Liquid Helium Heat Load Within the Cornell Mark II Cryostat

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The 7 main sources of heat loading LHe within the cryostat itself (no transfer lines) are:

1) RBT beampipe thermal transition,
2) FBT beampipe thermal transition,
3) Waveguide thermal transition,
4) Radiation from LN_2 shield to LHe vessel,
5) LHe boil-off gas cooling the waveguide thermal transition,
6) RF wall dissipation in the SRF cavity,
7) Radiation impinging from beamline apertures and waveguide duct.

Calculations of heat leak for items #1-3 were performed with a computer code that takes into account thermal and electrical conductivity variation with temperature. These results are presented below. Heat leak for item #7 has not been thoroughly addressed, but briefly discussed below.

1: RBT Beampipe Thermal Transition

The beampipe wall is comprised of 1.245 mm (0.049") thick stainless with the interior plated with 3.81 μm (150 μin) thick copper. The end attached to the LHe vessel is at 4.2K and the end attached to the vacuum vessel is at 300K. A copper ring indirectly cooled by LN_2 is welded to the beampipe 2/3 of the way from the LHe to vacuum vessel. Initially we assumed this ring was at 77K, but thermometers on the beampipe have shown it to be close to 100K.

Setting the copper ring at 100K, the static heat leak for the RBT Thermx is calculated to be 4.31 W. The additional heat due to image current of a 1.0 A beam is 0.10 W. The additional heat due to 5 kW of HOM RF power (1 GHz in TM_{01} mode) is 0.16 W.

The total calculated operational heat leak of the RBT Thermx with beam is then 4.57 W.

2: FBT Beampipe Thermal Transition

The FBT thermx is very similar to the RBT thermx, with the "flutes" approximately doubling the cross-sectional area. Thus, simply multiplying the RBT calculations by 2, the static heat leak for the FBT Thermx is calculated to be 8.62 W. The additional heat due to image current of a 1.0 A beam is 0.20 W. The additional heat due to 5 kW of HOM RF power (1 GHz in TM_{01} mode) is 0.32 W.

The total calculated operational heat leak of the FBT Thermx with beam is then 9.14 W.

3: Waveguide Thermal Transition (HEX)

The waveguide wall is comprised of 1.60 mm (0.063") thick stainless with the interior plated with 25.4 μm thick copper. The end attached to the LHe vessel is at 4.2K and the end attached to the LN_2 cooled waveguide "elbow" is taken to be 100K. There is a gas channel welded to the exterior of the waveguide thermx, into which 4.2K LHe vessel boil-off gas (item #5) is delivered during RF operation, thus referred to as a heat exchanger or HEX. The heat leak is quite sensitive to this gas flow rate. Original design stipulated a flow rate of 50 mg/s, but commissioning showed more stable cavity operation with 268 mg/s flow. Subsequent cryostats have better waveguide components and may not require such high flow. Considering the heat load introduced by the warm HEX gas (item #5), lower HEX gas flow (134 mg/s) will be investigated during Fall 1999 CESR operation.

With no cold He gas flowing through the HEX and no RF power, the static heat leak for the Waveguide Thermx is calculated to be 8.81 W.

With 50 mg/s cold He gas flow and no RF power the heat leak is 4.77 W.
With 134 mg/s cold He gas flow and no RF power the heat leak is 1.99 W.
With 268 mg/s cold He gas flow and no RF power the heat leak is 0.69 W.

With 50 mg/s cold He gas flow and 350 kW of RF through the waveguide the heat leak is 9.54 W.
With 134 mg/s cold He gas flow and 350 kW of RF through the waveguide the heat leak is 5.30 W.
With 268 mg/s cold He gas flow and 350 kW of RF through the waveguide the heat leak is 3.19 W.

The calculated conductive heat leak of the Waveguide Thermx with baseline conditions 134 mg/s cold He gas flow and 350 kW of RF through the waveguide is then 5.30 W.

4: Radiation from LN_2 Shield to LHe Vessel

The surface area of the LHe vessel exterior is approximately 4.1 m^2, including beampipe apertures. The radiative heat transfer from the LN_2 shield to the LHe vessel is then approximately $\sigma(T_{LN}^4 - T_{LHe}^4) \times$ Area, where $\sigma = 5.67 \times 10^{-8}$ W/m^2K^4 is Boltzman's constant. **This is then a heat leak of 8.2 W!** The Mark I Cornell cryostat included superinsulation between the LN_2 shield and LHe vessel. Meyer Tool omitted this superinsulation in the Mark II cryostat, erroneously thinking the radiative heat load was < 1 W. It may be wise to re-insert such superinsulation to save several Watts of radiative heat load.

5: LHe Boil-Off Gas Cooling of the Waveguide Thermx (HEX)

The LHe boil-off gas cooling the waveguide thermx is warmed to room temperature and returned to the refrigerator. A flow of 268 mg/s LHe = 2.14 ml/s of LHe = 185 l/day of LHe = 1.5 l/s of 273K He gas = 90 l/min of 273K He gas = 130 kl/day of 273K He gas. (The mass flow meter for HEX gas converts to STP). This He gas heat load on the Cornell refrigerator/liquifier with 268 mg/s HEX flow consumes 5.6 W for refrigeration and 22.4 W for liquifaction, or a total of 28 W.

The high 268 mg/s gas flow was required for the first Cornell cryostat for stable RF operation. However, subsequent cryostats have better waveguide components and may not require such high flow. From calculations in item #3, there would be a net refrigeration savings by lowering the HEX gas flow and depositing more heat in the LHe vessel rather than re-cooling warm He gas. **If the HEX flow is reduced to 134 mg/s, the heat load on the Cornell refrigerator/liquifier becomes 14 W.** If the HEX flow is reduced to 50 mg/s, the heat load on the Cornell refrigerator/liquifier becomes 5.2 W. Lower HEX gas flow will be investigated during Fall 1999 CESR operation.

6: RF Wall Dissipation in the CESR B-cell SRF Cavity

The CESR B-cell has a design $R/Q_o = V^2 / Q_o P_{wall} = 89$. Operating at $Q_o = 10^9$ and a gradient of 6 MV/m with an effective gap of 0.3 m gives 1.8 MV acceleration and $P_{wall} = 36.4$ W. However, 2 of 3 CESR B-cells have achieved only $Q_o = 5 \times 10^8$ which raises $\mathbf{P_{wall} = 72.8}$ **W**.

7: Radiation Impinging from Beamline Apertures and Waveguide Duct

It is expected that nearly all IR radiation along the beampipe simply passes through the cavity apertures unreflected. The few divergent IR rays that impinge on the cell are most likely completely reflected unattenuated by the highly IR reflective Niobium cavity.

IR radiation impinging from the waveguide duct is also most likely completely reflected unattenuated by the highly IR reflective Niobium waveguide coupler. The worse-case IR radiation impinging the coupler is launched by the exposed cross section of the ceramic window (251 cm^2) and the remaining cross section of 4" x 17" room-temperature waveguide (188 cm^2). The hottest possible ceramic window has a quadratic radial temperature profile with 80˚C at the center and 20˚C at the edge. The average ceramic temperature is then 60˚C. This gives a radiation power launched from the ceramic of $\sigma \times 333^4 \times 0.0251 = 17.5$ W. The remaining cross section of 4" x 17" room temperature waveguide launches $\sigma \times 293^4 \times 0.0188 = 7.8$ W. **The maximum IR radiation power impinging the coupler via the waveguide duct is then 25.3 W**. Most of this IR power is attenuated in the waveguide double-E-bend if it has even a slightly IR dull surface, as discussed in Ref. [1]. And as mentioned previously, the small IR power making its way to the waveguide coupler will most likely be completely reflected unattenuated by the Niobium surface.

Measurements of heat load in the Cornell Mark II Cryostat have been performed in several instances, the most reliable of which was during a recent warm-up of 3 cryostats installed in CESR in which the decreasing LHe levels were monitored with time. In this static condition there was no HEX gas flow and of course no beam or RF. The measurements yielded **E1 = 37.0 W**, **E2 = 34.5 W**, and **W1 = 31.0 W**, thus averaging **34.2 W**. (Note, the copper plating on the E2 HEX is about 4 times thinner (6.35 μm) than on E1 and W1, which did not reveal itself in these measurements by an expected heat leak reduction of 6 W). Future measurements will include HEX flow to see if the expected multi-Watt reduction in heat leak occurs with flow.

Table I summarizes the above calculated heat loads for operational and static conditions, with measurements to be compared to static conditions. Operational conditions were taken as: 134 mg/s HEX flow, 350 kW waveguide RF, 1.0 A beam, total of 10 kW HOM RF, cavity $Q_o = 5 \times 10^8$, and cavity V = 1.8 MV.

Table I. Calculated and measured liquid helium heat loads within the Cornell Mark II cryostat.

Heat Source	Operation [W]	Static [W]	Avg Measured [W]
RBT Thermx	4.57	4.31	—
FBT Thermx	9.14	8.62	—
Waveguide HEX Thermx	5.30	8.81	—
LN_2 Shield Radiation	8.2	8.2	—
HEX Gas Flow	14.0	—	—
RF Cavity Wall Dissipation	72.8	—	—
Total	**114.01**	**29.94**	**34.2**

[1] N. Jacobsen and E. Chojnacki, "Infra-Red Propagation Through Various Waveguide Inner Surface Geometries", Cornell SRF Note SRF990301-01 (1999).