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Design and Development of the SDC Barrel Electromagnetic Calorimeter*

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I. Introduction

A. Purpose of Paper and Statement of Work

In fulfillment of contract SSC92-W-17743, Argonne National Laboratory is required to closeout and document all work performed in the design and development of the central calorimeter for the Solenoidal Detector Collaboration (SDC) Detector at the Superconducting Super Collider Laboratory (SSCL). This report will summarize the work performed, and identify all documents (technical reports, memo's, drawings, etc.) that resulted from that effort.

The work under this contract was shared in collaboration with the Westinghouse Science and Technology Center (WSTC) of Pittsburgh, Pennsylvania. It is the intent of this report to provide information that can be useful in the development of future detectors for high energy physics particle research.

II. ANL Involvement

A. General Overview of ANL Involvement in SDC

The High Energy Physics Division at Argonne National Laboratory was involved with the SDC collaboration from its inception. As a primary contributor, ANL participated in the conceptual design of both the barrel and endcap calorimeters, the design and development of the barrel electromagnetic calorimeter (in collaboration with WSTC), particle beam testing, response simulation of the calorimeters, development and testing of the tile-fiber optics systems, assembly of the barrel and endcap calorimeter modules, and their subsequent installation into, and alignment with the other detector subassemblies.

B. Design of the Barrel and Endcap Calorimeters

One of the initial tasks, undertaken by Argonne for the SDC collaboration, was a conceptual design for both the barrel and endcap calorimeters. The original design in the Expression of Interest (EOI) dated 24 May 1990 was for a 1/128 stacked wedge using wavelength-shifter plates and having an absorber of either depleted uranium or lead. This design was similar to that of the ZEUS detector, except that it required the use of a tensioned center steel plate connected to a solid backbone providing support for the structure, and compression for the stack. The steel backbone was intended to provide support for the structure, connect the modules in the calorimeter, and to provide a flux return path for the magnetic field. Initial finite element analysis (FEA) and classical engineering calculations were performed to examine this structure. In addition to this design, there were three other competing detector designs. They were a scintillating tile/fiber calorimeter, a scintillating fiber, or spaghetti calorimeter, and a liquid Argon calorimeter.

With the submission of the Conceptual Design Report dated 03 September 1991, the absorber structure was fixed as a lead/steel construction. Due to the similarity of the ANL design with that of the Scintillating Tile/Fiber Group, it was determined that combining efforts and supporting a single design would be advantageous.

In collaboration with WSTC and Fermilab, two similar versions of the barrel calorimeter were developed. One version had a lower resolution, in comparison to that of the liquid Argon design, and was composed of a lead EM and first hadronic section (HAD1) and a steel second hadronic section (HAD2). The other was a high-resolution lead EMC with steel HAD1 and HAD2. At this time, the

Argonne design group focused it's efforts on the design of the EM calorimeter with WSTC, and acted in a support role to Fermilab on the hadronic sections.

To supplement and confirm designs of the calorimeters, the ANL Engineering Group provided finite element analysis on both the barrel and endcap wedges, and on the fully assembled barrel and endcap calorimeters. These analyses were conducted on individual modules suspended at primary locations around the barrel calorimeter. FEA models were also created and analyzed on the barrel and endcap assemblies. This analysis required iteration as each individual module was added to the assembly.[A30-34] An updated FEA analysis of the barrel assembly, using the Fermilab designed hadron calorimeter, was underway at the time of the work stoppage order in October, 1993.

C. Design of the Barrel Electromagnetic Calorimeter

The initial design for the EM Calorimeter required a structure using alternating layers of 4 mm thick lead sheets and a 6 mm scintillator space for 4 mm scintillating tiles and their corresponding readout fibers. The absorber/tile structure was to be inset slightly to provide a space between modules for routing of the fibers to the outside radius of the barrel. The segmentation was to be $0.05\ \eta \times 0.05\ \phi$, (approximately 10 cm × 10 cm at the inner radius) making each 1/32 wedge 4 towers in ϕ, and 28 towers in η. The stack was compressed using a stainless steel perimeter frame secured by a series of tensioned, high-strength steel wires, as was used in the ZEUS EM Calorimeter. The ZEUS design used clad depleted uranium plates for absorber, separated in the radial direction by aluminum spacers, which acted as scintillator tile boundaries and prevented loading of the scintillator tiles. This design was not compatible with a stacked lead design due to the high concentrated loads applied to the lead by the compression forces acting through the spacers. This loading resulted in deformation and unwanted deflections in the lead absorber.

The tensioned wire concept required a fairly thick set of front and rear plates with machined radii to accommodate the wires. This placed unwanted material in front of the barrel EM and affected the shower maximum and massless gap regions. Without spacers, the required compressive load on the stack would result in high compression loads on the scintillator. Although compression tests were being conducted on scintillator plates at that time, it was felt that there was insufficient data to predict long term results. Preliminary findings showed that it was not feasible to use spacers to protect the scintillator as in the ZEUS calorimeter, due to coining of the lead absorber.

In addition, the number of tensioning wires needed to achieve full compression in the stack was great enough that, when combined with the amount of fibers required for readout, would result in a fairly large region of dead space in the ϕ crack between modules. It was at this point that the concept of casting a lead absorber structure around a stainless steel frame was presented.

D. Prototype Design and Casting

The idea of casting an absorber structure for a calorimeter was a unique approach to solving the design problems faced in developing the EM calorimeter. However, because of the small amount of information available on lead and it's properties, and the fact that this was a totally new concept, required an extensive and rigorous testing/design program to be developed. The basic premise was to cast the absorber inside a stainless steel frame, using thin radial perforated plates (bulkheads) for structural support.[A42] Removable spacer plates would be situated inside the frame during casting, providing the space allotted for scintillator and fibers. Because of the sheer size of each EM module (approximately 14 feet long) and the precision required for the absorber, this concept would push lead casting techniques to their limits.[A43-46]

Several lead casting facilities were contacted for cost information and ideas for casting such a large object. Also due to leads ductility and susceptibility to creep effects, methods of reinforcing it, while maintaining it's uniformity, were experimented with. Some of these ideas included reinforcing the lead with fibers of either fiberglass, or a ceramic composite, using perforated steel tubes that would fill with lead during casting and add support, and using alloyed lead.[A5,7,9,19,26]

1. *18-Cell Castings*

The SDC 18-cell test castings were designed to be an initial test of the feasibility of casting a lead absorber structure, and for initial evaluation of the required techniques. The basic design was to construct a 3 mm stainless steel frame with two intermediate bulkheads, so that when cast, three towers of six cells each were created (18-cells total). The mold was a stainless steel shell with machined grooves in the bottom plate to accept machined aluminum spacer plates.[A35] These spacer plates occupied the space reserved for scintillator during casting, and were sized to compensate for thermal expansion from room temperature to the pouring temperature of 800°F.

The mold and frames were designed at WSTC, and several trial castings of pure lead were made. Two additional castings were poured, one of pure lead, and one of .06% Ca-.5% Sn Lead for initial evaluation of the alloyed lead.[A27]

2. *10 Tower Test Beam Castings*

The 10-tower test beam castings were cast from commercially pure lead. These represented the low-η region of the EM calorimeter. There were two 1/64 castings produced, each consisting of 10 towers (2 - 0.05 towers in $\phi \times 5$ in η) and 28 layers of absorber, including a shower maximum region. The basic construction was similar to that of the 18-cell castings, in that they were produced in a rectangular mold with a machined base for location of machined aluminum spacer plates.[A36-37,39] The frame for the absorber was fabricated from a 1/8" (3 mm) front plate, with 1/2" (12 mm) end plates, and a 1" (25 mm) back plate, with perforated bulkheads (.020" [.25 mm] thick) at every 0.05 η.[D24-25]

The casting process was established with these castings. The mold was assembled, the frame and spacer plates were sprayed with a graphite based mold-release and inserted into the mold. Clamps and hold-down fixtures were placed over the top to ensure alignment of the plates to the frame at the top, and to prevent the frame from floating in the molten lead. The assembly was placed over a vat of molten lead to pre-heat the system to approximately 500°F. The casting was submerged and filled with the lead at a temperature of 800°. After filling, it was removed from the vat and placed in a bath of water to initiate cooling from the bottom. To ensure even cooling, and prevent voids in the center of the casting, a gas torch was applied to the top keeping the upper half liquid. Additional lead was ladled in to compensate for shrinkage.

After cooling, the clamps and hold-down fixtures were removed, and L-shaped pulling devices were used to individually extract each spacer plate from the mold. Next, the casting itself was removed from the mold, and the dross region on the top side was machined off. It was found on the first casting that the amount left for dross formation was insufficient, and some voids were found at the leading edge. This was corrected by adding a 1" spacer to the top of the mold, allowing a larger lead reserve. It was also found that precise line-to-line contact between the spacer plates and the bulkheads was not achieved, and a small amount of flashing was situated throughout the scintillator gaps. Scraping tools were fabricated by ANL technicians to remove this flash.

After both castings were cleaned, they were instrumented,[A37] light-tight side covers were placed on them and they were mated. They were then placed into the MP-9 test beam at Fermilab (see Section II.G.3.). In order to manipulate the castings in the beam, a remote manipulating table was designed and fabricated.[D4] The process of laying the fibers turned out to be tedious and time consuming. This effort revealed a need for working on a simple method of routing the fibers up the side of the modules. Further work on this was performed, in conjunction with Fermilab, on paper and wooden models of the barrel HAD and EM sections.

3. 10-Tower Mechanical Test Module

In order to supplement the design of the EM calorimeter, an additional 10-tower casting was commissioned. Acting as a precursor to the full scale prototypes, this casting was to reflect the latest design of the EM.[A38-39,D26] This casting was designed to demonstrate that the structural changes made for physics reasons were still castable, and to act as an additional step in the refinement of the casting process before attempting a full size casting. An FEA analysis was performed on a model of this casting,[A23] and mechanical tests were subsequently performed to assist in confirming the accuracy of the FEA models used in designing the full scale prototypes.[A8,15,19]

The basic design and casting process of the 10-tower mechanical test module was the same as the prior 10 tower castings, however, during development, the prototype design was modified.

In the mechanical test module the end plates were removed, the 3 mm front plate was formed to wrap continuously and form the ends, and new lead end connections were designed. The terminations of the bulkheads, at the front plate, were changed to be tabs that passed through the front plate, were bent over, and welded. The bulkhead segmentation was changed to 0.1 in η for the first bulkhead, and the bulkhead at $\eta = 0.15$ was terminated at the shower max region to test the termination design. To demonstrate that the source tubes could be cast into the absorber structure with a double 90° bend, two tubes were included in the module. This module was cast using the .062% Ca, .5% Sn Lead alloy (#L-50737) in order to examine the structural stiffness and the castability of the alloyed lead.

a. FEA Analysis of the 10 Tower Mechanical Test Module

One of the principle functions of the mechanical test module was to confirm the accuracy of the finite element analysis process (software and modeling style). To this end, an FEA model of the test module was constructed, and analyses were conducted on the module in various loaded and unloaded conditions.[A19,23] One of the concerns with the FEA analysis, conducted on full scale prototype designs, was that the stiffness of the lead absorber could not be accurately predicted because of it's ductility and creep characteristics. It was felt that if testing done to the physical module matched up with the predicted response from the FEA analysis, the predicted results from full scale prototype models and the other analysis conducted on the Barrel and Endcap Calorimeters, would be confirmed.

b. Mechanical Testing of the 10-Tower Mechanical Test Module

In order to confirm the accuracy of the FEA models, a series of tests were conducted on the 10-tower mechanical test module.[A8-10,15] Strain gauges were attached to the module at strategic locations across the front and sides of it. The module was then placed in a fixture designed to completely secure the back plate, and provide a stable reference point for measurements. It was positioned to represent various load conditions that matched the iterations performed by FEA. The deflection and stress measurements were compared, and found to basically match the predicted results, with one exception; it appeared the Ca-Sn lead was adding no additional strength to the structure as predicted by the materials testing. Additional stress concentrations were noted in the physical module that were not represented in the FEA model. It was determined that these stress concentrations were measured because some of the strain gauges were placed near exit slots for source tubes which had not been included in the FEA model.

4. *Additional Test Castings*

a. High-η Test Castings

In order to examine the effects on the lead absorber in the longer plates of the high-η region of the EM, a series of high-η test castings were made.[A13] These castings were representations of several layers of the $\eta = 1.2\text{-}1.4$ region of the module. These castings were designed to test the structural stability of the lead absorber in this region, with and without the stainless steel perforated reinforcing tubes, and at points where absorber plates terminated at a bulkhead. These steps were located where lead plates terminated at a bulkhead in the shower max region.

b. Lead-Bulkhead Connection Castings

Another area of concern was the point where the lead absorber terminates at a bulkhead, due to the stepped shower maximum region, and at the 3 mm plates. In order to test the strength of these connections, several samples were cast and placed under load to determine the point at which they would fail.[A20]

5. *Mechanical Testing of Alloys*

Due to the malleable nature of lead, and the size and precision required to cast the EM calorimeter absorber structure, it was necessary to conduct extensive testing on the lead alloys, the structural framework surrounding the castings, and the casting components themselves. Materials testing was conducted on specimens from the series of 18-cell castings made by WSTC,[A1,A13] the 10-tower castings,[A1,A9,A15] and various samples of several lead alloys cast specifically for testing and material evaluation.[A1,A6,A9] This included creep testing, tensile testing, and chemical analysis to confirm material composition. In addition, mechanical testing was performed on the 10-tower mechanical module to confirm FEA analysis,[A8-10,15] and on the connections between the lead absorber structure, and the steel bulkheads.[A20] Additional testing of the one pre-production prototype is to be conducted, and will be released as an addendum to this report.

E. Full Scale Pre-Production EM Prototype

The prototype cast lead EM was well into production[A41-46,D5-12] when funding was cut off for the second half of FY1993. These prototypes reflected the current, and final, design of the EM calorimeter. They were to provide information on how well the casting techniques, used in earlier tests, would extrapolate to full size castings, and to gain experience on handling and assembly techniques. There were to be four castings of 1/64 EM modules - two "A" halves and two "B" halves, which were to be joined into two 1/32 EM modules. Mechanical testing was to be conducted on the modules to confirm FEA analysis, and determine if any structural changes for production modules was necessary. Subsequently, the two 1/32 modules were to be mated to two barrel hadron calorimeter modules fabricated by Fermilab. These full prototype modules were then to be instrumented, and would undergo beamline testing at Fermilab.

Design and fabrication of frames for four castings, the mold,[A47] and most of the related casting hardware were completed (see Appendix C). The casting facilities at Taracorp (St. Louis, MO) were completed, but not commissioned. As part of an extension to the closeout of the SDC project, one prototype casting is scheduled to be completed, and be mechanically tested as a 'proof of principle' in certifying that the design was, in fact, valid and feasible. Results of this effort will be documented and issued as an addendum to this report.

F. Installation, Integration, and Alignment

Although no fixtures or devices were produced, the High Energy Physics Division Engineering Design Team was involved in the planning and organization of the process of assembling the barrel and endcap modules, installation of the calorimeter modules into the detector, and alignment of the calorimeter with respect to the rest of the detector elements and the particle beam.[A2] Preliminary space layouts were provided on the IR-8 surface assembly building and detector hall.[A12,A17-18] Initial scheduling of module shipments to the SSC Laboratory for installation,[A11,A17] and reviews of the Title I and Title II design plans for the IR-8 assembly building were conducted.[A22] Conceptual designs were produced for the installation fixtures to be used for assembling both barrel and endcap calorimeters,[A11,A17] the storage stands, and the testing/repair stands for the modules.[A22,23]

G. Physics Testing

1. *Simulation Studies*

Simulation was an important part of Argonne's work throughout the development of the central calorimeter. Initial calculations of calorimeter performance were made with EGS4, GEANT, and CALOR simulation codes.[B14] In addition, work was done to optimize and validate calculations with these codes using available test beam data (see Section G.3). As the design of the calorimeter evolved, the various proposed configurations were modeled and analyzed, and the absorber materials and thicknesses were varied to study performance versus cost.[B2-3,B10-11]

The focus of the analyses were somewhat different for the electromagnetic (EMC) and hadronic (HAD) sections of the calorimeter. For the EMC, the focus was on optimizing the resolution for electrons and photons as a function of energy.[B7] This lead to many of the structural changes made in the design of the frame and bulkheads.[B4] For the HAD section, in addition to optimizing resolution, efforts were directed towards providing a compensating calorimeter, for which electrons, photons, and hadrons would give the same response for a given energy.

A number of compromises had to be made at the time of issue of the Technical Design Report (TDR) to keep the cost within bounds. In particular, the idea of compensation in the HAD section was largely abandoned. Much calculation was done in connection with beam tests of both the EMC and the HAD sections, using the 10 Tower EM beam test modules, and a corresponding HAD section provided by Fermilab. The question of the choice of lead or steel for the HAD absorber led to detailed calculations to compare with the reconfigurable "hanging file" beam test carried out at Fermilab.[B8,B20] Although simulations and experimental data agreed for most configurations, puzzling disagreements remained for the configuration of the steel HAD absorber eventually adopted for SDC.

For the last year of active work on SDC, the problem of high neutron fluxes, within the detector, received active attention. Because the amount of neutrons, generated throughout the detector, depended strongly on the material near the beam pipe, Argonne used its simulation tools, especially the CALOR hadronic transport code, to evaluate proposed shielding configurations.[B19,22] Argonne worked with others at SSCL and LANL to compare the calculations of a number of simulation codes, and to evaluate several configurations. During this year of activity, neutron fluxes had been reduced by an order of magnitude, although more reduction was still needed.[B17]

2. *Calibration Studies*

In order to determine the accuracy with which source tubes need to be positioned in the lead and stainless steel sections of the EM, the effect of displacing a source along either of these media was recorded.[A21] A source driver, provided by Purdue University, was used to move a ^{137}Cs source over a scintillator tile with varying amounts of air, Pb, or Fe absorber between them and the resulting integrated currents were recorded. We measured $\delta(1)/\delta(x)$ to be 25%/mm in Pb, 20%/mm in Fe, and 10%/mm in air.

The photons from the ^{137}Cs illuminated scintillators on either side of the absorber, so that by summing both tiles, the effect of a displaced source tube is minimized. If uniform tile response is assumed, it was found that by summing two tiles the source can be displaced by up to ± 0.5 mm and still maintain a 1% calibration.

Another series of tests involving longitudinal source scans was conducted, investigating the possibility of eliminating the machining of source tube slots in the HAD sections [A4,16] Edge scans of a test scintillator stack were in very good agreement with calculations. The source and driver were also used to determine to what extent the source tubes, embedded inside the cast lead absorber of the test beam calorimeter modules, were misplaced.[A16]

3. *10-Tower Test Beam Results*

The two 10-tower EM test beam modules were exposed to beams of high-energy pions and electrons in the MP9 test beam at Fermilab in the fall of 1991. Data were collected on the resolution, light yield, signal timing, and hermiticity of the calorimeter. These data demonstrated that the design met the specifications for the barrel EM calorimeter, as set forth in the Conceptual Design Report (03 September 1991).

4. *Optics Testing and Development*

There were several goals in the work on tile-fiber optics for the SDC EM calorimeter. A reasonable light output was needed, per minimum ionizing particle, in a shower to get adequate resolution. Uniform response, over the area of a tower, was needed to minimize the constant term in the resolution. Uniformity in the response from tile-to-tile within a tower was needed to minimize the constant term in the resolution. Stability over 10 to 20 years, under the influence of mechanical pressure, aging, and radiation damage was needed. The design had to be buildable and cost efficient.

There were a number of considerations derived from these basic requirements. One was whether tiles, with beveled edges, could be used to match the boundaries of cells defined by bulkheads in the mechanical construction. Another was the need for knowledge of how much pressure (uniform, or otherwise), and bending could be applied to the scintillator tiles without damaging the tile or degrading the light output. Compatibility of scintillator, waveshifter, and phototube was also required for adequate light output and stability.

While some aspects of the design could be handled in an analytical manner, other aspects required a trial and error approach. The emission and absorption spectra of the basic processes in the materials were known fairly well. Related parameters, such as the attenuation and filtering in both wavelength and phase space, were generally determined experimentally. Monte-Carlo studies of light collection in tiles was successful only for simple prototypes with no bends in the waveshifter fibers in the tile and using simplified coupling with no air gaps or rough surfaces.[B1,16,21]

We concentrated on the following programs of study.

a. Optimization of a tile-fiber assembly. (This was done separately for low rapidity and high rapidity scintillator tile shapes.)

b. The uniformity and efficiency of light collection from a scintillator tile. This depends on many inter-related factors:

i) The geometry of the waveshifter fiber at the scintillator.

ii) The reflective wrapping of the scintillator, which may be specular or diffuse.

iii) The black masking of areas of high response.

iv) The aluminization of the end of the shifter fiber.

v) The splicing of the shifter fiber to a clear fiber with long attenuation length, as a function of the distance of the splice from the scintillator.

vi) The surface finish of the edges of the scintillator.

vii) The attenuation of various wavelengths in the scintillator.

viii) The surface finish of the grooves in the scintillator which held the fibers.

ix) The presence or absence of glue, with an index of refraction higher than air, between the scintillator and the shifter.

It was found that the so-called "sigma" tiles, with only one fiber exiting from the tile, were difficult to design satisfactorily at low η, and impossible at high η.

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APPENDIX A

SDC Barrel Electromagnetic Calorimeter Documentation List

Engineering Design

Reference No.	Title	Date	Document No.
A1	Selection and Characterization of Lead Alloys for Use in the SDC EM Calorimeter	10/1/93	ANL-HEP-TR-93-90
A2	SDC Barrel and Endcap Alignment Systems	9/1/93	Internal Report
A3	SDC Installation Meeting Summary	6/10/93	
A4	Measurement of Source Tube Radial Position in Cast EMC Test Beam Module	5/5/93	SDC-93-499 ANL-HEP-TR-93-36
A5	Lead Deflections and Properties	5/20/93	Internal Report
A6	Scintillator Compression Test - Proposal	5/21/93	Internal Memo
A7	Memo: Ca-Pb Strain Hardening	4/15/93	Internal Report
A8	EMC Cell Deflections	4/20/93	Internal Report
A9	Transparencies - Alloyed lead for SDC Cast Lead EM	4/1/93	
A10	Transparencies - ANL Internal Design Review	3/1/93	
A11	SDC Final Assembly Transparencies - SSCL Presentation	2/2/93	
A12	Memo - IR-8 Assembly Building	2/2/93	Internal Memo
A13	Memo - High η Test Casting	2/4/93	Internal Memo
A14	Memo - Brass Tubes	2/5/93	Internal Memo
A15	Memo - Revised Test Plan for the 10-Tower Mechanical Model	2/16/93	Internal Memo
A16	Precision of Source Response Inside Dimpled HAD Brass Tubes	2/22/93	SDC-93-453 ANL-HEP-TR-93-14
A17	Memo - SDC Assembly Building Crane Height	11/6/92	Internal Memo
A18	Transparencies - SDC Detector Installation	11/20/92	

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Reference No.	Title	Date	Document No.
A19	Memo - EM Frame Analysis to Reduce Cell Deflections	10/14/92	Internal Memo
A20	Memo - Strength of Lead Connection at Bulkhead	10/19/92	Internal Memo
A21	Effect of Pb and Air Absorber Thickness of ^{137}Cs Signal	10/22/92	SDC-92-350 ANL-HEP-TR-92-97
A22	Memo - SDC Assembly Building - Title I Proposal	9/1/92	Internal Memo
A23	Memo - Cell Deflections	9/11/92	Internal Memo
A24	Memo - Barrel Module Connecting Forces with a Steel HAD1	9/16/92	Internal Memo
A25	Memo - Analysis of Connections in EM Section	9/29/92	Internal Memo
A26	Response to Concerns of the EM Review Committee	8/1/92	SDC-92-00299 ANL-HEP-TR-92-67
A27	Mechanical Testing of SDC 18-Cell Test Casting	5/5/92	Internal Report
A28	FEA Analysis of EM Module	4/20/92	Internal Report
A29	Mechanical Design and Finite Element Analysis of the SDC Central Calorimeter	3/4/92	ANL-HEP-CP-92-13
A30	Finite Element Analysis of the SDC Barrel and Endcap Calorimeters	3/11/92	SDC-92-222 ANL-HEP-TR-92-20
A31	Memo - Thermal Analysis of EM Module Frame	3/13/92	Internal Memo
A32	Memo - Analysis of EMC Module	6/6/91	Internal Memo
A33	A Design Study of a Cast Lead Electromagnetic Calorimeter for the Solenoidal Detector Collaboration at SSC	3/13/91	ANL-HEP-CP-91-18
A34	Memo - SDC Endcap Calorimeter Model B and Model G Analysis		Internal Memo
A35	Photograph - 18-Cell Casting		Neg. # 12975K

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Reference No.	Title	Date	Document No.
A36	Photograph - 10-Tower Test Beam Module # 1		Neg. # 10963K-3
A37	Photograph - Fiber Routing and Instrumentation of Test Beam Module (Module # 1)		Neg. # 11664K-11
A38	Photograph - 10-Tower Mechanical Test Module Frame		Neg. # 13188
A39	Photograph - Mold and Al Spacer Plates for 10-Tower Castings		Neg. # 13898K
A40	Photograph - High-η Test Casting		Neg. # 14857-8
A41	Photograph - Full Scale Prototype - Preparing Stainless Steel HAD Section for Welding		Neg. # 14857-4
A42	Photograph - Full Scale Prototype - Bulkheads being Attached to HAD Section		Neg. # 93-01-5
A43	Photograph - Full Scale Prototype - Assembled Frame with Perforated Reinforcement Tubes		Neg. # 93-02-5
A44	Photograph - Dimpling of Brass Tubes for Source Tube Location		Neg. 14534-5#
A45	Photograph - Fully Assembled Frame and Mold Base		Neg. # 93-03-17
A46	Photograph - Fully Assembled Frame and Mold		Neg. # 93-03-13
A47	EM Prototype Mold Assembly		WSTC # 2D29231

APPENDIX B

SDC Barrel Electromagnetic Calorimeter Documentation List

Physics Testing

Reference No.	Title	Date	Document No.
B1	Radiation Tolerance Implications for the Mechanical Design of a Scintillator Calorimeter for the SSC	3/19/90	ANL-HEP-CP-90-34
B2	A First Simulation Study of the Barrel-Endcap Transition Region in a Calorimeter of the Scintillator Tile Design	8/24/90	ANL-HEP-TR-90-77 SDC-90-073
B3	Simulation Studies for Design Optimisation of a Scintillator Plate Calorimeter	10/15/90	ANL-HEP-CP-90-88
B4	Optimisation Studies for Scintillator Plate Calorimeter	11/5/90	ANL-HEP-TR-90-102
B5	Report on Radiation Exposure of Lead-Scintillator Stack	11/8/90	ANL-HEP-TR-90-108
B6	Systematic Effects in CALOR Simulation Code to Model Experimental Configurations	4/8/91	ANL-HEP-CP-91-27
B7	Estimate of Hadronic and EM Resolution for Scintillator Plate Calorimeter Configurations	5/6/91	ANL-HEP-TR-91-19 SDC-91-013
B8	Comparison of CALOR89 Model Predictions with Scintillator Plate Calorimeter Data	6/18/91	ANL-HEP-PR-91-52
B9	Fiber-Tile Optical Studies at Argonne	7/23/91	SDC-91-052 ANL-HEP-TR-91-69
B10	Design Considerations for a Scintillating Plate Calorimeter for SDC	7/26/91	ANL-HEP-TR-91-68 SDC-91-048

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Reference No.	Title	Date	Document No.
B11	Design Considerations for a Scintillating Plate Calorimeter	12/1/91	ANL-HEP-PR-91-83
B12	Simulation of Hanging File Experiments with CALOR89	4/6/92	SDC-92-223 ANL-HEP-TR-92-22
B13	Conference Summary	4/28/92	ANL-HEP-CP-92-46
B14	Unix Version of CALOR89 for Calorimeter Applications	5/12/92	SDC-92-257 ANL-HEP-TR-92-38
B15	The SDC Central Calorimeter	9/29/92	ANL-HEP-CP-92-80
B16	Some Fiber-Tile Optical Studies for SDC Electromagnetic Calorimeter	9/29/92	ANL-HEP-CP-92-94
B17	Estimates of the Neutron Fluence for the SDC Detector	11/20/92	SDC-92-354 ANL-HEP-TR-92-112
B18	Measurements of Radiation Dose Using Radiochromic Film	11/24/92	SDC-92-373 ANL-HEP-TR-92-114
B19	Incident Energy Dependence of Hadronic Activity	1/11/93	ANL-HEP-CP-93-12
B20	Simulation of the Reconfigurable-Stack Test Calorimeter Experiments with CALOR89	10/11/93	ANL-HEP-PR-93-80
B21	ANL/WSU Radiation Damage Studies	10/24/93	ANL-HEP-CP-93-107
B22	Neutron Fluence Calculations for the S C Detector and the Results of Codes Comparison	4/1/94	ANL-HEP-CP-94-08

APPENDIX C

SDC Barrel Electromagnetic Calorimeter Documentation List

Cast Lead EM Prototype Parts Inventory

Reference No.	Title	Quantity	Part No.
C1	Mold Frame (Westinghouse)	1	
C2	Mold Base Plate	1	
C3	Aluminum Wire for Base Plate to Frame Seal		
C4	Aluminum Spacer Plates - Tower 1, Layers 1-7, 11-32	1 Set	# 5650-B01
C5	Aluminum Spacer Plates - Tower 3, Layers 1-7, 11-32	1 Set	# 5650-B03
C6	Aluminum Spacer Plates - Tower 4, Layers 1-7, 11-32	1 Set	# 5650-B4
C7	Aluminum Spacer Plates - Tower 5, Layers 1-7, 11-32	1 Set	# 5650-B5
C8	Aluminum Spacer Plates - Tower 7, Layers 1-6, 10-29	1 Set	# 5650-B7
C9	Aluminum Spacer Plates - Tower 8, Layers 1-6, 10-29	1 Set	# 5650-B87
C10	Aluminum Spacer Plates - Tower 9, Layers 1-5, 9-26	1 Set	# 5650-B9
C11	Aluminum Spacer Plates - Tower 10, Layers 1-5, 9-24	1 Set	# 5650-B10
C12	Aluminum Spacer Plates - Tower 11, Layers 1-4, 8-32	1 Set	# 5650-B11
C13	Aluminum Spacer Plates - Tower 12, Layers 1-4, 8-21	1 Set	# 5650-B12
C14	Module 1A, Assembly	1	ANL Dwg. # 34-402-2-0
C15	Module 1B, Stainless Steel HAD1 Section	1	ANL Dwg. # 34-402-4-0

APPENDIX C (Continued)

Reference No.	Title	Quantity	Part No.
C16	Module 1B, 3 mm Front Plate	1	ANL Dwg. # 34-402-3-1
C17	Module 2A, 3 mm Front Plate	1	ANL Dwg. # 34-402-2-1
C18	Module 2B, 3 mm Front Plate	1	ANL Dwg. # 34-402-3-1
C19	Module 1B, Bulkhead Assemblies $\eta = 0.1 - 1.3$	1 Set	ANL Dwg. # 34-402-3-2 through 21
C20	Module 2A, Bulkhead Assemblies	1 Set	ANL Dwg. # 34-402-2-2 through 21
C21	Module 2B, Bulkhead Assemblies	1 Set	ANL Dwg. # 34-402-3-2 through 21
C22	Reinforcing Tubes - Module 1B	1 Set	ANL Dwg. # 34-402-3-147
C23	Reinforcing Tubes - Raw Stock	550 Feet	
C24	Source Tubes	2,516 Feet	ANL Dwg. # 34-402-2-147
C25	EM Stainless Steel HAD1 Material		
C26	1/32 Wedge Adapter Plate	1	ANL Dwg. # 34-402-5-1
C27	Connector Bars	2 Sets	ANL Dwg. # 34-402-5-2 through 6
C28	Keys - Short and Long	2 Sets	ANL Dwg. # 34-402-5-7
C29	Strongback Lifting Fixture - Module A	1	ANL Dwg. # 34-402-53-1
C30	Strongback Lifting Fixture - Module B	1	ANL Dwg. # 34-402-53-2
C31	Lifting Fixture Lugs	4	ANL Dwg. # 34-402-53-3
C32	Lifting Fixture Trunnions	8	ANL Dwg. # 34-402-53-72
C33	3 mm Plate Machining Fixture Assembly	1 Set	ANL Dwg. # 34-402-51-0
C34	EM/HAD Welding Table and Clamps	1 Set	ANL Dwg. # 34-402-52-0
C35	Steel for the 1/32 Module Handling Fixture		
C36	10-Tower Casting Mold Assembly	1	

APPENDIX D

SDC Barrel Electromagnetic Calorimeter Documentation List

Engineering Design

Reference No.	Title	Document No.
D1	Full Drawing List	
D2	Test Mold - Lead-Bulkhead Connections Assembly	SSC-1040-0
D3	Scintillator Compression Test Fixture Assembly	SSC-40-0
D4	10-Tower Test Beam Adjusting Table Assembly	SSC-51-0
D5	Prototype Module - A Assembly EM/HAD1 Stainless Steel Section - 2 Sheets	34-402-1-0
D6	Prototype Module - A Assembly EM/HAD1 Stainless Steel Section - Parts List	34-402-1-PL
D7	Prototype Module - A Assembly - 12 Sheets	34-402-2-0
D8	Prototype Module - A Assembly - Parts List - 5 Sheets	34-402-2-PL
D9	Prototype Module - B Assembly - 12 Sheets	34-402-3-0
D10	Prototype Module - B Assembly - Parts List - 5 Sheets	34-402-3-PL
D11	Prototype Module - B Assembly EM/HAD1 Stainless Steel Section - 2 Sheets	34-402-4-0
D12	Prototype Module - B Assembly EM/HAD1 Stainless Steel Section - Parts List	34-402-4-PL
D13	Prototype Module - 1/32nd Wedge Assembly	34-402-5-0
D14	Prototype Module - 1/32nd Wedge Assembly - Parts List	34-402-5-PL
D15	Bending/Machining Fixture - Center Section	43-402-51-1
D16	HAD1 Welding Fixture - Layout	34-402-52-0
D17	1/64th Wedge Strongback Fixture	34-402-53-0
D18	1/32nd Wedge Strongback Fixture	34-402-54-0
D19	1/32nd Wedge Strongback Fixture - Parts List	34-402-54-PL
D20	Prototype Assembly Fixture - Temporary Load Bracket "A"	34-402-55-1
D21	Prototype Assembly Fixture - Temporary Load Bracket "B"	34-402-55-2
D22	Prototype Module - Cosmic Ray Test Stand	34-402-56-0

APPENDIX D (Continued)

Reference No.	Title	Document No.
D23	Prototype Module - Cosmic Ray Test Stand Parts List	34-402-56-PL
D24	10-Tower Test Beam Module - Assembly	SSC-42-0
D25	10-Tower Test Beam Module - Parts List - 2 Sheets	SSC-42-PL
D26	10-Tower Mechanical Test Module - Assembly	SSC-43-0