

CRYOGENIC STORAGES AND DISTRIBUTION LINES

THIS DOCUMENT IS

ALaT Sassenage • 04/10/2019
Gas & Cryogenics... S.DUVAL...

**ADVANCED BUSINESS
& TECHNOLOGIES**

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Context & Overview

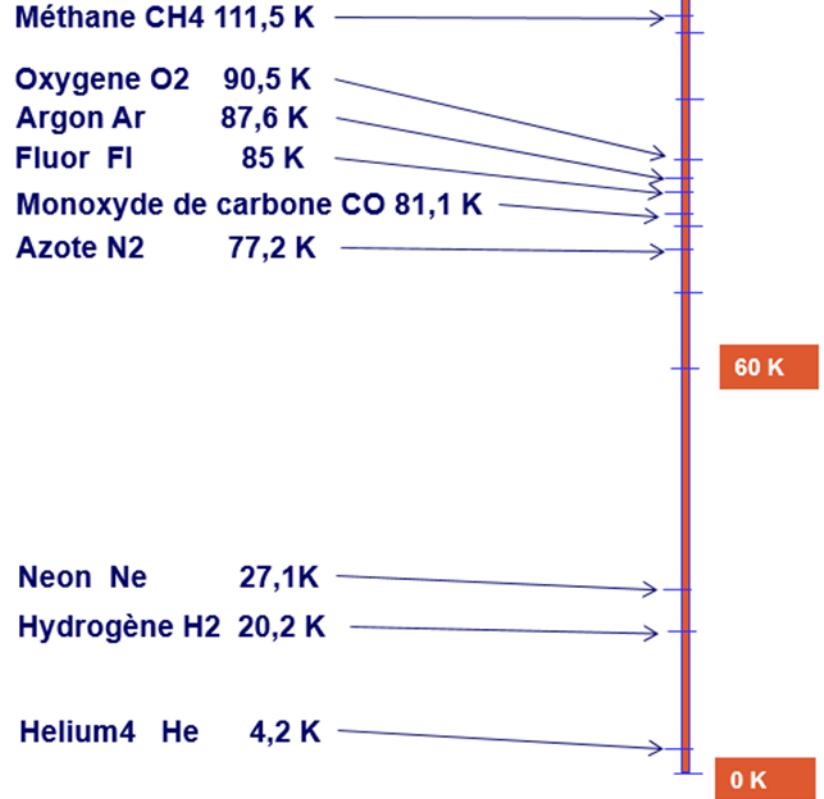
1. Context § Overview

Cryogenic storages and distribution lines are used for storing, transport and delivering at customer site or customer application cryogenic fluids.

They have to be designed in order to preserve in the best way liquid state of the fluid and so on to limit as much as possible flash and boil-off

Definition of cryogenic fluid

Boiling point (BP) at atmospheric pressure < 120 K (exception with ethylene of 170K)

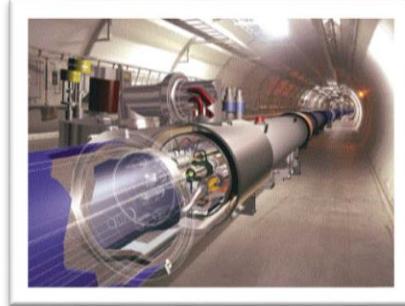


1. Context § Overview – Product&market

Cryogenics storages and distribution lines (most of them with vacuum insulation) can be split in 3 mains market



SPACE GROUND FACILITIES



- SCIENTIFICS RESEARCH

- INDUSTRY&TRANSPORT



1. Context § Overview - market

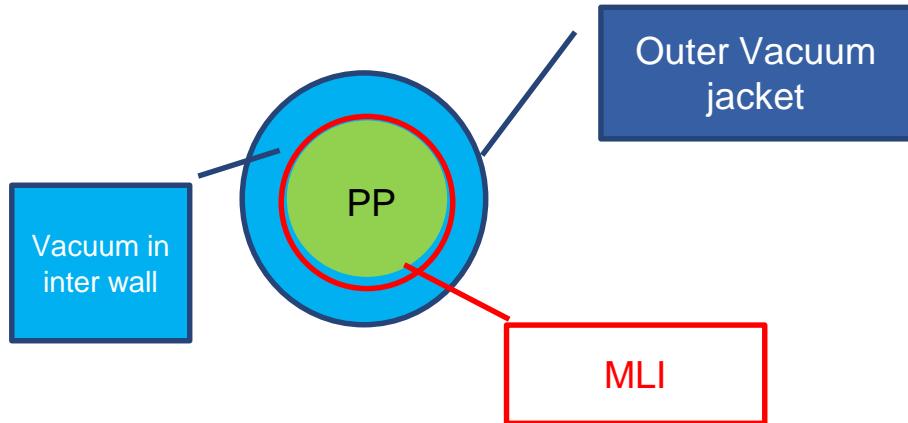
SPACE GROUND FACILITIES



1. Context § Overview – Ground space facilities

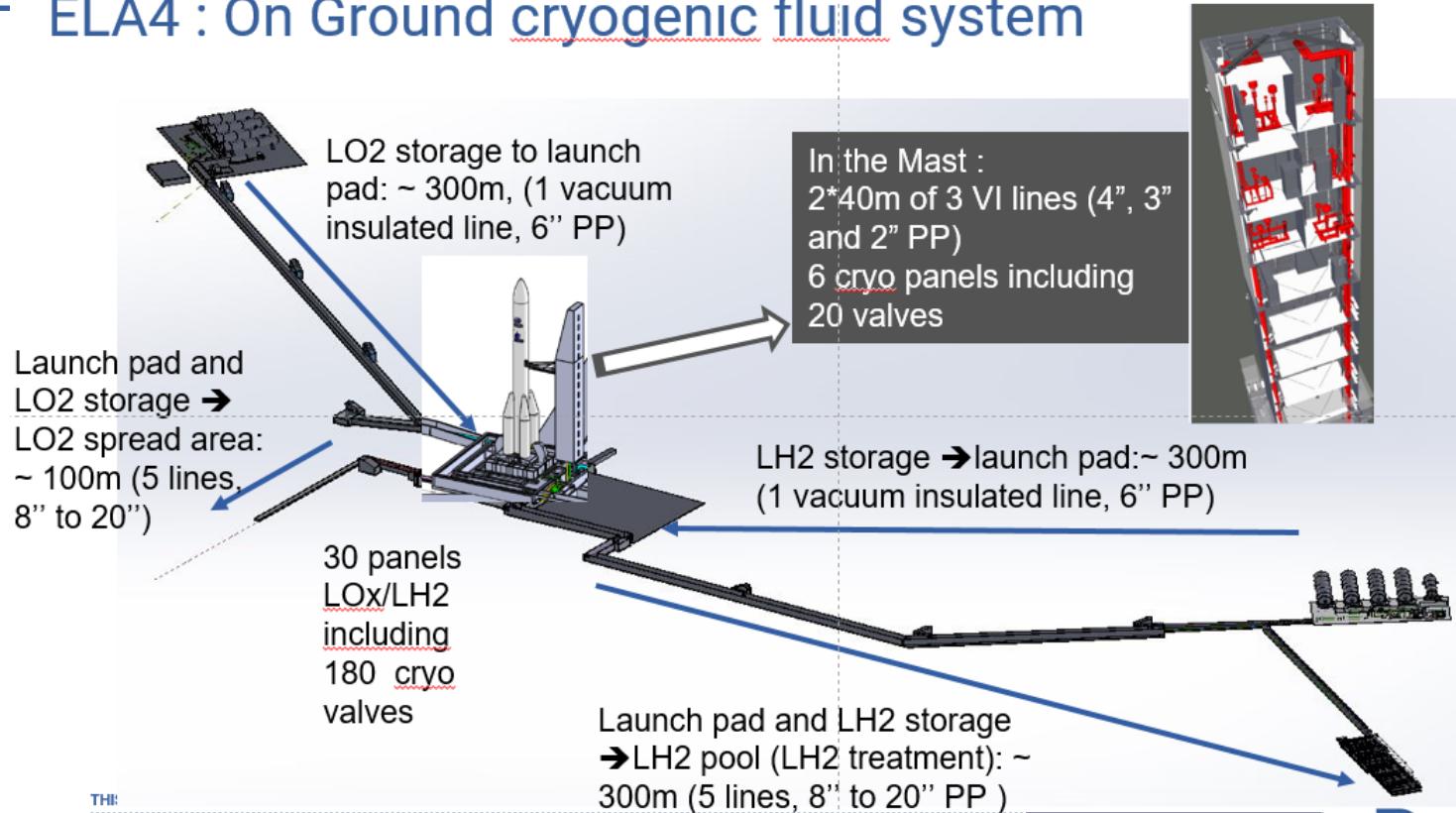
Equipment : Cryo Storages and distribution lines of liquids and gases on launch pads for propulsion (Liquid oxygen, Liquid hydrogen), pressurizing (helium), inerting (nitrogen, helium)

Main of cryogenic lines are mono lines vacuum insulated with MLI (multi layers insulation) that means one process pipe inserted in Outer vacuum jacket with vacuum in the interwall + MLI



1. Context & Overview – Ground space facilities

- ELA4 : On Ground cryogenic fluid system



THI:

1. Context § Overview – Ground space facilities

LOX and LH₂ semi mobile Storages from 140m³ et 360m³



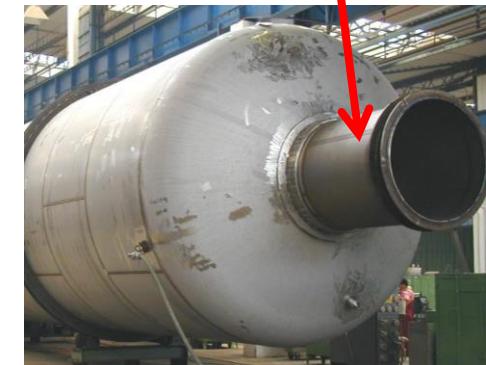
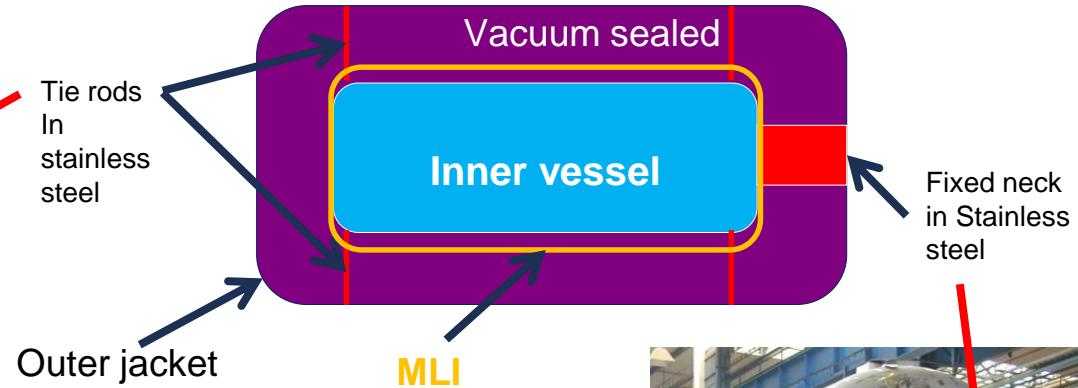
Empty weight : 50 t
IxLxh : 18,2*5,4*5,5m
Water capacité : 110m³
Net volume at 20K : 100m³
Max Operating pressure : 10 bar g
Insulation : MLI under vacuum
Loss rate: < 0,3%



Empty weight : 80 t
IxLxh : 24*5,4*5,6m
Water capacité : 360m³
Net volume at 20K : 320m³
Max Operating pressure : 3,3 bar g
Insulation : MLI under vacuum
Loss rate: < 0,3%

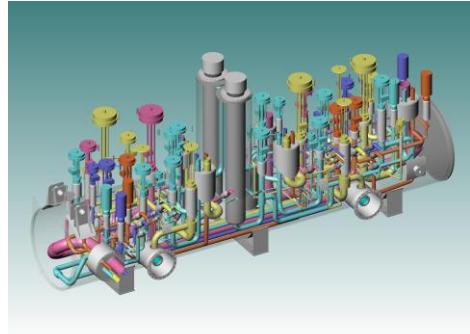
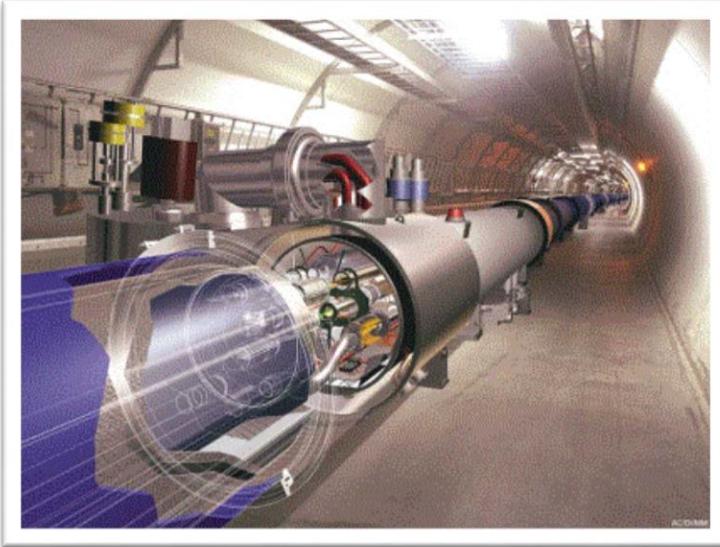
1. Context § Overview – Ground space facilities

Design concept of Vacuum insulated tank



1. Context § Overview - market

SCIENTIFICS RESEARCH



1. Context § Overview – Scientific research

Equipment : Generally, for such particular application, it's mainly Helium cryogenics multi lines that are used and implemented with very efficient heat load protection

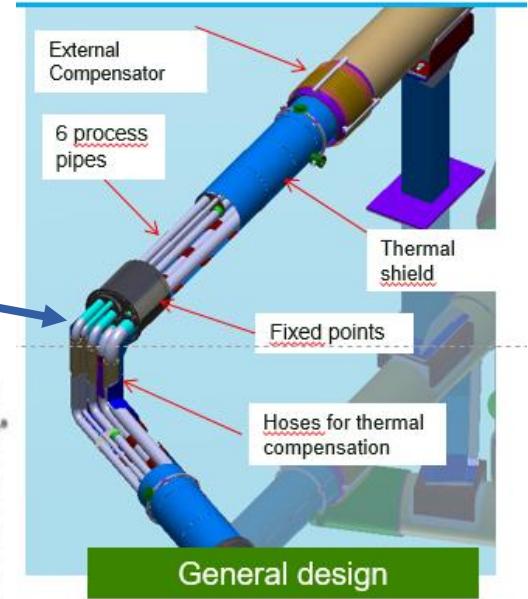
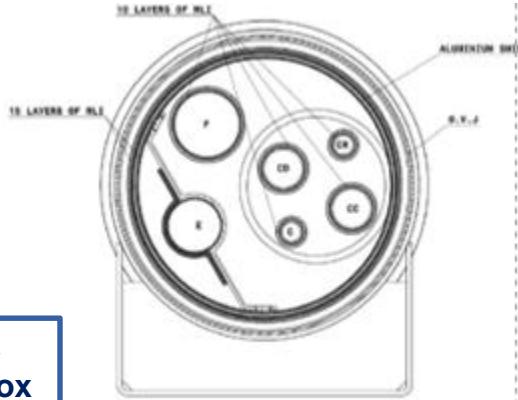
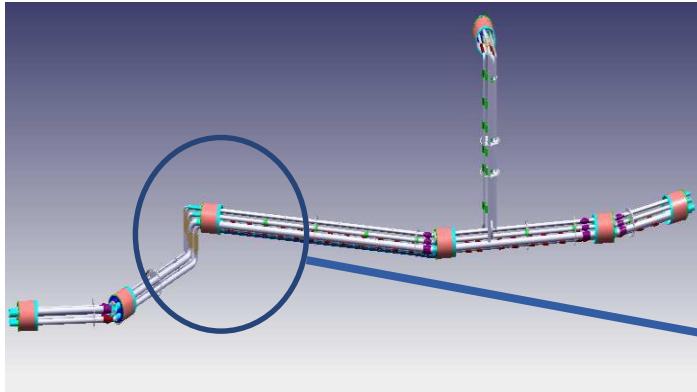
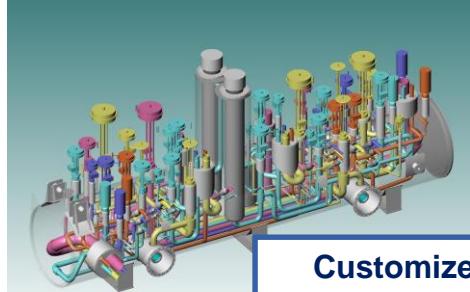
Then design consist in several process pipes (between 3 and 8 – diameter comprise between 25ND to ND200) inserted in common outer vacuum jacket (can be comprised between DN200 to DN1000)

All process pipes are insulated with MLI, and some of them (with fluid at the lower temperature) are protected inside by a thermal shield (usually in aluminium) thermalized by 80K process pipe

Usually, we have dynamic vacuum (Outer jacket connected to vacuum pump for permanent or discontinue pumping) in interwall to maintain very efficient vacuum (<1.10-6mb)

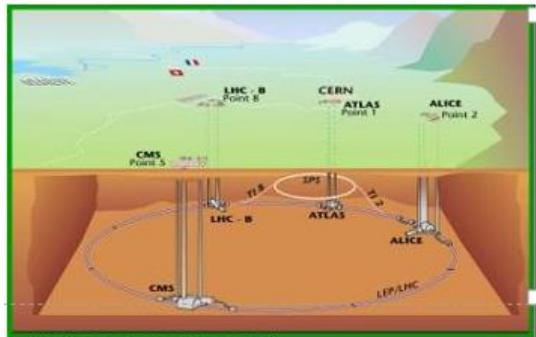
1. Context § Overview – Scientific research

Equipments :

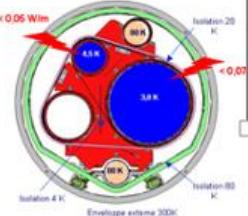


1. Context § Overview – Scientific research Main Huge Project

CERN – Multi cryogenic lines 27 km (2005)



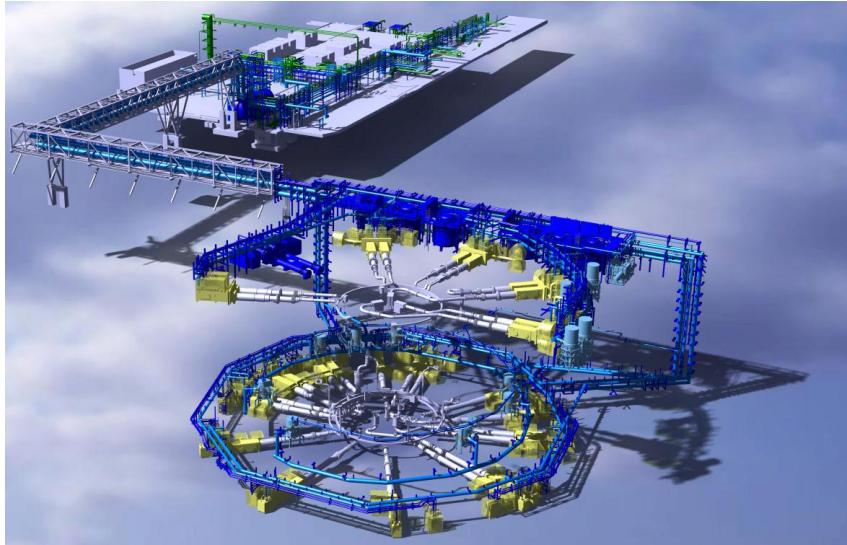
Cryogenic transfer lines



- ✓ 5 Inner process pipes at 3K, 4.5K, 20K et 2 x 80K
- ✓ Heat loads at 4.5K et 20K < 0,05 W/m
- With
 - 220 specific Pipe elements (PE)
 - 1650 standard PE ($\varnothing 610\text{mm}$ - L = 11,5 m)
 - 240 PE with fixed points (diam610 & 650 - L = 6,8 m)
 - 309 valves boxes with 42 design configuration
 - 53 Elbow&step elements
 - 2500 interconnections
 - 100 000 on site welds

1. Context § Overview – Scientific research Main Huge Project

ITER Cryolines – August 2015 – Ongoing project



19 Helium Multi Cryo Lines (with 2 to 8 process pipes) :

1,6 km + 1 prototype 27m

- ✓ 199 PE to manufacture (all differents)
- ✓ Process pipes diameter between DN40 et DN250
- ✓ Vacuum jacket diameter between DN400 et DN1000
- ✓ 75 interfaces with equipments (Cryoplants, valves box, feeders,...)
- Design /Supply/
Fabrication/Installation/ Tests

1. Context § Overview - market

INDUSTRY & TRANSPORT



1. Context § Overview – Industry an transport

Equipment :

- ❑ Industry and transport markets are more linked to LH₂ application (electronic, metallurgic,. And now for H₂ mobility) and required essentially :
 - ✓ Cryogenic Vacuum insulated fixed storage from 10m³ to 300m³ – 12bar– same design concept given than these given in ground space market chapter even if here tanks are in vertical position



- ✓ Cryogenic Vacuum insulated mono lines (process pipe diameter around ND80 – ND100) and cryo skids (with valves under vacuum)

1. Context § Overview – Industry an transport

Equipment :

- ✓ Cryogenic semi trailer for road (and sometime sea) transportation around 50m³ - 12bar - same design concept given than these given in ground space market chapter



Empty weight : 18 t
IxLxh : 13,95*2,55*3,9m
Water capacité : 51 m3
Net volume at 20K : 43,4 m3
Max Operating pressure : 13 bar g
Insulation : MLI under vacuum
Loss rate: < 1%
Autonomy : 150 hours

1. Context § Overview – Industry and transport

Equipment :

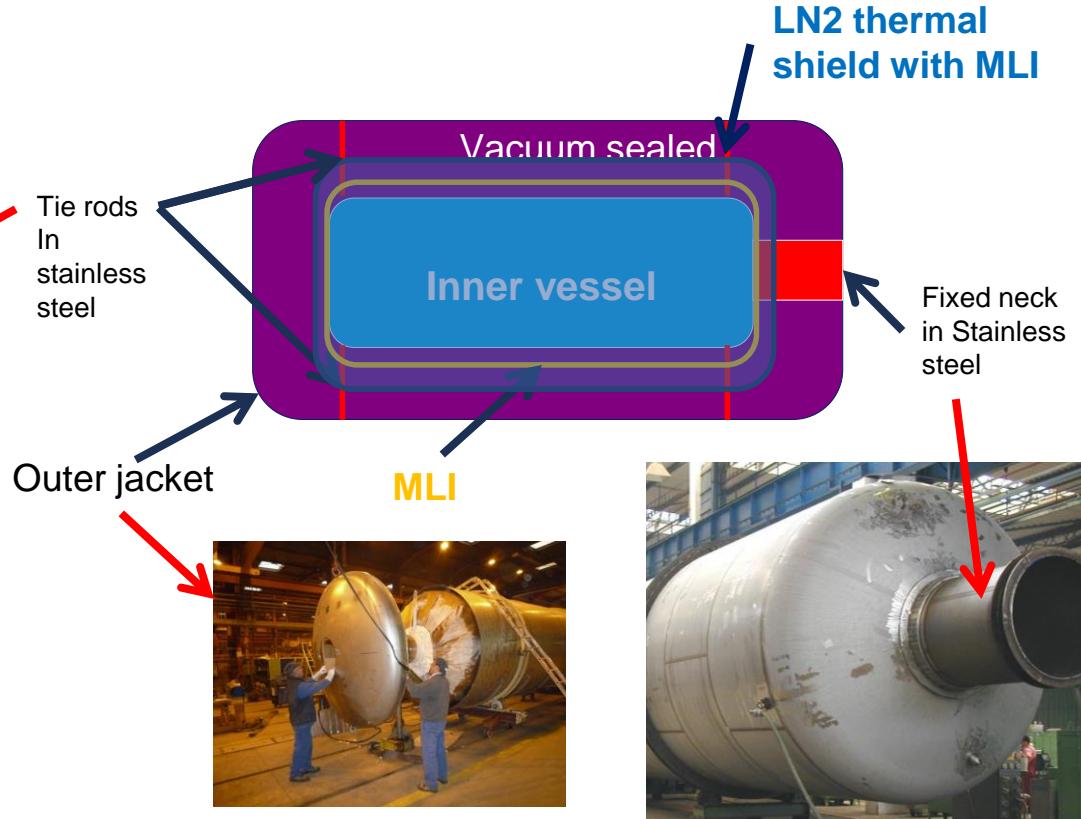
- ✓ 11000GUS LH2 Container : specific design and LN2 thermal shield for increasing thermal performance



Empty weight : 19,4t
h x Ø: 12,2*2,4*2,6m
Water capacité : 38,2 m3
Net volume at 20K : 34,6 m3
Max Operating pressure : 12 bar g
Insulation : MLI under vacuum with LN2 thermal shield
Loss rate: < 0,1% by day
Autonomy : From 30 to 45 days

1. Context § Overview – 11000GUS LH2 Container

Design principle of LH2 CNT



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Design Constraints Design Rules

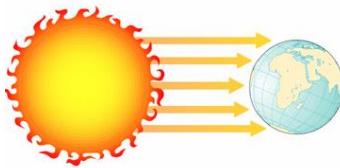
2. Design Rules

2.1 Thermal Insulation

2.1 Thermal Insulation

→ Thermal performances are evaluated with HEAT LOAD Calculations :

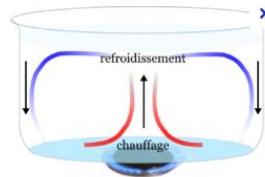
→ Heat loss by radiation



→ Heat loss by conductivity

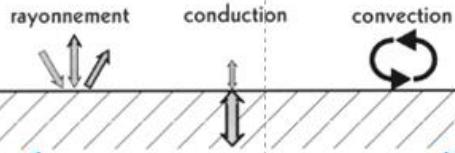
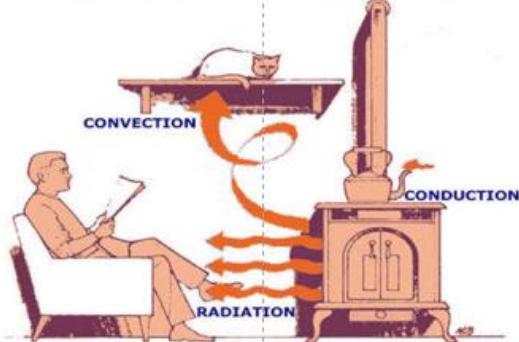


→ Heat loss by convection



2.1 Thermal Insulation

Three Modes of Energy Transfer



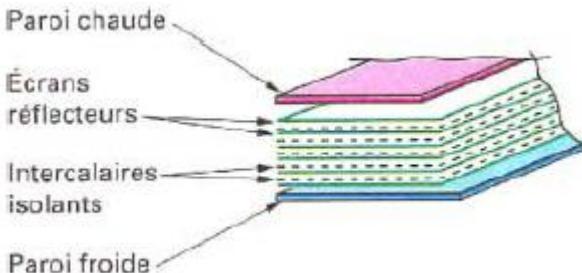
Put some reflective
isolation
MLI

Make a design with long
thermal path
No direct contact between
2 temperatures

No air movement :
vacuum insulation

2.1 Thermal Insulation - MLI

- Super insulation is used when the acceptable thermal leaks are very low. It uses combination of :
 - Low emissivity shields : → reflectors
 - Insulated between each other thanks to high thermal resistance material
- Always associated with **vacuum** (1.10^{-3} / 1.10^{-4} mbar / more) to have a very low gaseous conduction



2.1 Thermal Insulation - MLI

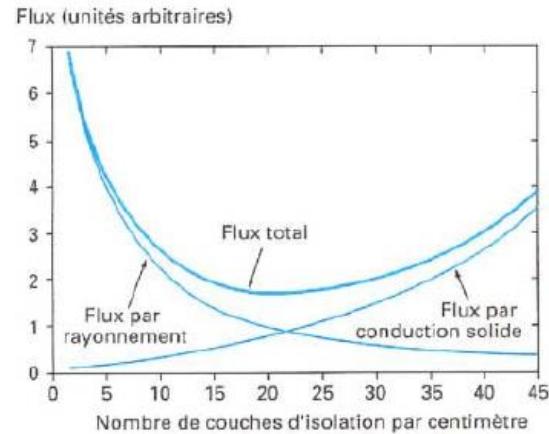
- For non flammable fluids
 - Reflecting material: Mylar (polyester) with aluminum film (150-400 Angst.)
 - Cryotherm 233 layer
 - For H₂ and O₂ applications, because of flammability risks:
 - Reflecting material: aluminium 9 µm
 - Glass fiber layers
 - ... fragile and easily compacted (=> lower performances)
- => Careful handling

2.1 Thermal Insulation - MLI

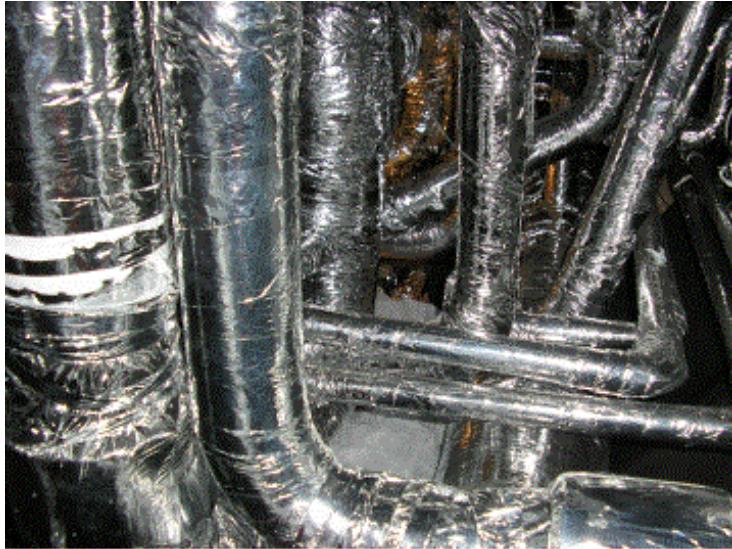
- For non flammable fluids
 - Reflecting material: Mylar (polyester) with aluminum film (150-400 Angst.)
 - Cryotherm 233 layer
 - For H₂ and O₂ applications, because of flammability risks:
 - Reflecting material: aluminium 15 µm
 - Glass fiber layers
 - ... fragile and easily compacted (=> lower performances)
- => Careful handling

2.1 Thermal Insulation - MLI

- For a setting of **15 to 20 layers / cm**, equivalent thermal conductivity :
 - Between 90 and 300 K: $\lambda_{\text{éq}} = 0.1 \text{ mW/m/K}$
 - Between 4 and 90 K: $\lambda_{\text{éq}} = 0.05 \text{ mW/m/K}$
- For high thermal efficiency, thermal shields must be used:
 - LN_2 shields
 - Vapour helium shields

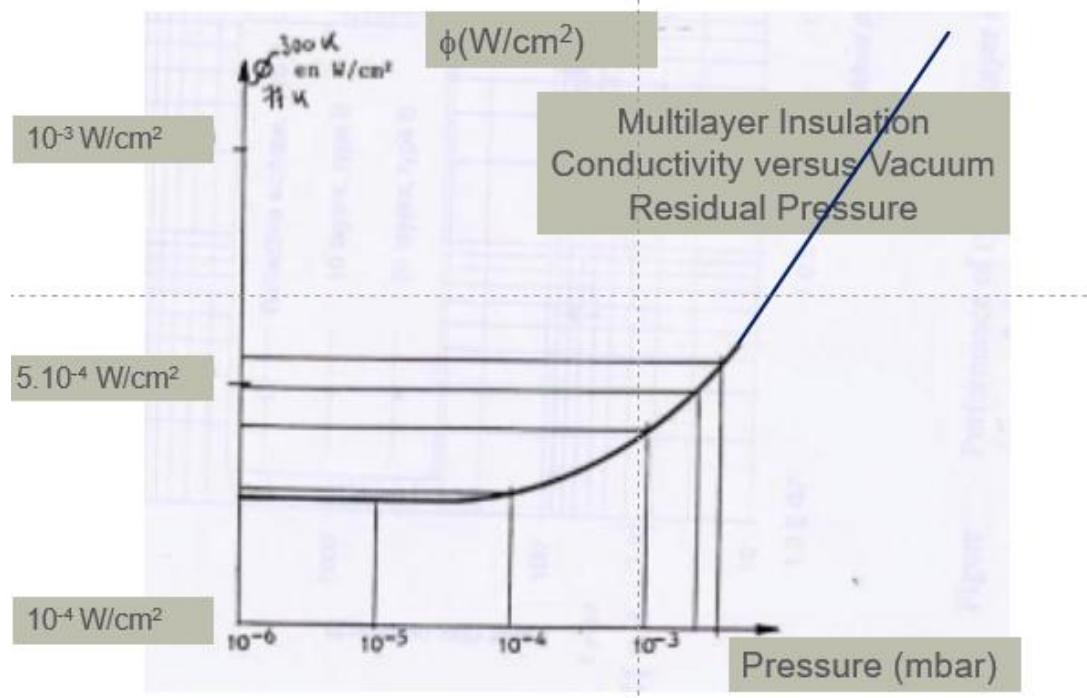


2.1 Thermal Insulation - MLI



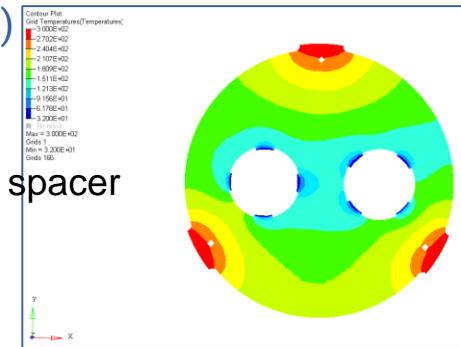
2.1 Thermal performances - Vacuum

- **Vacuum insulation :** Heat flux varies with residual pressure



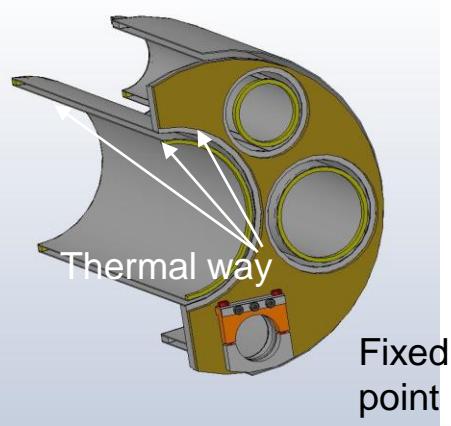
2.1 Thermal Insulation - Conduction

- **Conduction through piping and supports:**
 - Ruled by the Fourier's law
- For spacer put in place in the interwall for maintaining process pipes inside vacuum jacket, we use composite material like G10-G11, excepted for Oxygen lines for which we prefer Teflon or similar (for pb of O₂ compatibility)



→ For fixed point, we use stainless steel support (due to mechanical resistance but then with necessity to increase thermal path)

Material	λ , Thermal Conductivity (W / (m.K))
Copper	400
Aluminium	250
Stainless steel	15
Composite	1



2.1 Thermal insulation -Heat flux vs insulation techno

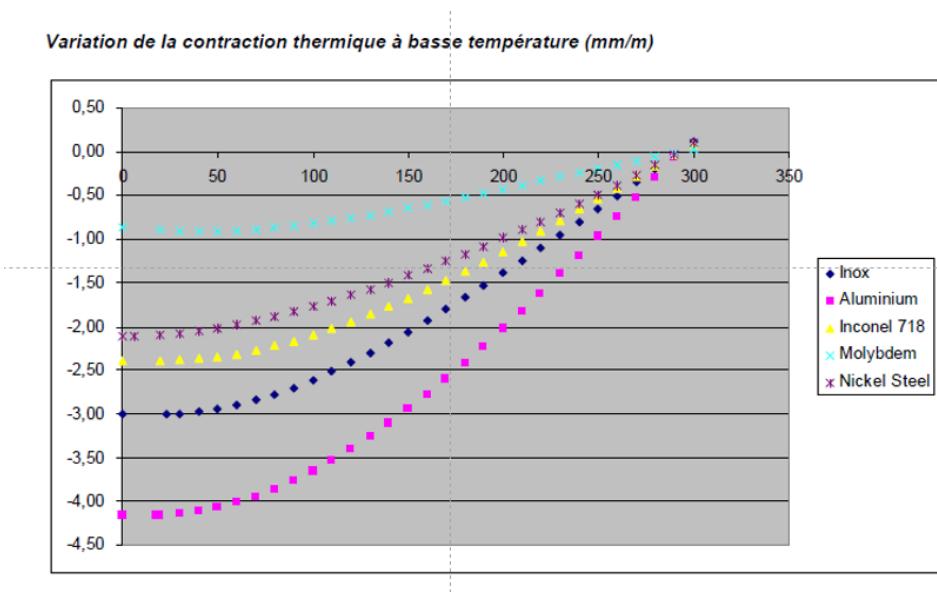
Tableau 6 – Flux de chaleur transmis entre deux plaques planes séparées par divers types d'isolants

Isolant	Flux transmis entre 300 et 77 K (W/m ²)
Vide poussé 10 ⁻⁶ mbar (émissivité 0,02)	9
Gaz à la pression atmosphérique : H ₂	29
He.....	256
N ₂ ou air....	41
(épaisseur de la lame de gaz 10 cm, sans convection)	
Perlite sous vide poussé (épaisseur 10 cm)	4,5
Perlite sous vide primaire < 10 ⁻² mbar (épaisseur 10 cm)	56
Klégécell 35 kg /m ³ (épaisseur 10 cm)	58
Superisolant $k = 0,3 \times 10^{-7}$ mW/(m · K) (épaisseur 2 cm)	0,33

2.2 Thermal contraction effect

- **Thermal contraction effect**

→ Because of the « double jacket » design, cryogenic devices have to be planned to support (without harm) the different thermal expansion effects of the two jackets



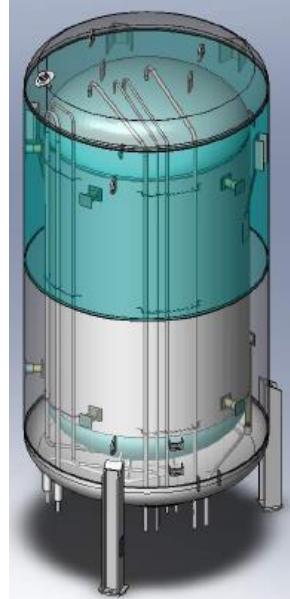
2.2 Thermal contraction problem

- For Vacuum insulated tank, the main rules are :

- A fix point is set at one side of the shell (usually at bottom side)
- A guide is installed at the other side
- Internal pipes are designed to fit with the less possible stress due to the thermal contraction (using natural flexibility with elbow – flexible hose are forbidden in interwall)

- For Vacuum insulated tank, the main rules are :

- Different solutions:
 - Natural flexibility of the pipe line (the first and best solution)
 - Flexible hoses
 - Install expansion joints on vacuum jacket or process (CAUTION: generates background effects)



2.3 Main Material used

- For process pipes or inner vessel

→ **Austenitics stainless steel: type 304 L / 316 L or 321 ***

- Easy to transform , to weld
- High ductile material
- Excellent for cryogenics application

* For H₂ application, only grade 316L or equivalent is accepted to avoid risk of H₂ embrittlement (Air Liquide rules)

→ **No carbon steel : too brittle for cryogenic application**

2.3 Main Material used for our cryogenic application

- For Outer vessel or outer jacket
 - carbon or stainless steel
 - For tanks : usually outer vessel is in carbon steel(cost reduction reason)
 - For cryogenic lines : In stainless steel
- For thermal shield
 - Aluminium
- For spacer
 - composite (G10-G11 or PTFE for oxygen application)

2.4 Regulation conformity – Mechanical calculation

- **Equipment have to be in accordance with :**
 - Customer Specification
 - State of the art
 - AND MORE IMPORTANT : REGULATION or CONSTRUCTION CODE of the final country destination
 - In **EUROPEAN countries**, pressure equipment put on the market have to be **CE marked** and so on be designed and manufactured in conformity with CE regulation and recognized norms and codes and for the main ones :
 - For fixed pressure equipment → PED 2014/68/UE with a known construction code as CODAP, EN13445, EN13485
 - For pressure equipment used for transport → ADR(road) / IMO 8 (sea) / RID (train)
 - For equipment under explosive atmosphere → ATEX 2014/34/UE
 - **For international : be aware of local regulation.**

2.4 Regulation conformity – Construction code

- **Pressure vessels**

- French construction code : CODAP
- American construction code : ASME VIII
- European Construction code : EN13445

- **Piping**

- French construction code : CODETI
- American construction code : ASME B31-3
- European construction code : EN13480

- **Structure**

- European construction code : Eurocode

- All the construction codes give guidance to the design : material choices, kind of assemblies, mechanical calculations, maintenance, controls
- So for equipment sold out of UE, be careful of local regulation



Thank you!