US LHC Accelerator Research Program

brookhaven - fermilab – berkeley

US LHC Accelerator Research Program
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6 June 2003

Dr. John R. O'Fallon
U.S. LHC Joint Oversight Group

Dear ~~Dr. O'Fallon~~ John,

Attached is a draft letter to you and Jack Lightbody, which represents our report on an enhanced U.S. LHC Accelerator Research Program. This more powerful program is the one that we would have presented in our Proposal, had we not been constrained by the DOE funding guidance. It is one which we believe would more fully expoit the LHC for accelerator research by American scientists, and lead more quickly and surely to the highest possible performance of the LHC in support of US-ATLAS and US-CMS.

This letter has been approved by the U.S. LHC Accelerator Collaboration. I have also discussed it with Steve Holmes, but has not yet been fully vetted by the Directorates of the three Laboratories. Thus it remains a draft. However, we feel that it is important that this information be made available before the Lehman Review on June 10 and 11.

I look forward to discussing this with you and your colleagues at the Review.

Sincerely,

James Strait
Program Leader
U.S. LHC Accelerator Research Program

Attachment

cc: S. P. Rosen, DOE
R. Staffin, DOE
A. Byon-Wagner, DOE
M. Pripstein, DOE
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Dr. John R. O'Fallon
Dr. John W. Lightbody, Jr.
U.S. LHC Joint Oversight Group

Dear Dr. O'Fallon and Dr. Lightbody,

The Proposal for the U.S. LHC Accelerator Research Program which we submitted to you two weeks ago puts forward an excellent program of accelerator research and development. However, as noted in the cover letter, it has been necessary to make compromises to fit the program within the funding guidance, compromises that delay some work and add some technical risk. In this letter, we outline a more powerful program, that would more fully exploit the LHC for accelerator research by American scientists, and lead more quickly and surely to the highest possible performance of the LHC as a tool for High Energy Physics research by providing stronger support for the commissioning of the baseline machine and greater assurance of success of the R&D for high-performance magnets for a luminosity upgrade.

We attach the tables and figure from the cost estimate chapter of the Proposal [http://www-td.fnal.gov/LHC/USLARP/ LARP_Proposal.pdf], but with numbers corresponding to the program that we would have proposed had we not been constrained by the funding guidance. This is fundamentally the same research program, that is, the goals are the same, and no additional elements or lines of R&D have been added. However, it starts more vigorously, provides for a stronger accelerator physics program, and permits more robust instrumentation and magnet R&D. It is clearly desirable that we pursue R&D in both quadrupoles and dipoles, both for the strength of our domestic program and to put us in a leadership position no matter what type of new interaction region is required. With additional funding at the level indicated below, we can accomplish this goal, and substantially reduce the risk that we will need to abandon one of the magnet types to be sure of achieving success with at least one of them.

Table 4.1-1 and Fig. 4.1-1 summarize the cost estimate for this more enhanced program. An additional $0.8M and $1.1M is requested in FY2004 and 2005 respectively. The "plateau" funding level is about $17M, rather than $12M per year, and there is a modest peak in FY2007, the year of LHC startup. Labor and M&S costs are summarized in Table 4.1-2. From FY2007 and beyond, this program requires about 55 FTEs, as compared with about 40 in the program in the Proposal. The M&S budgets in FY2007-09 average $5.4M, versus $3.4M in the submitted plan.

The program management cost estimate, Table 4.2-1, shows an increase in effort from 3.2 to 4.5 FTEs in the out years, commensurate with the greater level of activity in this more vigorous program. Travel and M&S budgets are also correspondingly larger.

The Accelerator Systems cost estimate is summarized in Table 4.3-1. As in the Proposal, the budget peaks in FY2007, but at about $2M higher. The roll off in FY2008 and 2009 is somewhat steeper; the increase above the budget in the Proposal is only $1.3M in these years. Details are shown in Table 4.3-2, 4.3-3 and 4.3-4 for Instrumentation, Beam Commissioning and Accelerator Physics, and Hardware Commissioning respectively.

The effort on Tune Feedback is essentially doubled relative to the Proposal, which we believe will transform this effort from one that is barely at the critical level, to one that can make a strong contribution to LHC performance, utilizing expertise and building on tune, chromaticity and coupling measurement and feedback systems being developed for RHIC and the Tevatron. It should be noted that the effort shown here is in addition to a comparable or larger effort supported by the base programs at the two labs for the specific development work for our machines. The overall effort level on the Luminosity Monitor is similar to that in the Proposal, but it is distributed differently. Additional M&S funding is provided, which would allow us to take full responsibility for the construction of these devices. The effort on the Longitudinal Density Monitor is moved earlier by about a year, which allows its development to be completed in time for implementation in late 2007 or early 2008, rather than a year later than that. Also, a small additional amount of labor and additional M&S budget is included here to allow us to build the system for installation in LHC, in addition to carrying out the R&D. The budget allowed for additional instrumentation is also moved earlier by about a year, allowing us to start initial R&D on other instruments in FY2006, and serious R&D in FY2007.

The effort on Beam Commissioning and Fundamental Accelerator Physics (Table 4.3-3) is increased in FY2007 and beyond from 9.5 to 12 FTEs. This will allow us to meet our goal of having one American physicist on each commissioning shift with some margin, and allow us to contribute to commissioning activities outside the control room. The additional effort on fundamental accelerator physics will allow us to better exploit the opportunities presented by the LHC once it is fully operational. The travel budget for those people who will spend an extended time at the LHC has also been increased, which will allow us to more fully cover the additional cost to American scientists of living near CERN. The budget for Hardware Commissioning (Table 4.3-4) has not been changed.

The cost estimate for the enhanced Magnet R&D program is summarized in Table 4.4-1, and details are given in Tables 4.2-2 and 4.2-3. The sequence of subscale technology tests and model magnets in the Proposal is compared with a more robust program in the Tables below. Additional

Proposal

		FY04	FY05	FY06	FY07	FY08	FY09	FY10
Subscale Tests		1	3	6	5	4	3	2
Simplified 1m Q				1	1			
1m Q					1	2	2	2
1m D					1	1	1	1
4m D or Q models							0.25	1

Enhanced Program

		FY04	FY05	FY06	FY07	FY08	FY09	FY10
Subscale Tests		2	4	6	6	5	4	3
Simplified 1m Q				1	2			
1m Q					1	3	3	3
1m D					2	2	2	2
4m D or Q models						0.25	1	2

subscale tests are performed in the next two years, prior to the construction of the first model magnets, and a more vigorous technology development program is included in parallel with the model magnet program. Three rather than two simplified models are built prior to the construction of the first full-featured models, and five models per year (shown here as 3 quadrupoles and 2 dipoles) rather than 3 are built. The 4 m model program is started a year earlier.

The task we have set for ourselves is very challenging: to develop accelerator-ready designs of two different types of magnets of unprecedented field strength, with superb field quality over a very large aperture, and which must operate in an extreme radiation environment. We feel that the program sketched here, with more vigorous technology development, more model magnets, and an earlier opportunity to assess length-dependent effects, will more surely yield success than the more constrained program in the Proposal. As discussed in the Proposal, we are prepared to concentrate our resources on a single magnet type, most likely a quadrupole, to maximize our ability to successfully deliver a complete magnet design for the Luminosity Upgrade. (Even then, of course, success cannot guaranteed.) The more aggressive magnet R&D program presented here will substantially increase the chances that we can successfully develop both quadrupoles and dipoles for the new interaction regions, and truly take the lead in the development of this crucial system for the luminosity upgrade.

We know you agree that the U.S. LHC Accelerator Research Program is an essential element of the overall U.S. High Energy Physics program. It will help exploit our large investment in the LHC and its detectors by working to maximize the physics output for American scientists. It leverages our investment in the machine by providing opportunities for American accelerator scientists to pursue their research. And it will keep the U.S. Labs at the forefront of the science and technology of high energy hadron colliders. While the program that we presented in the original Proposal is a strong one, we believe that for the relatively modest increase in funding that we are requesting here, we could execute a program that would more fully exploit the LHC for accelerator research by American scientists, lead more quickly and surely to the highest possible performance of the LHC as a tool for High Energy Physics research, and place the U.S. Labs in a true leadership position in the development of new IRs for the Luminosity Upgrade.

We look forward to hearing from you regarding this request for additional funding for the U.S. LHC Accelerator Research Program. If you have any questions, or if there is any additional information that we can provide about this more powerful program, please, do not hesitate to ask.

Sincerely,

James Strait
Program Leader
U.S. LHC Accelerator Research Program
For the BNL-FNAL-LBNL
U.S. LHC Accelerator Collaboration

cc: S. P. Rosen, DOE
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LARP Proposal Co-Authors

Table 4.1-1 Enhanced LARP Cost Estimate Summary.

		FY04	FY05	FY06	FY07	FY08	FY09
Sub-program Costs							
Program Management	$k	139	428	962	990	1,020	1,051
Accelerator Systems	$k	1,083	2,272	4,472	6,457	5,444	5,181
Magnet R&D	$k	598	1,878	7,942	9,818	10,402	10,411
Total Program Cost	**$k**	**1,821**	**4,579**	**13,376**	**17,265**	**16,866**	**16,643**
DOE Funding Guidance	**k$**	**1,050**	**3,500**	**11,000**	**11,000**	**12,000**	**12,000**

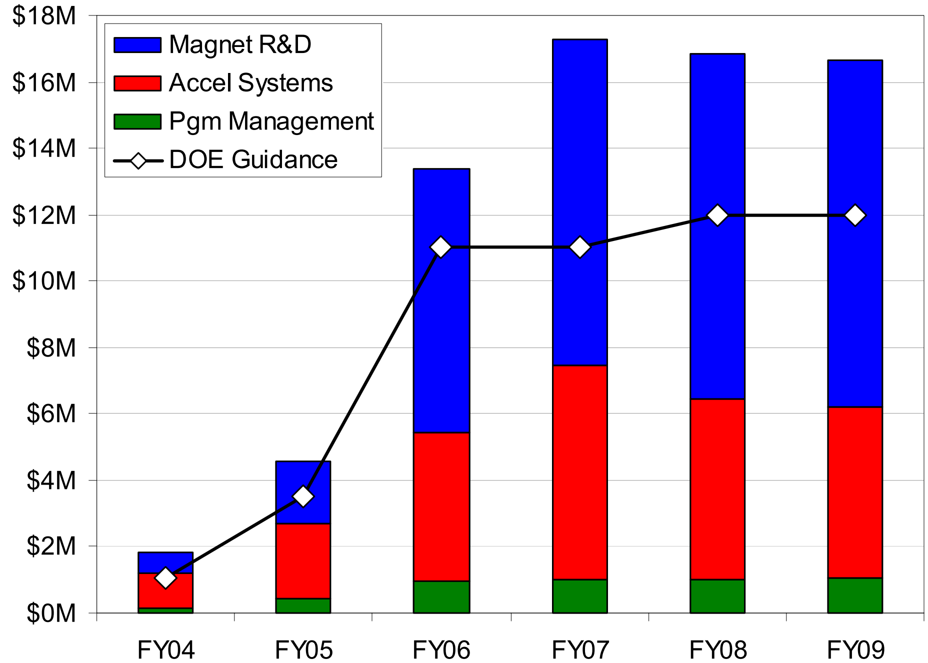

Fig. 4.1-1 Cost estimate for the enhanced U.S. LHC Accelerator Research Program, compared with the DOE funding guidance.

Table 4.1-2 Enhanced LARP M&S and Labor Cost Estimate Summary

		FY04	FY05	FY06	FY07	FY08	FY09
Labor count							
Program Management							
Scientist/Engineer	FTE	0.6	1.6	3.5	3.5	3.5	3.5
Administrator	FTE		0.6	1.0	1.0	1.0	1.0
SUB-TOTAL	FTE	0.6	2.1	4.5	4.5	4.5	4.5
Accelerator Systems							
Scientist/Engineer	FTE	3.6	7.1	10.7	15.1	12.4	10.5
Post-doc/Student	FTE	1.3	1.5	5.1	10.6	11.0	10.5
Technician/Designer	FTE					1.0	2.0
SUB-TOTAL	FTE	4.9	8.6	15.8	25.7	24.4	23.0
Magnet R&D							
Scientist/Engineer	FTE	1.7	4.0	9.1	11.1	11.2	10.8
Technician/Designer	FTE	0.8	3.1	13.9	17.4	17.0	15.6
SUB-TOTAL	FTE	2.5	7.1	23.0	28.5	28.2	26.4
Materials & Services							
Program Management	$k03	3	11	23	23	23	23
Accelerator Systems	$k03	150	470	1,240	1,255	630	640
Magnet R&D	$k03	137	579	3,735	4,360	4,637	4,633
Travel							
Program Management	$k03	6	17	37	37	37	37
Accelerator Systems	$k03	52	102	202	402	366	309
Magnet R&D	$k03	9	20	46	56	56	54
SUB-TOTALS							
Labor count							
Scientist/Engineer	FTE	5.9	12.7	23.3	29.7	27.1	24.8
Post-doc/Student	FTE	1.3	1.5	5.1	10.6	11.0	10.5
Technician/Designer	FTE	0.8	3.1	13.9	17.4	18.0	17.6
Administrator	FTE		0.6	1.0	1.0	1.0	1.0
TOTAL LABOR	FTE	8.0	17.8	43.3	58.7	57.1	53.9
Labor cost	$k03	1,412	3,118	6,958	9,208	8,800	8,242
Travel	$k03	66	139	285	495	459	400
Materials & Services	$k03	290	1,060	4,998	5,638	5,290	5,296
TOTAL COST							
Constant dollars	$k03	1,768	4,316	12,241	15,340	14,549	13,938
With 3.0%/year escalation	$k	1,821	4,579	13,376	17,265	16,866	16,643

Table 4.2-1 Enhanced LARP Management Cost Estimate

		FY04	FY05	FY06	FY07	FY08	FY09
Labor count							
Program Office							
Scientist/Engineer	FTE	0.3	0.8	1.5	1.5	1.5	1.5
Administrator	FTE		0.3	0.5	0.5	0.5	0.5
SUB-TOTAL	FTE	0.3	1.0	2.0	2.0	2.0	2.0
Accelerator Systems							
Scientist/Engineer	FTE	0.2	0.4	1.0	1.0	1.0	1.0
Administrator	FTE		0.2	0.3	0.3	0.3	0.3
SUB-TOTAL	FTE	0.2	0.6	1.3	1.3	1.3	1.3
Magnet R&D							
Scientist/Engineer	FTE	0.2	0.4	1.0	1.0	1.0	1.0
Administrator	FTE		0.2	0.3	0.3	0.3	0.3
SUB-TOTAL	FTE	0.2	0.6	1.3	1.3	1.3	1.3
Materials & Services							
Misc. Supplies ($5k/FTE)	$k03	3	11	23	23	23	23
SUB-TOTALS							
Labor count							
Scientist/Engineer	FTE	0.6	1.6	3.5	3.5	3.5	3.5
Administrator	FTE	0.0	0.6	1.0	1.0	1.0	1.0
TOTAL LABOR	FTE	0.6	2.1	4.5	4.5	4.5	4.5
Labor cost	$k03	126	376	820	820	820	820
Travel	$k03	6	17	37	37	37	37
Materials & Services	$k03	3	11	23	23	23	23
TOTAL COST							
Constant dollars	$k03	135	404	880	880	880	880
With 3.0%/year escalation	$k	139	428	962	990	1,020	1,051

Table 4.3-1 Enhanced Accelerator Systems Cost Summary

		FY04	FY05	FY06	FY07	FY08	FY09
Labor Count							
Instrumentation	FTE	3.4	3.9	6.8	11.7	11.4	11.0
Beam Comm & Acc Phys	FTE	1.0	2.7	7.0	12.0	12.0	12.0
Hardware Commissioning	FTE	0.5	2.0	2.0	2.0	1.0	
TOTAL	FTE	4.9	8.6	15.8	25.7	24.4	23.0
Labor Cost							
Instrumentation	$k03	550	680	1100	1730	1600	1540
Beam Comm & Acc Phys	$k03	200	490	1150	1950	1900	1850
Hardware Commissioning	$k03	100	400	400	400	200	
TOTAL	$k03	850	1570	2650	4080	3700	3390
Travel							
Instrumentation	$k03	34	39	68	117	104	90
Beam Comm & Acc Phys	$k03	10	33	104	255	247	219
Hardware Commissioning	$k03	8	30	30	30	15	
TOTAL	$k03	52	102	202	402	366	309
Materials & Services							
Instrumentation	$k03	140	400	1160	1190	590	600
Beam Comm & Acc Phys	$k03	10	20	30	40	40	40
Hardware Commissioning	$k03		50	50	25		
TOTAL	$k03	150	470	1240	1255	630	640
TOTAL COSTS (escalated)							
Instrumentation	$k	746	1187	2544	3418	2659	2663
Beam Comm & Acc Phys	$k	227	576	1403	2527	2535	2518
Hardware Commissioning	$k	111	509	525	512	249	
GRAND TOTAL	**$k**	**1083**	**2272**	**4472**	**6457**	**5444**	**5181**

Table 4.3-2 Enhanced Instrumentation Cost Summary

		FY04	FY05	FY06	FY07	FY08	FY09
Labor count							
Tune feedback							
Scientist/Engineer	FTE	1.0	1.0	1.0	1.0	0.5	
Post Doc/Student	FTE	1.0	1.0	1.0	1.0	0.5	
Designer/Technician	FTE						
SUB-TOTAL	FTE	2.0	2.0	2.0	2.0	1.0	
Luminosity monitor							
Scientist/Engineer	FTE	0.5	1.2	0.8	1.2	0.7	
Post Doc/Student	FTE	0.1		0.6	2.0	2.0	
Designer/Technician	FTE						
SUB-TOTAL	FTE	0.6	1.2	1.4	3.2	2.7	
Longitudinal density monitor							
Scientist/Engineer	FTE	0.6	0.7	2.0	2.4	1.7	
Post Doc/Student	FTE	0.2		1.0	2.1	2.0	
Designer/Technician	FTE						
SUB-TOTAL	FTE	0.8	0.7	3.0	4.5	3.7	
Additional Instrumentation							
Scientist/Engineer	FTE			0.4	1.0	1.5	4.0
Post Doc/Student	FTE				1.0	1.5	5.0
Designer/Technician	FTE					1.0	2.0
SUB-TOTAL	FTE			0.4	2.0	4.0	11.0
Materials & Services							
Tune feedback	$k03	40	70	180	180	50	
Luminosity monitor	$k03	60	310	570	135	45	
Longitudinal density monitor	$k03	40	20	370	805	95	
Additional Instrumentation	$k03			40	70	400	600
SUB-TOTALS							
Labor count							
Scientist/Engineer	FTE	2.1	2.9	4.2	5.6	4.4	4.0
Post Doc/Student	FTE	1.3	1.0	2.6	6.1	6.0	5.0
Designe/Technician	FTE					1.0	2.0
TOTAL LABOR	FTE	3.4	3.9	6.8	11.7	11.4	11.0
Labor cost	$k03	550	680	1100	1730	1600	1540
Travel	$k03	34	39	68	117	104	90
Materials & Services	$k03	140	400	1160	1190	590	600
TOTAL COST							
Constant dollars	$k03	724	1119	2328	3037	2294	2230
With 3.0%/year escalation	$k	746	1187	2544	3418	2659	2663

Table 4.3-3 Enhanced Beam Commissioning and Accelerator Physics Cost Summary

		FY04	FY05	FY06	FY07	FY08	FY09
Labor count							
At a U.S. Lab	*FTE*	*0.5*	*1.1*	*2.0*	*1.0*		
At CERN	*FTE*		*0.5*	*2.0*	*8.0*	*8.0*	*7.0*
Scientist/Engineer	FTE	0.5	1.1	2.5	5.5	5.0	4.0
Post Doc/Student	FTE		0.5	1.5	3.5	3.0	3.0
SUB-TOTAL	FTE	0.5	1.6	4.0	9.0	8.0	7.0
Cost sub-totals							
Labor	$k03	100	270	650	1450	1300	1100
Travel	$k03	5	22	74	225	207	169
FUNDAMENTAL ACCELERATOR PHYSICS							
Labor count							
At a U.S. Lab	*FTE*	*0.5*	*1.1*	*2.0*	*2.0*	*2.5*	*3.5*
At CERN	*FTE*			*1.0*	*1.0*	*1.5*	*1.5*
Scientist/Engineer	FTE	0.5	1.1	2.0	2.0	2.0	2.5
Post Doc/Student	FTE			1.0	1.0	2.0	2.5
SUB-TOTAL	FTE	0.5	1.1	3.0	3.0	4.0	5.0
Cost sub-totals							
Labor	$k03	100	220	500	500	600	750
Travel	$k03	5	11	30	30	40	50
BEAM COMMISSIONING + FUNDAMENTAL ACCELERATOR PHYSICS							
Labor count	FTE	1.0	2.7	7.0	12.0	12.0	12.0
Labor cost	$k03	200	490	1150	1950	1900	1850
Travel	$k03	10	33	104	255	247	219
Materials & Services	$k03	10	20	30	40	40	40
TOTAL COST							
Constant dollars	$k03	220	543	1284	2245	2187	2109
With 3.0%/year escalation	$k	227	576	1403	2527	2535	2518

Table 4.3-4 Hardware Commissioning Cost Summary

		FY04	FY05	FY06	FY07	FY08	FY09
Labor count							
At a U.S. Lab	*FTE*	*0.5*	*0.5*				
At CERN	*FTE*		*1.5*	*2.0*	*2.0*	*1.0*	
Scientist/Engineer	FTE	0.5	2.0	2.0	2.0	1.0	
SUB TOTALS							
Labor count	FTE	0.5	2.0	2.0	2.0	1.0	
Labor cost	$k03	100	400	400	400	200	
Travel	$k03	8	30	30	30	15	
Materials & Services	$k03		50	50	25		
TOTAL COST							
Constant dollars	$k03	108	480	480	455	215	
With 3.0%/year escalation	$k	111	509	525	512	249	

Table 4.4-1 Enhanced Superconducting Magnet R&D Cost Estimate Summary

		FY04	FY05	FY06	FY07	FY08	FY09
LABOR COUNT							
Technology Development	FTE	1.9	3.4	5.0	5.0	4.2	3.4
Quadrupole R&D (1m + 4m)	FTE	0.3	2.8	9.5	13.0	14.0	13.5
Dipole R&D (1m)	FTE	0.3	0.9	8.5	10.5	10.0	9.5
TOTAL	FTE	2.5	7.1	23.0	28.5	28.2	26.4
LABOR COST							
Technology Development	$k03	316	552	808	808	680	552
Quadrupole R&D (1m + 4m)	$k03	60	440	1420	1920	2080	2020
Dipole R&D (1m)	$k03	60	180	1260	1580	1520	1460
TOTAL	$k03	436	1172	3488	4308	4280	4032
TRAVEL							
Technology Development	$k03	6	9	13	13	11	9
Quadrupole R&D (1m + 4m)	$k03	2	7	18	23	25	25
Dipole R&D (1m)	$k03	2	5	15	20	20	20
TOTAL	$k03	9	20	46	56	56	54
MATERIAL & SERVICES							
Technology Development	$k03	130	325	455	520	455	390
Quadrupole R&D (1m + 4m)	$k03	7	247	1667	2945	3287	3344
Dipole R&D (1m)	$k03	0	7	1612	895	895	899
TOTAL	$k03	137	579	3735	4360	4637	4633
TOTAL COSTS (escalated)							
Technology Development	k$	465	940	1394	1509	1329	1136
Quadrupole R&D (1m + 4m)	k$	70	736	3393	5501	6251	6435
Dipole R&D (1m)	k$	63	203	3155	2808	2823	2840
GRAND TOTAL	**$k**	**598**	**1878**	**7942**	**9818**	**10402**	**10411**

Table 4.4-2 Enhanced Superconducting Magnet R&D M&S Cost Details

		FY04	FY05	FY06	FY07	FY08	FY09	FY10
Subscale Tests		2	4	6	6	5	4	3
Simplified 1m Q				1	2			
1m Q					1	3	3	3
1m D					2	2	2	2
4m D or Q models						0.25	1	2
		FY04	FY05	FY06	FY07	FY08	FY09	FY10

Materials & Services								
Technology								
Subscale tests	$k03	100	200	300	300	250	200	
Component Development	$k03		50	50	100	100	100	
Technology total	**$k03**	**100**	**250**	**350**	**400**	**350**	**300**	
tooling			1m	1m	4m	4m	4m	
long oven	$k03				250			
cable	$k03	5	5	5	5	5	5	
D	$k03		5	5	5	5	5	
coil, Q	$k03		123	368	860	860		
D	$k03			490				
collared coil, Q	$k03			74		3		
D	$k03			74			3	
cold mass, Q	$k03			144				
D	$k03			144				
total tooling, Q	$k03	5	128	591	865	868	5	
D	$k03		5	713	5	5	8	
Tooling total	**$k03**	**5**	**133**	**1304**	**1120**	**873**	**13**	
models			1m	1m	1m	1m	1m	
cable, Q	$k03		63	250	375	375	375	
D	$k03			250	250	250	250	
coil, Q	$k03			318	381	381	381	
D	$k03			254	254	254	254	
collared coil, Q	$k03			46	35	35	35	
D	$k03			23	23	23	23	
cold mass, Q	$k03			43	130	130	130	
D	$k03				86	86	86	
test, Q	$k03			35	105	105	105	
D	$k03				70	70	70	
total models, Q	$k03		63	692	1025	1025	1025	
D	$k03			527	683	683	683	
Models total	**$k03**		**63**	**1219**	**1709**	**1709**	**1709**	
4 m Models						4m	4m	
cable	$k03				125	500	1000	
coil	$k03					90	358	
collared coil	$k03					12	46	
cold mass	$k03					26	103	
cryostat	$k03							
test	$k03					9	35	
4m Models total	**$k03**				**125**	**636**	**1542**	
Total M&S	$k03	105	445	2873	3354	3567	3564	
Total M&S + 30% G&A	**$k03**	**137**	**579**	**3735**	**4360**	**4637**	**4633**	

Table 4.4-2 Superconducting Magnet R&D Labor and Total Cost Summaries

		FY04	FY05	FY06	FY07	FY08	FY09	FY10
Subscale Tests		2	4	6	6	5	4	3
Simplified 1m Q				1	2			
1m Q					1	3	3	3
1m D					2	2	2	2
4m D or Q models						0.25	1	2
		FY04	FY05	FY06	FY07	FY08	FY09	FY10
Total M&S + 30% G&A	**$k03**	**137**	**579**	**3735**	**4360**	**4637**	**4633**	
Labor								
Technology								
Scientist/Engineer	FTE	1.1	1.8	2.6	2.6	2.2	1.8	
Designer/Technician	FTE	0.8	1.6	2.4	2.4	2	1.6	
Technology Total	**FTE**	**1.9**	**3.4**	**5.0**	**5.0**	**4.2**	**3.4**	
Quad+4m								
Scientist/Engineer D&F	FTE	0.3	1.3	3	3	3.5	3.5	
Designer D&F	FTE		1	2.5	2.5	2.5	2	
Scientist/Engineer Test	FTE			0.5	1.5	1.5	1.5	
Technician Fab	FTE		0.5	3	4.5	5	5	
Technician Test	FTE			0.5	1.5	1.5	1.5	
Dipole								
Scientist/Engineer D&F	FTE	0.3	0.9	3	3	3	3	
Designer D&F	FTE			2.5	2.5	2	1.5	
Scientist/Engineer Test	FTE				1	1	1	
Technician Fab	FTE			3	3	3	3	
Technician Test	FTE				1	1	1	
Dipole+ Quadrupole								
Scientist/Engineer D&F	FTE	0.6	2.2	6	6	6.5	6.5	
Designer D&F	FTE		1	5	5	4.5	3.5	
Scientist/Engineer Test	FTE			0.5	2.5	2.5	2.5	
Technician Fab	FTE		0.5	6	7.5	8	8	
Technician Test	FTE			0.5	2.5	2.5	2.5	
Dipole + Quad Total	**FTE**	**0.6**	**3.7**	**18.0**	**23.5**	**24.0**	**23.0**	
Labor Total	**FTE**	**0.6**	**3.7**	**18.0**	**23.5**	**24.0**	**23.0**	
Labor Cost	**$k03**	**436**	**1172**	**3488**	**4308**	**4280**	**4032**	
Travel ($5k each S/E)	**$k03**	**9**	**20**	**46**	**56**	**56**	**54**	
Total Cost		FY04	FY05	FY06	FY07	FY08	FY09	
Constant dollars	**$k03**	**581**	**1771**	**7268**	**8723**	**8973**	**8719**	
Escalated at 3%/year	**$k**	**598**	**1878**	**7942**	**9818**	**10402**	**10411**	

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