THE CEBAF CRYOGENIC SYSTEM*

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Introduction

The CEBAF superconducting linear accelerator incorporates cryogenic refrigeration equipment at three locations within the site as presented in Figure 1: the Central Helium Liquefier, located in the center of the accelerator; the experimental end station refrigerator; and the test laboratory refrigerator located in the Cryogenic Test Facility(CTF) adjacent to the test laboratory.

The CEBAF cryogenic system will provide 2K refrigeration to the linacs of the accelerator and test laboratory and 4.5K refrigeration for the end station experimental halls. The Central Helium Liquefier and the test laboratory systems will produce 45K supercritical gaseous helium for shield refrigeration. Liquid nitrogen shields will also be incorporated in the test laboratory and end stations.

CEBAF Central Helium Liquifier (CHL)

The Central Helium Liquefier, as presented in Figure 2, will include a warm compressor system, an oil removal system, and two cold boxes — a "standard" 4.5K cold box incorporating vacuum furnace brazed plate fin heat exchangers, and four pressured helium gas bearing turbines; and another cold box which will incorporate four stages of cold compressors with an additional heat exchanger to produce 2K refrigeration.

The system will incorporate six oil injected helical screw compressors with slide valves for efficient capacity control. Four machines, two first stage and two second stage, will operate and supply at least 85 percent of the required cycle capacity. In essence, one first stage and one second stage compressor will be spare. The oil removal system will be composed of a bulk oil removal stage on each compressor skid to attain a level of 10 ppm(w) of oil in the helium. The final oil removal will be three coalescer stages in separate vessels. The gas velocity, based upon the filter inlet area, is less than 5 cm/sec and the maximum tangential component of velocity in the outlet annular space is less than 30 cm/sec.

The Central Helium Liquefier required at CEBAF will simultaneously produce a minimum of 12kW of shield refrigeration load at 45K, 4.8kW of refrigeration at 2.0K, and liquid production of 10 g/sec. at 4.5K. The 10 g/sec of liquid production will be returned to the interstage of the main compressor system by way of a cryogenic purifier. Figure 3 presents the refrigerator room of the CHL complex.

There are two types of resistive losses in a superconducting rf cavity: residual resistance and BCS (Bardeen, Cooper, and Schrieffer) resistance. The residual resistance is caused by localized resistive areas where defects, impurities, or surface dirt disturbs the superconductive properties. The BCS resistance increases with increasing frequency, and decreases as the operating temperature decreases. Other sources of 2K heat include static heat leaks, conduction of heat dissipated in the input waveguides, and absorption of higher-order-mode power generated by the beam currents.

The operating range is 2.0 to 2.5K; we have chosen to size the distribution system to be optimized for 2K operation with a flow safety factor of two times the calculated heat load. Figure 4 presents the total heat load as a function of temperature. Since the possibility of higher cavity gradients in the future will tend to shift the optimum toward lower temperatures, this will permit future beam energy increases without requiring replacement of the relatively expensive distribution system. The projected loads and capacities are presented in Table 1.

Table 1
Refrigeration Requirements

	He Temp (K)	Calculated Load (W)	Design Load (W)	Pressure (atm)	Safety Factor (%)	Flow (g/sec.)
Linac cavities	2.0	2711	4800	0.031	177	240
Linac heat shields	38–52*	6663	12000	3.5	180	160*
End station liquefaction	4.4	165 L/hr	288 L/hr	2.8	175	10

Because of the 2K load temperature selected, the pressure at the cryomodule must be closely maintained at 0.031 atm. There are several methods of maintaining this pressure:

1. Operate with main compressor subatmospheric plus use cold compressors,
2. Operate with warm vacuum pumps,
3. Operate with cold compressors.

CEBAF has chosen to operate the system incorporating cold compressors. The cold compressor will be designed to compress approximately 240 grams per second from 0.030 atm to 1.2 atm. This choice will eliminate the two major problems of subatmospheric warm pumps:

1. Keeping the warm piping mass spectrometer tight,
2. Gigantic low pressure heat exchangers.

The 2.0K Control System consists of two subsystems: 0.031 atm Pressure Control (vapor pressure at 2.0K) and the 43 Module Liquid Levels. In addition, there is a tuner to adjust the resonant frequencies of the cavities. These control loops have supervisory level controls superimposed on them to prevent instabilities and to provide a "feed forward" function to handle changing rf loads.

The 0.031 atm Pressure Control has three functions:

1. Regulate pressure,
2. Keep the cold compressors in the stable operating regions,
3. Cope with a step from 20 to 80% of full refrigeration capacity.

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The regulation at full capacity is done by adjusting the cold compressor speed which sets the compression ratio. The steps in rf heating loads will be controlled by a 5KW bypass heater. The heater circuit will take 2.8 atm 2.2K helium through a heater to warm it and then through a J-T valve to drop the pressure.

The rf load is three times the static heat load and therefore represents a major perturbation to refrigerator stability. The interface of the rf and cryogenic system is done at the supervisory computer level; the 338 rf gradients are supplied to the Cryogenic Supervisor whenever a major change in the rf load is made. The gradient, liquid level, and inlet J-T valve are continously data logged in the Cryogenic Supervisor to permit a background program to calculate the cavity Q.

Experimental End Station Refrigeration (ESR)

The design for the CEBAF experimental area is three end stations, each fed by an independent transfer line which cool large superconducting quadrupoles, a six coil toroid, and miscellaneous users' equipment.

The toroid and quadrupole magnets will be force flow cooled and the others may be refrigerated by poolboiling. The magnets will be powered and protected individually, thus avoiding the problems of quench propagation possible with systems that are series connected.

The end stations will be supplied by a refrigerator capable of producing 1450 watts plus 3 grams per second at 4.42K, or in the pure liquefaction mode, 11.7 grams per second, or 348 litres per hour, at 4.42K. In addition, a transfer line from the CHL can supply 10 g/sec of liquid helium steady state, or 50 g/sec for cooldown.

Cryogenic Test Facility (CTF)

This facility is designed to provide 4.5K to 2.0K refrigeration and liquefaction to multiple users in the test laboratory. Figure 5 presents the CTF. The users include:

- production testing of cavities, cryomodules and end stations magnets,
- injector R and D,
- advanced accelerator R and D.

The refrigeration system consists of three compound helical screw compressors capable of each compressing 58 grams per second gaseous helium from 1.05 to 20 atmospheres, three cold boxes, a warm vacuum pumping system and the necessary auxillary distribution equipment.

The system is designed to supply the following simultaneous users:

- a pair of cryomodules,
- four pairs of vertical dewars for cavity testing,
- injector cryounit,
- and two pairs of end station magnets.

The warm vacuum pump is incorporated to produce 0.031 atmosphere pressure in the 2.0K loads, and the 4.5K loads will return directly to the compressor suction.

All three cold boxes incorporate LN_2 precooling. The small supercritical unit incorporates a Brayton cycle with four heat exchangers and one reciprocating expander, a Koch "1400-3." This expander is identical to the two incorporated in the refrigerator. This machine requires about 20 grams per second of compressed flow and will produce about 1000 watts to cool the shields in the cryomodule/vertical dewar transfer line and cryomodule shield.

The second cold box, the refrigerator, operates with two Koch "1400-3" expanders and LN_2 precooling. It is capable of the following operating modes:

- 4.5K liquefier: 5 grams per second, 2.8 atmosphere,
- 4.5K refrigeration: 550 watts,
- 2.0K liquefier: 8 grams per second, 2.8 atm, 4.5K.

The 2.0K liquefier mode requires a 24K 1.2 atmosphere return; this is achieved by using a cold compressor. The cold expander is switchable from series to branch flow. Series flow would be used for fast cooldown from 45 to 20K and for refrigeration modes, while branch flow would be used for liquefier modes.

The third cold box, a CTI2800 with two turbine expanders in series, is incorporated as a liquefier. The unit is configured to produce liquid into a 1000 liter dewar. This liquid will normally be utilized to fill load dewars with a maximum flow rate of 10 grams per second, 288 litres per hour. Also if the refrigerator is down, the CTI2800 can be operated as a back up.

Within the facility, there is also a 10 grams per second gaseous helium purifier. The system consists of the "standard" molecular sieve drier, and a charcoal absorber operating at 80K; a plate fin heat exchanger is incorporated for precooling and reheating of the gaseous helium.

All compressor oil and vacuum pump oil is UCON LB170X and is processed in an oil processor located within the CTF. The oil is heated to 220F, vacuum pumped and circulated simultaneously until it satisfies our criteria for purity.

Status

The CTF facility is operational and has been used to test cavities. The ESR is an existing CTI 1500 watt machine which will be moved to CEBAF this spring from LBL. It will be overhauled, including new controls and additional oil removal equipment before it is commissioned in FY92.

The CHL is being built by CVI/L'Air Liquide. The building will be finished this September, with installation starting in October. The acceptance test is planned for July 90.

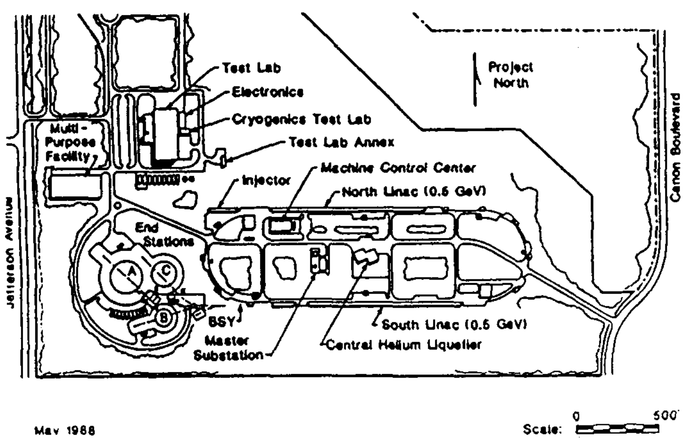

Figure 1: Site Plan

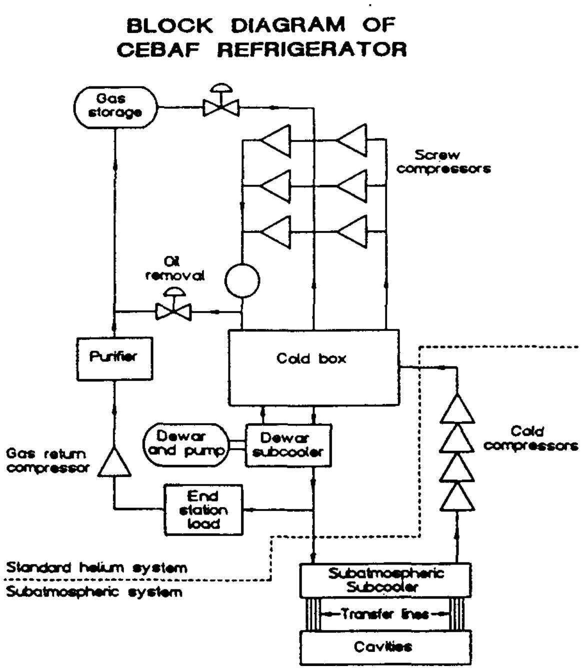

Figure 2: Block Diagram

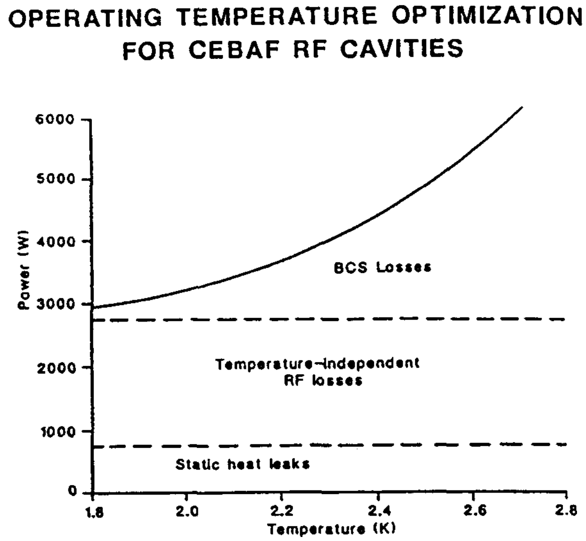

Figure 4: Power versus Operating Temperature

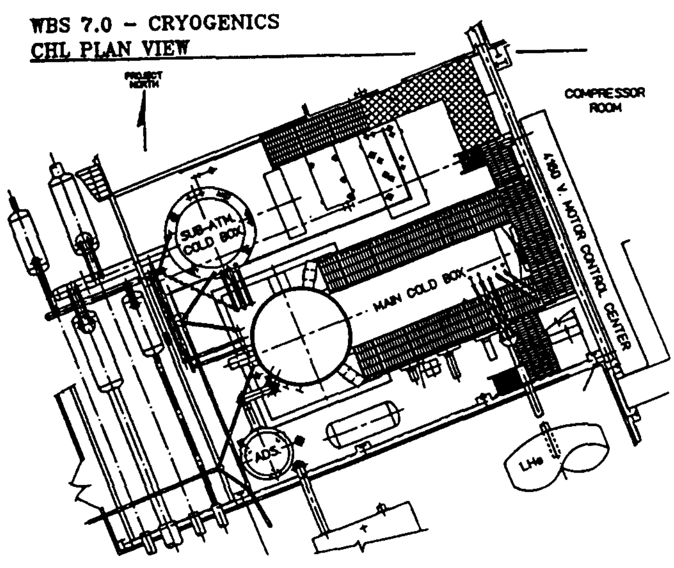

Figure 3: CHL Plan View

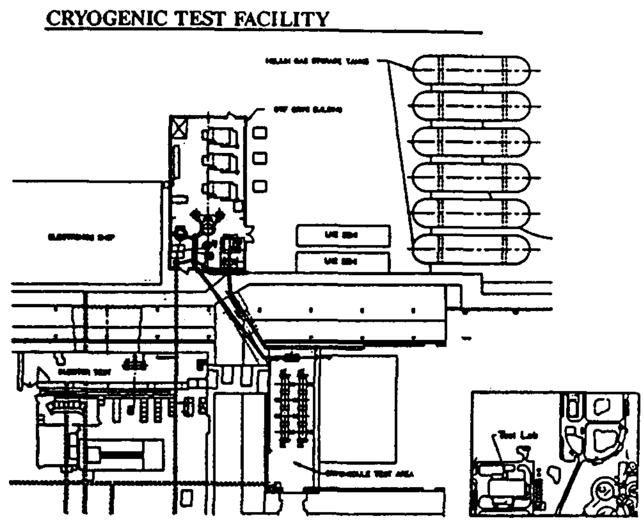

Figure 5: Cryogenic Test Facility

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