0**	**0**	**180**	**652**	**832**	**136**	**968**
5	1.3.1.2.1	Power Supply	0.58	100	58	8	0.14	94	13	250	0.00	0	0	0	0	71	258	329	53	382
5	1.3.1.2.2	Buswork	0.34	100	34	8	0.05	94	5	57	0.00	0	0	0	0	39	65	104	27	131
5	1.3.1.2.3	Breakers/Dump Resistors	0.26	100	26	4	0.13	94	12	250	0.00	0	0	0	0	38	254	292	35	327
5	1.3.1.2.4	Quench Det and Diagn	0.25	100	25	0	0.08	94	8	75	0.00	0	0	0	0	33	75	108	22	129
4	**1.3.1.3**	**Cryogenics**	**4.26**	**100**	**426**	**132**	**1.36**	**94**	**128**	**7994**	**0.00**	**0**	**0**	**0**	**0**	**554**	**8126**	**8680**	**1418**	**10097**
5	**1.3.1.3.1**	**Liquid Nitrogen System**	**1.12**	**100**	**112**	**28**	**0.35**	**94**	**33**	**2011**	**0.00**	**0**	**0**	**0**	**0**	**145**	**2039**	**2184**	**328**	**2512**
6	1.3.1.3.1.1	LN Storage Dewar	0.10	100	10	8	0.04	94	4	1109	0.00	0	0	0	0	14	1117	1131	136	1266
6	1.3.1.3.1.2	LN Subcooler	0.25	100	25	4	0.13	94	12	700	0.00	0	0	0	0	37	704	741	133	875
6	1.3.1.3.1.3	LN Piping and Distribution	0.77	100	77	16	0.18	94	17	202	0.00	0	0	0	0	94	218	312	59	371
5	**1.3.1.3.2**	**Liquid Helium System**	**3.14**	**100**	**314**	**104**	**1.01**	**94**	**95**	**5983**	**0.00**	**0**	**0**	**0**	**0**	**409**	**6087**	**6496**	**1089**	**7585**
6	**1.3.1.3.2.1**	**Thermosyphon System**	**0.87**	**100**	**87**	**24**	**0.22**	**94**	**21**	**236**	**0.00**	**0**	**0**	**0**	**0**	**108**	**260**	**368**	**67**	**434**
7	1.3.1.3.2.1.1	Magnet Supply Dewars	0.10	100	10	8	0.04	94	4	25	0.00	0	0	0	0	14	33	47	6	52
7	1.3.1.3.2.1.2	LHe Thermosyphon Piping/Di	0.77	100	77	16	0.18	94	17	211	0.00	0	0	0	0	94	227	321	61	382
6	**1.3.1.3.2.2**	**Forced-Flow System**	**1.02**	**100**	**102**	**24**	**0.31**	**94**	**29**	**461**	**0.00**	**0**	**0**	**0**	**0**	**131**	**485**	**616**	**114**	**730**
7	1.3.1.3.2.2.1	LHe Circulator	0.25	100	25	8	0.13	94	12	250	0.00	0	0	0	0	37	258	295	53	348
7	1.3.1.3.2.2.2	Forced-Flow LHe Piping/Dist	0.77	100	77	16	0.18	94	17	211	0.00	0	0	0	0	94	227	321	61	382
6	**1.3.1.3.2.3**	**LHe Sup/Storage/Recov Sys**	**1.25**	**100**	**125**	**56**	**0.48**	**94**	**45**	**5286**	**0.00**	**0**	**0**	**0**	**0**	**170**	**5342**	**5512**	**908**	**6421**
7	1.3.1.3.2.3.1	Refrigerator	0.15	100	15	12	0.08	94	8	2901	0.00	0	0	0	0	23	2913	2936	470	3405
7	1.3.1.3.2.3.2	LHe Storage Dewar	0.10	100	10	4	0.04	94	4	780	0.00	0	0	0	0	14	784	798	96	893
7	1.3.1.3.2.3.3	LHe Recovery System	0.50	100	50	16	0.18	94	17	1443	0.00	0	0	0	0	67	1459	1526	290	1816
7	1.3.1.3.2.3.4	LHe Supply Sys Piping/Dist	0.50	100	50	24	0.18	94	17	162	0.00	0	0	0	0	67	186	253	53	306
4	**1.3.1.4**	**Magnet Vacuum System**	**1.50**	**100**	**150**	**20**	**1.00**	**94**	**94**	**415**	**0.00**	**45**	**0**	**0**	**0**	**244**	**435**	**679**	**76**	**755**
5	1.3.1.4.1	Vacuum Pumps	0.50	100	50	5	0.25	94	24	130	0.00	45	0	0	0	74	135	209	15	223
5	1.3.1.5.2	Vacuum Piping	1.00	100	100	15	0.75	94	71	285	0.00	45	0	0	0	171	300	471	61	532
4	**1.3.1.5**	**Magnet Control Systems**	**0.62**	**100**	**62**	**20**	**0.19**	**94**	**18**	**185**	**0.00**	**0**	**0**	**0**	**0**	**80**	**205**	**285**	**51**	**336**
5	1.3.1.5.1	Power controls	0.14	100	14	8	0.05	94	5	40	0.00	0	0	0	0	19	48	67	11	77
5	1.3.1.5.2	Protection controls	0.15	100	15	4	0.05	94	5	35	0.00	0	0	0	0	20	39	59	9	68
5	1.3.1.5.3	Cryogenics controls	0.23	100	23	8	0.05	94	5	60	0.00	0	0	0	0	28	68	96	21	117
5	1.3.1.5.4	Vacuum controls	0.10	100	10	0	0.04	94	4	50	0.00	0	0	0	0	14	50	64	10	74
4	1.3.1.5.6	Return Field Mitigation	0.77	100	77	0	0.17	94	16	575	0.00	0	0	0	0	93	575	668	214	882
4	**1.3.1.7**	**Installation Tooling**	**5.33**	**100**	**533**	**204**	**2.23**	**94**	**210**	**1400**	**1.80**	**45**	**81**	**50**	**131**	**824**	**1654**	**2477**	**675**	**3153**
5	1.3.1.7.1	Central Detector Support	0.50	100	50	8	0.90	94	85	300	0.00	45	0	0	0	135	308	442	137	579
5	1.3.1.7.2	Coil Assemblies	2.00	100	200	90	0.70	94	66	500	1.80	45	81	50	131	347	640	987	257	1243
5	1.3.1.7.3	Pole Assemblies	2.00	100	200	90	0.50	94	47	250	0.00	45	0	0	0	247	340	587	153	740
5	1.3.1.7.4	Testing Equipment	0.83	100	83	16	0.13	94	12	350	0.00	45	0	0	0	95	366	461	129	590
4	**1.3.1.8**	**Installation**	**2.64**	**100**	**264**	**523**	**11.40**	**95**	**1084**	**300**	**41.15**	**50**	**2057**	**735**	**2792**	**3405**	**1558**	**4963**	**1255**	**6218**
5	1.3.1.8.1	Solenoid Magnet Installation	1.00	100	100	466	9.30	94	874	150	22.50	43	968	500	1468	1942	1116	3058	764	3822

5	1.3.1.8.2	**Power/Prot Sys Inst**	0.00	100	0	0	0.19	137	26	50	1.90	43	82	20	102	108	70	178	31	209
6	1.3.1.8.2.1	Power Supply Installation	0.00	100	0	0	0.05	137	7	50	0.47	43	20	10	30	27	60	87	14	101
6	1.3.1.8.2.2	Buswork Installation	0.00	100	0	0	0.07	137	10	0	0.73	43	31	5	36	41	5	46	10	56
6	1.3.1.8.2.3	Breakers and Dump Res Inst	0.00	0	0	0	0.04	137	5	0	0.35	43	15	5	20	21	5	26	4	30
6	1.3.1.8.2.4	Quench Det and Diag Inst	0.00	0	0	0	0.03	137	4	0	0.35	43	15	0	15	19	0	19	3	22
5	1.3.1.8.3	**Cryogenic System Installat**	1.08	100	108	32	0.76	94	71	100	5.00	45	225	50	275	404	182	586	164	751
6	1.3.1.8.3.1	LN System Installation	0.39	100	39	16	0.38	94	36	50	2.50	45	113	25	138	187	91	278	78	356
6	1.3.1.8.3.2	LHe Systems Installation	0.69	100	69	16	0.38	94	36	50	2.50	45	113	25	138	217	91	308	86	395
5	1.3.1.8.4	Vacuum System Installation	0.50	100	50	15	1.00	94	94	0	6.00	48	288	150	438	432	165	597	137	734
5	1.3.1.8.5	Control System Installation	0.06	100	6	10	0.10	137	14	0	1.25	43	54	15	69	73	25	98	22	120
5	1.3.1.8.6	Testing	0.00	100	0	0	0.05	94	5	25	4.50	98	441	0	441	446	25	471	137	607
4	1.3.1.9	**Subsystem Mgmt & Integ**	0.00	0	0	524	26.00	116	3028	0	0.00	0	0	0	0	3028	524	3552	568	4120
5	1.3.1.9.1	Project Mgmt and Admin	0.00	0	0	292	12.00	93	1116	0	0.00	0	0	0	0	1116	292	1408	225	1633
5	1.3.1.9.2	Resource Management	0.00	0	0	40	4.00	93	372	0	0.00	0	0	0	0	372	40	412	66	478
5	1.3.1.9.3	ES&H	0.00	0	0	48	4.00	154	616	0	0.00	0	0	0	0	616	48	664	106	770
5	1.3.1.9.4	Quality Assurance	0.00	0	0	48	3.00	154	462	0	0.00	0	0	0	0	462	48	510	82	592
5	1.3.1.9.5	System Integration	0.00	0	0	96	3.00	154	462	0	0.00	0	0	0	0	462	96	558	89	647
			grand totals		8312	7102	59.18		6159	57940	117.37			2092	7573		67134	87086	21743	108829

WBS no.	Item	No.	Units	Estimate Type	Risk factors Technical	Risk factors Cost	Risk factors Schedule	Risk percentages Technical	Risk percentages Cost	Risk percentages Schedule	Total contingency percentage
											25%
1.1	GEM Research and Dev										
1.1.1	**Magnet R&D**										33%
1.1.1.1	**Magnet Concept Dev**										35%
1.1.1.1.1	Magnetic Field Analysis	N/A	N/A	ED	6	4	4	18%	8%	4%	30%
1.1.1.1.2	Future Detector Options	N/A	N/A	ED	6	6	8	18%	12%	8%	38%
1.1.1.2	**Conductor/Winding Dev**										33%
1.1.1.2.1	Conductor Dev and Testing	N/A	N/A	ED	6	4	6	18%	8%	6%	32%
1.1.1.2.2	Joint Dev and Testing	N/A	N/A	ED	6	4	6	18%	8%	6%	32%
1.1.1.2.3	Conductor Tooling Dev	N/A	N/A	ED	6	4	6	18%	8%	6%	32%
1.1.1.2.4	Winding Tooling Dev	N/A	N/A	ED	6	4	8	18%	8%	8%	34%
1.1.1.3	**Component Verification**										35%
1.1.1.3.1	Materials Verification Testin	N/A	N/A	ED	6	4	6	18%	8%	6%	32%
1.1.1.3.2	Component Verification Testi	N/A	N/A	ED	6	4	6	18%	8%	6%	32%
1.1.1.3.3	Model Coil Test	N/A	N/A	ED	6	6	8	18%	12%	8%	38%
1.2	GEM Conceptual/Prelim Design										
1.2.1	**Magnet subsystem**										23%
1.2.1.1	Pre-LOI Engineering/Design	N/A	N/A	(actual)	0	0	0	0%	0%	0%	0%
1.2.1.2	**LOI to Eng Design Report (EDR)**										25%
1.2.1.2.1	**Preliminary Design**										25%
1.2.1.2.1.1	**Solenoid Magnet**										26%
1.2.1.2.1.1.1	**Coil Assemblies**										27%
1.2.1.2.1.1.1.1	**Coil Subassemblies**										32%
1.2.1.2.1.1.1.1.1	Coil form	N/A	N/A	ED	4	3	8	12%	6%	8%	26%
1.2.1.2.1.1.1.1.2	Conductor	N/A	N/A	ED	6	4	6	18%	8%	6%	32%
1.2.1.2.1.1.1.1.3	Diagnostics	N/A	N/A	ED	1	1	2	3%	2%	2%	7%
1.2.1.2.1.1.1.1.4	Winding Tooling	N/A	N/A	ED	6	6	8	18%	12%	8%	38%
1.2.1.2.1.1.1.2	Thermal Radiation Shields	N/A	N/A	ED	4	3	4	12%	6%	4%	22%
1.2.1.2.1.1.1.3	Vacuum Vessel Subassemblie	N/A	N/A	ED	4	4	4	12%	8%	4%	24%
1.2.1.2.1.1.1.4	Cold Mass Supports	N/A	N/A	ED	3	3	2	9%	6%	2%	17%
1.2.1.2.1.1.1.5	Internal Cryogenic Systems	N/A	N/A	ED	3	4	2	9%	8%	2%	19%
1.2.1.2.1.1.1.6	Cryogenic Current Leads	N/A	N/A	ED	2	4	2	6%	8%	2%	16%
1.2.1.2.1.1.1.7	Assy/Testing Equipment	N/A	N/A	ED	4	6	4	12%	12%	4%	28%
1.2.1.2.1.1.2	End Poles/Supports	N/A	N/A	ED	4	5	2	12%	10%	2%	24%
1.2.1.2.1.1.3	Detector Supports	N/A	N/A	ED	2	6	6	6%	12%	6%	24%
1.2.1.2.1.2	Power/Protection System	N/A	N/A	ED	2	4	2	6%	8%	2%	16%
1.2.1.2.1.3	Cryogenics	N/A	N/A	ED	2	4	2	6%	8%	2%	16%
1.2.1.2.1.4	Vacuum System	N/A	N/A	ED	2	2	3	6%	4%	3%	13%
1.2.1.2.1.5	Magnet Control Systems	N/A	N/A	ED	2	4	2	6%	8%	2%	16%
1.2.1.2.1.7	Installation Tooling	N/A	N/A	ED	4	6	2	12%	12%	2%	26%
1.2.1.2.1.8	Conv/Technical Facilities	N/A	N/A	ED	4	6	2	12%	12%	2%	26%

1.2.1.2.2	**Analysis**										26%
1.2.1.2.2.1	Magnetic Field/Force Anal	N/A	N/A	ED	6	4	4	18%	8%	4%	30%
1.2.1.2.2.2	System Thermal Anal	N/A	N/A	ED	2	4	2	6%	8%	2%	16%
1.2.1.2.2.3	System Structural Anal	N/A	N/A	ED	4	4	4	12%	8%	4%	24%
1.2.1.2.2.4	Magnetic Shielding Anal	N/A	N/A	ED	6	4	2	18%	8%	2%	28%
1.2.1.2.2.5	Safety/reliability analy	N/A	N/A	ED	6	4	4	18%	8%	4%	30%
1.2.1.2.8	EDR Preparation	N/A	N/A	ED	6	4	4	18%	8%	4%	30%
1.2.1.2.9	Magnet Subsys Mgmt/Int	N/A	N/A	ED	4	1	2	12%	2%	2%	16%
1.3	GEM Construction										
1.3.1	**Magnet subsystem**										25%
1.3.1.1	**Solenoid Magnet**										27%
1.3.1.1.1	**Coil Assemblies**										28%
1.3.1.1.1.1	**Coil Subassemblies**										31%
1.3.1.1.1.1.1	Coil form	24	ea	BU	4	3	8	12%	6%	8%	26%
1.3.1.1.1.1.2	Conductor	24	km	BU	6	4	6	18%	8%	6%	32%
1.3.1.1.1.1.3	Diagnostics			ED	1	1	2	3%	2%	2%	7%
1.3.1.1.1.1.4	Winding Tooling	1	ea	ED	6	6	4	18%	12%	4%	34%
1.3.1.1.1.1.5	**Assembly**										38%
1.3.1.1.1.1.5.1	Off-Site Assembly							0%	0%	0%	0%
1.3.1.1.1.1.5.2	On-Site Assembly	2	ea	BU	6	6	8	18%	12%	8%	38%
1.3.1.1.1.2	**Thermal Radiation Shields**										20%
1.3.1.1.1.2.1	LN Thermal Rad Shields	2	ea	BU	4	3	4	12%	6%	4%	22%
1.3.1.1.1.2.2	Superinsulation	8000	lbs	BU	1	1	2	3%	2%	2%	7%
1.3.1.1.1.2.3	Shield supports/thermal inte	128	ea	ED	2	1	2	6%	2%	2%	10%
1.3.1.1.1.3	**Vacuum Vessel Subassy's**										23%
1.3.1.1.1.3.1	Vessel Weldment	1	ea	BU	4	4	4	12%	8%	4%	24%
1.3.1.1.1.3.2	Vessel Support Saddles	1	ea	BU	3	3	2	9%	6%	2%	17%
1.3.1.1.1.4	**Cold Mass Supports**										17%
1.3.1.1.1.4.1	Radial Supports	64	ea	BU	3	3	2	9%	6%	2%	17%
1.3.1.1.1.4.2	Axial Supports	32	ea	BU	3	3	2	9%	6%	2%	17%
1.3.1.1.1.5	**Internal Cryogenic Systems**										17%
1.3.1.1.1.5.1	LN Piping and Distribution	2	pairs	BU	2	4	2	6%	8%	2%	16%
1.3.1.1.1.5.2	LHe Thermosyphon Piping/Dis	2	pairs	BU	2	4	2	6%	8%	2%	16%
1.3.1.1.1.5.3	LHe Forced-Flow Piping/Dist	2	pairs	BU	3	4	2	9%	8%	2%	19%
1.3.1.1.1.6	Cryogenic Current Leads	2	pairs	SA	2	4	2	6%	8%	2%	16%
1.3.1.1.1.7	Assy and Test Equipment	1	ea	ED	4	6	4	12%	12%	4%	28%
1.3.1.1.1.8	**Assembly**										48%
1.3.1.1.1.8.1	Off-site assembly							0%	0%	0%	0%
1.3.1.1.1.8.2	On-site assembly	2	ea	BU	8	8	8	24%	16%	8%	48%
1.3.1.1.1.9	Testing	2	ea	ED	8	1	8	24%	2%	8%	34%
1.3.1.1.2	**End Poles/Supports**										23%

1.3.1.1.2.1	End Pole Subassemblies	1	ea	ED	2	4	2	6%	8%	2%	16%
1.3.1.1.2.2	End Pole Support Subass'ys	1	ea	ED	6	6	2	18%	12%	2%	32%
1.3.1.1.2.3	End Pole Field Shaper	2	ea	ED	6	8	8	18%	16%	8%	42%
1.3.1.1.3	**Detector Supports**										**24%**
1.3.1.1.3.1	Central Detector Support	1	ea	BU	2	6	6	6%	12%	6%	24%
1.3.1.1.3.2	Forward Calorimeter Support	2	ea	BU				0%	0%	0%	0%
1.3.1.2	**Power/Protection System**										**16%**
1.3.1.2.1	Power Supply	1	ea	ED	2	4	2	6%	8%	2%	16%
1.3.1.2.2	Buswork	280	m	BU	4	6	2	12%	12%	2%	26%
1.3.1.2.3	Breakers/Dump Resistors	1	ea	ED	2	2	2	6%	4%	2%	12%
1.3.1.2.4	Quench Det and Diagn	1	ea	ED	2	6	2	6%	12%	2%	20%
1.3.1.3	**Cryogenics**										**16%**
1.3.1.3.1	**Liquid Nitrogen System**										**15%**
1.3.1.3.1.1	LN Storage Dewar	1	ea	BU	2	2	2	6%	4%	2%	12%
1.3.1.3.1.2	LN Subcooler	1	ea	ED	2	4	4	6%	8%	4%	18%
1.3.1.3.1.3	LN Piping and Distribution	250+	m	BU	3	4	2	9%	8%	2%	19%
1.3.1.3.2	**Liquid Helium System**										**17%**
1.3.1.3.2.1	**Thermosyphon System**										**18%**
1.3.1.3.2.1.1	Magnet Supply Dewars	2	ea	BU	2	2	2	6%	4%	2%	12%
1.3.1.3.2.1.2	LHe Thermosyphon Piping/Di	260+	m	BU	3	4	2	9%	8%	2%	19%
1.3.1.3.2.2	**Forced-Flow System**										**19%**
1.3.1.3.2.2.1	LHe Circulator	1	ea	ED	2	4	4	6%	8%	4%	18%
1.3.1.3.2.2.2	Forced-Flow LHe Piping/Dist	260+	m	BU	3	4	2	9%	8%	2%	19%
1.3.1.3.2.3	**LHe Sup/Storage/Recov Sys**										**16%**
1.3.1.3.2.3.1	Refrigerator	2	ea	BU	2	4	2	6%	8%	2%	16%
1.3.1.3.2.3.2	LHe Storage Dewar	1	ea	BU	2	2	2	6%	4%	2%	12%
1.3.1.3.2.3.3	LHe Recovery System	1	ea	ED	3	4	2	9%	8%	2%	19%
1.3.1.3.2.3.4	LHe Supply Sys Piping/Dist	1200	ft	BU	3	4	4	9%	8%	4%	21%
1.3.1.4	**Magnet Vacuum System**										**11%**
1.3.1.4.1	Vacuum Pumps	1	ea	BU	1	1	2	3%	2%	2%	7%
1.3.1.5.2	Vacuum Piping	1	ea	BU	2	2	3	6%	4%	3%	13%
1.3.1.5	**Magnet Control Systems**										**18%**
1.3.1.5.1	Power controls	1	ea	ED	2	4	2	6%	8%	2%	16%
1.3.1.5.2	Protection controls	1	ea	ED	2	4	2	6%	8%	2%	16%
1.3.1.5.3	Cryogenics controls	1	ea	ED	4	4	2	12%	8%	2%	22%
1.3.1.5.4	Vacuum controls	1	ea	ED	2	4	2	6%	8%	2%	16%
1.3.1.5.6	Return Field Mitigation	N/A	N/A	ED	6	6	2	18%	12%	2%	32%
1.3.1.7	**Installation Tooling**										**27%**
1.3.1.7.1	Central Detector Support	1	ea	ED	4	6	7	12%	12%	7%	31%
1.3.1.7.2	Coil Assemblies	1	ea	ED	4	6	2	12%	12%	2%	26%
1.3.1.7.3	Pole Assemblies	1	ea	ED	4	6	2	12%	12%	2%	26%
1.3.1.7.4	Testing Equipment	1	ea	ED	4	6	4	12%	12%	4%	28%
1.3.1.8	**Installation**										**25%**
1.3.1.8.1	Solenoid Magnet Installation	1	ea	BU	3	4	8	9%	8%	8%	25%

1.3.1.8.2	**Power/Prot Sys Inst**										**18%**
1.3.1.8.2.1	Power Supply Installation	1	ea	BU	2	4	2	6%	8%	2%	16%
1.3.1.8.2.2	Buswork Installation	1	ea	BU	4	4	2	12%	8%	2%	22%
1.3.1.8.2.3	Breakers and Dump Res Inst	1	ea	BU	2	4	2	6%	8%	2%	16%
1.3.1.8.2.4	Quench Det and Diag Inst	1	ea	BU	2	4	2	6%	8%	2%	16%
1.3.1.8.3	**Cryogenic System Installation**										**28%**
1.3.1.8.3.1	LN System Installation	1	ea	BD	4	6	4	12%	12%	4%	28%
1.3.1.8.3.2	LHe Systems Installation	1	ea	BD	4	6	4	12%	12%	4%	28%
1.3.1.8.4	Vacuum System Installation	1	ea	BU	3	3	8	9%	6%	8%	23%
1.3.1.8.5	Control System Installation	1	ea	BD	4	4	2	12%	8%	2%	22%
1.3.1.8.6	Testing	1	ea	BD	3	6	8	9%	12%	8%	29%
1.3.1.9	**Subsystem Mgmt & Integ**										**16%**
1.3.1.9.1	Project Mgmt and Admin			BD	4	1	2	12%	2%	2%	16%
1.3.1.9.2	Resource Management			BD	4	1	2	12%	2%	2%	16%
1.3.1.9.3	ES&H			BD	4	1	2	12%	2%	2%	16%
1.3.1.9.4	Quality Assurance			BD	4	1	2	12%	2%	2%	16%
1.3.1.9.5	System Integration			BD	4	1	2	12%	2%	2%	16%

		Administration				Engin/design				Inspec/Admin				Proc/Fab				Inst/Assy			
		start		end		start		end		start		end		start		end		start		end	
WBS no	Item	month	year	month	year	month	year	month	year	month	year	month	year	month	year	month	year	month	year	month	year
1.1	GEM Research and Dev																				
1.1.1	**Magnet R&D**																				
1.1.1.1	**Magnet Concept Dev**																				
1.1.1.1.1	Magnetic Field Analysis					12	91	10	93												
1.1.1.1.2	Future Detector Options					12	91	10	93												
1.1.1.2	**Conductor/Winding Dev**																				
1.1.1.2.1	Conductor Dev and Testing					12	91	10	93												
1.1.1.2.2	Joint Dev and Testing					12	91	10	93												
1.1.1.2.3	Conductor Tooling Dev					12	91	10	93												
1.1.1.2.4	Winding Tooling Dev					12	91	10	93												
1.1.1.3	**Component Verification**																				
1.1.1.3.1	Materials Verification Testing					12	91	10	93												
1.1.1.3.2	Component Verification Testing					12	91	10	93												
1.1.1.3.3	Model Coil Test					12	91	10	93												
1.2	GEM Conceptual/Prelim Design																				
1.2.1	**Magnet subsystem**																				
1.2.1.1	Pre-LOI Engineering/Design	8	91	12	91	8	91	12	91												
1.2.1.2	**LOI to Eng Design Report (EDR)**																				
1.2.1.2.1	**Preliminary Design**																				
1.2.1.2.1.1	**Solenoid Magnet**																				
1.2.1.2.1.1.1	**Coil Assemblies**																				
1.2.1.2.1.1.1.1	**Coil Subassemblies**																				
1.2.1.2.1.1.1.1.1	Coil form					12	91	12	92												
1.2.1.2.1.1.1.1.2	Conductor					12	91	12	92												
1.2.1.2.1.1.1.1.3	Diagnostics					12	91	12	92												
1.2.1.2.1.1.1.1.4	Winding Tooling					12	91	12	92												
1.2.1.2.1.1.1.2	Thermal Radiation Shields					12	91	12	92												
1.2.1.2.1.1.1.3	Vacuum Vessel Subassemblies					12	91	12	92												
1.2.1.2.1.1.1.4	Cold Mass Supports					12	91	12	92												
1.2.1.2.1.1.1.5	Internal Cryogenic Systems					12	91	12	92												
1.2.1.2.1.1.1.6	Cryogenic Current Leads					12	91	12	92												
1.2.1.2.1.1.1.7	Assy/Testing Equipment					12	91	12	92												
1.2.1.2.1.1.2	End Poles/Supports					12	91	12	92												
1.2.1.2.1.1.3	Detector Supports					12	91	12	92												
1.2.1.2.1.2	Power/Protection System					12	91	12	92												
1.2.1.2.1.3	Cryogenics					12	91	12	92												
1.2.1.2.1.4	Vacuum System					12	91	12	92												
1.2.1.2.1.5	Magnet Control Systems					12	91	12	92												
1.2.1.2.1.7	Installation Tooling					12	91	12	92												
1.2.1.2.1.8	Conv/Technical Facilities					12	91	12	92												

1.2.1.2.2	**Analysis**																				
1.2.1.2.2.1	Magnetic Field/Force Anal					12	91	12	92												
1.2.1.2.2.2	System Thermal Anal					12	91	12	92												
1.2.1.2.2.3	System Structural Anal					12	91	12	92												
1.2.1.2.2.4	Magnetic Shielding Anal					12	91	12	92												
1.2.1.2.2.5	Safety/reliability analy					12	91	12	92												
1.2.1.2.8	EDR Preparation	8	92	12	92	8	92	12	92												
1.2.1.2.9	Magnet Subsys Mgmt/Int	12	91	12	92																
1.3	GEM Construction																				
1.3.1	**Magnet subsystem**																				
1.3.1.1	**Solenoid Magnet**																				
1.3.1.1.1	**Coil Assemblies**																				
1.3.1.1.1.1	**Coil Subassemblies**																				
1.3.1.1.1.1.1	Coil form					1	93	12	94	1	93	12	94	1	93	12	94				
1.3.1.1.1.1.2	Conductor					1	93	2	95	1	93	2	95	1	93	2	95				
1.3.1.1.1.1.3	Diagnostics					9	93	2	94	9	93	2	94	9	93	2	94				
1.3.1.1.1.1.4	Winding Tooling					5	93	4	94	5	93	4	94	5	93	4	94				
1.3.1.1.1.1.5	**Assembly**																				
1.3.1.1.1.1.5.1	Off-Site Assembly																				
1.3.1.1.1.1.5.2	On-Site Assembly					3	94	4	95	3	94	4	95	3	94	4	95	3	94	4	95
1.3.1.1.1.2	**Thermal Radiation Shields**																				
1.3.1.1.1.2.1	LN Thermal Rad Shields					2	93	11	94	2	93	11	94	2	93	11	94				
1.3.1.1.1.2.2	Superinsulation					5	94	10	94	5	94	10	94	5	94	10	94				
1.3.1.1.1.2.3	Shield supports/thermal intercepts					11	93	10	94	11	93	10	94	11	93	10	94				
1.3.1.1.1.3	**Vacuum Vessel Subassy's**																				
1.3.1.1.1.3.1	Vessel Weldment					9	92	9	93	9	92	1	95	1	93	1	95				
1.3.1.1.1.3.2	Vessel Support Saddles					9	92	9	93	9	92	1	94	10	92	10	93				
1.3.1.1.1.4	**Cold Mass Supports**																				
1.3.1.1.1.4.1	Radial Supports					3	93	10	94	3	93	10	94	3	93	10	94				
1.3.1.1.1.4.2	Axial Supports					3	93	10	94	3	93	10	94	3	93	10	94				
1.3.1.1.1.5	**Internal Cryogenic Systems**																				
1.3.1.1.1.5.1	LN Piping and Distribution					4	94	9	94	4	94	9	94	4	94	9	94				
1.3.1.1.1.5.2	LHe Thermosyphon Piping/Dist					4	94	9	94	4	94	9	94	4	94	9	94				
1.3.1.1.1.5.3	LHe Forced-Flow Piping/Dist					4	94	9	94	4	94	9	94	4	94	9	94				
1.3.1.1.1.6	Cryogenic Current Leads					9	94	2	95	9	94	2	95	9	94	2	95				
1.3.1.1.1.7	Assy and Test Equipment					11	94	10	95	11	94	10	95	11	94	10	95				
1.3.1.1.1.8	**Assembly**																				
1.3.1.1.1.8.1	Off-site assembly																				
1.3.1.1.1.8.2	On-site assembly					5	95	10	95	5	95	10	95	5	95	10	95	5	95	10	95
1.3.1.1.1.9	Testing					4	93	4	94	4	93	1	95	4	93	1	95	1	95	1	96
1.3.1.1.2	**End Poles/Supports**																				

	1.3.1.1.2.1	End Pole Subassemblies					3	93	3	94	3	93	12	95	9	94	12	95				
	1.3.1.1.2.2	End Pole Support Subass'ys					3	93	3	94	3	93	12	95	9	94	12	95	10	95	12	95
	1.3.1.1.2.3	End Pole Field Shaper					1	94	12	95	1	94	12	95	1	94	12	95	1	94	12	95
	1.3.1.1.3	**Detector Supports**																				
	1.3.1.1.3.1	Central Detector Support					9	92	3	93	9	92	12	93	3	93	12	93				
	1.3.1.1.3.2	Forward Calorimeter Support																				
	1.3.1.2	**Power/Protection System**																				
	1.3.1.2.1	Power Supply					1	93	10	94	1	93	10	95	10	94	10	95				
	1.3.1.2.2	Buswork					1	93	10	94	1	93	10	95	10	94	10	95				
	1.3.1.2.3	Breakers/Dump Resistors					1	93	10	94	1	93	10	95	10	94	10	95				
	1.3.1.2.4	Quench Det and Diagn					1	93	10	94	1	93	10	95	10	94	10	95				
	1.3.1.3	**Cryogenics**																				
	1.3.1.3.1	**Liquid Nitrogen System**																				
	1.3.1.3.1.1	LN Storage Dewar					8	94	4	95	8	94	4	95	8	94	4	95				
	1.3.1.3.1.2	LN Subcooler					1	95	6	95	1	95	6	95	1	95	6	95				
	1.3.1.3.1.3	LN Piping and Distribution					3	94	2	95	3	94	2	95	3	94	2	95				
	1.3.1.3.2	**Liquid Helium System**																				
	1.3.1.3.2.1	**Thermosyphon System**																				
	1.3.1.3.2.1.1	Magnet Supply Dewars					6	94	2	95	6	94	2	95	6	94	2	95				
	1.3.1.3.2.1.2	LHe Thermosyphon Piping/Dist					3	94	2	95	3	94	2	95	3	94	2	95				
	1.3.1.3.2.2	**Forced-Flow System**																				
	1.3.1.3.2.2.1	LHe Circulator					9	94	2	95	9	94	2	95	9	94	2	95				
	1.3.1.3.2.2.2	Forced-Flow LHe Piping/Dist					3	94	2	95	3	94	2	95	3	94	2	95				
	1.3.1.3.2.3	**LHe Sup/Storage/Recov Sys**																				
	1.3.1.3.2.3.1	Refrigerator					4	94	3	95	4	94	3	95	4	94	3	95				
	1.3.1.3.2.3.2	LHe Storage Dewar					1	95	6	95	1	95	6	95	1	95	6	95				
	1.3.1.3.2.3.3	LHe Recovery System					7	94	6	95	7	94	6	95	7	94	6	95				
	1.3.1.3.2.3.4	LHe Supply Sys Piping/Dist					3	94	2	95	3	94	2	95	3	94	2	95				
	1.3.1.4	**Magnet Vacuum System**																				
	1.3.1.4.1	Vacuum Pumps					9	92	12	92	9	92	9	93	9	92	9	93				
	1.3.1.5.2	Vacuum Piping					9	92	12	92	9	92	9	93	9	92	9	93				
	1.3.1.5	**Magnet Control Systems**																				
	1.3.1.5.1	Power controls					1	93	10	94	1	93	10	94	10	94	10	95				
	1.3.1.5.2	Protection controls					1	93	10	94	1	93	10	94	10	94	10	95				
	1.3.1.5.3	Cryogenics controls					1	93	10	94	1	93	10	94	10	94	10	95				
	1.3.1.5.3	Vacuum controls					1	93	10	94	1	93	10	94	10	94	10	95				
	1.3.1.5.6	Return Field Mitigation					1	93	12	93	1	94	1	96	1	94	1	96				
	1.3.1.7	**Installation Tooling**																				
	1.3.1.7.1	Central Detector Support					9	92	3	93	9	92	9	95	3	93	12	93				
	1.3.1.7.2	Coil Assemblies					1	93	1	94	1	93	12	95	6	93	12	94	12	94	12	95
	1.3.1.7.3	Pole Assemblies					1	93	1	94	1	93	12	95	6	93	12	94				
	1.3.1.7.4	Testing Equipment					1	94	12	94	1	95	12	95	1	95	12	95				
	1.3.1.8	**Installation**																				
	1.3.1.8.1	Solenoid Magnet Installation					6	92	6	93	1	95	12	96	1	93	1	96	1	96	12	96

	1.3.1.8.2	**Power/Prot Sys Inst**																			
	1.3.1.8.2.1	Power Supply Installation									10	95	4	96					10	95	4	96
	1.3.1.8.2.2	Buswork Installation									10	95	4	96					10	95	4	96
	1.3.1.8.2.3	Breakers and Dump Res Inst									10	95	4	96					10	95	4	96
	1.3.1.8.2.4	Quench Det and Diag Inst									10	95	4	96					10	95	4	96
	1.3.1.8.3	**Cryogenic System Installation**																			
	1.3.1.8.3.1	LN System Installation					6	95	5	96	6	95	5	96	6	95	5	96	12	95	5	96
	1.3.1.8.3.2	LHe Systems Installation					6	95	5	96	6	95	5	96	6	95	5	96	12	95	5	96
	1.3.1.8.4	Vacuum System Installation					9	92	12	92	9	92	12	96					1	95	12	96
	1.3.1.8.5	Control System Installation					1	93	10	94	1	93	4	96					10	94	4	96
	1.3.1.8.6	Testing					7	96	12	96	7	96	12	96	7	96	12	96	7	96	12	96
	1.3.1.9	**Subsystem Mgmt & Integ**																			
	1.3.1.9.1	Project Mgmt and Admin	1	93	1	97																
	1.3.1.9.2	Resource Management	1	93	1	97																
	1.3.1.9.3	ES&H	1	93	1	97																
	1.3.1.9.4	Quality Assurance	1	93	1	97																
	1.3.1.9.5	System Integration	1	93	1	97																

9.0 Basis of Estimate Sheets

The following pages contain a detailed description of each element estimated. These pages are arranged in order by WBS number, and therefore occur in the same sequence as the lines in the cost matrix. No sheets have been included for those elements that are merely the sum of other elements (indicated by bold letters in the matrix in Section 8.0).

Basis of Estimate

WBS: 1.3.1.1.1.1.1 Item: Coil Subassemblies - Coil Form

Date: 12/11/91 Rev: 0C By: R. Yamamoto

Element Scope: This element comprises the coil form within which the coil is wound. The coil form includes ribs to accept axial conductor loads and attachment points for the cold-mass supports.

Technical design description: The present design is shown on drawing AAA91-103681-00; the coil form is comprised of twelve (12) 1.2m long cylindrical sections bolted together; these sections are basically 2" thick aluminum rings (6061-T6) with a nominal diameter of 58' with 1.5" thick circular flanges welded to either end. The superconducting coil is wound onto the inside diameter of each of these 1.2m long sections and joined together at final coil assembly. Two coil forms are required to make up the entire detector resulting in twenty four (24) coil form sections. Drawing AAA91-110287 is a detail sketch of a 1.2m long coil form section.

Engineering/Design (my): .33 Rate ($k/my): 100 Dur: 1/93 -12/94

Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: overall coil layout, coil section assembly, coil form details (4). Total of 6 dwgs @ 1mw/dwg =6mw of design. Engineering support will also be 6mw. GEM engineering will be at 5% level for 24mo = 5mw. Total labor is 17mw = .33 my. Total cost is $33.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .83 Rate ($k/my): 94 Dur: 1/93-12/94

Basis: Assume 2mm effort required to place contract after specs written; 0.1 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (24 mo) = 2.4mm; inspection of coil form sections (24 sections * 1mw/section) = 24mw (5.5mm). Total labor is 9.9mm = .83 my. Total cost is $78k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 48 Dur: 1/93-12/94

Basis: Assume 1 trip/2 mo by two people to vendor at $2.0k/trip per person for 24 months = $48k

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Procurement/Fabrication ($k): 7211 Dur: 1/93-12/94

Basis: Received three vendor estimates ranging from $6500 to $7000k for 24 coil form sections but does not include the field work required to assemble/weld each section (four 90° segments must be welded together to form a single 1.2m long coil section). Estimate that additional 15% cost required for all field work required.
$6500k/ 1.0366 (FY '92-'91 de-escalation factor) *1.15 = $7211k

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Installation/Ass'y (my): 0 Rate ($k/my): 0 Dur:

Material ($k): 0

Basis: Assembly of the conductor onto the coil form is completed during on-site assembly (WBS 1.3.1.1.1.1.5.2)

Unit type: ea **Number of units:** 24

Estimate Type: <u>BU</u>

Risk Factors:
Technical: <u>4</u> Basis: Eddy current heating of coil form is being analyzed and may require a current break.
Cost: <u>3</u> Basis: Vendor quote based on layout drawing; full details are not shown but details should not significantly affect cost.
Schedule: <u>8</u> Basis: Item required early in assembly sequence of winding the superconducting coil. ***Critical Path Item.***

Misc Comments: Cost may decrease if stainless steel is used instead of aluminum (approx. $1000k cost decrease estimated). Section length of coil form may increase from 1.2m to 2.4 m to reduce the number of bolt/flange interfaces (assembly time reduced) and possibly reduce coil form fabrication costs.

Basis of Estimate

WBS: 1.3.1.1.1.1.2 Item: Coil Subassemblies - Conductor

Date: 12/11/91 Rev: 0C By: R. Yamamoto

Element Scope: This element includes all activities required to provide the conductor which makes up the coil. The conductor includes the superconducting wire, the stabilizer, and the passage for the forced-flow LHe. This element includes all of these parts, even if they are designed to be physically separate. The conductor is to be delevered on large spools, ready for winding into the coil forms. This does not include the cost of facilities in which the work will be performed. It does include raw materials, conductor processing, storage drums, tooling, etc.
Technical design description: The present design is shown on drawing AAA91-110284-00; the supercondutor is a niobium/titanium type, having a copper sheathing to superconductor ratio of 2:1. The SC is contained in a 1"O.D. by 0.75"I.D. stainless steel tube where LHe flows through. An aluminum stabilizer with a rectangular cross-section of 2.58" wide by 3.00" high is press-fit to the stainless steel tube/SC wire subassembly. Approx. total length required is 15 miles (24km) of conductor (79,200').

Engineering/Design (my): .54 Rate ($k/my): 100 Dur: 1/93 -2/95
Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: overall superconductor layout, conductor cross-section detail, conductor fabrication details (4), and details of tooling for fabrication (10). Total of 16 dwgs @ 1mw/dwg =16mw of design. Engineering support will be 6mw. GEM engineering will be at 5% level for 26mo = 6mw. Total labor is 28mw = .54 my.

Inspection/Admin (my): 1.21 Rate ($k/my): 94 Dur: 1/93-2/95
Basis: Assume 2mm effort required to place contract after specs written; 0.25 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (26 mo) = 6.5mm; inspection of superconductor and conductor fabrication is (1mw per month)*(26 mo.) = 26mw (6mm). Total labor is 14.5mm = 1.21my. Total cost is $114k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 78 Dur: 1/93-2/95
Basis: Assume 1 trip/2 mo by three people to vendor at $2.0k/trip per person for 26months = $78k

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Procurement/Fabrication ($k): 6946 Dur: 1/93-2/95
Basis: Superconductor cost is broken down into these areas:

1) Superconductor wire cost: 11,340 km length required @$.4478/m = $5080k
   Copper sheating to superconductor ration is 2:1
   Extra lengths required for cabling waste, strand damage, dummy cable, test lengths, etc. = approx. 10% of total; cost =$530k
2) Cost to make cable from SC wire is approx. $8.20/meter.
   ($8.20/meter)*(24 km)=$190k
3) Cost of aluminum stabilizer:
   Cost of aluminum extrusion is $3.3/kg

(need approx. 22,815 meters or 255,000 kg)
(255,000 kg)*($3.3/kg)=<u>$840k</u>

4) Cost to make stainless steel sheath around SC cable:
material cost is <u>$260k</u>
tooling cost is <u>$50k</u>
cost per unit length = $10/m = <u>$230k</u>
(extra length required is approx. 5% =<u>$20k</u>

$7200k/ 1.0366 (FY '92 - '91 de-escalation factor) = $6946k

<u>TOTAL COST</u>: $6946k

<u>Installation/Ass'y</u> (my): <u>1.35</u> **Rate ($k/my):** <u>45</u> **Dur:** <u>1/93-2/95</u>

Material ($k): <u>75</u>

Basis: Assembly of SC conductor has the following steps:

* press-fit stainless steel sheathed SC cable into the aluminum stabilizer (extrusion)
* vacuum leak check/pressure test the conductor assy (stainless steel sheath)
* wind conductor assy on large spools for shipment

Assume the assembly operation can be done at a rate of (3ft/min):
(79,200ft)/(3ft/min)=26,400mins=440hr
(440hr)*(4 men)=1760 man hrs=.85 my
Assume leak checking can be done by 2 men in 2 months=4mm=.33my
Assume spooling of conductor can be done by 2 men in 1 month=2mm=.17my
Total manpower required: .85+.33+.17=1.35my. Average labor rate is $52k/yr.
Assume $75k of fixturing, hardware, etc. are required.

Unit type: <u>km</u> **Number of units:** <u>24</u>

Estimate Type: <u>BU</u>

Risk Factors:

Technical: <u>6</u> Basis: This type of "cable in conduit" SC conductor needs significant R&D to assure a reliable, leak tight conductor assembly. It is "state of the art".

Cost: <u>4</u> Basis: Additional research and correspondence with industry is required to develop a "real" cost basis.

Schedule: <u>6</u> Basis: Item requires early partial delivery so that assembly of the superconductor onto the coil form (bobbin) can start. ***Critical Path Item.***

Misc Comments: Cost of this type of superconductor is not well understood at this time. A cost comparison between the "cable in conduit" design vs. the more standard design of the SC wire separate from the LHe cooling tube will be investigated.

Basis of Estimate

WBS: 1.3.1.1.1.1.3 Item: Coil Subassemblies - Diagnostics
Date: 12/11/91 Rev: 0B By: R. Yamamoto

Element Scope: This element includes all hardware and activities associated with any controls or diagnostics which are actually installed on the coil subassembly. This includes voltage taps, temperature sensors, etc. This element does not include the electronics necessary to read out these sensors or to effect control.
Technical design description: The present design is conceptual in nature. Included in the hardware required would be sensors such as carbon glass resistors, thermistors/thermocouples, etc. All such instrumentation would be bought commercially. Custom designed hardware may be required to interface the sensors to the component of interest.

Engineering/Design (my): .12 **Rate ($k/my):** 100 **Dur:** 9/93-2/94
Basis: The basic design has been completed during preliminary engineering. This item covers only final design effort. Drawings required include: details of instrumentation placement on major subassemblies, details of cable routing, details of custom fixtures/hardware required for installation (2). Total of 4 dwgs @ 1mw/dwg =4mw of design. Engineering support will half of the required design support = 2mw. Total labor is 6mw = .12 my. Total cost is $12.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .04 **Rate ($k/my):** 94 **Dur:** 9/93-2/94
Basis: Assume 0.5mm effort required to place contract after specs written; Total labor is 0.5mm = .04 my. Total cost is $4k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 4 **Dur:** 9/93-2/94
Basis: Assume 1 trip by two people to vendor at $2.0k/trip = $4k

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Procurement/Fabrication ($k): 25 **Dur:** 9/93-2/94
Basis: Assume cost of instrumentation and custom fixtures/hardware = $25k

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Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**
Material ($k): 0
Basis: Assembly of all instrumentation will be done at component subassembly.

Unit type: ea **Number of units:** XXX
Estimate Type: EO

Risk Factors:
Technical: 1 Basis: Off the shelf hardware.
Cost: 1 Basis: Catalog item for most parts; simple fabrication for required hardware.
Schedule: 2 Basis: Non-critical path item.

Basis of Estimate

WBS: 1.3.1.1.1.1.4 Item: Coil Subassy - Winding Tooling
Date: 12/11/91 Rev: 0B By: R. Yamamoto

Element Scope: This element includes all of the tooling required to remove the conductor from the storage drums and wind it into final position in the coil form. Any tooling or hardware required for gluing or otherwise affixing the conductor in place is included in this element.
Technical design description: The present concept is to place a rotating platform inside of a vertically oriented coil form (bobbin) and have it move (rotate) as it winds the conductor onto the inside diameter of the fixed coil form. A conductor straightening fixture will be used to straighten the conductor as it comes off the storage drums. Additional fixturing and hardware will be needed to correctly position the conductor onto the coil form, to make conductor to conductor splices, to leak check the completed subassembly, to administer and cure the epoxy coating onto the conductor/coil form assembly, to hold the conductor in place prior to epoxy bonding, etc.

Engineering/Design (my): 1.25 **Rate ($k/my):** 100 **Dur:** 5/93 -4/94
Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: overall layout of coil winding facility, layout drawing of coil form/conductor and rotating platform, assembly drawings of all system hardware (7), flow schematic of assembly process, detail drawings of fixtures, jigs, etc. (30) Total of 40 dwgs @ 1mw/dwg =40mw of design. Engineering support will be half of the design support required = 20mw. GEM engineering will be at 10% level for 12mo = 5mw. Total labor is 65mw = 1.25my. Total cost is $125k. Average labor rate is $100k/yr.

Inspection/Admin (my): .5 **Rate ($k/my):** 94 **Dur:** 5/93-4/94
Basis: Assume 2mm effort required to place contracts after specs written; 0.2 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (12 mo) = 2mm; inspection of coil form winding fixtures and misc. hardware = 2mm. Total labor is 6mm = 0.5 my. Total cost is $47k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 24 **Dur:** 5/93-4/94
Basis: Assume 1 trip/2 mo by two people to vendor at $2.0k/trip per person for 12 months = $24k

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Procurement/Fabrication ($k): 2400 **Dur:** 5/93-4/94
Basis: Estimate includes: rotating platform, conductor straightening fixture, machine to half-lap the conductor with insulation, tooling to form and secure conductor to the inside of the coil form during the winding operation, tooling to position the conductor during epoxy impregnation, machines to hold, mix and pump epoxy, resistance heater assemblies to cure epoxy, etc. For two (2) sets of winding tooling, the cost is (2 sets)*($1200k/set). Total cost: $2400k.

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0

Basis: Assembly of the conductor onto the coil form is completed during on-site assembly (WBS 1.3.1.1.1.1.5.2)

Unit type: ea **Number of units:** 2

Estimate Type: EO

Risk Factors:
Technical: 6 Basis: Basic technology exists although this application requires additional understanding due to its larger scope and physical size.
Cost: 6 Basis: Estimate done with no formal drawings or details on how the conductor is wound onto the coil form.
Schedule: 4 Basis: Item required early in assembly sequence but should be available prior to coil forms and superconductor.

Misc Comments: Cost may increase/decrease depending on level of design effort applied over the next few months which will increase job understanding and definition.

Basis of Estimate

WBS: 1.3.1.1.1.1.5.1 Item: Coil Subassy - Off-Site Assembly

Date: 10/17/91 Rev: 00 By: R. Yamamoto

Element Scope: None required.
Technical design description:

Engineering/Design (my): **Rate ($k/my):** **Dur:**
Basis:

Inspection/Admin (my): **Rate ($k/my):** **Dur:**
Basis:

EDIA/QA Material&Services ($k): **Dur:**
Basis:

Procurement/Fabrication ($k): **Dur:**
Basis:

Installation/Ass'y (my): **Rate ($k/my):** **Dur:**

Material ($k):
Basis:

Unit type: **Number of units:**

Estimate Type:

Risk Factors:
Technical:
Cost:
Schedule:

Misc Comments:

Basis of Estimate

WBS: 1.3.1.1.1.1.5.2 Item: Coil Subassy - On-Site Assembly

Date: 11/06/91 Rev: 0B By: R. Yamamoto

Element Scope: This element covers all of the activity required to complete two 15m long coil subassemblies, starting from the basic parts identified in 1.3.1.1.1.1.1-4. This includes all activities required to prepare the coil form for winding, to actually remove the conductor from the storage drum and wind it into final position in the coil form, to install any diagnostics, sensors, or controls, to complete the electrical and fluid connections within the coil subassemblies, and to perform tests as required to verify proper function at this level. This does not include any activity required to install the radiation shields, cold mass supports, or vacuum vessels. Because of the size of the completed coil subassemblies, all assembly takes place on-site at SSCL.

Technical design description: The present concept is to wind the superconductor onto the twenty four (24) coil forms using the fixturing described in the previous WBS sections. Included in this will be the attachment of any diagnostics and the epoxy potting of the conductor onto the coil form itself. Once done, twelve (12) 1.2m long coil forms will be stacked, aligned and bolted together to make one (1) complete coil. Two (2) 15m long coils will be fully assembled and tested at the completion of this activity.

Engineering/Design (my): 0 **Rate** ($k/my): 100 **Dur:** 3/94 -4/95

Basis: Engineering supervision is costed in Inspection/Administration.

Inspection/Admin (my): 3.0 **Rate** ($k/my): 94 **Dur:** 3/94-4/95

Basis: Assume 4mm effort required to place contracts for manpower required and interface with Union shops, etc. ; effort requires one engineer and one lead designer for supervision (2 men)*(14 mo)=28mm; 0.1 FTE (GEM LLNL coordinator) to monitor contracts for duration of procurement and to support small purchases during on-going assembly of the coil = 1.4mm; final inspection of two completed coils will take two people two weeks per coil = 2mm. Total labor is 35.4mm = 3 my. Total cost is $282k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): **Dur:**

Basis:

Procurement/Fabrication ($k): 100 **Dur:** 3/94-4/95

Basis: Most of the large tooling fabrications will have been procured under 1.3.1.1.1.1.4 Winding Tooling; however, additional tooling may be required due to breakage, unanticipated design modifications, etc. In addition, items bought under this WBS will need to be expedited quickly due to schedule constraints and consequently a premium price will have to be paid. Estimate that $100k will be required.

Installation/Ass'y (my): 5.6 **Rate** ($k/my): 45 **Dur:** 3/94-4/95

Material ($k): 1000

Basis: The prevailing concept for coil assembly is as follows:

- Two parallel coil winding stations will be used to wind the superconductor onto the twenty four (24) coil forms. Each station will consist of 1 lead technician, 3 senior technicians and 2 junior technicians: (6 men)*(14 mo.)*(2 stations) = 168mm=14my (it is estimated that each station can wind 3 coils/2mo. and that the time required for a station to set up the winding tooling, clean and prepare the coil forms, be "de-bugged" and up and running is approx. 4-6 mos).

* Stacking, aligning and bolting individual coil forms together after the conductor has been wound will be done in parallel to the winding operation once the production line has begun. This operation includes compressing the conductor into the correct position on the coil form so that epoxy potting of the conductor can commence, joining coil form sections together, splicing conductor ends together at the coil form flange interfaces, electrical checkout of the conductor, vacuum leak checking, etc. The final product will be two complete coils each made up of 12 coil sections. This assembly activity will also have two stations with each station consisting of: 1 lead technician, 2 senior technicians, 1 welder/technician and 2 junior technicians: (6 men)*(14 mo.)*(2 stations) = 168mm=14my. Total labor is 28my but will be using two shifts. Total cost is (2 shifts)*(28my)*($45k/yr) = $2520k; (56my total). Average labor rate is $45k/yr.

* Materials to be purchased include: epoxy, insulating materials, fasteners, vacuum leak detectors, welding machines and glove boxes, brazing areas with ventilation systems, weld rod and associated welding supplies and clothing, small machine and hand tools, cryogen storage dewars, etc. = $1000k.

See note below for comparison to vendor estimates.

Unit type: ea **Number of units:** 2

Estimate Type: BU

Risk Factors:

Technical: 6 Basis: Stiffness of superconductor and winding coil on the inside diameter of the coil form are parameters that require additional investigation and understanding.

Cost: 6 Basis: Labor estimates based on experience on winding both conventional and superconducting magnets.

Schedule: 8 Basis: Item required to continue assembly of the entire detector. ***Critical Path Item.***

Misc Comments:

Two vendor estimates of manpower required for magnet winding and assembly have been obtained, but have not yet been analyzed in detail. These estimates covered all of the activities under WBS 1.3.1.1.1.1.5.2(coil winding), 1.3.1.1.1.8.2(coil assembly), 1.3.1.1.9(coil testing), and 1.3.1.8(installation). The average of the two vendor estimates for the sum of these tasks is 117,000man-hr; assuming, very conservatively, 1760man-hr per man-yr, this is 66.5man-years. The total assembly/installation labor included in this estimate for all four tasks is 56 + 10 + 2.7 + 16.6 = 85.3 man-years, or 28% higher than the vendor estimates.

Basis of Estimate

WBS: 1.3.1.1.1.2.1 Item: LN Thermal Radiation Shields

Date: 11/06/91 Rev: 0A By: R. Yamamoto

Element Scope: This element covers all hardware and activities required to produce the LN-cooled thermal radiation shields. Included in this element are the inner, outer, and end shields and attachment points for mechanical supports. This does not include thermal intercept hardware, shield supports or standard piping and manifolding for LN distribution within the vacuum vessel. Any tooling required to assemble the radiation shield is included.

Technical design description: The present design is shown on drawing AAA91-106407-00; the shield is comprised of an inner and outer 3/16" thick aluminum shell with two 1" end rings on the outer ends to provide mechanical stability to the assembly and also to provide solid attachment points for the mounting hardware. A 1 3/8" square extruded aluminum tube with a 1" I.D. hole serpentines across the length of the shield. LN2 circulates through this tube and provides the cooling medium to maintain the shield at approx. LN2 temperature. Two shields are required, one for each coil and are nominally 62' in diameter and 49' long.

Engineering/Design (my): .23 **Rate** ($k/my): 100 **Dur:** 2/93 -11/94

Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: shield assembly, shield details (5). Total of 6 dwgs @ 1mw/dwg =6mw of design. Engineering support will be half of the design support required = 3mw. GEM engineering will be at 3% level for 22 mo = 3mw. Total labor is 12mw = .23 my. Total cost is $23.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .58 **Rate** ($k/my): 94 **Dur:** 2/93-11/94

Basis: Assume 2mm effort required to place contract after specs written; 0.05 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (22 mo) = 1.0mm; full inspection of two shields plus cooldown acceptance tests = 4mm. Total labor is 7 mm = .58 my. Total cost is $55k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 44 **Dur:** 2/93-11/94

Basis: Assume 1 trip/2 mo by two people to vendor at $2.0k/trip per person for 22 months = $44k

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Procurement/Fabrication ($k): 2000 **Dur:** 2/93-11/94

Basis: Received two vendor estimates ranging from $3000 to $7079k (price includes delivery and assembly of each shield and requires 70 weeks after receipt of final approved plans.) We anticipate welding the annular caps rather than bolting as shown on the drawing estimated and also simplifying the design such that the total cost will be approximately $2000k.

Installation/Ass'y (my): 0 **Rate** ($k/my): 0 **Dur:**

Material ($k): 0

Basis: Assembly of the LN2 radiation shields are done after installation of the cold mass (bobbin) in the vacuum chamber.

Unit type: ea **Number of units:** 2

Estimate Type: BU

Risk Factors:

Technical: 4 Basis: Concern about distortion of thin shell due to welding.

Cost: 3 Basis: Vendor quote based on layout drawing; full details are not shown including the option to make the shield in modular units.

Schedule: 4 Basis: Item not on critical path.

Misc Comments: Cost may decrease significantly by designing shields in a more modular and hence more production efficient manner.

Basis of Estimate

WBS: 1.3.1.1.1.2.2 Item: Superinsulation

Date: 12/11/91 Rev: 0B By: R. Yamamoto

Element Scope: This element covers all of the necessary engineering and associated tasks to specify and procure superinsulation for use as a radiation shield between the superconducting magnet assembly (cold-mass/bobbin) and the LN thermal radiation shields and any tooling required to prepare it for installation or to install it.

Technical design description: The superinsulation will be 1/4 mil (.00025") thick polyester film with one side having a high purity aluminum deposit of approx. 250 angstroms. 60 layers per inch of insulation will be wraped between all LHe cooled surfaces of the superconducting magnet and the LN thermal radiation shield. Total amount of superinsulation required: (60' dia.)*(50' lg.)*(Π)*(60 layers/inch)*(2 layers/coil)*(2 coils)= approx. 2.3 million square feet; for LN2 shielding, 15 layers/inch is required rather than 60 layers/inch = 0.6 million square feet; Total wt: 2.3 + 0.6 = 2.9 million sq. ft. of superinsulation; weight of superinsulation is approx. 581 sq. ft./lb. which equates to approx. 5000 lbs. Nominal roll is 54" wide and 1240 linear ft. per 10 lb roll.

Engineering/Design (my): .08 **Rate ($k/my):** 100 **Dur:** 5/94 -10/94

Basis: Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: overall layout, superinsulation details (3). Total of 4 dwgs @ 1mw/dwg =4mw of design. Total labor is 4mw = .08 my. Total cost is $8.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .04 **Rate ($k/my):** 94 **Dur:** 5/94-10/94

Basis: Assume 0.5mm effort required to place contract after specs written; Total labor is 0.5mm = .04 my. Total cost is $4k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 8 **Dur:** 5/94-10/94

Basis: Assume 1 trip/3 mo by two people to vendor at $2.0k/trip per person for 6 months = $8k

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Procurement/Fabrication ($k): 112 **Dur:** 5/94-10/94

Basis: Phone quote from Metallized Products, Inc. (MPI), Winchester, MA. (Trade name for product is NRC-2 Superinsulation); (5000 lbs.)*($13.25/lb)=$66k; Tooling required includes a support fixture which allows the cold mass (bobbin) to rotate about its longitudinal axis so that the superinsulation can wrap around it = $50k.

$116/k1.0366 (FY '92-'91 de-escalation factor) = $112K

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0

Basis: Wrapping of the superinsulation around the superconducting magnet is done just prior to the assembly of the LN thermal radiation shields around the magnet itself.

Unit type: lbs **Number of units:** 5000

Estimate Type: BU

Risk Factors:

Technical: 1 Basis: Off the shelf catalog item; large quantity required is a potential concern.

Cost: 1 Basis: Standard product

Schedule: 2 Basis: Item not on critical path.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.1.1.2.3 Item: Shield Supports/Thermal Intercepts

Date: 12/11/91 Rev: 0B By: R. Yamamoto

Element Scope: This element covers all LN shield support hardware, not including the cold mass supports. Also included is the hardware required for 80°K thermal intercepts on the cold-mass supports.

Technical design description: The LN shield supports are 1"ø 300 series stainless steel rods which are attached to the weld rings on either end of the LN thermal radiation shield. They are arranged in a radial pattern (similar to the cold mass radial rod supports) which allows for movement of the shield during cooldown yet provides adequate strength to support the weight of the shield. Sixteen rods (16) are used at each end of a LN shield. The thermal intercepts are used as an intermediate 80°k heat sink on the cold mass support rods (both radial and axial rods) and are attached between the cold mass (@4°k) and the inner vacuum vessel wall (@300°k). These intercepts are flexible to allow for thermally induced movement.

Engineering/Design (my): .19 Rate ($k/my): 100 Dur: 11/93 -10/94

Basis: Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: overall layout, LN support rod details (2), Thermal intercept details (2). Total of 5 dwgs @ 1mw/dwg =5mw of design. Engineering support will be half of the required design support = 2.5mw. GEM engineering will be at 5% level for 12mo = 2.5mw. Total labor is 10mw = .19 my. Total cost is $19.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .18 Rate ($k/my): 94 Dur: 11/93-10/94

Basis: Assume 1mm effort required to place contract after specs written; 0.05 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (12mo) = 0.6mm. Spot (10%) inspection of parts = 0.5mm. Total labor is 2.1mm = .18my. Total cost is $17k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 12 Dur: 11/93-10/94

Basis: Assume 1 trip/4 mo by two people to vendor at $2.0k/trip per person for 12 months = $12k

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Procurement/Fabrication ($k): 172 Dur: 11/93-10/94

Basis: Cost for 1"ø stainless steel LN shield support rods scaled from WBS 1.3.1.1.1.4.1 Cold Mass Supports - Radial Rods:

	FACTOR Titanium	Stainless Steel	
Density	1	2	stainless twice as dense as titanium
Cost per lb	3	1	Titanium three times as expensive
Area	16	1	Ti rods have sixteen times the area

(1*3*16)/(2*1*1)=24 . . . a 1"ø stainless rod is twenty four times less expensive than a 4"ø titanium rod of identical length. $1376/24 = $57k ($0.9k each)

Thermal intercepts required are: 64 (radial rods) + 64 (axial rods) = 128; estimate that each thermal intercept costs the same as a LN shield support rod = (128)*($0.9k)=$115k. Total: $57+ $115 = $172k.

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0

Basis: Assembly of LN thermal radiation shield support rods and thermal intercepts done at installation of the LN shield to the cold mass(bobbin).

Unit type: ea. **Number of units:** 64/128

Estimate Type: EO

Risk Factors:

Technical: 2 Basis: Design similar to supports used in MFTFB.

Cost: 1 Basis: Stainless steel fabrication techniques well understood

Schedule: 2 Basis: Item not on critical path.

Misc Comments: LN thermal radiation shield support design may change significantly to allow for a much simpler type of support system and consequently reduce cost . . . additional concepts will be investigated.

Basis of Estimate

WBS: 1.3.1.1.1.3.1 Item: Vessel weldment

Date: 11/4/91 Rev: 00 By: J. Bowers

Element Scope: This element includes the inner and outer vacuum vessel as well as any stiffening hardware required to withstand vacuum and magnetic loads. It also includes attachment points for the cold-mass supports and muon detectors.

Technical design description: Reference drawing AAA91-106403.
The Vessel Weldment is an annular vacuum vessel consisting of a low carbon steel stiffened external vessel and an stainless steel inner vessel. The inner and outer vessels are connected at the ends with annular plates. The annular space between the inner and outer vessels is evacuated and provides foundations for the cold mass. The complete vessel assembly consists of two identical and independent vessel halves joined end to end at the detector midplane. The central detector support structure (WBS1.3.1.1.3.1) is held by the outer vessel midplane stiffening ring. The total weight of the vessel weldment (both vessel halves) is about 1600 tons.

Each outer shell is constructed from 25 rolled shell sections weighing about 17 tons each. Outer wall thickness is two inches, stiffened by three outer rings. Eight longitudinal stiffeners resist the axial magnetic loads in the shell.

Each inner shell is constructed from 20 rolled shell sections weighing about 9 tons each. Inner wall thickness is one inch, with no stiffeners.

Ports are provided for pretensioning access to radial and axial cold mass supports, rough vacuum pumping, electrical penetrations, and cryogenic penetrations.

Engineering/Design (my): 1.75 Rate ($k/my): 100 Dur: 9/92-9/93
Basis: Detail design will be contracted to a vendor per a design specification.

drawing estimates:
assembly: 1
weldment: 1, 5 sheets
shop/fab drawings: 20

total time: .25 MY

engineering analysis/design: 0.5 MY

fabrication planning: 1 MY

Inspection/Admin (my): 1.9 Rate ($k/my): 94 Dur: 9/92 - 1/95
Basis:

contract administration to place order	2 mm
leak checking personnel	4 mm
vendor qualification	1 mm
on site and off site inspections	4 mm
Administrative overhead	6 mm
coordinator support during fabrication	6 mm

total 23mm = 1.9 my

<u>EDIA/QA Material&Services</u> ($k): <u>204</u> Dur: <u>1/92 - 1/95</u>
Basis:1.5 trip/month x 36 month x 2.5k/trip = $135k
weld inspection QA time (visual and dye pen) 2 inspectors x 4 months = 8 mm
@ $103k/ year = $69k

<u>Procurement/Fabrication</u> ($k): 7006 Dur: <u>1/93 - 1/95</u>
Basis: (per vessel half)
raw materials
620 tons A516 grade 70 in finished vessel
add 8% waste for drops and machining giving 670 tons of raw material
mill rate = $0.36/ lb (including ultrasound testing) yielding $482K

171 tons 304L in finished vessel
add 8% waste for drops and machining giving 185 tons of raw material
mill rate = $2.25/ lb (including ultrasound testing) yielding $833K

total number of sheets per vessel half = 107
20 inner vessel sheets
25 outer vessel sheets
3 rings x 5 sections each = 15 outer ring flange sheets
3 rings x 5 sections each = 15 outer ring web sheets
8 beam flanges x 2 sections each = 16 beam flange sheets
8 beam webs x 2 sections each = 16 beam web sheets

Finishing cost to yield 250 RMS finish on raw material
= $3100/sheet x 107 sheets = $332K

Bead blasting stainless steel to matte finish
= $2000/sheet x 20 sheets = $40k

weld material cost is included in welding cost

welding cost = 10000 lb weld/ 10 lb/hour * $100/hour = $100k

weld fixturing and alignment
8 hours per part, 4 riggers+ 1 crane operator = $500/hour, 100 ton crane cost $250/hour, $750/ hour x 8 hours/part x 107 parts = $642K

transportation $2500/load x 60 loads x 2 trips = $300k

plate section rolling 3 days/ section, $2400/ section x 45 sections = $108k

rolled plate weld prep machining 4 days/section, $3200/section x 45 sections = $144k

ring rolling 3 days/section, $2400/section x 15 sections = $36k

web section burning 2 days/section, $1600/section x 15 sections = $24k burn ports 4 hours/port, $400/port x 48 rod access ports = $19k

machine ports 12 hours/port, $1200/port x 48 ports = $58k

machine port covers $58k

cold mass connections machining 4 hours/ padeye, $400/padeye x 64 padeyes = $27k

scaffolding $50k

painting low carbon steel shell $50k

other rigging and handling (stacking, unloading, etc) $200k

cost per vessel half = $3503k

total cost = $7006k

Installation/Ass'y (my): 0 **Rate ($k/my):** 48 **Dur:** 10/91-10/91

Material ($k):

Basis: This is covered in WBS 1.3.1.8.1 Magnet Installation

Unit type: ea **Number of units:** 2

Estimate Type: BU

Risk Factors:

Technical: 4 Basis: Fabrication techniques are standard. Assembly techniques not yet defined. Vessel is engineered using standard vessel construction technology and common materials.

Cost: 4 Basis: Vendor quotes and LLNL experience constructing large vessels. Mill costs for steel will vary based on the state of the national economy at the time of construction. Variation can be 50%.

Schedule: 4 Basis: Outdoor construction may be affected by weather. Mill schedule will depend on state of economy. Fabrication is based on vendor estimates. Outer shell is probably on critical path.

Misc Comments:

Number of ports can vary depending on cold mass support design and number of feedthroughs. This will change machining costs.

Basis of Estimate

WBS: 1.3.1.1.1.3.2 Item: Vessel Support Saddles
Date: 10/16/91 Rev: 00 By: J. Bowers

Element Scope: This element includes all of the hardware required to physically support the coil assemblies in the underground hall. This will include the saddles to support the outer vessel as well as any jacking hardware provided to align the magnet or to compensate for ground motion. This does not include any concrete structures, such as piers or support beams, which are assumed to be part of the hall facility.

Technical design description:
The saddle support structure is a low carbon steel weldment consisting of large flat plate sections. Three saddles are provided to support the complete vessel assembly, including the magnet and all internal detectors. Total weight supported by the three saddles is about 6800 tons.

The center saddle structure, located under the midplane of the central detector, supports about 75% of the total vessel assembly weight, and interfaces with the vessel at the center support ring. The vessel assembly is anchored at the center saddle, and is free to change dimensionally (due to thermal excursions) using rollers under the end saddles.

All three saddles can be hydraulically jacked to align the vessel system to compensate for foundation settling. The jacking system will be capable of lifting the weight of the vessel system plus the saddles, and have sufficient control to enable pitch, roll and elevation positioning.

Interface to the building foundation is through shims and embedded studs at the center saddle location. The end saddles interface through large Hilman type rollers on embedded case hardened steel plates.

Weight of the center saddle is 56 tons. Weight of each end saddle is 39 tons.

Engineering/Design (my): 1 **Rate** **($k/my):** 100 **Dur:** 9/92-9/93
Basis: Detail design will be contracted to a vendor per a design specification.

drawing estimates:
assembly: 1
weldment: 3 sheets x 2 weldments = 6 sheets
hydraulic system: 10 sheets
shop/fab drawings: 30

total time: .5 MY

fabrication planning: .5 MY

Inspection/Admin (my): 1.25 **Rate** **($k/my):** 94 **Dur:** 9/92-1/94
Basis:

contract administration to place order	2 mm
vendor qualification	1 mm
on site and off site inspections	4 mm

Administrative overhead 2 mm
coordinator support during construction 6 mm

total 15mm = 1.25 my

EDIA/QA Material&Services **($k):** 107 **Dur:** 6/92-6/94
Basis:
1 trip/month x 24 month x 2.5k/trip = $60k
weld inspection QA time 2 inspectors x 3 months = 6 mm
@ $94k/ year = $47k

Procurement/Fabrication **($k):** 668 **Dur:** 10/92-10/93
Basis:
raw materials
134 tons A36 in finished vessel
add 8% waste giving 145 tons of raw material
mill rate = $0.36/ lb yielding $104K

weld material cost is included in welding cost

transportation $2500/load x 8 loads = $20k

plate section burning 0.5 days/ section, $600/ section x 150 sections = $90k

machine base plate 10 days/ saddle x 3 saddles = 30 days = $24k

weld fixturing and alignment $60k

welding $40k

scaffolding $20k

painting $60k

rigging $50k

total weldment cost = $468k

Cost of hydraulic jacking system $200k

Installation/Ass'y **(my):** 0 **Rate ($k/my):** 48 **Dur:** 10/91-10/91
Material ($k): 0
Basis:
This is covered in WBS 1.3.1.8.1 Magnet Installation

Unit type: ea **Number of units:** 3
Estimate Type: BU

Risk Factors:

Technical: 3 Basis: Fabrication techniques are standard. Simple shapes and interfaces. Loose tolerances. Common materials.
Cost: 3 Basis: Vendor quotes on hydraulics and bottom up construction factorsfor structural assemblies. Mill costs for steel will vary based on the state of the national economy at the time of construction.
Schedule: 2 Basis: If built in sections off site, will have minimal inpact on vessel installation schedule.

Misc Comments:
Interface to foundation not thoroughly defined. Thermal expansion of vessel assembly not analyzed.

Extent of foundation settling unknown. It is suggested the vessel halves should be allowed to settle independantly upon installation for some period such as a month, after which they would be aligned and welded together. This may have certain schedule impacts which are yet to be defined.

The saddle weldments need to be studied to minimize on site construction. Parting lines for prefabbed sections will have to be studied to maximize shipping efficency.

Basis of Estimate

WBS: 1.3.1.1.1.4.1 Item: Cold Mass Supports - Radial Rods
Date: 12/11/91 Rev: 0B By: R. Yamamoto

Element Scope: This element includes all of the cold-mass supports which will support the weight of the cold mass in final position in the underground hall. This element does not include the attachment points on the cold mass, LN shields, or vacuum vessels; it also does not include thermal intercept hardware.
Technical design description: The present design is shown on drawing AAA91-106406-00 tab 01; material is titanium 6Al-4V; support rod diameter is 4"; overall rod length is 127".

Engineering/Design (my): .19 Rate ($k/my): 100 Dur: 3/93 -10/94
Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: overall layout, rod assembly, rod details (4). Total of 6 dwgs @ 1mw/dwg =6mw of design. Engineering support will be 2mw. GEM engineering will be at 2% level for 20 mo = 2mw. Total labor is 10mw = .19 my. Total cost is $19.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .42 Rate ($k/my): 94 Dur: 3/93-10/94
Basis: Assume 1mm effort required to place contract after specs written; 0.05 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (20 mo) = 1mm; full inspection of part including non-destructive testing @ 1md/part * 64 parts = 64 md (3mm). Total labor is 5 mm = .42 my. Total cost is $39.5k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 20 Dur: 3/93-10/94
Basis: Assume 1 trip/4 mo to vendor by two people at $2.0 k/trip per person for 20 months = $20k

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Procurement/Fabrication ($k): 849 Dur: 3/93-10/94
Basis: Vendor estimates range from $880 to $1376k (includes material cost).

$880k /1.0366 (FY '92-'91 de-escalation factor) = $849K

Installation/Ass'y (my): 0 Rate ($k/my): 0 Dur:
Material ($k): 0
Basis: Assembly of cold mass supports done at installation of the cold mass (bobbin) in the vacuum chamber.

Unit type: ea **Number of units:** 64
Estimate Type: BU

Risk Factors:

Technical: 3 Basis: Design similar to supports used in MFTFB.
Cost: 3 Basis: Vendor quote on good drawing; likely modifications will not change cost significantly.
Schedule: 2 Basis: Item not on critical path.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.1.1.4.2 Item: Cold Mass Supports - Axial Rods

Date: 12/11/91 Rev: 0B By: R. Yamamoto

Element Scope: This element includes all of the cold-mass supports which will support the axial magnetic forces on the cold mass in final position in the underground hall. This element does not include the attachment points on the cold mass, LN shields, or vacuum vessels; it also does not include thermal intercept hardware.
Technical design description: The present design is shown on drawing AAA91-106406-00 tab 02; material is titanium 6Al-4V; support rod diameter is 4"; overall rod length is 282".

Engineering/Design (my): .19 **Rate ($k/my):** 100 **Dur:** 3/93 -10/94
Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: overall layout, rod assembly, rod details (4). Total of 6 dwgs @ 1mw/dwg =6mw of design. Engineering support will be 2mw. GEM engineering will be at 2% level for 20 mo = 2mw. Total labor is 10mw = .19 my. Total cost is $19.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .29 **Rate ($k/my):** 94 **Dur:** 3/93-10/94
Basis: Assume 1mm effort required to place contract after specs written; 0.05 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (20 mo) = 1mm; full inspection of part including non-destructive testing @ 1md/part * 32parts = 64 md (1.5mm). Total labor is 3.5 mm = .29 my. Total cost is $27k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 20 **Dur:** 3/93-10/94
Basis: Assume 1 trip/4 mo to vendor by two people at $2.0k/trip per person for 20 months = $20k

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Procurement/Fabrication ($k): 631 **Dur:** 3/93-10/94
Basis: Vendor estimates range from $1307 to $1728k (includes material cost). We believe that only 32 and not 64 rods are required, reducing the cost from $1307k to $654k.

$654k /1.0366 (FY '92-'91 de-escalation factor) = $631K

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0
Basis: Assembly of cold mass supports done at installation of the cold mass (bobbin) in the vacuum chamber.

Unit type: ea **Number of units:** 32

Estimate Type: BU

Risk Factors:
Technical: 3 Basis: May be able to simplify design concept;
Cost: 3 Basis: Vendor quote on good drawing; likely modifications will not change cost significantly.
Schedule: 2 Basis: Item not on critical path.

Misc Comments: Alternative design utilizing compression mounts (i.e. Heim columns) is being pursued; heat leak + ability to move during cooldown are outstanding issues; proposed materials are NEMA G-10 and aluminum.

Basis of Estimate

WBS: 1.3.1.1.1.5.1 Item: Internal Cryo Sys - LN Piping & Dist

Date: 11/06/91 Rev: 0A By: R. Yamamoto

Element Scope: This element includes all of the in-vessel LN distribution piping which is not actually mounted on the radiation shields. It also includes the LN feedthroughs through the vacuum vessel wall. It does not include any external LN piping.
Technical design description: All LN piping will be vacuum insulated with pump-out ports provided at discrete intervals.

Engineering/Design (my): .15 **Rate ($k/my):** 100 **Dur:** 4/94-9/94
Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: details of bayonet placement on coil subassemblies, details of transfer line routing, details of custom fixtures/hardware required for installation (2). Total of 4 dwgs @ 1mw/dwg =4mw of design. Engineering support will be half of the required design support = 2mw. GEM engineering will be at 8% level for 6mo = 2mw. Total labor is 8mw = .15 my. Total cost is $15.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .07 **Rate ($k/my):** 94 **Dur:** 4/94-9/94
Basis: Assume 0.5mm effort required to place contract after specs written; 0.05 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (6 mo) = .3mm; Total labor is 0.8mm = .07 my. Total cost is $7k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 8 **Dur:** 4/94-9/94
Basis: Assume 2 trips by two people to vendor at $2.0k/trip = $8k

---

Procurement/Fabrication ($k): 7.2 **Dur:** 4/94-9/94
Basis: Assume cost of transfer line is approx. $130/linear ft.:($130/ft)*(10ft/bayonet)*(4 bayonets)=$5.2k; One (1) pair of LN2 bayonets cost approx. $2k. Total cost:$7.2k

---

Installation/Ass'y (my): 0 **Rate ($k/my):** **Dur:**

Material ($k): 0
Basis: Installation will be done under 1.3.1.1.1.8.2 On-site Coil Assembly.

Unit type: pairs **Number of units:** 2

Estimate Type: BU

Risk Factors:
Technical: 2 Basis: Minor modifications to an existing design.
Cost: 4 Basis: In-house estimate for item within current product line.
Schedule: 2 Basis: Delays completion of non-critical path subsystem item.

Basis of Estimate

WBS: 1.3.1.1.1.5.2 Item: Intrnl Cryo Sys - LHe Thermosyphon

Date: 11/06/91 Rev: 0A By: R. Yamamoto

Element Scope: This element includes all of the in-vessel piping and manifolding required for the LHe thermosyphon system which cools the coil form. It includes only the hardware which is not mounted physically on the coil form. Feed-throughs through the vacuum vessel are included.

Technical design description: All LHe piping will be vacuum insulated with pump-out ports provided at discrete intervals.

Engineering/Design (my): .15 **Rate ($k/my):** 100 **Dur:** 4/94-9/94

Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: details of bayonet placement on coil subassemblies, details of transfer line routing, details of custom fixtures/hardware required for installation (4). Total of 4 dwgs @ 1mw/dwg =4mw of design. Engineering support will be half of the required design support = 2mw. GEM engineering will be at 8% level for 6mo = 2mw. Total labor is 8mw = .15 my. Total cost is $15.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .07 **Rate ($k/my):** 94 **Dur:** 4/94-9/94

Basis: Assume 0.5mm effort required to place contract after specs written; 0.05 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (6 mo) = .3mm; Total labor is 0.8mm = .07 my. Total cost is $7k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 8 **Dur:** 4/94-9/94

Basis: Assume 2 trips by two people to vendor at $2.0k/trip = $8k

---

Procurement/Fabrication ($k): 8 **Dur:** 4/94-9/94

Basis: Assume cost of transfer line is approx. $150/linear ft.:($150/ft)*(10ft/bayonet)*(4 bayonets)=$6k; One (1) pair of LHe bayonets cost approx. $2k. Total cost:$8k

---

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0

Basis: Installation will be done under 1.3.1.1.1.8.2 On-site Coil Assembly.

Unit type: pairs **Number of units:** 2

Estimate Type: BU

Risk Factors:

Technical: 2 Basis: Minor modifications to an existing design.

Cost: 4 Basis: In-house estimate for item within current product line.

Schedule: 2 Basis: Delays completion of non-critical path subsystem item.

Basis of Estimate

WBS: 1.3.1.1.1.5.3 Item: Intrnl Cryo Sys - LHe Forced-Flow

Date: 11/06/91 Rev: 0A By: R. Yamamoto

Element Scope: This element includes all of the in-vessel piping and manifolding required for the forced-flow LHe loop, including vacuum feed-throughs.
Technical design description: All LHe piping will be vacuum insulated with pump-out ports provided at discrete intervals.

Engineering/Design (my): .15 Rate ($k/my): 100 Dur: 4/94-9/94
Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: details of bayonet placement on coil subassemblies, details of transfer line routing, details of custom fixtures/hardware required for installation (2). Total of 4 dwgs @ 1mw/dwg =4mw of design. Engineering support will be half of the required design support = 2mw. GEM engineering will be at 8% level for 6mo = 2mw. Total labor is 8mw = .15 my. Total cost is $15.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .07 Rate ($k/my): 94 Dur: 4/94-9/94
Basis: Assume 0.5mm effort required to place contract after specs written; 0.05 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (6 mo) = .3mm; Total labor is 0.8mm = .07 my. Total cost is $7k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 8 Dur: 4/94-9/94
Basis: Assume 2 trips by two people to vendor at $2.0k/trip = $8k

---

Procurement/Fabrication ($k): 8 Dur: 4/94-9/94
Basis: assume cost of transfer line is approx. $150/linear ft.:($150/ft)*(10ft/bayonet)*(4 bayonets)=$6k; One (1) pair of LHe bayonets cost approx. $2k. Total cost:$8k

---

Installation/Ass'y (my): 0 Rate ($k/my): 0 Dur:

Material ($k): 0
Basis: Installation will be done under 1.3.1.1.1.8.2 On-site Coil Assembly.

Unit type: pairs **Number of units:** 2

Estimate Type: BU

Risk Factors:

Technical:	3	Basis: Minor modifications to an existing design.
Cost:	4	Basis: In-house estimate for item within current product line.
Schedule:	2	Basis: Delays completion of non-critical path subsystem item.

Basis of Estimate

WBS: 1.3.1.1.1.6 Item: Cryogenic Current Leads

Date: 12/11/91 Rev: 0B By: R. Yamamoto

Element Scope: This element covers the current leads which are installed after the coil is assembled into the vacuum vessel, and which are at cryogenic temperature. It does not include the warm current busses which are external to the vacuum vessel.
Technical design description: Current leads are rated for 50 kilo-amps. Two (2) pairs are required.

Engineering/Design (my): .25 **Rate ($k/my):** 100 **Dur:** 9/94-2/95
Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: Assembly drawing of leads, detail drawings (7). Total of 8 dwgs @ 1mw/dwg =8mw of design. Engineering support will half of the required design support = 4mw. GEM engineering will be at 5% level for 6mo = 1mw. Total labor is 13mw = .25 my. Total cost is $25.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .07 **Rate ($k/my):** 94 **Dur:** 9/94-2/95
Basis: Assume 0.5mm effort required to place contract after specs written; 0.05 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (6 mo) = .3mm; Total labor is 0.8mm = .07 my. Total cost is $7k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 4 **Dur:** 9/94-2/95
Basis: Assume 1 trip by two people to vendor at $2.0k/trip = $4k

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Procurement/Fabrication ($k): 100 **Dur:** 9/94-2/95
Basis: Cost scaled from purchase of 5 kiloamp current leads @ $5k/pr.
50 kiloamp leads=$50k; Two (2) pairs = ($50k)*(2 pairs)=$100k.

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0
Basis: Assembly will be done at on-site assembly of the Coil Subassembly.

Unit type: pair **Number of units:** 2

Estimate Type: SA

Risk Factors:
Technical: 2 Basis: Minor modifications to an existing design.
Cost: 4 Basis: In-house estimate for item within current product line.
Schedule: 2 Basis: Delays completion of non-critical path subsystem item.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.1.1.7 Item: Assembly and Testing Equipment

Date: 12/11/91 Rev: 0B By: R. Yamamoto

Element Scope: This element covers all of the hardware required to assemble the wound coil subassembly into the radiation shields and vacuum vessel, make up all internal electrical and fluids connections, verify all connections, rotate the assembly into its final orientation, and perform all checks prior to installation in the underground hall. It does not include provision for testing the coil assemblies at LHe temperature, or under significant current. It does include provision of leak hunting equipment and LN as required for thermal-shock testing. It also includes any temporary supports for the assemblies (other than those to be used for permanent installation in the underground hall).

Technical design description:

Engineering/Design (my): .62 **Rate ($k/my):** 100 **Dur:** 11/94-10/95

Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: details of major fixture subassemblies (4), details of jigs/fixtures required for leak checking (4), details of custom fixtures/hardware required for installation (10). Total of 18 dwgs @ 1mw/dwg =18mw of design. Engineering support will be half of the required design support = 9mw. GEM engineering will be at 10% level for 12mo = 5mw. Total labor is 32mw = .62 my. Total cost is $62.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .18 **Rate ($k/my):** 94 **Dur:** 11/94-10/95

Basis: Assume 1mm effort required to place contract after specs written; 0.1 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (12 mo) = 1.2mm; Total labor is 2.2mm = .18 my. Total cost is $17k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 20 **Dur:** 11/94-10/95

Basis: Assume 5 trips by two people to vendor at $2.0k/trip = $20k

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Procurement/Fabrication ($k): 350 **Dur:** 11/94-10/95

Basis: Cost of custom fixtures/hardware + vacuum leak checking equipment + non-destructive leak checking equipment is estimated to be $350k.

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0

Basis: Assembly will be done at on-site coil assembly.

Unit type: ea **Number of units:** 1

Estimate Type: EO

Risk Factors:

Technical: 4 Basis: New design within established product line.

Cost:	6	Basis: In-house estimate for item within current product line.
Schedule:	4	Basis: Delays completion of non-critical path subsystem item.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.1.1.8.1 Item: Off-Site Assembly

Date: 10/18/91 Rev: 00 By: R. Yamamoto

Element Scope: None required.
Technical design description:

Engineering/Design (my): Rate ($k/my): Dur:
Basis:

Inspection/Admin (my): Rate ($k/my): Dur:
Basis:

EDIA/QA Material&Services ($k): Dur:
Basis:

Procurement/Fabrication ($k): Dur:
Basis:

Installation/Ass'y (my): Rate ($k/my): Dur:

Material ($k):
Basis:

Unit type: Number of units:

Estimate Type:

Risk Factors:
Technical:
Cost:
Schedule:

Misc Comments:

Basis of Estimate

WBS: 1.3.1.1.1.8.2 Item: On-site Assembly

Date: 11/06/91 Rev: 0B By: G. Deis/J. Bowers/R. Yamamoto

Element Scope: All assembly activities outlined in 1.3.1.1.1.8 are included in this element: This element covers all of the activities necessary to assemble complete coil assemblies, ready for installation into the underground hall. It includes final assembly of the coil subassembly into the radiation shields and vacuum vessels, installation of the cold-mass supports, installation of all in-vessel cryogenic distribution hardware, final make-up of all diagnostic, control and current connections within the vacuum vessel, closure of the vacuum vessel, vacuum and helium leak hunting, and rotation of the assembly into final orientation. It does not include any testing activities under cryogenic conditions or to significant current. Due to the sizes involved, all assembly will be on-site at SSCL.

Technical design description:

Engineering/Design (my): 1.1 **Rate ($k/my):** 100 **Dur:** 5/95-10/95

Basis: Assembly will be supervised by GEM staff. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: overall building layouts, major subassembly layouts/details, details of cable routing , details of custom fixtures/hardware required for assembly, etc. Total of 25 dwgs @ 1mw/dwg =25mw of design. Engineering support will also be 25mw. GEM engineering will be at 25% level for 6mo = 7mw. Total labor is 57mw = 1.1 my. Total cost is $110k. Average labor rate is $100k/yr.

Inspection/Admin (my): .63 **Rate ($k/my):** 94 **Dur:** 5/95-10/95

Basis: Assume 1mm effort required to place contract after specs written; 0.25 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (6 mo) = 1.5mm; supervision labor is 8.7% of $451k labor dollars = $39k. Total labor is 2.5mm = .21 my. Total cost is $20k + $39k = $59k . Average labor rate is $94k/yr. ($59k/$94k=.63my)

EDIA/QA Material&Services ($k): 40 **Dur:** 5/95-10/95

Basis: Assume 10 trips by two people to vendors at $2.0k/trip = $40k

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Procurement/Fabrication ($k): 0 **Dur:** 5/95-10/95

Basis: Assume cost of custom fixtures/hardware and misc. items already accounted for in 1.3.1.1.1.7 Assembly and Test Equipment.

Installation/Ass'y (my): 10.04 **Rate ($k/my):** 45 **Dur:** 5/95-10/95

Material ($k): 100

Basis: The following items are the basis for this estimate:

1) Manifolds: 24 ea. LHe forced flow connections - "T" weld, 1"ø stainless steel.
48 ea. LHe thermosyphon - 1"ø aluminum weld to header.
2 ea. in/out manifold/bayonets.

Weld: (74 welds)*(2 welds/day)=37md + 25% for QA=46md=	.18my
Leak hunt and repair=1mm=	.08my
Pipe fitting=37md=	.14my

Total: .40my

2) Multi-layer Insulation: wrapped on vertical axis; 12 rolls high by 60 turns + taping, etc. (12 men)*(60 turns/4 turns per hour) *(50% efficiency)= 360mh= .17my

Set-up: (5 men)*(1 weeks)=5mw= .10my

Total: (.27my)*(2 for inner/outer surfaces of bobbin) .54my

3) Install axial supports: (16 rods)*(2 ends)=32 rods

(4 men)*(2 weeks)=8mw= .15my

4) Install thermal radiation shield:

(4 men)*(3 weeks)=12mw= .23my

5) Install bayonets: 4 LN (alum)+ 8 LHe (stainless)=12 welds

4mw to weld + 2 mw to leak check = 6mw= .12my

6) Multi-layer Insulation for thermal radiation shields: .14my

15 layers vs. 60 layers is .25 times .54my = .14my

7) Install radial rods: (16 rods)*(2 ends)=32 rods

(4 men)*(3 weeks)=12mw= .17my

8) Lift/Lower bobbin/thermal shield subassembly into the vessel:

(6 men)*(2 weeks)=12mw= .23my

9) Make-up axial and radial supports in vacuum vessel/insulate with MLI

(4 men)*(2 weeks)=8mw= .15my

10) Close (weld) vessel and leak check (one end only):

(4 men)*(1 mo)=4mm= .33my

11) Complete torque settings on cold mass supports (64 rods):

(4 men)*(64 rods/4 rods per day)=64md= .25my

12) Rotate vacuum vessel:

(6 men)*(2 weeks)=12mw= .23my

13) Complete lead installation and leak check:

Vapor cooled leads: (4 men)*(2 mo)=8mm

Cryo:(9 men)*(1 mo)=9mm

Misc. diagnostics: (2 men)*(2 mo)=4mm

Misc. clean-up:(2 men)*(2 mo)=4mm

Total: 8+9+4+4=25mm= 2.08my

TOTAL: 5.02my

(5.02my)*($45k/yr)*(2 assemblies)=$451k. Average labor rate:$45k/yr.
Total of 10.04 man-years.

See note below for comparison with vendor estimates.

Unit type: ea **Number of units:** 2

Estimate Type: BU

Risk Factors:

Technical: 8 Basis: Concepts of how to assemble this complex system is still being developed; additional understanding and system definition is required to arrive at a more detailed and better understood estimate.

Cost: 8 Basis: In-house estimate for item with minimal company experience with the assembly of such a large structure.

Schedule: 8 Basis: Delays completion of critical path subsystem item.

Misc Comments:

Two vendor estimates of manpower required for magnet winding and assembly have been obtained, but have not yet been analyzed in detail. These estimates covered all of the activities under WBS 1.3.1.1.1.1.5.2(coil winding), 1.3.1.1.1.8.2(coil assembly), 1.3.1.1.9(coil testing), and 1.3.1.8(installation). The average of the two vendor estimates for the sum of these tasks is 117,000man-hr; assuming, very conservatively, 1760man-hr per man-yr, this is 66.5man-years. The total assembly/installation labor included in this estimate for all four tasks is 56 + 10 + 2.7 + 16.6 = 85.3 man-years, or 28% higher than the vendor estimates.

Basis of Estimate

WBS: 1.3.1.1.1.9 Item: Testing

Date: 12/11/91 Rev: OC By: R. Yamamoto/G. Deis

Element Scope: This element covers all "acceptance" testing of the coil assemblies in the above-ground area, prior to their installation in the underground hall. At present, this element includes only a cool-down test to LN temperature for all cryogenic lines in the coil assemblies (including radiation shields). No testing under superconducting conditions or with LHe is planned, and no significant current will be used in these tests.
Technical design description: Test sequence: 1) pump down and leak check; 2) pressurize all helium passages and leak check; 3) cool to LN temp and leak check. Assume that all passages are filled with LN to cool them down.

Engineering/Design (my): .38 **Rate ($k/my):** 100 **Dur:** 4/93-4/94
Basis: Assume that temporary cryogenics will require 10 new drawings, and just as much engineering, for a total of 20mw. Use standard labor rate

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Inspection/Admin (my): .25 **Rate ($k/my):** 94 **Dur:** 4/93-1/95
Basis: Relatively light effort here, except for coordination of cryogenics system and supplies. Assume 1mm coordination, plus 0.5 FTE during testing (4mo). Total is 0.25my; assume standard rate

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EDIA/QA Material&Services ($k): 8 **Dur:** 4/93-1/95
Basis: Assume 4 trips at 2k.

Procurement/Fabrication ($k): 300 **Dur:** 4/93-1/95
Basis: Assume we need to purchase leak detectors, vacuum pumps, and some special piping and distribution for this test. This could easily be $300k, including LN supply.

Installation/Ass'y (my): 2.7 **Rate ($k/my):** 43 **Dur:** 1/95-1/96

Material ($k): 32
Basis: Assume testing each half takes 2mo, with an average crew of 8. Total effort is 2.7my. Supplies will be $1k/fte-mo, or $32k

See note below for comparison with vendor estimates.

Unit type: ea **Number of units:** 2

Estimate Type: EO

Risk Factors:
Technical: 8 Basis: Technical requirements are not well-understood
Cost: 1 Basis: Catalog item for most parts; simple fabrication for required hardware.
Schedule: 8 Basis: On the critical path for subsystem and entire detector.

Misc Comments:
Two vendor estimates of manpower required for magnet winding and assembly have been obtained, but have not yet been analyzed in detail. These estimates covered all of the activities under WBS 1.3.1.1.1.1.5.2(coil winding), 1.3.1.1.1.8.2(coil assembly), 1.3.1.1.9(coil testing), and 1.3.1.8(installation). The average of the two vendor estimates for the sum of these tasks is 117,000man-hr; assuming, very conservatively, 1760man-hr per man-yr, this is 66.5man-years. The total assembly/installation labor included in this estimate for all four tasks is 56 + 10 + 2.7 + 16.6 = 85.3 man-years, or 28% higher than the vendor estimates.

Basis of Estimate

WBS: 1.3.1.1.2.1 Item: End Pole Subassemblies

Date: 12/11/91 Rev: 0B By: J. Bowers

Element Scope: This element include the magnetic steel end poles themselves, and does not include the structure required to support their weight or move them in the underground hall.

Technical design description:
The end pole subassemblies are large cast steel plate sections keyed or fastened to the end pole support structure.

A lower grade steel such as 1020 will be used.

total weight of pole material for this WBS = 2300 tons

Engineering/Design (my): .8 Rate ($k/my): 100 Dur: 3/93-3/94
Basis: Detail design will be contracted to a vendor per a design specification.

drawing estimates:
casting: 1 sheet
shop/fab drawings: 1

total time: .1 MY

engineering analysis: .5 MY

fabrication planning: .2 MY

Inspection/Admin (my): 0.9 Rate ($k/my): 94 Dur: 3/93-12/95
Basis:

contract administration to place order	2 mm
vendor qualification	1 mm
on site and off site inspections	1 mm
Administrative overhead	2 mm
coordinator support during construction	3 mm

total 11 mm = 0.9 my

EDIA/QA Material&Services ($k): 109 Dur: 9/94-12/95
Basis:
.5 trip/month x 12 months x 2.5k/trip = $15k
inspection QA 12 mm @ $94k/ year = $94k

Procurement/Fabrication ($k): 9865 Dur: 9/94-12/95
Basis:
raw materials
4600 tons cast steel

@$1.00/ lb   yielding $9200K
(note that the end pole weighs 3000 tons, 700 of which are in 1.3.1.1.2.1)

transportation $2500/load x 115 loads = $288k
rigging time to off load and store material = 2 hours/load x 115 loads x $750/hour = $172k

extra machining 2 days/ section, $1600/ section x 128 sections = $205k

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Installation/Ass'y **(my):** 0   **Rate ($k/my):** 48   **Dur:** 10/91-10/91

Material ($k): 0

Basis:

Unit type: ea   **Number of units:** 2

Estimate Type: EO

Risk Factors:

Technical:	2	Castings are relatively simple shapes.
Cost:	4	Basis: Cost per pound. Can vary greatly depending on mill supply and demand.
Schedule:	2	Basis: Many unknowns

Misc Comments:

More thorough analysis and design required. Vendors suggest less expensive materials may be suitable. Newer pole designs are all significantly less massive (this design is conservative)

Basis of Estimate

WBS: 1.3.1.1.2.2 Item: End Pole Support subassemblies
Date: 12/11/91 Rev: 0B By: J. Bowers

Element Scope: This element covers the structures which support the weight of the end poles, and move the end poles axially to allow access inside the detector.

Technical design description:
The end pole support is a cast or fabricated frame assembly which must withstand dead loads plus magnet forces applied parallel to the beam line of sight. The transport system is a rail mounted undercarriage, drive system, and space frame which supports the frame. The end pole support interfaces the vessel weldment at hard spots which correspond to longitudinal stiffeners on the outer shell. Total supported weight for each end pole is about 3000 tons. Total weight of end pole support frame (both ends) is about 700 tons.

Engineering/Design (my): 3.5 **Rate ($k/my):** 100 **Dur:** 3/93-3/94
Basis: Detail design will be contracted to a vendor per a design specification.

drawing estimates:
assembly: 1
support frame: 5 sheets
space frame weldment:10 sheets
under carriage assembly: 30 sheets
track system: 5 sheets

shop/fab drawings: 50

total time: 1.5 MY

engineering analysis: 1 MY

fabrication planning: 1 MY

Inspection/Admin (my): 1.9 **Rate ($k/my):** 94 **Dur:** 3/93-12/95
Basis:

contract administration to place order	4 mm
vendor qualification	1 mm
on site and off site inspections	4 mm
Administrative overhead	4 mm
coordinator support during construction	6 mm

subtotal 19 mm = 1.6 my

Add to this supervision during assembly, which is 8.7% of the total assembly effort of 3.3my, or 0.3my.

total is 1.9my

EDIA/QA Material&Services ($k): 218 **Dur:** 9/94-12/95

Basis:
1 trip/month x 12 months x 2.5k/trip = $30k
inspection QA 24 mm @ $94k/ year = $188k

Procurement/Fabrication ($k): 3809 Dur: 9/94-12/95
Basis:
raw materials
1400 tons cast steel

@$1.00/ lb yielding $2800K

transportation $2500/load x 35 loads = $88k

time to off load: 2 hours/ load x 35 loads x $750/hour = $53k

machining 5 days/ section, $4000/ section x 32 sections = $128k

backbone space frame estimate 200 tons each @ $3/lb = $240k

undercarriages (2) @ $250k each = $500k

Installation/Ass'y (my): 3.0 Rate ($k/my): 43 **Dur:** 10/95-12/95

Material ($k): 50
Basis:

assemble carriage assemblies:
8 laborers 4 months = 3.3 my

For assembly tasks, supervision is 8.7%, leaving 91.3% of total effort here. This is 91.3% of 3.3my, or 3.0my.

material required $50k

Unit type: ea **Number of units:** 2

Estimate Type: EO

Risk Factors:
Technical: 6 Basis: Concept design is not yet defined.
Cost: 6 Basis: space frame costs are standard, undercarriage and drive mechanism undefined.
Schedule: 2 Basis: Highly variable, but mostly off site construction

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Misc Comments:
number of ports can vary depending on cold mass support design and number of feedthroughs. This will change machining costs.

Basis of Estimate

WBS: 1.3.1.1.2.3 Item: End Pole Field Shaper

Date: 12/11/91 Rev: 00 By: Deis et. al.

Element Scope: This element covers any additional parts on the poles which are used for shaping the magnetic field at low angles. This does not include the pole itself, but it does include any magnetic hardware which hangs from it.

Technical design description: Conical 9.5 degree (half angle) solid angle steel truncated cone, with a 50 mm bore along its axis centerline. Rough dimensions are 4 meters long, with outer diamter varying from 2.01 meters to 2.68 meters. Structural support is provided to carry load to the base of the pole transport system.

Engineering/Design (my): 0.77 **Rate ($k/my):** 100 **Dur:** 1/94 -12/95
Basis: Total of 20 dwgs @ 1mw/dwg = 20 mw of design. Engineering support will also be 20 mw. Total labor is 40 mw = .77 my. Total cost is $77.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): 0.75 **Rate ($k/my):** 94 **Dur:** 1/94-12/95
Basis:

Dimensional inspection	1 mm
vendor qualification	1 mm
contract administration	2 mm
administrative overhead	2 mm
coordinator support	3 mm
total	9 mm = .75 my

EDIA/QA Material&Services ($k): 76 **Dur:** 1/94-12/95
Basis:
Casting x-ray inspection = 4 man months = 0.33 my
Support frame weld inspection = 2 man months = 0.16 my
0.5 man years x $103k/year = $52k

Assume 1 trip/2 mo by two people to vendor at $2.0k/trip per person for 12 months = $24k

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Procurement/Fabrication ($k): 1518 **Dur:** 1/94-12/95
Basis:
150 tons per cone x 2 cones = 300 tons
cast steel at $2.00/lb x 600,000 lb x 1.05 (waste) = $1,260k

Shipping: 16 loads x $2500/load = $40k

casting cleanup/ bead blasting = 4 man weeks = 160 hours = $16k

10 ton support frame at each end x 2 ends = 20 tons of stainless

raw steel cost = 40,000 lb x $2.50/ lb = $100k

2000 lb weld deposition at 4 lb/hour = 500 hours of welding
welding cost = $100/hour x 500 hours = $50k

machining = 16 man weeks = 640 hours = $64k

support frame bead blasting = 2 man weeks = 80 hours = $8k

fastening hardware = $20k

total cost = $1518k

Installation/Ass'y (my): 1.33 **Rate ($k/my):** 45 **Dur:** 1/94-12/95
Material ($k): 0
Basis:

8 man months of cone assembly per end = 16 man months total = 1.33 my

Installation of the end pole field shaper is completed during on-site assembly (WBS 1.3.1.8.1)

Unit type: ea **Number of units:** 2
Estimate Type: EO

Risk Factors:
Technical: 6 Basis: Basic structural design problem, some trade offs.
Cost: 8 Basis: Cast material can vary in cost. Design constraints not completely defined.
Schedule: 8 Basis: Casting this size has small experience base. Schedule will depend on specific design.

Misc Comments: Design may revert to stacked plates instead of cast pieces. Structural problems of large cantelevered load will be balanced against procurement and quality issues associated with large castings.

Basis of Estimate

WBS: 1.3.1.1.3.1 Item: Central Detector Support

Date: 11/8/91 Rev: 00 By: J. Bowers

Element Scope: This element covers the structure which permanently supports the central detectors (formerly the "central membrane")

Technical design description:
The central detector support is a stainless steel weldment which provides structural support for the 3000 ton central detector. This structure interfaces the vacuum vessel weldment (WBS 1.3.1.1.1.3.1) at the midplane stiffening ring.

The structure consists of flat plates welded together in an axisymmetric pattern about the beam centerline. Principal design criteria include stress, fundamental vibration modes, and space constraints.

Engineering/Design (my): 1 **Rate** ($k/my): 100 **Dur:** 9/92-3/93
Basis: Detail design will be contracted to a vendor per a design specification.

drawing estimates:
assembly: 1
weldment: 1, 5 sheets
shop/fab drawings: 4

total time: .25 MY

engineering analysis: .5 MY

fabrication planning: .25MY

Inspection/Admin (my): 1.3 **Rate** ($k/my): 94 **Dur:** 9/92-12/93
Basis:

contract administration to place order	2 mm
vendor qualification	1 mm
on site and off site inspections	4 mm
Administrative overhead	6 mm
coordinator support during construction	3 mm
total	16mm = 1.3 my

EDIA/QA Material&Services ($k): 0 **Dur:** 9/92-12/93
Basis:
trips included in vessel weldment WBS1.3.1.1.1.3.1

Procurement/Fabrication ($k): 2354 **Dur:** 3/93-12/93
Basis: raw materials, cut and formed parts
welding cost is included in installation WBS

422 tons 304L in finished vessel

add 8% waste for drops and machining giving 456 tons of raw material
mill rate = $2.25/ lb yielding $2052K

finish cost for 250 RMS finish = $89k

weld material cost is included in welding cost

transportation $2500/load x 40 loads = $100k

central can rolling 14 days = $11k

flat plate weld prep machining 4 days/section, $3200/section x 32 sections = $102k

total cost = $2354k

Installation/Ass'y (my): 0 **Rate ($k/my):** 48 **Dur:** 10/91-10/91

Material ($k): xxx
Basis: This is covered in WBS 1.3.1.8.1 Magnet Installation

Unit type: ea **Number of units:** 1

Estimate Type: BU

Risk Factors:
Technical: 2 Basis: Fabrication techniques are standard. Assembly techniques not yet defined. Simple geometry is easy to charactorize.
Cost: 6 Basis: Raw material can vary greatly.
Schedule: 6 Basis: Construction will most likely occur after vacuum vessel halves are installed, making this a critical path construction item.

Misc Comments:
Interface between central detector support and central detector is not yet defined. This can have a significant impact on cost if additional alignment equipment and machining details are required.

Basis of Estimate

WBS: 1.3.1.2.1 Item: Power Supply

Date: 12/11/91 Rev: 0D By: G. Deis/M. Chaplin

Element Scope: This element covers the magnet power supply only. It includes all the hardware and controls between the AC power grid and the terminals of the warm bus. Only local controls on the power supply itself are included here.

Technical design description: The power supply is assumed to be able to charge the magnet in 2 hours to 50 kA. We assume that it connects directly to the 4160 3-phase line, and then directly to the warm current bus. This will be bought on spec. Actual design of supply is straightforward transformer with rectifier. This includes utility power design as well as design of installation.

Engineering/Design (my): 0.58 **Rate ($k/my):** 100 **Dur:** 1/93-10/94

Basis: Assume that vendor designs the supply after we write spec. There are two major parts, plus a simple control system. Spec writing (after C/P design) will require 0.5mm EE. Assume that design requires 2mm EE, 3mmED, and 1.5mmME for support, plumbing, all at nat'l average rates. Total is 7mm, or 0.58my at standard rate

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Inspection/Admin (my): 0.14 **Rate ($k/my):** 94 **Dur:** 1/93-10/95

Basis: There will be an acceptance test which will be required, plus continuous low-levelinterface with vendor during construction. Assume 2% EE (Nat'l Lab) to monitor this work continuously, plus another 1mm to check off on acceptance tests. This is 0.14my, at standard labor rate

---

EDIA/QA Material&Services ($k): 8 **Dur:** 1/93-10/95

Basis: 4 trips at 2k,. Total 8k

Procurement/Fabrication ($k): 250 **Dur:** 10/94-10/95

Basis: A guess from Mike Chaplin, based on his experience with this type of supply.

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0

Basis: Installation not included here

Unit type: ea **Number of units:** 1

Estimate Type: EO

Risk Factors:

Technical: 2 Basis: Similar to many large existing SC power supplies.

Cost: 4 Basis: We have experience with this type of supply, but we don't make them ourselves. No vendor quote, yet

Schedule: 2 Basis: No impact on other systems

Misc Comments:

Basis of Estimate

WBS: 1.3.1.2.2 Item: Buswork

Date: 11/6/91 Rev: 0A By: G. Deis/M. Chaplin

Element Scope: This element comprises all of the warm (normally-conducting) buswork which is connects the high-current components together. Major connections are with the power supply, the dump resistor, the breaker, and the coil.
Technical design description: I assume water-cooled bus, made of Al, but with roughly the same cross-section as an air-cooled bus. Assume 1.3MA/m2 current density, per Mike Chaplin's sheet, which gives a 40C temp rise for air-cooled bus, and 500kW power. Assume that busses are extruded sections.

Engineering/Design (my): 0.34 **Rate ($k/my):** 100 **Dur:** 1/93-10/94
Basis: At the vendor, this will be mainly a job in fitting the bus into the facility. Assume that there are 5 dwgs for the bus/holders: extrusion, 2 spacers, 2 holders. Assume that there are two type of bends, each with 2 drawings. Then assume 2 drawings to work out assembly and exact lengths. Total dwg count is 11 dwgs, or 11mw MD. Assume 20%ME, 2.2mw,to run this effort. All of the above at standard rate. Add in 1.0mm ME-NL to write spec and review design. Total is 0.337my.

Inspection/Admin (my): 0.05 **Rate ($k/my):** 94 **Dur:** 1/93-10/95
Basis: Relatively light inspection and administration load. Assume there will be 6mo design and 6 mo fab, with 5% Nat'l lab ME following. Use standard rate

---

EDIA/QA Material&Services ($k): 8 **Dur:** 1/93-10/95
Basis: Assume 4 trips at 2k each.

Procurement/Fabrication ($k): 57 **Dur:** 10/94-10/95
Basis: Assume there is a total of 280m of bus, with a cross section of 385cm^2. This gives a total of 28463kg of bus, not counting hangers, etc. Assume that the effective cost of the bus is $2/kg (which is about 6x the base material cost used by Mike Chaplin), which includes all components. This gives 57k total.

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0
Basis: Not included here

Unit type: m **Number of units:** 280

Estimate Type: BU

Risk Factors:

Technical:	4	Basis: New design, but no special requirements
Cost:	6	Basis: A rough guess, with some experience
Schedule:	2	Basis: No impact on other items

Misc Comments:

Basis of Estimate

WBS: **1.3.1.2.3** Item: **Breakers and Dump Resistor**

Date: 12/11/91 Rev: 0C By: G. Deis/M. Chaplin

Element Scope: This element includes only the breaker and dump resistor required for discharging the magnet.

Technical design description: This is a 50kA breaker system, and a 1.8GJ dump resistor. Resistor design uses SST tubes as the resistors, immersed in a tank of water for het capacity.

Engineering/Design (my): 0.26 **Rate ($k/my):** 100 **Dur:** 1/93-10/94

Basis: Breaker is extrapolation of existing designs used elsewhere. Dump resistor is similar to previous designs, just bigger. Assume resistor design package consists of 5 main drawings: tank, resistor, 2 clamps/connections, 1 miscellaneous. Assume breaker design package only needs 3 dwgs (it is smaller, and more standard). Assume engineering is equal to 2/3 design time, since inductance will be important for both components, and analysis will be required. Spec writing is included. Total is 8mw + 5.3mw = 0.26my. Standard Labor rate applies.

Inspection/Admin (my): 0.125 **Rate ($k/my):** 94 **Dur:** 1/93-10/95

Basis: Minimal inspection effort; assume 0.5mm. To follow procurement, assume total of 1mm. total 0.125my at standard labor rate

---

EDIA/QA Material&Services ($k): 4 **Dur:** 1/93-10/95

Basis: 2 trips at 2k each

Procurement/Fabrication ($k): 250 **Dur:** 10/94-10/95

Basis: A guess from Mike Chaplin, based on his experience with design and fab of similar devices.

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0

Basis: Installation not included here.

Unit type: ea **Number of units:** 1

Estimate Type: EO

Risk Factors:

Technical: 2 Basis: Minor mods to existing design

Cost: 2 Basis: Vendor quote from established dwgs

Schedule: 2 Basis: No impact on other items

Misc Comments:

Basis of Estimate

WBS: 1.3.1.2.4 Item: Quench Detection and Diagnostics

Date: 12/11/91 Rev: 0B By: G. Deis/M. Chaplin

Element Scope: This element includes hardware required for quench detection, excpet that which is mounted within the vacuum envelope. This includes voltage taps and other items.

Technical design description: This system includes the chasses to monitor voltages, and includes the fault monitors for the vapor-cooled leads.

Engineering/Design (my): 0.25 **Rate ($k/my):** 100 **Dur:** 1/93-10/94

Basis: approximately 3mm engineering and design time required. Standard rate applies

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Inspection/Admin (my): 0.08 **Rate ($k/my):** 94 **Dur:** 1/93-10/95

Basis: 1mm for coordination

EDIA/QA Material&Services ($k): 0 **Dur:** 1/93-10/95

Basis: nothing required...small effort

Procurement/Fabrication ($k): 75 **Dur:** 10/94-10/95

Basis: Several small chasses

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0

Basis: installation not included

Unit type: ea **Number of units:** 1

Estimate Type: EO

Risk Factors:

Technical: 2 Basis: Based on existing designs

Cost: 6 Basis: Based on Mike Chaplin's experience

Schedule: 2 Basis: No schedule impact

Misc Comments:

Basis of Estimate

WBS: 1.3.1.3.1.1 Item: LN Storage Dewar

Date: 11/07/91 Rev: 0A By: R. Yamamoto

Element Scope: This element covers the cost of the LN storage dewar itself, without piping.

Technical design description: The capacity of this dewar is 160,000 liters.

Engineering/Design (my): .10 Rate ($k/my): 100 Dur: 8/94-4/95

Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. An off-the-shelf item with little or no modification is to be procured. Estimate that a total of 3mw required by vendor to modify current product to GEM specification. 0.05 FTE engineering support required to oversee technical aspect of the procurement and interact with the vendor on design issues and performance parameters = 2mw. Total labor is 5mw = .10 my. Total cost is $10.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .04 Rate ($k/my): 94 Dur: 8/94-4/95

Basis: Assume 0.5mm effort required to place contract after specs written; Total labor is 0.5mm = .04 my. Total cost is $4k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 8 Dur: 8/94-4/95

Basis: Assume 2 trips by two people to vendor at $2.0k/trip = $8k

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Procurement/Fabrication ($k): 1109 Dur: 8/94-4/95

Basis: Estimate includes dewar cost and corresponding support structure.

Installation/Ass'y (my): 0 Rate ($k/my): 0 Dur:

Material ($k): 0

Basis: Installation will be done under 1.3.1.8.3.1 LN System Installation.

Unit type: ea **Number of units:** 1

Estimate Type: BU

Risk Factors:

Technical: 2 Basis: Minor modifications (if any) to an existing design.

Cost: 2 Basis: In-house estimate for item within current product line.

Schedule: 2 Basis: Delays completion of non-critical path subsystem item.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.3.1.2 Item: LN Subcooler

Date: 12/11/91 Rev: 0B By: R. Yamamoto

Element Scope: This element covers the cost of the LN subcooler only, without piping.
Technical design description: This element also includes the pumping system necessary for the LN subcooler.

Engineering/Design (my): .25 **Rate ($k/my):** 100 **Dur:** 1/95-6/95
Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. The system procured should be a modification to existing hardware as supplied by the vendor. Estimate that a total of 8mw required by vendor to modify current product to GEM specification. 0.2 FTE of engineering support required to oversee technical aspect of the procurement and interact with the vendor on design issues and performance parameters = 5mw. Total labor is 13mw = .25 my. Total cost is $25.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .13 **Rate ($k/my):** 94 **Dur:** 1/95-6/95
Basis: Assume 1mm effort required to place contract after specs written; 0.1 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (6 mo) = .6mm; Total labor is 1.6mm = .13 my. Total cost is $12k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 4 **Dur:** 1/95-6/95
Basis: Assume 1 trip by two people to vendor at $2.0k/trip = $4k

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Procurement/Fabrication ($k): 700 **Dur:** 1/95-6/95
Basis: Estimate includes subcooler pumping system.

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0
Basis: Installation will be done under 1.3.1.8.3.1 LN Systems Installation.

Unit type: ea **Number of units:** 1

Estimate Type: EO

Risk Factors:
Technical: 2 Basis: Minor modifications (if any) to an existing design.
Cost: 2 Basis: In-house estimate for item within current product line.
Schedule: 2 Basis: Delays completion of non-critical path subsystem item.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.3.1.3   Item: LN Piping and Distribution

Date: 11/07/91   Rev: 0A   By: R. Yamamoto

Element Scope: This element covers all of the piping required to complete the LN system, above and below ground, up to the coil vacuum vessel. It includes all of the LN piping within the cryogenics building, and the transfer lines to the coil vessel.
Technical design description: There is approx. 200 meters of 2"ø transfer line from the cryogenics building to the coil vacuum vessel. All piping will be vacuum insulated with vacuum pump-out ports provided at discrete intervals.

Engineering/Design (my): 0.77   Rate ($k/my): 100   Dur: 3/94-2/95
Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: overall layout of transfer line plumbing, layout in cryogenic building, assembly details of transfer line routing (8), details of custom fixtures/elbows/hardware required for installation (15). Total of 25 dwgs @ 1mw/dwg =25mw of design. Engineering support will half of the required design support = 12.5mw. GEM engineering will be at 5% level for 12mo = 2.5mw. Total labor is 40mw = 0.77 my. Total cost is $77k. Average labor rate is $100k/yr.

Inspection/Admin (my): .18   Rate ($k/my): 94   Dur: 3/94-2/95
Basis: Assume 1mm effort required to place contract after specs written; 0.1 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (12 mo) = 1.2mm; Total labor is 2.2mm = .18 my. Total cost is $17k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 16   Dur: 3/94-2/95
Basis: Assume 1 trip/3mo by two people to vendor at $2.0k/trip = $16k

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Procurement/Fabrication ($k): 202   Dur: 3/94-2/95
Basis: Assume cost of transfer line is approx. $130/linear ft. (Cryenco)
Transfer line cost from cryogenics building to vacuum vessel: ($130/ft.)*(200 meters)*(3.28ft/m)*(2 transfer lines)=$171k.
Bayonet cost:Two (2) pair of bayonets cost $2k/pair=$4k.
Misc. items such as pressure relief valves, control valves, instrumentation=$10k
Transfer line cost within the cryogenics building:($130/ft)*(40 meters)*(3.28ft/m)=$17k.
Total cost:171+4+10+17=$202k.

Installation/Ass'y (my): 0   Rate ($k/my): 0   Dur:
Material ($k): 0
Basis: Installation will be done under 1.3.1.8.3.1 LN Distribution System.

Unit type: m   **Number of units:** 250+
Estimate Type: BU

Risk Factors:

Technical: 3 Basis: Extensive modifications to an existing design.
Cost: 4 Basis: In-house estimate for item within current product line.
Schedule: 2 Basis: Delays completion of non-critical path subsystem item.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.3.2.1.1 Item: Magnet Supply Dewars

Date: 11/07/91 Rev: 0A By: R. Yamamoto

Element Scope: This element covers the local dewars required for the LHe thermosyphon system.

Technical design description: There will be one (1) local 1000 liter LHe supply dewar per coil subassembly equating to a total of two (2) dewars required.

Engineering/Design (my): .10 **Rate ($k/my):** 100 **Dur:** 6/94-2/95

Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. An off-the-shelf item with little or no modification is to be procured. Estimate that a total of 3mw required by vendor to modify current product to GEM specification. 0.05 FTE engineering support required to oversee technical aspect of the procurement and interact with the vendor on design issues and performance parameters = 2mw. Total labor is 5mw = .10 my. Total cost is $10.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .04 **Rate ($k/my):** 94 **Dur:** 6/94-2/95

Basis: Assume 0.5mm effort required to place contract after specs written; Total labor is 0.5mm = .04my. Total cost is $4k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 8 **Dur:** 6/94-2/95

Basis: Assume 2 trips by two people to vendor at $2.0k/trip = $8k

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Procurement/Fabrication ($k): 25 **Dur:** 6/94-2/95

Basis: Estimate includes the cost for two (2) dewars and a local support structure supplied with each.

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0

Basis: Installation will be done under 1.3.1.8.3.2 LHe System Installation.

Unit type: ea **Number of units:** 2

Estimate Type: BU

Risk Factors:

Technical: 2 Basis: Minor modifications (if any) to an existing design.

Cost: 2 Basis: In-house estimate for item within current product line.

Schedule: 2 Basis: Delays completion of non-critical path subsystem item.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.3.2.1.2 Item: LHe Thermosyphon Piping/Dist.

Date: 11/07/91 Rev: 0A By: R. Yamamoto

Element Scope: This element covers the piping required to connect the magnet supply dewar to the main helium plant, and to connect the magnet supply dewars to the coil assemblies.

Technical design description: There is approx. 200 meters of 2"ø transfer line from the cryogenics building to the coil vacuum vessel. There is approx. 10 meters of 2"ø transfer line from the magnet supply dewars to the coil assemblies. All piping will be vacuum insulated with vacuum pump-out ports provided at discrete intervals.

Engineering/Design (my): 0.77 **Rate ($k/my):** 100 **Dur:** 3/94-2/95

Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: overall layout of LHe transfer line plumbing, layout in cryogenic building, assembly details of transfer line plumbing (8), details of custom fixtures/elbows/hardware required for installation (15). Total of 25 dwgs @ 1mw/dwg =25mw of design. Engineering support will be half of the required design support = 12.5mw. GEM engineering will be at 5% level for 12mo = 2.5mw. Total labor is 40mw = 0.77 my. Total cost is $77.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .18 **Rate ($k/my):** 94 **Dur:** 3/94-2/95

Basis: Assume 1mm effort required to place contract after specs written; 0.1 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (12 mo) = 1.2mm; Total labor is 2.2mm = .18 my. Total cost is $17k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 16 **Dur:** 3/94-2/95

Basis: Assume 1 trip/3mo by two people to vendor at $2.0k/trip = $16k

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Procurement/Fabrication ($k): 211 **Dur:** 3/94-2/95

Basis: Assume cost of 2"ø transfer line is approx. $150/linear ft. (Cryenco)
Transfer line cost from supply dewar to main helium plant: ($150/ft.)*(200 meters)*(3.28ft/m)*(2 transfer lines)=$197k.
Bayonet cost: Two (2) pair of bayonets cost $2k/pair=$4k.
Transfer line cost from supply dewar to coil vessel: ($150/ft)*(10 meters)*(3.28ft/m)*(2 transfer lines)=$10k.
Total cost: 197+4+10=$211k.

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0

Basis: Installation will be done under 1.3.1.8.3.2 LHe Distribution System.

Unit type: m **Number of units:** 260

Estimate Type: BU

Risk Factors:

Technical:	3	Basis: Extensive modifications to an existing design.
Cost:	4	Basis: In-house estimate for item within current product line.
Schedule:	2	Basis: Delays completion of non-critical path subsystem item.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.3.2.2.1 Item: LHe Circulator

Date: 12/11/91 Rev: 0A By: R. Yamamoto

Element Scope: This element includes the pump which forces the helium flow, as well as any associated hardware other than piping.

Technical design description:

Engineering/Design (my): .25 **Rate ($k/my):** 100 **Dur:** 9/94-2/95

Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: details of pump placement in cryogenic system, details of pump interfaces with plumbing, details of custom fixtures/hardware required for installation (6). Total of 8 dwgs @ 1mw/dwg =8mw of design. Engineering support will be half of the required design support = 4mw. GEM engineering will be at 5% level for 6mo = 1mw. Total labor is 13mw = .25 my. Total cost is $25.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .13 **Rate ($k/my):** 94 **Dur:** 9/94-2/95

Basis: Assume 1mm effort required to place contract after specs written; 0.1 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (6 mo) = .6mm; Total labor is 1.6mm = .13 my. Total cost is $12k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 8 **Dur:** 9/94-2/95

Basis: Assume 2 trips by two people to vendor at $2.0k/trip = $8k

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Procurement/Fabrication ($k): 250 **Dur:** 9/94-2/95

Basis: Assume cost of LHe circulator (pump system) is $250k.

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0

Basis: Assembly will be done at LHe Systems Installation 1.3.1.8.3.2

Unit type: ea **Number of units:** 1

Estimate Type: EO

Risk Factors:

Technical: 2 Basis: Minor modifications (if any) to an existing design.

Cost: 4 Basis: In-house estimate for item within current product line.

Schedule: 4 Basis: Delays completion of non-critical path subsystem item.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.3.2.2.2 Item: Forced-Flow LHe Piping/Dist.

Date: 11/07/91 Rev: 0A By: R. Yamamoto

Element Scope: This element includes all of the piping which is required to connect the forced-flow loop, external to the vacuum vessel.

Technical design description: There is approx. 125 meters of 2"ø transfer line from the cryogenics building to the coil vacuum vessel. There is approx. 10 meters of 2"ø transfer line from the magnet supply dewars to the coil assemblies. All piping will be vacuum insulated with vacuum pump-out ports provided at discrete intervals.

Engineering/Design (my): 0.77 **Rate ($k/my):** 100 **Dur:** 3/94-2/95

Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: overall layout of LHe transfer line plumbing, layout in cryogenic building, assembly details of transfer line plumbing (8), details of custom fixtures/elbows/hardware required for installation (15). Total of 25 dwgs @ 1mw/dwg =25mw of design. Engineering support will be half of the required design support = 12.5mw. GEM engineering will be at 5% level for 12mo = 2.5mw. Total labor is 40mw = 0.77 my. Total cost is $77.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .18 **Rate ($k/my):** 94 **Dur:** 3/94-2/95

Basis: Assume 1mm effort required to place contract after specs written; 0.1 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (12 mo) = 1.2mm; Total labor is 2.2mm = .18 my. Total cost is $17k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 16 **Dur:** 3/94-2/95

Basis: Assume 1 trip/3mo by two people to vendor at $2.0k/trip = $16k

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Procurement/Fabrication **($k):** 211 **Dur:** 3/94-2/95

Basis: Assume cost of 2"ø transfer line is approx. $150/linear ft. (Cryenco)
Transfer line cost from supply dewar to main helium plant: ($150/ft.)*(200 meters)*(3.28ft/m)*(2 transfer lines)=$197k.
Bayonet cost: Two (2) pair of bayonets cost $2k/pair=$4k.
Transfer line cost from supply dewar to coil vessel: ($150/ft)*(10 meters)*(3.28ft/m)*(2 transfer lines)=$10k.
Total cost: 197+4+10=$211k.

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0

Basis: Installation will be done under 1.3.1.8.3.2 LHe Distribution System.

Unit type: m **Number of units:** 260

Estimate Type: BU

Risk Factors:

Technical:	3	Basis: Extensive modifications to an existing design.
Cost:	4	Basis: In-house estimate for item within current product line.
Schedule:	2	Basis: Delays completion of non-critical path subsystem item.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.3.2.3.1 Item: Refrigerator

Date: 11/07/91 Rev: 0A By: R. Yamamoto

Element Scope: This element covers the Helium refrigerator only.
Technical design description: The capacity of the liquid helium refrigerator required will be 2.0 kW @ 4.5°K.

Engineering/Design (my): .15 **Rate** ($k/my): 100 **Dur:** 4/94-3/95
Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. An off-the-shelf item with little to no modification is to be procured. Estimate that 4mw required by the vendor to re-design component as per GEM specification. 0.08 FTE of engineering support required to oversee the technical aspect of the procurement and interact with the vendor on design issues and performance parameters = 4mw. Total labor is 8mw = .15 my. Total cost is $15.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .08 **Rate** ($k/my): 94 **Dur:** 4/94-3/95
Basis: Assume 1mm effort required to place contract after specs written; Total labor is 1mm = .08 my. Total cost is $7.5k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 12 **Dur:** 4/94-3/95
Basis: Assume 1 trip/4 mo by two people to vendor at $2.0k/trip = $12k

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Procurement/Fabrication ($k): 2901 **Dur:** 4/94-3/95
Basis: Includes cost of refrigerator/liquifier and compressor.

Installation/Ass'y (my): 0 **Rate** ($k/my): 0 **Dur:**

Material ($k): 0
Basis: Installation will be done under 1.3.1.8.3.2 LHe Systems Installation.

Unit type: ea **Number of units:** 1

Estimate Type: BU

Risk Factors:
Technical: 2 Basis: Minor modifications (if any) to an existing design.
Cost: 4 Basis: In-house estimate for item within current product line.
Schedule: 2 Basis: Delays completion of non-critical path subsystem item.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.3.2.3.3 Item: LHe Recovery System

Date: 12/11/91 Rev: 0B By: R. Yamamoto

Element Scope: This element covers all the hardware required to handle returned He gas and liquid from the magnet. This includes the warm helium system and all compressors, oil filtration components and associated valves, instrumentation, plumbing, etc.

Technical design description: A series of high speed screw compressors and oil filtration units will be used on the warm helium side of the refrigeration system to provide adequate helium gas pressure and flow rate for proper LHe production.

Engineering/Design (my): .50 **Rate ($k/my):** 100 **Dur:** 7/94-6/95

Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: overall system schematic, subsystem assembly drawings, installation drawings (2), component details (10). Total of 14 dwgs @ 1mw/dwg =14mw of design. Engineering support will half of the required design support = 7mw. GEM engineering will be at 10% level for 12mo = 5mw. Total labor is 26mw = .50 my. Total cost is $50.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .18 **Rate ($k/my):** 94 **Dur:** 7/94-6/95

Basis: Assume 1mm effort required to place contract after specs written; 0.1 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (12 mo) = 1.2mm; Total labor is 2.2mm = .18 my. Total cost is $17k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 16 **Dur:** 7/94-6/95

Basis: Assume 1 trip/3mo by two people to vendor at $2.0k/trip = $16k

---

Procurement/Fabrication ($k): 1443 **Dur:** 7/94-6/95

Basis: ______________________________

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0

Basis: Installation will be done under 1.3.1.8.3.2 LHe Systems Installation.

Unit type: ea **Number of units:** 1

Estimate Type: EO

Risk Factors:

Technical: 3 Basis: Extensive modifications to an existing design may be required.

Cost: 4 Basis: In-house estimate for item within current product line.

Schedule: 2 Basis: Delays completion of non-critical path subsystem item.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.3.2.3.4 Item: LHe Supply Sys Piping/Dist.

Date: 11/07/91 Rev: 0A By: R. Yamamoto

Element Scope: This element includes all of the piping within the above-ground helium plant. It does not include any transfer lines to below ground systems.
Technical design description: There is approx. 100 feet each of 2"ø and 4"ø warm helium gas transfer line within the helium liquification plant. The plumbing associated with the discharge side of the helium compressor will be stainless steel and the suction side will utilize aluminum piping. Approx. 150 meters each of vacuum insulated transfer pipe will be used between the plant and the LN2 storage dewar and the plant and the LHe storage dewar.

Engineering/Design (my): .50 **Rate ($k/my):** 100 **Dur:** 3/94-2/95
Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: overall layout of LHe/warm helium gas compressor system, layout of system in and around cryogenic building, assembly details of transfer line plumbing (6), details of custom fixtures/elbows/hardware required for installation (6). Total of 14 dwgs @ 1mw/dwg =14mw of design. Engineering support will be half of the required design support = 7mw. GEM engineering will be at 10% level for 12mo = 5mw. Total labor is 26mw = .50my. Total cost is $50.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .18 **Rate ($k/my):** 94 **Dur:** 3/94-2/95
Basis: Assume 1mm effort required to place contract after specs written; 0.1 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (12 mo) = 1.2mm; Total labor is 2.2mm = .18 my. Total cost is $17k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 24 **Dur:** 3/94-2/95
Basis: Assume 1 trip/2mo by two people to vendor at $2.0k/trip = $24k

---

Procurement/Fabrication ($k): 162 **Dur:** 3/94-2/95
Basis: Assume cost of 2"ø transfer line is approx. $150/linear ft. (Cryenco)
Transfer line cost from storage dewar to main helium plant: ($150/ft.)*(150 meters)*(3.28ft/m)*(2 lines)=$148k.
Bayonet cost: Two (2) pair of bayonets cost $2k/pair=$4k.
Warm helium transfer line cost from compressor to refrigerator: ($50/ft)*(100 feet)**(2 transfer lines)=$10k.
Total cost: 148+4+10=$162k.

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0
Basis: Installation will be done under 1.3.1.8.3.2 LHe Distribution System.

Unit type: ft **Number of units:** 1200

Estimate Type: BU

Risk Factors:

Technical:	3	Basis: Extensive modifications to an existing design.
Cost:	4	Basis: In-house estimate for item within current product line.
Schedule:	4	Basis: Delays completion of non-critical path subsystem item.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.4.1 Item: Vacuum Pumps

Date: 11/8/91 Rev: 00 By: J. Bowers

Element Scope: This element covers all the vacuum pumps for the magnet vessels, including any foreline pumps, roughing pumps, or booster pumps. Installation is not included here.

Technical design description:
4 - 20" diffusion pumps backed by one 300 CFM mechanical pump
2- 4000 CFM roots blowers each backed by a 300 CFM mechanical pump

---

Engineering/Design (my): .5 **Rate ($k/my):** 100 **Dur:** 9/92-12/92
Basis:

Vacuum pumps will be contracted to a vendor to a specification

vacuum pumping equipment will consist of existing catalog items with no custom parts.

Design/ engineering effort will consist of pump down and outgassing calculations, plant packaging.

Inspection/Admin (my): .25 **Rate ($k/my):** 94 **Dur:** 9/92 - 9/93
Basis:

vendor qualification	1 mm
on site and off site inspections	1 mm
coordinator support during construction	1 mm
total	3mm = .25 my

EDIA/QA Material&Services ($k): 5 **Dur:** 9/92 - 9/93
Basis:
1 trip/month x 2 month x 2.5k/trip = $5k

Procurement/Fabrication ($k): 130 **Dur:** 9/92 - 9/93
Basis:
4 - 20" diffusion pumps backed by one 300 CFM mechanical pump: $50k
2- 4000 CFM roots blowers each backed by a 300 CFM mechanical pump: $80k

---

Installation/Ass'y (my): 0 **Rate ($k/my):** 48 **Dur:** 10/91-10/91

Material ($k): 0
Basis:

Unit type: ea **Number of units:** 1

Estimate Type: BU

Procurement/Fabrication ($k): 285 Dur: 9/92 - 9/93

Basis:

piping, cutting, welding: $75k
Nitrogen supply: $50k
4 - nitrogen traps above diffusion pumps: $40k
4 - 20" poppet valves for diffusion pumps: $40k
2 - refrigerated traps for roots blowers: $20k
2 - 8" gate valves for roots blowers: $10k
various bypass lines and valves: $50k

Installation/Ass'y (my): 0 **Rate ($k/my):** 48 **Dur:** 10/91-10/91

Material ($k): $
Basis:

Unit type: ea **Number of units:** 1

Estimate Type: BU

Risk Factors:

Technical: 2 Basis: Simple design
Cost: 2 Basis: Experience
Schedule: 3 Basis: Needs careful planning based on access and cleanliness.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.5.1 Item: Power Controls

Date: 12/11/91 Rev: 0D By: G. Deis/M. Chaplin

Element Scope: This element includes only the controls, operational interlocks, and monitor readouts for the magnet power supply. This element includes all of the magnet-system interlock logic required to permit operation of the magnet power supply; individual permissives for each part of the system are included in each element.
Technical design description: The power supply is assumed to have it's own internal controls. It must be supplied with commands to turn on, a reference voltage to set output current (or voltage), and a permissive to indicate all interlocks are closed. It will send out signals for ready/not ready, on/off, actual values of output current and voltage, plus 5 other status/fault indicators (like lcw on/off, ac power on/off, etc). All these input and output functions are assume to be handled by a Modicon-like device, which is shared with all other parts of the magnet local control system. The modicon interfaces with a vax-like computer (somewhere else) via ethernet; the computer is not costed here.

Engineering/Design (my): 0.14 **Rate ($k/my):** 100 **Dur:** 1/93-10/94
Basis: Drawing count: overall interlock logic (1), electronics wiring diagrams for modicon input/output (2), misc special control chassis (2); Total 5, implying 5mw design time. Engineering (including modicon programming) will about half that. Grand total 7.5mw or 0.14 my. Standard Eng/Des labor rates will apply.

Inspection/Admin (my): 0.05 **Rate ($k/my):** 94 **Dur:** 1/93-10/94
Basis: Rather light effort here. To check design and administer contract will be a total effort of a little more than 0.5man-mo, so use 0.05my. Normal Insp/Admin labor rate applies.

EDIA/QA Material&Services ($k): 8 **Dur:** 1/93-10/94
Basis: Assume 1 trip, 1 person, every 5 months for 22 mo. This is 4 trips at 2k, or 8k.

Procurement/Fabrication ($k): 40 **Dur:** 10/94-10/95
Basis: Assume a modicon costs 100k, and this element covers 1/4 of that, or 25k. In addition, there will be 2 control chasses at 5k each (10k total), and 5k of miscellaneous interlocks, etc

---

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0
Basis: not included in this element

Unit type: 1 **Number of units:** ea

Estimate Type: EO

Risk Factors:

Technical:	2	Basis: This will be off-the-shelf parts.
Cost:	4	Basis: Reasonable good experience in this type of system
Schedule:	2	Basis: This should not be a significant schedule item.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.5.2 Item: Protection Controls

Date: 12/11/91 Rev: 0C By: G. Deis/M. Chaplin

Element Scope: This element includes the controls, operational interlocks, and readouts for the magnet protection system, which includes quench detection, breaker control, dump resistor status, etc.

Technical design description: This system must decide when there is a quench and when a dump should be initiated. As inputs, it will take signals from all the diagnostics on the magnet coil (assumed to be 24 internal voltage taps, plus another 24 internal monitors I don't know about), plus 10 channels of permissive/status information from breakers, dump resistor, and power supply. It will output its status (ready, on/off, ac power on/off, DC power on/off, dump on/off), as well as measured temperatures and voltages from the breakers, the dump resistor, and the busses; there will be 25 output channels altogether. All this is handled through a modicon-like device, which will make the dump decision. The modicon interfaces with the control system microvax.

Engineering/Design (my): 0.15 Rate ($k/my): 100 Dur: 1/93-10/94

Basis: Drawing count: System schematic(1), interlock logic(1), modicon i/o wiring (1), special control chasses(1); total 4, implying 4mw. Engineering will be about the same, since programming for modicon will be more complex than for power controls. Total effort 8mw = 0.15my. Standard E/D labor rate applies.

Inspection/Admin (my): 0.05 Rate ($k/my): 94 Dur: 1/93-10/94

Basis: Very light effort here, mainly contract placement. Assume 0.05 my (a bit more than 1/2 mm). Standard labor rate applies here

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EDIA/QA Material&Services ($k): 4 Dur: 1/93-10/94

Basis: Assume 2 trips at 2k, or 4k.

Procurement/Fabrication ($k): 35 Dur: 10/94-10/95

Basis: Assume a modicon costs 100k, and this element covers 1/4 of that, or 25k. In addition, there will be 2 control chasses at 5k each (10k total).

Installation/Ass'y (my): 0 Rate ($k/my): 0 Dur:

Material ($k): 0

Basis: not included in this element

Unit type: 1 **Number of units:** ea

Estimate Type: EO

Risk Factors:

Technical: 2 Basis: This will be off-the-shelf parts.

Cost: 4 Basis: Good experience base.

Schedule: 2 Basis: This should not be a significant schedule item.

Basis of Estimate

WBS: 1.3.1.5.3 Item: Cryogenics Controls

Date: 12/11/91 Rev: 0C By: G. Deis/M. Chaplin

Element Scope: This element includes all of the controls, operational interlocks, and readouts for the LN and LHe systems. This includes controls for the refrigerators and all cryogenic valves.

Technical design description: Assume refrigerator comes complete with an interface to the control computer. This also covers control of the gas recovery system. All that remains is to control valves, components and sensors in the plumbing. These controls consist mainly of open/closed valves, metering-type valves, pressure, temperature, and level sensors. We assume that some backfitting os required to make some standard items controllable.

Engineering/Design (my): 0.23 **Rate ($k/my):** 100 **Dur:** 1/93-10/94

Basis: Controls are complex because of the number of channels involved, but each channel will be off-the-shelf hardware, easily interfaced to the modicon. Drawing count: interlock logic(1), p&i diagram(3, for 1 LN and 2 LHe systems), modicon wirng diagrams (2), special interface chasses(0); total 6 dwgs, implying 6mw. Relatively heavy engineering load required to deal with all the data, and to figure out how to program modicon; assume another 6mw. Total 12mw/52=0.23my. Standard labor rate applies.

Inspection/Admin (my): 0.05 **Rate ($k/my):** 94 **Dur:** 1/93-10/94

Basis: Rather light effort here. To check design and administer contract will be a total effort of a little more than 0.5man-mo, so use 0.05my. Normal Insp/Admin labor rate applies.

EDIA/QA Material&Services ($k): 8 **Dur:** 1/93-10/94

Basis: Assume 1 trip, 1 person, every 5 months for 22 mo. This is 4 trips at 2k, or 8k.

Procurement/Fabrication ($k): 60 **Dur:** 10/94-10/95

Basis: Assume a modicon costs 100k, and this element covers 1/4 of that, or 25k. Assume 2 other chases are required at 5k each..

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0

Basis: not included in this element

Unit type: 1 **Number of units:** ea

Estimate Type: EO

Risk Factors:

Technical: 4 Basis: This will be off-the-shelf parts;but mods may be req'd.

Cost: 4 Basis: Mike Chaplin's estimate..
Schedule: 2 Basis: This should not be a significant schedule item.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.5.4   Item: Vacuum Controls

Date: 12/11/91   Rev: 0C   By: G. Deis/M. Chaplin

Element Scope: This element covers all of the controls required to operate the magnet vacuum system, which includes pump controls, pressure readouts, valve controllers, etc.

Technical design description: This is a relatively simple and standard system. Assume we have 4 high-vacuum pumps, 2 roots blowers, and 2 mechanical pumps, plus 10 valves, and 15 pressure monitors. Hi-vac pumps come with their own power-supply/controllers, other pumps are on/off controls. Valves are all binary. Pressure monitors all go through Granville-Phillips=type controllers, 2 channels per controller. All operator control is done through the modicon, which communicates with pressure controllers and all binary points.

Engineering/Design (my): 0.10 Rate ($k/my): 100 Dur: 1/93-10/94

Basis: The main effort here is to simply wire everything together. Pressure interlocking is done by pressure controllers. Drawing count: interlock logic (1), wiring diagrams (1), rack layout for press controllers, pump power supplies (1); total 3, meaning 3mw. Engineering/modicon programming will be light, assume 2mw. Total 5mw/52=0.10my

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Inspection/Admin (my): 0.04 Rate ($k/my): 94 Dur: 1/93-10/94

Basis: Very light effort here. Assume 0.5mm, or 0.04my. Standard labor rate applies

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EDIA/QA Material&Services ($k): 0 Dur: 1/93-10/94

Basis: None required, all parts off-the-shelf.

Procurement/Fabrication ($k): 50 Dur: 10/94-10/95

Basis: Assume a modicon costs 100k, and this element covers 1/4 of that, or 25k. In addition, there will be 8 pressure controllers at 5.0k each, plus 5% misc. Total 68k

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Installation/Ass'y (my): 0 Rate ($k/my): 0 Dur:

Material ($k): 0

Basis: not included in this element

Unit type: 1 **Number of units:** ea

Estimate Type: EO

Risk Factors:

Technical: 2 Basis: This will be off-the-shelf parts; additional complexity is unlikely.

Cost: 4 Basis: Mike Chaplin has checked this estimate.

Schedule: 2 Basis: This should not be a significant schedule item.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.6 Item: Return Field Mitigation

Date: 12/11/91 Rev: 00 By: G. Deis

Element Scope: This element covers all of the hardware required to shield individual components or small volumes from the return field of the magnet, or alternatively, the additional cost of over-specifying components so that they will work properly in the field. This includes shielding for vacuum pumps, gages, etc, as well as shielding of local counting rooms and electronic racks below ground. It does not include hardware to shield the above-ground field.

Technical design description:
Assume lower counting house (20 x 20 x 4m) must be shielded from 50 Gauss down to 5 Gauss, which requires 338t of iron. Assume electronics breakers, etc, must be oversized by 20%. Assume double-shielded enclosures for electrical motors and remote mounting for lamp ballasts. Assume some cryogenic equipment must be shielded.

Engineering/Design (my): 0.77 **Rate ($k/my):** 100 **Dur:** 1/93-12/93
Basis: For counting room shielding, approximately 10 dwgs will be needed, plus magnetic-field analysis. This will give about 15 mw. Extra design effort to remote-mount lamp ballasts (from many locations) 5 mw. Design of 10 misc shield enclosures, each with average 2 parts: 20mw. Total effort 40mw = 0.77my

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Inspection/Admin (my): 0.17 **Rate ($k/my):** 94 **Dur:** 1/94-1/96
Basis: Coordination required for placing small procurements: 2mm =

EDIA/QA Material&Services ($k): 0 **Dur:**
Basis:

Procurement/Fabrication ($k): 575 **Dur:** 1/94-1/96
Basis: 338t iron at $1.50/kg (covers installation costs) = 500k. Assume all other (incremental costs) are counted as procurements as well. $55k for electrical equipment and $20k for cryogenic equipment.

Installation/Ass'y (my): 0 **Rate ($k/my):** **Dur:**

Material ($k): 0
Basis:

Unit type: NA **Number of units:** NA

Estimate Type: EO

Risk Factors:
Technical: 6 Basis: Not unusual parts, but not well-considered yet
Cost: 6 Basis: Limited analysis, and rough costing, but conservative
Schedule: 2 Basis: Non-critical path item

Misc Comments: See also Ryszard Stroynowski's white paper.

Basis of Estimate

WBS: 1.3.1.6 Item: **Return Field Mitigation**

Date: 12/11/91 Rev: 00 By: G. Deis

Element Scope: This element covers all of the hardware required to shield individual components or small volumes from the return field of the magnet, or alternatively, the additional cost of over-specifying components so that they will work properly in the field. This includes shielding for vacuum pumps, gages, etc, as well as shielding of local counting rooms and electronic racks below ground. It does not include hardware to shield the above-ground field.

Technical design description:
Assume lower counting house (20 x 20 x 4m) must be shielded from 50 Gauss down to 5 Gauss, which requires 338t of iron. Assume electronics breakers, etc, must be oversized by 20%. Assume double-shielded enclosures for electrical motors and remote mounting for lamp ballasts. Assume some cryogenic equipment must be shielded.

Engineering/Design (my): 0.77 **Rate ($k/my):** 100 **Dur:** 1/93-12/93
Basis: For counting room shielding, approximately 10 dwgs will be needed, plus magnetic-field analysis. This will give about 15 mw. Extra design effort to remote-mount lamp ballasts (from many locations) 5 mw. Design of 10 misc shield enclosures, each with average 2 parts: 20mw. Total effort 40mw = 0.77my

---

Inspection/Admin (my): 0.17 **Rate ($k/my):** 94 **Dur:** 1/94-1/96
Basis: Coordination required for placing small procurements: 2mm =

EDIA/QA Material&Services ($k): 0 **Dur:**
Basis:

Procurement/Fabrication ($k): 575 **Dur:** 1/94-1/96
Basis: 338t iron at $1.50/kg (covers installation costs) = 500k. Assume all other (incremental costs) are counted as procurements as well. $55k for electrical equipment and $20k for cryogenic equipment.

Installation/Ass'y (my): 0 **Rate ($k/my):** **Dur:**

Material ($k): 0
Basis:

Unit type: NA **Number of units:** NA

Estimate Type: EO

Risk Factors:
Technical: 6 Basis: Not unusual parts, but not well-considered yet
Cost: 6 Basis: Limited analysis, and rough costing, but conservative
Schedule: 2 Basis: Non-critical path item

Included in WBS 1.3.1.7.2

Unit type: ea **Number of units:** 2

Estimate Type: EO

Risk Factors:

Technical:	4	Basis: Rigging techniques will be custom, but not state of the art.
Cost:	6	Basis: Best guess based on experience
Schedule:	7	Basis: Critical path item

Misc Comments:

Basis of Estimate

WBS: 1.3.1.7.2 Item: Coil Assemblies

Date: 12/11/91 Rev: 0B By: J. Bowers

Element Scope: This element includes all of the tooling required to handle the coil assemblies from the location at which they were tested above ground to their final position in the underground hall. It als includes any tooling required to anchor them and their support hardware in place and align them.

Technical design description:
This WBS consists mainly of rigging and temporary positioning equipment. Some of the vertical jacking capability is included in WBS 1.3.1.1.1.3.4 Support Saddles. Major components of this effort include lifting strongbacks, temporary shoring and track/drive systems, alignment targets and fiducials, and general rigging equipment

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Engineering/Design (my): 2 **Rate ($k/my):** 100 **Dur:** 1/93-1/94
Basis: Detail rigging and positioning will be contracted to a vendor per a design specification.

drawing estimates:
positional layouts: 10
strongback weldments, special jigs: 10 sheets
shop/fab drawings: 20

total time: 1 MY

engineering analysis/design: .5 MY

On site construction support from engineering: .5 MY

Inspection/Admin (my): 0.7 **Rate ($k/my):** 94 **Dur:** 1/93 - 12/95
Basis:

contract administration to place order	2 mm
vendor qualification	2 mm
inspections	2 mm
subtotal	6mm = 0.5 my

add in supervision of storage/materials management yard, 8.7% of total effort (2my), or 0.2my.

Total is 0.7my

EDIA/QA Material&Services ($k): 90 **Dur:** 1/93 - 12/95
Basis: 1 trip/month x 36 month x 2.5k/trip = $135k

Procurement/Fabrication ($k): 500 **Dur:** 6/93 - 12/94
Basis:

Strong back: $50k

Special rigging equipment: $200k

shoring: $50k

temporary track/winch system $100k

surveying/alignment aids $100k

Installation/Ass'y (my): 1.8 **Rate ($k/my): 43** **Dur: 12/94-12/95**

Material ($k): 50

Basis:

equipment storage and materials management: 2 MY
Of this activity, 8.7% is supervision, so only 91.3% is reported here. This is 91.3% of 2my, or 1.8my.

storage area: 50k

Unit type: ea **Number of units: 1**

Estimate Type: EO

Risk Factors:

Technical: 4 Basis: Rigging techniques will be custom, but not state of the art.
Cost: 6 Basis: Best guess based on experience
Schedule: 2 Basis: Critical path item

Misc Comments:

Basis of Estimate

WBS: 1.3.1.7.3   Item: Pole Assemblies
Date: 12/11/91   Rev: 0A   By: J. Bowers

Element Scope: This element includes all of the tooling required to move the pole assemblies from the surface to the underground hall and place them in position. If they are to be assembled in the underground hall, the tooling required for assembly is included here as well. This also covers tooling required to mount the supports.transporters, and align the poles.

Technical design description:
This WBS consists mainly of rigging and temporary positioning equipment. Major components of this effort include temporary shoring and lifting padeyes, alignment targets and fiducials, and general rigging equipment.

Engineering/Design (my): 2   **Rate** ($k/my): 100   **Dur:** 1/93-1/94
Basis: Detail rigging and positioning will be contracted to a vendor per a design specification.

drawing estimates:
positional layouts: 10
strongback weldments, special jigs: 10 sheets
shop/fab drawings: 20

total time: 1 MY

engineering analysis/design: .5 MY

On site construction support from engineering: .5 MY

Inspection/Admin (my): 0.5   **Rate** ($k/my): 94   **Dur:** 1/93 - 12/95
Basis:

contract administration to place order	2 mm
vendor qualification	2 mm
inspections	2 mm
total	6mm = 0.5 my

EDIA/QA Material&Services ($k): 90   **Dur:** 1/93 - 12/95
Basis:1 trip/month x 36 month x 2.5k/trip = $135k

Procurement/Fabrication ($k): 250   **Dur:** 6/93 - 12/94
Basis:

Special rigging equipment: $100k

grouting and studs: $50k

surveying/alignment aids $100k

Installation/Ass'y (my): 0 **Rate ($k/my):** 48 **Dur:** 12/94-12/95

Material ($k): 0
Basis: Included in 1.3.1.7.2

Unit type: ea **Number of units:** 1

Estimate Type: EO

Risk Factors:

Technical:	4	Basis: Basic rigging
Cost:	6	Basis: Best guess based on experience
Schedule:	2	Basis: Critical path item

Misc Comments:

Basis of Estimate

WBS: 1.3.1.7.4 Item: Testing Equipment

Date: 12/11/91 Rev: 0A By: R. Yamamoto

Element Scope: This element covers all of the equipment required for testing the magnet system after installation. The primary testing equipment will be a system for mapping the magnetic field inside the magnet.

Technical design description: The magnetic field mapper will use a "Hall probe" to physically measure the field at discrete locations. A system will be employed to move, position and set the probe for field measurements and record both positional data as well as the "B" field vector.

Engineering/Design (my): .83 **Rate ($k/my):** 100 **Dur:** 1/94-12/94

Basis: Design will be contracted to a vendor. This item covers only final design effort. Drawings required include: overall magnetic mapper layout, interface drawing, detail drawings. Total of 20 drawings required @ 1mw/dwg = 20mw of design. Engineering support will also be 20mw. Gem engineering will be at 5% level for 12 mo. = 3mw. Total labor is 43mw = .83my. Total cost is $83k. Average labor rate is $100k/yr.

Inspection/Admin (my): .13 **Rate ($k/my):** 94 **Dur:** 1/95-12/95

Basis: Assume 1mm effort required to place contract after specs written; 0.05 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (12 mo.) = 0.6mm; Total labor is 1.6mm = .13my. Total cost is $12k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 16 **Dur:** 1/95-12/95

Basis: Assume 4 trips by two people to vendor at $2.0k/trip = $16k.

Procurement/Fabrication ($k): 350 **Dur:** 1/95-12/95

Basis: This includes the data acquisition system to sense, display and record the measurements, the magnetic field mapper hardware and all necessary equipment and fixtures. Total cost is estimated at $350k.

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k):

Basis: Installation of the magnetic field mapper will be done at 1.3.1.8.6 Testing.

Unit type: ea **Number of units:** 1

Estimate Type: EO

Risk Factors:

Technical: 4 Basis: Basic concept of field mapping is not an issue. The "how" to do it as efficiently as possible is the biggest concern.

Cost: 6 Basis: In-house estimate for item with minimal company experience but related to existing capabilities.

Schedule: 4 Basis: Delays completion of non-critical path subsystem item.

Misc Comments:

Basis of Estimate

WBS: **1.3.1.8.1** Item: **Solenoid Magnet Installation**

Date: 12/12/91 Rev: 0B By: J. Bowers

Element Scope: This element covers the installation of the solenoid magnet assembly in the underground hall. It includes installation of the coil assemblies, coil supports, the pole/pole support assemblies, and the central detector support in the hall. It does not include installation of the power or cryogenics systems.

Technical design description:
This includes the pole transporter and end pole field shaper installation.

This is primarily a labor category for installation. Major installation components are included in WBS 1.3.1.7.2 Coil Tooling.

Engineering/Design (my): 1 **Rate ($k/my):** 100 **Dur:** 6/92-6/93
Basis:
Installation planning will be contracted to a vendor per a design specification.

Design effort will consist of special lifting strongbacks, shoring and track arrangements, and alignment plans.

Some of this effort for installation planning is included in the design phase of individual equipment.

Inspection/Admin (my): 9.3 **Rate ($k/my):** 94 **Dur:** 1/95 - 12/96
Basis:

contract administration to place order	2 mm
vendor qualification	2 mm
progress inspections	6 mm
Administrative overhead	12 mm
coordinator support	24 mm
engineering support	36 mm
subtotal	82mm = 6.8 my

add in supervision of iunnstallation, at 10% of overall installation effort (25 my), or 2.5 my.

Total is 9.3 my for this category.

EDIA/QA Material&Services ($k): 466 **Dur:** 6/95 - 12/96
Basis:
average 2 trips/month x 18 month x 2.5k/trip = $90k
weld inspection QA time: 4 inspectors x 12 months = 48 mm
@ $94k/ year = $376k

Procurement/Fabrication ($k): 150 **Dur:** 1/93 - 1/96

Basis:
miscellaneous rigging equipment, ie straps, chainfalls, swivel eyes, shackles, come-alongs, scaffolding, sand blasting: $50k
installation stud drilling, welding, shimming equipment cost $100k

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Installation/Ass'y (my): 22.5 **Rate ($k/my):** 43 **Dur:** 1/96-12/96

Material ($k): $500
Basis:
materials: core drills, epoxy anchors, pipe hangers: 100k
Track system for subterranean installation: $100k
Surveying equipment: $50k
welding fixtures: $150k

vessel:
20 man rigging team for 2 months = 40 man months = 3.3 my
fit up welding, misc. welding 2 my
surveying = .5 my

saddles:
20 man rigging team for 2 months = 40 man months = 3.3 my
welding: .5 my
surveying = .5 my

central detector support:
surveying = .5my
weld fixturing and alignment 2 my
welding 4 my
bead blasting 1 my
5 man rigging team for 2 months = 10 man months = .8 my

pole transporter:
5 riggers + 5 techs for 2 months = 20 man months

End pole installation:
assemble = 10 man months each end x 2 ends = 20 mm
install = 10 man months each end x 2 ends = 20 mm
total = 40 mm

end pole field shaper:
10 men x 2 months = 20 mm

$100k for field shaper installation fixturing, shoring and survey setups.

subtotal for all of above = 25 my. This includes 10% supervision, included in another category, so only 90% of 25 is reported here....22.5my

See note below for comparison with vendor estimates.

Unit type: ea **Number of units:** 1

Estimate Type: BU

Risk Factors:
Technical: 3 Basis: Large activity
Cost: 4 Basis: Experience
Schedule: 8 Basis: Critical path

Misc Comments:
Two vendor estimates of manpower required for magnet winding and assembly have been obtained, but have not yet been analyzed in detail. These estimates covered all of the activities under WBS 1.3.1.1.1.1.5.2(coil winding), 1.3.1.1.1.8.2(coil assembly), 1.3.1.1.9(coil testing), and 1.3.1.8(installation). The average of the two vendor estimates for the sum of these tasks is 117,000man-hr; assuming, very conservatively, 1760man-hr per man-yr, this is 66.5man-years. The total assembly/installation labor included in this estimate for all four tasks is 56 + 10 + 2.7 + 16.6 = 85.3 man-years, or 28% higher than the vendor estimates.

Basis of Estimate

WBS: 1.3.1.8.2.1   Item: Power Supply Installation

Date: 11/11/91   Rev: 0B   By: G. Deis/M. Chaplin

Element Scope: This element covers the physical installation of the power supply, connection to the AC line, and connection to all facilities systems (such as LCW). This also covers installation of local power supply interlocks. This does not include any interfacing to the control system.

Technical design description: The power supply is assumed to come to the site in 2 large boxes. Each box must be put in place, and heavy wiring must be pulled between them (they are adjacent to each other). LCW must be plumbed to them from the nearest wall. The supply will then be shorted and exercised under panel control to verify its performance.

Engineering/Design (my): 0   **Rate ($k/my):** 0   **Dur:**

Basis: All necessary design completed under 1.3.1.2.1

Inspection/Admin (my): .05   **Rate ($k/my):** 137   **Dur:** 10/95-4/96

Basis: Supervision of installation is 10% of installation labor (0.05my).

EDIA/QA Material&Services ($k): 0   **Dur:**

Basis: none required

Procurement/Fabrication ($k): 50   **Dur:**

Basis: Covers miscellaneous conduit, wire, and breakers.

Installation/Ass'y (my): 0.47   **Rate ($k/my):** 43   **Dur:** 10/95-4/96

Material ($k): 5

Basis: This effort will require a 3-man crew, and will take 5 weeks to complete. Testing will require another month, with a 3-man crew. Use 90% to cover actual labor (minus supervision) => 0.47my. Use standard labor rate. Assume 5k misc supplies, since power supplies will come with almost everything.

Unit type: 1   **Number of units:** ea

Estimate Type: BU

Risk Factors:

Technical:	2	Basis: A Standard job.
Cost:	4	Basis: A Standard job.
Schedule:	2	Basis: No schedule impact likely.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.8.2.2 Item: Buswork Installation

Date: 11/11/91 Rev: 0B By: G. Deis/M. Chaplin

Element Scope: This element covers the installation of all the high-current buswork for the magnet, from the terminals on the power supply/breakers to the terminals on the magnet coils. It does not include connection of the dump resistor.
Technical design description: The busses are assumed to be aluminum, with internal water cooling. They will be installed within safety cages. Total bus length is assumed to be 180m. Busses will be delivered in 15m lengths, and the buss cross-section will consist of 4 pieces. Separate parts will be used for bends. Parts will be bolted together, in place. Insulating hangers will hold busses off each other and off the wall. These must be anchored to the wall.

Engineering/Design (my): 0 Rate ($k/my): 0 Dur:
Basis: All necessary design completed under 1.3.1.2.2

Inspection/Admin (my): 0.07 Rate ($k/my): 137 Dur: 10/95-4/96
Basis: Supervision of installation is 10% of installation labor (0.07my).

EDIA/QA Material&Services ($k): 0 Dur:
Basis: none required

Procurement/Fabrication ($k): 0 Dur:
Basis: All procurement covered under 1.3.1.2.2

Installation/Ass'y (my): 0.73 Rate ($k/my): 43 Dur: 10/95-4/96

Material ($k): 10
Basis: Assume hangers are every 15m, so there are 18 of these. A 3-man crew will install at a rate of approximately 1 per day, or all of these in 4 weeks (note that many are on vertical walls). Then, the bus pieces will be installed; this will require a 5-man crew for 1 month, again at a rate of about 1 piece per day. (Actually, the rate is more like 2 pieces/day, and there are approximately as many corners as straight pieces.) This includes installation of the guards as well. Finally, allow 3 men for 2 weeks to make up the final connections at both ends and to connect cooling. Total effort is then (3*4 + 5*4 + 3*2.0)/52=0.73my, at standard labor rate. Use 90% to cover actual labor (minus supervision) => 0.0.32my. Allow 5k for supplies, since this will require lots of nuts, bolts, expanded metal, etc.

Unit type: 1 **Number of units:** ea

Estimate Type: BU

Risk Factors:

Technical:	4	Basis: Design is not clear at this time, worst case estimated.
Cost:	4	Basis: Parts are not too complex.
Schedule:	2	Basis: No schedule impact likely.

Basis of Estimate

WBS: 1.3.1.8.2.3 Item: Breakers and Dump Resistor Inst.

Date: 11/6/91 Rev: 0A By: G. Deis/M. Chaplin

Element Scope: This element includes the physical installation of the breakers and dump resistor, connection to lcw, connection to the high-current bus, and installation of local controls on the physical devices.
Technical design description: The breaker is assumed to be one large box, which connects to the high-current bus. It will have one rack of local controls. The dump resistor is assumed to be a large tank with immersed SST tube resistors. It is positioned below the current bus, and connects to it over a long length of the bus. Assume one rack of local wiring for the dump resistor. Both breakers and dump resistor are assumed to be connected to LCW.

Engineering/Design (my): 0 **Rate ($k/my):** 0 **Dur:**
Basis: All necessary design completed under 1.3.1.2.3

Inspection/Admin (my): 0.04 **Rate ($k/my):** 137 **Dur:** 10/95-4/96
Basis: Supervision of installation is 10% of installation labor (0.04my).

EDIA/QA Material&Services ($k): 0 **Dur:**
Basis: none required

Procurement/Fabrication ($k): 0 **Dur:**
Basis: All procurement covered under 1.3.1.2.3

Installation/Ass'y (my): 0.33 **Rate ($k/my):** 43 **Dur:** 10/95-4/96

Material ($k): 5
Basis: The breakers can be installed by a 3-man crew in 0.5 mo, including local controls and wiring. The dump resistor will require a 3-man crew for 1 mo, due to its size, and the long connection to the bus. Use 90% to cover actual labor (minus supervision) => 0..333my. Standard labor rates apply. Supplies will be about $5k.

Unit type: 1 **Number of units:** ea

Estimate Type: BU

Risk Factors:
Technical: 2 Basis: A Standard job.
Cost: 4 Basis: Reasonable experience with this type of task
Schedule: 2 Basis: No schedule impact likely.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.8.2.4 Item: Quench Det and Diag Installation

Date: 11/11/91 Rev: 0B By: G. Deis/M. Chaplin

Element Scope: This element consists of installation of all systems required to diagnose the magnet or to signal a magnet quench. This includes all systems external to the magnet vacuum vessel, and before the control system.

Technical design description: Assume that the detection/diagnostic function is actually handled by the modicon and control computer. This element then contain only the wiring between the outside of the vacuum vessel (where internal diagnostics are assumed to be terminated) and the modicon. This is of order 50 channels.

Engineering/Design (my): 0 Rate ($k/my): 0 Dur:

Basis: All necessary design completed under 1.3.1.2.4

Inspection/Admin (my): 0.03 Rate ($k/my): 137 Dur: 10/95-4/96

Basis: Supervision of installation is 10% of installation labor (0.03my).

EDIA/QA Material&Services ($k): 0 Dur:

Basis: none required

Procurement/Fabrication ($k): 0 Dur:

Basis: All procurement covered under 1.3.1.2.4

Installation/Ass'y (my): 0.35 Rate ($k/my): 43 Dur: 10/95-4/96

Material ($k): 0

Basis: Assume 5 cables to be pulled and terminated. This will require about 4 men for 5 weeks, or 20mw or 0.38my. Use 90% to cover actual labor (minus supervision) => 0.35my. Standard labor rates apply. Supplies will be negligible.

Unit type: 1 **Number of units:** ea

Estimate Type: BU

Risk Factors:

Technical: 2 Basis: A Standard job.

Cost: 4 Basis: A Standard job.

Schedule: 2 Basis: No schedule impact likely.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.8.3.1 Item: LN System Installation

Date: 12/11/91 Rev: 0B By: R. Yamamoto

Element Scope: This element covers the installation of all of the LN system for the magnet subsystem. It includes installation of the major components in the cryogenics building, as well as installation of the piping and distribution lines within the building and to the underground hall.

Technical design description:

Engineering/Design (my): 0.39 **Rate ($k/my):** 100 **Dur:** 6/95-5/96

Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: details of major subassemblies. Total of 2 dwgs @ 1mw/dwg =2mw of design. Engineering support will be = 2mw. Additional 16 man weeks of engineering to write cryogenic safety note and startup procedure. Total labor is 20 mw = 0.39 my. Total cost is $39.0k. Average labor rate is $100k/yr.

Inspection/Admin (my): .38 **Rate ($k/my):** 94 **Dur:** 6/95-5/96

Basis: Assume 1mm effort required to place contract after specs written; 0.05 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (12 mo) = 0.6mm; Supervision will be 0.25 men for one year = 3mm. Total labor is 4.6mm = .38my. Total cost is $36k., Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): $16 **Dur:** 6/95-5/96

Basis: Assume 4 trips by two people to vendor at $2.0k/trip = $16k

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Procurement/Fabrication ($k): 50 **Dur:** 6/95-5/96

Basis: Assume cost of custom fixtures/hardware/pipe hangers and misc. fixtures required = $75k.

Installation/Ass'y (my): 2.5 **Rate ($k/my):** 45 **Dur:** 12/95-5/96

Material ($k): 25

Basis: Assembly team consists of 5 men (1 lead tech, 3 techs, 1 welder). (5 men)*(6 mo)=30mm=2.5my. Total cost = $113k. Average labor rate=$45k/yr. Assume $25k for misc. hardware required.

Unit type: ea **Number of units:** 1

Estimate Type: EO

Risk Factors:

Technical: 4 Basis: New design within established product line.

Cost: 6 Basis: In-house estimate for item with minimal company experience but related to existing capabilities.

Schedule: 4 Basis: Delays completion of non-critical path subsystem item.

Basis of Estimate

WBS: 1.3.1.8.3.2 Item: LHe System Installation

Date: 12/11/91 Rev: 0B By: R. Yamamoto

Element Scope: This element covers the installation of all of the LHe system for the magnet subsystem. It includes installation of the major components in the cryogenics building, as well as installation of the piping and distribution lines within the building and to the underground hall.

Technical design description:

Engineering/Design (my): .69 **Rate ($k/my):** 100 **Dur:** 6/95-5/96

Basis: Design will be contracted to a vendor. Specifications are written by GEM during preliminary design. This item covers only final design effort. Drawings required include: details of major subassemblies. Total of 2 dwgs @ 1mw/dwg =2mw of design. Engineering support will half of the required design support = 2mw. Additional 32 man weeks to write cryogenic safety note and startup procedure. Total labor is 36mw = .69 my. Total cost is $69.0k. Average labor rate is $100k/yr.

Inspection/A1min (my): .38 **Rate ($k/my):** 94 **Dur:** 6/95-5/96

Basis: Assume 1mm effort required to place contract after specs written; 0.05 FTE (GEM LLNL coordinator) to monitor contract for duration of procurement (12 mo) = 0.6mm; Supervision will be 0.25 men for one year = 3mm. Total labor is 4.6mm = .38my. Total cost is $36k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k):$16 **Dur:** 6/95-5/96

Basis: Assume 4 trips by two people to vendor at $2.0k/trip = $16k

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Procurement/Fabrication ($k): 50 **Dur:** 6/95-5/96

Basis: Assume cost of custom fixtures/hardware/pipe hangers and misc. fixtures required = $75k.

Installation/Ass'y (my): 2.5 **Rate ($k/my):** 45 **Dur:** 12/95-5/96

Material ($k): 25

Basis: Assembly team consists of 5 men (1 lead tech, 3 techs, 1 welder). (5 men)*(6 mo)=30mm=2.5my. Total cost = $113k. Average labor rate=$45k/yr. Assume $25k for misc. hardware required.

Unit type: ea **Number of units:** 1

Estimate Type: EO

Risk Factors:

Technical: 4 Basis: New design within established product line.

Cost: 6 Basis: In-house estimate for item with minimal company experience but related to existing capabilities.

Schedule: 4 Basis: Delays completion of non-critical path subsystem item.

Basis of Estimate

WBS: 1.3.1.8.4 Item: Vacuum System Installation

Date: 12/6/91 Rev: 0A By: J. Bowers

Element Scope: This element covers installation of all the pumps, valves, piping, traps, pressure sensors, etc required for the magnet vacuum system. Installation and wiring of controls is not included here (see 3.1.8.5).

Technical design description:

This is primarily a labor activity. Some rigging, welding, leak checking, and mechanical assembly will be required.

Engineering/Design (my): .5 **Rate ($k/my):** 100 **Dur:** 9/92-12/92

Basis:

Design effort consists mainly of installation and checkout procedures.

Inspection/Admin (my): 1.6 **Rate ($k/my):** 94 **Dur:** 9/92 - 12/96

Basis:

contract administration to place order	2 mm
leak checking personnel	6 mm
vendor qualification	2 mm
inspections	2 mm
subtotal	12mm = 1.0 my

add in supervision of installation, at 10% of total effort (6my), or 0.6my.

Total is 1.6my.

EDIA/QA Material&Services ($k): 15 **Dur:** 1/95 -12/96

Basis:

1 trip/month x 6 month x 2.5k/trip = $15k

Procurement/Fabrication ($k): **Dur:** 1/93 - 1/95

Basis:

Installation/Ass'y (my): 5.4 **Rate ($k/my):** 43 **Dur:** 1/95 -12/96

Material ($k): $150k

Basis:

Leak checking equipment : $100k
core drilling/ epoxy stud installation $50k
on site welding activity: 2 my
mech tech assembly: 4 my

subtotal = 6my. Supervision (10%) is included, so remove it, and report 90% of this here: 5.4my

Unit type: ea   Number of units: 1

Estimate Type: BU

Risk Factors:

Technical: 5 Basis: Standard vacuum system installation

Cost: 3 Basis: Experience

Schedule: 7 Basis: Leak checking always poses a schedule risk.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.8.5 Item: Control System Installation

Date: 12/11/91 Rev: 0E By: G. Deis/M. Chaplin

Element Scope: This element covers the installation of all the magnet controls, including readouts and controls for power/protection, cryogenics, and vacuum system. It does not include any computers or local control room.

Technical design description: This element covers mainly the installation and wiring of the modicon itself. This is a 2-rack system, with a fair number of connections to be made. This also includes all wiring to sensors and all controlled items.

Engineering/Design (my): 0.06 Rate ($k/my): 100 Dur: 1/93-10/94

Basis: Drawing count: overall system instrumentation control layouts (in addition to those covered under 1.3.1.5), detailed wiring diagrams for racks (2), total 3. Engineering effort will be light, so assume it is included in drawing effort. Total 3mw/52=0.06my. Standard Labor rate applies

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Inspection/Admin (my): 0.1 Rate ($k/my): 94 Dur: 1/93-4/96

Basis: Supervision of installation is 10% of installation labor (0.1my).

EDIA/QA Material&Services ($k): 10 Dur: 1/93-10/94

Basis: Some travel required to confer with facilities people at SSCL. Assume 5 trips at 2k each.

Procurement/Fabrication ($k): 0 Dur:

Basis: No major procurements included in this element

Installation/Ass'y (my): 1.25 Rate ($k/my): 43 Dur: 10/94-4/96

Material ($k): 15.0

Basis: This covers installation of about 2 racks for the modicon, I/O hardware, and misc controls, and (the big item) wiring to all the various controlled items, such as compressors, valves, sensors, etc. Assume that this requires a 5-man team, for 3 months, for a total of 15mm, or 1.25my (supervision is extra). In addition, this will require a large amount of conduit, boxes, wire, etc, so allow $15k.

Unit type: 1 **Number of units:** ea

Estimate Type: EO

Risk Factors:

Technical: 4 Basis: Design is not very detailed at this time.

Cost: 4 Basis: Reasonably standard effort.

Schedule: 2 Basis: No schedule impact likely

Misc Comments:

Basis of Estimate

WBS: **1.3.1.8.6** Item: **Testing**

Date: 12/11/91 Rev: 0B By: R. Yamamoto

Element Scope: This element covers all testing of the magnet subsystem after installation. This includes initial system checkout testing and extends through magnetic-field mapping. This element includes only testing performed prior to installation of the internal detector subsystems; testing of the detector as a whole is included in operations.

Technical design description: Includes set-up of equipment prior to testing.

Engineering/Design (my): 0 **Rate ($k/my):** 100 **Dur:** 7/96-12/96
Basis: Engineering supervision is costed in Installation.

Inspection/Admin (my): .05 **Rate ($k/my):** 94 **Dur:** 7/96-12/96
Basis: Effort requires 0.1 FTE (GEM LLNL coordinator) to monitor small purchases during on-going testing = .6mm. Total effort is 0.6mm = .05my. Total cost is $5k. Average labor rate is $94k/yr.

EDIA/QA Material&Services ($k): 0 **Dur:** 7/96-12/96
Basis:

Procurement/Fabrication ($k): 25 **Dur:** 7/96-12/96
Basis: Incidental fabrication is estimated to be $25k.

Installation/Ass'y (my): 4.5 **Rate ($k/my):** 98 **Dur:** 7/96-12/96
Material ($k): 10
Basis: The "team mix" required to map the field of the magnet is as follows:
1 National Lab engineer/physicist: $154k/yr
1 National Lab electro-mechanical engineer: $154k/yr
1 National Lab mechanical engineer: $154k/yr.
1 National Lab senior tech: $103k/yr.
2 job shop senior tech: $54k/yr.
4 job shop junior tech: $39k/yr.
1 contractor riggor: $52k/yr.
Average rate:$881k/9 men = $98k/yr.
Total effort required: (9 men)*(6 mo) = 54mm = 4.5my. Total cost is $441k.

Unit type: ea **Number of units:** 1
Estimate Type: EO

Risk Factors:

Technical: 3 Basis: Field mapping is well understood; size of magnet to map is a key variable.
Cost: 6 Basis: In-house estimate for item with minimal company experience but related to existing capabilities.
Schedule: 8 Basis: Delays completion of critical path subsystem item.

Misc Comments:

Basis of Estimate

WBS: 1.3.1.9.1 Item: Project Management/Administration
Date: 10/20/91 Rev: 00 By: G. Deis

Element Scope: This element covers subsystem-level management, including periodic reviews and reporting upward to GEM management.
Technical design description: Assume that this is one full-time manager plus secretaries.

Engineering/Design (my): 0 **Rate ($k/my):** 0 **Dur:**
Basis: none required

Inspection/Admin (my): 12.0 **Rate ($k/my):** 93 **Dur:** 1/93-1/97
Basis: Assume one manager at National Lab Rate, plus two secretaries, one of which is covered by overhead. Total rate is (216 + 62)/3

EDIA/QA Material&Services ($k): 292 **Dur:** 1/93-1/97
Basis: assume $25k/yr to cover supplies, plus 2 trips/month at 2k each.

Procurement/Fabrication ($k): xxx **Dur:**
Basis: none required

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**
Material ($k): 0
Basis: none required

Unit type: 1 **Number of units:** ea
Estimate Type: EQ

Risk Factors:
Technical: 4 Basis: Not certain of SSCL requirements
Cost: 1 Basis: Standard rate
Schedule: 2 Basis: No impact

Misc Comments:

Basis of Estimate

WBS: 1.3.1.9.2 Item: Resource Management

Date: 10/20/91 Rev: 00 By: G. Deis

Element Scope: This element includes the effort required to maintain magnet subsyste cost/schedule projectiuons, and to monitor actual progress and spending, in order to identify trends and provide information for subsystem and detector management.
Technical design description: Assume that this requires one full-time resource analyst.

Engineering/Design (my): 0 Rate ($k/my): 0 Dur:
Basis: none required

Inspection/Admin (my): 4.0 Rate ($k/my): 93 Dur: 1/93-1/97
Basis: Assume one resource analyst at National Lab coordinator rate. Secretary is shared with project manager

---

EDIA/QA Material&Services ($k): 40 Dur: 1/93-1/97
Basis: assume $10k/yr to cover supplies, computer time.

Procurement/Fabrication ($k): xxx Dur:
Basis: none required

Installation/Ass'y (my): 0 Rate ($k/my): 0 Dur:

Material ($k): 0
Basis: none required

Unit type: 1 **Number of units:** ea

Estimate Type: EO

Risk Factors:
Technical: 4 Basis: Not certain of SSCL requirements
Cost: 1 Basis: Standard rate
Schedule: 2 Basis: No impact

Misc Comments:

Basis of Estimate

WBS: 1.3.1.9.3 Item: ES&H
Date: 10/20/91 Rev: 00 By: G. Deis

Element Scope: This element covers all activities required to ensure that magnet subsystem activities are conducted in the safest possible manner, with minimal impact on the environment and the health of the workers and public. It includes safety reviews of subsystem designs, as well as adequate tracking to ensure ES&H requirments are identified and met.
Technical design description: Assume that this requires one full-time engineer.

Engineering/Design (my): 0 **Rate ($k/my):** 0 **Dur:**
Basis: none required

Inspection/Admin (my): 4.0 **Rate ($k/my):** 154 **Dur:** 1/93-1/97
Basis: Assume one engineer at National Lab rate. Secretary is shared with project manager

---

EDIA/QA Material&Services ($k): 48 **Dur:** 1/93-1/97
Basis: Assume 6 trips/yr at 2K each.

Procurement/Fabrication ($k): xxx **Dur:**
Basis: none required

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**
Material ($k): 0
Basis: none required

Unit type: 1 **Number of units:** ea
Estimate Type: EO

Risk Factors:
Technical: 4 Basis: Not certain of SSCL requirements
Cost: 1 Basis: Standard rate
Schedule: 2 Basis: No impact

Misc Comments:

Basis of Estimate

WBS: 1.3.1.9.4 Item: Quality Assurance

Date: 10/20/91 Rev: 00 By: G. Deis

Element Scope: This element includes the development and maintenance of a magnet subsystem quality assurance plan (QAP), consistant with the overall GEM QAP. It includes the neccessary oversight and documentation.

Technical design description: see below

Engineering/Design (my): 0 Rate ($k/my): 0 Dur:

Basis: none required

Inspection/Admin (my): 3.0 Rate ($k/my): 154 Dur: 1/93-1/97

Basis: Assume one engineer at National Lab rate for the first two years, then only half-time for the last two years . Secretary is shared with project manager

---

EDIA/QA Material&Services ($k): 48 Dur: 1/93-1/97

Basis: Assume 6 trips/yr at 2K each.

Procurement/Fabrication ($k): xxx Dur:

Basis: none required

Installation/Ass'y (my): 0 Rate ($k/my): 0 Dur:

Material ($k): 0

Basis: none required

Unit type: 1 Number of units: ea

Estimate Type: EO

Risk Factors:

Technical: 4 Basis: Not certain of SSCL requirements

Cost: 1 Basis: Standard rate

Schedule: 2 Basis: No impact

Misc Comments:

Basis of Estimate

WBS: 1.3.1.9.5 Item: Subsystem Integration

Date: 10/20/91 Rev: 00 By: G. Deis

Element Scope: This element covers activities required to ensure proper integration of the various subsystems within GEM, as well as between GEM and the physical facilities on-site.

Technical design description: see below

Engineering/Design (my): 0 **Rate** ($k/my): 0 **Dur:**

Basis: none required

Inspection/Admin (my): 3.0 **Rate** ($k/my): 154 **Dur:** 1/93-1/97

Basis: Assume one engineer at National Lab rate for the first two years, then only half-time for the last two years . Secretary is shared with project manager

---

EDIA/QA Material&Services ($k): 96 **Dur:** 1/93-1/97

Basis: Assume 12 trips/yr at 2K each.

Procurement/Fabrication ($k): xxx **Dur:**

Basis: none required

Installation/Ass'y (my): 0 **Rate** ($k/my): 0 **Dur:**

Material ($k): 0

Basis: none required

Unit type: 1 **Number of units:** ea

Estimate Type: EO

Risk Factors:

Technical: 4 Basis: Not certain of SSCL requirements

Cost: 1 Basis: Standard rate

Schedule: 2 Basis: No impact

Misc Comments:

Basis of Estimate

WBS: 1.3.1.9.5 Item: Subsystem Integration

Date: 10/20/91 Rev: 00 By: G. Deis

Element Scope: This element covers activities required to ensure proper integration of the various subsystems within GEM, as well as between GEM and the physical facilities on-site.

Technical design description: see below

Engineering/Design (my): 0 **Rate ($k/my):** 0 **Dur:**

Basis: none required

Inspection/Admin (my): 3.0 **Rate ($k/my):** 154 **Dur:** 1/93-1/97

Basis: Assume one engineer at National Lab rate for the first two years, then only half-time for the last two years . Secretary is shared with project manager

---

EDIA/QA Material&Services ($k): 96 **Dur:** 1/93-1/97

Basis: Assume 12 trips/yr at 2K each.

Procurement/Fabrication ($k): xxx **Dur:**

Basis: none required

Installation/Ass'y (my): 0 **Rate ($k/my):** 0 **Dur:**

Material ($k): 0

Basis: none required

Unit type: 1 **Number of units:** ea

Estimate Type: EO

Risk Factors:

Technical: 4 Basis: Not certain of SSCL requirements

Cost: 1 Basis: Standard rate

Schedule: 2 Basis: No impact

Misc Comments:

10.0 Vendor Estimates

This section on cost estimates received from vendors is bound under separate cover (document # GEM-LLNL-91-002). The information provided to us by the vendors is proprietary and is to be used for budgetary purposes only. This document can be reviewed as required with the strict understanding that the document contains proprietary information such that no copy or other reproduction of the vendor estimate document may be made either in whole or in part.

Estimates received from vendors that were used to develop the cost estimate totaled $34,617k. Conceptual/preliminary design and construction costs (WBS 1.2 & 1.3) totaled $82,215k ($4,903k + $77,312k respectively). Approximately 42% of the total conceptual/preliminary design and construction costs were based upon actual vendor estimates. These estimates were provided based on drawings, sketches, specifications and direct communications between the vendor and LLNL/MIT.

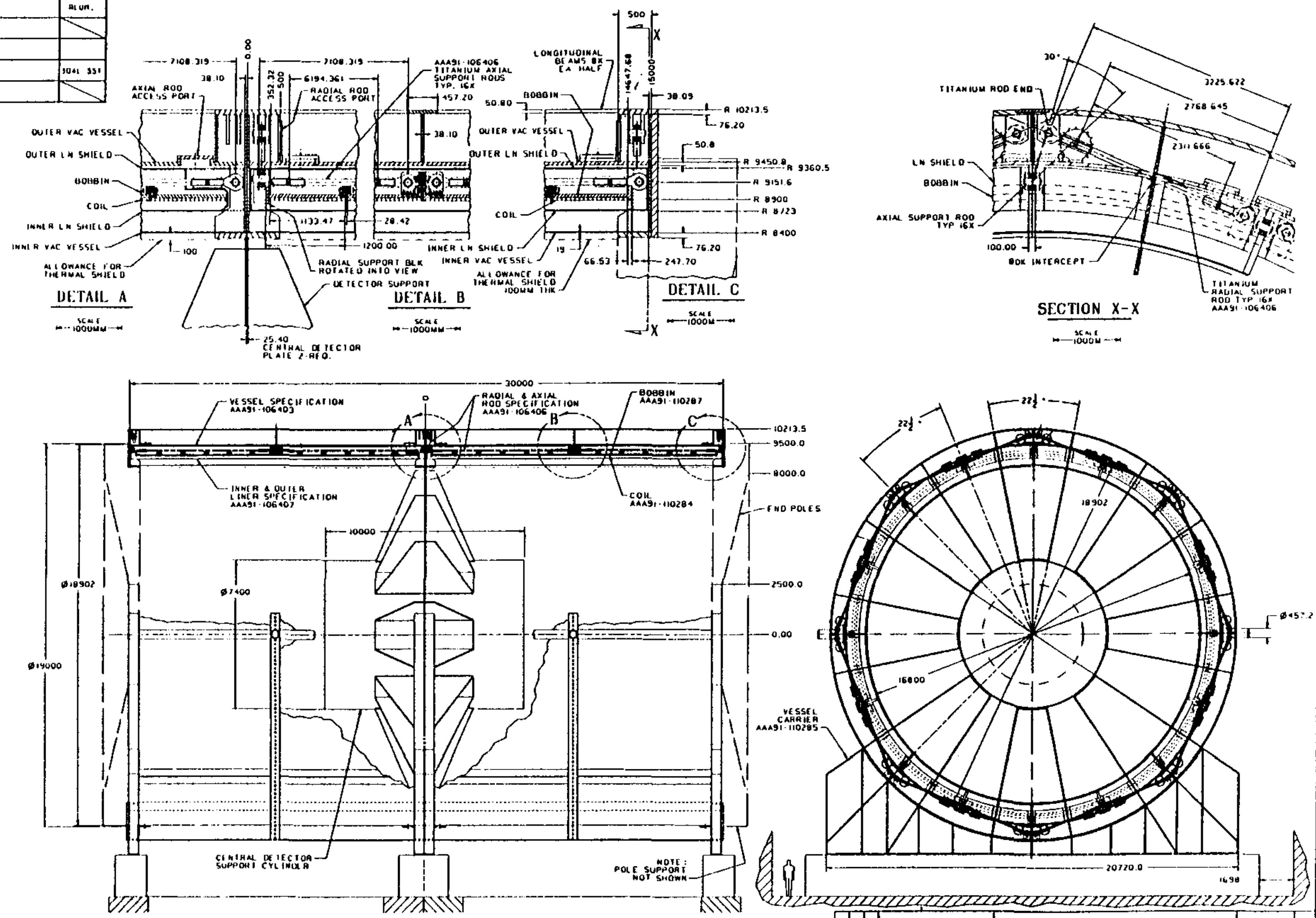
11.0 GEM Drawings

12/04/91

Number	Title
AAA91-106424-00	Final Concept Assembly
AAA91-106403-0A	Vessel Concept Weldment
AAA91-110285-00	Vessel Carrier
AAA91-103681-00	Magnet Winding Config.
AAA91-103683-00	Cold Mass Configuration
AAA91-110287-00	1 Meter Bobbin
AAA91-110284-00	"C" Coil Configuration
AAA91-110283-00	Coil Configuration
AAA91-106433-00	"A-2C" Coil Configuration
AAA91-106407-0A	Inner & Outer Shield Spec.
AAA91-106406-0A	Radial & Axial Rod Spec.

STRUCTURE	THICKNESS METERS	WEIGHT METRIC TONS	MATERIAL
OUTER VAC VESSEL	0.0635		A516 STL GRADE 70
OUTER LN SHIELD	0.020		
BOBBIN	0.050		ALUM. 6061-T6
COIL	0.100		ALUM.
BOBBIN & COIL TOTAL	0.150		
INNER LN SHIELD	0.020		
INNER VAC VESSEL	0.019		304L SST
TOTAL ASSEMBLY	0.2725		

NOTES
UNLESS OTHERWISE SPECIFIED:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982. MILLIMETERS UNITS
2. SURFACE TEXTURE PER ANSI B46.1-1978.



10-17-91

NO REQD	PART/LINE ITEM NO	DESCRIPTION/MATERIAL	SPEC NO	ITEM

DRN POSEY 8/91
CLASSIFICATION
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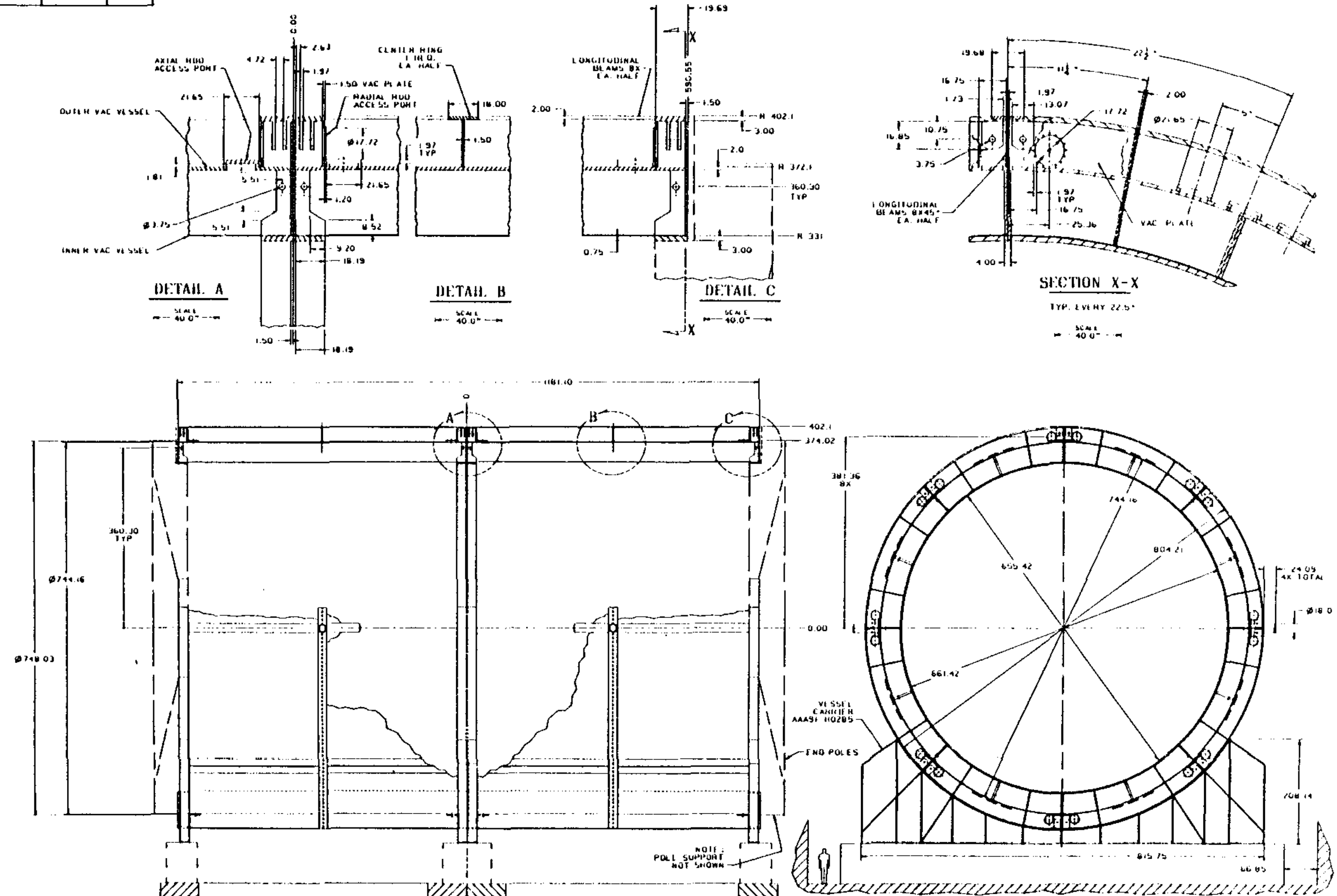
MAJOR UNIT: GEM
SUBASSY: COIL ASSEMBLY 3.1.1.1
DETAIL: FINAL CONCEPT ASSEMBLY
LAWRENCE LIVERMORE NATIONAL LABORATORY MECHANICAL ENGINEERING
OFFICIAL USE
DRAWING NO AAA91-106424-00
SHEET 1 OF 1

STRUCTURE	THICKNESS INCHES	WEIGHT METRIC TONS	MATERIAL
OUTER VAC VESSEL	2.000		A516 STL GRADE 70
INNER VAC VESSEL	.750		304L SST
TOTAL ASSEMBLY			

NOTES
UNLESS OTHERWISE SPECIFIED:

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M 1982. INCH UNITS
2. SURFACE TEXTURE PER ANSI B46.1 1978



REFERENCE ONLY
NOT FOR FABRICATION
10-17-91

DRN	POSEY 8/91
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MAJOR UNIT	COIL ASSEMBLY 3.1.1.1
SUBASSY	VACUUM VESSEL SUBASSY 3.1.1.1.3
DETAIL	VESSEL CONCEPT WELDMENT
DRAWING NO	AAA91-106403-0A

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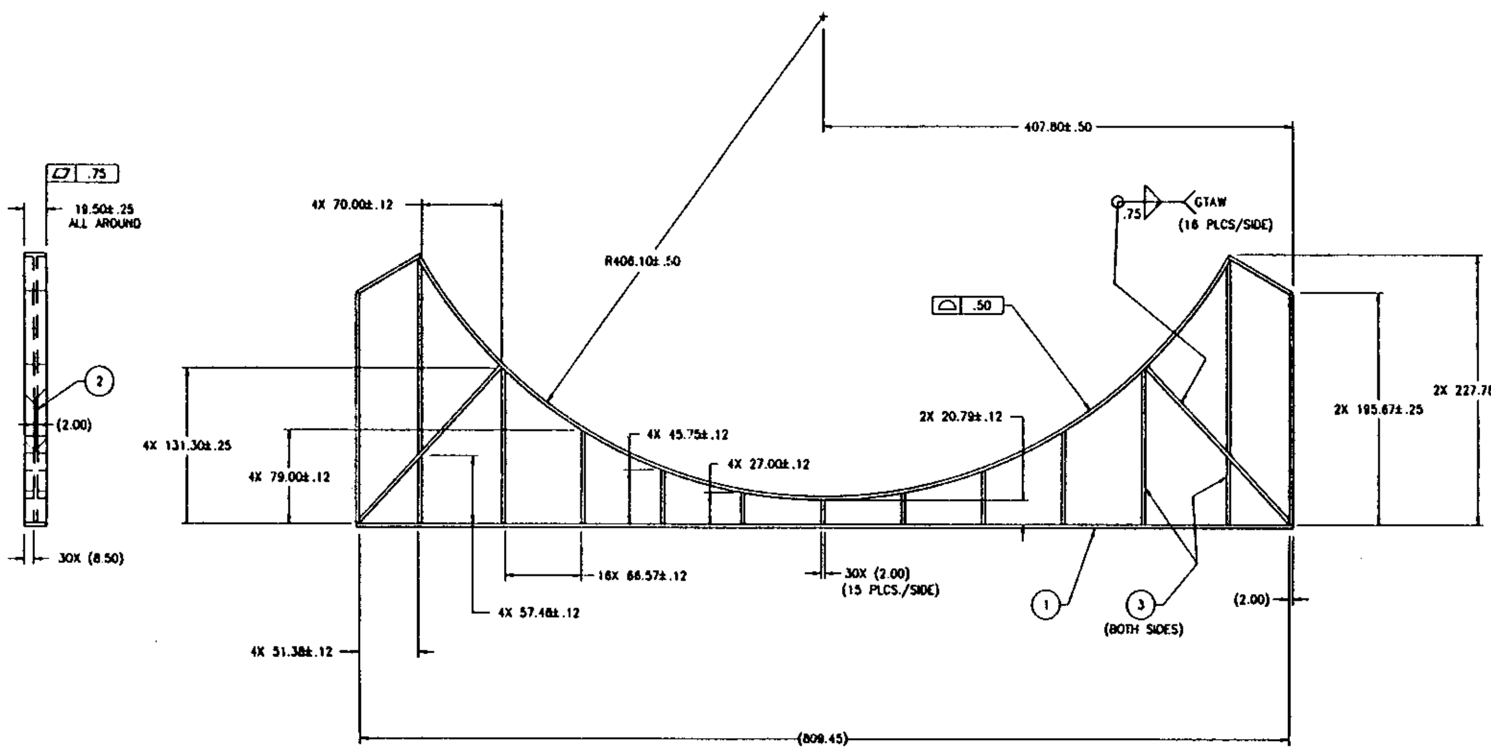
A GEN. REV.

NOTES
UNLESS OTHERWISE SPECIFIED:

1. ALL DIMENSIONS ARE IN INCHES.
2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
3. SURFACE TEXTURE PER ANSI B46.1-1978.
4. 250/ FINISH ALL MACHINED SURFACES.
5. REMOVE BURRS AND BREAK SHARP EDGES .375/500.
6. APPROX. WEIGHT = 81,000 LBS.
7. LLNL/AutoCAD(tm) Release 11 USER FILENAME: 1XXXXXX1.DWG
8. ALL STRUCTURAL STEEL WELDS PER ANSI/AWS D1.1-85.
9. ALL WELD SYMBOLS ARE PER ANSI/AWS A2.4-76.
10. INSPECTION AND CERTIFICATION OF ALL WELDS ARE PER ANSI/AWS B1.0-77.
11. SANDBLAST, PRIMER AND PAINT.



PRELIMINARY ONLY - NOT FOR FAB

	AR		BAR, 8.50" X 2.00"	A529(STEEL)		3
	AR		PLATE, 2.00" THICK	A529(STEEL)		2
	AR		PLATE, 2.00" THICK	A529(STEEL)		1
NO REQD		PART / LLNL STK NO	DESCRIPTION / MATERIAL		SPEC NO	ITEM

DWN W J WONG 8/91

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UNIVERSITY OF CALIFORNIA

GEM
DETECTOR
VESSEL CARRIER

DRAWING NO
AAA91-110285-00

SHEET 1 OF 1

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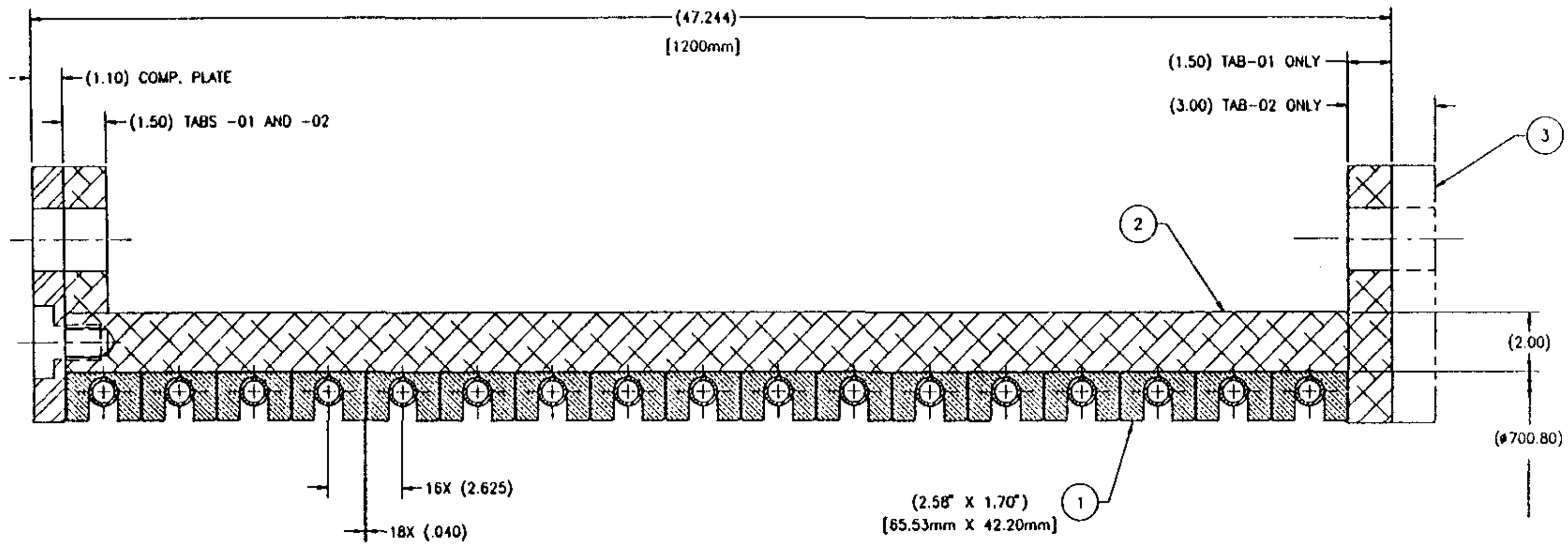
NOTES
UNLESS OTHERWISE SPECIFIED:

1. ALL DIMENSIONS ARE IN INCHES.
2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
3. SURFACE TEXTURE PER ANSI B46.1-1978.
4. CLEAN FINISHED PART OF ALL OIL, DIRT, GREASE, ETC.
5. LLL AutoCAD(tm) REL. 11 USER FILENAME: 11036811.DWG



NOTE: DETAIL SHOWN IN CROSS-SECTION.

FOR INFORMATION OR REVIEW ONLY - DO NOT USE FOR PROCUREMENT OR FABRICATION

NO REQD		PART / LLNL STK NO	DESCRIPTION / MATERIAL		SPEC NO	ITEM
1		AAA 91-110287	1 METER BOBBIN	TAB-02		3
	1	AAA 91-110287	1 METER BOBBIN	TAB-01		2
AR	AR	AAA 91-110284	"C" COIL CONFIGURATION			1
TAB-02	TAB-01					

DWN	W J WONG	10/91	
CHK			
APVD			

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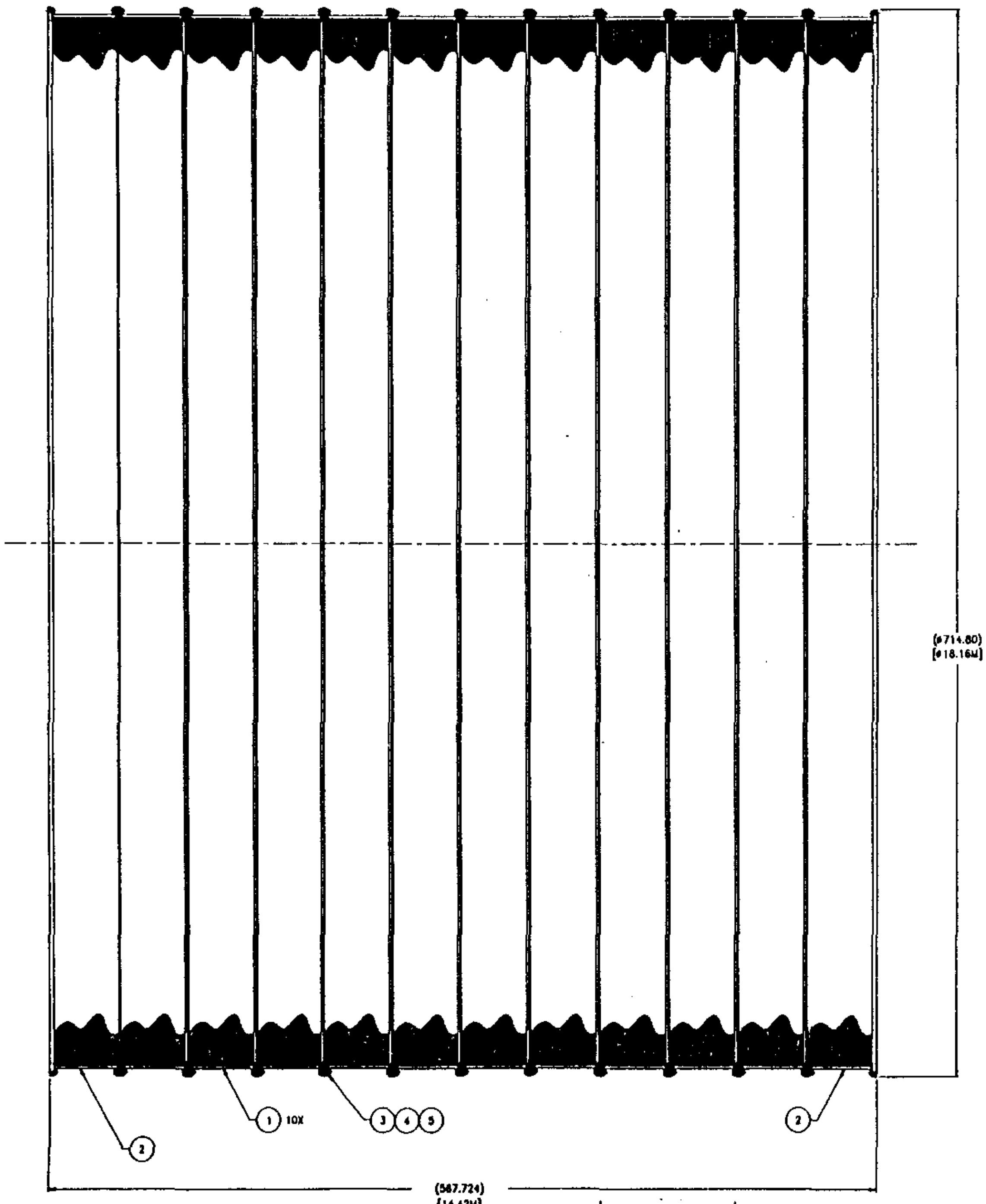
MAJOR UNIT: GEM
SUBASSY: COLD MASS
DETAIL: MAGNET WINDING CONFIGURATION

SHOWN ON AAA 91-108424
DRAWING NO AAA 91-103681-00
0875-12

LTR	DWN	CHK	APVD	DATE	ZONE	CHANGE

NOTES
UNLESS OTHERWISE SPECIFIED.

1. ALL DIMENSIONS ARE IN INCHES.
2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
3. SURFACE TEXTURE PER ANSI B46.1-1978.
4. APPROX. WEIGHT = 880,000 LBS. = 400 MTons
5. LLNL/AutoCAD(tm) Release 10 USER FILENAME: 11036831.DWG



NO REQD	PART / LINE SEE NO	DESCRIPTION / MATERIAL	SPEC NO	ITEM
1584		WASHER, SPRING, 2" I.D. X 4.5" O.D. X .250" THICK (CRES)		5
792		HEX NUT, 2"-8UN (CRES)		4
792		HEX HD SCREW, 2"-8UN X 6"L (CRES)		3
2	AAA 91-103681	MAGNET WINDING CONFIGURATION TAB-02		2
10	AAA 91-103681	MAGNET WINDING CONFIGURATION TAB-01		1

GEM
COLD MASS
COLD MASS CONFIGURATION
DRAWING NO AAA91-103683-00

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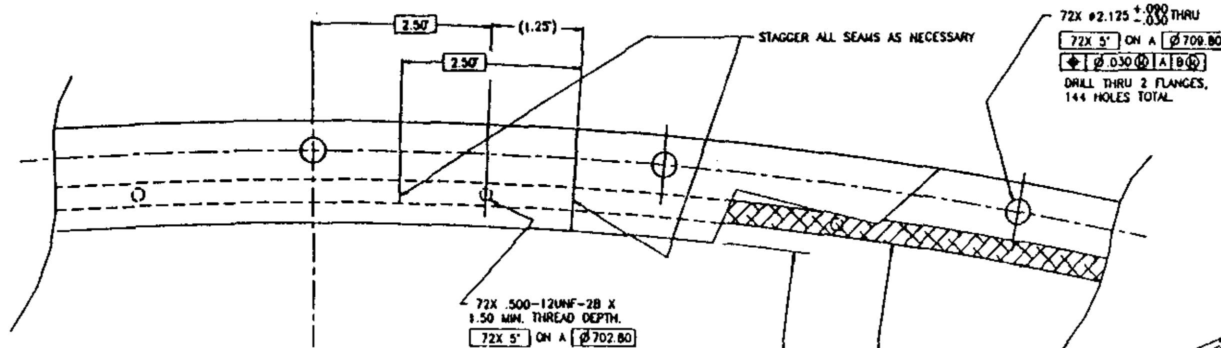
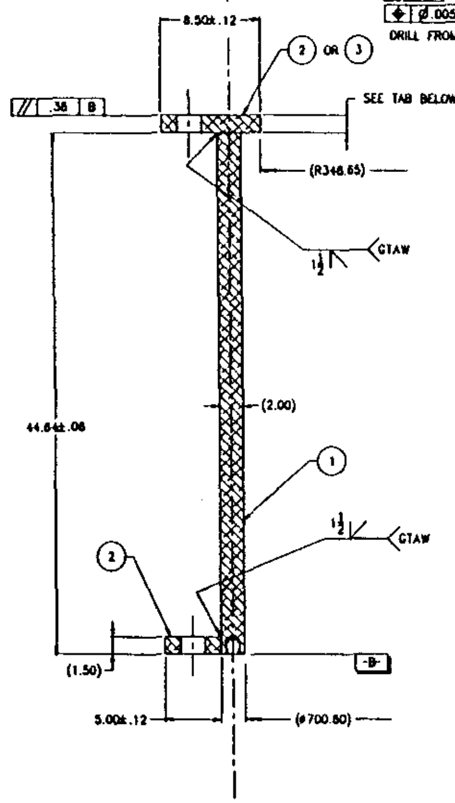
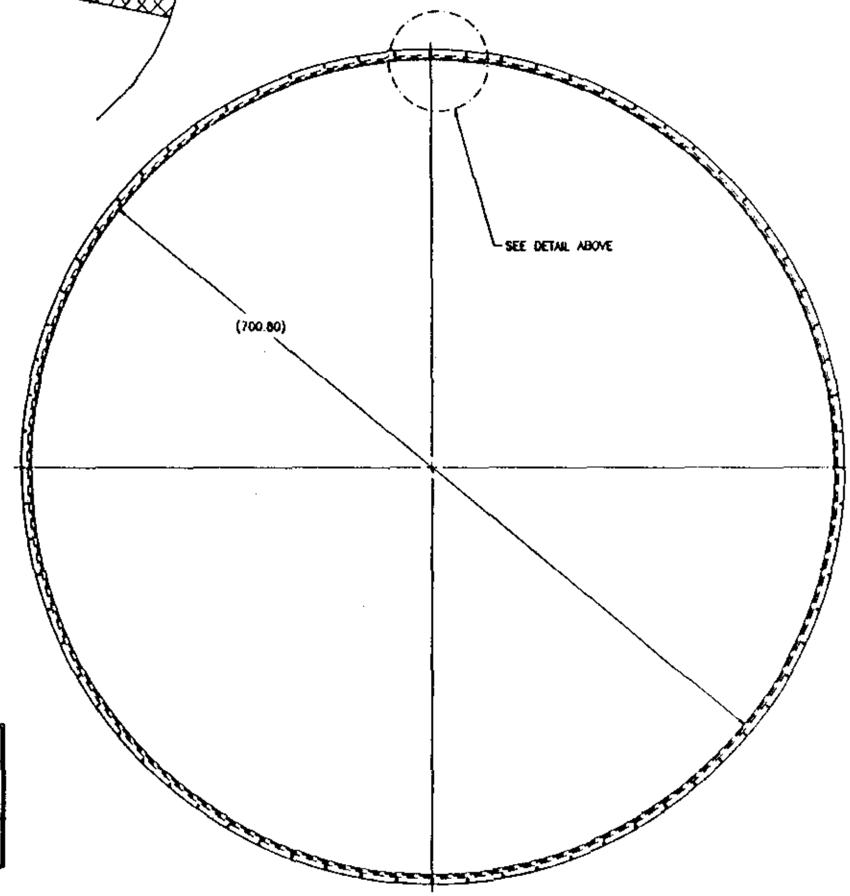
UNIVERSITY OF CALIFORNIA





BOBBIN DETAIL
NO SCALE



NOTES
UNLESS OTHERWISE SPECIFIED:

1. ALL DIMENSIONS ARE IN INCHES.
2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
3. SURFACE TEXTURE PER ANSI B46.1-1978.
4. 250 FINISH ALL MACHINED SURFACES.
5. REMOVE BURRS AND BREAK SHARP EDGES .25/.38.
6. ALL WELDS TO BE CLEAN AND FREE OF SLAG AND SPLATTER.
7. ALL WELD SYMBOLS ARE PER ANSI/AWS A2.4-78.
8. WELDS ARE PER ANSI/AWS D1.2-83 AND ANSI/AWS D1.2A-83.
10. LLNL/AutoCAD(tm) Release 11 USER FILENAME: 1XXXXXX1.DWG

TAB NO.	DESCRIPTION	APPROX. WEIGHT
TAB-01	USE ITEM 2 (1.50")	24,160 LBS. (10.96 MTons)
TAB-02	USE ITEM 3 (3.00")	26,980 LBS. (12.26 MTons)

PRELIMINARY ONLY
NOT FOR FABRICATION

TAB-02	TAB-01	PART / IDENT NO	DESCRIPTION / MATERIAL		SPEC NO	ITEM
1			PLATE, 3.00" THICK	6061-T6 (ALUM)		3
1	2		PLATE, 1.50" THICK	6061-T6 (ALUM)		2
1	1		PLATE, 2.00" THICK	6061-T6 (ALUM)		1

DWN W J WONG

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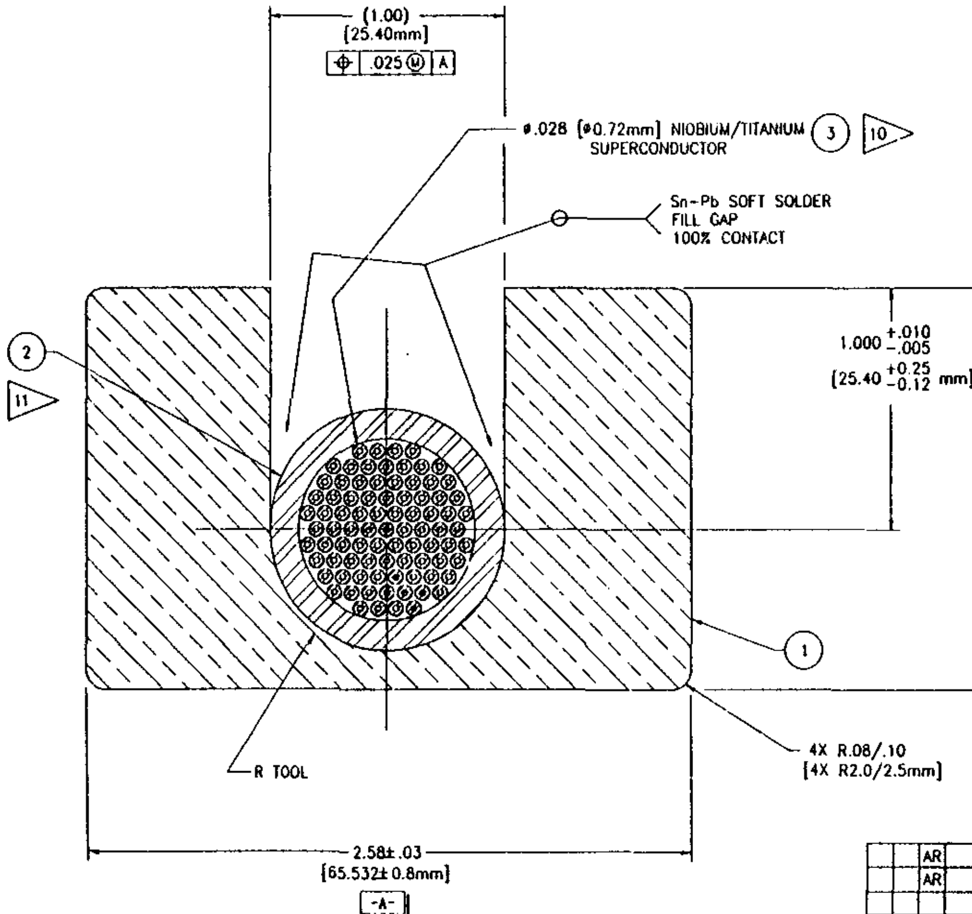
UNIVERSITY OF CALIFORNIA

GEM
MAGNET
1 METER BOBBIN

DRAWING NO
AAA91-110287-00



NOTES
UNLESS OTHERWISE SPECIFIED:

1. ALL DIMENSIONS ARE IN INCHES.
2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
3. SURFACE TEXTURE PER ANSI B46.1-1978.
4. 125/ FINISH ALL OVER.
5. REMOVE BURRS AND BREAK SHARP EDGES .05/.15.
6. CLEAN FINISHED PART OF ALL OIL, DIRT, GREASE, ETC.
7. ASSEMBLE AS LONGEST SINGLE LENGTH POSSIBLE WITH MINIMAL JOINTS.
8. LLL AutoCAD(tm) REL. 11 USER FILENAME: 11102841.DWG
9. APPROXIMATE WEIGHT PER LINEAR FOOT OF LENGTH = 14.00 LBS.
10. COPPER SHEATHING TO SUPERCONDUCTOR CROSS-SECTIONAL AREA RATIO IS 2:1.
11. OPTIONAL: TUBE MAY BE FABRICATED USING (OFHC) COPPER OF SIMILIAR DIMENSIONAL SIZE.
12. APPROXIMATE TOTAL LENGTH REQUIRED = 15 miles [24.1km].
13. APPROXIMATE TOTAL WEIGHT REQUIRED = 1,108,800 LBS. [508 MTons].

PRELIMINARY ONLY

NOT FOR FABRICATION

NO REQD	PART / IDENT STK NO	DESCRIPTION / MATERIAL	SPEC NO	ITEM
AR		SUPERCONDUCTOR		3
AR		TUBE, ø1.00" X .125"W, FLASH WITH COPPER .0005"/.001" THICK 316/321(CRES)		2
AR		COPPER BAR (OFHC)		1

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LTR	DWN	CHK	APVD	DATE	ZONE	CHANGE
A	W²			10/91		GEN. REV.

DWN W J WONG 9/25/91
CHK
APVD
CLASSIFIED BY:
TITLE / DATE

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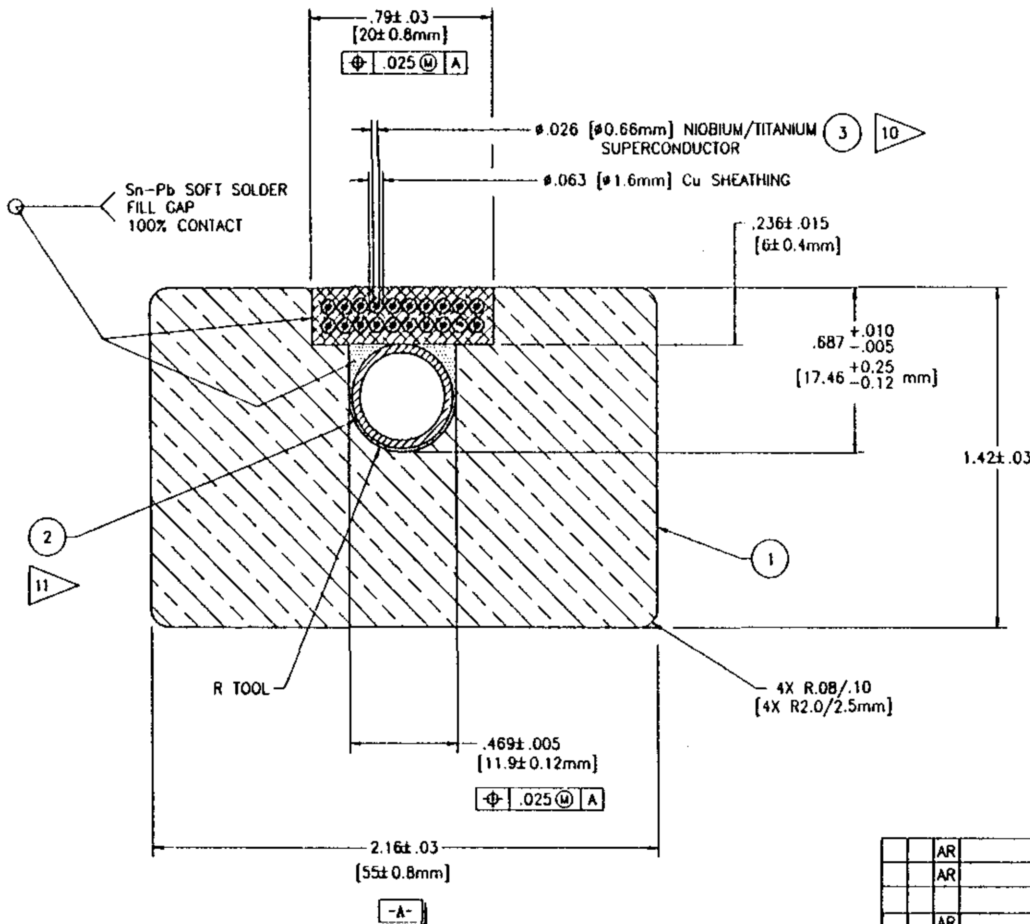
MAJOR UNIT: GEM
SUBASSY: COIL
DETAIL: "C" COIL CONFIG.
SHOWN ON AAA 91-XXXXXX
ACCT NO 0875-12
DRAWING NO AAA 91-110284-0A
SCALE / SHEET 1 OF 1

OFFICIAL USE



NOTES
UNLESS OTHERWISE SPECIFIED:

1. ALL DIMENSIONS ARE IN INCHES.
2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
3. SURFACE TEXTURE PER ANSI B46.1-1978.
4. 125/ FINISH ALL OVER.
5. REMOVE BURRS AND BREAK SHARP EDGES .05/.15.
6. CLEAN FINISHED PART OF ALL OIL, DIRT, GREASE, ETC.
7. ASSEMBLE AS LONGEST SINGLE LENGTH POSSIBLE WITH MINIMAL JOINTS.
8. LLL AutoCAD(tm) REL. 11 USER FILENAME: 1XXXXXX1
9. APPROXIMATE WEIGHT PER LINEAR FOOT OF LENGTH = 11.25 LBS.
10. COPPER SHEATHING TO SUPERCONDUCTOR CROSS-SECTIONAL AREA RATIO IS 2:1.
11. OPTIONAL: TUBE MAY BE FABRICATED USING (OFHC) COPPER OF SIMILIAR DIMENSIONAL SIZE.

PRELIMINARY ONLY

NOT FOR FABRICATION

NO REQD	PART / LLNL STK NO	DESCRIPTION / MATERIAL	SPEC NO	ITEM
AR		SUPERCONDUCTOR		3
AR		TUBE, ø.438" X .028"W, FLASH WITH COPPER .0005"/.001" THICK 316/321(CRES)		2
AR		COPPER BAR (OFHC)		1

DWN	W J WONG 9/91
CHK	
APVD	
CLASSIFIED BY	
TITLE	DATE

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MAJOR UNIT: GEM
SUBASSY: COIL
DETAIL: COIL CONFIGURATION
SHOWN ON AAA 91-XXXXXX
ACCT NO 0875-12
DRAWING NO AAA 91-110283-00
SCALE .50" SHEET 1 OF 1

LTR | DWN | CHK | APVD | DATE | ZONE | CHANGE

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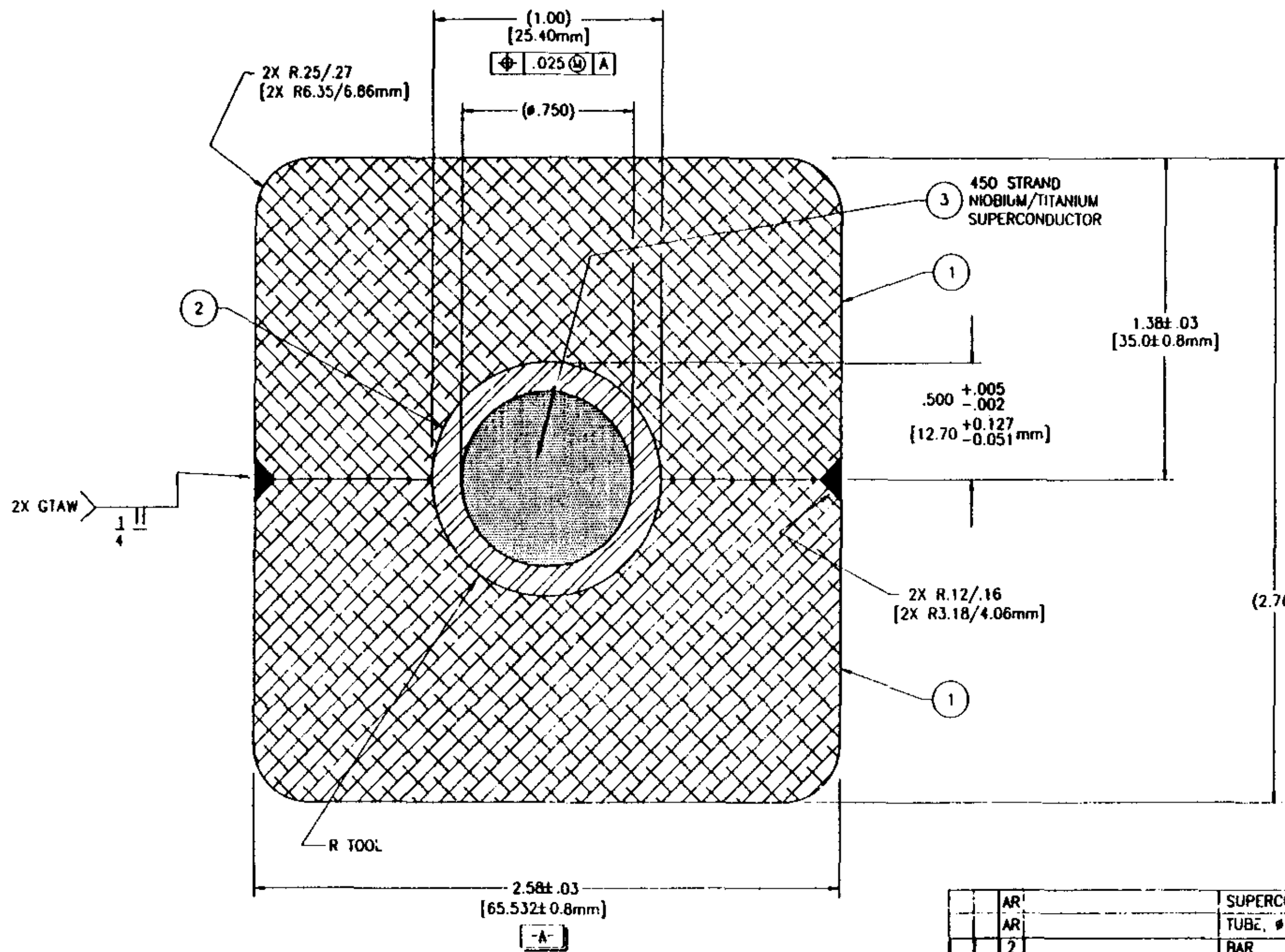

NOTES
UNLESS OTHERWISE SPECIFIED:

1. ALL DIMENSIONS ARE IN INCHES.
2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
3. SURFACE TEXTURE PER ANSI B46.1-1978.
4. 125/ FINISH ALL OVER.
5. REMOVE BURRS AND BREAK SHARP EDGES .05/.15.
6. CLEAN FINISHED PART OF ALL OIL, DIRT, GREASE, ETC.
7. ASSEMBLE AS LONGEST SINGLE LENGTH POSSIBLE WITH MINIMAL JOINTS.
8. LLL AutoCAD(tm) REL. 11 USER FILENAME: 11064331.DWG
9. APPROXIMATE WEIGHT PER LINEAR FOOT OF LENGTH = 9.00 LBS.
10. APPROXIMATE TOTAL LENGTH REQUIRED = 15 miles [24.1km].
11. APPROXIMATE TOTAL WEIGHT REQUIRED = 712,800 LBS. [324.0 MTons].

PRELIMINARY ONLY

NOT FOR FABRICATION

NO REQD	PART / IDENT STK NO	DESCRIPTION / MATERIAL		SPEC NO	ITEM
AR		SUPERCONDUCTOR			3
AR		TUBE, ⌀1.00" X .125"W	316/321(CRES)		2
2		BAR	1100-0(ALUM)		1

DWN	W J WONG 12/2/91
CHK	[illegible]
APVD	R M [illegible]
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MAJOR UNIT	GEM
SUBASSY	COIL
DETAIL	"A-2C" COIL CONFIG.
SHOWN ON AAA	91-XXXXXX
ACCT NO	0875-12
DRAWING NO	AAA 91-106433-00
SCALE	50"
SHEET	1 OF 1

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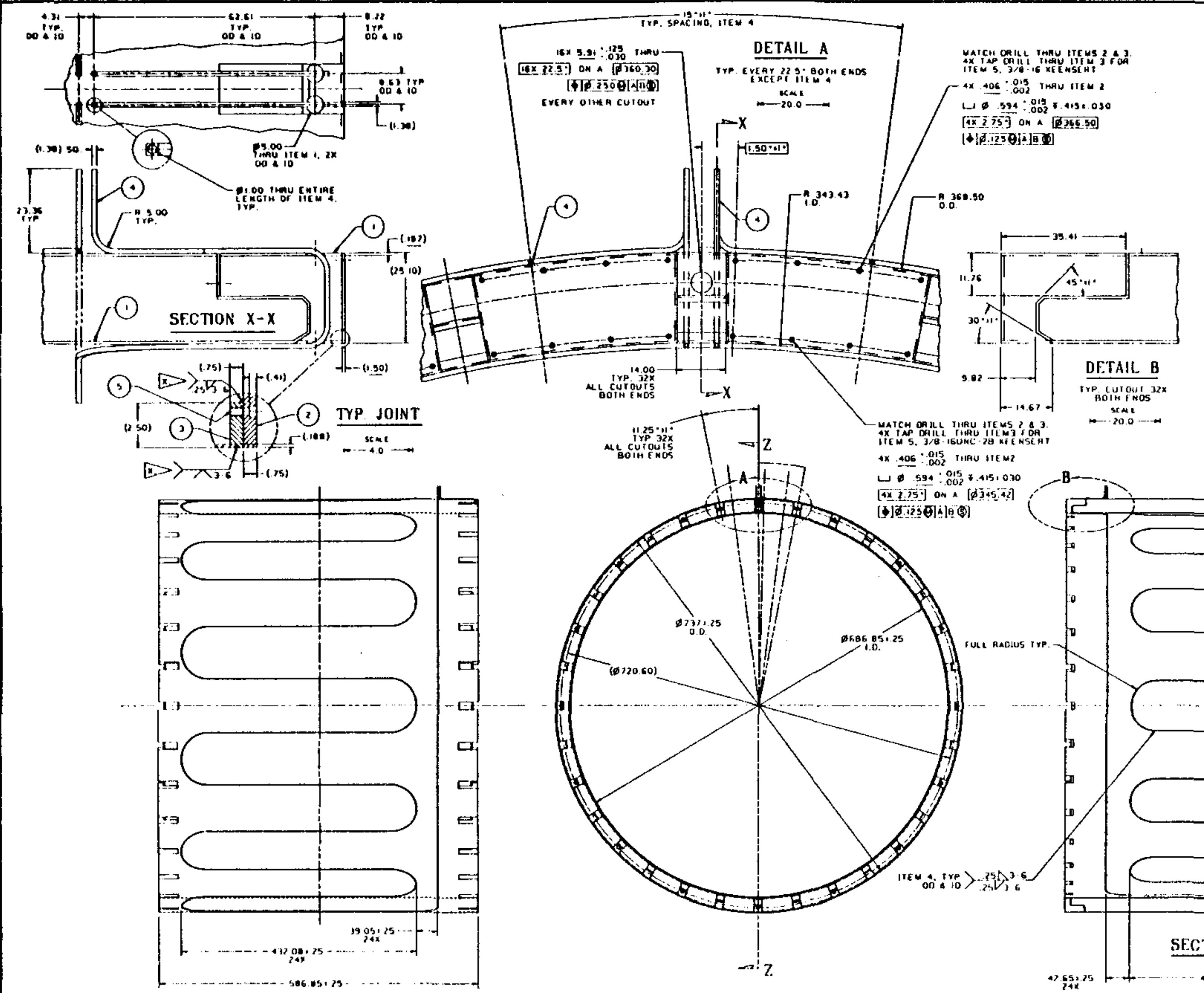
UNIVERSITY OF CALIFORNIA

LTR	DWN	CHK	APVD	DATE	ZONE	CHANGE

OFFICIAL USE



NOTES
UNLESS OTHERWISE SPECIFIED:

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M 1982. INCH UNITS USED.
2. SURFACE TEXTURE PER ANSI B46.1 1978.

REFERENCE ONLY
NOT FOR FABRICATION
9-27-91

NO REQD	PART/LINE STK NO	DESCRIPTION/MATERIAL		SPEC NO	ITEM
		3/8-16 UNC-28 KEENSERT	SST		5
		1 3/8" SQ. EXTRUSION WITH 1" I.D.	1060F ALUM		4
		3/4" PLATE	6061-T6 ALUM		3
		3/4" PLATE	6061-T6 ALUM		2
		3/16" SHEET	6061-T6 ALUM		1

DWN POSEY 9/91
CHK
APVD
TITLE

CLASSIFICATION

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LAWRENCE LIVERMORE NATIONAL LABORATORY
MECHANICAL ENGINEERING DEPT
UNIVERSITY OF CALIFORNIA

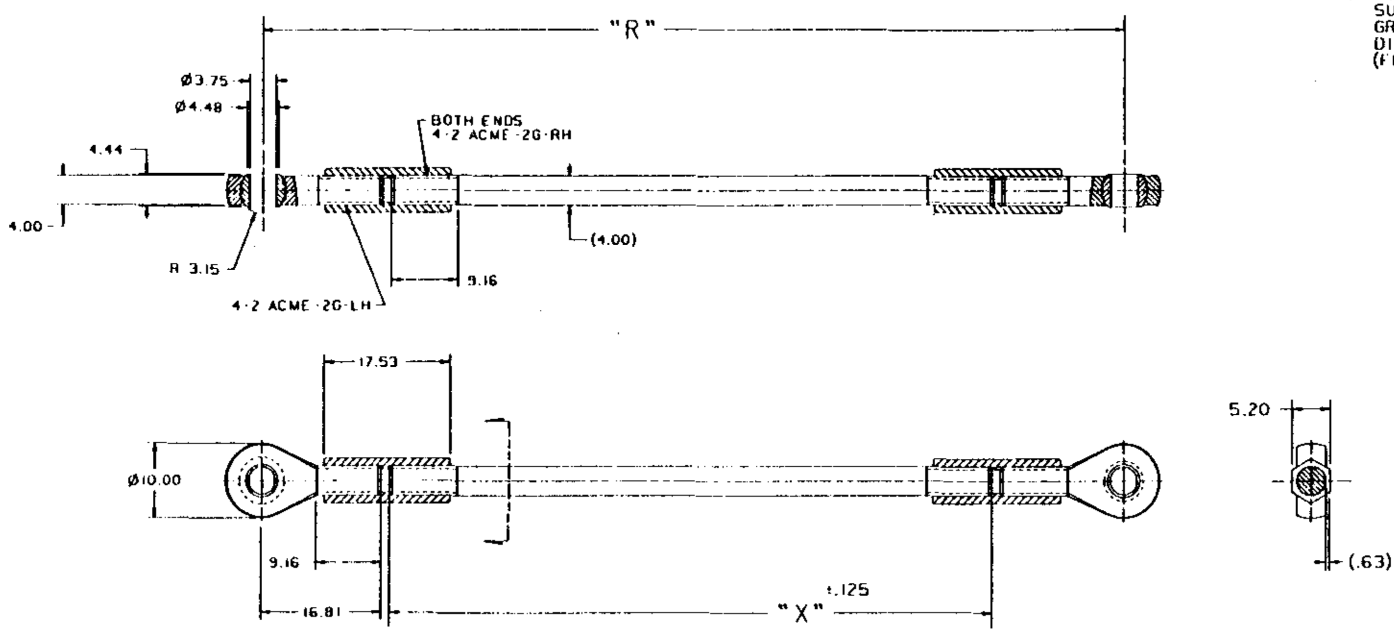
MAJOR UNIT: COIL ASSEMBLIES 3.1.1.1
SUBUNIT: THERMAL RADIATION SHIELD 3.1.1.1.2
DETAIL: INNER & OUTER SHIELD SPECIFICATION

DRAWING NO: AAA91-106407-0A
SCALE 1/20
SHEET 1 OF 1

TAB NO.	DIM "X"	DIM "R" REF	NO. REQ.	ORIENTATION
-01	81.00	127.00	64	RADIAL
-02	245.84	281.82	64	AXIAL

NOTES
UNLESS OTHERWISE SPECIFIED:

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982. INCH UNITS USED.
2. SURFACE TEXTURE PER ANSI B46.1-1978.
3. SCREW THREADS PER ANSI B1.5-1973 AFTER NICKLE FLASH & SILVER PLATING PER QQ-S-365, TYPE I, GRADE A.
4. NICKLE FLASH & SILVER PLATE ALL BALL SURFACES PER Q-Q-S-365 TYPE I, GRADE A. (.0005 MIN. THICK). DIMENSIONS TO BE MET AFTER PLATING. (FLATS & CHAMFERS OPTIONAL).



REFERENCE ONLY
NOT FOR FABRICATION
10-17-91

A	AP	BY			REVISED NO. OF AXIAL RODS
LTR	DWN	CHK	DATE	ZONE	CHANGE

COLD DRAWN OR FORGED A/R 6AL-4V TITANIUM

NO REQD	PART/LLNL STK NO	DESCRIPTION/MATERIAL	SPEC NO	ITEM

DWN POSEY 9/91
CHK
APVD R Yamamoto 10/91
TITLE
DATE

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MAJOR UNIT: COIL ASSEMBLIES 3.1.1.1
SUBASSY: COLD MASS SUPPORTS 3.1.1.1.4
DETAIL: RADIAL & AXIAL ROD SPECIFICATION

91-XXXXXX
ACT0875-12
DRAWING NO: AAA91-106406-0A
COPY
SCALE 16
SHEET 1 OF 1

OFFICIAL USE

12.0 References

1. "GEM Cost Estimating Plan," September 15, 1991, by Rick Sawicki, LLNL, printed and approved 9/30/91.

2. "GEM - Magnet Subsystem Vendor Estimates," GEM-LLNL-91-002, LLNL, December, 1991