RHEL/R 236

RHEL/R 236
Rutherford Laboratory Report

NAL LIBRARY
MAR 31 1972

Continuous Refrigeration at 1.8°K in Laboratory Cryostats using a 4.2°K Liquid Helium Dewar Supply

W T Smith

Science Research Council

Nimrod Design Group
Rutherford High Energy Laboratory
Chilton Didcot Berkshire
1971

Available from HMSO
price 13p net

SBN 90237627 6

RHEL/R236

SCIENCE RESEARCH COUNCIL

CONTINUOUS REFRIGERATION AT 1.8°K IN LABORATORY CRYOSTATS USING A 4.2°K LIQUID HELIUM DEWAR SUPPLY

W T Smith

ABSTRACT

The production of 1.8°K liquid using 4.2°K liquid from the standard helium dewars incurs large liquid losses. The proposed scheme considerably reduces these losses and can provide continuous refrigeration in the region of 1.8°K for laboratory cryostats. A potential 45% improvement in 1.8°K liquid production is feasible.

Nimrod Design Group
Rutherford High Energy Laboratory
Chilton Didcot Berkshire
October 1971

CONTENTS

		Page
1.	Introduction	1
2.	Theoretical Consideration	1
3.	Low Temperature Liquid Trap	2
4.	Continuous Refrigeration	2
	(a) Operational problems	2
	(b) Proposed Scheme	2
	References	3
	Acknowledgements	3
	Illustrations	
Fig.1	Temperature v Entropy diagram for helium showing isenthalpic expansion	4
Fig.2 (a)	Enthalpy v Temperature diagram for helium liquid at 1 atm.pressure	5
Fig.2 (b)	Enthalpy v Temperature diagram for helium vapour at 12.5 Torr pressure	5
Fig.3	Diagram showing calculated increase in liquid production v sub-cooled temperatures	6
Fig.4 (a)	Diagram showing potential sub-cool temperature v size of heat exchanger	6
Fig.4 (b)	Diagram showing potential increase in liquid production v size of heat exchanger	6
Fig.5	Typical cryostat and dewar assembly	7

1. INTRODUCTION

Low temperature environment in the region of 1.8°K in laboratory cryostats is usually achieved by the evaporative refrigeration of liquid helium. Rotary vacuum-type pumps are used to pump off the vapour until the required vapour pressure and associate temperature is reached. In a typical cryostat about 50% of the initial liquid fill would be lost in evaporation during this process of cooling from 4.2°K to 1.8°K and thus at best only 50% is available for experiment at 1.8°K. For longer experimental periods the low temperature liquid can be replenished by feeding 4.2°K liquid through a transfer pipe and control valve direct into the low pressure cryostat where it expands isenthalpically to produce a mixture of vapour and liquid at the lower temperature. During this second process about 50% of this feed liquid is lost in producing additional expansion vapour and to maintain a comparable refrigeration load, the vapour pumping capacity would need to be doubled. The filling scheme proposed will give a considerable increase in potential 1.8°K liquid production and also a proportional decrease in expansion vapour, from a 4.2°K liquid helium dewar supply. Further this scheme can be operated with a supply dewar changeover method to give a continuous refrigeration facility. Calculation shows that an increase of greater than 45% in liquid production at 1.8°K is feasible.

4.2°K liquid from a supply dewar is fed through a transfer pipe into a heat exchanger in the cryostat, where it is sub-cooled using the sensible heat of the low temperature vapour. This sub-cooled liquid is then expanded through a variable Joule-Thompson control valve and the resultant liquid vapour spray is finally directed through a liquid separator unit.

2. THEORETICAL CONSIDERATION

From helium data it can be seen that when 4.2°K liquid helium at 1 atmosphere is expanded isenthalpically to 12.5 Torr it converts to 41% vapour and 59% liquid at 1.8°K. If however this 4.2°K liquid is first sub-cooled to say 2.4°K and then expanded to 12.5 Torr it converts to 13% vapour and 87% liquid at 1.8°K. Thus we have a 47% increase in 1.8°K liquid production by sub-cooling to 2.4°K along with only 33% of the volume of unwanted vapour. This is shown on Temperature - Entropy diagram, Fig.1.

The value of sub-cooling before expansion is summed up by the graph Fig.3, where the potential increase in cooled liquid production is plotted against the sub-cooled temperature.

Calculation using the available helium data shows that a tubular heat

exchanger design is feasible. Fig. 2a and 2b show this data, i.e.temperature -enthalpy for liquid Helium at atmospheric pressure 4.2°K to 2°K and also for vapour at 12.5 Torr 1.8°K to 4°K. It is noted that the specific heat of the vapour is greater than the liquid in the region concerned thus sub-cool temperatures lower than the arithmetic mean are possible in the heat exchanger design. The effect of the heat exchanger size on the attainable sub-cool temperature is shown on Fig 4 (a) (as calculated for a typical tubular coil design heat exchanger). Fig.4 (b) is derived from Figs. 4 (a) and Fig.3. It gives a measure of the potential increase in refrigeration efficiency (i.e. increase cooled liquid production) achievable by varying the size of the sub-cooling heat exchanger.

3. LOW TEMPERATURE LIQUID TRAP

The liquid produced from the Joule-Thompson valve forms a very fine particulate spray and must be trapped before it "floats off" to warmer parts of the cryostat to be evaporated and lost. The liquid-vapour spray is directed through a filter of fine glass fibres where it will coagulate to form droplets and so fall into the helium liquid well.

4. CONTINUOUS REFRIGERATION

(a) Operational problems

When the cryostat cool-down load is large or when extended experimental time is needed, the use of more than one supply dewar is inevitable. A straight dewar changeover has operational difficulties, it incurs large refrigeration losses and interrupts the experiment. During the dewar changeover the exposure of the cooled transfer ports to the ambient air creates conditions for cryo-pumping and frozen moisture and air can readily build up to choke the cold inlet pipes and control valves. When the replacement dewar is assembled, further time is needed to re-establish the refrigeration temperature condition for the experiment to continue.

(b) Proposed Scheme

The following scheme is proposed to solve operational difficulties and to produce 1.8°K refrigeration without interruption during a supply dewar changeover period, i.e. continuous refrigeration.

A 'slave' supply dewar is permanently connected to the cryostat via a liquid transfer pipe. A second transfer port and suitable level censors fitted in the slave dewar allows it to be filled and 'topped up' at any time from a normal supply dewar. The capacity and filling times of the slave dewar are chosen so that it does not run dry - especially during the changeover of an empty

supply dewar. In this way a constant supply of $4.2^{\circ}K$ liquid is given to the cryostat. The variable liquid level and the slight pressure changes in the slave dewar during the supply dewar changeover period causes only a slight variation in the flowrate of the cryostat control valve. An attractive alternative to the slave dewar is to have an equivalent $4.2^{\circ}K$ liquid container built in to the cryostat. Fig. 5 shows a typical assembly.Transfer pipe losses are saved and the same benefits and system still apply.

The provision of a bleed of helium gas into the exposed cold transfer ports, to prevent the ingress of ambient air and moisture, will virtually remove the cryo-pumping hazard. This transfer port connection is also used to purge the transfer pipe and exhaust the surplus helium gas that is created each time the transfer pipe is re-cooled in order to re-establish the $4.2^{\circ}K$ liquid flow.

REFERENCES: Helium 4 data: N.B.S. Report 9762 - Aug.1970.

ACKNOWLEDGEMENTS: The Author is very grateful for the help and encouragement given by D A Gray, A R Mortimer and A T Gresham.

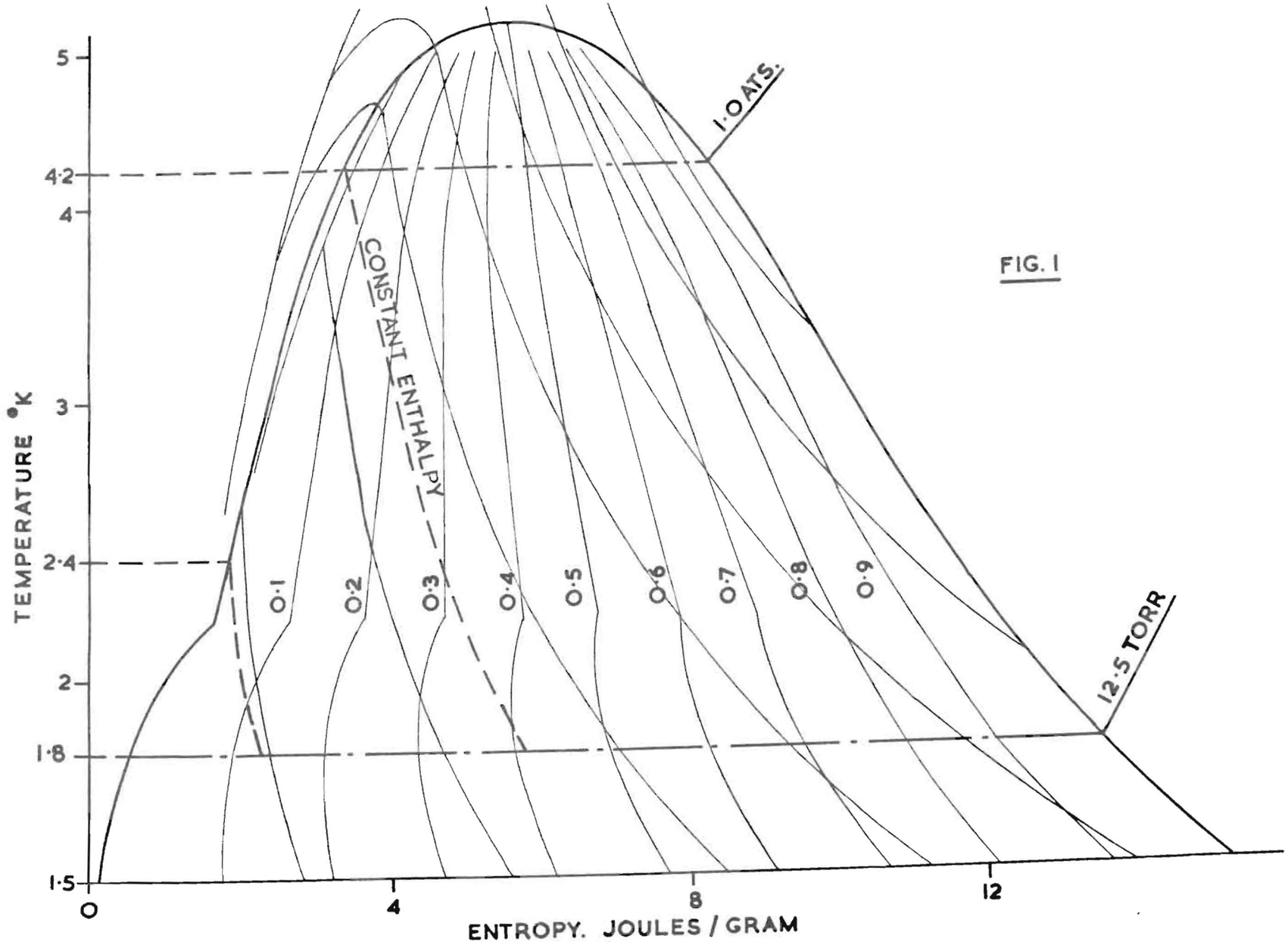
TEMPERATURE °K
5
4·2
4
3
2·4
2
1·8
1·5
0
4
8
12
ENTROPY. JOULES / GRAM
1·0 ATS.
12·5 TORR
CONSTANT ENTHALPY
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9

FIG. 1

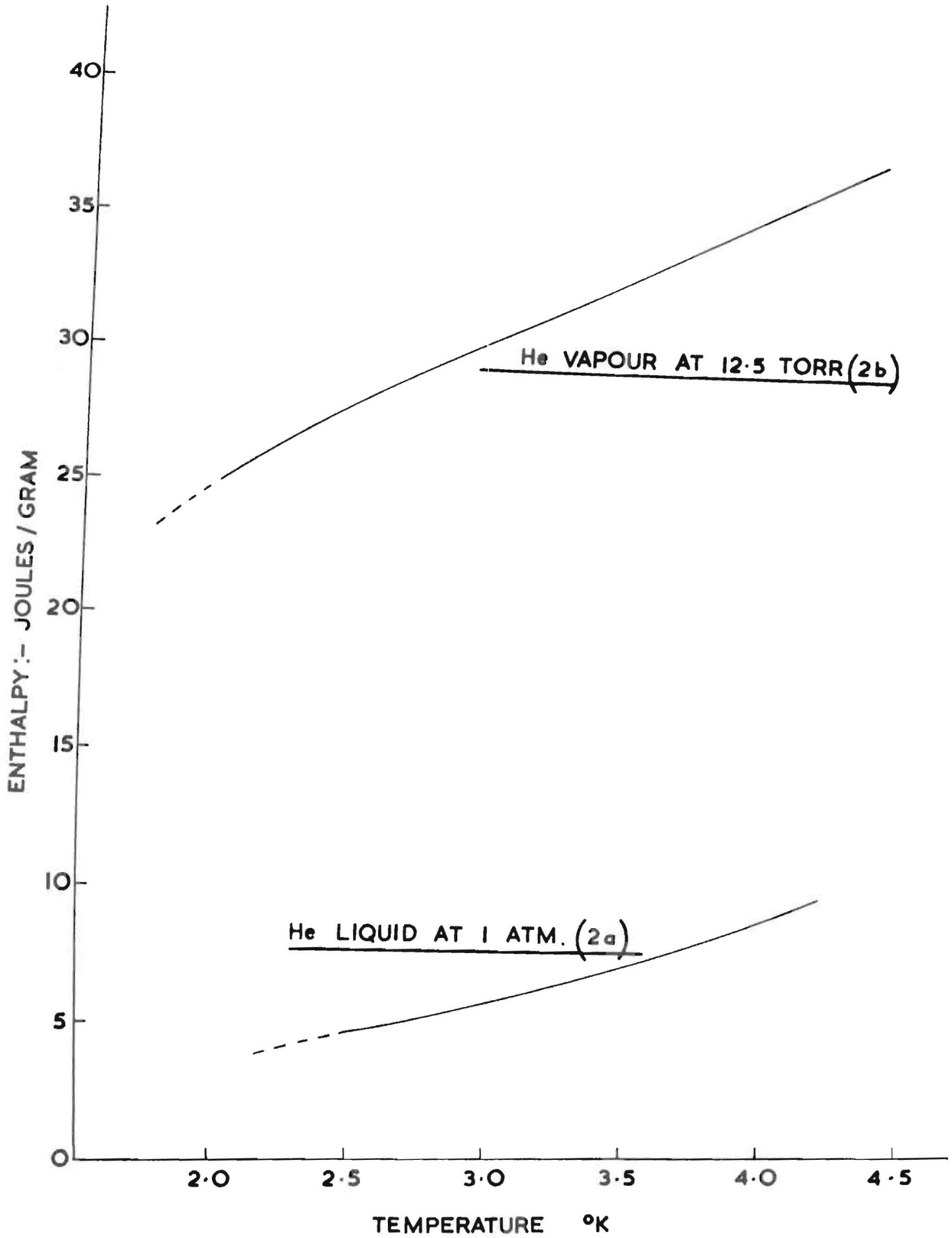
40
35
30
25
20
15
10
5
0
ENTHALPY :- JOULES / GRAM
He VAPOUR AT 12·5 TORR (2b)
He LIQUID AT 1 ATM. (2a)
2·0
2·5
3·0
3·5
4·0
4·5
TEMPERATURE °K

FIG. 2a & 2b

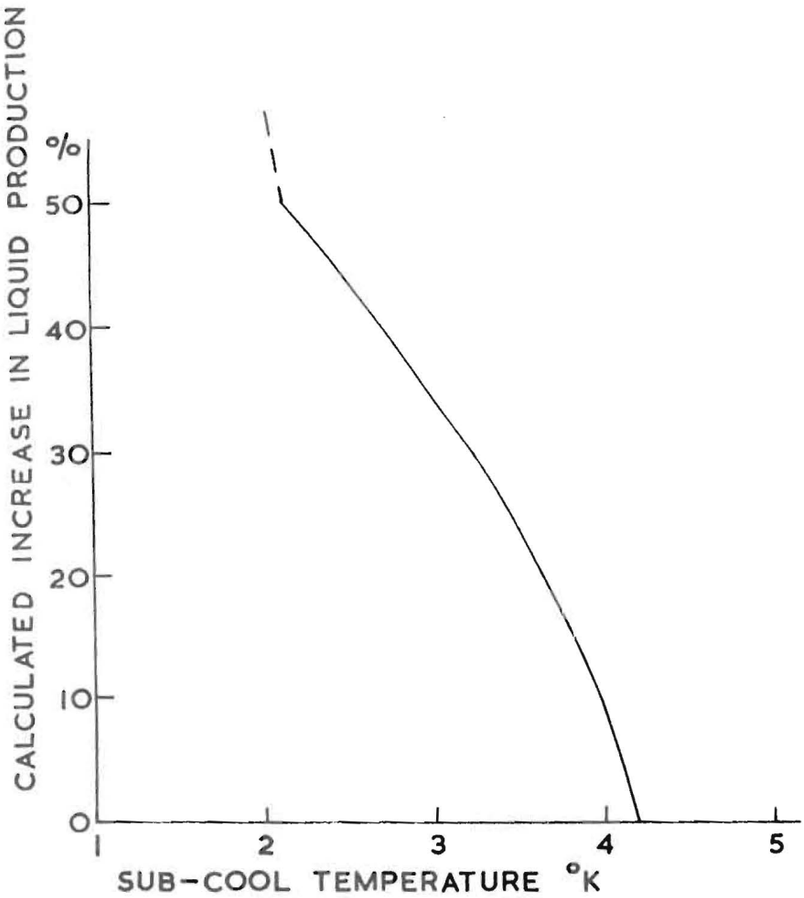

FIG. 3

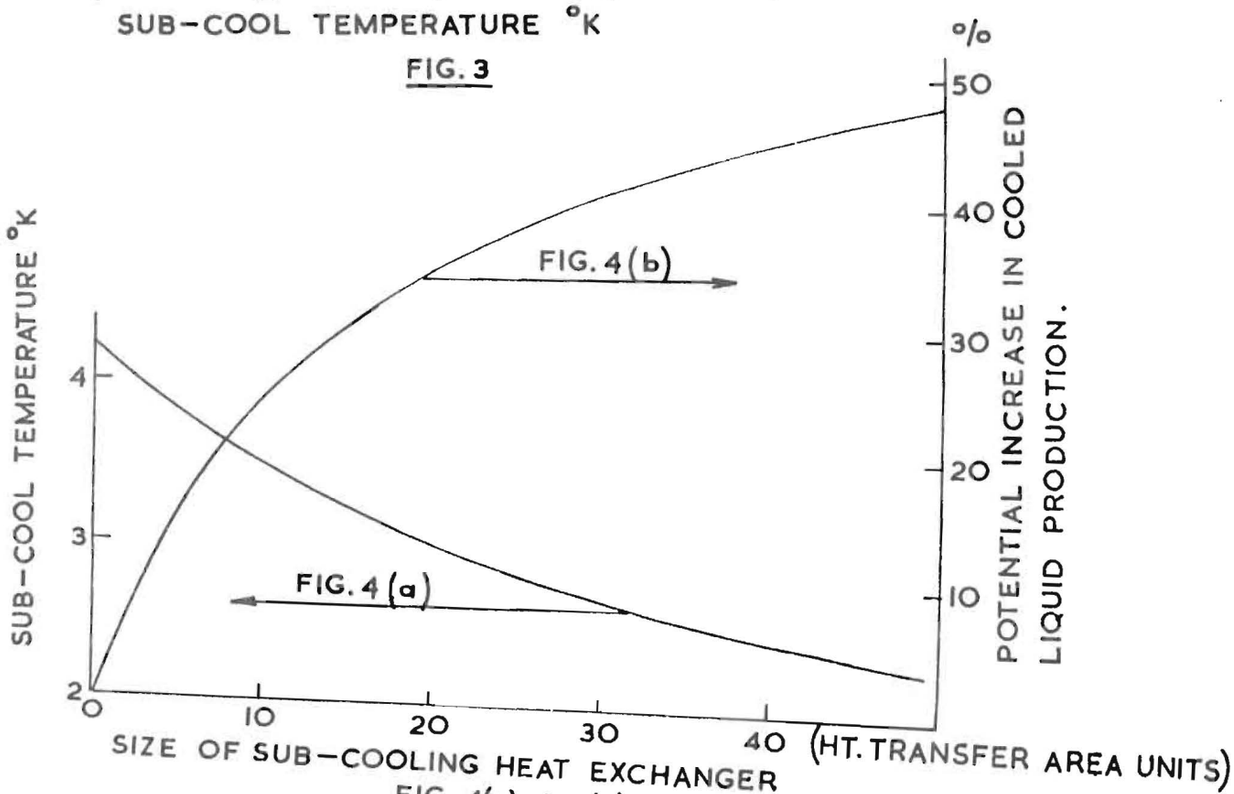

FIG. 4(a) & 4(b)

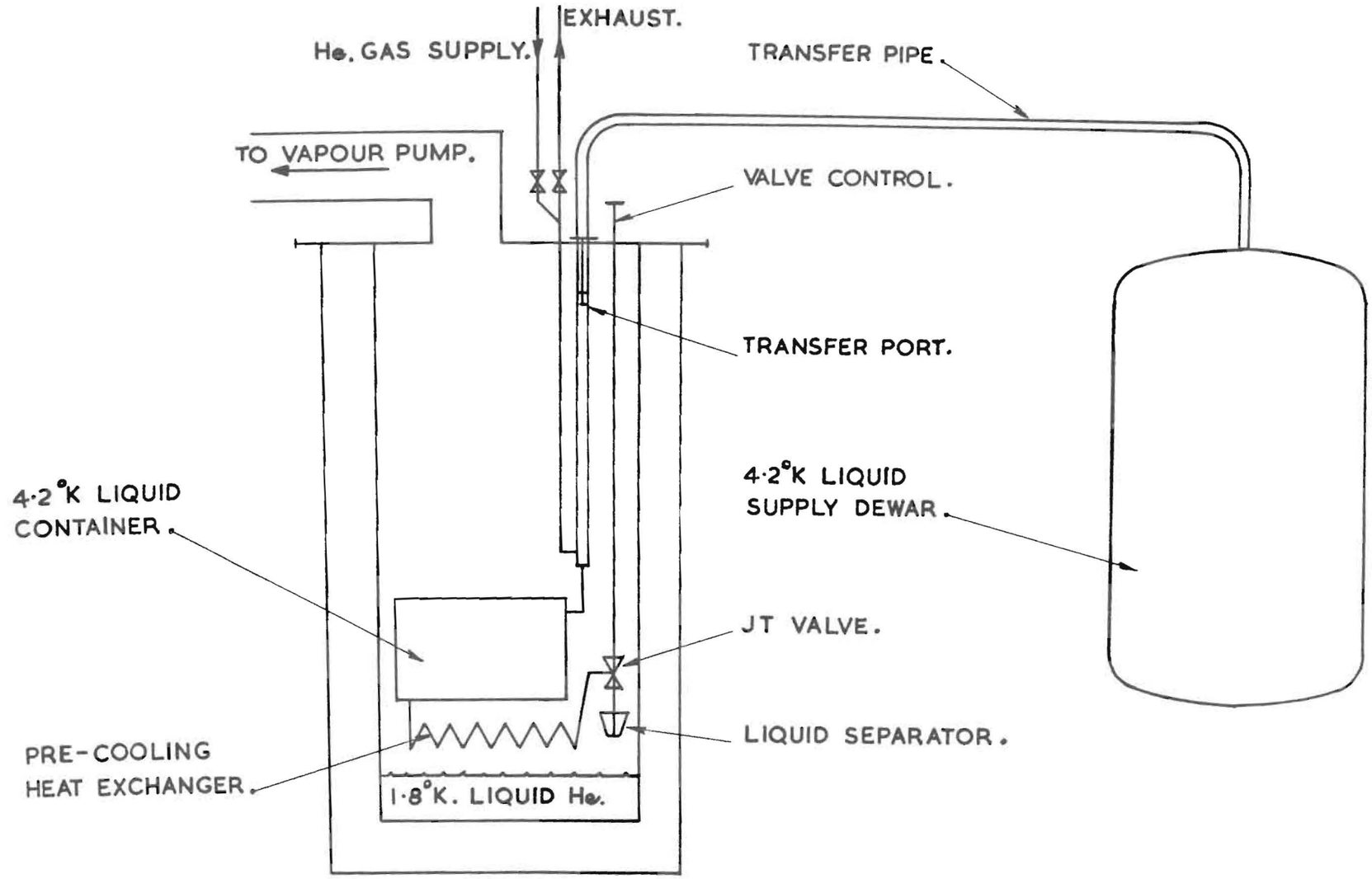

FIG. 5 TYPICAL CRYOSTAT & DEWAR ASSEMBLY