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SDC
SOLENOIDAL DETECTOR NOTES

RESPONSE TO QUESTIONS FROM THE SDC COST REVIEW PANEL

April 24, 1991

Response to Questions

from the

SDC Cost Review Panel

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Management, EDIA, Installation, R&D, and General Estimating Approach

1. *In doing an estimate evaluation it is useful to look at the labor rates in values other than man-days as given in the estimate roll-up. Please provide the conversion of man-days to man-weeks, man-years, and man-hours, for each of the labor categories, that is consistent with the estimating approach.*

8 man -hours	=	1	man-day
1 man-week	=	5	man-day
1 man-month	=	22	man-days
1 man-year	=	260	man-days

Table 1 – Labor Bins for Costing($)

	Engineer	Designer	Technician	Laborer	Admin
Hourly	53	29	23	15	15
Daily	423	235	180	119	119
Weekly	2115	1175	900	595	595
Monthly	9165	5092	3900	2578	2578
Yearly	109980	61100	46800	30940	30940

2. *There appear to be Installation and Project Management costs that were estimated but not included in the SDC estimate roll-up,because they were designated as "SSCL" effort. We have identified about $15 million for Installation and $6 million for Project Management from the estimate back-up information (dated Dec. 3, 1990) which was not included in the SDC roll-up. Is this correct?*

The costs for Installation and Project Management were divided into two categories for the December 3 presentation. We assumed approximately $15M of the costs under Installation will be supported by the operating and experimental facilities budgets of the SSCL. Similarly we assumed about $6M of the Project Management costs will be supported by these budgets.

3. *Please explain the detailed basis for the subsystem installation estimates. Include an explanation or justification for the $7.450 million for installation procurements. What is the impact if the four years specified in the installation estimate is not available (current schedules provide about 36 months for installation)? What impact on the cost estimate may be expected if the installation schedule is compressed?*

An installation and test schedule was provided in the Dec. 3 presentation material. This material also included a cost estimate for moving components from the surface to the underground

hall, for their assembly into the detector and for their test. Manpower estimates were made in a time-phased way and reflect best estimates of the engineering and labor time required. Inasmuch as the total time for installation and as the detailed procedure were uncertain at the time of the Letter of Intent, detailed estimates were not generated. We are in the process of making these estimates. Similarly, procurement costs given in the Dec. 3 presentation represent fixtures and services that would be required during the installation process and were not estimated in detail.

We do not have a quantitative estimate of the impact of a 36 month installation schedule since we are in the process of developing this schedule and the associated cost. Obviously it is our intent to minimize both the installation time and cost.

4. *The labor rates used in the estimate in general appear to be low. The EDIA composite average of $43/hour seems to be offset by a sufficient quantity of effort. Is this the case or should the existing man-day estimates be extended through a more realistic labor rate?*

The specific labor categories and associated rates are provided in the answer to question 1 above and question 5 below.

5. *The Assembly and Installation labor rate average of $19/hour also appears to be low. Explain the justification for the labor rates used in the estimate. How do these rates compare with rates expected to be charged by collaborative institutions like LBL, Los Alamos, Argonne National Lab, and Fermilab?*

We answer questions 4 and 5 together. Man-day estimates for all labor categories were made first and then a uniform set of labor rates applied. It is the estimate of man-days that is the primary estimated quantity not the total cost of labor.

We assume the comment about Assembly and Installation labor rate average to apply to the mean of our Technician and Laborer categories. We note that most of the non-engineering labor during installation and assembly is in our technician category at $23/hr. We have included engineering supervision in our estimate for installation and test, further raising the average rate. Finally, a large fraction of the labor for installation and test will come from either the SSCL or the Dallas area. The rates for the SSCL and the Dallas area are given in the table below and are about equal to the rates we assumed in the cost estimate.

Labor rates were "binned" in five categories: engineer, designer, technician, laborer and administrative support. Laborer in this categorization refers to unskilled personnel that are trained for repetitive assembly tasks or for installation tasks. In general these are not permanent members of laboratories or universities. There is ample precedent from previous experiments for using this type

of personnel for many production, assembly and testing tasks, under the supervision of technicians and engineers.

In the table below we present a summary of labor rates(for construction projects) obtained from the major laboratories within the collaboration. In some cases our categories do not precisely overlap with those used in the laboratories, requiring some interpolation. The rates are in $/hr.

Table 2

Location	Engineer	Designer	Technician	Laborer	Admin
ANL	46	37	24		
FNAL	38	24	24		
LBL	54	39	36	20	23
LANL	52	36	36		
LLNL	66	39	43	23	23
ORNL	<-------52-------->		55		
PSL	45	32	38		
SSCL	36	26	23	13	13
Dallas area	47	26	25	13	
SDC values	53	29	23	15	15

The SSCL and Dallas area values are contained in a letter from Dave Etherton to George Trilling dated November 4, 1990.

We are in the process of producing a revised cost estimate by July 1 that takes into account rates by institution and that expands the number of labor categories.

6. *Provide a breakdown of the FY91 and 92 request for pre-construction and R&D funding by subsystem. Identify the amount requested for engineering/integration prior to construction start versus the amount requested to support detector R&D separate from FY 91 subsystem R&D. R&D requested in FY91 and FY92 seems too low for a project of this scale. Are there additional R&D costs included in the years FY93-FY99?*

The breakdown requested for FY91 was given in the Letter of Intent(Table 12). The precise division between R&D and engineering/integration in FY91 is still subject to negotiation(all funds have not been allocated yet). An approximate division is 80% for engineering/integration and 20% for R&D. We are in the process of preparing an FY92 R&D and Engineering Plan that will

provide the requested information in great detail. A draft of this plan will be available by July 1. In the Letter of Intent(Table 12) we provided an estimate of about $25M for the total of R&D and engineering in FY92. At this time we estimate that about one-half of the $25M will be required to support R&D and the other one-half engineering design and management.

We certainly agree that the funds requested in FY91 are low but the request significantly exceeds the supply. A similar comment can be made about FY92.

There are additional R&D costs beyond FY92 and we are in the process of estimating these costs more precisely for our July 1 milestone. All engineering-related costs are included in the construction cost estimate.

7. *Provide a "clean" copy of the Solenoidal Detector Cost Roll-up(dated Nov. 30, 1990). Also provide any additional lower level estimate roll-up information that supports this database. In general, the information in the cost estimate is not well organized, and it's difficult to fish out relevant data.*

   A clean copy of the SDC cost roll-up is attached to this report.

8. *There is a problem in correlating the back-up information with the roll-up cost estimate at least for the SC magnet (WBS 4.1) and Cryogenic Systems (WBS 7.4). Please demonstrate how the labor estimates are transferred into the estimate roll-up.*

   The labor estimates in the backup information for 4.1 and for 7.4 presented on Dec. 3 were in man-weeks. These estimates were transferred to the roll-up as man-days. However, a mistake was made in doing so. The numbers in the backup information are correct.

9. *In general, there are two basic ways to manage contingency: By setting aside moneys in the beginning, or by scope adjustment. To what extent can scope adjustments in mid-construction be used instead of allocating moneys up front?*

   We believe that our contingency should consist partly of monies set aside at the start of construction and partly of potential scope reductions. We plan to set aside contingency funds of the amount indicated in the cost estimate presented in the Letter of Intent at the beginning of the project. We believe that it will be possible, if necessary, to stage some elements of the detector. Since this will degrade performance when the detector is first turned on, we prefer to delay such staging decisions until the necessity is demonstrated during construction. Of course, scope reductions are also possible before starting construction.

Tracking Systems

1. *The beam pipe may be greatly underestimated. The Electrofusion quote of $170 K for 21 feet of beryllium seems very low based on recent SLD, D0, and CDF experience. Additionally there is much more to a beam pipe than just beryllium to connect to the rest of the world. It isn't apparent that a beryllium beam pipe is necessary in the first place. Please comment.*

The quote from Electrofusion was based upon two trips to the vendor where the specifications were covered in some detail. Their quote was based upon a 37.1-mm diameter, 3.7-m long pipe that had recently had been supplied to Fermilab. The cost of that component was given as $103K by Electrofusion. The same drawing was used as a basis for our configuration except the diameter was increased to 50 mm and the length to 21 ft. Since the component that was bid was very similar to a recent part, Electrofusion's confidence in the engineering required is high. Included in the quote were stainless transition pipes and a flange on each end. Bellows were not included, but a follow-up call indicated that adding two 321 stainless steel, rolled bellows would be about $264 for parts and about $2K for labor. Electrofusion has supplied many beam pipes to various experiments over the last few years.

The design of the vacuum system for the interaction region is at a very early stage. How much of this system is detector specific and how much is determined by the accelerator requirements remains to be defined.

Precision secondary vertex location is one of the goals of the silicon tracker. We believe this requires a beam pipe with a minimum allowable thickness in radiation lengths, consistent with safety and other requirements.

2. *How will luminosity be measured? The costs associated with this may not be trivial.*

Measurement of luminosity is of interest to the operation of accelerator, independent of the existence of the detector. It is our understanding that the feedback system required to keep the beams colliding will provide at least a crude measurement of the relative luminosity as a function of time. In any event we have assumed the luminosity monitoring system to be the responsibility of accelerator operations.

3. *Is the estimate for butane cooling for the silicon detector reasonable? The system design calls for high liquid and gas transfer rates that may lead to problems with vibrations. Likewise, are there safety implications that may affect cost? Are there alternatives to butane, and if so, what are their relative costs?*

The butane cooling system is a passive, thermo-siphon system; there are no pumps or compressors. The total system liquid flow is set by the heat of evaporation, for butane this requires

nominally 2.38 grams per sec per Kw of thermal heat load. For a maximum design of 40 Kw's, the system maximum liquid flow rate would be 95 grams/sec, as contained in the RRR document. This flow is dispersed throughout many secondary feed lines that supply fluid to the wicks; the flow rate and pressure drop is negligible(see "Superconducting Super Collider Silicon Tracking Subsystem Research and Development", Los Alamos LA-12029 Report.)

The vapor rate is 923 cubic centimeters (cc) per sec per Kw thermal heat load. For a 40 Kw maximum design thermal load, the return vapor flow rate is 37 liters per sec. The vapor volume is low and the 25 meter vapor return line to the condenser was sized to minimize any pressure drop. The vapor velocity is roughly 2.35 m/sec (5.3 miles/hr). Vibration is not a problem, because there are no pumps involved.

Considerable effort has gone into the choice of the butane for the cooling system. Safety planning is one of our priority issues and we have had meetings with cognizant SSCL safety representatives. No negative comments have been returned from this review, and the safety committee was particularly impressed by the small quantity of butane that is required to cool our system, and precautions being taken to eliminate hazards. Our preliminary cost analysis was predicated on costs associated with all major procurement items and related development issues. We feel at this juncture we have covered the cost associated with incorporating the safety features as well. As part of the safety analysis for the SSCL, information is being assimilated to substantiate the selection of butane. Many of the engineering reasons are contained in LA-12029. The report to the safety committee will cite the physics issues as well. In brief, the silicon detectors operate at zero degrees or lower to enhance the radiation hardness. Mechanical stability issues support the choice of an open vapor return path, i.e., the silicon is exposed to the butane vapor. Fluids that would breakdown and chemically attack the silicon after exposure to the radiation have to be avoided. Also, fluids which do not change phase at one atmosphere and at/or near O°C were eliminated because of the added structural mass and increased required to provide proper containment and structural stability. These considerations narrowed the field of candidates greatly.

4. *No backup was provided for the silicon support system of $8M. This is a difficult and crucial element to the silicon tracker. How can we be certain the estimate isn't off by a large factor?*

Extensive backup was provided in the April 1 supplement.

5 *Can you reconcile the differences in channel count for the central and intermediate trackers as given in the parameters lists of April 8, 91 and Dec 3, 90? The outer tracker shows 360K fibers vs zero, and the intermediate tracker shows 235K vs 50K straws.*

As was stated in the supplementary information of April 1, we are in the process of continuing the design of the detector and of producing a much more detailed cost estimate by July 1. The parameters table dated April 8, 1991 represents the status of the evolving design on that day and has no connection with the cost estimate presented in the Letter of Intent.

6. *What has been allocated to test 188K straws in the central tracker, and however many in the intermediate tracker?*

The straws as well as the straw components or subassemblies must be tested several times during the tracker manufacturing process. It is assumed that vendor components through procurement specifications requirements will have received some level of testing prior to receipt. With respect to SDC fabrication, WBS items 1.2.10 designated as Facilities for Support Assembly, Module Assembly and Electronics Assembly lists a Tech QA (Quality Assurance) function for a total of 15 man-years. This is an aggregate number of which at least three man-years is to be designated for "testing" of components including straw module assemblies. Note, at this stage in the manufacturing process, these straw module assemblies should be complete with front end electronics. After the modules and support structure are assembled, WBS item 1.2.6 designated as Pre-Installation Tests, allocates an additional 51 man-days plus equipment for assembled "straw" tests.

For the intermediate tracker, see the answer to question 7.

7. *No backup was given for the intermediate tracker costs. The technology required may be different than for the central tracker. Please comment.*

This is correct. At the time of the Letter of Intent, there were many options for the intermediate tracker, including no intermediate tracker. Hence, the cost was estimated by scaling on the basis of channel count from the central tracker.

8. *How will the central tracker be insulated thermally from the silicon tracker at 0°C, and what would it cost?*

The outer shell for the silicon tracker will be a thin double walled structure with a gas barrier for safety reasons. The outer surface of the system will remain at or very near room temperature. This situation arises from the rather high thermal resistance afforded by the outer shell design, and the low gas convective film coefficients on the inside and outside of this shell wall. The wall contains a dead gas space, and heat flow is limited by the low thermal conductivity of gas (e.g., N_2), similar to an insulated house wall construction. Natural convective gas film coefficients, which are inherently quite low, exist on the outside and inside surfaces of the containment vessel. If

the central detector incorporates forced circulation of nitrogen gas, then the outer gas film coefficient will increase by a factor of ten, but this will have little effect on the containment shell external temperature and no effect on the outer tracker elements. We anticipate a small heat leak into the silicon subsystem, but the evaporative state point of 0 °C will not be affected because of the large cooling capacity in the tracker. The thermal barrier design is a natural consequence of the design and no additional monies are needed to effect this thermal isolation.

9. *The muon system has very little backup for a $31M request. It is difficult to judge the accuracy of this estimate. Please comment!*

This refers to the muon chamber system. At the time of the Letter of Intent, designs for the muon chambers were not explicit enough to support a detailed estimate. Hence, simple scaling rules(cost per wire, etc) were used to derive the cost. We recognize that this was a crude estimate. In the last four months we have started a much more intense design effort at Draper Laboratories and the Physical Science Laboratory at the University of Wisconsin. We have also contracted with Martin Marietta to provide a much more detailed cost estimate for the muon chamber system(and other parts of the muon system). This estimate will be available by July 1.

10. *EDI/A for the muon system is a very low fraction of the total. Please comment!*

The muon system contains two subsystems, the iron toroids and scintillation/Cerenkov counters, that are relatively "low-tech". These systems do not need the level of engineering design that is required for other more technically complicated systems. For the muon chambers see the answer to question 9.

11. *In general, the ratio of engineers to designers was exceptionally large, not uncommonly two to one. More commonly this would be one to two. Is the estimate for the number engineers too large or is the number of designers too small.*

Does this refer to the total muon system, part of it or the total detector? In any case, the ratio is closer to one-to-one for the muon system. In principle, this may be too large. However, we were conservative in our assignment of times to the higher cost "bin" in the labor estimate. A more detailed estimate, in preparation, will assign costs by institution in the engineering category and will differentiate between designer and draftsman.

Electronics

1. *For the silicon tracking system, please provide more information to substantiate the cost of readout electronics.*

A conservative design of the readout electronics is a two chip arrangement with one larger analog amplifier chip and a smaller digital storage chip. We asked the United Technologies Microelectronic Center to provide a quote for their radiation hard process to produce two chips. The quote was for 128-channel chips and is representative for other technologies such as bipolar. For the estimate using 64-channel chips, we have scaled the costs using the cost/area formula deduced from the quote and added non-recurring engineering costs for two chips. This results in a per chip cost of $17.83 for the 64-channel combination of amplifier+storage chips.

Costs associated with the assembly of the detectors and the front-end electronics were engineering estimates. It was assumed that an additional $5/assembly in material would be required and that the assembly could be tested at the rate of 6/hour. The costs of the checkout was estimated at $75/hr using developed automatic machines and fixtures ($20k). The estimated total cost/assembly was about $50. The total number of assemblies were estimated from the number of detectors and chips.

Discussions have been held with OLIN and K & S on wire bonding. K &S have an automatic wire-bonding machine (1471) that will bond at a rate of 29000/hr or 14500 wires/hour. The rate was reduced by a factor of 4 to allow for setup and down time. During operation, this machine would cost about $100/hr.

2. *The Hamamatsu estimate for silicon detectors seems somewhat optimistic. (Especially for double sided detectors.) Is there a second source to confirm this estimate?*

The silicon detectors will be provided as a foreign contribution, thus the Hamamatsu estimate is the most relevant. Groups interested in providing these include our Japanese and Soviet collaborators. The Soviets have begun to make working detectors, but it is too early to have a clear estimate in their case.

We can, however, look more closely at the Hamamatsu estimate. The cost of unprocessed wafers for detectors is a very small part of the cost, as are mask costs for very large numbers of detectors. Thus the cost is mainly for processing, but depends on yield. Detector costs, per wafer, have been typically about $1,000 for single sided detectors. In our case we are choosing the detector dimensions very carefully to be able to get two per wafer and to stay well away from

the wafer edges, which negatively impacts the yield. Hamamatsu has estimated a cost of $1,500 for such a pair of detectors obtained from one wafer. Past experience, which is limited, has indicated that double sided detectors cost about three times as much as single sided detectors because of additional processing and lower yield. Thus the $1,000 per wafer would have led to an expectation of $3,000 per wafer for double-sided detectors. The Hamamatsu verbal quote is a factor of two below this, which is not unreasonable for such a large volume of detectors.

3. *For the central tracking - straw tube readout please explain the placement of electronics at the ends of the chamber. How is this to be realized?*

For each module of straws, there will be an individual board mounted to the module that contains the front-end electronics, high voltage connections and calibration connections. Viewed end on, the readout board will be located radially outward from the module, since the module area is not large enough to allow all electronics and other devices to be located within the module area. The size of the module + readout board is about 10 x 12 cm. Of the 10 cm, about 3 cm is taken up by the readout board overlapping with the module and 7 cm for the remainder of the readout board. The Universities of Colorado and Pennsylvania are constructing a prototype readout board. This is the conservative solution to attachment of the electronics. Advanced packaging solutions that would reduce the "footprint" of the readout board are being studied.

4. *Also for the straw tubes in the central tracker, where is the cost of assembly for electronics included? (Motherboards for anode wire connections and readout circuits.)*

The assembly labor for electronics is listed under Electronic Assembly in WBS item 1.2.10.3 as Tech (Assembly) and has a value of nine man-years. In addition, these are six man-years for QA and testing.

5. *For the central and forward calorimetry, please explain the cost of readout front-end electronics. It appears too low considering the requirements of the dynamic range, linearity and speed.*

It should be noted that we have chosen to put a large fraction of the costs of the total electronics chain under the data acquisition and trigger costs. The front-end systems, as we have defined them, include the bare minimum to produce and store suitable signals for the data acquisition and trigger systems. In order to estimate the cost of calorimeter front-end electronics we have considered two possible approaches that could provide the requisite dynamic range, linearity, and speed.

The first approach is based upon analog storage of the data in parallel switched capacitor arrays. Each calorimeter channel is equipped with two storage channels to provide two gain ranges

of 12 bits for an overall dynamic range of 17-18 bits. Readout from the switched capacitor arrays after a Level 2 Trigger is highly multiplexed. The cost estimate for this approach includes the preamplifier, connection to a shaper/storage board, shaper/storage boards for 300 channels, crate, and power supplies. Analog summation for the trigger in groups of approximately eight input channels is included; however, remaining trigger electronics is costed elsewhere. Data multiplexing, some simple data preprocessing (e.g.:zero-suppression, pedestal correction), and local calibration and clock/gate control are included; however, remaining data collection, acquisition, and processing are costed elsewhere.

Table 3 – First Cost Approach

Hybrid or hybrid/IC preamp	20$/ch
Connections to shaper/storage board	2$/ch
Shaper/storage board and crate 4500$/board (300 ch/board * 250 mw/chan)	15$/ch
Subtotal	37$/ch
Design and misc @ 30%	12$/ch
Total	49$/ch

In the second approach, data is flash encoded following a gated integrator and stored in digital fashion. The gated integrator and FADC are assumed to be in the base of the PMT. They employ parallel 8-bit scales to achieve 18-20 bit dynamic range. Data storage and readout multiplexing occur in the trigger crate, where the fine-granularity digitized data is used to form a Level 1 Trigger. The front-end cost estimate includes only the electronics through the FADC. The cost of the remaining electronics is attributed to the trigger, including the input connections to the trigger crate and the digital storage function (which shares an IC with calibration correction circuitry used in the trigger), and to data acquisition. Note that in this approach there is some double counting of FADC's between the front-end and trigger estimates.

Table 4 – Second Cost Approach

Gated Integrator ASIC		15$/ch
FADC (60 MHz 8-bit)		18$/ch
Calibration circuit		5$/ch
Assembly		10$/ch
	Subtotal	48$/ch
Design and misc @30%		14$/ch
	Total	62$/ch

Either of these approaches utilize custom integrated circuits to achieve the requisite performance while achieving cost effectiveness through more highly integrated functionality.

6. *For the muon chambers, is there a second coordinate readout in any of the chambers? If not, explain the reasoning. If yes, where is the cost of electronics included.*

The layout of the muon chambers is described in some detail in Table 7 of the Letter of Intent. There is no second coordinate readout but there are crossed and stereo wires.

Magnet Iron

1. *The muon steel is similar in diameter to L3 (LEP at CERN), but approximately twice the length. The number of pieces for the muon steel seems to be greater than L3 and involving a more complex joining and supporting system. The L3 installation involved 70 man-years of effort and the contract was fixed at SF1.4M. If an extrapolation is carried out for SDC, the installation cost for muon steel would seem too low by a factor of three. Please comment.*

Does 70 man-years refer to the total L3 steel and coil installation effort or only the steel part? If it is the latter, it would seem rather high. In any event, our preliminary estimate for installation of the barrel muon toroids is about $2.0M, for the steel alone. Of this total, $0.5 is included as fixtures under the barrel muon toroid cost and the remainder as manpower and procured services or items under installation and test.

2. *We would appreciate a more detailed estimate of the return steel cost on the outside of the calorimeter. The steel would seem to require extensive machining in order to accommodate the interface with the calorimeter and this item should be more clearly defined.*

This question is assumed to pertain to WBS elements 2.1.2.1.4 and 2.2.2.1.4. Based on calorimeter design version 4136A21.R5, the total mass of flux return steel in the central and end cap

calorimeters was calculated. A representative piece of the flux return steel was designed and drafted in Westinghouse drawing 1D33361, Rev. 1. The drawing shows fully machined surfaces, and provisions for fastening to the Hadron 2 section and to adjacent modules. The piece is one of 64 identical pieces, and this group of 64 pieces comprises 321,600 kg, or 26% of the total flux return steel mass. Quotes were obtained for costing and final machining of the pieces. The average of all quotes was used. Based on these quotes, the total average cost of material, casting, and machining of the flux return steel pieces is $5.48/kg.

Table 5

	Central	Two End Caps
WBS no.	2.1.2.1.4	2.2.2.1.4
Flux return steel mass (kg)	561,181	666,418
Material, casting, machining ($/kg)	5.48	5.48
Steel cost ($)	3,075,272	3,651,971
Bolts and connection keys ($)	36,874	22,029
2.5% development cost ($)	77,804	----------
Total procurement ($)	3,189,950	3,674,000

Superconducting Solenoid

1. *Between the preliminary cost estimate dated December 3, 1990 and the SDC cost roll up dated November 30, 1990, there appears to be a reduction of ten man-years in EDIA effort for the solenoid/cryostat and an increase of 3 man-years for the cryogenics. Is this factual and if so, is it as a result of reassessment?*

No, it is a mistake in the roll up. The backup information from December 3, 1990 is the proper estimate.

2. *The latest summary of FY91 and FY92 R&D plans by Bob Kephart dated April 12, 1991 proposes a R&D budget of $1.786M. The proposed KEK component of $750K appears to be be supplied by KEK? If not, are the proposed resources adequate to carry out the planned program.*

Japan plans to allocate 180 M yen (approximately $1.3M) for the first year of the prototype solenoid development (three years estimated for completion). The cost includes EDI/A. The KEK Physics Department Engineering Group led by A. Yamamoto, and including Y. Doi, Y.

Makita, M. Kimura, H. Yamaoka, and K. Tanaka will closely supervise the prototype construction by Japanese industry. The above staff are supported by KEK.

3. *As indicated in Table 4 of the EOI, all solenoids to date have been built with a ratio of stored energy to cold mass (in units of kJ/kg) that is less than 5.5. What is the justification for assuming that a ratio greater than 6.2 for the SDC design is acceptable?*

The development of thin superconducting solenoids in various projects, especially in Japan, has indicated that the solenoid will be safe with an E/M ratio of 7 kJ/kg or more under a condition with higher quench propagation velocity. A new technique to enhance the quench velocity by using pure aluminum strips glued transversely to the coil conductor has been recently developed at KEK. It has enabled us to expect, in the case of a quench, a homogeneous energy dump in the coil. It will result in a coil temperature rise of less than 80 K. This condition is quite safe because that thermal stress is still negligibly small. Please refer to the proceedings of the International Workshop on Solenoidal Detectors for the SSC (KEK Report 90-10, p. 141). The E/M ratio of 7 kJ/kg is a result of hard development effort at KEK. An E/M ratio of 10 kJ/kg has also been achieved in a magnet with a stored energy level of 10 MJ at KEK.

4. *The proposal to work harden the pure aluminum cladding of the conductor to enable it to carry some of the magnetic hoop force has been considered by earlier workers. Kim and Wang carried out a study which indicated that pure aluminum can be annealed at room temperature and certainly at hot bonding temperatures. Has this point been taken into account in relation to the SDC proposal to work harden the conductor aluminum cladding?*

We understand that pure aluminum with 4N purity well-controlled may keep its hardened condition even after a curing period with a temperature of 150 degrees as the result of our experiment. We may agree that 5N pure aluminum may easily be annealed at hot temperature and may not keep its hardened condition after cold work. This has also been consistent with our experience. The data presented at recent meetings were measured after heat treatment to simulate the coil curing condition. Please check the data presented by Kim and Wang as to whether the purity is very high (5N) or lower (4N).

Calorimetry

1. *How much R&D/prototype work has been done for casting the EM and Hadronic modules? How much experience does Westinghouse have in estimating casting? How much R&D work is proposed for verifying this process?*

The R&D/prototype work on cast lead EM and hadron calorimeter modules falls into two categories:

a) structural design and materials studies plus conceptual and preliminary engineering designs for the full-size and test calorimeter modules;

b) experimental materials tests and cast lead test module fabrication.

In the first area, a cooperative program of R&D involving Argonne National Laboratory and Westinghouse Science and Technology Center has been underway since January 1990. Results to date on this aspect of the R&D program have focussed on the detailed consideration of conceptual designs based on several candidates for the passive absorber of the calorimeter. These have included rolled uranium plates, rolled lead plates, lead composite materials and steel reinforced cast lead. For cost, mechanical strength, physics capability and fabrication reasons, the reinforced cast lead option has emerged as the technology of choice. Studies of the materials properties, mechanical suitability and physics effectiveness of the cast lead option have been completed and documented. We believe that a central calorimeter meeting or exceeding all the present SDC LoI technical specifications can be built using the cast lead absorber technology, in conjunction with an iron "tail catcher".

Work in the second area (casting experiments and cast lead test modules) is in progress and is partly completed. Several small test castings have been made to demonstrate the dimensional and density properties and to demonstrate the efficacy of mold construction and mold release techniques. These test have been very successful. A larger test module is presently being constructed that comprises ten full-size towers of the SDC EM calorimeter design in a single casting. This test module represents 20% of a final EM calorimeter module(which will contain 56 towers in a 2 x 28 array). Results so far in the R&D casting program are very positive and have been documented in reports and notes. Results on the 20%-scale EM test module will be available in May 1991.

On the question of Westinghouse experience in estimating casting costs,we note that the estimates in this area are based on technical conversations with Teracorp Corporation, a lead foundry and fabricating firm that will cast the test module presently under construction. The LoI

related estimates should be regarded as budgetary cost estimates at this stage since they could not be based on construction drawings of the parts to be estimated.

The remaining R&D work to confirm the viability of the steel reinforced cast lead absorber technique will involve further detailed mechanical design studies to incorporate all the necessary full-detector mechanical requirements as well as production of full size prototypes of the EM and hadron modules. This work will be accomplished during FY 1992 and FY 1993; progress is likely to be limited by rate of funding rather than by design pace and schedule.

2. *What precision/tolerances will be required from the casting process? How much machining will be required?*

Molds have been built and castings have been made that achieve local dimensional tolerances of +/- 0.003 inches and which will have runout tolerances of +/- 0.030 inches over the full modules. These tolerances will meet our requirements. Finish machining on the tile-loading faces is likely to be necessary. These faces are expected to be fly cut in a single pass operation to face off the cast lead surfaces. More definite results will be available on this subject by June 1991.

3. *Where are the machining costs included in the WBS, how much is estimated, and how was the estimate made?*

Machining costs are included primarily in the "PROC" column, and in some cases in the "TECH-MAN DAYS" column, depending on how the quote was obtained. Based on the knowledge available, a detailed manufacturing drawing was made for each family of parts. These drawings were sent to various machine shops for quotations. Most quotations were in $, and went into the "PROC" column. A few quotes were in labor hours, and thus went into the "TECH-MAN DAYS" column. Final machining of the lead castings was not included. Development work is currently in progress to determine how much machining is required, and what it will cost. The major machining costs are contained in the flux return steel, which was previously discussed, the stainless steel reinforcement plates for the EMC and Hadron 1 and the punched steel laminations for Hadron 2. These costs are summarized on the following page:

Table 6

Type of Part	Drawing No	Mach. Cost ($/kg)	Basis of Estimate
HAC1 bulkhead	2931C07	8.14	Quote
HAC1 horiz. plates	2931C09, 10	21.46	Quote
EMC bulkhead	——	50.63	Est. based on Dwg.No. 2931C07
EMC horiz. plates	——	8.14	Est. similar to Dwg. No. 2931C07
HAC2 lams	——	8.14	Est. similar to Dwg. No. 2931C07

4. *The calorimeter derived cost to weight ratio is $8/lb. This is very low when compared to other detectors such as $14/lb for scintillating fiber (E/T SPACAL) which also utilized a casting process, $13/lb for liquid scintillator (L*), $12/lb for Liquid Argon (E/T), $14/lb for scintillator (CDF), and $29/lb for scintillator (ZEUS). Please justify this large decrease in cost for a system which is very large, contains over 40,000 towers, and requires assembly of over 1 million tiles with very high precision and reliability, a very formidable task when compared to other detectors whose calorimeter costs were at a much higher $/lb.*

We note that the calorimeter has about 10,000 towers, each divided into four longitudinal depth segments. Also about 25% of the weight is in un-instrumented steel at the back of the calorimeter. This steel is used for module support and for additional flux return.

It is the goal of the SDC to design and produce a calorimeter that meets or exceeds our design goals. Our engineering and R&D effort is aimed at minimizing cost while meeting these design goals. Although much work remains to be done, it is our belief that the cast lead-punched iron design costed for the LoI will meet our design goals at minimum cost. We continue to explore means to lower cost either by design modifications(eg. a lower sampling fraction with more iron) or improved methods of producing scintillator tiles(eg. injection molding).

The ZEUS cost involves the use of uranium and is not directly relevant for comparison. We can attain sufficient performance without using uranium and have no plans to explore this possibility.

Scaling cost by weight does not take into account differences in channel counts, electronics costs or costs that are approximately independent of weight, such as design costs. Furthermore, one expects that economies of scale and efficient mass production techniques will reduce the cost per unit weight. The cost estimate produced for the LoI was our best estimate at the time of the actual costs, derived as much as possible from a "bottoms -up" approach.

5. *What was the material cost assumed for the scintillator (e.g. in $/cm^2)? What happens to this cost if the radiation requirements cannot be achieved?*

Charles Hurlbut of Bicron quoted a cost of 0.0294 $/cm^2 for 24,000 m^2 of 2.5 mm thick scintillator tile. Radiation hardness was not specified for this quote.

The requirements of radiation hardness are under evaluation as part of the subsystem R&D program and by the SDC. We note that radiation hardness is a concern only in the electromagnetic section of the calorimeter, except possibly for a small region near $|y| = 3$. Further, the radiation dose depends very strongly on rapidity(see Fig. 4 in the LoI) such that the barrel region is in a relatively low dose rate region. Extensive radiation damage tests of conventional polystyrene based scintillators will be completed this summer at KEK, Orsay, IHEP(Beijing) and in the USSR.

6. *Summarize the tile manufacturing process outlined on pp.236-238 in the April 1, 1991 Cost Supplement into the following format.*

The estimate for tile manufacture was performed as an overall system breakdown not a per piece effort as your requested table indicated.

The tile manufacturing study only deals with tooling and labor estimate and not material costs. Material cost is covered in the WBS items associated with scintillating tiles. Table 7 below covers the material cost for the scintillating tiles/fiber/etc. Table 8 shows the tile count for both the barrel and end cap calorimeters. Table 9 provides the information requested based on data from Table 7 and 8. Note the 0.5 hr./unit time is machine operation time on each tile and not the total cycle time per tile.

Table 7 – Material Cost

		Direct Cost	Assume 20% scrap
Scintillator	($/m^2)	292.00	350.40
Mask	($/m^2)	85.00	102.00
Mylar	($/m^2)	4.84	5.81
Acetate	($/m^2)	2.33	2.80
Color Fiber	($/km)	330.00	—
Clear Fiber	($/km)	240.00	—

Table 8 – Electronic Channel Count

		Tiles	Segments
Barrel	EMC	204288	2
	SPD	36480	2.5
	HAC1	443008	1
	HAC2	69632	1
End Caps	EMC	64512	2
	SPD	11520	2.5
	HAC1	232704	1
	HAC2	74240	1

Table 9 – Requested Table

	# Units	Machine Mfg. Time Hrs/Unit	Material $/Unit	Average Tooling $/Unit
EM	268800	0.49	9.38	5.72
SPD	48000	0.49	9.39	5.72
HAC1	675712	0.49	11.62	5.72
HAC2	143872	0.49	12.23	5.72

7. *Have any comparisons of the cost estimates been made to the ongoing upgrade at CDF for manufacturing of the scintillator tiles (contact J. Freeman/B. Foster) to verify the 0.5 hours/tile estimated? How much confidence is there in achieving this assembly time?*

The laser cutting experience of CDF and our own quotes for test module tiles constitute the basis for the present estimate. We anticipate that significant economies of scale will be realized when production quantities of tiles are being cut and assembled. For example, each individual tile in a barrel tower must be replicated at least 128 times in the full barrel. Setup time for tooling and fixturing is reduced by significant factors in such volume production of identical parts. As far as fiber splicing and gluing are concerned, automated methods are already being developed and tested by members of the Subsystem R&D Collaboration during FY 1991. These systems are well along toward successful development. Fiber routing is under intensive study and is a soluble problem. The exact optimum methods are still being considered with respect to fixturing, hold-downs, etc. for production level fabrication of towers.

8. *For the fabrication facility, the estimate of $200,000 (p.202 of the April 1 Cost Supplement) seems low. Please justify. Where in the WBS is this accounted for?*

The cost of the lead casting fabrication facility shown on page 202 [(W) D.389.4136A42.R1] is correct at $200,000. This value was estimated in meetings with TARACORP Industries of Granite City, IL. They are a qualified major lead supplier with a facility presently available for casting. The value of $200,000 was to set up the facility shown in the figure in their shop. Some of the equipment shown (60 ton kettle and pump system) is presently available as part of their standard melting/casting system. The SDC fabrication facility cost is only for the additional equipment particular to the SDC calorimetry.

The WBS area in which the facility cost for the casting facility is divided between the barrel and end cap, since they will both use the same facility. Under barrel calorimetry WBS 2.1.7.3.1 and end cap calorimetry WBS 2.2.7.3.1, a total of $250,000 is indicated as procurement in these two WBS items. The additional $50,000 is for casting disassembly/cleaning facilities.

9. *Because of the varying module shapes many different size molds will be required. How many molds are needed and at what unit cost? Where are these costs included in the WBS?*

There are six different molds/castings required. They are:

Table 10

Mold	No. of Castings to Be Made
HADRON 1 barrel-center	64
HADRON 1 barrel-end	128
EMC barrel-center	64
EMC barrel-end	128
HADRON 1 end cap	64 (both end caps)
EMC end cap	64 (both end caps)

It was assumed that two each, or a total of 12 molds will be made at a cost of 5 $/lb of mold weight. Mold weight was calculated by assuming the mold encloses the casting on five sides with one inch thick steel. This cost appears in the "PROC" column of the tasks marked "mold fabrication." The WBS items are as follows:

Central Calorimeter	2.1.2.1.1.5	EM Section Mold Fabrication
	2.1.2.1.2.5	Hadron 1 Section Mold Fabrication
End Cap Calorimeter	2.2.2.1.1.5	EM Section Mold Fabrication
	2.2.2.1.2.5	Hadron 1 Section Mold Fabrication

10. *How many module castings will there be made? What is the manufacturing time for each EM and Hadronic module casting?*

The sequence of tasks in producing a lead casting are:

1) Buy stainless steel plate
2) Machine stainless steel plate
3) Weld stainless steel plate
4) Ship steel weldment to casting facility
5) Install steel welded reinforcement in mold
6) Install slot inserts in mold

7) Make casting
   a) Place mold in facility
   b) Pour lead
   c) Cool and remove casting from lead facility
8) Strip mold and go back to step 5

Steps 5-8 would occur at the lead foundry and would take about one week per cycle. The lead casting facility, which can accommodate one to four castings at a time in step 7, has a two to three day turnaround, so that step 7 could be repeated twice per week.

Table 11

Module	Quantity	No. of Modules in Casting Facility at Once	Duration in Casting Facility (Wks)
HADRON 1 barrel-center	64	1	32
HADRON 1 barrel-end	128	1	64
EMC barrel-center	64	4	8
EMC barrel-end	128	4	16
HADRON 1 end-cap	64	1	32
EMC end-cap	64	4	8
TOTAL			160

11. Were the labor estimates for each manufacturing step outlined on pp. 239-253 of the April 1 Cost Supplement developed? If yes, please provide them. If no, how were the labor estimates arrived at for each step in the manufacturing process?

The manufacturing plan on pages 239-253 was developed after the WBS and cost estimates were produced. Labor estimates were not made for each line item in the manufacturing plan. When labor estimates were made originally, a similar, yet less detailed task structure was used. Many tasks listed in the manufacturing plan, such as the purchasing of material, and the machining of plates, for example, were covered with quotes, and therefore appear as procurement $ instead of man-hours.

12. Where are the costs for Calorimeter Segment Manufacture and Assembly tasks outlined on pp. 246-252 of the April 1 Cost Supplement included in the WBS?

Module manufacture and assembly refer to the assembly of all the subassemblies into a module for either the central or end cap calorimeter. Included in these subassemblies are the tile/fiber assemblies, individual segments of EMC, Hadron 1, Hadron 2, back iron and instrumentation (phototubes, etc.). This module assembly operation was costed under:

Central Calorimeter	2.1.1.2 Front End Electronics Installation
	2.1.1.3 Readout-Module Assembly
End Cap Calorimeter	2.2.1.2 Front End Electronics Installation
	2.2.1.3 Readout-Module Assembly

The overall calorimeter assembly is an item to be handled at the SSCL and was not costed under WBS 2.1 or 2.2. Handling fixtures, cradles and shipping are included in WBS 2.1 and 2.2, but the labor requirements were assumed to be covered in WBS 8.0, Installation and Test.

13. Please break out the material and labor estimates for assembling one EM and Hadronic module? How many total modules are there to be assembled?

Each module, whether it be an end cap or a central calorimeter module, contains an EM, Hadron 1, Hadron 2 and outer steel section. There are a total of 192 modules in the central calorimeter, and 32 modules in each end cap. Of the 192 center calorimeter modules, there is a set of 64 identical modules at the middle of the central calorimeter, and two sets of 64 identical modules at each end of the central calorimeter. All 64 end cap modules are identical. Thus, there are 256 modules, coming in three varieties. The breakdown of the material cost and labor requirement for module assembly are shown below in Table 12 for the barrel calorimeter and Table 13 for the end cap calorimeter.

Table 12– Barrel

Item Description	Man Days Eng.	Design	Tech	Labor	$ Procurement
192 Modules					
Mold Parts	867	340	2287	0	761495
Matls. Parts & Labor	4647	1770	5679	0	12820780
Readout Tooling	3978	1989	1658	0	4309500
Readout Parts a& Labor	3483	1495	11522	43824	20319572
Hardware ASMB Labor	0	0	108	0	0
Readout Installation Labor	0	0	1824	0	0
Electronics Installation Labor	0	0	167	0	0
Per Module					
Mold Parts	5	2	12	0	3966
Materials, Parts & Labor	24	9	30	0	66775
Readout Tooling	21	10	9	0	22445
Readout Parts and Labor	18	8	60	228	105831
Hardware ASMB Labor	0	0	1	0	0
Readout Installation Labor	0	0	10	0	0
Electronics Installation Labor	0	0	1	0	0

Table 13 – End Caps

Item Description	Man Days Eng.	Design	Tech	Labor	$ Procurement
Mold Parts	574	240	610	0	248200
Matls. Parts & Labor	3041	1180	2024	0	8988400
Readout Tooling	2022	1011	842	0	2190500
Readout Parts a& Labor	1517	505	5676	22276	6624279
Hardware ASMB Labor	0	0	122	0	0
Readout Installation Labor	0	0	576	0	0
Electronics Installation Labor	0	0	83	0	0
Per Module					
Mold Parts	9	4	10	0	4003
Materials, Parts & Labor	49	19	33	0	144974
Readout Tooling	33	16	14	0	35331
Readout Parts and Labor	24	8	92	359	108843
Hardware ASMB Labor	0	0	2	0	0
Readout Installation Labor	0	0	9	0	0
Electronics Installation Labor	0	0	1	0	0

14. What is included in WBS items 2.1.2.2.1 and 2.1.2.2.2? How does this differ from what is included in WBS item 2.1.2.2.3 for the EM, Hadronic, and SPD modules?

WBS items 2.1.2.2.3 are raw material expenses for scintillating plate (292 $/m^2 for 2.5 mm thick), clear scintillating fiber (240 $/km for 0.7 mm diameter), and wave shifting fiber (330 $/km for 0.7 mm diameter), WBS item 2.1.2.2.3.1 is the masking raw materials, which include Dynamark aluminum (85$/m^2), acetate transparencies for photo imaging (2.33$/m^2), and mylar (4.84 $/m^2).

15. *Support structures (WBS items 2.1.3 and 2.2.3) and Assembly and Handling Fixtures (WBS items 2.1.4 and 2.2.4) seem quite low. How were these estimates derived and what is included?*

2.1.3 Cradle Plates

Machining:	14 pcs. x $8400 ea.	$117,600
Material:	479,248 lbs x 0.425 $/lb	203,680
Misc.	rails and leveling devices:	200,000
		$521,000

2.2.3 Cradle Plates

Machining:	10 x $8400 ea	$ 84,000
Material:	72,941 lb x 0.425 $/lb	31,000
Misc.	rails and leveling devices:	50,000
		$165,000

Assembly and handling fixtures WBS items 2.1.4 and 2.2.4 are general fixtures and do not include all fixturing. Additional fixtures can be found in WBS items:

Central Calorimeter

2.1.2.3.1.6	Phototube Assemblies EM Section Fixtures and Assemblies
2.1.2.3.2.1	Phototube Assemblies Shower Max. Profile Detector Fixtures and Assemblies
2.1.2.3.3.5	Phototube Assemblies Hadron 1 Fixtures and Assemblies
2.1.2.3.4.5	Phototube Assemblies Flux Return Section Fixtures and Assemblies
2.1.5.1	Transportation System and Handling Fixtures

End Cap Calorimeter

2.2.2.3.1.5	Phototube Assemblies EM Section Fixtures and Assemblies
2.2.2.3.2.1	Phototube Assemblies Shower Max. Profile Detector Fixtures and Assemblies
2.2.2.3.3.5	Phototube Assemblies Hadron 1 Fixtures and Assemblies
2.2.2.3.4.5	Phototube Assemblies Flux Return Section Fixtures and Assemblies
2.2.5.1	Transportation System and Handling Fixtures

WBS items 2.1.4 and 2.24 do seem to be low (WBS 2.1.4 } $235,000 and WBS 2.2.4 } $117,500), but a lot of the fixturing indicated in WBS items 2.1.5 and 2.2.5 should be included. WBS item 2.1.5 is costed at $1,318,000 and 2.2.5 at $659,000.

16. What is included in Calorimeter Installation and Test (WBS 8.2.3)? Breakout above ground and below ground activities.

For the cost estimate in the LoI, we assumed that most of the calorimeter assembly work would be done in the underground hall. A total of 5 man-years of engineer/designer time(for supervision) and 43 man-years of technician time was allocated for the total installation process. Approximately 15% of this was allocated to above ground activities. In addition, we assumed a total of 13 man-years of engineer/designer time and 13 man-years of technician time for testing of the calorimeter and its electronics. All of this work would nominally occur underground, except that performance would be monitored in the ground level control room. To these activities we added $350K for miscellaneous expenses during the installation and testing process.

We are in the process of evaluating the relative cost effectiveness of above ground vs. below ground assembly.

17. The manufacturing of the modules requires more than engineering, technician, and assembly labor. How is other manufacturing support activities accounted for (e.g. production control, inventory, IE, factory management, factory operations, utilities, contracts, finance, planning., etc.) during the fabrication phase of the module subassemblies? How is the enormous quality control function going to be accomplished and how was this estimate made?

Module manufacture definitely requires more than just engineers, technicians and assembly labor. Support activities will be required throughout the project. The type of support activities indicated in the question should be covered in the Administration column of the overall detector costing. However, where operations are procured from outside vendors, these items are included in the procurement cost and not added elsewhere. It is also a standard accounting system at industrial members such as Westinghouse STC that the support activities described are not direct charges but a function of the engineering, technician and assembly labor rates.

In addition to the explanation provided above, WBS sections 2.1.7 and 2.2.7 of the barrel and end cap calorimeter respectively, have labor estimates to cover assembly activities. These activities estimated in these two WBS areas will cover general supervision during assembly, design modification/revision as required and Quality Assurance activities through each phase of the assembly. The estimates were based on the expected duration of each assembly operation and providing individuals to oversee the process on a full time basis. You will notice that engineering man-days are double the technician and designer time. This is to provide two engineers; one to handle supervision and one to handle design modifications and QA.

18. What is the possible price increase for procurement of radiation hard scintillator fibers or glue?

We believe we have an RTV-based glue in hand that is both inexpensive and sufficiently radiation hard.

Radiation hardened fibers are required, primarily, only in the electromagnetic sections of the calorimeter. We are evaluating the performance of fibers in beam tests this summer. Until these test are completed it is difficult to evaluate possible price differences among different fibers.

19. For over 1 million tiles of many different sizes, what is the precision of the manpower requirements given for fabrication, assembly, and test of the scintillator stacks?

Manpower estimates are based on reducing the operations down to the lowest component and estimating manpower at that level. Precision is improved in this method and should provide more realistic estimates by a reduction in missed items or generalities when only estimating at a high level WBS. Breakdown of the tile manufacturing was performed on a per piece operation with materials, equipment, facilities and manpower estimated throughout. Estimated fabrication times are based on standard machining feed rate and experienced engineer estimating operation times.

20. For the EM parts of the calorimeter, high precision is required. Has the collaboration tested the casting process in this respect and what are the results in terms of reproducibility of thickness and absence of voids in the absorber plates? Have alternative manufacturing concepts been investigated and at what cost impact?

As noted in the answer to question 1 of this section, a test casting was made to explore these exact questions (dimensional tolerances and porosity control). Careful studies of plate and slot dimensions showed a narrow distribution of tolerance errors around a mean error of +/- 0.002 inches. These tolerances were compared with EGS studies of allowable random thickness errors in the absorber plates and the result showed a margin of safety of a factor of 4. Porosity was seen at the top of poured castings (dross). In the current mold design, this will not be a problem (full immersion casting will be done). Reference: "Simulation Studies for Design Optimization of a Scintillator Plate Calorimeter", J. Proudfoot, et al., ANL-HEP-CP-90-88.

Again, as noted in the answer to question 1, we have already carefully studied several heavy element passive absorber technologies. Steel reinforced cast lead beats the others for cost effectiveness and for density uniformity and tolerance control at comparable fabrication costs. It should be recognized here that longitudinal sample frequency is also a key cost variable and that lower costs will result from coarser sampling frequencies, for example in the iron tail-catcher. The very high and uniform hadron sampling done in the ZEUS calorimeter certainly contributed to its high unit cost values. The present designs for EM, HAC1 and HAC2 have attempted to optimize

the three sampling frequencies for the best cost/performance ratio. This will be experimentally verified in particle beam tests by the Subsystem Collaboration at Fermilab in 1991 (hanging file calorimeter tests).

21. *To obtain a ratio of e/π response close to unity the collaboration intends to mix Pb and Fe in the iron part of the absorber. What are the possible cost consequences?*

The design costed for the Letter of Intent does not mix Pb into the Fe "tail-catcher". The front part of the calorimeter is all lead and back part all iron. In this configuration we expect to achieve an e/π response near unity. We have not yet estimated the cost of the finely mixed Pb/Fe option. We await the results of the beam test referred to in the previous question to guide the design for this option.

22. *The individual modules of the barrel calorimeter are very large. The mechanical assembly is unclear and certainly not trivial. Please explain the support structure for the modules and the completed calorimeters.*

A module for the calorimeter is 1/64th of a circle or a segment spanning 5.625 degrees. Maximum dimensions are approximately 0.45 meters thick, 2.38 meters wide and 5.1 meters long for a half barrel. These would weigh roughly 26,520 kg each or just under 30 tons without any support or lifting fixtures.

The supports for the individual modules are long beams with many contact and attachment points. The main support is provided at the back iron with additional supports on the interface plate between the hadrons and EMC. These allow the individual modules to be lifted and orientated for assembly into the barrel. Actual details must still be developed.

The supports for the barrel are temporary heavy structure spider frames which support the modules until the barrel is completely assembled. The bottom support is a semi-circular frame which holds the lower module sections and prevents them from flattening out. Another arch type support frame is used on the interior to support the upper sections from moving inward. When the last module is inserted the assembly can then become arch bound and support itself. The back iron acts as a ring and provides support to help contain the modules. The completed calorimeter is supported on cradles which span approximately 60 degrees on the bottom of the barrel and are spaced approximately 0.87 meters apart. A support frame is built under the cradles for movement of the completed barrel. A conceptual design of the frame and rolling mechanism has been completed.

23. What is the resolution of the EM and Hadronic calorimeter aimed at if high precision is wanted?

The predicted performance of the calorimeter(Table 5 in the LoI) costed for the LoI exceeds our design goals(Table 1 in the LoI). The trade-off between cost and performance continues to be under intense study and we also continue to evaluate the physics requirements.

24. What is the size of cracks between towers in phi and eta? Are the cracks filled or empty?

The cracks are not filled, except by clear fibers and other non-active materials. The design minimizes cracks as much as possible.

25. How do the cracks and support structure affect the constant term?

No response.

26. What is the strategy of the collaboration concerning test beams and calibration? Will each module be tested in a test beam?

We don't know the answer to this yet and are waiting, in part, to observe the ZEUS experience that did not include testing everything. The answer to this depends upon schedules, our calibration scheme and the availability of test beams. We have include in our cost estimate, however, substantial costs for set-up and operation of test beam facilities during construction so that if we decide to test modules, we will have the facilities to do so.

27. If luminosities of order $10^{34} cm^{-2}\text{-}sec^{-1}$ are achieved, what is the expected lifetime of the calorimeter in these circumstances?

Our goal is that the barrel part of the calorimeter have a lifetime of > 10 years at a luminosity of 10^{34}. Pending the outcome of additional exposures of scintillator modules to radiation, we plan to design the endcap so that the high dose region can be removed and the scintillator in the EM section be replaced. This might happen once or twice during the lifetime of the experiment. The ability to use data and other means for calibration are an important part of the design. These issues are under intense study by the collaboration.

28. *The collaboration quotes in the LOI (page 8, Table 1) a resolution of the Hadron calorimeter of less than 0.7/CE - 0.04, and for the EM calorimeter less than 0.25/C E - 0.02. On page 14 of the LOI the central calorimeter is stated as a "high precision" device and on page 16, Table 5 the parameters for the hadronic calorimeter resolution is ~0.4/CE - ~0.02 and for the EM calorimeter 0.15/C E - <0.01. Between these two resolutions there is a large impact on cost (e.g. CDF at $14/lb vs. ZEUS at $29/lb). Please explain the difference and the cost impacts.*

The comparison is between minimum acceptable performance for the SDC calorimeter (Table 1 on page 8 of the LoI) and projected performance of the proposed SDC calorimeter design in the LoI (Table 5 on page 16). We felt it was prudent to aim at a somewhat better design goal for the proposed calorimeter in order to establish some performance contingency in the conceptual design. Experience shows that a particular device as produced and operated typically suffers some degradation of expected performance relative to the early conceptual design. Although we will try to preserve all the capability through the detailed engineering design and production stages, it seemed unwise to set our goals at the minimum of allowable performance. Cost/performance optimization will continue to be an important consideration as our design evolves.