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A DESIGN STUDY OF A CAST LEAD ELECTROMAGNETIC CALORIMETER FOR THE SOLENOIDAL DETECTOR COLLABORATION AT SSC*

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ABSTRACT

In order to achieve the physics goals for the Solenoidal Detector Collaboration (SDC), it is necessary to design and construct a scintillating calorimeter which measures both position and energy of particles originating at the intersection of colliding beams from the SSC. As part of this design, the electromagnetic section of the calorimeter, which is the front end of the calorimeter, was the first priority. Our design goal was to build as an initial phase, two small prototype test sections of the electromagnetic calorimeter (EMC), within the constraint that the physics goal is to achieve 100% instrumentation of this section of the calorimeter. We based our design on minimization of ineffective structural mass to provide maximum calorimeter volume. We will present the design phases of this construction, including mechanical design, structural analysis, and fabrication of the structural frame ready for casting into test sections for test beam analysis. These test sections will be evaluated for mechanical feasibility and physics performance. The results of these evaluations will be incorporated into the detailed design of the calorimeter.

MECHANICAL DESIGN

Investigation of a Depleted Uranium/Scintillator Calorimeter

As an initial phase of the design exercise, it was decided to pursue an upgraded version of a depleted uranium/scintillator calorimeter that was designed for the eP colliding beam at the HERA accelerator facility at DESY in Hamburg, Germany. This phase lead to a completed conceptual design as shown in Fig. 1. This design used the principal of a compressed alternate stack of uranium plates and scintillator, with the uranium plates separated by spacers. The entire stack is compressed and stiffened by a tensioned center plate extending the full length and depth of each module.

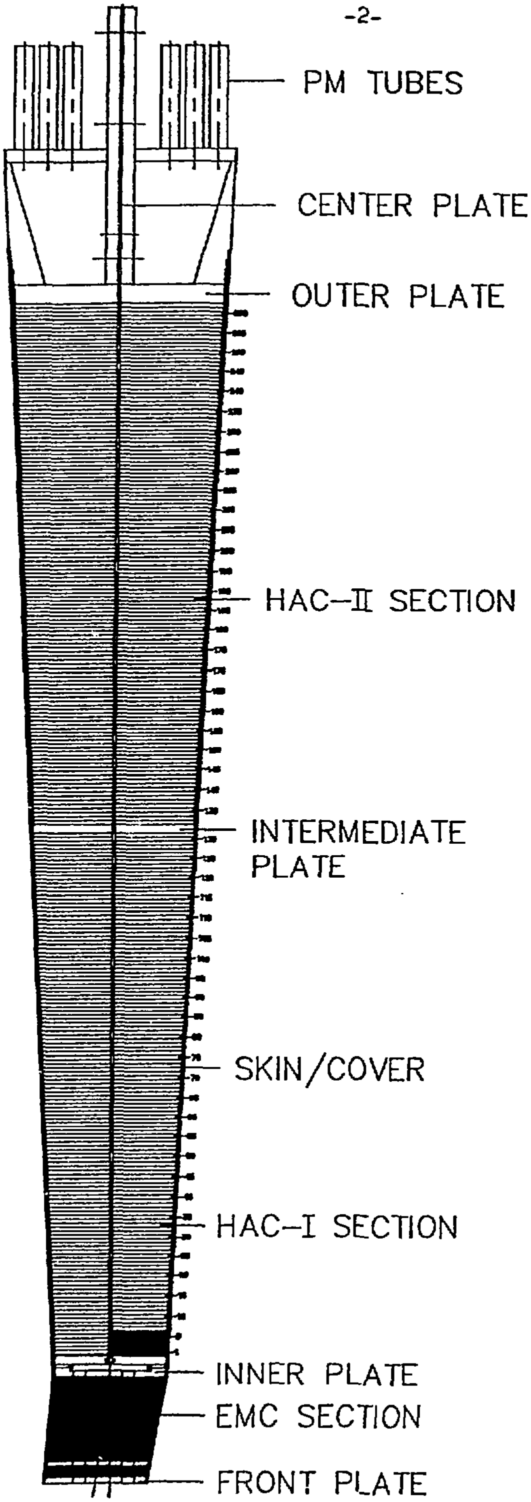

Fig. 1. SDC barrel calorimeter module cross section.

Preliminary calculations indicated that this design was feasible except when installed in positions other than 0° and 180°. When the module was supported at the 90° position, it required an intermediate support, see Figs. 2, 3 and 4. Figure 2 represents the module supported at the top, with all weight carried by the center plate. Figure 3 represents the module supported only at the two ends with stress stiffening. Figure 4 represents the module supported at two ends with an intermediate support. After an investigation of the cost of depleted uranium and its fabrication cost, the conclusion was reached that other absorber materials were more practical and a second phase investigation was started using basically the same configuration but substituting lead plates as the absorber material.

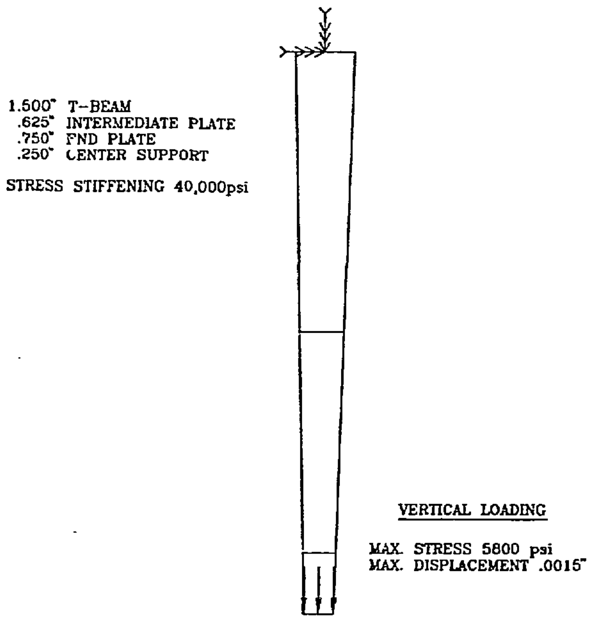

Fig. 2. SDC module 2D finite element analysis vertical loading.

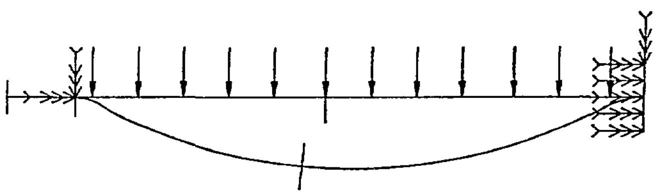

Fig. 3. Horizontal loading supported at ends only (maximum displacement .035").

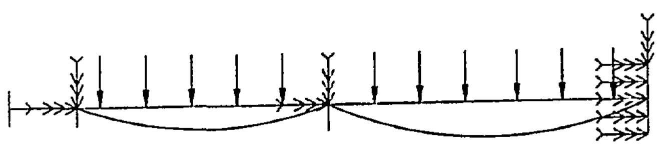

Fig. 4. Horizontal loading supported at ends and center (maximum displacement .012").

Investigation of a Lead Plate/Scintillator Calorimeter

If one considers the same design configuration represented by Fig. 1 but substituting lead plates in place of uranium, one of the major objections (cost) is significantly reduced. However this design is compromised by certain mechanical constraints required by the low modulus of lead.

Analytical calculations were performed assuming that the lead plates are parallel to the barrel axis in a ZEUS-style design. These calculations complemented the results from the conceptual design for depleted uranium absorber. It was assumed that the lead plates were compressed with aluminum spacers as represented in Fig. 5. The scintillator tiles fit between the spacers. One calculation considered a horizontal module supported only at the inner and outer barrel radius. The bending stress due to gravity, at the module center of gravity, was computed to be 177 lb/in^2 and the maximum compressive stress at the lead absorber/spacer interface was estimated to be approximately 11,600 lb/in^2, including preload and bending stresses.

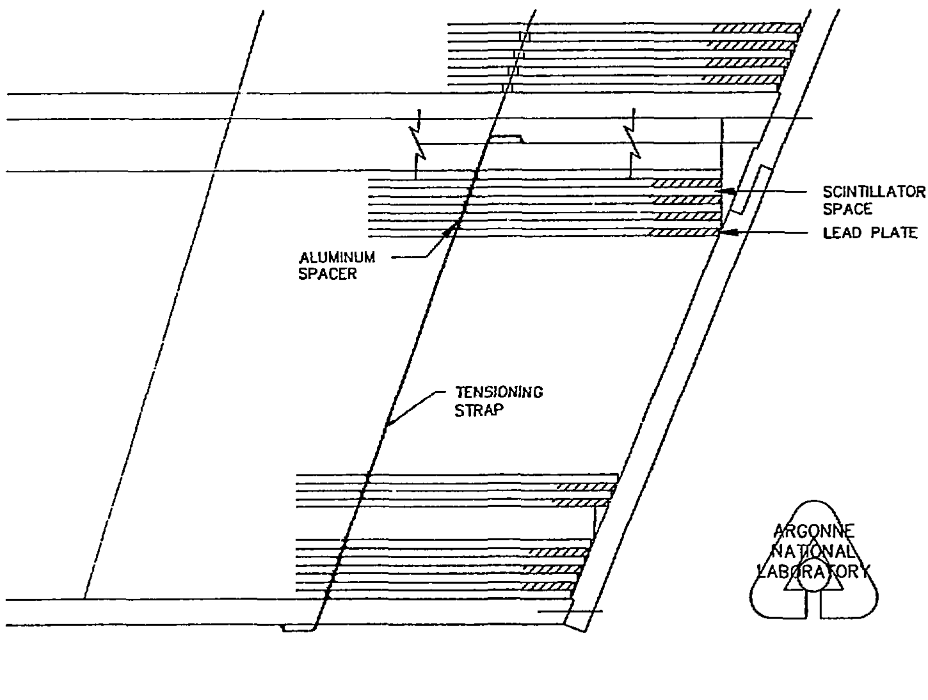

Fig. 5. EMC cross section showing lead plates supported by spacers.

A second calculation considered a horizontal module cantilevered from the outer 12" steel. In this case the bending stress at the module outer diameter was 210 lb/in^2, and the maximum compressive stress at the lead absorber/spacer interface was approximately 16,900 lb/in^2.

In both cases, the computed stresses are far higher than can be achieved with pure lead or lead alloy plates.

Decision to Use Cast Lead Absorber/Scintillator Tile Construction

After detailed investigation by Westinghouse Science and Technology Center, of the use of lead and lead composites for the absorber plates of the calorimeter, it was concluded that a calorimeter could be built using pure lead if the lead was not required to carry any load other than its own weight. The results of this conclusion were adopted and the Westinghouse engineering staff started conceptual design of the hadronic-portion of the barrel calorimeter using a steel/lead structure as shown in Fig. 6. The engineering staff at Argonne National Laboratory concentrated its effort on the higher precision portion of the barrel, that is to say the front end or electromagnetic portion.

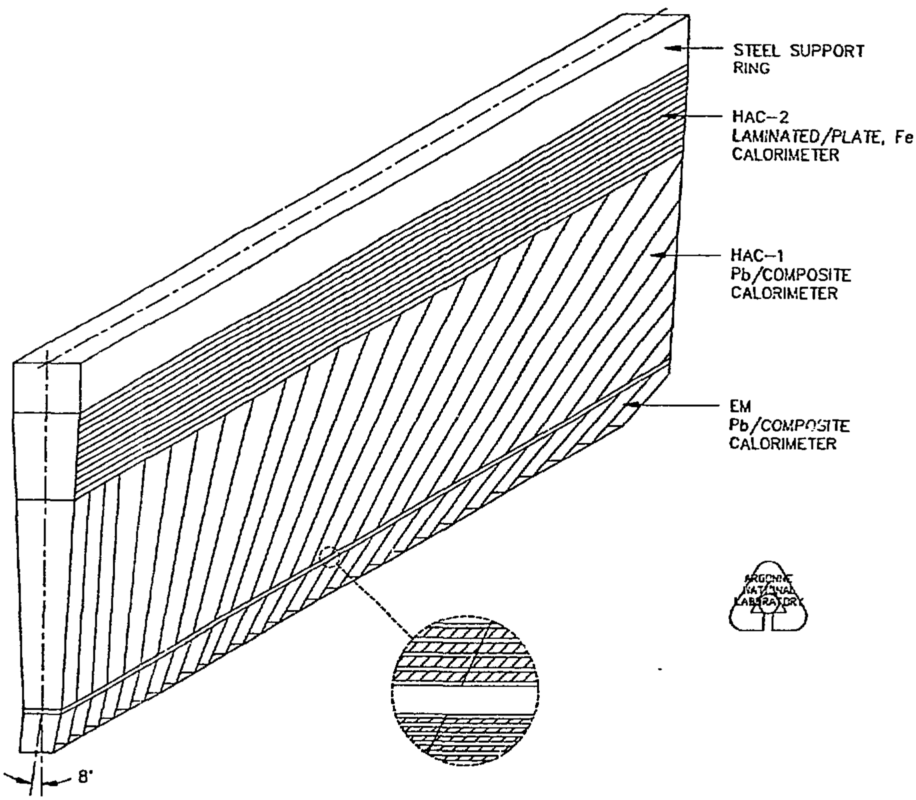

Fig. 6. SDC tile/fiber calorimeter, single module (half length).

Current Design of Test Section

The current design of the test barrel EM calorimeter is represented in cross section by Fig. 7. Using this design concept, two prototype segments will be constructed and undergo testing in the Fermilab test beam in early spring 1991. The structural frame of the short section prototype is shown in Fig. 8. The frame as shown in Fig. 8 will be cast with lead plates in the near future.

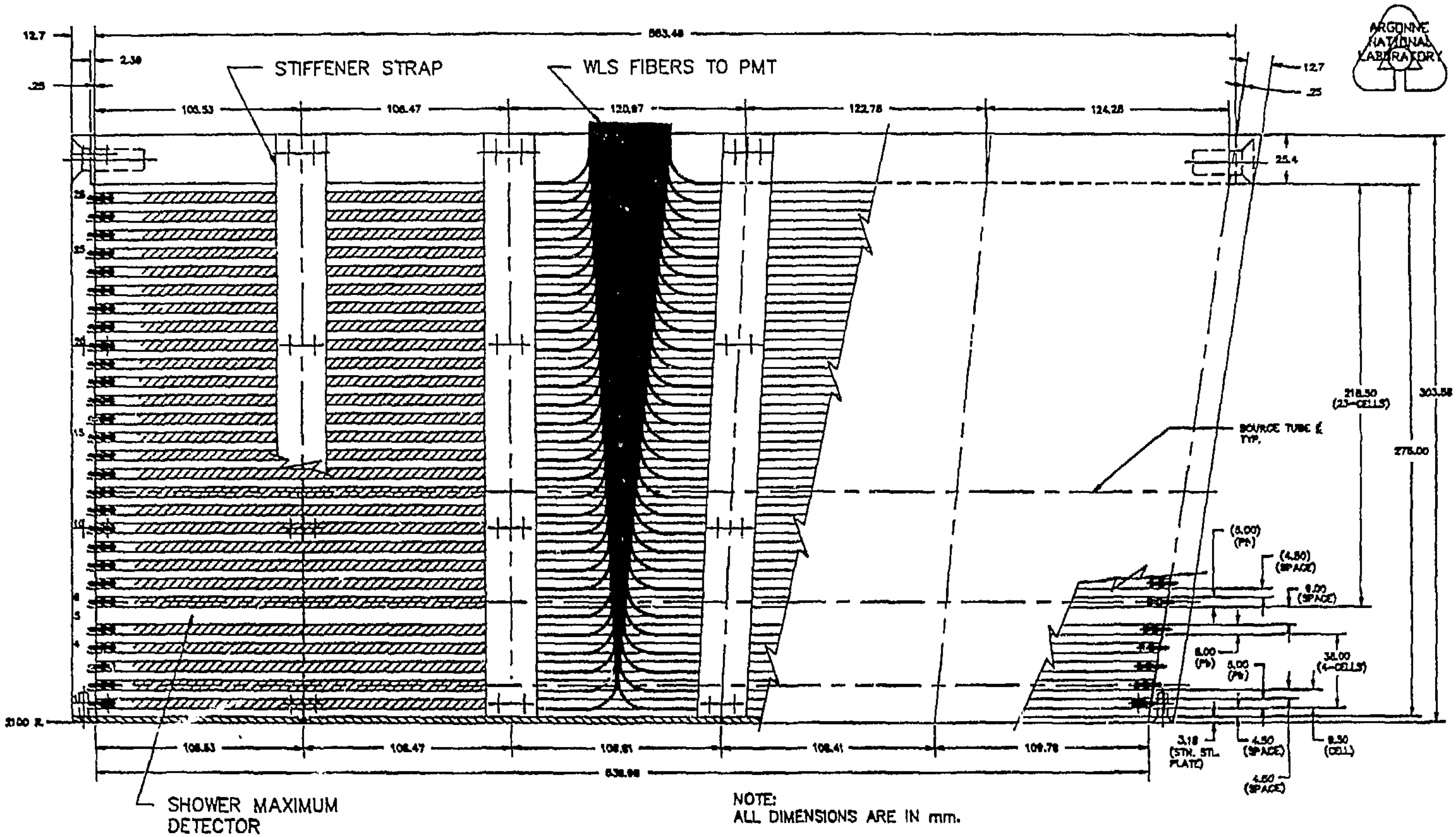

Fig. 7. SDC tile/fiber calorimeter, truncated EMC module for testbeam.

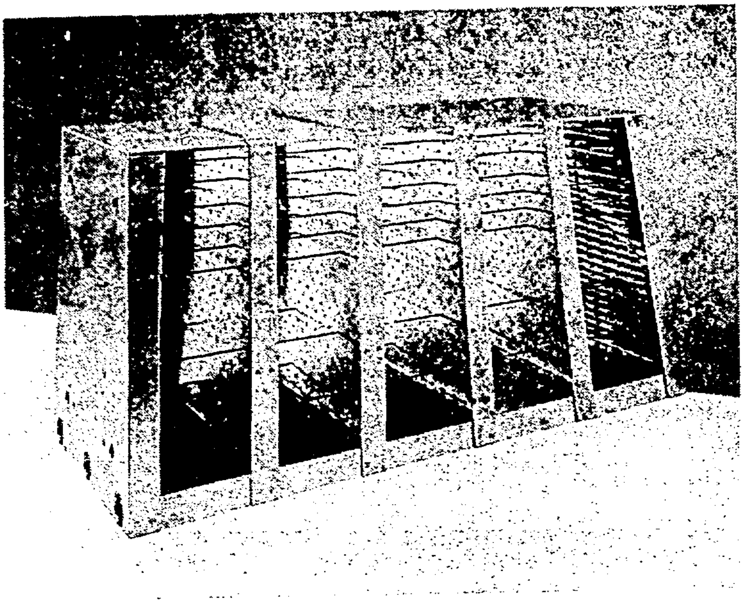

Fig. 8. The assembled structural frame of the EMC short section prototype.

ANALYSIS

The first step in the analysis of the test module, was to model the thin bulkheads and the thin front plate using Cosmos finite element modeler. The boundary conditions assumed the bulkheads were fixed along their top edge and the front plate was fixed rigidly to the two end plates. The model used is shown in Fig. 9. The second step was to apply the distributed weight of the lead along the bulkheads in their proper orientation. The bulkheads were represented in the FEA model as 4 node shell elements.

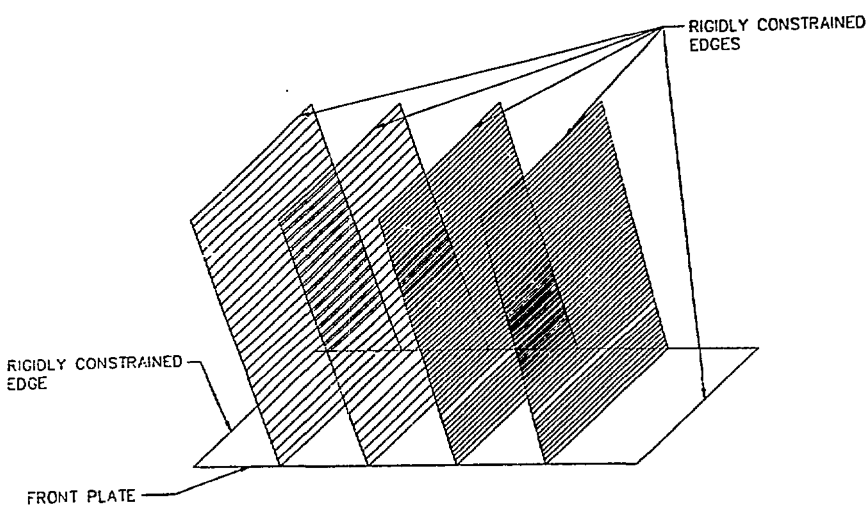

Fig. 9. Finite element model of EM test section.

Three load cases were analyzed:

Loadcase 1 EM section at top of barrel in 0° position.
Loadcase 2 EM section at bottom or 180° position.
Loadcase 3 EM section cantilevered at the 90° position.

The following conclusions were reached after analyzing the FEM data. In load case 1 and 2 the bottom or 1/8" plate does not carry any load. In load case 3 the bottom plate carries a portion of the bending load and the maximum stresses occur in the plate at the ends where they are fixed to the supporting end plates. In all three load cases the maximum stresses occur along the top edge of the bulkheads where they are fixed to the back or 1" thick plate.

Table 1 represents the stresses and deflections on the finite element model (FEM) of the EM test section.

Table 1. Stresses and Deflections of EM Test Section

Load Case	Maximum Stress (psi)	Maximum Deflection (inches)	
1	507	.0001	Radial Deflection of Front Plate
2	511	.0001	
3	773	.0017	Circumferential Deflection of Front Plate

FABRICATION

The fabrication of the necessary components went well with the following minor exceptions:

1. The cost of machining the slotted end plates was believed to be excessive. It is thought that these costs can be reduced to an acceptable level by using CNC machining.

2. The welding of the assembly produced abnormal distortions in both the 1/8" front plate and the 1" backplate. Final evaluation indicates that the amount of weld could be reduced thereby proportionally reducing the distortion.

3. To date the casting of the test module has not been completed and therefore unknown problems may occur as a result of the casting process.

CONCLUSIONS

The conclusions reach by this design exercise are the following:

1. Fabrication techniques and component machining must be analyzed to reduce the cost of full scale modules produced in the future.

2. All welding techniques will be reviewed for improvement or redesigned for mechanical connections.

3. FEM analysis of the full sized model indicate that changes can be made in the construction that will benefit both the physics and the mechanical construction.

4. A thorough investigation of component materials will be done with a cost/benefit analysis made of all components for full size modules.

5. In the final design of the EM section, it will be necessary to skew the module by 8° to avoid projective cracks. A cross section of this configuration is shown in Fig. 10.

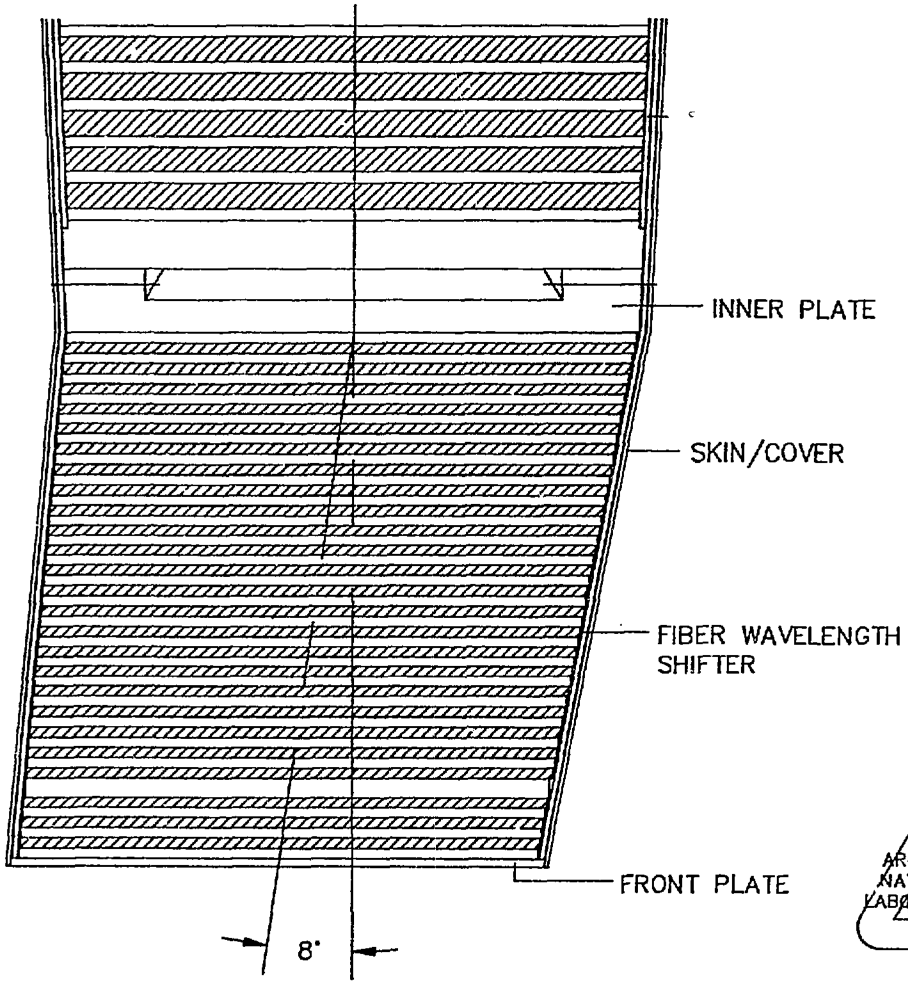

Fig. 10. SDC tile/fiber calorimeter EMC cross section.

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REFERENCES

Some of the figures and material presented here were previously presented in the following two unpublished papers:

1) Progress Report for the Scintillator Plate Calorimeter Subsystem, ANL-HEP-TR-90-39 (October, 1990).

2) Observations and Conclusions Drawn from Conceptual Design Excercises on Barrel Calorimeter for SDC, Argonne National Laboratory internal report, May 30, 1990.