NATIONAL RADIO ASTRONOMY OBSERVATORY
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Guidelines for the Design of Cryogenic Systems

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1.0 Introduction

The first elements in the signal path of a radio telescope contribute the greatest amount to the system noise temperature, and for this reason radio astronomy receivers are generally operated at cryogenic temperatures. In order to reach cryogenic temperatures, a vacuum chamber (Dewar) containing the receiver is evacuated to a very high vacuum, and a closed-cycle refrigerator is used to remove the heat. Thus, the cryogenic system is a crucial element governing a receiver's performance. When designing cryogenic systems, the designer is faced with conflicting requirements which require careful analysis to achieve optimum results.

Among the most important considerations are the performance of the refrigerator, *i.e.*, temperature reached and maintained, and the degree of vacuum achieved. Because vacuum levels are improved with the condensation of gases at the lower temperatures, and the convection loading is reduced with better vacuum, the vacuum and the refrigeration are interdependent and neither can be compromised. The cryogenic systems at NRAO often operate in the transition realm between ultra-high vacuum, $<10^{-8}$ torr, and high vacuum, $\sim10^{-8}$ Torr. In this realm, outgassing, due to lack of cleanliness and improper selection of materials, causes a degradation of vacuum over time. Also, the loading of the different stages due to radiation from the dewar walls, and the outgassing of materials inside the dewar are critical. All these quantities must be minimized.

Other important considerations in the performance of cryogenic systems are reliability and maintainability. Refrigerator selection, choice of materials for the vacuum chamber walls and internal components, fabrication techniques, cleaning procedures and evacuation procedures are important considerations affecting reliability. The purpose of these guidelines is to aid the designer in quantifying design parameters, improving the reliability and functionality by standardization, and documenting proper maintenance and cleaning procedures of cryogenic systems.

2.0 Refrigeration

In the past, at Green Bank, most of the cryogenically-cooled receivers were used for relatively short terms, *i.e.*, over periods of a few days to several weeks. Except for those receivers at the interferometer, the receivers were not required to operate continuously for periods over one year. However, with the advent of the GBT, receivers will be expected to run continuously for periods limited only by the mean time between failure (MTBF) of the refrigerators or for routine scheduled maintenance. Documentation from the manufacturer, the VLA site, and records here at Green Bank, show the MTBF for the different refrigerators to be as shown in Table 1. It is expected that a receiver remain cold for the length of the MTBF associated with the refrigerator being used, or for the normal scheduled maintenance period, which is typically one year.

TABLE 1.

Mean Time Between Failures and Refrigeration Capacity

REFRIGERATOR	**MTBF**			**CAPACITY, WATTS**	
	MANUFACTURER	**VLA**	**GREEN BANK**	**1ST STAGE**	**2ND STAGE**
MODEL 22	CTI	[1]8,400	[2]8,100	6.5 W @70K	0.8 W @15K
MODEL 350	CTI	[1]23,650	N/A	16 W @70K	2.5 W @15K
MODEL 1020	CTI	[1]10,750	N/A	38 W @70K	7 W @15K
UCH-130	LEYBOLD		N/A	105 W @70K	11 W @15

1. VLA Memo, March 1996, "MTTF Report on VLA and VLBA Cryogenic Refrigerators"
2. VLBA Memo 89, "CTI Model 22 Test Chronology"

2.1 Refrigerator Selection

Closed-cycle cryogenic refrigeration systems have been used at NRAO since the late 1960's. There are several companies manufacturing cryogenic refrigerators, but NRAO has purchased systems from only three of them: Cryogenic Technology Inc. (CTI), Waltham, MA; Leybold Cryogenic North America (formerly Balzers), Hudson, NH; and APD Cryogenics, Allentown, PA. Most of the refrigerators purchased in the past have been from CTI. However, more recently the Green Bank and Tucson sites have made purchases from Leybold Cryogenics. In general, the systems purchased from these two companies have performed reliably, with the exception of CTI's Model 22. On the other hand, the third company, APD Cryogenics, supplied refrigerators to the VLA many years ago; these proved to be unreliable and were replaced with CTI refrigerators. A representative from APD visited Green Bank recently and said that the problem they had with their systems was due to the compressors and that it had been corrected. The CTI Model 22 has proven to have unacceptable reliability and is difficult to maintain. Although the MTBF is approximately 8400 hours, the variance is quite large among refrigerators. The device was originally developed for short-term use and not for the way we have been trying to use it.

All of the refrigerators used at NRAO, both past and present, have operated on the Gifford-McMahon principle. Research is going on to develop better systems, *e.g.,* the pulse refrigerator which is supposed to minimize the number of moving parts and increase the reliability. Currently Gifford-McMahon seems to be the most practical for radiometer use. However, designers of cooled receivers should try to keep abreast of the newer systems and use them when they become practical.

2.2 Refrigerator Capacity Determination

To determine the capacity of the refrigerator required, the system designer must estimate both the conductive and radiation loading to be absorbed by the refrigerator cold head at both the first and second stages. A third heat load is due to the heat conducted from the dewar walls to the cold head by the residual gas inside the dewar (convection). This third component of heat load is negligible when the vacuum quality is good; therefore, it is not considered when estimating the total thermal load. However, if the vacuum quality is allowed to deteriorate, the load due to the convection mode of heat transfer may become the dominant component. Hence, the importance of obtaining high vacuum quality should be stressed during the design and operation of the system. Finally, any power dissipation due to active devices should be added.

2.3 Estimating Thermal Load Due to Conduction

Since the thermal conductivity of materials is in general variable with the temperature, to obtain an accurate estimate of heat transfer, the integral of the material's conductivity $\kappa(T)$needs to be obtained and applied as shown in the following equation:

$$H= \frac{A}{L} \int_{t_1}^{t_2} k \, dt \qquad (1)$$

where:

A = cross section area of the conducting element, cm^2
L = the conducting elements length, cm
k = the thermal conductivity, watts - cm^{-1} k^{-1}
T_1 = the colder temperature, K
T_2 = the warmer temperature, K

Since the integral of k between T_1 and T_2 is the area under the thermal conductivity curve bounded by the T_1 and T_2, the designer can simply estimate this area graphically. The thermal conductivity curves for different materials used in receiver design can be found in the NBS document, *Thermal Conductivity of Solids at Room Temperature and Below,* or other handbooks on cryogenics such as *Cryogenic Engineering*, R. B. Scott.

There are also computer programs available at NRAO which can be used for the more common materials and are probably the easiest way to estimate the conductive loading, providing the material in question is available in the program.

A program which calculates the heat transfer equation, along with other thermodynamic relations, is located at sadira/s/swhite/cryo/prgrams. However, the program was written by Ray Sarwinski in BASIC and only selection "A" will run. (Caution: Program used polynomial fit to K vs T curves, which gives gross errors for small temperature ranges.) To calculate heat transfer through solids:

1. Run gwbasic.exe
2. Load "crogeni.cs.cs"
3. Run
4. Select letter *A*

EXAMPLE: Determine the conductive heat transfer through a G-10 fiberglass rod whose length is 10 cm and whose O.D. = 1 cm and is connected at one end to a 70 K refrigerator station. The other end is attached to the 300 K dewar wall.

$$H=\frac{A}{L}\int_{T_1}^{T_2}\kappa\ dt=$$

$$A=\Pi r^2 = 0.785\ cm^2$$

$$L=10cm$$

$$\int_{70\text{K}}^{300\text{K}}\kappa\ dt = 8.80\ 10^2\ mw/cm$$

$$H=\frac{A}{L}\int_{T_1}^{T_2}\kappa\ dt = \frac{0.785\ cm^2}{10\ cm}\left[8.80\ 10^2\ mw/cm\right]= 69.1\ mw$$

NOTE: See Appendix 1 for Table of values over common temperature intervals for common materials. See Appendix 2 for example of thermal load calculation due to conduction by graphical estimation of thermal conductivity.

2.4 Estimating Thermal Load Due to Radiation

The net exchange of radiant energy between two surfaces is determined by the geometry of the two surfaces, their temperatures, and their emissivities at their respective temperatures. An exact value is difficult to obtain because of the geometry of most systems; however, the following equation is useful for making rough estimates of the radiation loading when sizing the refrigerator.

$$Q=\frac{\sigma A_1\ (T_2^4-T_1^4)}{\frac{1}{\epsilon_1}+\frac{A_1}{A_2}(\frac{1}{\epsilon_2}-1)}\ watts \qquad (2)$$

where:
Q = radiation heat transfer, *watts*
A_1 = area of inner surface, ft^2
A_2 = area of outer surface, ft^2
T_1 = temperature of inner surface, K
T_2 = temperature of outer surface, K
ϵ_1 = emissivity of the inner surface
ϵ_2 = emissivity of the outer surface
σ = 0.533×10^{-8} $watts/ft^2 - K$
Values of emissivity can be found in handbooks such as *Cryogenic Engineering*, R.B. Scott.

EXAMPLE: Determine the heat transferred by radiation from the walls of a stainless steel cylindrical dewar to a nickel-plated copper radiation shield, using equation 2, where the dimensions of the two devices are:

Stainless Steel Dewar: ID= 50.0 cm. X 50.0 cm. long
Nickel-plated copper radiation shield: ID=45.0 cm. X 45.0 cm. long

Determine A_1(radiation shield surface area): 7854.0 cm^2
Determine A_2(dewar inner surface area): 6361.7 cm^2

T_2=300.0 K
T_1=50.0 K

From Table on Emissivity of various materials:

$\epsilon_1=0.03$ for nickel-plated copper
$\epsilon_2=0.08$ for polished stainless steel

Substituting these values into equation 2 yields Q= 6.8 watts.

2.5 Estimating Thermal Load Due to Convection

Normally, the heat transfer by convection is negligible after the cold head has reached temperatures low enough to cause the gases within the dewar to condense (cryopumping). Typically, a good dewar will cryopump to a level of 10^{-7} to 10^{-8} torr, and at this pressure negligible heat is transferred by the residual gas. However, after many months of operation, the cryogenic surfaces will become coated with frost, the ability to cryopump will be diminished and the pressure will rise. The frost build up also increases the emissivity of the cold surface, thereby increasing the load due to radiation heat transfer. Also, hydrogen, helium, and neon, whose vapor pressures are relatively high at 15 K, will build up if the adsorber trap, whose function is to adsorb these gases, becomes saturated. When the pressure increases to 10^{-5} torr, the heat transfer due to convection will become significant. The temperature of the cold head will rise, causing more outgassing, and the pressure will rise even higher. This process will continue until the refrigerator warms up. The dewar should then be allowed to warm up and evacuated before cool-down is attempted again. The following equation gives the rate of heat transfer due to residual gas.

$$W = 2.426 \times 10^{-4} A_1 \frac{\alpha_1 \alpha_2}{\alpha_2 + \frac{A_1}{A_2}(1-\alpha_2)\alpha_1} \frac{\gamma+1}{\gamma-1} \frac{p}{\sqrt{MT}} (T_1 - T_2) \qquad (3)$$

with the accommodation coefficients $\alpha_w = \dfrac{T_i - T_e}{T_i - T_w}$

where: W = rate of heat transfer, *watts*
A_1 and A_2 = area (cm^2) of inner and outer walls,respectively
p = pressure, *microns*
T_1, T_2 = temperatures, K of inner and outer wall, respectively
T_i = effective temperature of incident molecules
T_e = effective temperature of reflected molecules
T_w = temperature of wall
γ = specific heat ratio, (C_p/C_v)
M = molecular weight of the residual gas.

By using this equation for typical values used in our systems, it can be shown that where $p \geq .01$ microns (10^{-5} torr) the heat transfer becomes significant.

2.6 Refrigerator Load Curves

Once the thermal load estimates are made for each stage of the refrigerator, these values may be plotted on the load curves (see Figure 1) supplied by the manufacturer. Normally, it is desirable to cool low noise amplifiers to 15 K or less. Plotting the estimated values on the load charts will show whether that particular refrigerator has sufficient capacity. Sometimes it is possible to shift loads between the two stages to achieve an optimum load distribution to give the desired temperatures. If this still does not provide enough cooling, a larger refrigerator should be selected. A margin of safety should also be considered, *e.g.*, select a refrigerator with twice the cooling capacity, if space and expenditures allow this.

3.0 Dewar Chamber Construction

Mechanical Strength Considerations:

Most dewar chambers are cylindrical, and the walls and end plates must be of sufficient thickness to withstand a pressure of 1 atmosphere (15 psi). The thickness of the cylindrical walls may be determined using the following equation:

$$P_a = \frac{k}{n} E(t/D)^3 \qquad (4)$$

where: P_a = atmospheric pressure, 15 psi
k = a correction factor found from Figure 3
E = is the modulus of elasticity, #/in^2 for the wall material
for stainless steel E = 2.77 x 10^7 #/in^2
for aluminum E = 1.05 x 10^7 #/in^2
D = the dewar diameter
t = the wall thickness
L = length
n = the safety factor (a typical value would be 4)

EXAMPLE: Determine the wall thickness of a stainless steel dewar whose diameter is 24 inches and whose length is 24 inches. A minimum safety factor of four is required.

1) Assume some standard thickness such as 0.100 in.

2) The length-to-width ratio, $L/D=\frac{24}{24}=1$ along with a $D/t=\frac{24}{0.1}=240$.

3) Using the data in step 2, a K factor of 48 is determined using equation (4), and solving for n yields a result of

$$n=\frac{k}{Pa}E(t/D)^3$$

$$n=\frac{48}{15}x\ 2.77x10^7(\frac{.1}{24})^3=6.41$$

Since $n>4$, the wall thickness is sufficient. A thinner wall thickness could be tried until the desired safety factor is obtained.

3.1 Circular End Plates

To determine the required thickness of the end plates, the following equation may be used.

$$Pp=\frac{256}{3(1-M^2)}\ \frac{E\cdot\ \delta\cdot\ t_1^3}{D_1^4} \qquad (5)$$

where: M is 0.3 for metals
E is the modules of elasticity, #/in^2
δ is the deflection at the center of the plate, in.
D is the plate diameter, in.
t_1 is the plate thickness, in.
Pp is atmospheric pressure, 15 #/in^2.

EXAMPLE: Determine the thickness of a 24-inch diameter stainless steel plate where the deflection is 0.01 in.

$$t_1 = \sqrt[3]{\frac{3(1-M^2)D_1^4}{256\,E\,\delta}}$$

$$t_1 = \sqrt[3]{\frac{3(1-0.3^2)24^4}{(256)\,(2.77x10^7)\,(0.1)}} = 0.234 inches$$

For aluminum, where E=1.05x10^7 #/in^2, t_1=0.323 in. or 38% thicker, but weight is reduced by a factor of 2.93.

3.2 Seals

There are basically two types of seals of concern in the construction of dewar chambers - metal seals and elastomer seals (o-rings). To minimize the effects of outgassing and permeation, metal seals should be used when practical. The most common types are conflat flanges, which are available in 12 different sizes ranging from 1-1/3 inch O.D. to 13-1/4 inches O.D. However, only the smaller sizes (up to 2-3/4 inches) are normally used in receiver dewar construction. This type of seal uses a non-reusable copper gasket. Typical places where this gasket is used are in mounting (1) roughing valves, (2) Vacion pumps, and (3) cold cathode ion gauge tubes.

3.3 O-rings

Where o-rings are required, the preferred material for vacuum use is butyl because of its low outgassing and permeability. Although nitrile (compound N6740-70) has been used in the past, its outgassing rate is almost 6 times that of butyl, and its permeability is no better than butyl.

To minimize the gas load contribution due to permeation and diffusion (outgassing), the number of o-rings and their diameters should be kept to a minimum. Table 2 gives recommended groove dimensions for different percent squeeze of the o-rings. To minimize permeation, at least 30% squeeze is recommended. Since o-rings are incompressible, the cross section of the groove (gland) should be slightly larger than the o-ring cross section or damage to the o-ring will result. The *Parker O-ring Handbook* is an excellent reference for determining available sizes and general information about o-rings.

3.4 Vacuum Grease

O-rings should receive only a very light coating of Apiezon Type L vacuum grease. The grease provides no sealing function, but is used only as a lubricant for the o-ring. Mention of vacuum grease application in books on vacuum stress not to use more than a very light coating of vacuum grease. There are several different types of Apiezon vacuum grease; however, Type L is recommended because of its low vapor pressure.

3.5 Roughing Valves

Types:

Several different valves have been used at NRAO in the past for evacuating dewar chambers. Butterfly valves, although previously used, have reliability problems and should be avoided. After reviewing literature on vacuum valves and talking to workers in the vacuum field, we have concluded that the right-angle bellows-sealed stainless steel valve is the most reliable valve available. The one manufactured by Varian, such as the 1-1/2 inch right-angle SST valve, P/N L659/1307, is of very good quality and is designed to work to 1×10^{-10} torr. One valve in common usage at NRAO is a diaphragm type solenoid valve made by Automatic Switch Company. However, this valve is rated to 10^{-6}

torr, which is a pressure well above the operational vacuum level of most dewar chambers (operational vacuum is normally in the 10^{-7} to 10^{-9} range), and it is not recommended for cryogenic dewar chambers. If a remote-operated valve is required, Varian's electromagnetic block valve, P/N L8724301, which operates to 10^{-9} torr, would be a good choice.

Sizes:

When open, a valve should have sufficient conductance to prevent undue reduction of the rough pumps effective speed. For example, a 1-1/2 inch valve (conductance = 46 l/sec), with a 2 foot by 1-1/2 inch I.D. hose, will reduce the pumping speed of the Tribodyne 30/120 from 20 cfm to 14.2 cfm. But if the valve and vacuum line are reduced to ½ inch and 3/4 inch respectively, as is the case in several receivers, the effective pumping speed drops to 1.75 cfm, increasing the pumping time by a factor of eight.

3.6 Charcoal Adsorber Traps

The typical operational cryogenic temperature range of most receiver dewar chambers is 12-25 K at the second refrigerator stage, and 50-100 K at the first stage. All gases in the atmosphere, except helium and hydrogen, become condensed at these temperatures due to the cryocondensation action of the refrigerated surfaces. The combined vapor pressures of the condensed gases and the partial pressures of helium and hydrogen at cool down yield a total pressure in the range of 10^{-7} - 10^{-9} torr in a typical cryogenic receiver dewar. The resultant pressure depends on the pumping speed of the cryogenic surfaces, the pumping speed of the ion pump (if one is used), the pumping speed of the charcoal adsorber trap due to the cryosorption mechanism, and the gas load. Those factors affecting the gas load magnitude are: (1) leaks to atmosphere, (2) virtual leaks (trapped air in cavities), (3) diffusion (gases dissolved in materials internal to the dewar that outgas), (4) permeation (atmospheric gases that travel from outside the dewar to inside the dewar by diffusion), (5) vaporization (molecules leaving the surfaces of internal dewar materials, (6) adsorption (atmospheric gas molecules that adhere to surfaces of the internal materials), and (7) the quantity of gas remaining in the dewar chamber after the rough pumping procedure is terminated.

At the normal operating pressures of 10^{-7} - 10^{-9} torr, insignificant heat transfer via conduction through gas occurs between the 300 K dewar walls and the refrigerated surfaces. However, since hydrogen and helium do not condense, and even though they are very small constituents of the atmosphere, with time, the partial pressure of these gases, along with the relatively high vapor pressure of neon, can cause vacuum deterioration to the point that the heat transfer by residual gas becomes a significant heat load on the refrigerator. This happens at pressures $>10^{-5}$ torr. How fast this pressure increase takes place depends on those factors mentioned above which determine the gas load.

Installing a charcoal trap on the 15° K second stage cryogenic surface reduces the number of free hydrogen and helium molecules. The activated charcoal, which is made from coconut shells heated to about 750° C, absorbs large quantities of hydrogen, helium, neon and other gases when cooled to temperatures near 15 K by a mechanism known as "cryosorption". Naturally, the more charcoal used, the longer cryosorption occurs. In most cases a trap whose charcoal surface area is about 50 square inches (a plate 5x5 inches, covered on both sides) is adequate for a year of cryosorption. The activated charcoal, Union Carbide JXC 6/8 Mesh, which was originally installed, is no longer manufactured. Calgon Carbon Corporation, X Trusorb 700, is currently available.

3.7 Charcoal Adsorber Construction and Installation

The adsorber panel geometry can have any configuration compatible with the other components in the dewar chamber. However, it should have adequate surface area so that at least 50 square inches of charcoal is available. When space is limited, the adsorber could be constructed similar to a finned heat sink. It is recommended that activated charcoal whose size is approximately 1/8-1/4 inch be bonded to 1/16 inch thick OHFC copper plate, cleaned for high vacuum use, with Torr Seal epoxy, which is specified to perform to 10^{-9} torr. To improve the bond between the charcoal, Torr seal, and the copper plate, the plate can be perforated with 1/32 inch diameter holes. The epoxy may be cured by heating to 60° C for two hours. Prior to bonding the charcoal to the copper plate, it is recommended that it be dried by heating in a vacuum oven overnight at a temperature of 400° C.

After the charcoal adsorber is constructed, it should be stored by wrapping in oiless aluminum foil until it is ready to be installed. Prior to installation, it is recommended it be baked at 120° C (the max temperature for cured Torr seal) overnight, and then immediately installed in the vacuum dewar. The time between installation and vacuum chamber evacuation should be kept to a minimum to keep the adsorber from becoming contaminated with water vapor from the atmosphere.

To facilitate maintenance of the adsorber trap, it is recommended that a thermostatically-controlled heater be installed on the copper plate to allow a low temperature bake-out be made whenever the dewar chamber requires evacuation. It is also suggested that a stainless steel tube be installed from the purging valve to a point close to the adsorber trap so that warm, dry nitrogen may be sprayed on the charcoal to help rid the charcoal of water vapor. The warm, dry nitrogen will also help remove water vapor adsorbed to other internal dewar surfaces. The nitrogen is warmed by a gas purge heater, obtained from CTI, which is installed in the nitrogen supply line.

It is also suggested that the trap be installed for easy removal, and that an identical trap be constructed for replacement when needed. This would allow the replacement of the traps with the spare that could be baked to 120° C. At this temperature, the trap would function more efficiently than one baked at the low temperature provided by the heater.

3.8 Materials for Dewar Construction

One of the most common metals used in vacuum use is stainless steel 304 (S/S-304). At pressures of 10^{-8} torr and lower, S/S-304 is widely used because it does not oxidize and can be heated to very high temperatures for bake-out to reduce the component of the gas load caused by diffusion (gases within the crystalline structure of the metal). Another reason for using S/S-304 is that it is easily electropolished, which provides a clean surface free of oxidation and contamination. Electropolishing minimizes the effective surface area and, in turn, the amount of gas captured on the surface by adsorption. Stainless steel is also easily welded with the (TIG) Tungsten Inert Gas (argon) method that is needed for producing vacuum tight welds for high and ultra-high vacuum operation.

One of the drawbacks of stainless steel is its weight. Where weight is of major concern, aluminum (whose specific gravity is 2.7, compared to stainless steel, whose specific gravity is 7.9), might be considered. Although the modules of elasticity of steel and aluminum are 2.77×10^7 #/in^3 and 1.05×10^7 #in^3, respectively, the extra thickness required for strength with aluminum is only 38% over what is required for stainless steel, but stainless steel weighs 2.9 times more than aluminum, allowing the weight to be at least cut in half. However, making vacuum tight welds with aluminum can be difficult, and additional thickness may be required to make the welded seams vacuum tight, with the result that the anticipated amount of weight reduction may not be achieved. Furthermore, aluminum is easily scratched and more prone to leaks at o-ring gland surfaces. If aluminum is chosen for the dewar chamber material, considerations might be given to having its internal surface polished and then electroplated with nickel to maintain a surface that won't oxidize and is easy to clean. The emissivity of nickel is constant (about 4% at 300 K); whereas, that for aluminum can vary from 3% to 75%, depending on the amount of oxide on the surface.

3.9 Materials for Radiation Shields

The function of the radiation shield (usually made of aluminum or copper) is to minimize the loading effects of the thermal radiation from 300 K dewar walls on the 15 K cryogenic surfaces. This is done by intercepting the thermal radiation on a thermally conductive enclosure which surrounds the 15 K cryogenic surface and is connected to the 70 K station. Thus, the radiation from the 300 K walls is captured and dissipated by the 70 K stage of the refrigerator, which has a much higher cooling capacity than the 15 K stage, thereby conserving the cooling capacity for the electronic components. However, the 15 K surfaces are radiated by thermal energy from the 70 K radiation shield, but the amount of irradiation is vastly reduced over what it would receive if there were no radiation shield.

To reduce the amount of radiation absorbed by the 70 K radiation shield and re-radiated by the shield to the 15 K surfaces, the material used for the radiation shield should have high conductivity at 70 K and low emissivity. The typical metals used are aluminum or copper, whose thermal conductivities at 70 K are approximately 2.5 and 5 watts-cm^{-1}-K, respectively. The emissivities of aluminum and copper can range between .018 to 0.7 for aluminum and 0.006 to 0.78 for copper, depending on the surface finish and oxide content. Because of this variability of emissivity with surface condition, and as an aid to maintain a clean, nonoxidized and highly reflective surface, it is suggested that the radiation shield be polished to a surface finish of 8μ in. or less and plated with an electroless nickel to a depth of .0005 inches (12 microns).

3.10 Vacuum Windows

The transition from the atmospheric pressure of the waveguide to the vacuum in the dewar requires a material with low electrical loss, low permeability to various gases and a low outgassing rate, while having the mechanical properties to withstand the 1 atmosphere pressure differential. Unfortunately, no single material possesses all the desired properties over a wide frequency range. Typically, a thin plastic film, with its low permeability to gases, is bonded to a low-loss foam material for strength. Mylar and the Hercules HR500/2S coated polypropylene packing film both have been used successfully (Electronics Division Internal Report No. 292 and Addendum #1). The polypropylene has a lower permeability to water vapor and comparable strength to Mylar.

The selection of foam depends upon the frequency range and, thus, the size of the window. Emerson-Cuming foam, Eccofoam PS 1.04, was tested and displayed good electrical properties as well as low outgassing rates. However, the foam was originally manufactured with CFC's, and the manufacturing technique has been changed, which increased the outgassing properties to unacceptable levels and has been found to be too lossy at millimeter wavelengths. A replacement for the Eccofoam is the expanded foam manufactured by Radva Corporation which is made out of ARCO Dylite beads. The Radva foam has comparable electrical properties, but the outgassing properties are unacceptable for windows on the order of tens of centimeters. Dow Corning manufactures a product called *bouyancy foam*, which has higher loss than the Radva foam but better outgassing properties. Another alternative is the Gortex RA-7957 expanded PTFE, which has excellent electrical and outgassing properties, but has only been recently used by the receivers at the 12 meter telescope (report in preparation). This foam should be considered for more applications as further results become available.

NOTE: Reference provides outgassing Data for various materials.

4.0 Flex Lines

Typically, compressors are located some distance from the refrigerators. The helium supply and return lines experience stresses from movement of the telescopes. The stresses are primarily from flexing, but sometimes twisting of the lines occurs. After several cycles of flexing and twisting, the jacket experiences fatigue and begins to leak.

From experiences with the 300-ft and 140-ft Telescopes, bronze type flex lines have proven to be superior to stainless steel where stresses are high. The traveling-feed receiver of the 300-ft flexed the lines over an approximate 3 inch bend radius, causing the stainless steel lines, which have a minimum bend radius specification of 8 inches, to last only one month. These lines were replaced with bronze lines, which have a 6 inch minimum bend radius specification, and lasted an average of one year. Experience with lines in the tail bearing of the 140-ft has dictated the use of bronze lines for longer life. Therefore, when selecting flex lines, the amount of stresses due to flexing and twisting must be considered.

5.0 Helium Line Fittings

In the past all helium lines, either rigid or flexible, were fitted with Aeroquip self-sealing fittings. These were good for disconnection, but occasionally leaked, especially in very cold weather. We now use a totally stainless steel compression fittings manufactured by Swagelok, which has proven to be very leak tight even at very cold temperatures. This type of fitting does not maintain pressure in the line when disconnected; therefore, they are only used on rigid lines where failures are extremely rare. We continue to use the Aeroquip fittings on flex lines that might possibly break, allowing the lines to be changed quickly without the loss of helium line pressure.

6.0 Compressor Selection

Presently, at Green Bank, two types of compressors supply pressurized helium to the cryogenic refrigerators. The older compressors are reciprocating, using piston and valve assemblies purchased from CTI and subsequently modified due to overheating problems. The piston type compressors are being replaced by rotary scroll compressors with either a 2.5 HP or 5 HP rating. The type and number of refrigerators operated from a particular compressor can be derived from helium mass flow rates of the compressors given in Table 3. The values for the CTI refrigerators are estimated since they will not divulge this information.

TABLE 3

Compressor Type	**Rating**	**Flow @ Pin**
Hitachi 250RHH	2.5 HP	25 scfm @ 84 psig
Hitachi 500RHH	5.0 HP	52 scfm @ 84 psig
CTI Piston 1020 (modified)	3.0 HP	44 scfm @ 84 psig

Compressor Capacities for use with CTI 1020 (35 scfm), 350 (15 scfm), 22(7 scfm) and the Leybold UCH-130 (52 scfm) refrigerators.

7.0 Cleaning Procedures - Vacuum Dewar

Proper cleaning of a vacuum dewar is the most critical step in having a good vacuum as opposed to having a great vacuum.

To clean a dewar properly takes several steps, each done methodically and thoroughly.

Step 1.

A dewar received from the machine shop is generally covered with cutting fluids. Therefore, it needs to be degreased first to remove these fluids, which may or may not be oil based. A good degreaser is tap water and any strong commercial detergent. If visible signs of contaminants remain, a solvent degreaser should be used.

Step 2.

After removing the outer layer of oil or other cutting fluids, the dewar needs to have the inner layers of contaminate removed. This is done best with a product called Citranox, a scouring pad, and a lot of scrubbing. After scrubbing, rinse with very hot tap water and follow with de-ionized water. Citranox is sufficient for systems with vacuums approaching 10^-9 Torr.

Step 3.

A final rinse with methanol will complete the cleaning procedure by removing the majority of surface water.

At this point care must be taken to prevent the dewar from becoming contaminated before it is assembled. If it is to be assembled immediately, no extra steps are needed; but if it will be a while before assembly, the dewar should be stored in an oven, clean work bench, or wrapped in oil-free aluminum foil.

Gloves should be worn to protect the hands during cleaning and to protect dewar during assembly.

7.1 Cleaning Procedures - Refrigerators/Compressors

Refrigerators and compressor parts are cleaned in a semi-clean environmen Petroleum ether effectively cleans grease laden components such as the bearings. A citrus cleaner, ADL enhanced for example, removes most contaminants from the displacers. The procedure is similar to that used cleaning dewars.

References:

[1] Childs, G. E., *et. al.*, "Thermal Conductivity of Solids at Room Temperature and Below," NBS Monograph 131, 1973.

Powell, R. L., and Blanpied, W. A., "Thermal Conductivity of Metals and alloys at Low Temperatures," NBS circular 556, September 1, 1954.

[2] Scott, R. B., *Cryogenic Engineering,* Van Nostrad, 1959.

[3] Ibid, p. 152

[4] Ibid, p. 146

[5] Kerr, A. R., et. als., "A Study of Materials for a Broadband Millimeter-Wave Quasi-Optical Vacuum Window," Electronics Division Internal Report No. 292, and MMA Memo No. 90, August 21, 1992, and Addendum #1 to both documents.

[6] Campbell, William A.,Jr., and Scialdone, John J., "Outgassing Data for Selecting Spacecraft Material," NASA Reference Publication 1124, Rev. 3, September 1993.

[7] A report on vacuum windows using GoreTex RA-7957 is in preparation.

Appendix 1

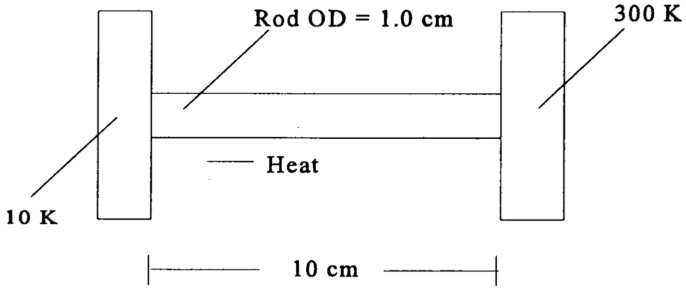
Thermal conductivity integrals of some common materials used in dewa construction.

MATERIAL	$\int_{15K}^{300K} K(t)$	$\int_{15K}^{300K} K(t)$	$\int_{15K}^{300K} K(t)$
Aluminum, 1100	7.12×10^5	5.25×10^5	1.87×10^5
Aluminum, 6061	4.18×10^5	3.62×10^5	5.58×10^4
Copper, pure	2.70×10^6	9.46×10^5	1.76×10^6
Copper, ETP	1.45×10^6	9.63×10^5	4.94×10^5
Bylerium Copper	1.503×10^5	1.38×10^5	1.20×10^4
304 Stainless Steel	3.08×10^4	2.82×10^4	2.61×10^3
G-10, Fiber Glass	9.77×10^2	8.80×10^2	9.75×10^1
Nylon	8.97×10^2	7.87×10^2	1.09×10^2
Teflon	6.97×10^2	5.91×10^2	1.06×10^2

Appendix 2

The following is an example showing how the thermal load due to conduction of a cryogenic component may be estimated, providing the component's thermal conductivity vs. temperature and its dimensions are known.

Determine the conductive load due to heat transfer from a 300 K heat sink to 10 K cryogenic station by a type 347 stainless steel rod whose O.D.=1.0 cm, and whose length is 10 cm.



1) Use graph H in Cryogenic Engineering, p.345, for type 347 stainless steel.
2) Since graph is presented in log form, re-plot in linear form as shown in Figure 1 using AUTOCAD.
3) Measure the area under the curve from 10 K to 300 K using the AUTOCAD command "area". In this case, the area measures 31164 mw/cm.
4) Estimated heat transfer is then

$$H = \frac{A}{L}\ [area\ under\ curve]$$

$$A = \pi R^2,\ where\ R = 0.5\ cm,\ L = 10\ cm$$

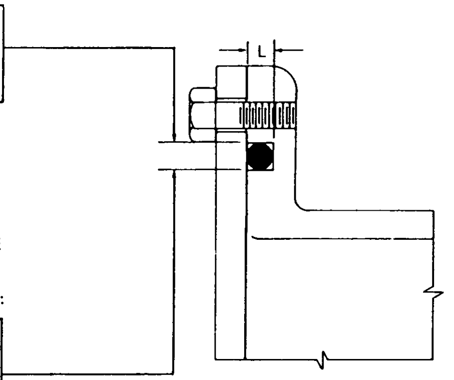
$$A = 0.785$$

$$H = \frac{0.785\,cm^2}{10\ cm}\ [31164\ mW/cm] = 2.446\ x\ 10^3\ mW$$

face seal glands

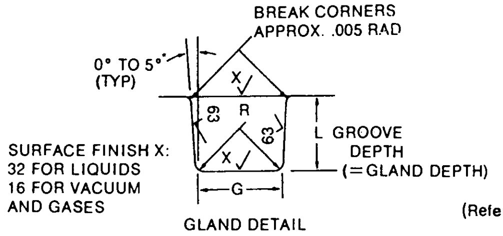
FOR INTERNAL PRESSURE
(outward pressure direction)
dimension the groove by its
outside diameter (H_O) and width:

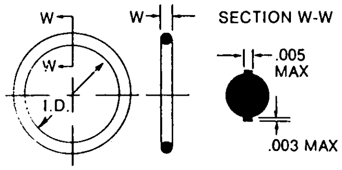
H_O = Mean O.D. of O-ring
(see Table A5-1)
Tolerance = Minus 1% of Mean
O.D., but not more than
–.060



FOR EXTERNAL PRESSURE
(inward pressure direction)
dimension the groove by its
inside diameter (H_i) and width:

H_i = Mean I.D. of O-ring
(see Table A5-1)
Tolerance = Plus 1% of Mean
I.D., but not more than
+.060.





(Refer to design chart A5-2 below)

DESIGN CHART A5-2

FOR O-RING FACE SEAL GLANDS

These dimensions are intended primarily for face type seals and low temperature applications.

O-RING SIZE PARKER NO. 2	W CROSS SECTION		L GLAND DEPTH	SQUEEZE		G GROOVE WIDTH		R GROOVE RADIUS
	NOMINAL	ACTUAL		ACTUAL	%	LIQUIDS	VACUUM AND GASES	
004 through 050	1/16	.070 ±.003	.050 to .054	.013 to .023	19 to 32	.101 to .107	.084 to .089	.005 to .015
102 through 178	3/32	.103 ±.003	.074 to .080	.020 to .032	20 to 30	.136 to .142	.120 to .125	.005 to .015
201 through 284	1/8	.139 ±.004	.101 to .107	.028 to .042	20 to 30	.177 to .187	.158 to .164	.010 to .025
309 through 395	3/16	.210 ±.005	.152 to .162	.043 to .063	21 to 30	.270 to .290	.239 to .244	.020 to .035
425 through 475	1/4	.275 ±.006	.201 to .211	.058 to .080	21 to 29	.342 to .362	.309 to .314	.020 to .035
Special	3/8	.375 ±.007	.276 to .286	.082 to .108	22 to 28	.475 to .485	.419 to .424	.030 to .045
Special	1/2	.500 ±.008	.370 to .380	.112 to .138	22 to 27	.638 to .645	.560 to .565	.030 to .045

*0° preferred

TABLE 4

FUNCTION	**COMPANY**	**PART NUMBER**
Purging	NUPRO	SS-4H
Vac-Ion Valve	Varian	L6591-307
Vacuum Pump	Vacoa	FD-ILS-62
DC Feed Thru	Detronics	DTIH-16-23
SMA Feed Thru	Omni Spectra	2084-8001-90

Suggested Dewar Components

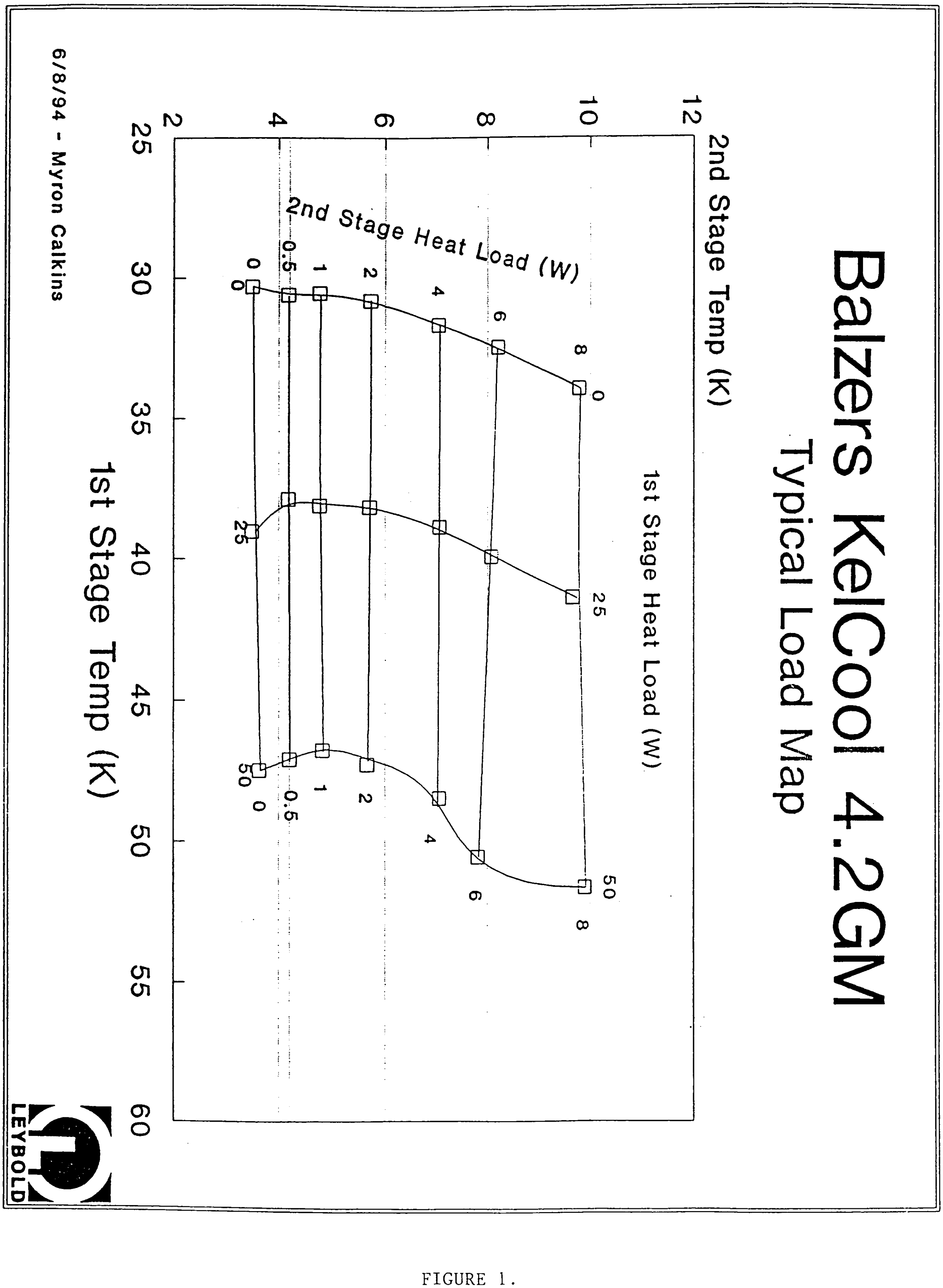

Balzers KelCool 4.2GM
Typical Load Map
2nd Stage Temp (K)
1st Stage Temp (K)
2nd Stage Heat Load (W)
1st Stage Heat Load (W)
2
4
6
8
10
12
25
30
35
40
45
50
55
60
0
0.5
1
2
4
6
8
25
50
6/8/94 - Myron Calkins
LEYBOLD

FIGURE 1.

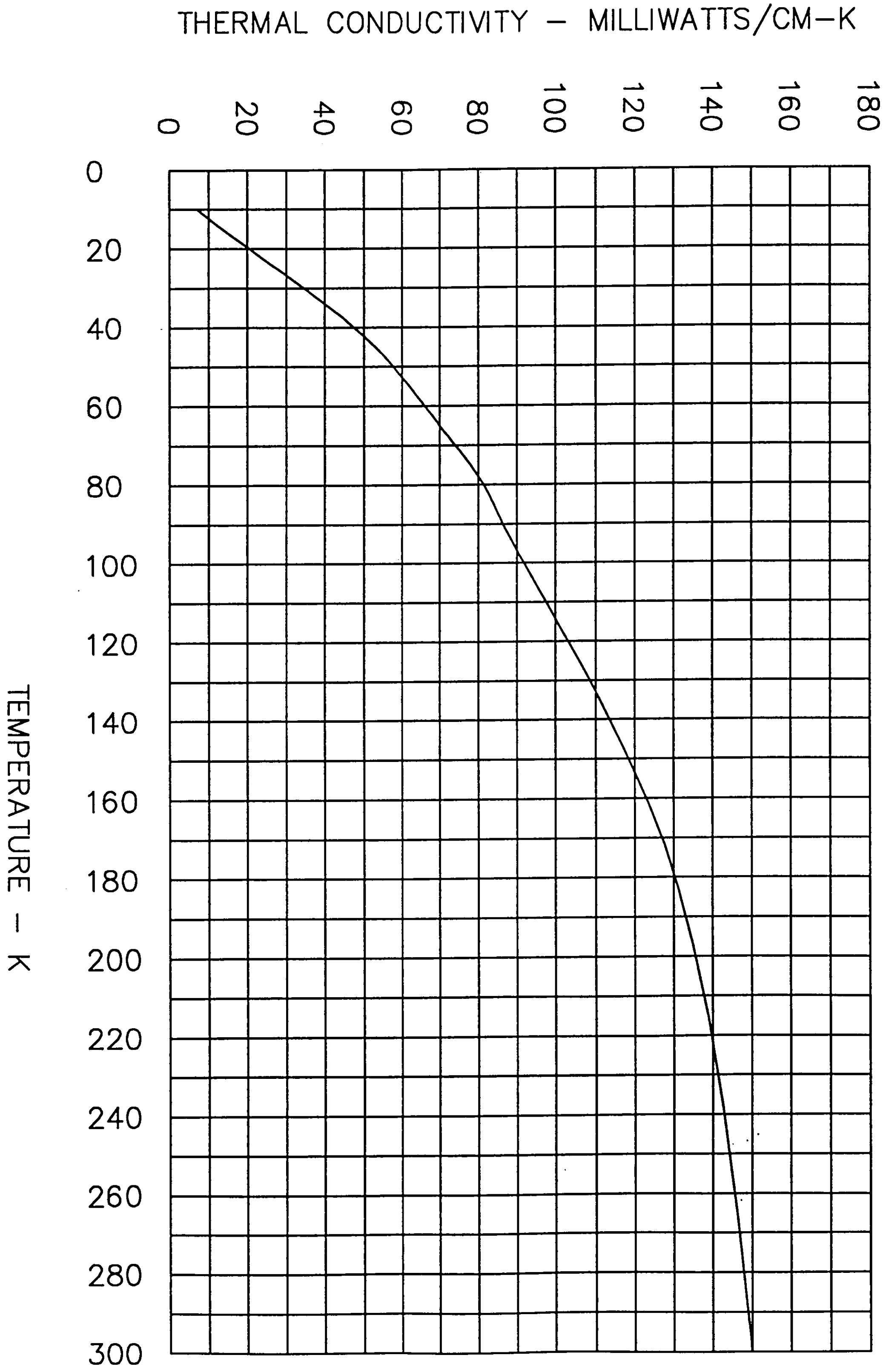


FIGURE 1. THERMAL CONDUCTIVITY OF TYPE 347 STAILESS STEEL. [1]

FIGURE 2.

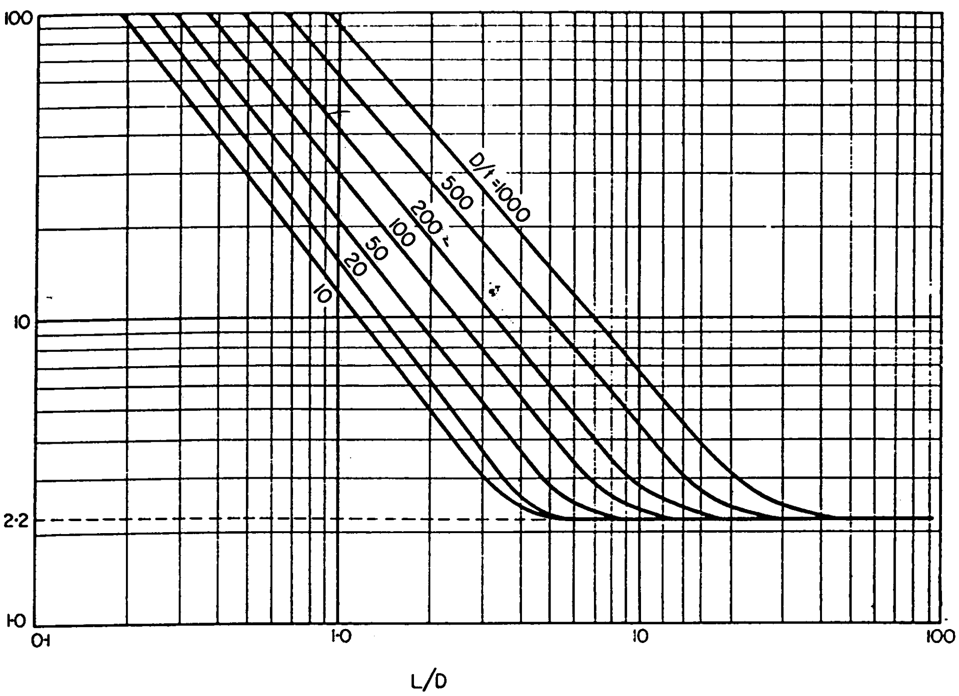


FIGURE 3.

rection factors for the calculation of the collapsing pressure cylindrical shells (after Strum[1209]).