Assessment of alternatives to R23

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R23 Mengenanalyse – Studie „Kältetechnologien Deutschland" (HsKA)

Prognose 2015 ca. 250t

R23 in Markt
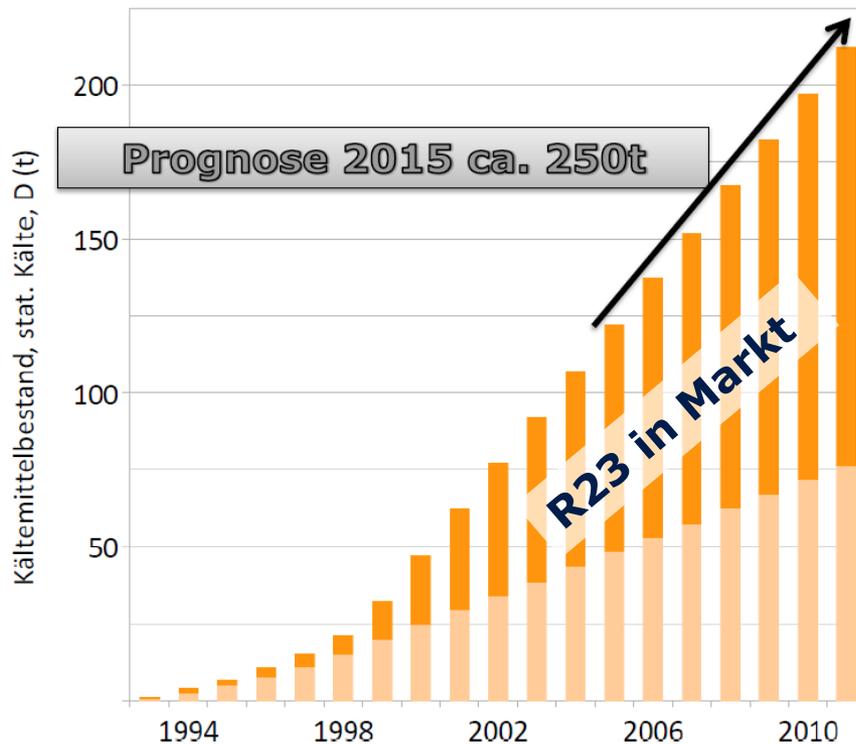
Demand in Germany

250 t (GWP R23 = 14.800)
→ 3,7 Mt CO_2 per year

Price development

from 7 €/t_{CO2} to > 35 €/t_{CO2}
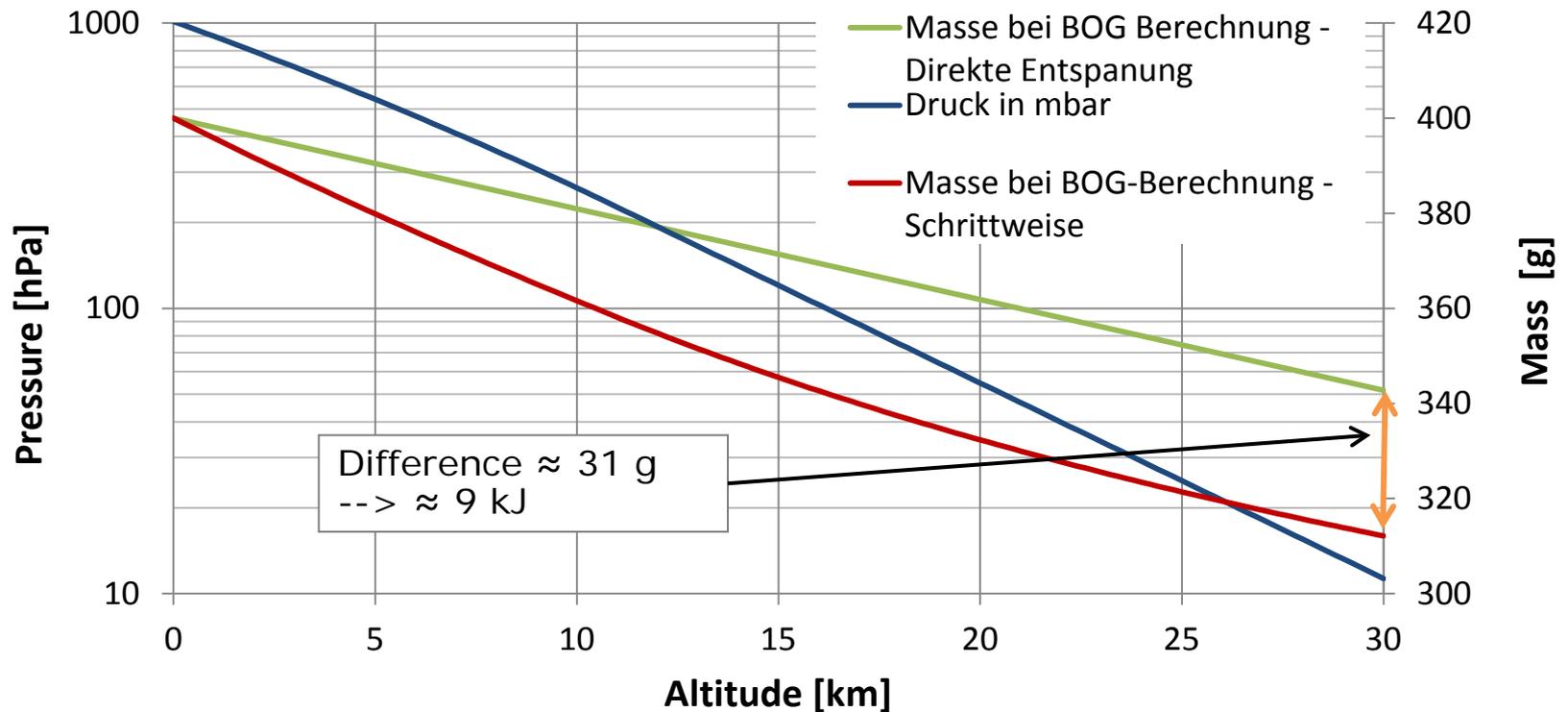
March 2018:

R23:   100 ... 300 € / kg

Thermometer

Flüssigkeits-
behälter

Frostbildung

Detektorlinse

Detektor

Infrarot LED

Senkbohrung

Kühlkörper

Heizung

Controller

Luftstrom

Strömungskanal
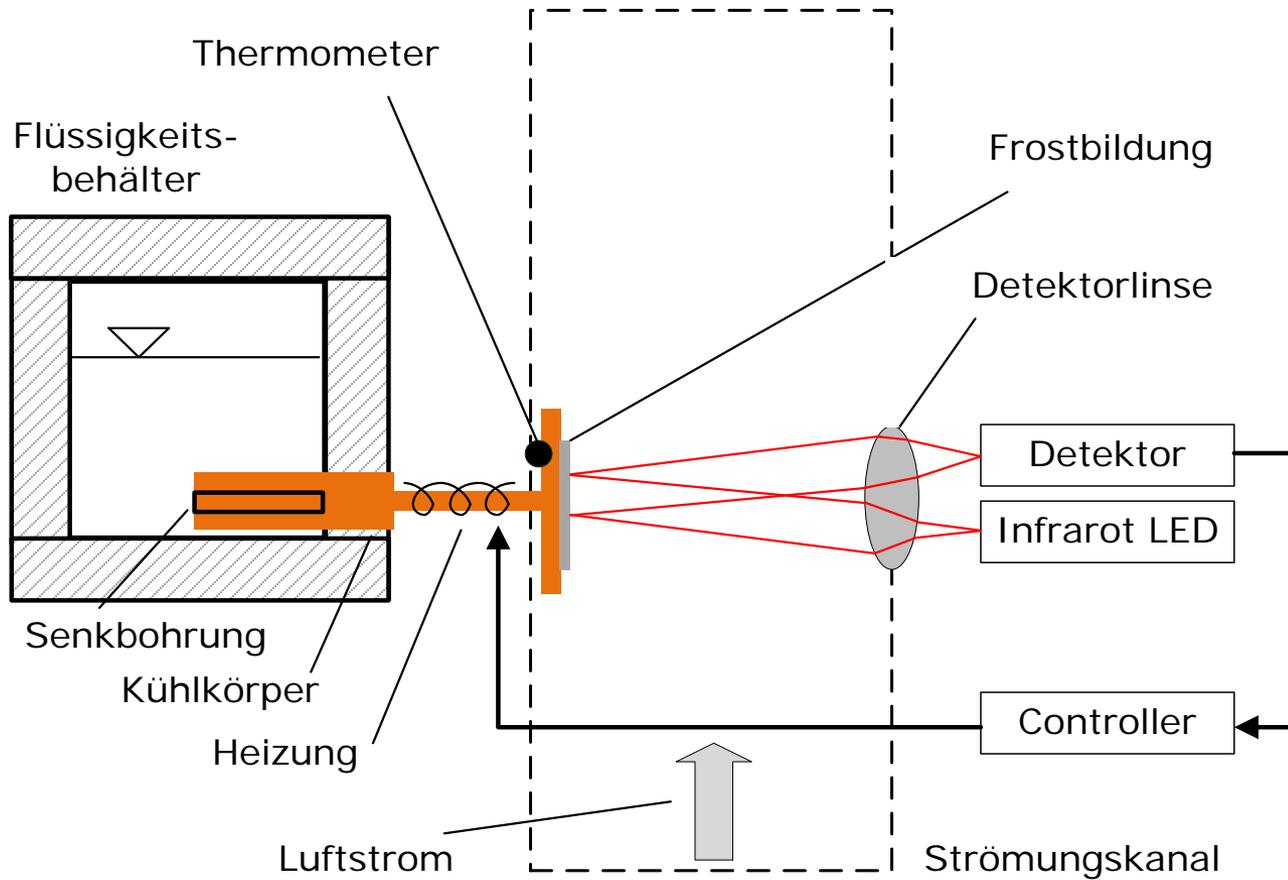
Estimate for a typical sounding

400 g R23 for 3 hr of CFH operation→ ≈ 117 kJ → 10,5 W

Losses due to „Boil-off"   (1000 hPa at surface, 11 hPa at 30 km)

Legend:
- Masse bei BOG Berechnung - Direkte Entspanung
- Druck in mbar
- Masse bei BOG-Berechnung - Schrittweise

Difference ≈ 31 g
--> ≈ 9 kJ

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Technical & physical constraints

Technical constraints	
Quantity	Value
Amount of R23 for 3h sounding [kg]	0,4
Max payload mass [kg]	4,5
Actual payload mass [kg]	2,5
Average cooling power [W]	10,5
Max cooling power [W]	12
Max mass density in [g/cm²]	13

Physical constraints	
Quantity	Value
Temperature at 1000 hPa in [K]	< 193
Temperature at 100 hPa [K]	< 178
Temperature at 5 hPa [K]	≈ 132
Triplepoint pressure [hPa]	< 5
Triplepoint temperature [K]	< 140

Cryogen has to be available commercially

Non toxic, -flammable, -corrosive/oxydative

Question: Which cooling mechanisms can be applied?
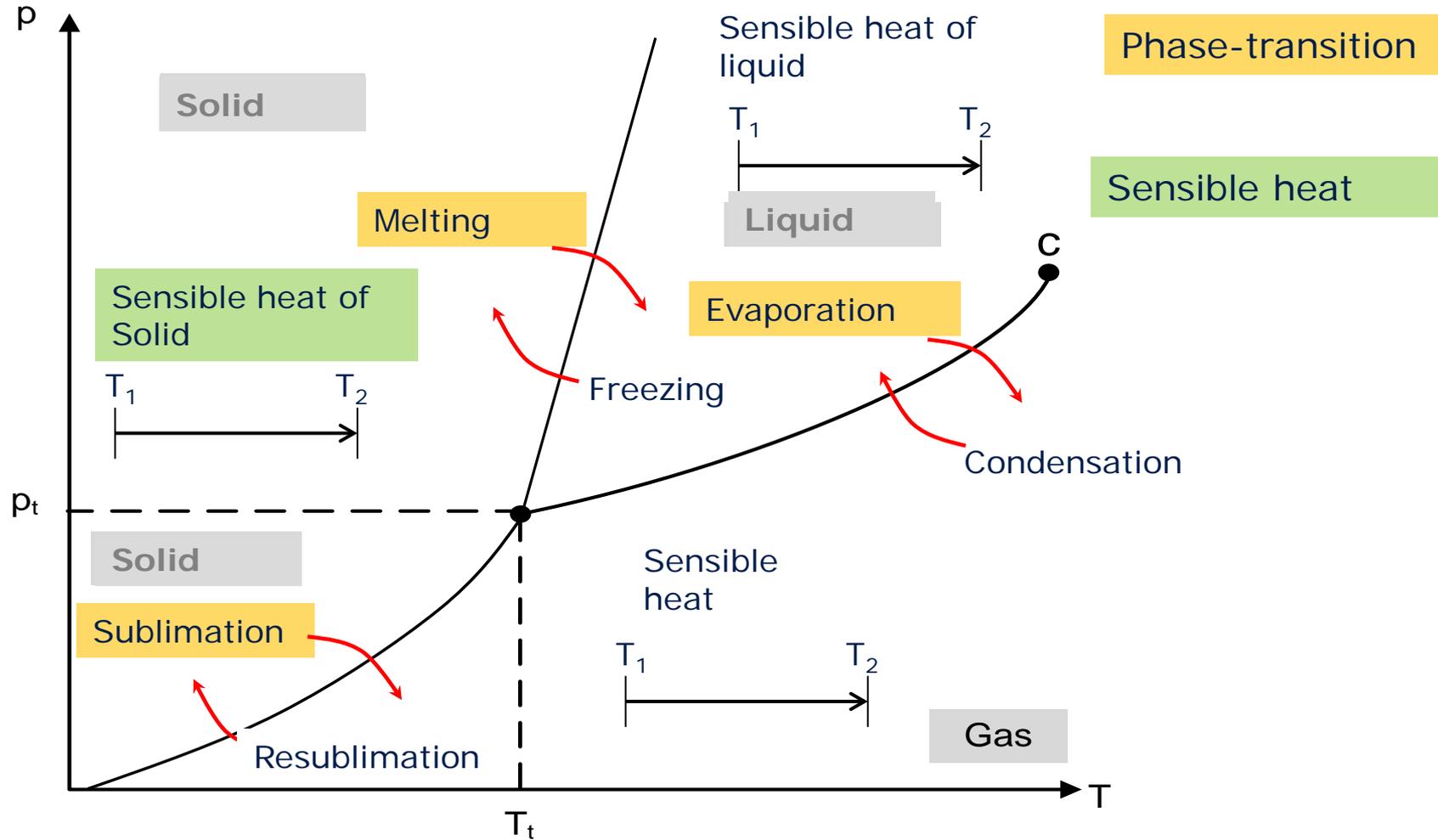
Mechanisms:

Baro-, magneto- and elasto- and Electrocalorimetry

Challenge (constraints):

Temperature difference: > 50 K

Power: up to 12 W

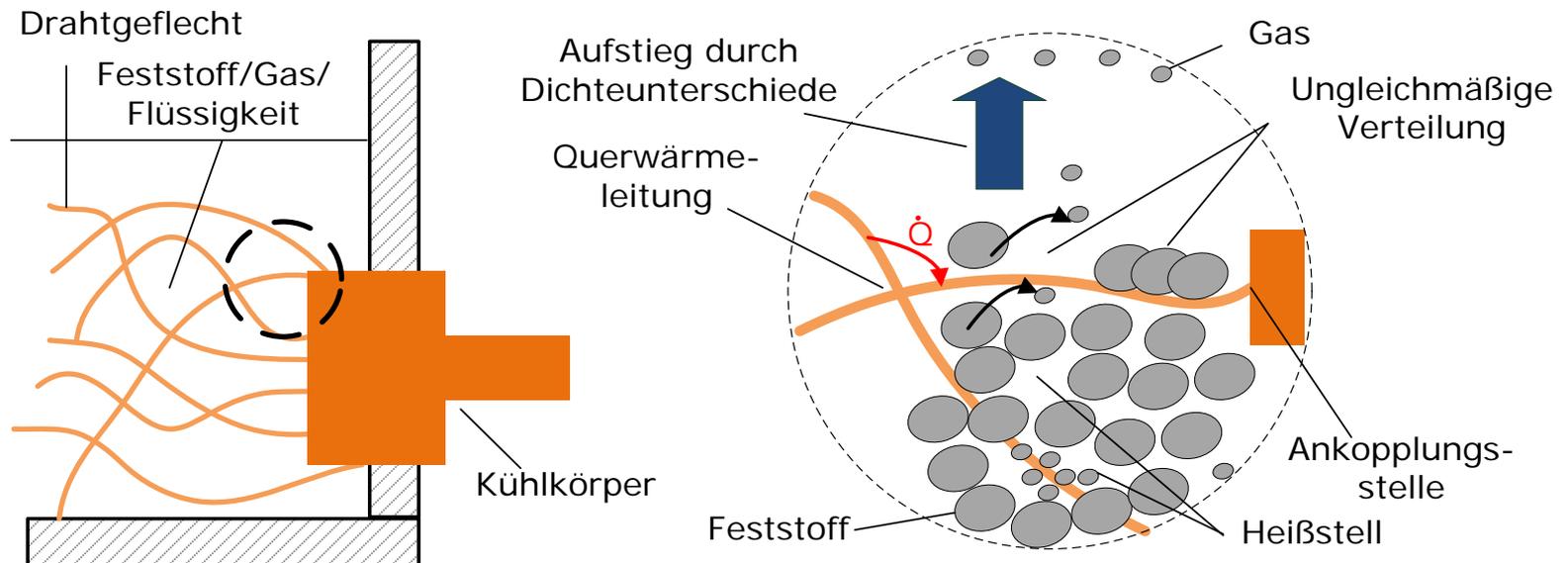Mass limit: 2 kg

→ No technical solution available

Evaporation:
Heat: 113 kJ → 0,5 kg (current design) → 230 kJ / kg

Melting:
Heat: 113 kJ → 2,4 kg (Maximum) → 50 kJ / kg

Sublimation: Heat capacity?

Evaporation: (Nr of assessed fluids: ≈2000)

Fluid	NBP [K]	T_{trip} [K]	p_{trip} [hPa]	T_{boil} @ 5 hPa [K]	Issue
Ethane	184,6	90,4	0,01	122,5	Flammable
Ethene	169,4	104,0	1,22	112,7	Flammable
Oxygen	90,2	54,4	1,46	58,6	Oxidative
Fluor	85,0	53,5	2,39	55,9	Reaktive, toxic
COS	223,0	134,3	0,64	150,1	Flammable, toxic
R32	221,5	136,3	0,48	153,5	Flammable, GWP = 650
R41	194,8	129,8	3,45	132,6	Flammable
R1141	201,0	113,0	0,34	132,5	Flammable

NBP = Normal boiling point (@ 1000 hPa)

Conclusion: No alternative that satisfies all criteria!
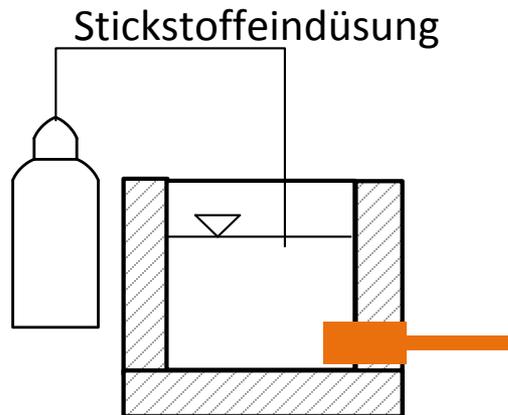
Melting :

Fluid: (T_{melt} < 153K)   Butane, Pentane, Hexan (Iso- and Normalforms)
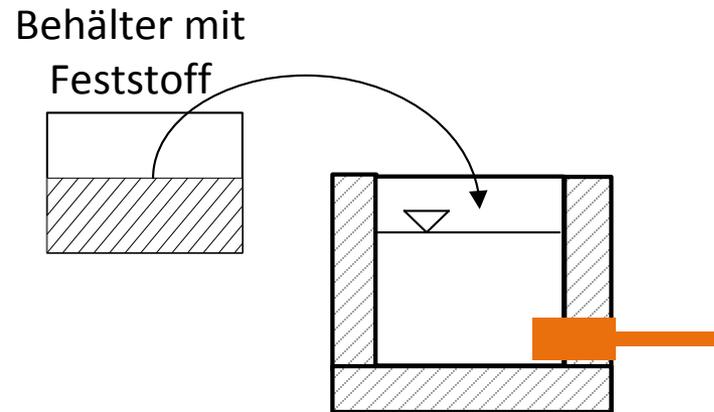Ethers

Fluid: (T_{melt} < 173K)   Alcohol, Polyflourether
Hydrofluorocarbon

Fluid	R134a	R245fa	R1234ze
kJ / kg	25	60	95

Feststofferzeugung in Apparatur   Feststofferzeugung Extern

Stickstoffeindüsung   Behälter mit Feststoff

Sublimation:

Fluids: (T_{sub} < 153K) Cryogenic (Ar, N_2, CH_4)

Fluids: (T_{sub} < 173K) Hydrofluorocarbons (R125, R1123 …)

Fluid	Ar	N_2	CH_4
kJ / kg	195	262	604

Example: N_2

Triplepoint nitrogen 125 hPa

Evaporation – large heat capacity
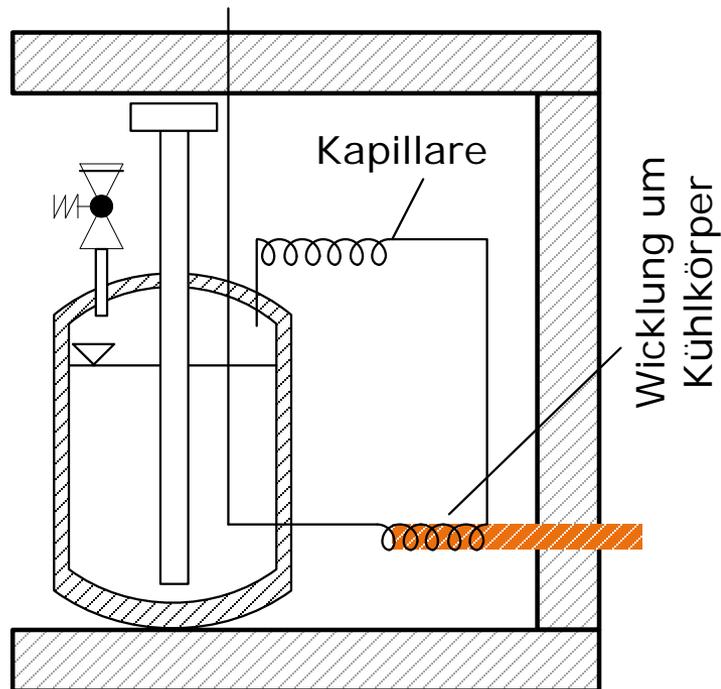
Sublimation – small heat capacity
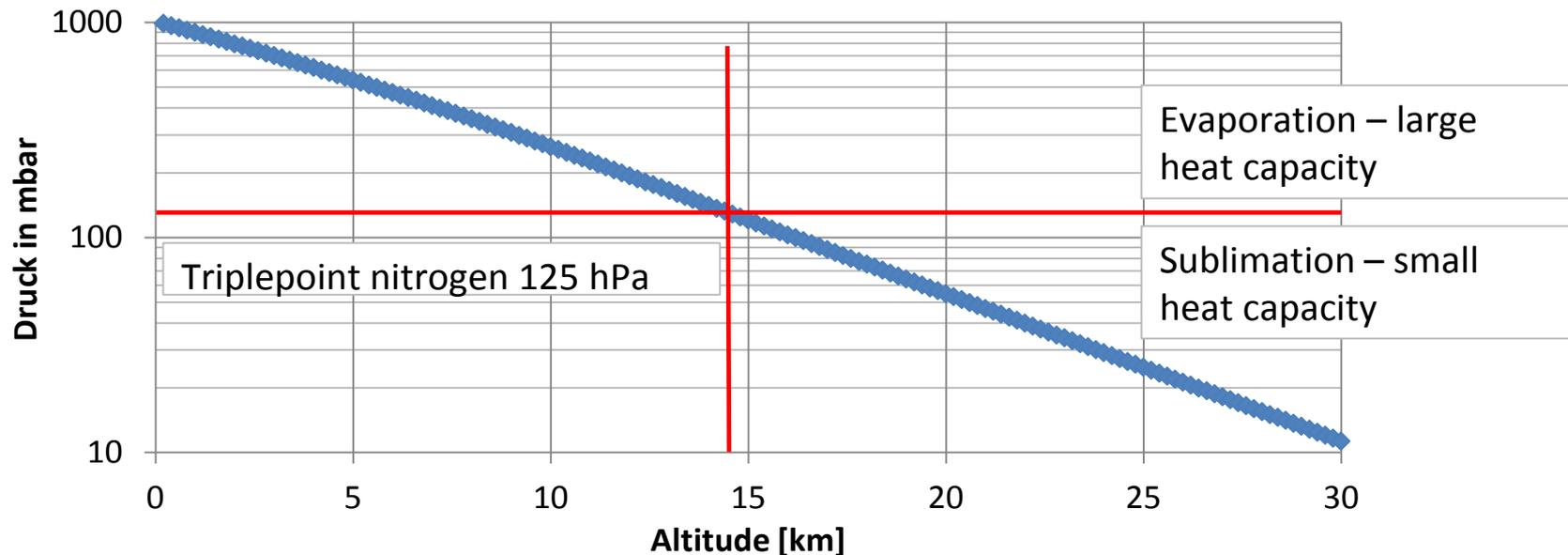
Problem: Triplepoint N_2 125 hPa >> p_{min} = 5(10) hPa Sublimation

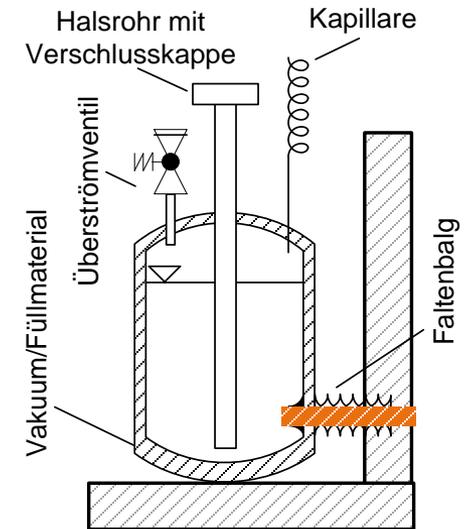<u>Idea</u>: Liquid N_2 in pressurized Dewar (0.83 l N_2 ≅ 0.66 kg)

Cooling with cold nitrogen gas

Kapillare

Wicklung um
Kühlkörper

Nutzung Kaltgas mit
Gasrückführung zur Druckhaltung

Approach:

Pressure retention in Dewar by capillary

Direkte Anbindung

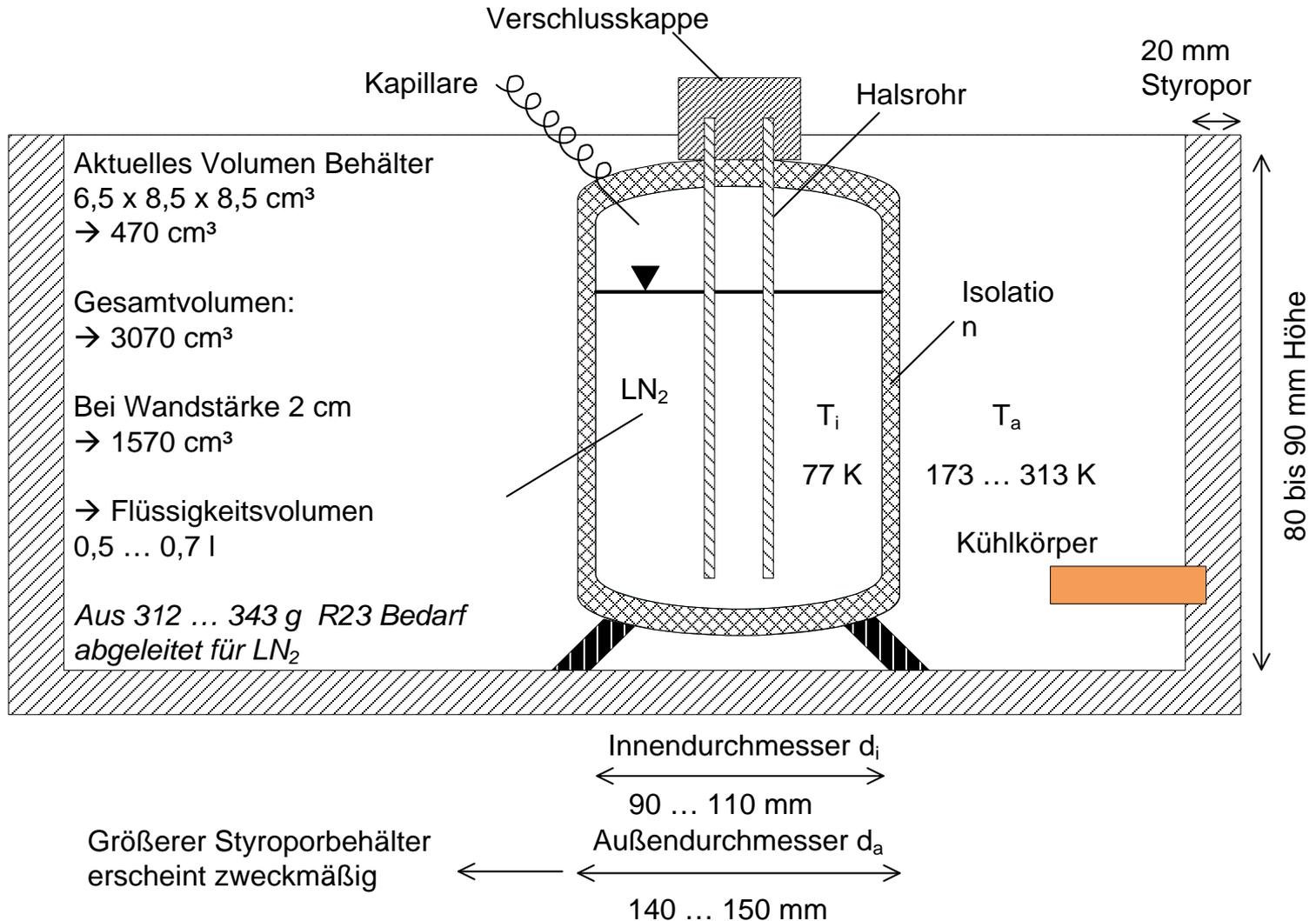### Parameters for capillaries:

Length   1 m
Internal diameter: 0,7 mm

Pressure [bar]	Exit pressure [hPa]	Mass flow [kg/h]	Cooling power [W]	Remarks
2,2	1000	0,27	15	-
2,0	5	0,27	15	Choke limit of capillary
1,4	5	0,18	10	Choke limit of capillary
0,7	5	0,09	5	Choke limit of capillary
0,2	5	0,025	1,5	minimal pressure to sustain flow

Verschlusskappe

Kapillare

Halsrohr

20 mm
Styropor

Aktuelles Volumen Behälter
6,5 x 8,5 x 8,5 cm³
→ 470 cm³

Gesamtvolumen:
→ 3070 cm³

Bei Wandstärke 2 cm
→ 1570 cm³

→ Flüssigkeitsvolumen
0,5 … 0,7 l

Aus 312 … 343 g R23 Bedarf abgeleitet für LN₂

LN_2

Isolation

T_i

77 K

T_a

173 … 313 K

Kühlkörper

80 bis 90 mm Höhe

Innendurchmesser d_i

90 … 110 mm

Größerer Styroporbehälter
erscheint zweckmäßig

Außendurchmesser d_a

140 … 150 mm

- Need for alternative to R23 as cryogen for frostpoint hygrometers

- Preferred cooling mechanisms: Evaporation, melting, sublimation

- A fluid is available for all transitions/mechanisms

- Sublimation: small heat capacity

- No alternative to R23 that matches required properties

- Alternative option: Liquid N_2 in Dewar with capillary for flow control (choke limit)

Next step: Testing of
- sublimation + Metal mesh
- Dewar + Capillary