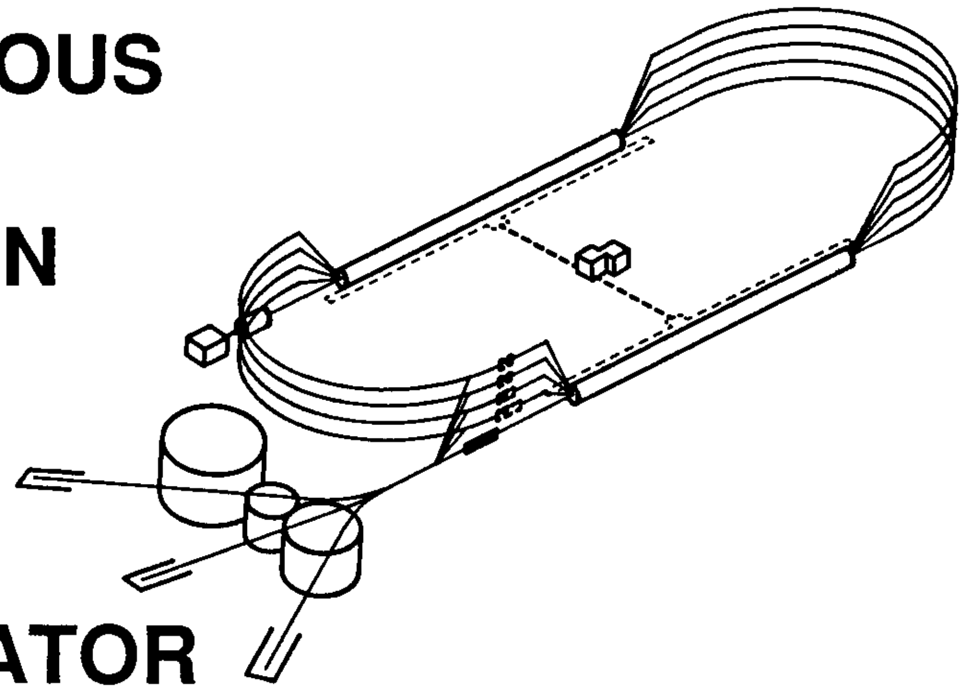
CEBAF PR-91-024
June 1991

CEBAF Transfer Line Systems

D. Kashy, W. C. Chronis, C. Rode, and J. Wilson
Continuous Electron Beam Accelerator Facility
12000 Jefferson Avenue
Newport News, VA 23606

CONTINUOUS
ELECTRON
BEAM
ACCELERATOR
FACILITY



SURA *Southeastern Universities Research Association*

CEBAF
The Continuous Electron Beam Accelerator Facility
Newport News, Virginia

Copies available from:

Library
CEBAF
12000 Jefferson Avenue
Newport News
Virginia 23606

The Southeastern Universities Research Association (SURA) operates the Continuous Electron Beam Accelerator Facility for the United States Department of Energy under contract DE-AC05-84ER40150.

CEBAF TRANSFER LINE SYSTEMS

D. Kashy, W. C. Chronis, C. Rode, and J. Wilson

Cryogenic Systems Group
Continuous Electron Beam Accelerator Facility
Newport News, Virginia

ABSTRACT

The Continuous Electron Beam Accelerator Facility (CEBAF) has three refrigeration systems which supply many users with liquid and gaseous helium and liquid nitrogen at different state points. Static vacuum transfer lines of varying sizes and geometries transport the cryogens. The simplest has 2 flow paths and the most complex has 5 flow paths including a 4.5 K subcooler. CEBAF will have nearly 2 km of transfer line varying in size from 11.4 cm to 40.6 cm outside diameter. The transfer lines have eccentric flow shield circuits which convey LN_2 or 40 K to 50 K helium gas to intercept the main 300 K heat leak. All of the transfer lines have been designed and fabricated at CEBAF.

INTRODUCTION

The transfer lines at CEBAF supply cryogens for prototype testing, production testing, and operation of superconducting magnets and cavities. This wide variety of cryogenic requirements required CEBAF to design nine different cross sections of transfer line. Three refrigerator facilities supply cryogens to the transfer lines.

The first operational facility at CEBAF was the Cryogenic Test Facility (CTF). The CTF has three refrigerators. Two are 4.5 K liquefying plants and one is a supercritical refrigerator which supplies 40 K gas. The CTF uses three transfer line cross sections to supply as many as four independent users simultaneously.

The Central Helium Liquefier (CHL) is the main refrigerator for the two superconducting linear accelerators (linacs) and is the largest 2 K helium plant in existence.[1,2] CEBAF uses two independent transfer lines to cool each linac. The supply transfer line has two different cross sections which supply 2.2 K supercritical gas and 40 K shield gas. The return transfer line also has two different cross sections and returns the cryogens at 2 K and 50 K to the CHL for precooling and reliquefaction.

The End Station Refrigerator (ESR) supplies the three experimental halls by way of three identical transfer lines. The capacity of the ESR can be increased by the transfer of liquid helium from the CHL using a cross connect transfer line.

The CEBAF transfer lines have been designed to provide maximum user flexibility with minimum effect on the refrigeration systems. The design of some of the CEBAF transfer lines are similar to the Fermilab Tevatron transfer line.[3] Others vary dramatically in size and complexity.

The transfer lines are made of a variety of materials. All of the pipe is 304 stainless steel with some 316 stainless steel fittings. The bellows and flexhoses are made of 316L stainless steel. The subatmospheric circuits have ceramic feedthroughs for temperature diode wiring. The flow circuits are insulated with super insulation made of aluminized mylar (with a maximum resistance of 0.8 ohm/square). Each layer of aluminized mylar is separated by three layers of Cerex. The insulation is installed at 24 layers per centimeter. The 2 K bayonets, reliefs, and instrumentation have heat intercepts at the shield temperature. The heat intercepts are copper rings which are silver brazed to the stainless steel. The heat is conducted to the shield circuit by copper straps or braid through a heat station pad which is brazed to the shield circuit pipe. The pad provides the surface area necessary for forced convection heat transfer to the shield fluid.

LINAC TRANSFER LINES

The majority of CEBAF's transfer lines provide cooling for the two linacs. The layout of the linac transfer lines resembles the letter "H" with the CHL centrally located (Figure 1). Four different cross sections are used to supply (Figure 2) and return (Figure 3) helium for the linacs. The four CHL Transfer Lines to the linacs are 85 m long. Expansion cans located in the CHL allow for thermal contraction of these lines. The CHL Supply Transfer Lines enter the linacs at the supply tees and tie into the Linac Supply TL which has the same cross section, except that the inner line is smaller. The north and south Linac Supply TL's have a total of 53 bayonet pairs for supply of shield and supercritical 2.2 K gases to the accelerator cryomodules. The purpose of the bayonets is to allow a faulty cryomodule to be removed and replaced while the accelerator remains cold. This allows the accelerator to have shorter shutdowns and, therefore, more operating time. The shield flow is controlled by a CEBAF designed Y-pattern valve located at the bottom of the bayonet and the 2.2 K flow is controlled by a J-T valve in the cryomodule. At each end of the "H" is a cooldown valve for the 2.2 K circuit and a bypass valve for the shield circuit. The 2.2 K cooldown flow connects to a cooldown header. The excess shield flow returns through the bypass valve and the Linac Return TL shield circuit. A schematic of the linac transfer lines and the connections to a cryomodule is shown as Figure 4.

The CEBAF accelerator cavities operate at 2 K which requires the return pressure of the primary circuit to be 0.031 bar. Because pressure drop is inversely proportional to pressure, the return transfer lines are much larger than the supply. The primary circuit of the Linac Return Transfer Line is a 16.8 cm OD line with a 32.4 cm OD vacuum jacket. The Linac Return TL also has 53 bayonet pairs with 53 Y-pattern valves on the 2 K circuit to control the pressure of the liquid bath in the cryomodule. At the middle of the linacs the lines tee together and return to the CHL via the CHL Return TL. It has a 21.9 cm OD inner line and a 40.6 cm OD vacuum jacket.

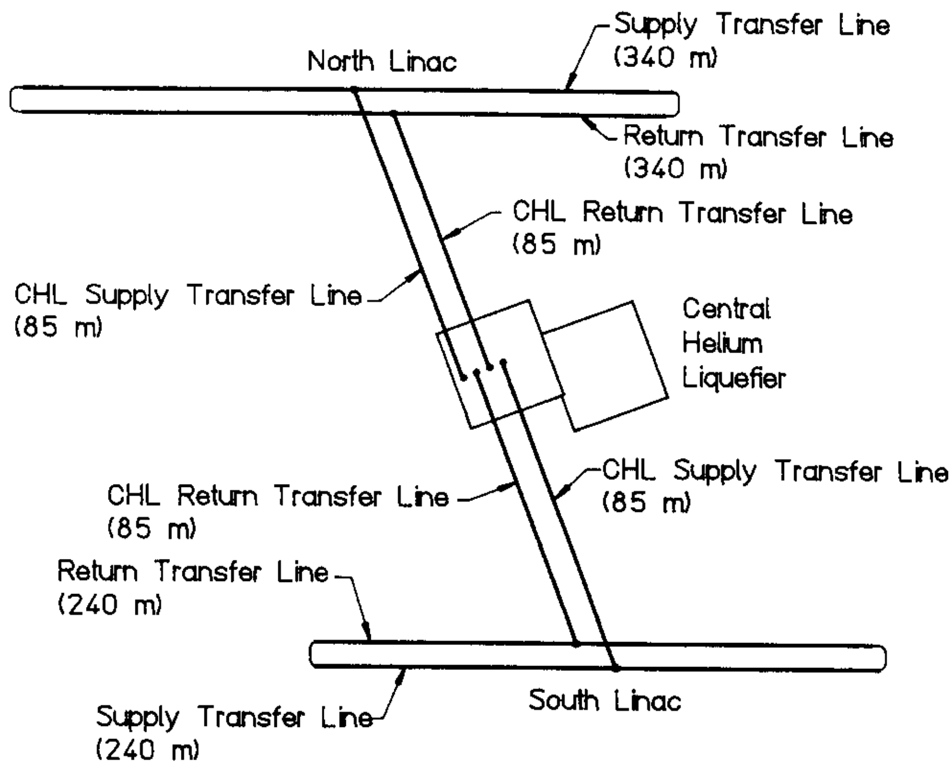


Figure 1. Linac transfer line system

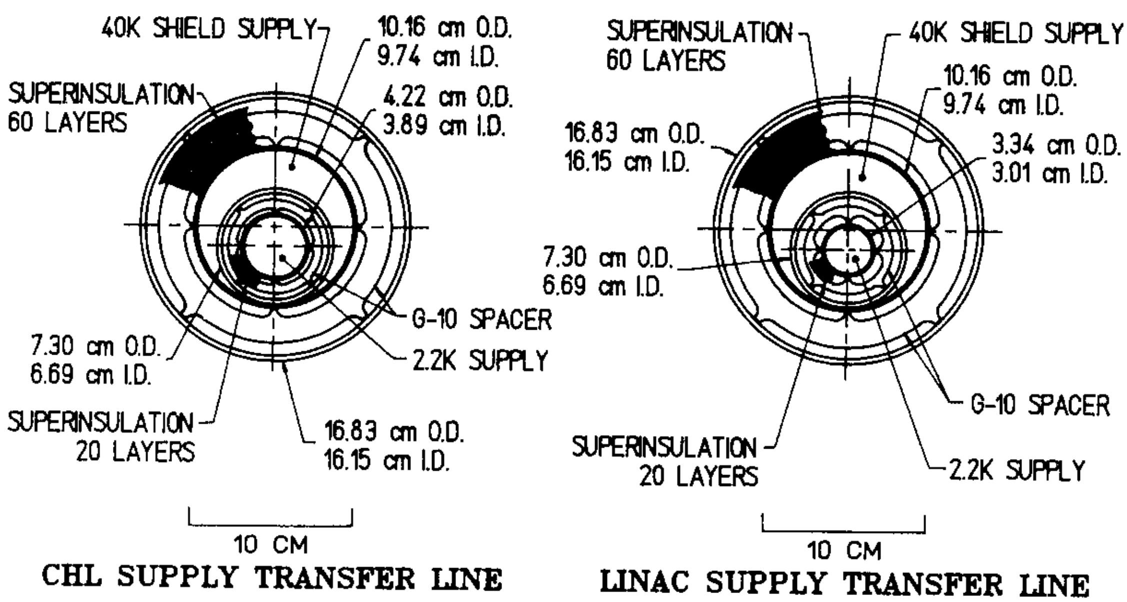


Figure 2. Linac supply transfer lines

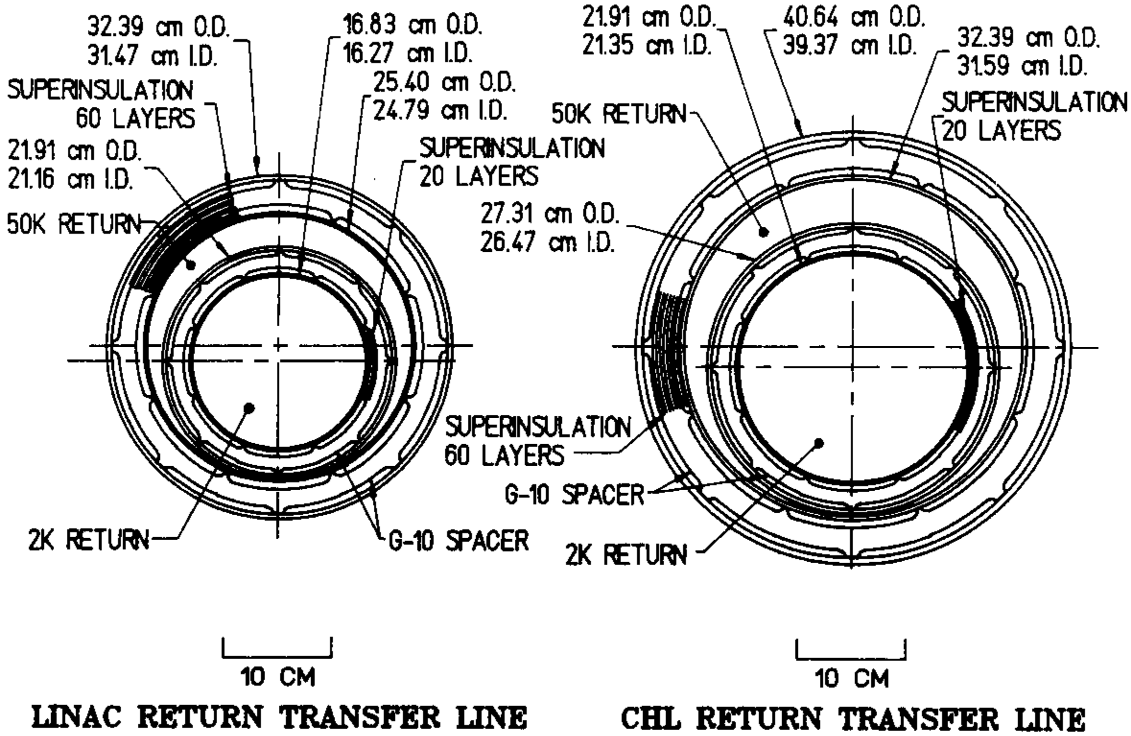


Figure 3. Linac return transfer lines

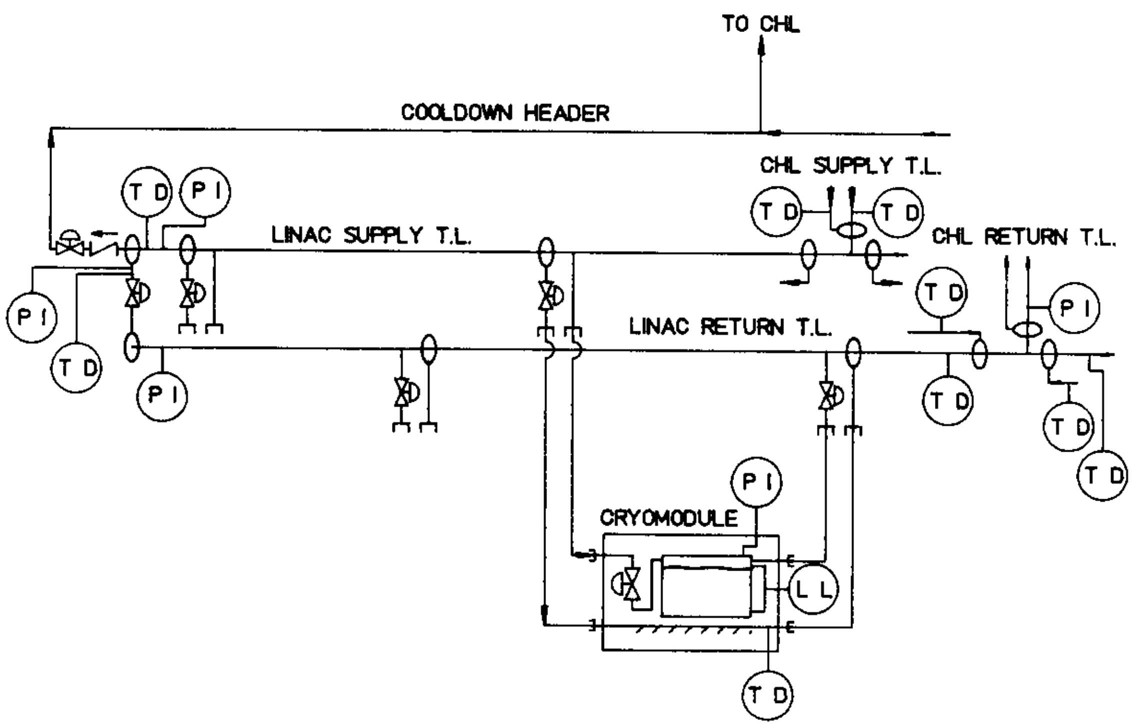


Figure 4. Linac transfer line schematic

When fully operational the linac helium distribution system is designed such that in a steady state mode, all cryogenic flows will be vacuum insulated and no "ice balls" will form. Each cryomodule is connected to the supply and return TL's with a total of four vacuum insulated U-tubes.

The Linac Supply and Return TL's are fabricated in 19.2 m modules (Figure 5). This length is two times the "cryomodule slot length" and services two cryomodules. There are a total of 22 standard modules of each type as well as many specialty modules due to nonstandard geometries at the end of the lines. Each standard module has two bayonet pairs. One pair of bayonets is an anchor location for the flow circuits of that module and is called the "anchor box". The other bayonet pair is at the "expansion box". The expansion boxes contain axial deflection bellows to allow for thermal contraction of the flow circuits. Axial bellows were chosen due to space limitations.

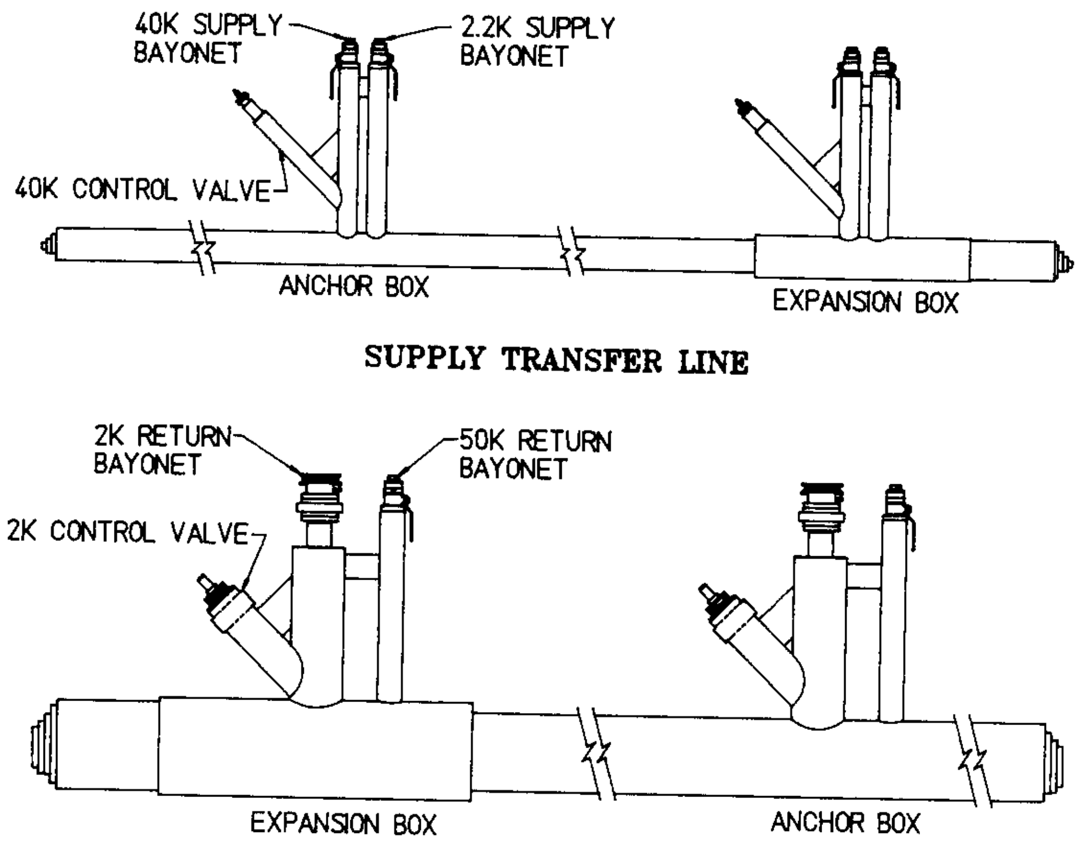


Figure 5. Linac transfer line standard modules

There are a total of twelve vacuum breaks in the linac TL's which divide the transfer lines into twelve separate vacuum spaces. Two vacuum breaks are located at each tee and one at each end of the "H". The purpose of the vacuum breaks are to:

1) Aid in installation.
2) Reduce time lost in troubleshooting
3) Reduce total heat leak if a small leak develops by allowing transfer line operation with vacuum pumps pumping on one segment of the line.
4) Allow operation of some sections of the line while other segments are not operational.

The design requirements of the TL are shown in Table 1 and are published in the CEBAF Specific Quality Assurance Plan, Transfer Lines. Table 2 shows the calculated heat leak of the linac transfer lines.

CTF TRANSFER LINES

The CTF uses three different transfer line cross sections (Figure 6) in two independent transfer lines (Figure 7) to supply four different locations in the test laboratory. The Test Lab Transfer Line is the Main line and supplies the Cryomodule Test Area through the Junction Box. The Vertical Dewar Transfer Line runs from the Junction Box to the Vertical Dewar Area. The CTF Magnet & Injector Transfer Line supplies the Injector Cave and the Magnet Test Area. This line is designed to have a LN_2 shield but has been used with a 40 K He gas shield for the injector testing.

END STATION REFRIGERATOR TRANSFER LINES

The ESR uses three identical transfer lines to supply the three experimental halls A, B and C (Figure 8). This transfer line called the End Station Magnet Transfer Line has a LN_2 shield and two helium supply and return circuits. One is a 4.5 K circuit with counter flow heat exchange. The other is 15 K circuit for target cooling and fast cooldown. Some of the End Station Magnets require very slow cooldown, so the ESR must be able to supply each hall with cryogens at different state points simultaneously. Therefore, a portable cooldown heat exchanger will be used to mix

Table 1. Design Requirements of Linac TL

1) The system shall require no dynamic pumping.
2) The bayonets must be in the correct locations to be connected to the cryomoduled with standard U-tubes.
3) Pressure rating of the circuits is as follows:

	SUPPLY	RETURN
2 K	19.7 bar	7.7 bar
SHIELD	19.7 bar	6.4 bar
VACUUM JACKET	4.9 bar	3.0 bar

4) Heat load of the lines must be less than 10% of the 4800 watt refrigerator capacity and less than 30% of the 12,000 watt shield capacity.
5) Pressure drop at full flow shall be less than 5% of the absolute pressure.

Table 2. Linac Transfer Line System Calculated Heat Leak

	Shield Load (watts)	2 K Load (watts)
CHL Supply TL's		
Radiation	110.0	1.8
G-10 spacers	35.0	1.0
Vacuum breaks	13.0	0.1
Expansion cans	22.0	0.1
U-tubes	3.7	3.7
Supply Header	17.0	2.8
SUBTOTAL	200.7	9.5
CHL Return TL's		
Radiation	285.0	0.3
G-10 spacers	156.0	3.0
Vacuum breaks	28.0	0.7
Expansion cans	58.4	1.1
U-tubes	3.7	21.6
Return Header	75.0	3.0
SUBTOTAL	606.1	29.7
Linac CHL Supply TL's		
Radiation	411.0	0.2
G-10 spacers	150.0	3.1
Bayonets & Valves	111.0	1.6
Supply U-tubes	19.1	19.1
SUBTOTAL	691.1	24.0
Linac CHL Return TL's		
Radiation	847.5	0.8
G-10 spacers	464.0	41.3
Bayonets & Valves	717.6	21.2
Return U-tubes	19.1	58.3
SUBTOTAL	2048.2	121.6
TOTAL	3546.1	184.7

300 K gas with 4.5 K liquid to a continuously variable temperature. To boost the capacity of the ESR a cross connect transfer line called the End Station Transfer Line (Figure 9) will connect the CHL to the ESR. It will supply up to 10 g/sec of supercritical helium continuously or 60 g/sec of liquid He for limited periods for cooldown. The ESTL has a LN_2 shield and supplies the refrigerator and the ESR Magnet TL's.

BAYONET DESIGN

Each end of all of the standard CEBAF U-tubes has one of six bayonet designs. The bayonets are designed to permit installation and removal under pressure (or vacuum) at cryogenic conditions without any contamination entering the system. There are four different size positive pressure bayonets to minimize heat leak and cost depending on the mass flow and pressure. There are two sizes of subatmospheric bayonets one for small flows and the other, a new design, to handle 118 g/sec at 2 K and .031 bar (one half of the refrigerator total 2 K flow). All of the bayonet designs

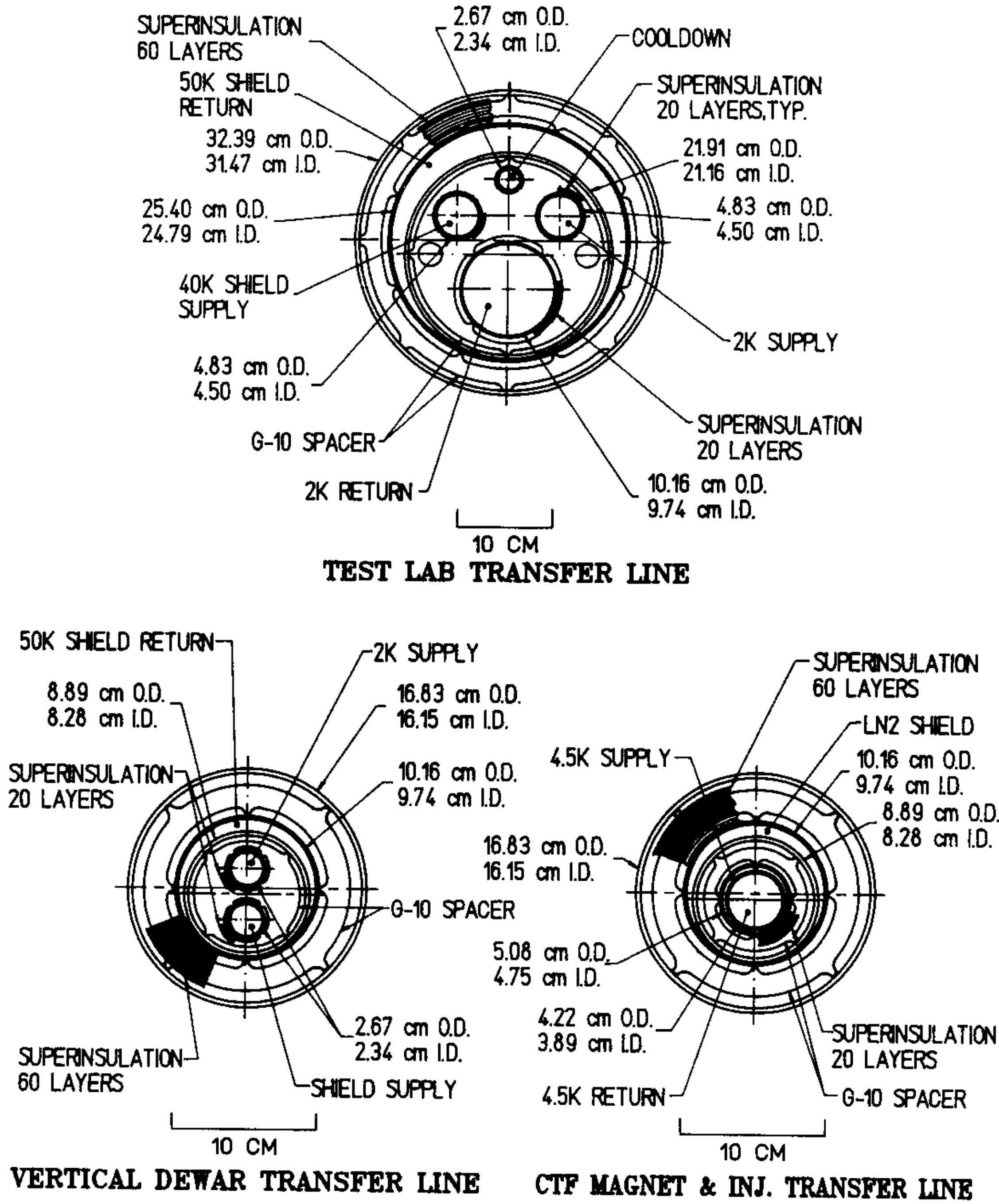


Figure 6. Cryogenic test facility transfer lines

have a labyrinth seal at the bottom to reduce the convection heat leak and prevent thermal-acoustic oscillations. They also use chevron seals at the top for temporary seals during U-tube installation and removal. The subatmospheric bayonets use a double chevron seal with 3 bar He injection to permit removal under vacuum conditions. A guard vacuum is used to protect the subatmospheric circuits from contamination. It separates the 0.031 bar helium from the atmosphere by a vacuum space between two O-rings.

The cryomodule shield supply, 2.2 K supply and shield return U-tubes all use the 3.8 cm positive pressure bayonet. The 2 K return U-tube is larger and uses the 7.9 cm subatmospheric bayonet (Figure 10). To make insertion of the linac U-tubes easier, each has a pair of expansion joints in the vertical legs to allow for minor misalignment.

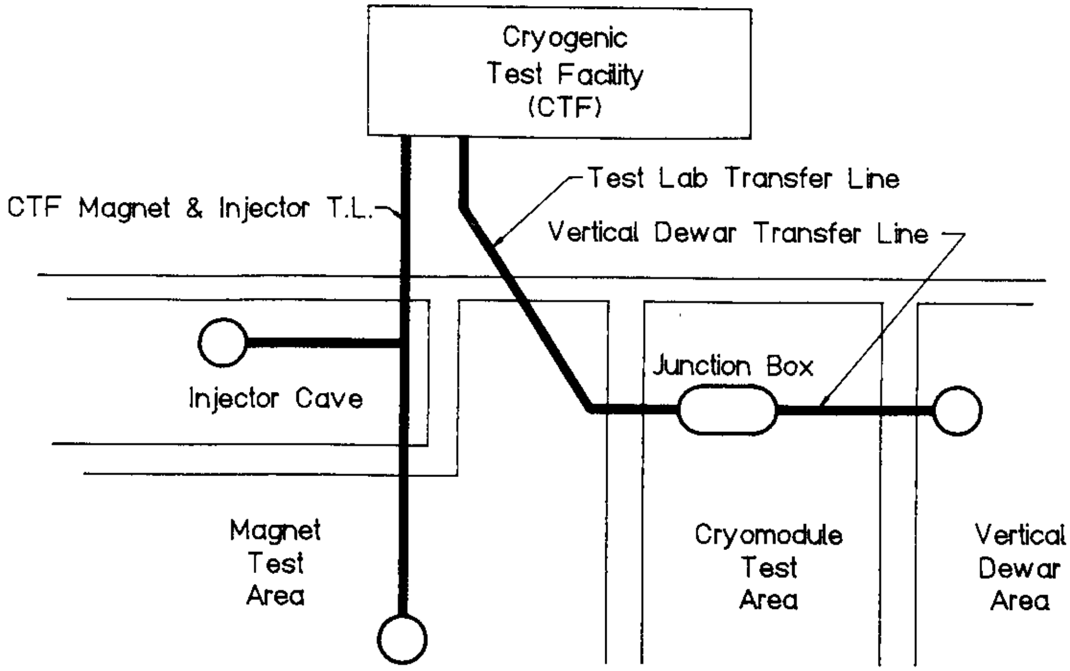


Figure 7. CTF distribution system

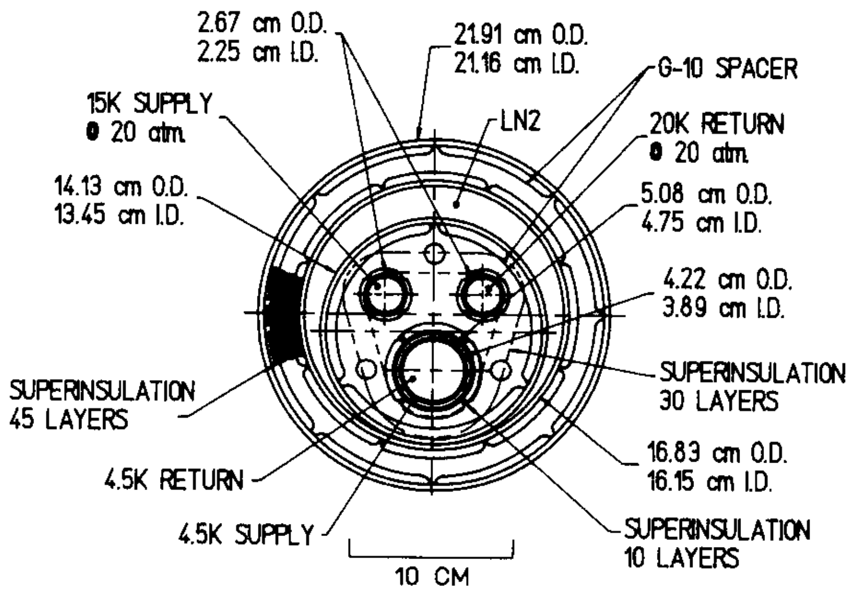


Figure 8. End station magnet transfer line

CONCLUSION

The wide variety of cryogenic requirements at CEBAF has created a complex system of refrigerators and transfer lines. Through the use of many different transfer line cross sections with bayoneted connections the CEBAF cryogenic systems can supply many users with a wide variety of cryogens at different state points.

ACKNOWLEDGMENTS

The author would like to thank M. Zarecky and D. Brown for their work in the design of the transfer line systems and also all the technicians who fabricated and installed the systems.

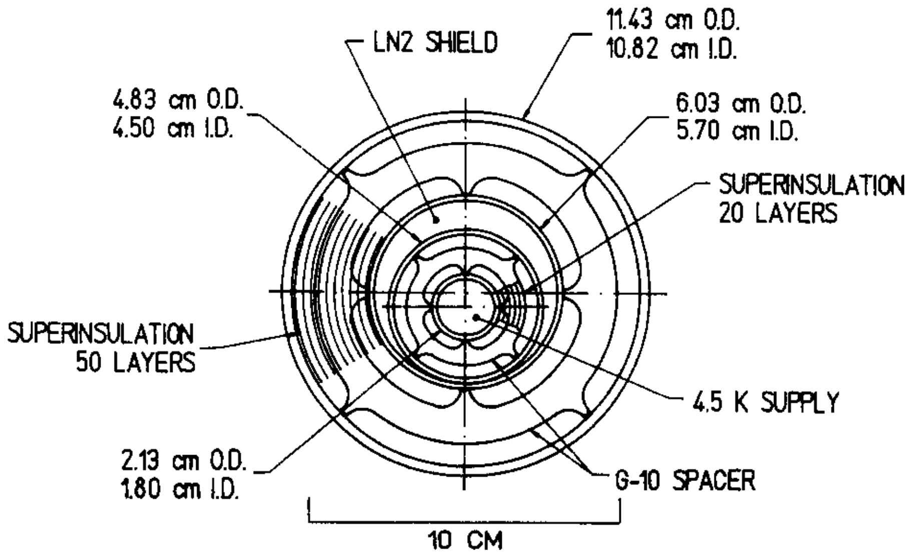


Figure 9. End station transfer line

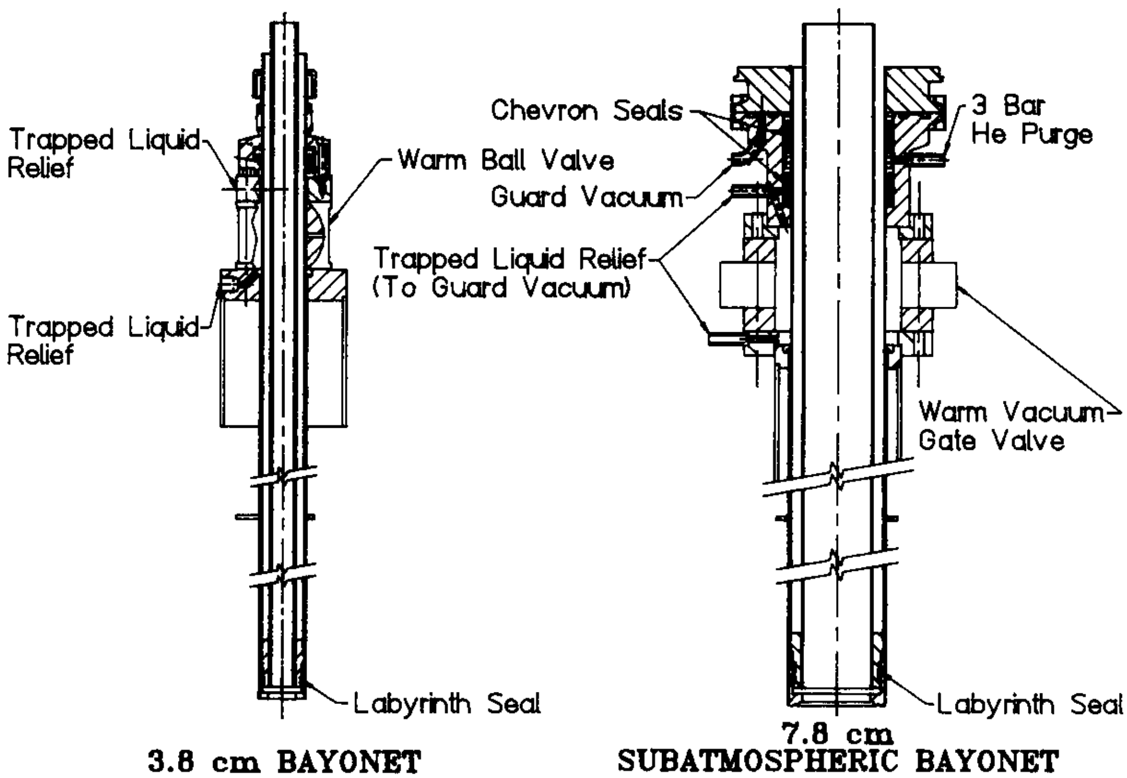


Figure 10. Linac standard bayonets

REFERENCES

1. C. H. Rode et al, 2.0 K CEBAF Cryogenics, in: "Advances in Cryogenic Engineering," Vol 35A, Plenum Press, New York (1990), p. 275.
2. D. Arenius et al, Commissioning and Operation of the CEBAF 2K Refrigeration System, in: " Proc. 1991 Cryogenic Engineering Conference," Paper GB-1.
3. C. Rode et al, Fermilab Tevatron Transfer Line, in: " Advances in Cryogenic Engineering," Vol 27, Plenum Press, New York (1982), p. 769.