HORIZONTAL DILUTION REFRIGERATOR
FOR USE IN INTENSE PROTON BEAMS

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ABSTRACT

A fast loading high-power horizontal dilution refrigerator insert has been built for use in the Michigan Polarized Proton Target (PPT V). This PPT will be used in measurements of spin effects in high P elastic p-p scattering at the Brookhaven AGS. The cooling power is compared with the existing interchangeable 3He evaporation insert, and with similar dilution refrigerators at CERN and Bonn. The relative merits of these two types of refrigerators in absorbing the heat loads of high intensity beams is discussed.

INTRODUCTION

The construction of high-power fast-loading\textsuperscript{1,2} interchangeable\textsuperscript{1} dilution refrigerators has been completed at several laboratories. The emergence of NH\textsubscript{3} as a radiation resistant target material\textsuperscript{3,4,5,6} has shifted the limiting factor in beam intensity from target materials to bead cooling. Arguments previously advanced\textsuperscript{7,8} suggest that the dilution refrigerator possesses a great advantage in this respect.

EVAPORATION VS. DILUTION

The performance of the three comparable dilution refrigerators (Fig. 1) is quite similar. The maximum cooling power is much less than that of the U of M 3He refrigerator. Also shown is the performance of a hypothetical dilution refrigerator, whose maximum cooling power is equal to that of the 3He refrigerator. It is seen (Fig. 2) that the calculated\textsuperscript{7,8} bead temperature (for 1.5 mm dia. beads) is a strong function of heat load for the 3He refrigerator, and surprisingly independent of maximum cooling power in the case of the 3He/4He refrigerator. In transforming the $Q_{\text{total}}$ of the lower scale in Fig. 2

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to protons per second in Fig. 3
the target mass was taken to be
10g for the $^3$He/$^4$He refrigerator
and 17g for the $^3$He refrigerator,
and $\mu$ wave heating 0.5 mwatt/g to
the beads. A Gaussian beam
profile is assumed with 95% (2$\sigma$)
of the beam in the target. Using
the calculated $T_{\text{beads}}$ of Fig. 2
it is possible to extrapolate a
target polarization $P = \tanh (E_{\text{enh}}$
$\mu B/kT)$. The numerical value of
the enhancement factor $E_{\text{enh}}$ is
found to be 237 by assuming 50%
proton polarization in a $^4$He
evaporation refrigerator with
1.1K bath (and bead) temperature.
Conversely, for thermal
equilibrium conditions $E_{\text{enh}}$=1
and bead temperature may be
calculated from the above
relation after measuring $P$
(the so-called 'inverse thermal'
technique).

\[ Q_{\text{TOTAL}} = Q_{\text{BEAM}} + Q_{\text{BEADS}} \]

\[ Q_{\text{TOTAL}} = \frac{Q_{\text{BEAM}}}{2} + Q_{\text{BEADS}} \]

Fig. 2
Bead Temperature vs
Internal Heating

Fig. 3
Target Polarization
vs. Beam Heating

Fig. 4
Viscous Heating in
the Concentrated Stream
CONCLUSION

While it appears that the $^3$He/$^4$He refrigerator is much more effective in cooling the beads, a direct measurement of relative bead temperatures has not yet been made. It should be possible to do this incidental to the operation of UM AGS experiment E748 in early 1983.

APPENDIX

The literature abounds with analyses of the operation of dilution refrigerators in the range 0-100 mK. The region 100-800 mK has received much less attention. In particular, viscous heating in the concentrated stream (Fig. 4) can be surprisingly large$^9$. These results are calculated for the as-built UM $^3$He/$^4$He refrigerator. Most of this heat load falls upon the excess enthalpy of the dilute stream rather than the mixing chamber$^{10}$, and the available cooling power is probably only slightly diminished.

![Graph showing target polarization vs. beam heating](image)

**Fig. 5 - Target Polarization vs. Beam Heating**

**NOTED ADDED IN PROOF**

It has been proposed$^{11}$ to combine the advantages of the two types of refrigerators in the subcooled $^4$He technique. The device described in the Yale-SLAC proposal would use a conventional $^3$He evaporation refrigerator and a heat exchanger to cool the $^4$He bath.

Figure 5 shows the performance of a device in which the cooling power of the $^3$He evaporation refrigerator of Figure 1 has somehow been used to subcool a $^4$He bead bath. The beam heating at $10^{11}$ protons per second corresponds to the 150 mw of cooling power shown in Figure 1.
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