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CONCLUSIONS FROM THE ENGINEERING SUBGROUP OF THE SSC LIQUID ARGON CALORIMETER WORKING GROUP*

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ABSTRACT

The SSC Calorimeter Workshop was organized to explore the feasibility of each calorimeter technology for use in a 4π detector at the SSC. The Liquid Argon Calorimeter group further subdivided into four subgroups; Hermeticity, Engineering, Module Details, and Electronics. This is the report of the Engineering Subgroup whose charge was to evaluate the cost, schedule, manpower, safety, and facilities requirements for the construction of a large liquid argon calorimeter for the SSC.

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1. INTRODUCTION

The SSC Calorimeter Workshop was organized to explore the feasibility of each calorimeter technology for use in a 4π detector at the SSC. The Liquid Argon Calorimeter group further subdivided into four subgroups; Hermeticity, Engineering, Module Details, and Electronics. This is the summary report of the Engineering Subgroup.

The charge of the Engineering subgroup was to evaluate the cost, schedule, manpower, safety, and facilities requirements for the construction of a large liquid argon calorimeter for the SSC. The starting point of the analysis was the vessel and support scheme embodied in the preliminary Martin Marietta 3-D Design (MM3D). The MM3D design (see Fig. 1), is based on the cryogenic cooling system, vacuum-insulated dewar design, and module support system already in place for the SLD detector's liquid argon calorimeter at SLAC. Intrinsic in this design is a highly modularized system of construction for the electromagnetic and hadronic radiator stacks and their signal paths, which are contained within a single common LAr volume, which itself is contained within a single vacuum-insulated vessel.

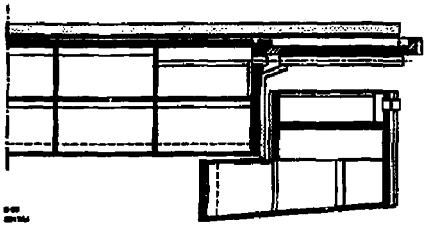

Fig. 1. Schematic of the Martin Marietta 3D design.

Variations of this scheme have now been successfully implemented for several larger experiments with cylindrical geometry (D0, SLD and H1). We have used the experience from these experiments as input into all our estimates.

2. DESIGN, FABRICATION AND ASSEMBLY SCHEDULE

We base our estimates on the experience of D0 and SLD for module and vessel fabrication and final assembly. We examined two possible scenarios. In the first, only minor R&D is assumed to be required to chose radiator and absorber materials, gap sizes, and readout schemes. The module design starts up quickly, and is verified by testing very early. Engineering on the dewar, supports and cryogenics goes on in parallel and their fabrication is assumed to *not* influence the final schedule. Industrialization is limited to fabrication of small subassemblies such as plates, tiles, PC boards, and spacers, rather than large assemblies such as the modules themselves. Module production and testing goes on simultaneously, and may overlap with the installation of modules into the dewar. We estimate about 7.5 years from start until closure and first cooldown. This should be viewed as a *minimum* time schedule.

In the second scenario, new R&D on optimizing module performance (e/π, resolution, hermeticity, and density) is assumed. Two years is allotted to address in detail the issues of Pb compensation, uranium plating or cladding, functional separation of readout and radiator structures, etc. We also assume a larger role of industry in module assembly and QC. Finally, a considerably slower pace for installation and vessel closure is assumed. This may be viewed as reflecting a more realistic scenario of unforeseen problems and interferences with other elements of the detector during assembly. Here, about 12.5 years are estimated from start until closure and cooldown. Neither scenario assumes potential delays associated with the procurement of radiator/absorber materials; the results are summarized in Table 1.

Several points should be emphasized. Modules design, fabrication and testing, and *not* installation into the cryostat and closure of the cryostat, will drive the pace. In either scenario, industry is heavily relied on to supply components. Final module testing must be done by physicists and technicians at or near the site of the assembly. To see this, the somewhat serial operations of calorimeter assembly in the experimental hall are detailed in Table 2.

Table 1. Calorimeter Schedule Scenarios

Activity	Fast Schedule (years)	Slow Schedule (years)
R&D phase	—	2.00
Select gap and absorber structure	0.50	—
Module design	1.00	1.00
Fabricate and verify design in beam tests	1.00	1.00
Technology transfer to industry	—	1.50
First articles	0.75	0.50
Test first articles	0.25	0.50
Redesign	—	0.50
Production and simultaneous testing	2.00	2.00
Completion of testing	0.50	0.50
Installation into vessels	1.00	1.50
Vessel closure and external connections	0.50	1.50
Total	7.50	12.50

Table 2. Calorimeter Assembly

Activity	Barrel (months)	Endcaps (months)
Deliver, setup and clean	2.0	1.5
Deliver, prepare and install modules	300 sh	65 sh
Insulate and assemble cryostat	3.0	1.5
Connect and test feedthroughs	3.0	2.0
Weld and leak test	3.0	3.0
Total	1.3 - 2.1 yrs	0.7 - 0.9 yrs

3. MODULE TESTING FACILITIES REQUIREMENTS

Testing of individual modules beyond the prototype and R&D phase may be done with LN_2 or LAr. The experience of D0 has been that LN_2 testing provides only mechanical performance testing of the design, while testing in LAr provided a complete test of the module, both mechanically and electrically. This conclusion however may be largely associated with the use of uranium absorber in the D0 modules which was not used in H1 or SLD. In SLD, all modules were cold tested in LN_2 for about 48 hours. A small number of production modules were tested more thoroughly in LAr for periods of time from several months to as much as one year.

Thus we conclude that initial testing of prototypes and the first production runs of modules must be carried out in not only LN_2, but in liquid argon as well. These tests should:

- Provide adequate statistics to establish the robustness of the final module design and its connections.
- Determine the testing requirements for the balance of the module production.

In the MM3D design for the LSD calorimeter, approximately 1000 modules must be tested. The total mass is approximately 4500 tons. At the peak of SLD cold testing, at most 42 tons/week of modules were being cold-cycled and electrically tested. This implies in excess of 100 weeks for testing of the LSD calorimeter system if a similar facility were built. It should be noted that SLD used two full-time cryogenics technicians, two electrical technicians, one mechanical technician and three physicists to maintain the peak operation of the testing facility. The test facility was active for about one year.

Warm electrical testing and final burn-in of modules will require one to two weeks/module. Large scale parallelism (20 to 40 modules/week) is therefore required for the LSD calorimeter to reduce testing time to two years or one year, respectively.

We have estimated that 40,000 sq ft of floor space is required for module testing, repair and storage. This should be in close proximity to the experimental hall, where the calorimeter assembly is expected to take place. Facilities for transporting modules and lifting modules must be provided. Techniques minimizing manpower should be emphasized.

4. CALORIMETER CONSTRUCTION AND OPERATING COST ESTIMATE

We have attempted to scale the detailed costs for the LSD liquid argon calorimeter from the most recent information from SLD and D0, in FY89 dollars (see Table 3).

Table 3. Calorimeter Costs

Item	Cost [Millions of $ (FY89)]
LAC vessels and int. cryogenic plumbing	15–20
Modules fabrication and testing	50–70
Storage dewars and transfer lines	3
Total	68–93

The cost of the calorimeter is largely associated with the module materials and construction costs, and *not* with the vessels and associated cryogenics systems.

The cost of vessels scaled from the existing SLD aluminum vessel or the D0 stainless steel vessel (cost converted into an equivalent aluminum vessel) agree well, and represent about one-quarter to one-third of the total calorimeter cost.

The large range given under module construction costs represents differences in radiator material (Pb sheet versus uranium) and differences in fabrication techniques, radiator structure, likely readout structures, handling, and testing.

The cost of 250,000 or more channels of readout electronics *is not* included in the estimate, however feedthroughs and cabling to the outside of the cryostat is included.

Storage dewars were priced assuming four 40,000-gallon liquid Argon tanks and one 40,000-gallon LN_2 tank. Transfer lines from the surface to the tanks and to the detector were included. The LN_2 tank size is driven by the availability and use of LN_2 during the cooldown, such that a cooldown time of about one month is achievable.

At a basic heat load of 4.8 kW (see Sec. 6) the operating cost of the device is driven by its LN_2 cooling. Assuming $0.07/liter, and availability of 45 W hours/liter for LN_2, the device costs about $66,000/year to operate. For front-end electronics a minimum of approximately 22 kW of additional heat load must be accommodated bringing the total minimum operating cost to \$370,000/year. Section 6 will further address these questions.

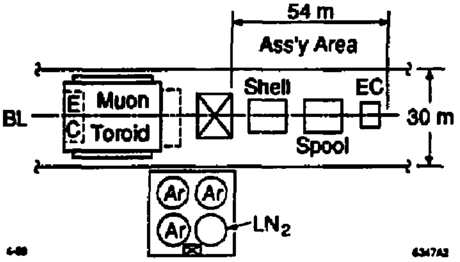

Fig. 2. On-beamline assembly.

5. ASSEMBLY HALL REQUIREMENTS

The LSD hall will have to accommodate the final assembly of the liquid argon calorimeter in the proximity of the beam line, because of its total mass. As the design and assembly procedure follows that of SLD rather closely, we have evaluated two hall designs and their respective requirements. Figures 2 and 3 show the layouts for assembly on- and off-beamline, respectively. Both design should be considered as reflecting *minimum* space requirements, ignoring possible coexistence requirements with other detector elements. The on-beamline hall requires:

- Dedicated crane of 25 ton capacity, with 35 m hook height for calorimeter assembly. Support from a second crane part-time.
- Layout to accommodate "clean environment" activities from other assembly activities.
- Serial assembly plan requires assembly to be built in a proper sequence and location. Note the EC to the left of the muon toroid.
- Cryogenic storage, insulated catch basin and exhaust systems to support safety and operations.

The off-beamline hall (Fig. 3), while requiring a third crane and additional vault space, has several advantages:

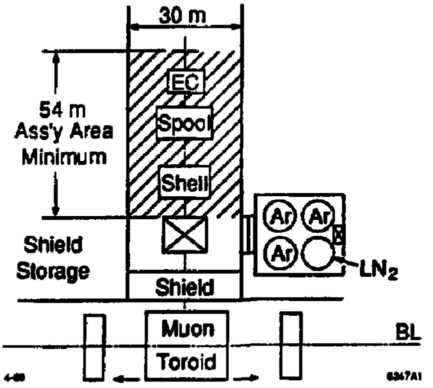

Fig. 3. Off-beamline assembly.

- Layout separates calorimeter assembly from other activities.
- Potential for assembly while the accelerator is brought up.
- More flexible assembly sequence.

The off-beamline assembly also requires the rotation of the core detector to accept the calorimeter, as is done in SLD.

6. CRYOGENIC SYSTEM, COOLDOWN RATES, AND SAFETY ISSUES

A schematic of the cryogenic system is shown in Fig. 4. Details of the system are described in the accompanying report of R. Watt. The basic system is patterned on that of SLD and contains storage dewars, for LN_2 and LAr, conditioning tanks for each, the dewar vessel, and two systems to convert liquid to a gas phase during cooldown (the LN_2) or in an emergency (the LAr). Cooling is achieved by a system of LN_2 cooling loops welded to the inside and outside surfaces of the LAr walls. The loops are subdivided into four circuits on each surface, allowing more local control of the cooling (see R. Watt and R. Schindler, these proceedings).

Cooldown rates have been estimated from SLD where the module design governs the maximum temperature differential between aluminum and Pb in the

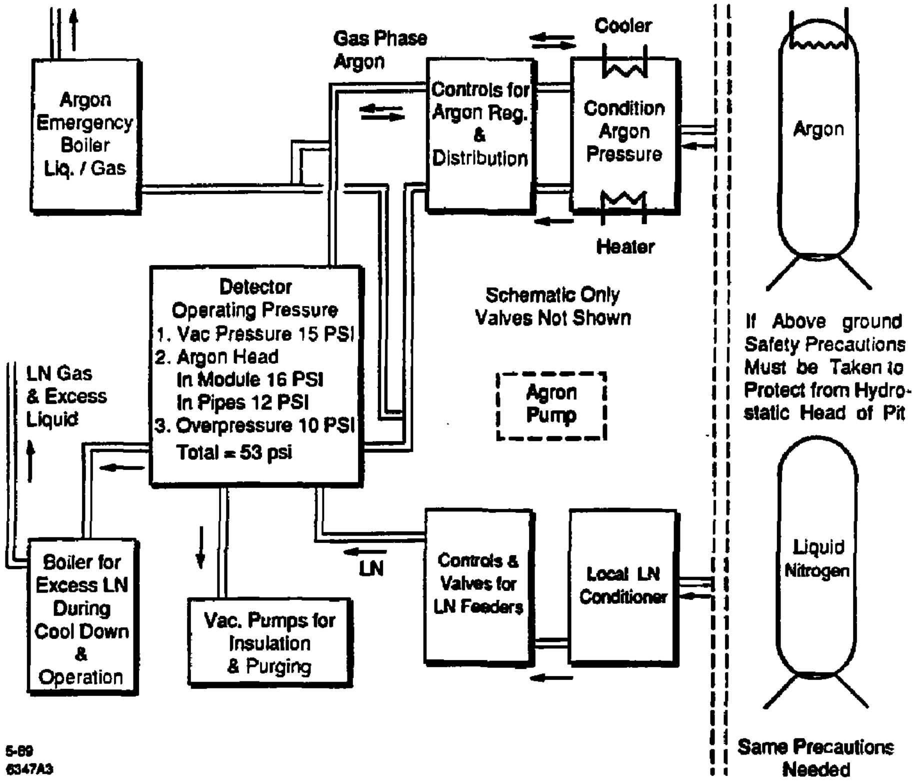

Fig. 4. Schematic cryogenic system.

system. Allowing a 50° C difference between aluminum and Pb in the module stacks allows cooldown to occur in 7 to 14 days. Scaling to the mass and surface areas being cooled, the expected cooldown for a Pb-radiator calorimeter of the MM3D design would be 15 to 32 days.

Pressure head buildup on the cryostat from surface filling of cryogens are eliminated by locating the storage tanks at the same elevation as the detector. Pressure heads from the surface would otherwise require the handling of 88 psi LN_2 and 152 psi LAr on the pit floor. The cryostat will then be required to handle a pressure of $\approx$ 40 psig, operating at 5–10 psig overpressure. Venting of gases to the surface will also require overcoming the 250-ft head using a system of blowers.

Safety in the proposed system is achieved by several measures: The handling of spills will be done by a combination of measures adopted from SLD and D0:

- Route lines to reduce or limit the quantity of liquid which can siphon out.
- Insulate spill paths to reduce boiloff rates.
- Provide liquid collection areas.
- Provide ventillation to remove boiloff.
- Provide gas barriers between the detector hall and the ring.
- Provide adequate monitoring and alarms.

This study does not address the safety questions of additives to the LAr. Suggested examples are methane and other gases which can combine with oxygen to yield an explosive mixture during a spill. In such cases the potential for separation of LAr and, for example, methane exists, allowing the establishment of an explosive mixture. A considerably more elaborate containment system, or dilution system, would be needed to handle such a spill and prevent an explosive environment from being established.

7. FEEDTHROUGHS

Carrying electrical signals out from the dewar, through the vacuum walls and to external electronics requires a high-density packing on the endwall. Conventional feedthroughs using glass-to-metal seals achieve a density of about 0.11×0.11 sq in. per penetration. The 80 ports in the MM3D design must carry ~ 2750 towers of data, and perhaps as many as two signals per tower through the endwall. This means about 100 sq in. of feedthrough, with a 1-in. transition ring. The ports would then be sized at a radius of about 6.6 in. The feasibility of such a large pin content in a glass-to-metal seal feedthrough must be evaluated because of low yields in industrial fabrication.

Another possibility explored previously by the Mark II group was to embed ribbon cables made by weaving stainless steel wire in fiberglass fabric into a Stycast epoxy, and then forming an epoxy/aluminum seal on the outer radius to an aluminum bellows/ring assembly.

Either of these seal techniques appear feasible at this time. Three potential schemes for handling the heat load of the cables are presented in the report of Watt and Schindler. In the last feedthrough LAr is used as the coolant, having the advantage of not creating a contaminating leak into the LAr volume, even if the cable seals are not perfect. Boiloff gas is trapped and recirculated through the LAr system condenser. Each of these systems has the problem of handling the cold gas on the outside wall of the detector. Presumably, by adequate flow of dry gas around these pipes, a buildup of frost can be reduced.

8. HANDLING OF OPERATIONAL HEAT LOADS

Table 4 shows an estimate of the heat input into the barrel cryostat in kilowatt units.

Table 4. Heat Input into Barrel Calorimeter in kW

Source	LN_2 Heat Load	Unintercepted Heat Load
Supports	1.1	0.1
Radiation	1.6	0.0
Feedthroughs	2.1	0.2
Total	4.8	0.3
Electronics	15–100	?
Total	20–105	?

Existing calorimeters (SLD and D0) each carry less than 1 kW of LN_2 heat load, and considerably less residual unintercepted load. While LN_2 cooling is expensive, the real issue is the necessity of preventing bubbles from forming in the liquid argon and propagating into the calorimeter modules, where sparking would result. The major question that arises from Table 4 is the potential for a large (15–100 kW) cooling requirment from the preamplifier (preamp), and possible summing electronics that must be located in the LAr bath, adjacent to the absorber towers. The lower end of the range is just preamps; the upper end is combined preamps and summing circuitry. To remove this heat load, which is 20–100 times that normally seen by SLD or D0, is a serious engineering problem.

Because of the need to cool components in close proximity to the modules, the preferable medium would be liquid argon itself, as opposed to LN_2. This avoids extra plumbing and the potential for a leak of LN_2 that could contaminate the LAr. If preamps can be moved to one location (for example, between the EM and Had sections of the innermost calorimeter stack), the necessary plumbing can be efficiently manifolded and therefore reduced. One possible solution is a schematic "Argon Cooling Pump." Preamps are mounted in thermal contact to a massive aluminum plate which may be the strongback of the module, or the stays that support the dewar. Tubes running through it pipe cold LAr from the low end and take gas out the top end. The gas from each module is then collected together and recondensed in the main LAr system. A typical plate carries about a 40 W load, therefore converting about one liter/hour from liquid to gas.

Alternate schemes would involve providing conductive cooling paths to the already cooled walls of the dewar and its endplates. There, the problem is typically one of guaranteeing intimate thermal contact of components to surfaces which are part of the main structure and which therefore move mechanically upon cooldown.

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