# Notes about the Limits of Heat Transport from a TESLA Helium Vessel with a Nearly Closed Saturated Bath of Helium II

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## Introduction

A reduced-volume helium vessel for TESLA will be completely filled with helium II (superfluid) up through a short pipe to the 100 mm tube or its equivalent, which supplies the liquid. The concept is illustrated in figure 1. Heat is transported from the RF cavity through the helium, out the short vertical entry pipe, to the helium II surface in the 100 mm tube by the unique heat transport properties of superfluid. Unlike earlier plans which included a large liquid surface area in a larger vessel, the heat must be transported through the relatively narrower restriction of the vertical entry pipe. Experimental and theoretical studies of heat transport in helium II in circular channels have been reported which provide numbers for practical limits of the heat flux through helium II. Some of the relevant results are described here.

The bottom line for us is that in a geometry as shown in figure 1, we can conservatively figure that 1 W/ sq.cm. can be transported through the vertical entry pipe without bubble formation, and much higher heat fluxes (by about a factor of 10) if we allow some bubbling.

## Experimental results for heat transport.

Like heat transport in an ordinary material, heat transport in helium II occurs through a temperature gradient in the helium. Unlike ordinary materials, for which a thermal conductivity can be defined as the ratio of the heat flux to the temperature gradient, the apparent thermal conductivity of helium II is a strong function of the heat flux, varying approximately as the inverse of the heat flux squared (reference 1). Some nice correlations of heat flux, temperature difference, and length of a circular channel, are presented in reference 2, based on work done by the authors at CEA Grenoble. Although these are based on experiments with superfluid pressurized at one atmosphere, there is only a weak dependence of heat transport in superfluid on the pressure, so one can use the figures in reference 2 to estimate a maximum heat flux.

Unlike the case of pressurized superfluid studied at CEA Grenoble, where the limiting heat flux is determined by the transition to normal fluid when the temperature rises above the lambda point at the warm end of the channel, in saturated liquid the temperature rise at the warm end of the channel is limited by the boiling point of the liquid. Thus, the allowable temperature rise down our short vertical pipe (figure 1) is determined by the pressure of the liquid in that pipe. For example, consider a point 8 cm deep. The pressure due to the liquid head is 1.1 mbar more than the surface pressure. With the liquid nominally at 1.8 K, this 1.1 mbar corresponds to 0.018 K higher boiling point than at the surface. So the liquid at the depth of 8 cm could be 0.018 K warmer than the 1.800 K liquid at the surface.

From the charts in reference 2, one can calculate that the heat flux over a length of 8 cm with 1.818 K at the warm end (8 cm deep) and 1.800 K at the cold end is 1.4 W/ sq.cm. For different depths into the liquid, the effect of the different pressure and the different length to the surface cancel. Thus, the data from reference 2 imply a limiting heat flux of 1.4 W/ sq.cm. through our vertical pipe.

In a paper by D. Gentile and M. X. Francois (reference 3), the onset of bubble formation in superfluid (not at the surface of the heat source, but in the liquid at a reduction in the channel area) due to a high heat flux was directly observed and measured. They confirmed that bubbles occurred at a temperature corresponding to the local saturation temperature for pressures from 9 Torr (1.7 K) to the lambda point. The authors say that bubble formation greatly increases the efficiency of heat transfer in the channel and heat fluxes as high as 10 W/ sq.cm. can be maintained while bubbles are forming in the channel. However, the authors unfortunately do not explicitly say what the critical heat flux for the formation of bubbles was.

In another paper by the same authors (reference 4) it can be seen in one figure that the transition to boiling in a channel with 1.8 K saturated liquid helium occurs between 1.3 and 1.6 W/ sq.cm.

In an earlier review article, V. Arp (reference 5) presents a theoretical curve of the critical heat flux versus temperature (reproduced here as figure 2) and data which support it. The maximum heat flux without boiling in the range of 1.8 to 1.9 K is again 1.4 W/ sq.cm.

## Conclusions.

The limiting factor for what heat flux can be obtained through saturated helium II without bubble formation is that the highest temperature not exceed the boiling temperature at that depth in the liquid. Since the increased pressure (hence boiling temperature) at an increased depth compensates for the increased distance to the surface through which the heat must be transported, the result is a number for critical heat flux through a channel to the surface which is approximately independent of depth. Calculations and experiments in 1.8 K liquid give approximately 1.4 W/ sq.cm. as this limit.

Since there is variation in the data, and geometrical factors may affect the transport of the heat through helium II, I suggest that we use 1.0 W/ sq.cm. to conservatively estimate the heat that can be transported through our helium vessel entrance tube without bubble formation. If nucleate boiling is tolerable, then more like 10 W/ sq.cm. can be transferred.

Calculations for loss of cavity vacuum to air with a vent from the liquid supply tube to the 300 mm header at each interconnect indicate that a 70 mm outer diameter tube is more than sufficient where we had a 100 mm tube for the larger helium vessel. So suppose the drop into the helium vessel is 70 mm O.D. This would have about 32 sq.cm. area, permitting a heat flow without bubble formation of 32 Watts from one RF cavity. If we can tolerate some boiling, this port could carry at least 300 Watts.

**References.**

1. S.W. Van Sciver, "Heat Transfer in Superfluid Helium II," Proceedings of the 8th International Cryogenic Engineering Conference, Genova, 1980, pp. 228 - 237.

2. G. Bon Mardion, G. Claudet, and P. Seyfert, "Practical Data on Steady State Heat Transport in Superfluid Helium at Atmospheric Pressure," Cryogenics, January 1979, pp. 45 - 47.

3. D. Gentile and M.X. Francois, "Thermal Instabilities in an He II Channel," in Advances in Cryogenic Engineering, Vol. 27, 1982, pp. 467 - 474.

4. D. Gentile and M.X. Francois, "Heat Transfer Properties in a Vertical Channel Filled with Saturated and Pressurized Helium II," in Cryogenics, April 1981, pp. 234 - 237.

5. V. Arp, "Heat Transport through Helium II," in Cryogenics, April 1970, pp. 96 - 105.

Figure 1

Additional Tube for Helium Gas Warmup
in a Reduced Inventory Helium Vessel
with 100 mm Tube Directly above Vessel

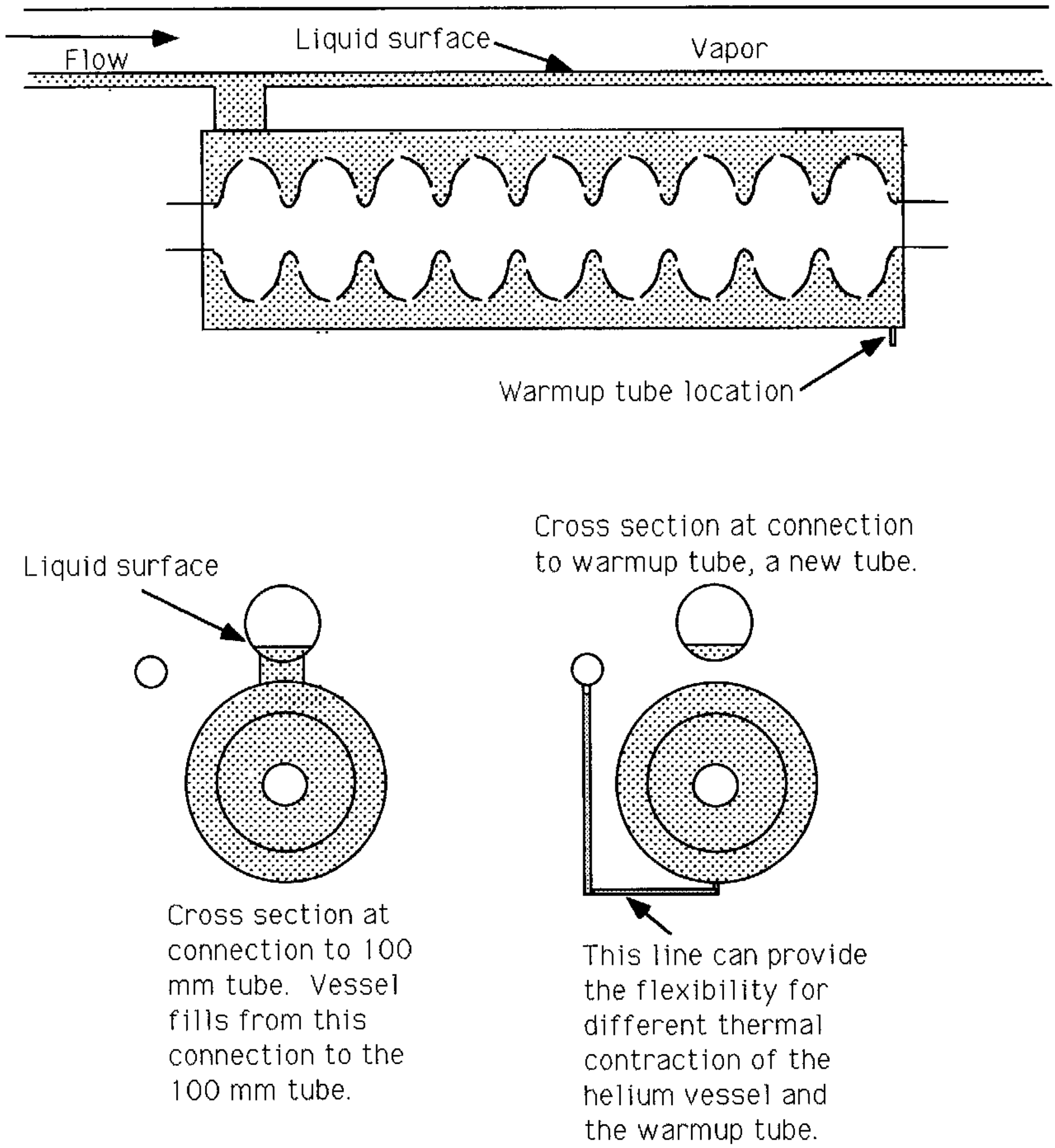

Figure 2

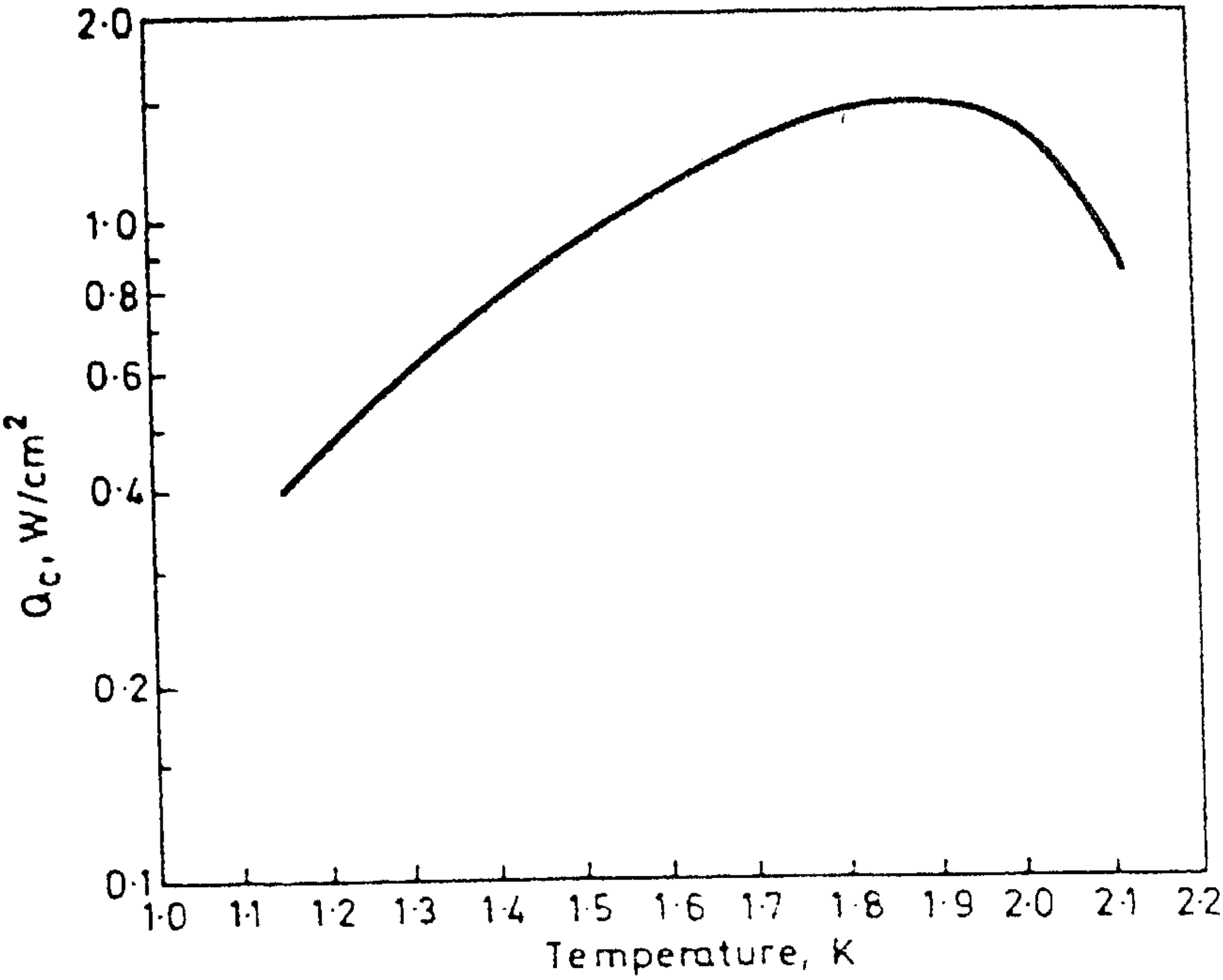


Figure 8. The critical thermal flux above which vapour formation may occur with He II

From V. Arp, "Heat Transport through Helium II," Cryogenics, April 1970.