Helium Storage and Transport

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Properties of He

Helium properties at vapor-liquid equilibrium

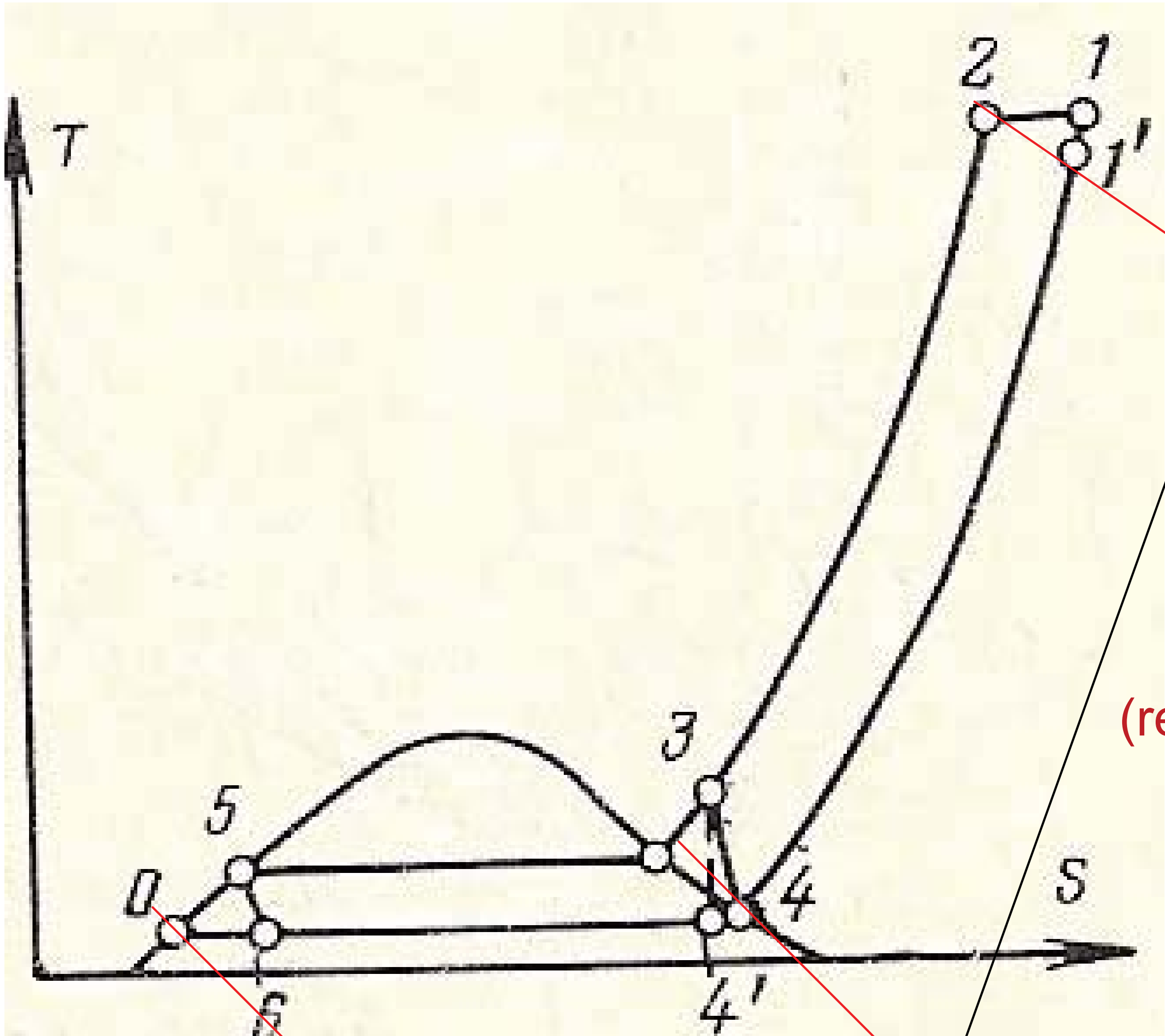
Pressure	Temp	Density of liquid	Density of vapor	Viscosity of liquid	Viscosity of liquid	Latent Ht
[bar]	[K]	[kg/m3]	[kg/m3]	[uPa-s]	[uPa-s]	[kJ/kg]
1	4,21	125	17	3,17	1,24	20,7
1,25	4,45	120	21	3,04	1,35	19,1
1,5	4,67	114	26	2,91	1,46	17,1
1,75	4,86	108	33	2,78	1,58	14,5
2	5,03	99	41	2,61	1,72	11,1
2,25	5,18	82	57	2,32	1,96	4,8
2,26	*5,20*	*68*	*68*	*2,14*	*2,14*	*0*

Critical point of He is very low.

Heat of vaporization is very low.

Properties

General shape of T-s diagram of gases



ambient

sensible heat
(relatively large at He)

heat of vaporization
(very small at He)

saturated liquid

saturated vapor

Properties of He

		Mol. mass	Normal Boiling Point	enthalpy of satur. liquid	enthalpy of satur. vapor	enthalpy gas 1 bar 77,4 K	enthalpy gas 1 bar 273 K	heat of vaporizati on	sensible heat to 273 K	sensible heat to 77,4 K
			[K]	[kJ/kg]	[kJ/kg]	[kJ/kg]	[kJ/kg]	[kJ/kg]	[kJ/kg]	[kJ/kg]
Methane	CH_4	16	111,7	-289,4	222,5		567,8	**511,9**	**345,3**	
Nitrogen	N_2	28	77,4	-122,5	76,6		283,5	**199,1**	**206,8**	
Helium	He	4	4,2	-5,8	15,0	400,0	1418,5	**20,8**	**1403,5**	**385,0**

Heat of vaporization of He is very low compared to other cryogenic gases.

Sensible heat between the normal boiling point and 273 K

-at nitrogen: nearly equal to the heat of vaporization

-at helium: 70 times larger than the heat of vaporization.

-Conclusion:
For successfull low evaporation losses storage
the sensible heat of helium must be used for „absorbtion“ of the heat leak.

Liquid nitrogen shielding can reduce the heat leak considerably.

Multilayer insulation

• is widely used with He storage and distribution equipment

• consists of wound layers of aluminum foil and glas-fiber paper
or from mylar covered with aluminum layer.

• Insulating effect reduces three ways of heat leak:
- radiation by a series of reflecting walls
- thermal conductivity with the low conductive paper
- gas convection by vacuuming to very low pressure (0,1 Pa or less)

• The presusure of the rest-gas is futher reduced at the operating temeprature by capturing the molecules of the gas by a getter, mostly molecular sieve or activated carbon, adjacent to the wall of the inner vessel of the liquid helium tank. Molecules of the rest gas are captured by the getter at the low temperature.

Example of winding of MLI

onto a Chart liquid hydrogen tank 360 m3

Example of MLI

onto a Chart standard tank 6 m3

Multilayer insulation

The thermal network of multilayer insulation showing the different heat transfer modes is shown in Figure 1. Exemplary boundary temperatures are 4 K and 80 K.

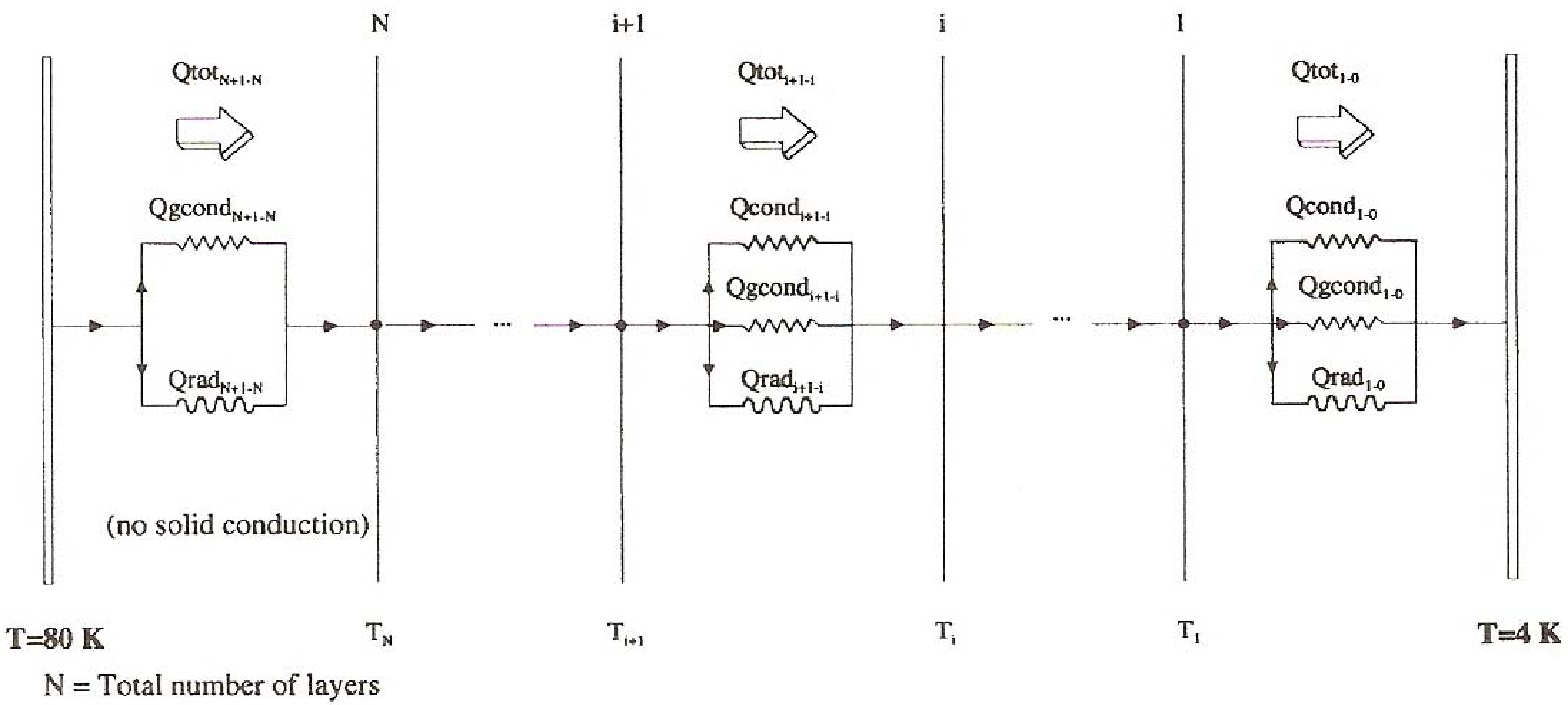
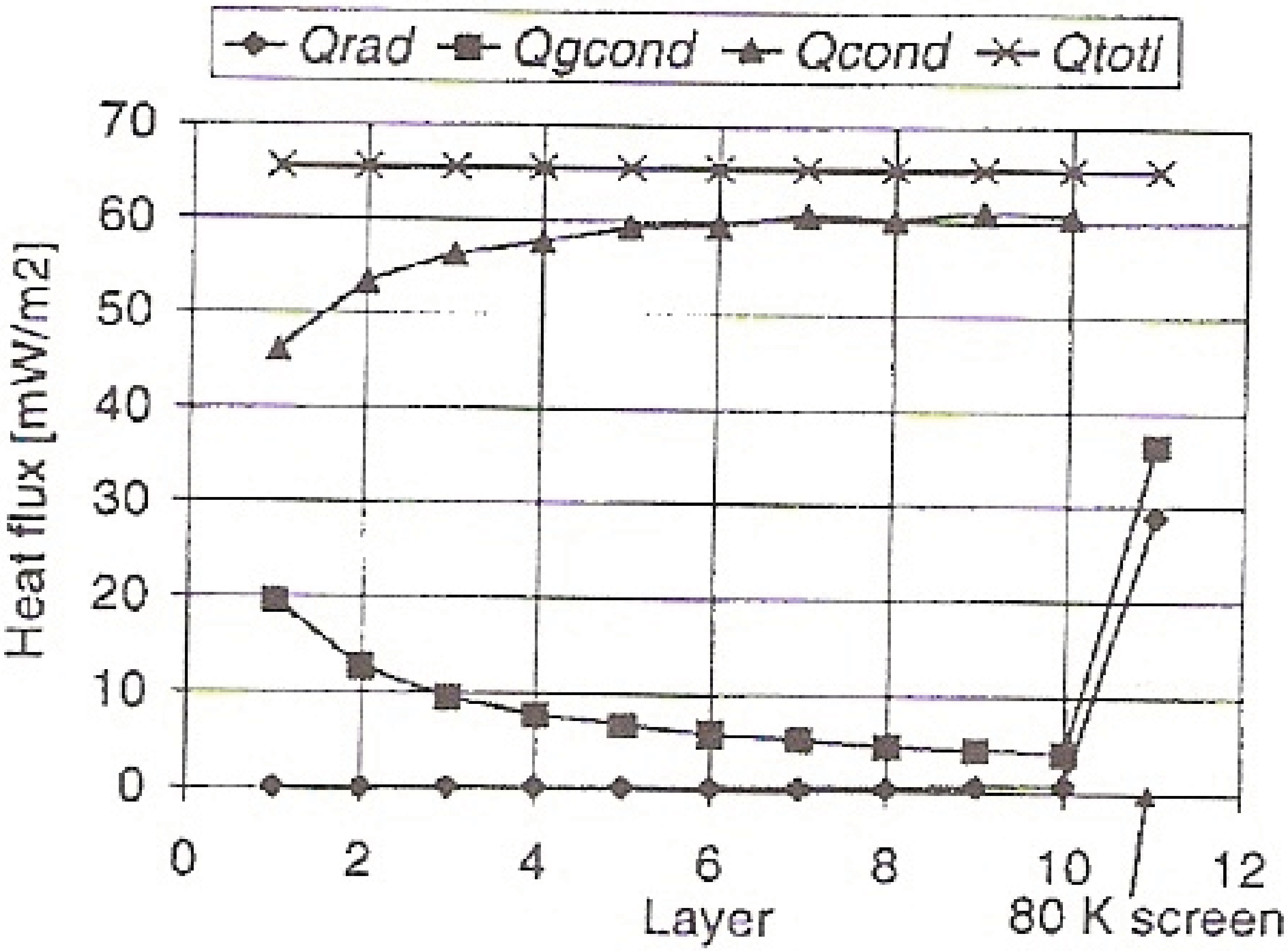


Figure 1. Thermal network of multilayer insulation.

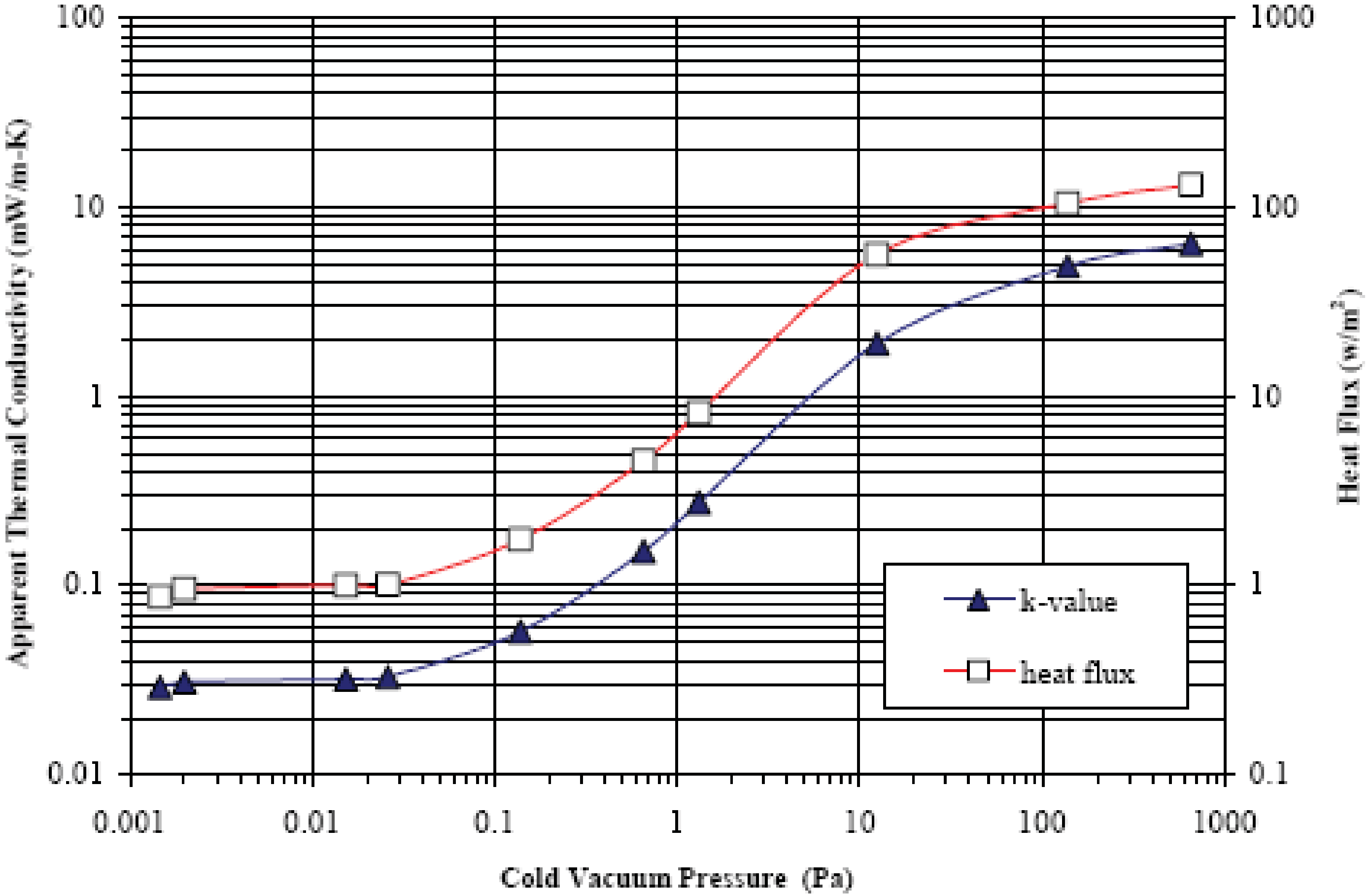
[Chorowski M., Cryogenics 2004]

Multilayer insulation



[Chorowski M., Cryogenics 2004]

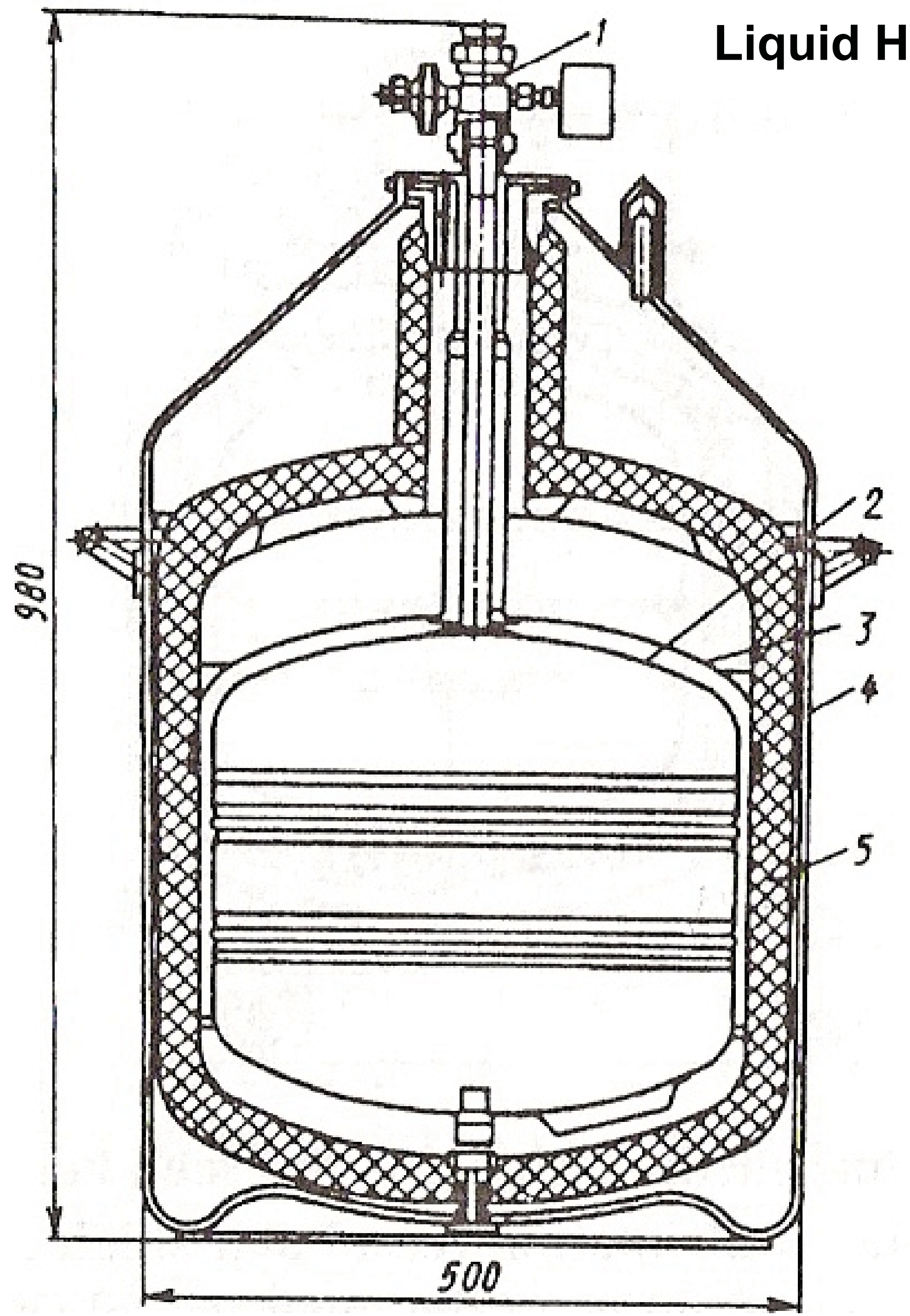
Measurement of integral properties of MLI



[Fesmire, Augustynowicz, NASA]

Laboratory LHe storage
Assembly of liquefier with Storage Dewar and portable Dewars

[Linde leaflet 2008]



Liquid Helium Dewar vessel with LIN shielding

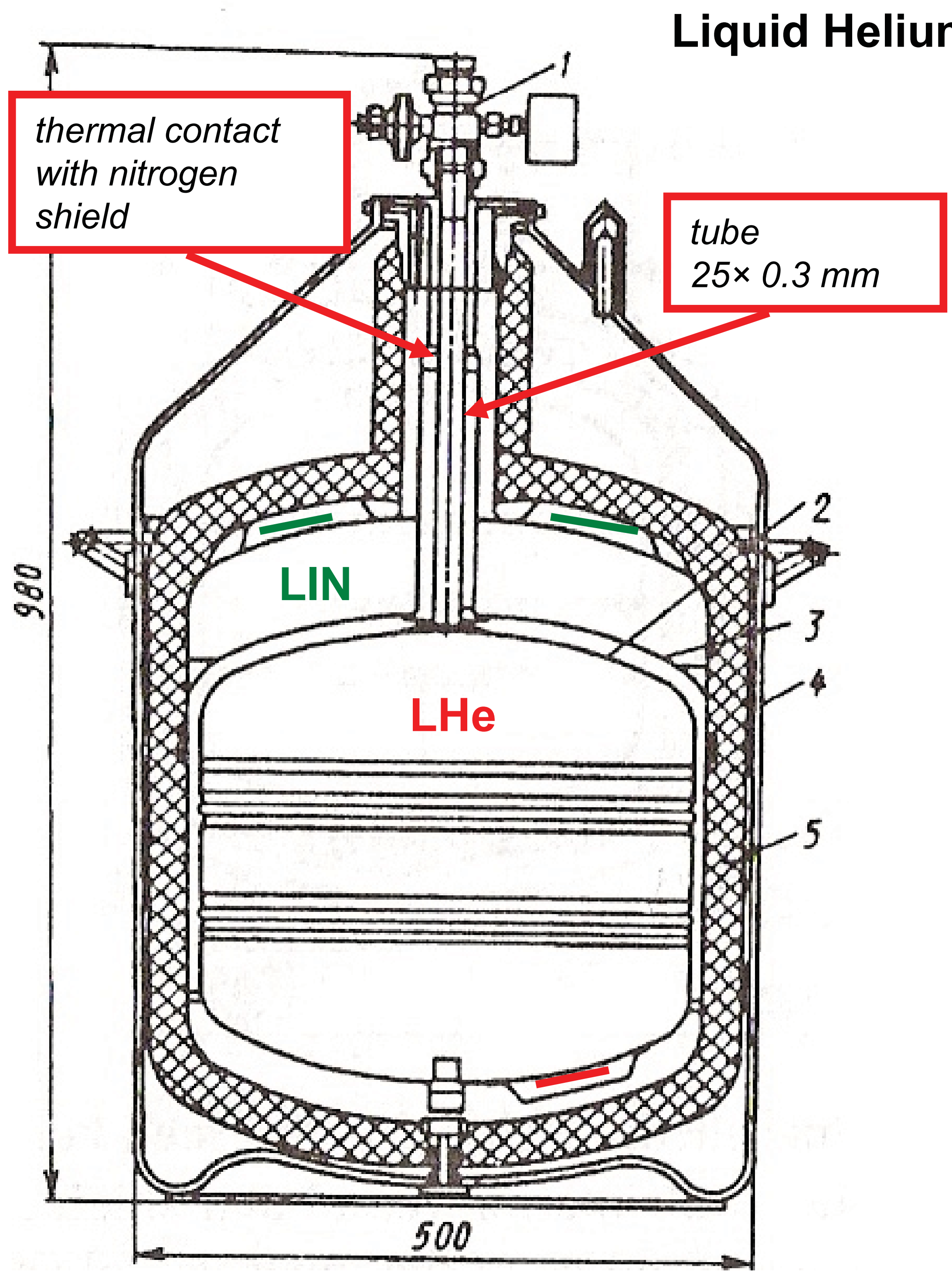
Capacity: 40 liters

Exercise 3:

Molecular weight of He: 4
Liquid density 125 kg/m3

Helium normal volume:
................Nm3 ??

Liquid Helium Dewar vessel with LIN shielding



Capacity: 40 liters
Liquid helium volume: **28 Nm3**

Remember: 700 liters gas from 1 liter liquid

1 – valve head with thread connections for liquid fill and gas withdrawal, manometr and safety membrane.

2 – inner vessel (12Cr18Ni1.0T)

3 – nitrogen vessel (12Cr18Ni1.0T) with nitrogen shield (copper – high thermal conductivity for uniform temperature)

4 - outer jacket

5 – multilayer vacuum insulation

high vacuum between the inner vessel and the nitrogen shield

getter at nitrogen temperature

getter at helium temperature

[Arkharov et all., Cryogenic Systems]

Fundamentals of calculation of heat leak

- Two main parts:

- Thermal bridges:
  supports of the inner vessels.
  At Dewar vessels mostly the neck.

- Insulation

Thermal conductivity of thermal bridge must be known for calculation of heat leak

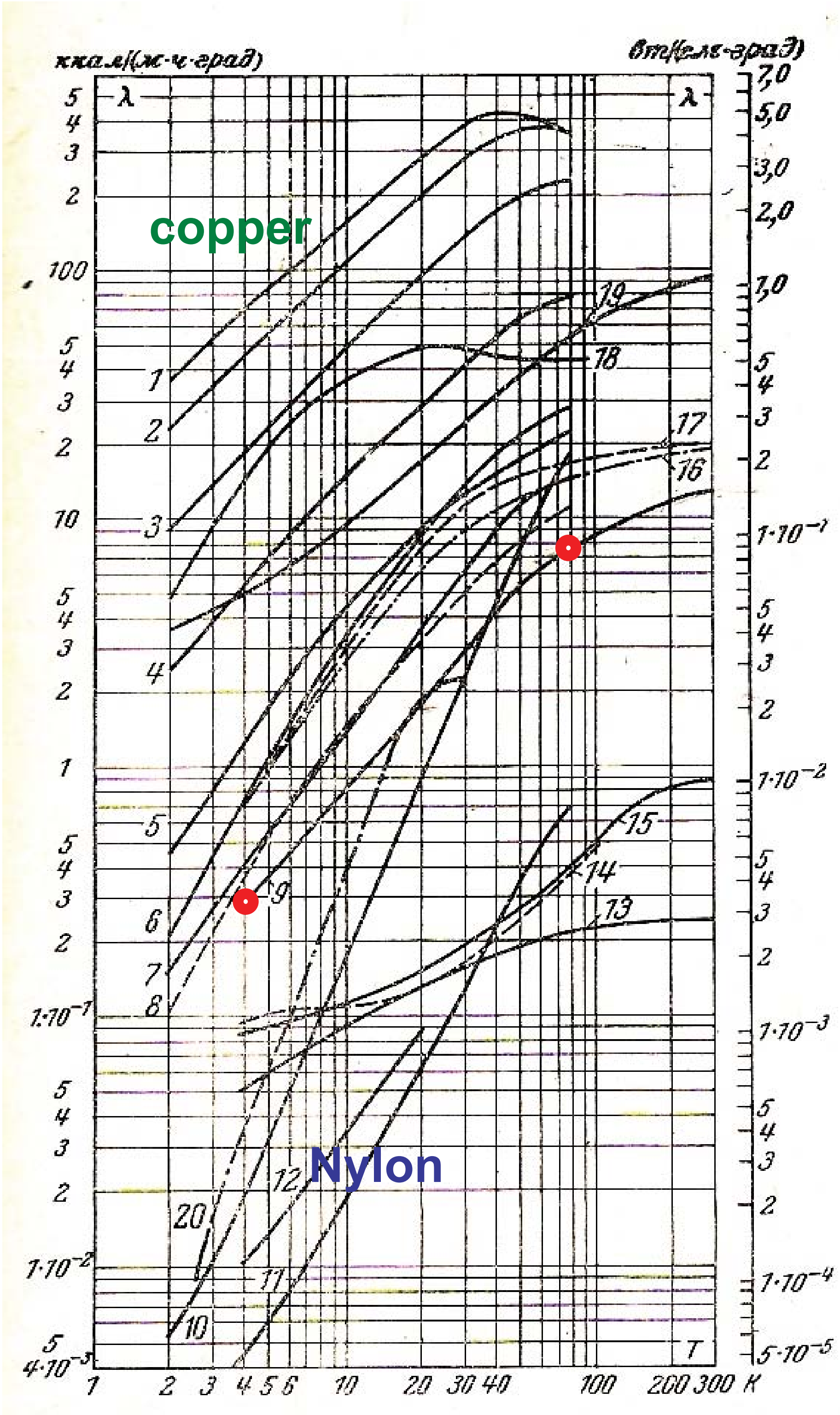


Рис. 4-35. Теплопроводность технических материалов.

1 — медь М-3 отожженная; *2* — медь неотожженная; *3* — купалой состава: 99,2% Cu, 0,61% Cr, 0,18% Ag; *4* — дюралюминий Д16 неотожженный; *5* — бронза фосфористая БрОФ 6,5-0,15 неотожженная состава: 99,2% Cu, 6,46% Sn, 0,20% P; *6* — мельхиор НМ-81 отожженный до 800 °C; *7* — мельхиор НМ-81 неотожженный; *8* — манганин НММЦ неотожженный; *9* — нержавеющая сталь Х18Н9Т и типа 18-8; *10* — графитер АУГ-4; *11* — графитер АУГ-3; *12* — нейлон; *13* — фторопласт-4; *14* — плавленый кварц; *15* — стекло; *16* — монель; *17* — константан; *18* — 50%-ный оловянно-свинцовый припой; *19* — латунь [341, 343, 859, 800]; *20* — сверхпроводящий сплав ниобий—олово состава: 70,5±0,5% Nb, $T_к = 18{,}3$ K, $\rho_{300} = 8{,}1 \cdot 10^{-6}$ *ом·см*, $\rho_{27} = 1{,}5 \cdot 10^{-6}$ *ом·см* [856].

9 – Stainless steel Cr18Ni9T

T = 4.2 K, **l**=3.5 W/(m.K)

T = 78 K, **l**=85 W/(m.K)

Calculations should be integrated.

For us „average“**l**=20 W/(m.K)

Fundamentals of calculation of heat leak
Thermal bridge: the neck

Exercise 6:

- Stainless steel tube 25 × 0.3 mm
- Length 230 mm
- Temperatures:
  Bottom: 4.2 K
  Top: 78 K
- $Q = \lambda / l \times S \times DT$
- Q = ...W (??)
- Heat of vaporization r = 20.7 kJ/kg = 20 700 J/kg
- Resulting vaporization of He:

Mvapor = Q/r = ...kg/day

Fundamentals of calculation of heat leak
Thermal bridge: the neck

- Stainless steel tube 25 × 0.3 mm
- Length 230 mm
- Temperatures:
  Bottom: 4.2 K
  Top: 78 K
- $Q = \boldsymbol{l/l \times S \times DT}$
- $Q = 0.12$ W
- Heat of vaporization r = 20.7 kJ/kg = 20 700 J/kg
- Resulting vaporization of He:

Mvapor = Q/r = 0.5 kg/day

Fundamentals of calculation of heat leak
Thermal insulation of the LIN vessel

- LIN vessel (plus shield) height: 600 mm
- LIN vessel diameter: 500 mm
  (consider cylinder)
- Temperatures:
  Inner: 78 K
  Outer: 273 K
- Aparent thermal conductivity: 50 mW/(m.K)
- 20 layers of insulation, thickness 20 mm.
- Q = ***l/t×S×DT***
- Q = ...W (??)
- Resulting vaporization of LIN:

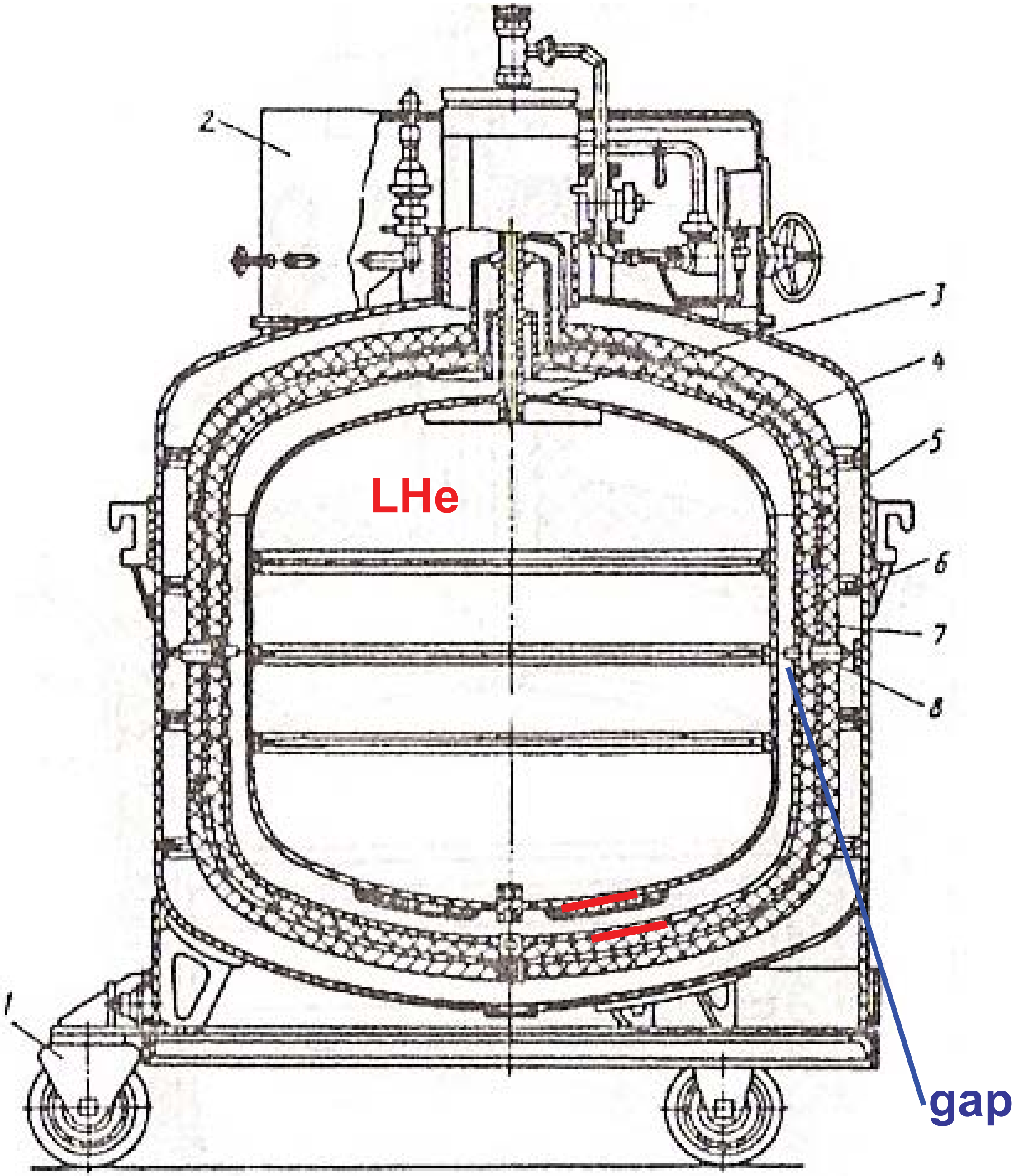
Mvapor = Q/r =................ kg/day

Fundamentals of calculation of heat leak Thermal insulation of the LIN vessel

- LIN vessel (plus shield) height: 600 mm
- LIN vessel diameter: 500 mm
  (consider cylinder)
- Temperatures:
  Inner: 78 K
  Outer: 273 K
- Aparent thermal conductivity: 50 mW/(m.K)
- 20 layers of insulation, thickness 20 mm.
- $Q = \boldsymbol{l/t \times S \times DT}$
- $Q = 0.65$ W
- Resulting vaporization of LIN:

Mvapor = Q/r = 0.28 kg/day

Liquid Helium Dewar vessel without LIN shielding



Capacity: 500 liters

1 – valve head with thread connections for liquid fill and gas withdrawal, manometr and safety membrane.

3 – suspension neck

4 – inner vessel (12Cr18Ni10T)

5 - outer jacket (12Cr18Ni10T)

6 – two thermal shields cooled by He vapor from the...
7- ...pipe coil of vapor vent.

Each shield covered by multilayer vacuum insulation

8 – side movement limiters (gap)

high vacuum between the inner vessel and the first thermal shield

getter at helium temperature

Daily losses: 1,3% of LHe content
Mass: 430 kg (0,86 kg/liter)

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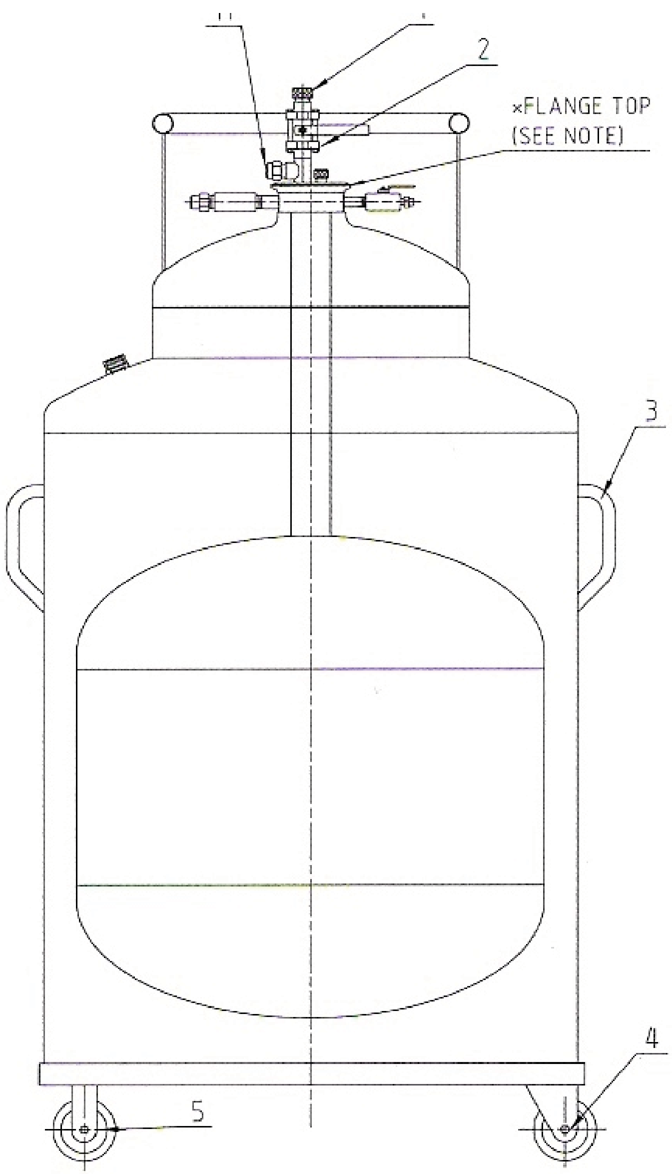
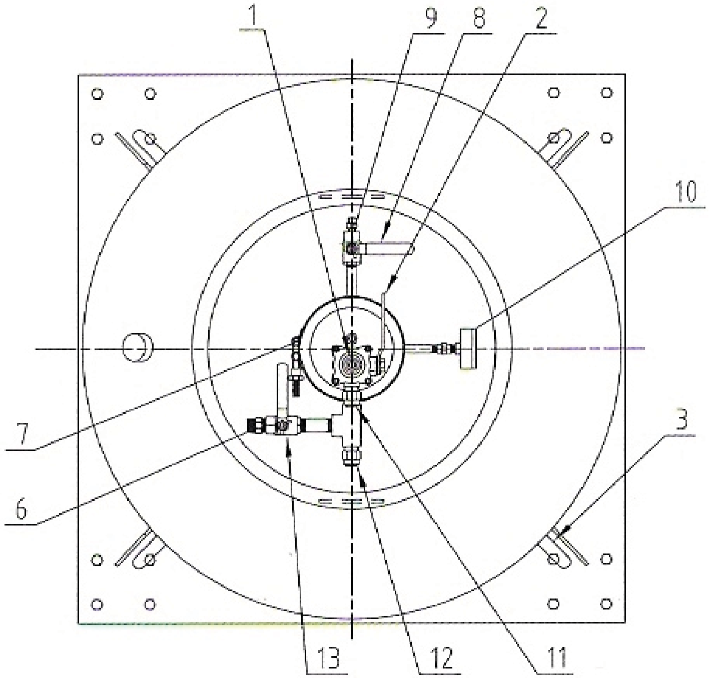
ULTRA-HELIUM DEWARS

Volume gross	liters	550	275	110
Volume net	liters	500	250	100
Net evaporaion	%/day	1.0	1.0	1.25
Tare mass	kg	278	181	114

(0,56 kg/liter)





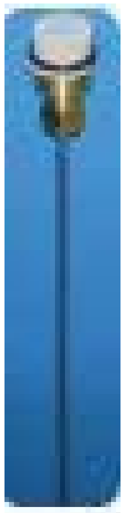
Nomenclature

1. Quick Coupling Stack
2. Liquid Valve
3. Handle Assembly
4. Swivel Caster Non-Magnetic
5. Rigid Caster Non-Magnetic
6. Vent Valve Connection
7. V-Band Clamp
8. Aux. Relief Iso ation Valve
9. Aux. Relief Valve
   1.0 psig (.07 bar)
10. Pressure Gauge
11. Secondary Relief Valve
    12 psig (.8 bar)
12. Main Relief Valve
    10 psig (.7 bar)
13. Main Vent Valve



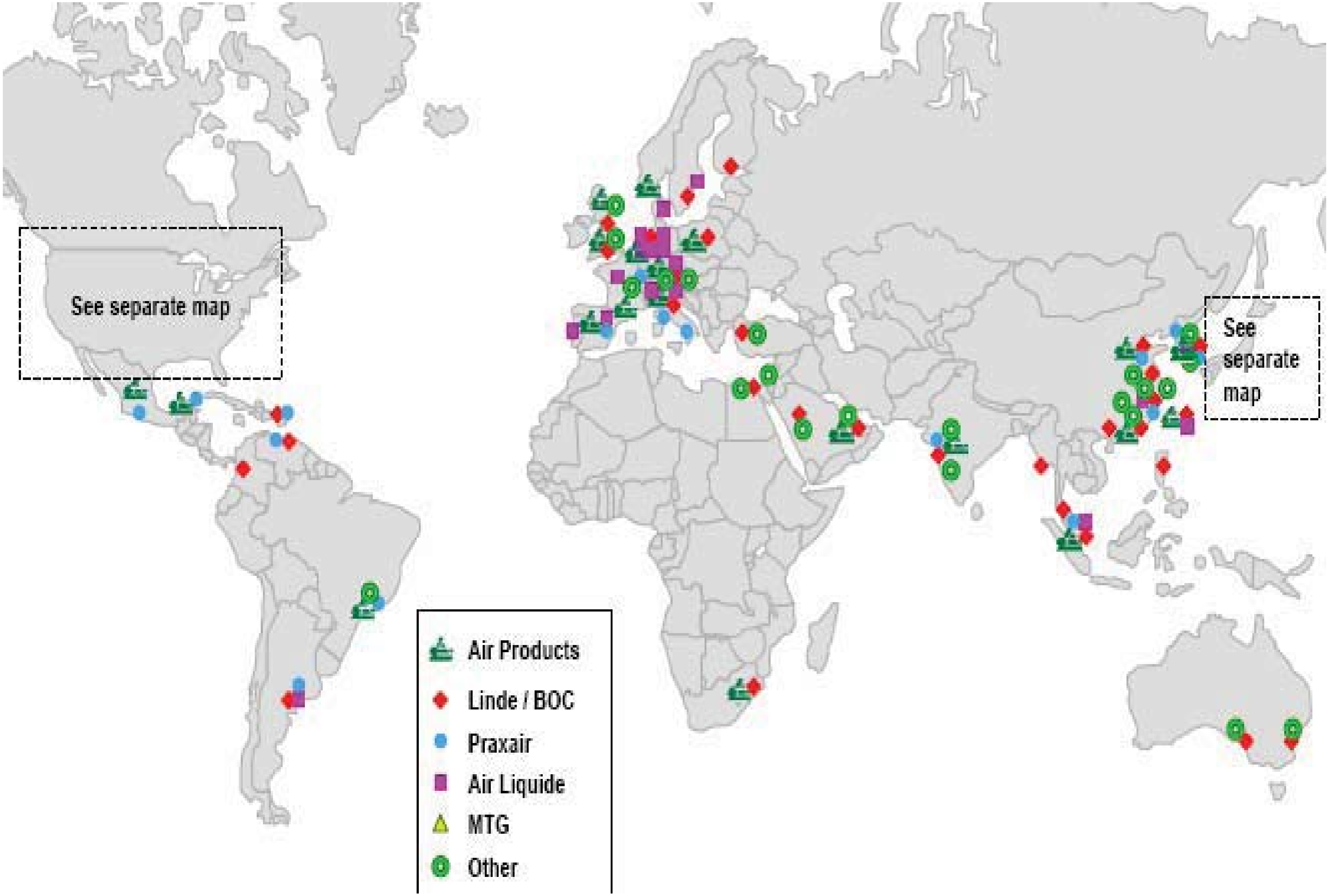
HELIUM
REFRIGERATED
LIQUID
UN-1963
CAUTION
UN-1963

Helium level measurement in open Dewars

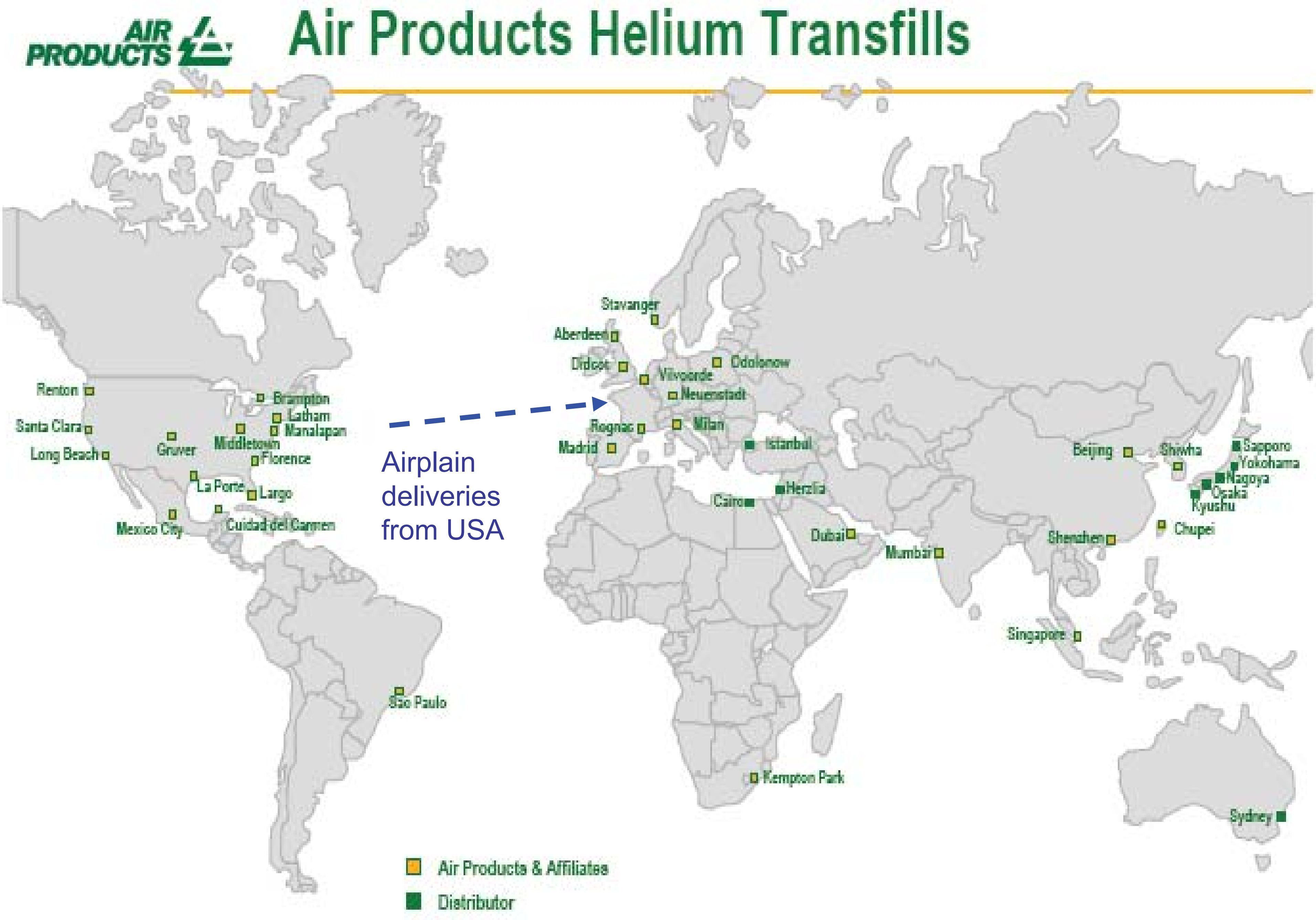


Pulsation Dipstick
This simple liquid helium probe provides an accurate indication of the liquid level in a storage dewar or research cryostat.
The configuration has a thin rubber diaphragm o-ring sealed over the upper portion of the dipstick. The assembly is connected to a small diameter stainless steel tube that is inserted into the liquid helium.
The dipstick produces a steady low frequency pulsation when immersed in liquid helium which can easily be felt at the diaphragm with a finger tip.
When the dipstick is raised just above the liquid level, a high frequency pulsation occurs.

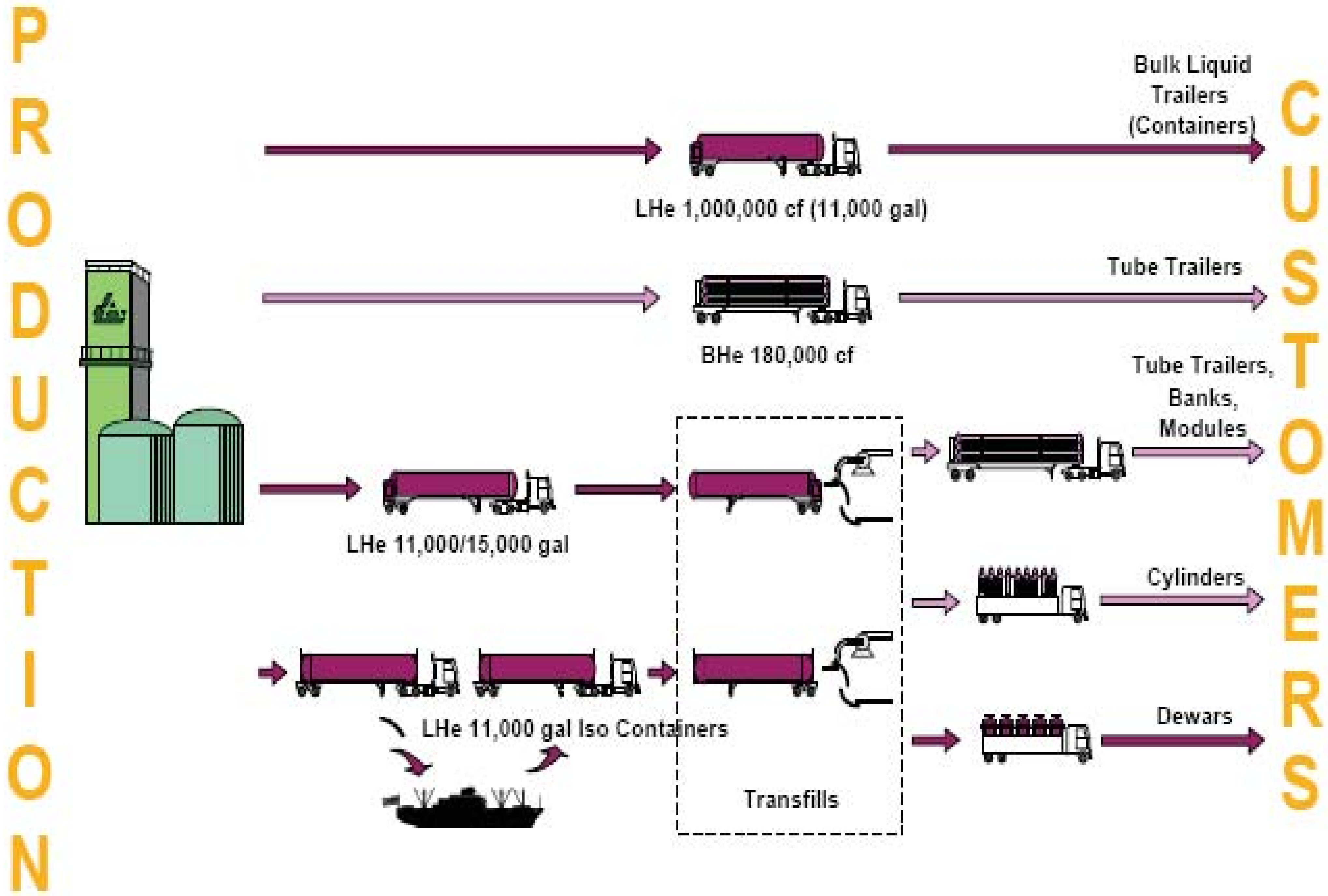
Helium logistics worldwide



Helium logistics (example from Air Products)



Helium logistics

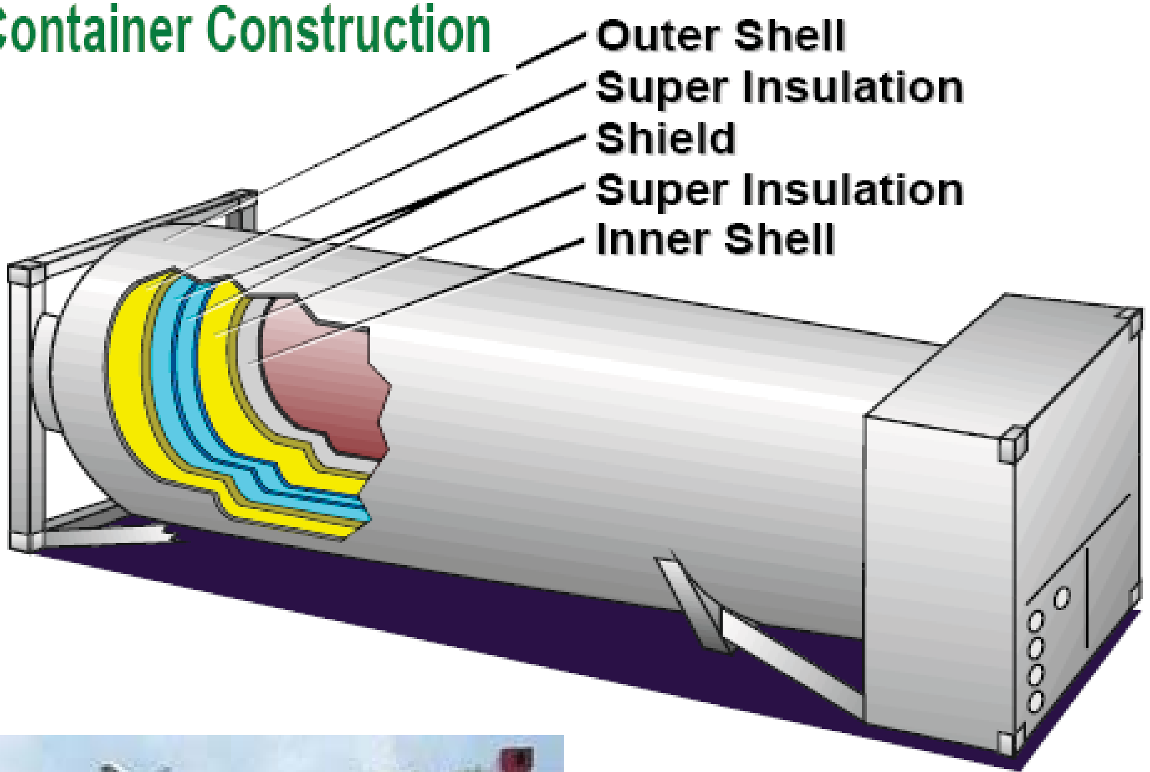


Helium logistics

- **Pure helium distributed from source in 11,000 gallon cryogenic containers**
  - direct to large end-users
  - to local transfill (domestic or overseas)

Helium logistics

Typical ISO Container Construction



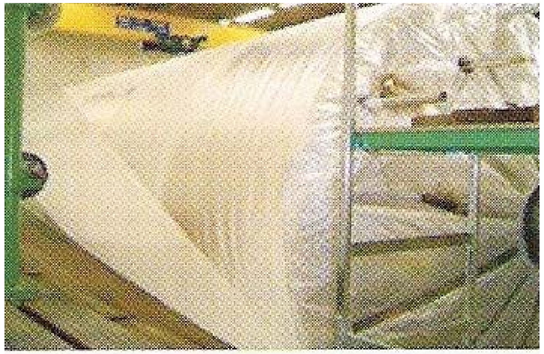
Large Bulk Helium Transport

ISO Container with LIN shield

A 40' liquid helium transport container

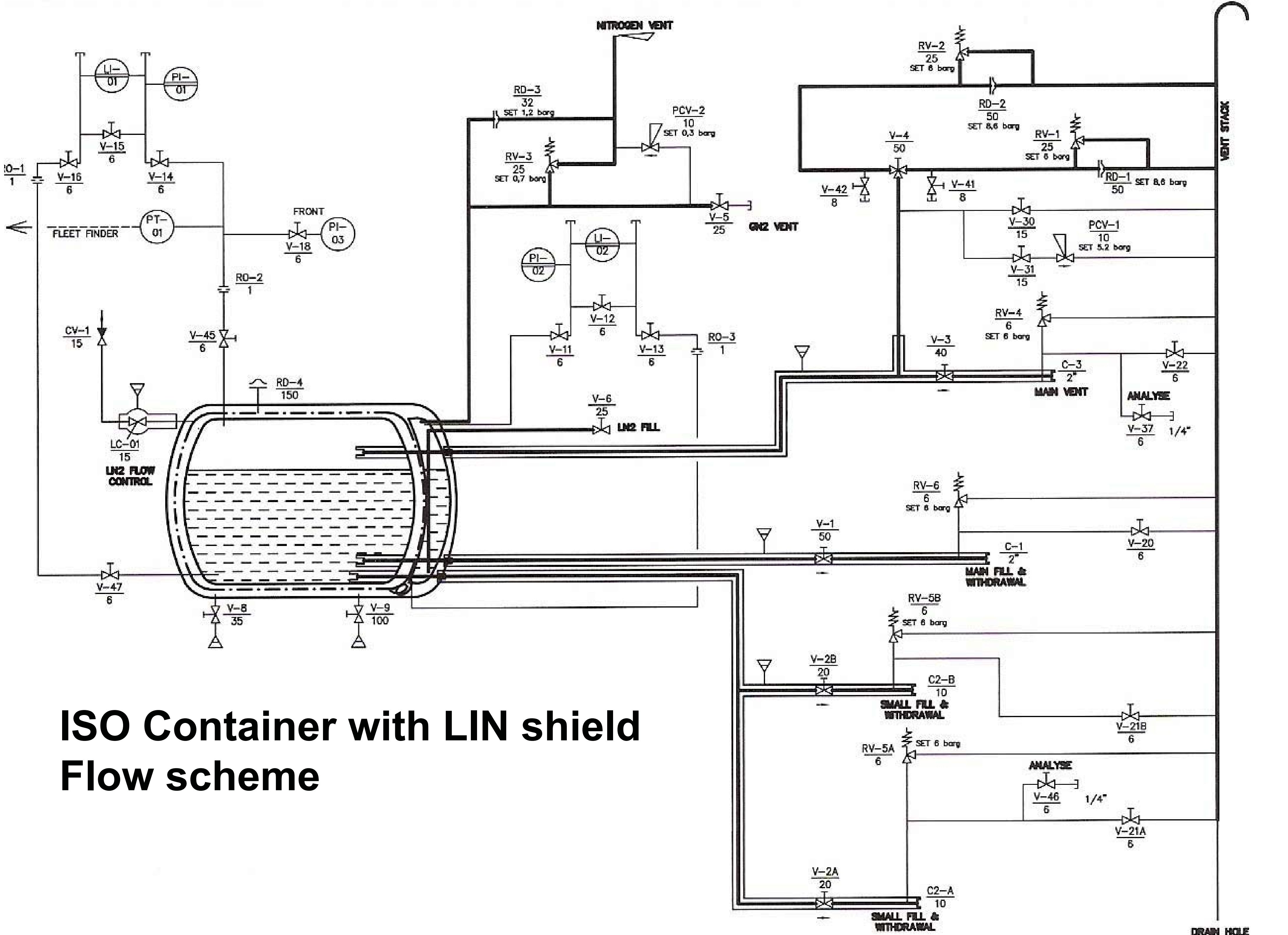
Helium:
41 000 líters, 6 bar

Nitrogen:
1 660 liters, 0.3 bar
LIN evaporation 30 kg/day



45 days holding time, no-loss-operation at 10% ullage
5 W (17.5 BTU/h) heat inleak
Consumption of LIN <30 kg (66 lbs)/24 h

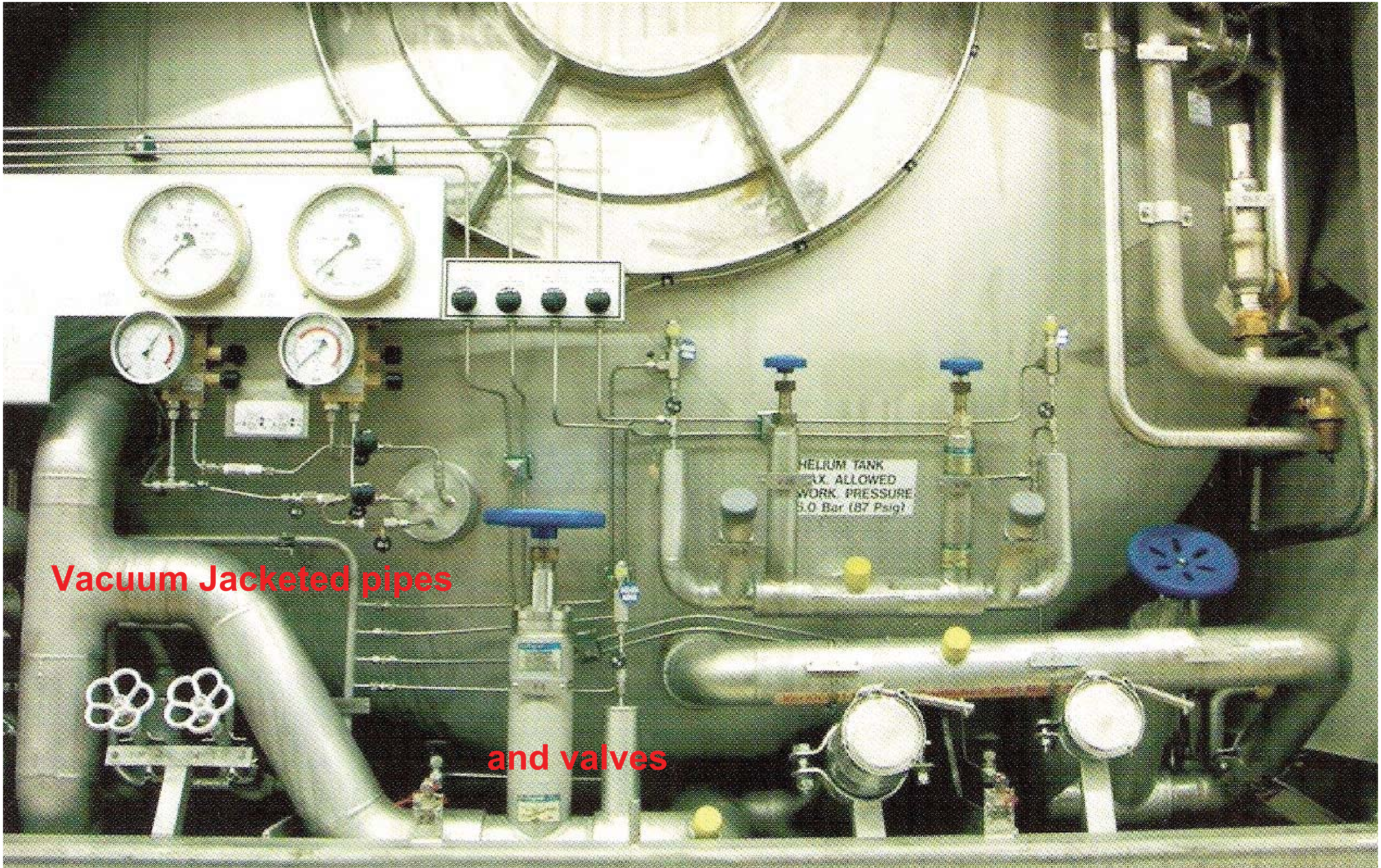
[Linde leaflet, 2008]



ISO Container with LIN shield Flow scheme

Large Bulk Helium Transport

ISO Container with LIN shield – operation cabinet



Large Bulk Helium Transport

ISO Container

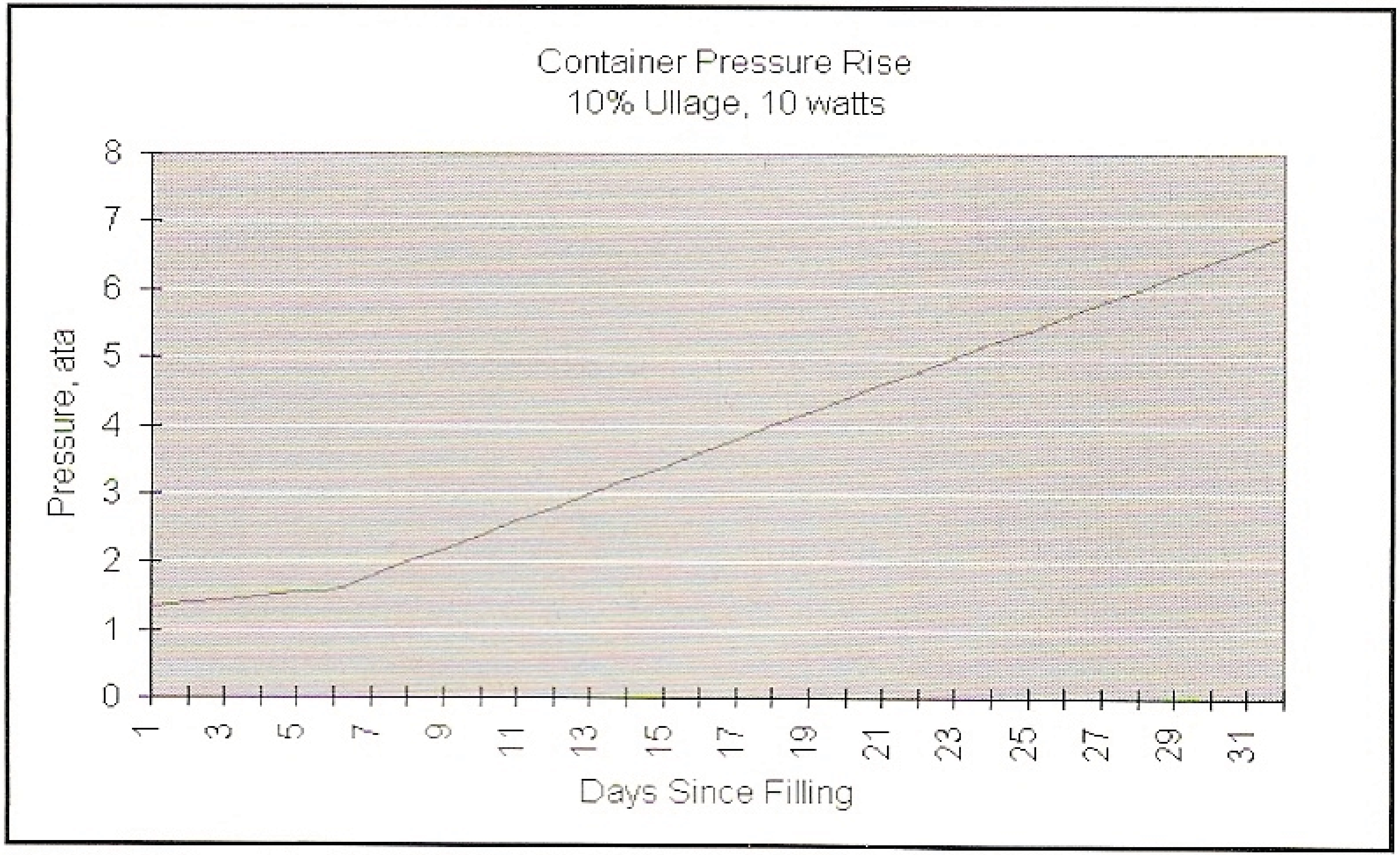


Figure 2

[West, CryoGas International, January 2004]

Large Bulk Helium Transport

ISO Container

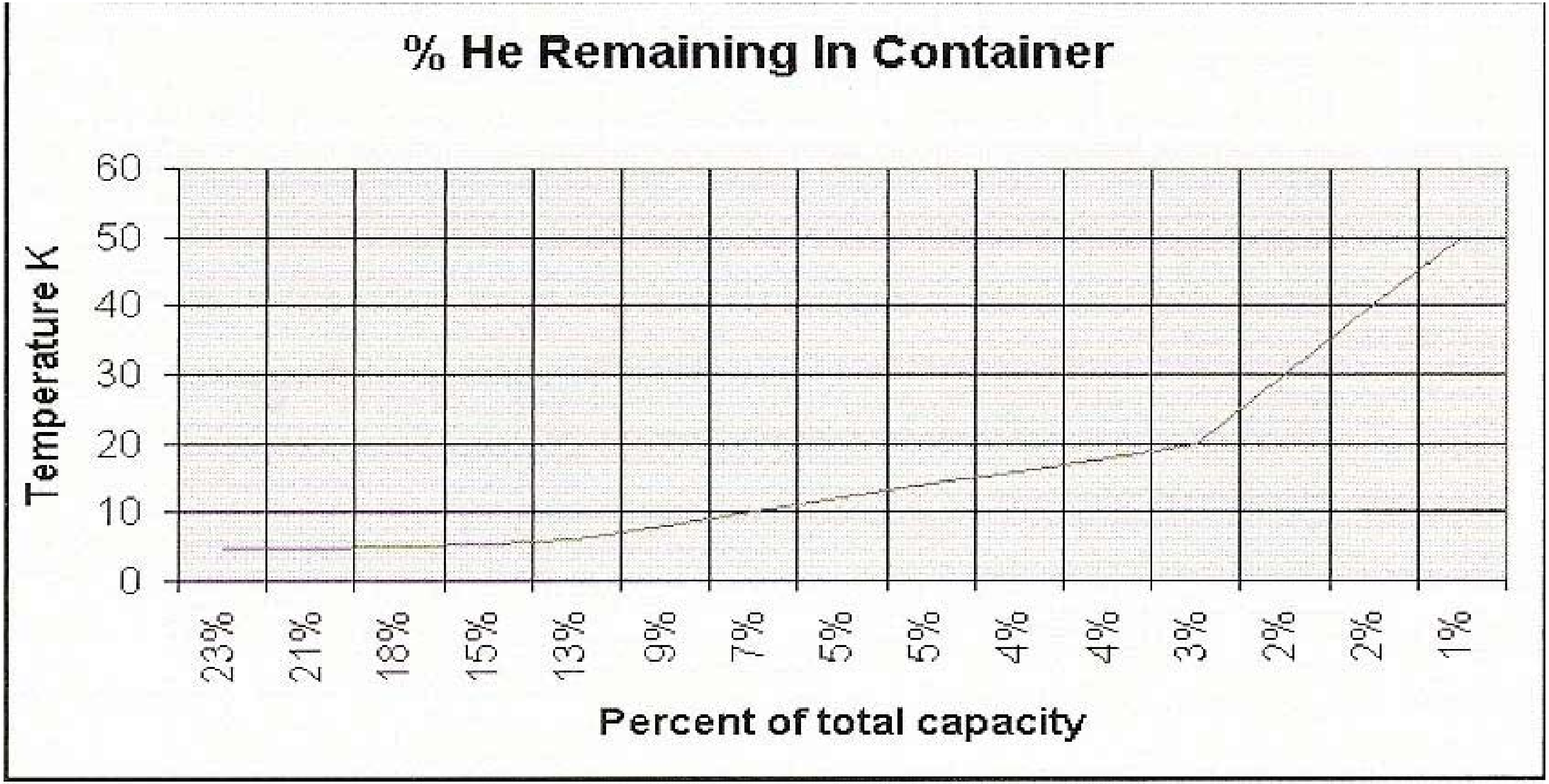


Figure 4

[West, CryoGas International, January 2004]

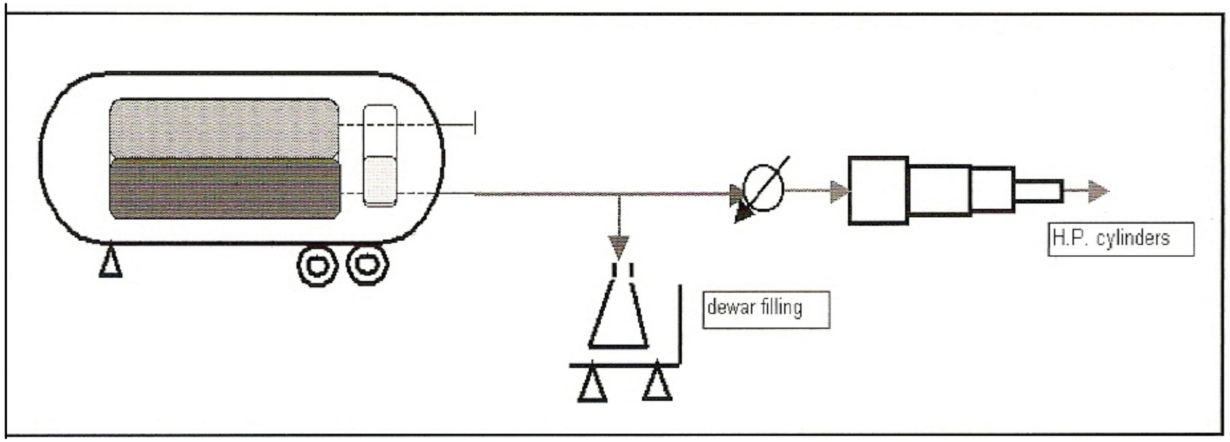
Helium re-distribution

in small liquid Dewars or as high pressure gas

- **Redistribution from transfill in:**
  - tube-trailers
  - liquid dewars
  - cylinders / cylinder packs

Helium re-distribution

for filling Dewars and high-pressure cylinders



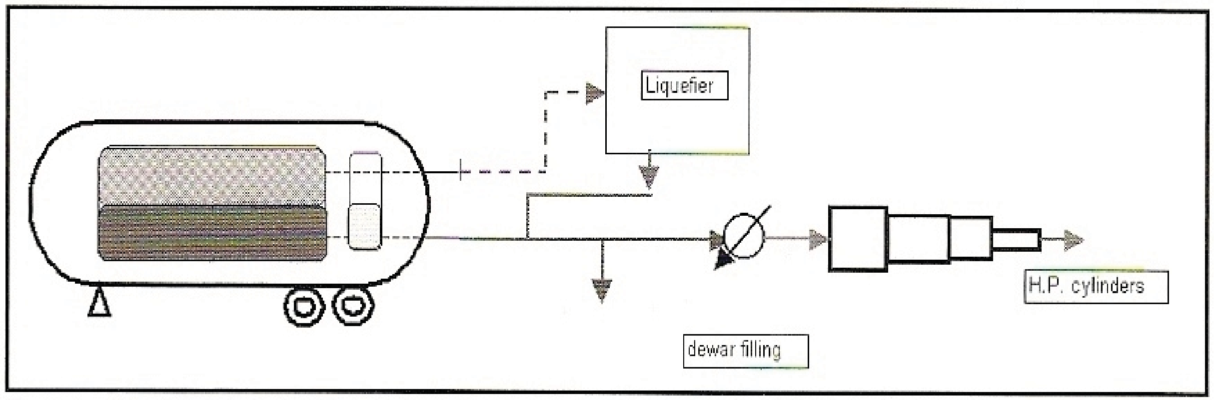


Figure 5

Helium recovery from cyogenic laboratories

general scheme

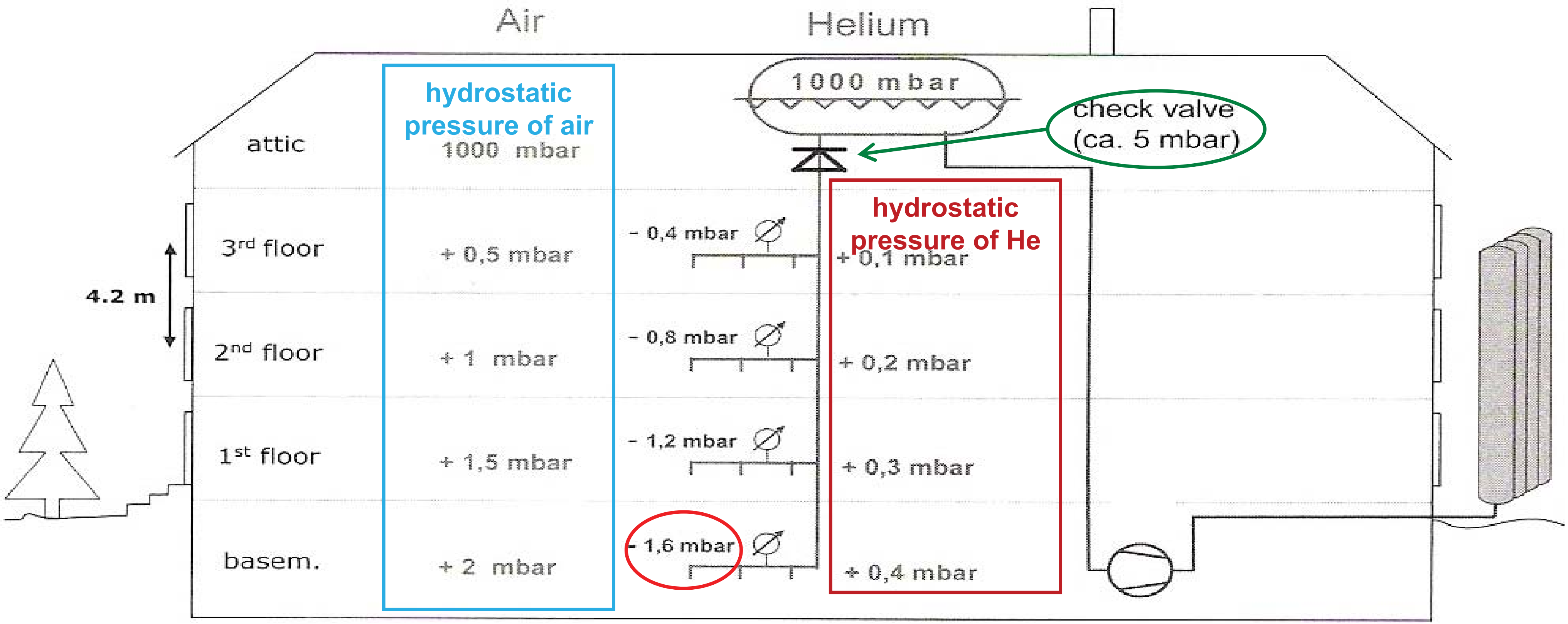


Figure 1: *Scheme of a helium recovery system in a multi-storage laboratory building with sub atmospheric pressure at the inlet ports.*

Negative pressure at the exprimental points causes helium contamination by air.
Solution: Use the check valve, as marked in the figure.

[Haberstroh, University of Dresden, Cryogenics 2008]

Helium recovery from cyogenic laboratories

wasting helium

Table 2: *Balance example of poor utilization of a LHe dewar vessel*

	dewar filling level
order	100 l
filling ex factory and account	96 l
after transport	94 l
after 14 days stand-by	80 l
after cryostat refill	20 l
liquid return	20 l

[Haberstroh, Cryogenics 2008]

Helium recovery from cyogenic laboratories

practical advisory

- Always connect portable dewars to the recovery system
- Always connect experimental cryostats to the recovery system,
  especially <u>during filling</u>.
- Don‘t open Dewars under pressure for venting to the atmosphere
- Cool down transfer lines before inserting into the cryostat by liquid helium to the minimum time possible
- Order appropriate quantities and „just on time“.

Conclusions

- Liquid helium is currently distributed globally using large bulk ISO containers.
- Liquid helium Dewars with volumes in hundreds of liters withput LIN shielding have evaporation rate 1%/day
- Liquid helium is apllicable also for long distance transport and subsequent filling of high-pressure cylinders.
- Management of prevention of helium losses and contamination should be primary concern of every larger helium laboratory.