Fermi National Accelerator Laboratory

TM-1626
[SSC-N-669]

SSC Supplementary Conceptual Design Report - Cryogenics for Detectors*

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September 27, 1989

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SSC SUPPLEMENTARY CONCEPTUAL DESIGN REPORT--CRYOGENICS FOR DETECTORS

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Summary

This technical memorandum contains text provided to the SSC for their use in the Supplementary Conceptual Design Report. It was written as part of a Fermilab effort under the guidance of Ray Stefanski of the Fermilab Research Division. This particular memorandum considers the cryogenic systems required to support the superconducting magnets and liquid argon calorimeters asociated with SSC detectors.

Text

5. Experimental Systems

5.4 Engineering Systems Description

5.4.3 Cryogenics

In this consideration of the cryogenic systems required, the following detector elements were assumed:

1. At IR2 the Large Solenoid Detector, with a 9 m ϕ x 16 m pool-boiling superconducting solenoid and a liquid argon calorimeter.
2. At IR5 the D0 Upgrade Detector, with a liquid argon calorimeter.
3. At IR8 the Bottom Collider Detector, with two pool-boiling superconducting dipole magnets much like the CCM analysis magnet at Fermilab.

5.4.3.1 Superconducting Magnets

5.4.3.1.1 Helium refrigeration system

The 4.5-K heat load of the LSD solenoid is estimated to be 214 W + 51 L/h. The transfer line from the utility building to the magnet and ancilliary cryogenic vessels, piping, etc are estimated to add another 64 W of heat load. The total 4.5-K heat load is therefore estimated to be 278 W + 51 L/h. A helium refrigerator/liquefier with a pure liquefier capacity of 250 L/h and a pure refrigerator capacity of 1250 W is proposed for the LSD. Two two-stage screw compressors with 400 hp motors will provide this capacity; a third such compressor will be installed as a spare and will be used during cooldown. A separate cooldown refrigerator, consisting of a liquid nitrogen-gas helium heat exchanger and a 200 hp cold-gas circulator should be sufficient to cool the 1328 metric tonnes of cold mass to 80 K in about three weeks. The main refrigerator, with the three compressors operating, should cool the magnet to 4.5 K and accumulate the 20,000-L liquid helium inventory in about another six weeks. Should this cooldown time be considered too long, a expansion engine could be added to the cooldown refrigerator.

The heat load of the CCM at Fermilab is known to be about 7 W + 3 L/h. The BCD system consisting of two such magnets and the transfer line, etc., mentioned above, is estimated to have a 4.5-K heat load of 80 W + 6 L/h. The refrigerator/liquefier for this system should have a capacity of 125 L/h or 625 W. This can be achieved by coupling two 200 hp screw compressors to a refrigerator/liquefier identical to that installed at IR2. One compressor should be adequate for steady state operation, the second compressor would be used during cooldown and would serve as a spare. Each magnet will have a cold mass of about 10 metric tonnes. Both magnets could be cooled down and filled with liquid helium in about a month, using the refrigerator with an auxiliary liquid nitrogen-gas helium heat exchanger.

Cold compressors could be used on the lines returning cold gas to the surface from either of these systems to insure that the liquid helium reservoirs on the magnets remain at about 1.3 atmospheres (4.5 K).

Both of these refrigerator plants will produce liquid helium into a phase separator-storage dewar. This is done to separate somewhat the plant control system from the cryogenic control system for the magnets. A liquid-nitrogen shielded transfer line will carry liquid helium from the phase separator dewar to the magnet reservoirs in the detector hall.

There will be a multi-stage helium gas purifier associated with each of the helium plants. The liquid nitrogen cooled charcoal stage will have two elements in parallel to provide purification through one element while the other is being regenerated.

If these helium plants are completely independent of the collider system, sufficient gas storage at 250 psig might be provided for the helium inventory in the event that the magnet is warmed to room temperature. The frequency at which it is expected that the magnets will be warmed up and the replacement value of the helium (20,000 liquid liters for the LSD and 5000 liquid liters for the BCD) will determine the economic necessity for this storage. Aesthetic considerations may also be a factor in the decision.

The computer control systems for the refrigerator/liquefier and for the cryogenic aspects of the superconducting magnets will be independent yet coupled, more coupled during cooldown and more independent during steady state operation.

All indoor areas containing gas or liquid helium piping, vessels or other components will be analyzed for the oxygen deficiency hazard caused be an accidental release of liquid or gas helium into the area. Because helium is lighter than 80°C air at temperatures warmer than 8.5 K, oxygen monitors will be located on the ceilings of the utility building and the detector halls (both Assembly and Collision Halls at IR8). These monitors will activate audible and visual alarms, close automatic shutoff valves on the liquid and gas supply lines, and open louvers in the ceiling if necessary.

The liquid and gas helium vessels and piping will be designed, fabricated, and tested in accordance with the appropriate ASME codes, the *ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 and 2* for the ambient and cryogenic vessels and the *ASME Code for Pressure Piping, B31* for the ambient and cryogenic piping.

Table 5.4.3.1.1.a summarizes the capacities of the helium cryoplants at IR2 and IR8. The physical location of the equipment associated with these plants is given in Table 5.4.3.1.1.b.

Table 5.4.3.1.1.a Capacity of Helium Cryoplants

IR/Magnet	Heat Load	Refrigerator Capacity	Installed hp	Compressors g/s
2/solenoid	278 W + 51 L/h	1250 W/250 L/h	1200	180
	1328 tonnes	cooldown/circ	200	
8/2 dipoles	80 W + 6 L/h	625 W/125 L/h	400	60

Table 5.4.3.1.1.b Equipment Location: Helium Cryoplant

Item	Above ground outdoors	In utility hall	In detector hall
Refrig-heat exchanger	x	x	
" -expanders		x	
Phase separator-dewar		x	
Refrig-compressors		x	
Purifier	x		
Cooldown-heat exchanger	x	x	
" -circulator		x	
Gas storage tanks	x		
Transfer line		x	x
Cold compressors			x
Magnet reservoirs			x
Vent-relief line			x
Control room		?	
Oxygen monitors, helium ODH		x	x

5.4.3.1.2. Liquid nitrogen system

Liquid nitrogen will be used for a variety of purposes associated with the detectors. It will be used as liquid in the precooling heat exchanger of the helium refrigerator/liquefier and to refrigerate radiation and conduction intercepts in the magnets and transfer lines. If the detector has a liquid argon calorimeter, liquid nitrogen will be used as a refrigerant in recondensors in the calorimeter vessels and the liquid argon storage dewars. Nitrogen gas, from evaporated liquid, will be used for a number of purging and inerting purposes.

Liquid nitrogen will be stored in large vessels at each interaction region. (IR2 and IR3 could share the same storage vessel, as could IR5 and IR8.) The storage vessels will be filled periodically from over-the-road tankers by a contracted vendor of liquid nitrogen.

The size of the storage vessels is determined by the nitrogen usage, and should be sufficiently large that it need not be filled more frequently than once a day, even during times of peak usage, e.g. a magnet or calorimeter cooldown. Experience at other high energy physics collider detectors suggests that the liquid nitrogen storage vessels at the SSC detectors should have a capacity of at least 20,000 gallons and should be larger if the vessel is shared by two detectors.

The liquid nitrogen demand/heat load of the LSD consists of several major components: (1) the superconducting magnet (about 5 kW steady state), (2) the subcooled liquid nitrogen circulator in the detector hall (about 3 kW), (3) the helium refrigerator/liquefier (15 gal/h), (4) the magnet cool-down refrigerator (50 kW) and (5) the liquid argon calorimeter (500 gal/h during cooldown). The demand for low-pressure nitrogen gas cannot be estimated at this time. A 50,000 gallon liquid nitrogen storage tank should be installed at IR2. A horizontal vessel is recommended for aesthetical reasons.

The liquid nitrogen storage vessels at IR5 and IR8 should be 20,000 gallons each, with a 50,000 gallon vessel recommended if the two detectors share the same vessel.

The liquid storage vessels will be typically operated at a pressure/temperature of about 30 psig (3 atm)/88 K. Because the detectors are about 200 feet below ground, liquid nitrogen delivered directly to the detector hall will be at about 8 atm/100 K. This temperature is too high for magnet radiation shields and conduction intercepts and for the liquid argon recondensors. A liquid nitrogen subcooler-circulator system similiar, or identical, to that used for the collider will be installed in each detector hall. This system will supply 8-atm liquid nitrogen at 77 K to the various loads. Only cold gas nitrogen will be returned to the surface.

Because nitrogen gas at 289 K (60.8^{o}C) or below is heavier than air at 80^{o}C, an accidental release of a substantial amount of cold nitrogen gas into the detector hall, either Assembly Hall or Collision Hall at IR5 and IR8, constitutes a serious potential oxygen deficiency hazard. This hazard must be analyzed, but the below ground halls will probably have oxygen monitors near the floor. These monitors will activate audible and visual alarms, close automatic valves on the liquid nitrogen supply lines, and turn on exhaust blowers or increase the air flow from the HVAC system. Since some of the detectors will be self-shielding against nuclear radiation and the detector halls might therefore be routinely open for personnel access, the response of those persons in the hall to an ODH alarm must be guaranteed by egress procedures and adequate training.

The ODH hazard caused by a liquid or cold gas nitrogen spill in the utility building is less severe, but monitors, alarms and exhaust fans may nevertheless be required.

The liquid and gas nitrogen vessels and piping will be designed, fabricated, and tested in accordance with the ASME codes mentioned earlier.

The locations of the various components of the liquid nitrogen systems are given in Table 5.4.31.2.a.

Table 5.4.3.1.2.a Location of Liquid Nitrogen Equipment

Item	Above ground outdoors	In utility hall	In detector hall
Liquid storage vessels			
IR2-50,000 gal	x		
IR5-20,000 gal	x		
IR8-20,000 gal	x		
Vaporizers	x		
Transfer line		x	x
Liquid subcoolers			x
Subcooled liquid circulators			x
Oxygen monitors, nitrogen ODH		x	x

5.4.3.2 Liquid Argon Calorimetry

5.4.3.2.1 Liquid argon system

Liquid argon calorimeters are used in the detectors at IR2 and IR5. Even though the calorimeters may differ somewhat the liquid argon support system will probably be quite similar; they are assumed here to be identical.

Liquid argon storage will be located in the detector hall. The storage volume will be large enough to contain all the liquid argon needed for the calorimeter, with a 10 to 20% gas space. This liquid storage could be provided either with several vertical vessels or a single horizontal vessel. The vessel(s) at IR5 will have a total nominal capacity of 20,000 gallons; those at IR2 could be the same. The storage vessels will each have a liquid nitrogen cooled recondensing heat exchanger at the top of the inner (argon) vessel. This recondensor will remove the vessel heat load by boiling liquid nitrogen; no argon will be lost unless the flow of liquid nitrogen ceases for a time of the order of hours. The storage vessel must be located at about the same elevation as the calorimeter to avoid placing a large liquid head on the calorimeter (the head at the bottom of a liquid line to the surface exceeds 110 psig).

The liquid argon storage vessel(s) will be filled from over-the-road tankers by a commercial vendor. The purity of all incoming liquid will be tested before it is transferred to the storage vessel.

Vacuum jacketed liquid and cold gas transfer lines will connect the storage vessel and the calorimeter. A vacuum jacketed line will run from the outdoor delivery point to the storage vessel. Vent/relief lines will run from the calorimeter and storage vessel up to the surface. Because of the relatively low design pressure of the calorimeters the vent/relief line from the calorimeter must never contain flowing liquid.

There is a potentially serious oxygen deficiency hazard in the detector hall(s) because of the large volume of liquid argon present. In fact, the argon ODH is more worrisome than the nitrogen ODH because of the larger potential flow rates into the hall. A catchment sump will be provided under the storage vessel(s) and drainage troughs will lead from under the calorimeter to the sump. Boil-off gas from the sump will be exhausted outdoors by a blower activated by a sensor in the sump. Oxygen monitors will be placed low in the IR5 Assembly Hall and Collision Hall. Monitors low in the IR2 and IR8 halls will detect low oxygen partial pressure due to either argon or nitrogen releases.

The liquid and gas argon vessels and piping, including the calorimeter, will be designed, fabricated, and tested in accordance with the ASME codes cited earlier.

5.4.3.2.2 Liquid nitrogen system

The liquid nitrogen systems required for the liquid argon calorimeters are discussed in section 5.4.3.1.2.