EP-DT
Detector Technologies

Outsourced production and the design of Phase-2 CO2 cooling systems.

29th May 2024

K. Sliwa

On behalf of EP-DT-FS section

Introduction and Background

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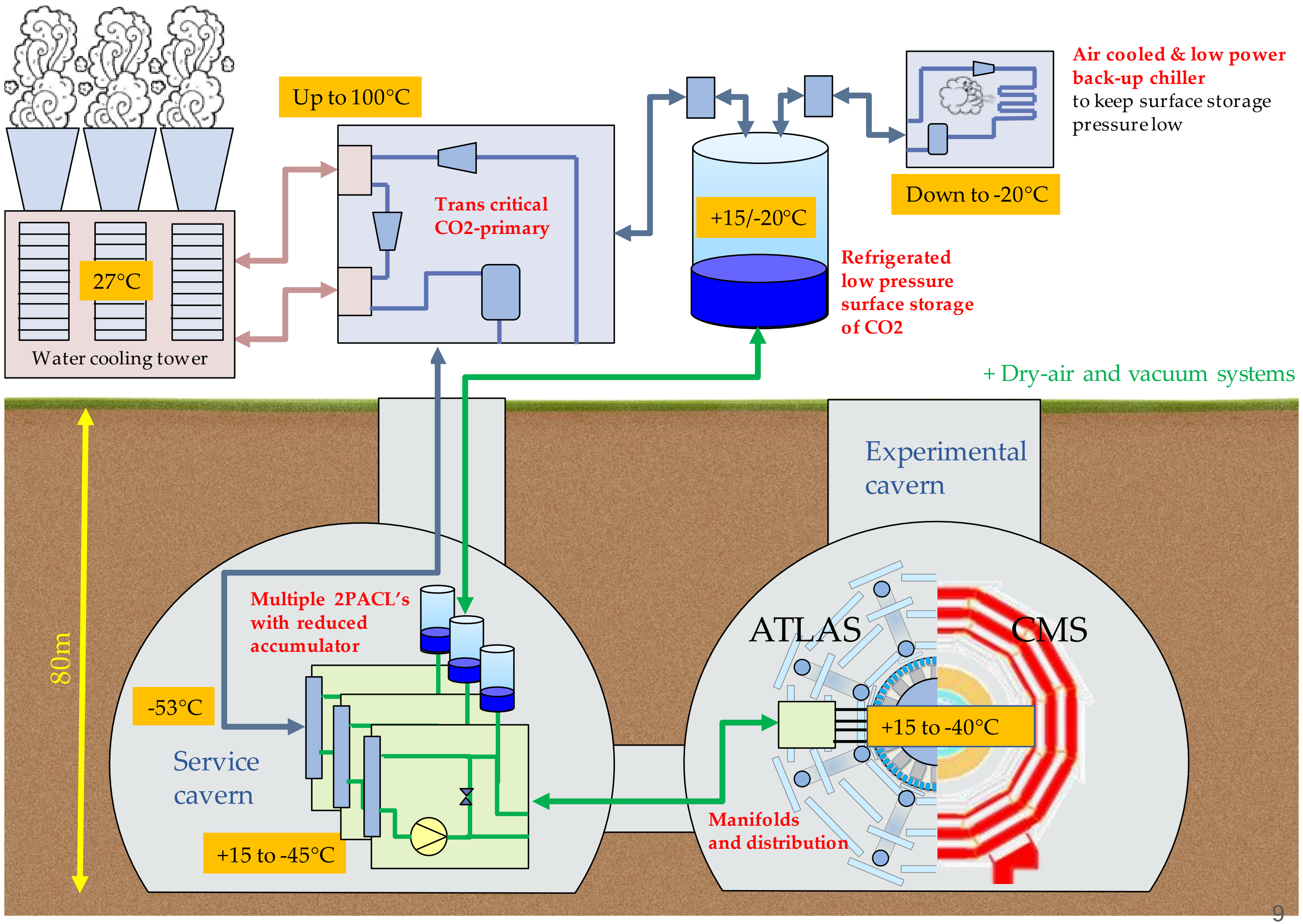
Phase 2 CO2 cooling systems



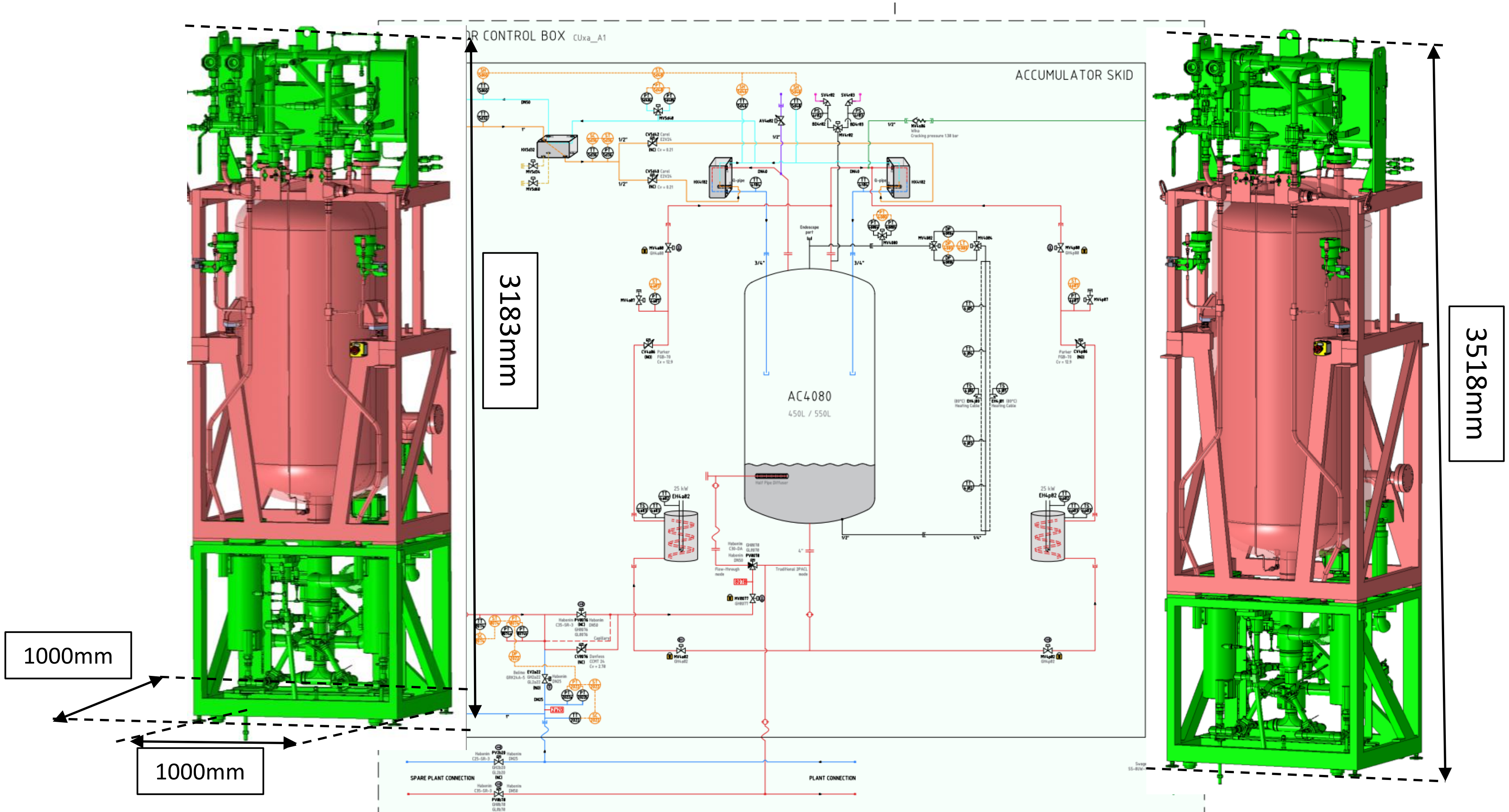
- The 2PACL cooling plants are located in USA-15 / USC-55
- Detector evaporator loops are connected via manifolds and concentric transfer lines to the 2PACL plants
- The 2PACL plants are cooled by the primary R744 which is located on the surface
- The primary R744 plants are cooled by water from the towers and air cooling
- Surface storage of CO_2 to control the charges of the underground 2PACL plants
  - Optimize accumulator volume in the caverns
  - Level control is important

2PACL final cooling system

- 2PACL final cooling system specs
  - 433L and 543L accumulator
  - 3-head plant → 1.58 kg/s
  - 100 kW dummy load
  - -45°C on Accumulator
  - -50°C on R744 chiller evaporator
  - 1 back-up plant per experiment

Plant and Accumulator design

Accumulator design overview



Short version Accumulator

Long version Accumulator

Main functions :

- **Cooling : Pressure decrease**
- **Heating : Pressure increase**
- **Level measurement : Empty/Fill to/from surface storage**
- **Back pressure regulator : Pressurize detector**
- **3way valve : 2PACL/Flow through mode swap**

2 Different designs :
Short version: ST1647910_01
Long version : ST1681442_01

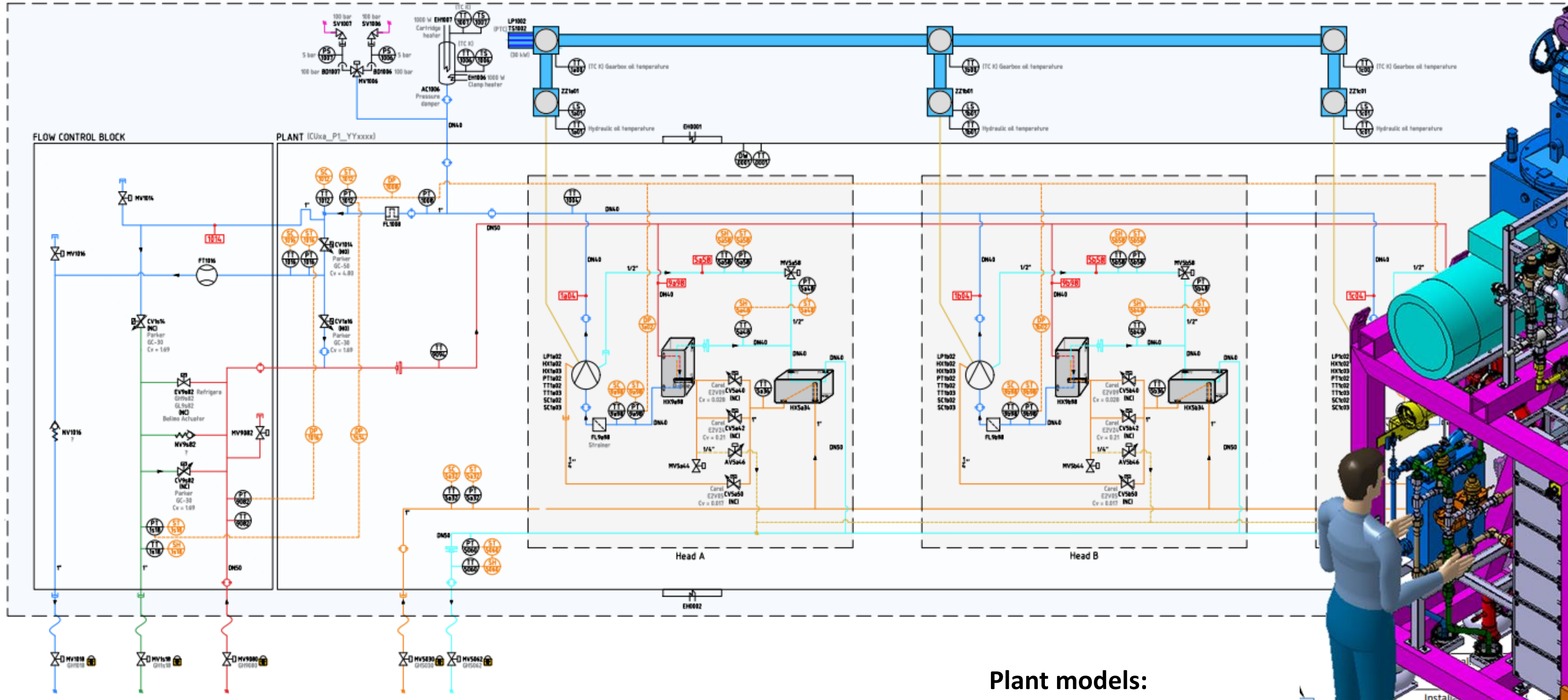
Design compliant with Pressure equipment directive 2014-68-UE

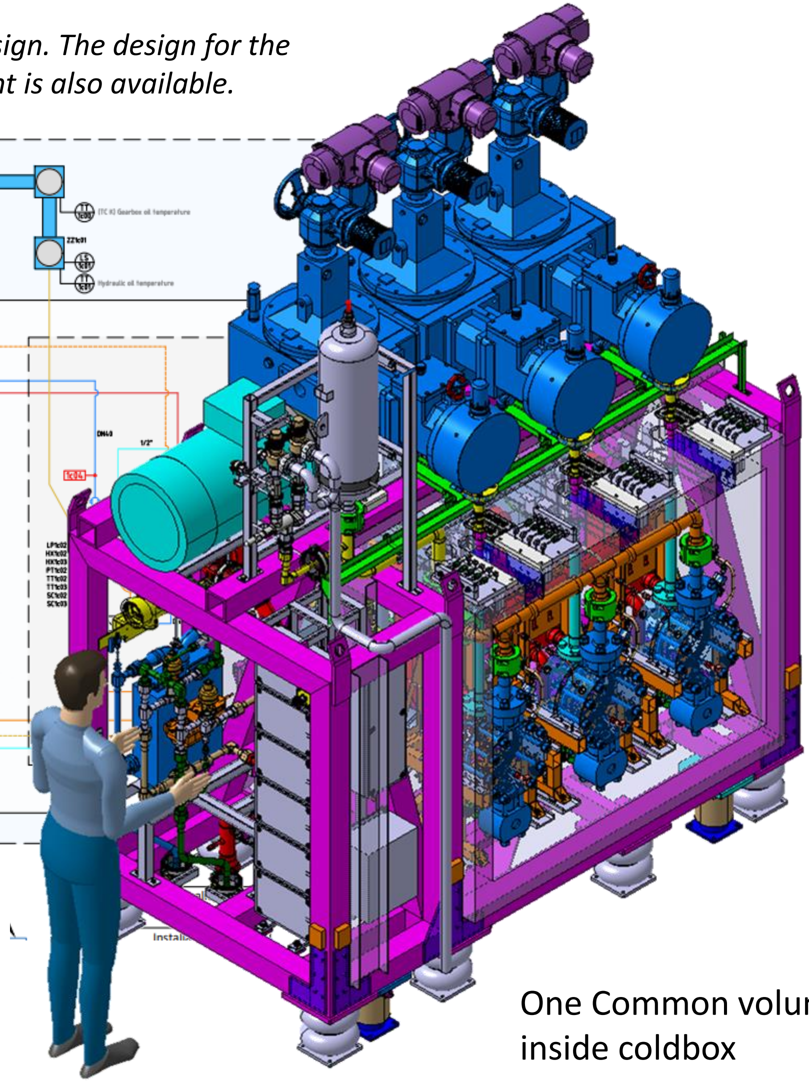
Common between short/ long version

Different in height

2PACL Design – Overall view

This presentation is focused on the 3heads plant design. The design for the 2Heads and 1Head plants based on 3Head final plant is also available.





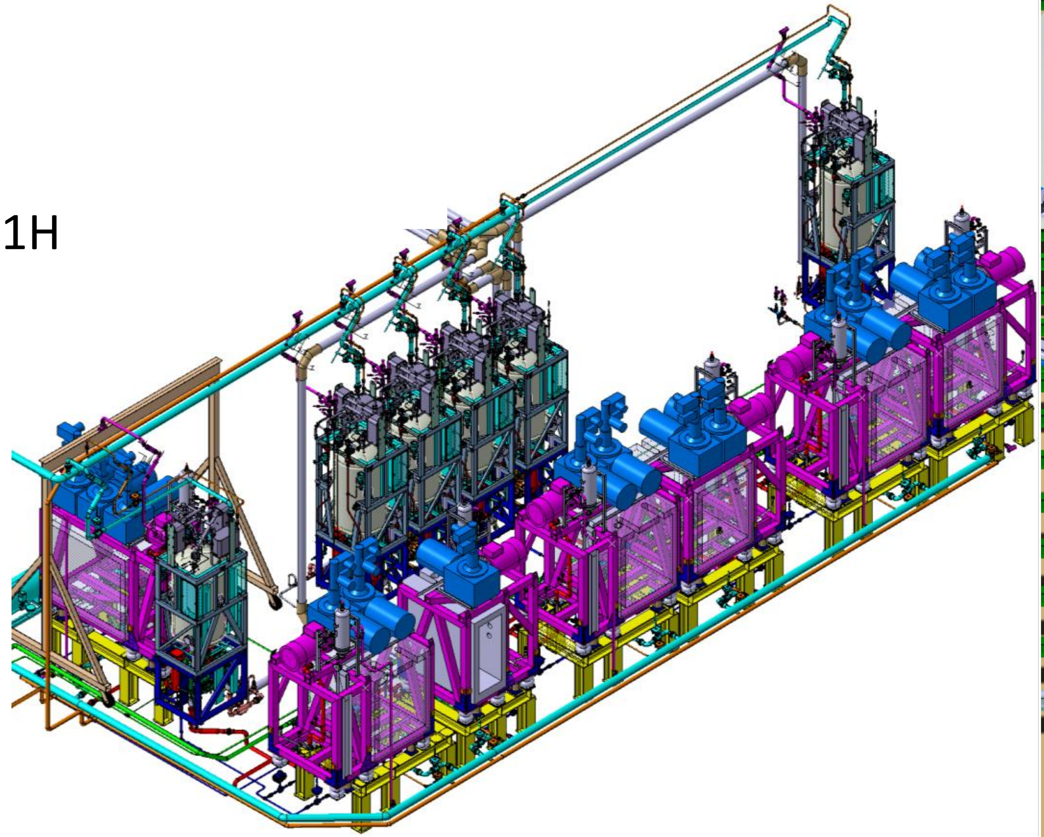
Plant models:
ST1442045_01 3H Plant
ST1534838_01 2H Plant
ST1534855_01 1H Plant

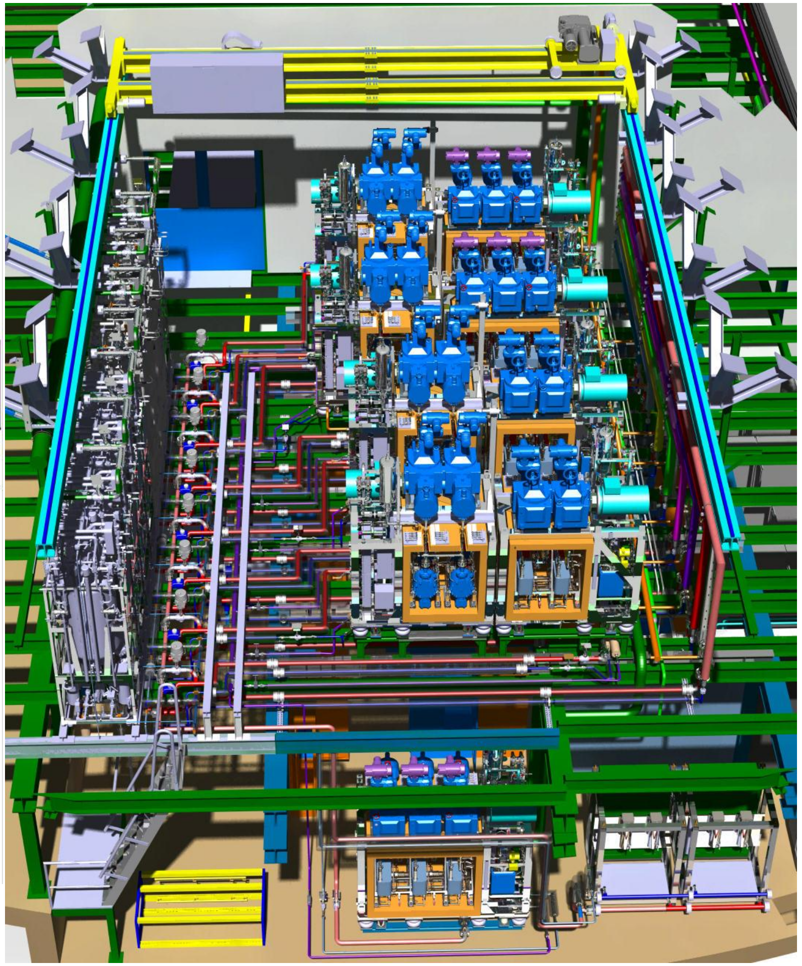
One Common volume inside coldbox

2PACL P&ID: https://edms.cern.ch/document/2603473/1.3

ATLAS and CMS systems

- ATLAS:
  - 7 cooling plants
    - 1x3H, 5x2H, 1x1H
  - 6 accumulators
- CMS:
  - 9 cooling plants
    - 3x3H, 6x2H
  - 8 accumulators





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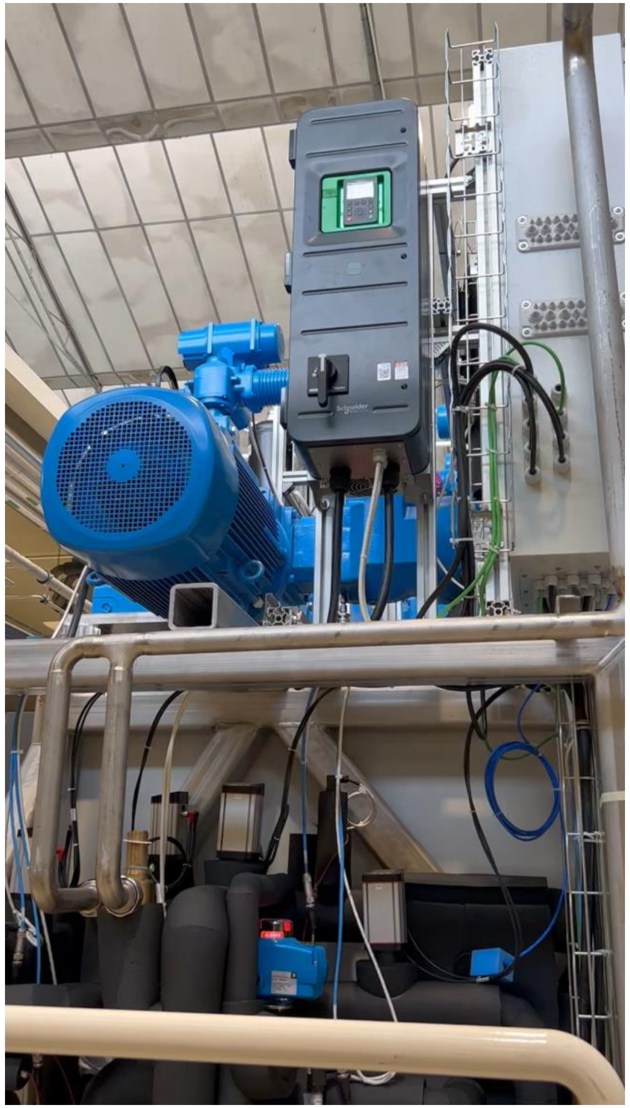
Detectors numbers

Detector type			Evaporator set point (°C)	Detector design load (kW)	Ambient Pick-up (kW)	Pre-heaters or Warm-nose (kW)	Maximum load for cooling plant (kW)	# of units	# of pump heads	Load per unit (kW)	Load per head (kW)	Design VQ @ cold	Detector flow(g/s)	Flow incl.MTFL By-pass (10%)	Flow Incl. plant by-pass (10%)	Cooling plant name
CMS	OT		-35°C	114.9	0	0.0	163.4	2	3	81.7	27.2	0.42	621	683	752	P1, P2
	IT			48.5	0	0.0										
	BTL		-35°C	36.1	6.5	1.2	43.8	1	2	43.8	21.9	0.33	424	466	513	P3
	CE		-35°C	242	15	0.0	257	4	2	64.3	32.1	0.42	488	537	591	P4, P5, P6, P7
	ETL		-35°C	69.5	2	3.0	74.5	1	2	74.5	37.3	0.42	566	623	685	P8
ATLAS	HGTD	Nominal	-40°C	35.2	2.5	0.0	39.3	1	2	39.3	19.7	0.33	369	406	447	P1
		Maximal		36.8												
	SBR	Nominal	-37°C	45.1	10.2	8.6	102.9	2	2	51.4	25.7	0.33	492	541	595	P2, P3
		Maximal		54.1												
	SEC	Nominal		26.1												
		Maximal		30.0												
	POB	Nominal	-40°C	50.6	9.2	9.4	112.7	2	2	56.4	28.2	0.33	530	583	641	P4, P5
		Maximal		60.7												
	PEC	Nominal		27.8												
		Maximal		33.4												
	PXI	Nominal	-40°C	20.1	2.7	3.0	29.8	1	1	29.8	29.8	0.33	280	308	339	P6
		Maximal		24.1												

Vibration

2PACL System vibration



Vibration measurements for 1H 2PACL plant was done as a worst-case scenario with help of EN-MME.

- Test performed:
  - warm and cold saturation temperature on without dummy load (fully liquid worst possible scenario).
  - damping solutions: passive dampers (rubber metal isolators), fixed solution (system fixed to the floor)
- Instrumentation used:
  - 2 seismic accelerometers (impact of the 2PACL plant on the floor)
  - 4 ICP triaxial accelerometers (EN-MME select worst case piping and flanges)
- Standards used to estimate system vibration levels
  - Engines / pumps ISO 10816-7

Room temperature	35 Hz	50 Hz
fixe	3.0 mm/s - B	3.0 mm/s - B
With dumper	2.5 mm/s - B	35 mm/s - D

-40 °C	35 Hz	50 Hz
fixe	1.0 mm/s - A	1.8 mm/s - A
With dumper	2.0 mm/s - A	36 mm/s - D

2PACL plant – Vibration campaign

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- Pipes / connections API618

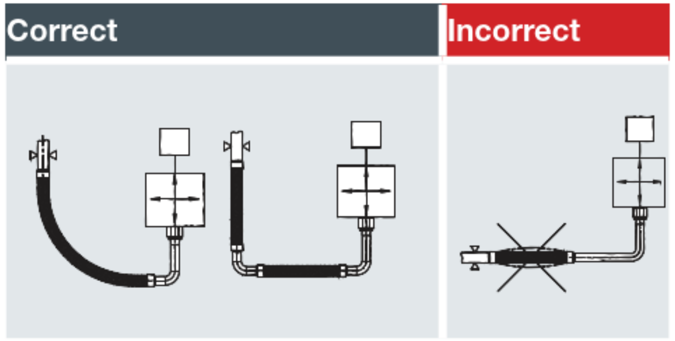
		Fixe support				Dumper support			
		base line 35Hz		worse case 50 Hz		base line 35Hz		worse case 50 Hz	
Temperature		Room Temp. & 58 bar	Cold Temp. & 10 bar	Room Temp. & 58 bar	Cold Temp. & 10 bar	Room Temp. & 58 bar	Cold Temp. & 10 bar	Room Temp. & 58 bar	Cold Temp. & 10 bar
Requirements		< 32 mm/s	< 32 mm/s	< 32 mm/s	< 32 mm/s	< 32 mm/s	< 32 mm/s	< 32 mm/s	< 32 mm/s
Inlet Pipe	X	17 mm/s	14 mm/s	22 mm/s	16 mm/s	18 mm/s	11 mm/s	30 mm/s	20 mm/s
	Y	27 mm/s	8 mm/s	46 mm/s	12 mm/s	29 mm/s	6 mm/s	36 mm/s	10 mm/s
	Z	28 mm/s	12 mm/s	43 mm/s	20 mm/s	29 mm/s	10 mm/s	48 mm/s	13 mm/s
Outlet Pipe	X	13 mm/s	8 mm/s	13 mm/s	16 mm/s	14 mm/s	8 mm/s	21 mm/s	14 mm/s
	Y	11 mm/s	6 mm/s	28 mm/s	10 mm/s	12 mm/s	7 mm/s	20 mm/s	10 mm/s
	Z	10 mm/s	12 mm/s	22 mm/s	20 mm/s	20 mm/s	12 mm/s	30 mm/s	20 mm/s
condenseur	X	39 mm/s	25 mm/s	75 mm/s	34 mm/s	34 mm/s	35 mm/s	68 mm/s	60 mm/s

		Fixe support				Dumper support			
		base line 35Hz		worse case 50 Hz		base line 35Hz		worse case 50 Hz	
Temperature		Room Temp. & 58 bar	Cold Temp. & 10 bar	Room Temp. & 58 bar	Cold Temp. & 10 bar	Room Temp. & 58 bar	Cold Temp. & 10 bar	Room Temp. & 58 bar	Cold Temp. & 10 bar
Requirements		< 0.5 mm	< 0.5 mm	< 0.5 mm	< 0.5 mm	< 0.5 mm	< 0.5 mm	< 0.5 mm	< 0.5 mm
Inlet Pipe	X	0.3 mm	0.3 mm	0.4 mm	0.3 mm	0.7 mm	0.5 mm	0.6 mm	0.4 mm
	Y	0.2 mm	0.1 mm	0.3 mm	0.1 mm	0.8 mm	0.7 mm	1.4 mm	1.6 mm
	Z	0.4 mm	0.3 mm	0.5 mm	0.3 mm	0.5 mm	0.4 mm	4.3 mm	4.0 mm
Outlet Pipe	X	0.2 mm	< 0.1 mm	0.1 mm	< 0.1 mm	0.2 mm	0.4 mm	0.5 mm	0.4 mm
	Y	0.1 mm	< 0.1 mm	< 0.1 mm	< 0.1 mm	0.1 mm	0.4 mm	2.0 mm	2.0 mm
	Z	0.2 mm	< 0.1 mm	0.1 mm	< 0.1 mm	0.2 mm	0.3 mm	2.5 mm	2.6 mm
condenseur	X	0.3 mm	0.1 mm	0.3 mm	0.2 mm	2.0 mm	1.6 mm	2.0 mm	1.2 mm

Flexible hoses- Selection & installation guide

All the information taken from the manufacturer catalogue

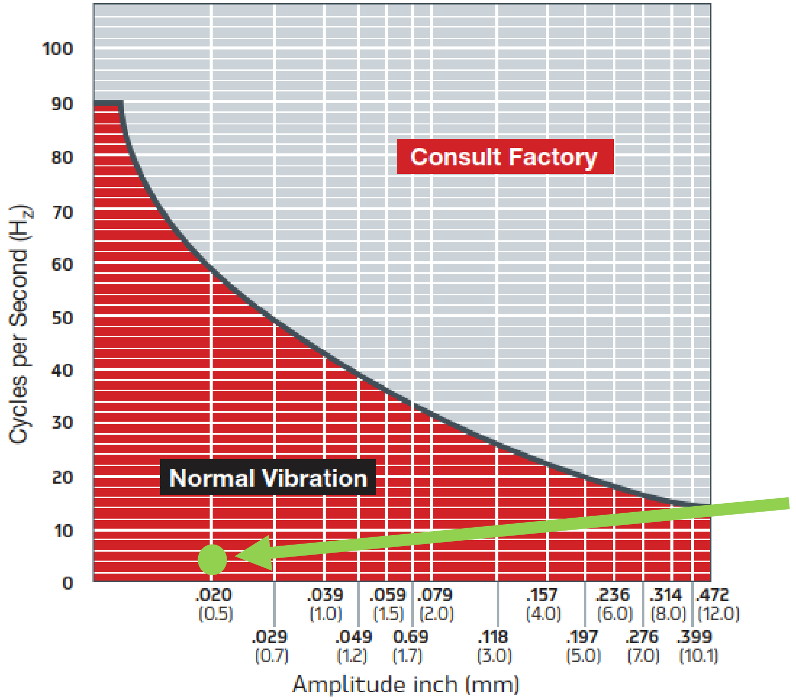
If there is vibration in more than one direction, either install a longer hose bent at 90° or install a “Dog Leg” assembly.



Vibration:

The following graph is a representative guideline for estimation purposes only. For any questions, or if your application is near the “Consult Factory” region, please contact your HAM-LET local representative.

Vibration Chart :



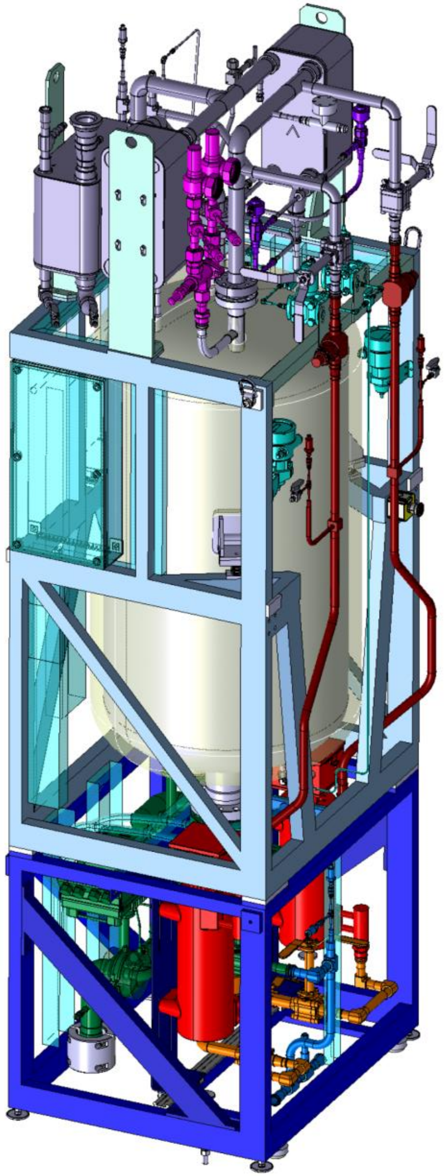
Vibration measurements campaign:

- Max Amplitude 0.5 mm
- Cycles per second 3 (Hz)

According to the manufacturer no need of additional fatigue tests.

Accumulator & Plant construction

Accumulators – construction partner



FOR ATLAS:
6 x Short Accumulator
0 x Long Accumulator

FOR CMS:
5 x Short Accumulator
3 x Long Accumulator

FOR CMS Inheritance:
1 x Long Accumulator

Tender for the Accumulator construction was won by consortium:

KOMPRESSOR TEKNIK Industri   JOH SJÖ

Norrköping, Sweden

15x Accumulators
According PED and Machine directive
All units will be CE marked

Completed by the July 2025

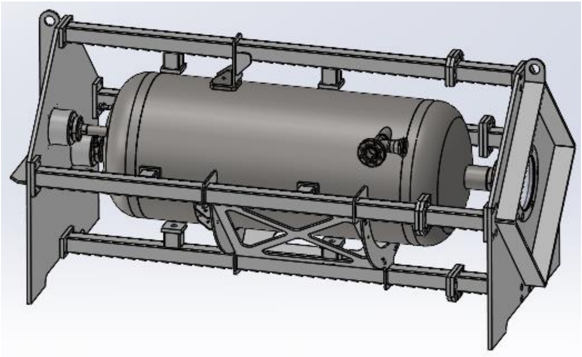
Accumulator vessel due to wall thickness will be made by:

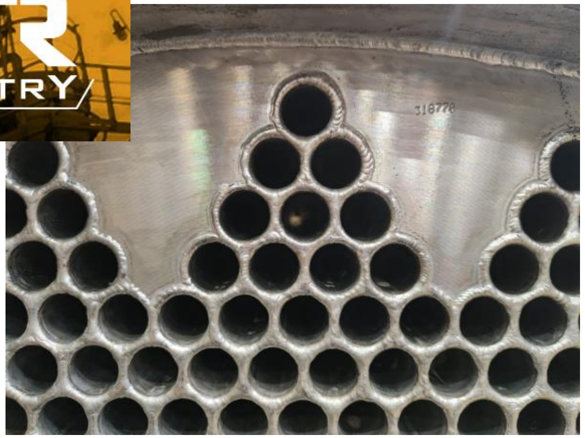
BTR INDUSTRY

Pålsboda, Sweden

JohSjo, BTR – discussions, design, documentation, construction

- Technical discussions on weekly basis since 19th of October 2023
- Design started by company from the October 2023
- Documentation ITP, WPS, WPQR, and many others received
- Drawings received
- Construction of first batch (4 Accumulators) started from 18th of March 2024
- Free issued components from CERN were delivered to Kompressor Teknik in three batches
- Visit of CERN representative on the 14th - 15th of March 2024 JohSjo and BTR





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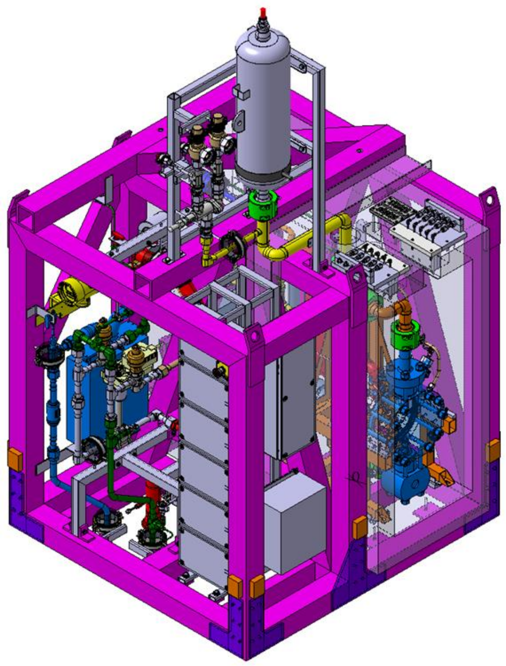
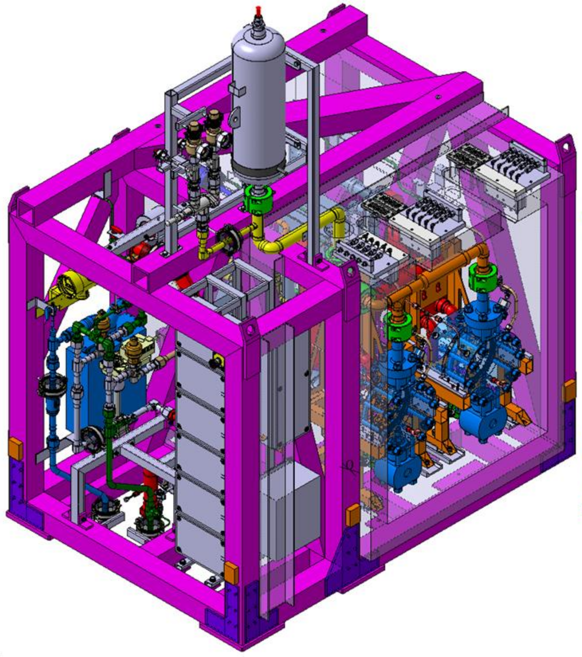
2PACL plant types – construction partner

1 Head 2PACL plant



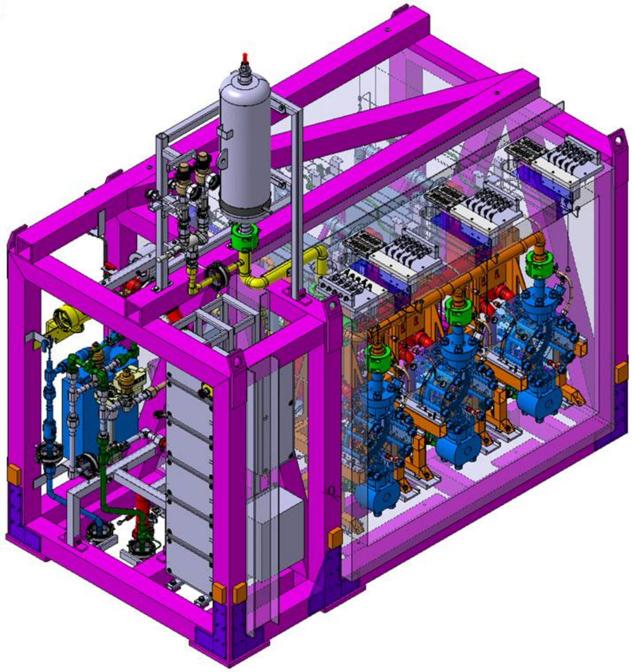
1x 1 Head 2PACL plant

2 Head 2PACL plant



11x 2 Head 2PACL plant

3 Head 2PACL plant



4x 3 Head 2PACL plant

FOR ATLAS:
1 x 1 Head 2PACL plant
5 x 2 Head 2PACL plant
1 x 3 Head 2PACL plant

FOR CMS:
0 x 1 Head 2PACL plant
6 x 2 Head 2PACL plant
3 x 3 Head 2PACL plant

Tender for the 2PACL construction was won by:

Sub C

Esbjerg, Denmark

16 x 2PACL Plants
According PED and Machine directive
All units will be CE marked

Completed by the July 2025

Tender for the 2PACL cold insulation boxes construction was won by:

Thalheimer
Comfort in Life

Ellwangen, Germany

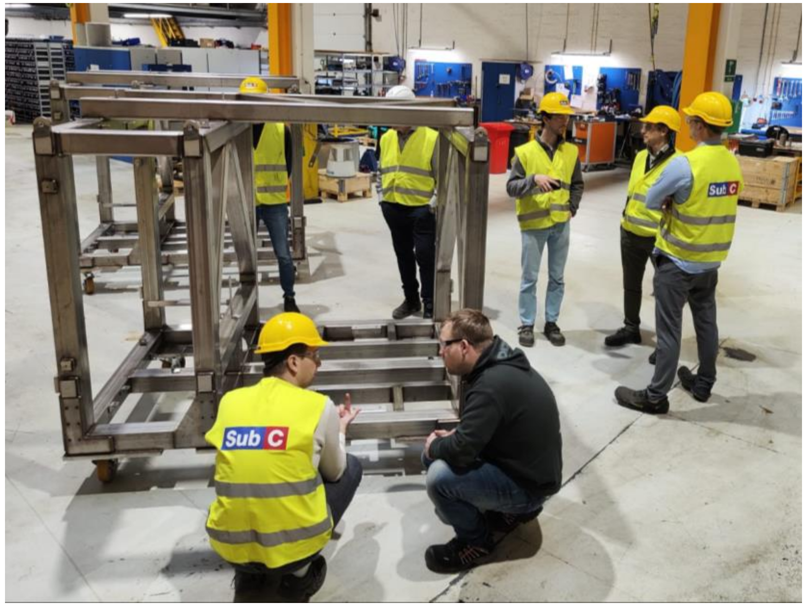
17 x Cold insulations boxes

SubC, Thalheimer – discussions, design, documentation, construction

SubC

- Technical discussions on weekly basis since 19th of October 2023
- Design started by company from the October 2023
- Documentation ITP, WPS, WPQR, and many others received
- Drawings received
- Construction of first batch (2x 2 Head Plants and 1x 1Head Plant) started from 23rd of February 2024
- Free issued components from CERN were delivered to SubC in three batches
- Visit of CERN representative on the 13th of March 2024

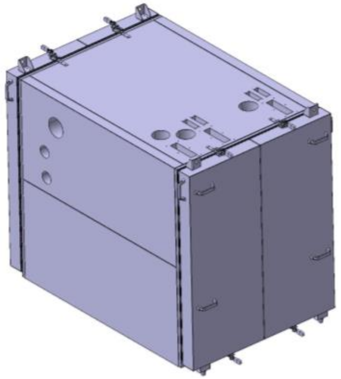
SubC



Thalheimer Comfort in Life

- Technical discussions on daily basis since 2nd of February 2023
- 3 D Design received (few correction was needed)
- 3D models and 2D Drawings received - approved
- Construction of first batch started from 4th of February 2024
- Factory acceptance tests of first units on the 16th of May 2024

Thalheimer Comfort in Life



First 2PACL Frames

The CE marking process

1. Applicable Directive:
- Pressure equipment
- Machine
- Euro code

2. Requirements for applicable directive:
- Harmonised standards
  - Metallic industrial piping EN 13480
  - Unfired pressure vessels EN 13445
  - Euro code EN 1090-1

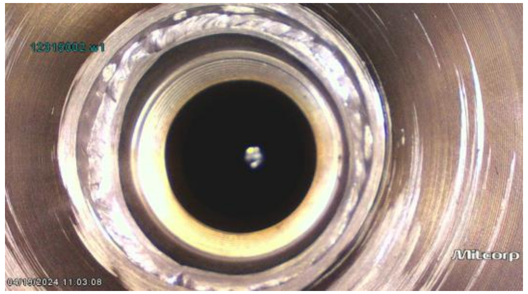
3. Route to conformity:
- Third party
- Notified body
- Inspection and test plan

4. The Product conformity :
- NDT weld test(x-ray)
- Pressure test, leak test
- Risk assessment and HAZOP

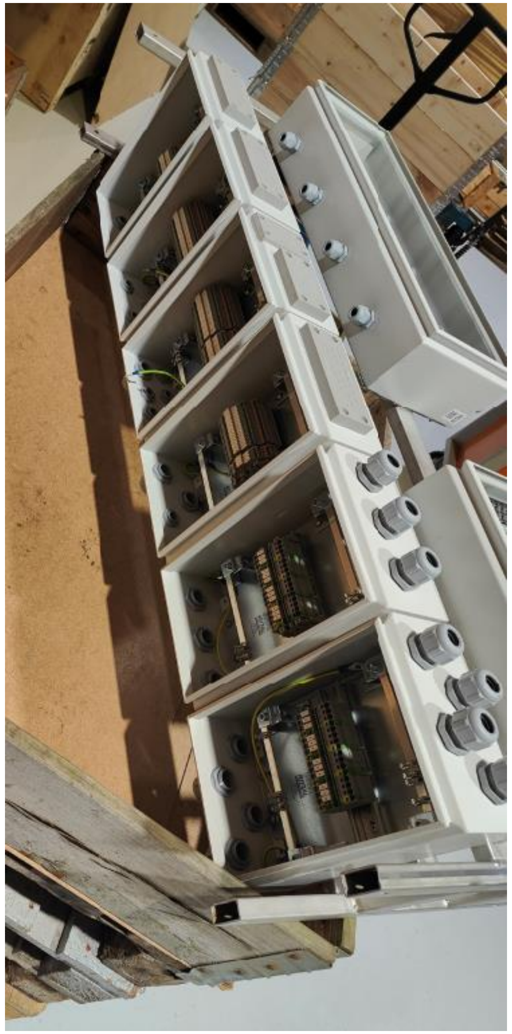
5. The Technical documentation:
- Technical description.
- Drawings, circuit diagrams and photos.
- Bill of materials.
- Specification and, where applicable, Declarations of Conformity for the critical components and materials used.
- Details of any design calculations.
- Test reports and/or assessments.
- Instructions.
- As-built documentation

6. Declaration and affix the CE Mark:
- EU Declaration of Conformity
- Marking plates on the unit (from cat 2 NoBo stamp)

2PACL plant current construction status



2PACL plant current construction status



Accumulator current construction status

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Delivery & Future plans

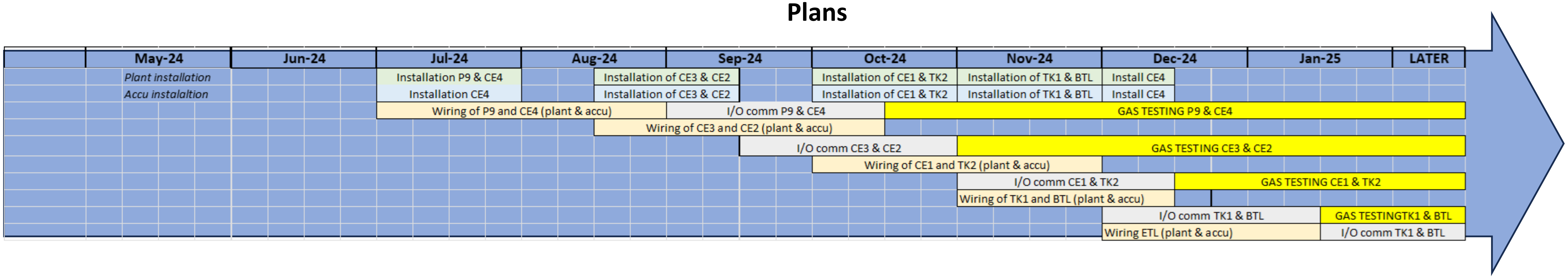
Delivery schedule for 2PACL plants

Label	Description (CERN use)	Type of plant	Due by date AT CERN
CU5A_P9	1 - CMS P9 Back-up	**3-heads**	02.07.2024
CU5A_P7	2 - CMS CE4	2-heads	02.07.2024
CU5A_P6	3 - CMS CE3	2-heads	22.08.2024
CU5A_P5	4 - CMS CE2	2-heads	22.08.2024
CU5A_P4	5 - CMS CE1	2-heads	04.10.2024
CU5A_P2	6 - CMS TK2	**3-heads**	04.10.2024
CU5A_P8	9 - CMS ETL	2-heads	02.12.2024
CU5A_P9	10 - ATLAS P9 Back-up	**3-heads**	02.12.2024
CU5A_P1	7 - CMS TK1	**3-heads**	01.11.2024
CU5A_P3	8 - CMS BTL	2-heads	01.11.2024
CU1A_P1	11 - ATLAS HGTD	2-heads	28.02.2025
CU1A_P2	12 - ATLAS A side; SEC, SBR	2-heads	28.02.2025
CU1A_P3	13 - ATLAS C side; SEC, SBR	2-heads	25.04.2025
CU1A_P4	14 - ATLAS A side; PEC, POB	2-heads	25.04.2025
CU1A_P5	15 - ATLAS ATLAS C side; PEC,	2-heads	27.06.2025
CU1A_P6	16 - ATLAS PXI	**1-heads**	27.06.2025

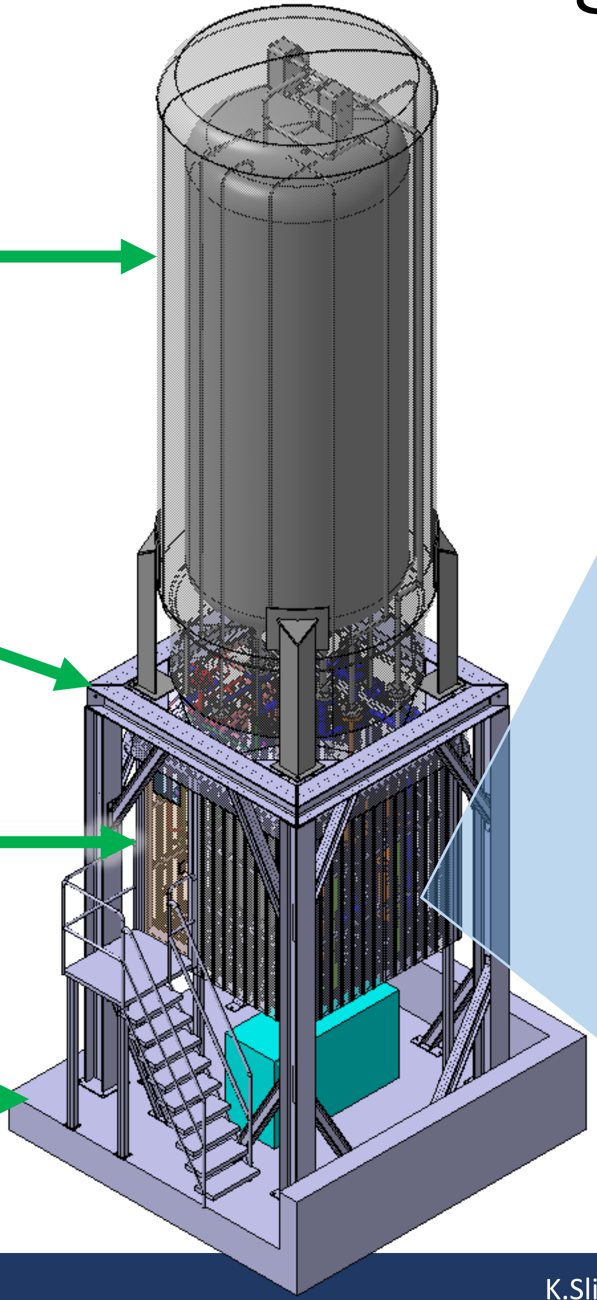
Delivery schedule for Accumulators

Label	Description (CERN use)	Type of accumulator	Due by date AT CERN
CS5D_A1	CMS INH	**Long**	05.07.2024
CU5A_A7	CMS CE4	Short	05.07.2024
CU5A_A6	CMS CE3	Short	04.09.2024
CU5A_A5	CMS CE2	Short	04.09.2024
CU5A_A4	CMS CE1	Short	18.10.2024
CU5A_A2	CMS TK2	**Long**	18.10.2024
CU5A_A8	CMS ETL	**Long**	15.11.2024
CU1A_A1	ATLAS HGTD	Short	15.11.2024
CU5A_A1	CMS TK1	**Long**	08.01.2025
CU5A_A3	CMS BTL	Short	08.01.2025
CU1A_A2	ATLAS A side; SEC, SBR	Short	28.02.2025
CU1A_A3	ATLAS C side; SEC, SBR	Short	28.02.2025
CU1A_A4	ATLAS A side; PEC, POB	Short	25.04.2025
CU1A_A5	ATLAS C side; PEC, POB	Short	25.04.2025
CU1A_A6	ATLAS PXI	Short	27.06.2025

Plans



Surface Storage - Design



The Vessel

Double wall vessel with internal piping and two heat exchangers

- The pressure rating may vary between 45bar to 60 bar
- Temp. range **-25ºC to 15ºC**

The Frame

H-beam with overall dimension of ~ 2.1m x 2.1m x 4.3m for ATLAS

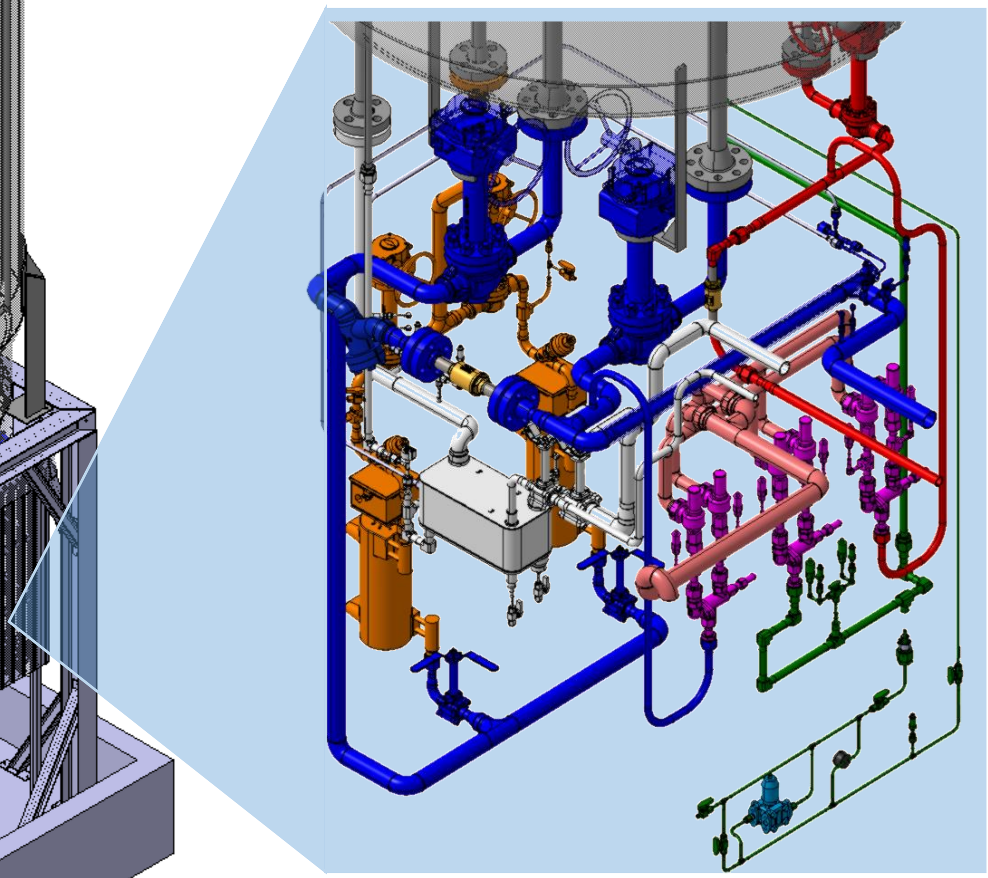
The Shed

Everything inside will be protected from weather conditions.

The Slab

Dimensions are 3.2m x 3.2m x 0.35m.
Reenforced concrete.

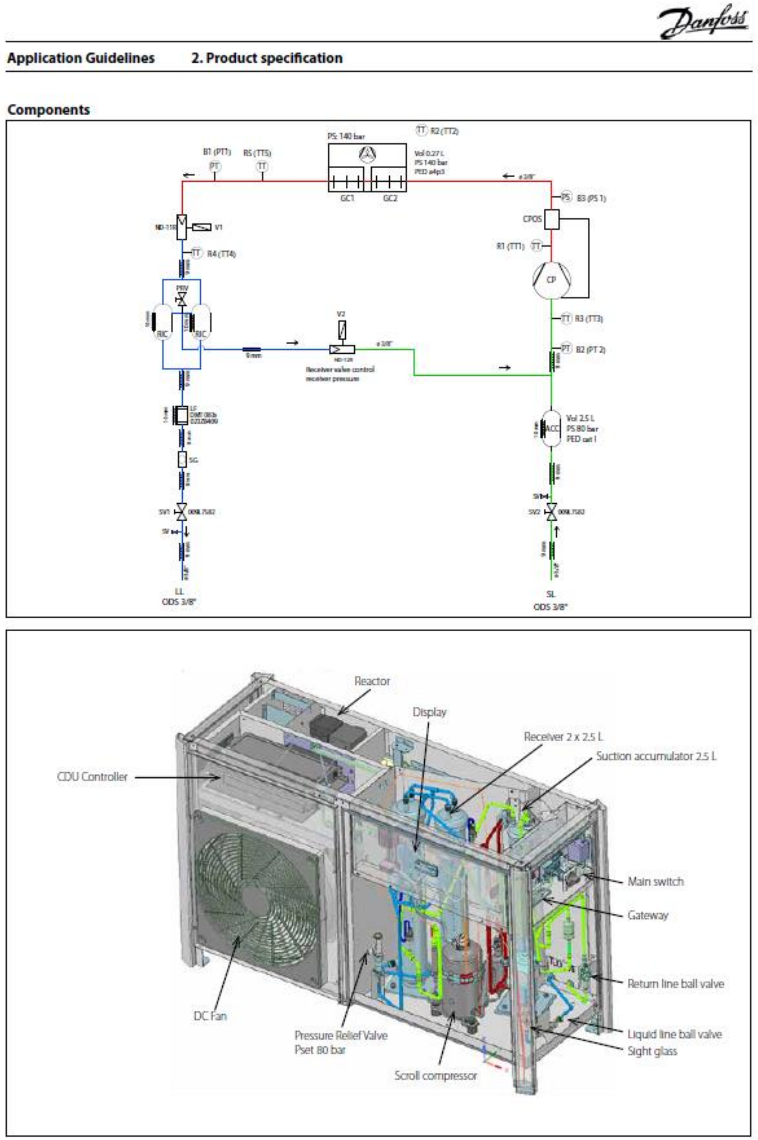
Piping



Blue: Liquid supply line.
Red: Gas return line.
Orange: Heaters
White: R744 HE & lines
Green: Main sensors
Pink: Safety valves

Back-up Chiller

Back-up chiller selected is the **Danfoss iCO_2** unit of **~5 kW** together with an expansion valve on the liquid line.



Conclusions:

- Visit of CERN representative on the week 11th 2024
    - No doubts about the work quality make by the companies
        - mechanical, electrical, storage
- Construction of the 2PACL Plants & Accumulator ongoing
- A lot of effort was made to collect all documentation needed for achieve CE mark
- Realising invitation for tender for Surface Storage vessel
- Testing back-up chiller soon

FOR CMS installation:
Starts July 2024
Ends December 2024
First circulation tests January 2025 (no liquid test allowed during ongoing installation in the cavern)
No limitation during beam run

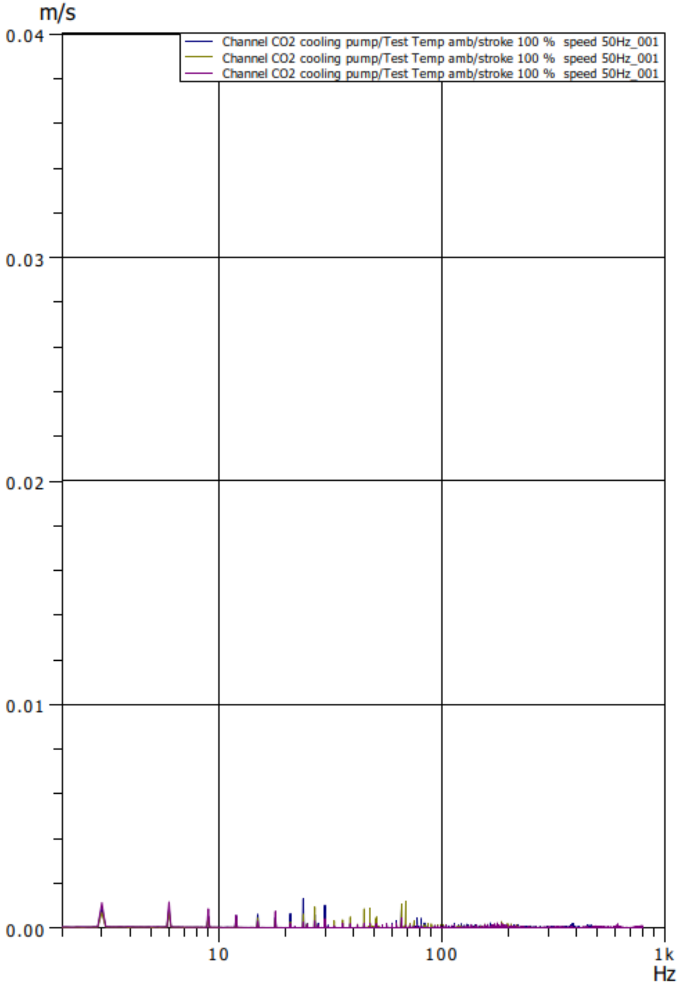
FOR ATLAS installation:
Starts YETS 2024-2025 (I 2PACL plant and 1 Accu for early testing)
The rest of equipment will be installed during LS3
First circulation tests early 2025
Only serious intervention/installation during the beam run

Thank you !

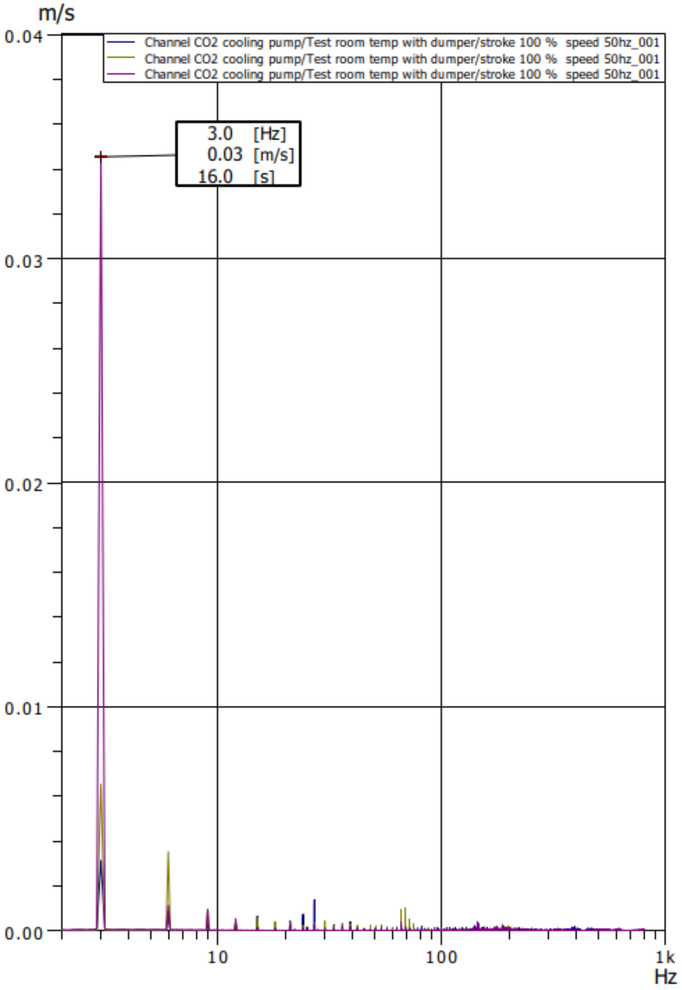
BACK-UP Slides

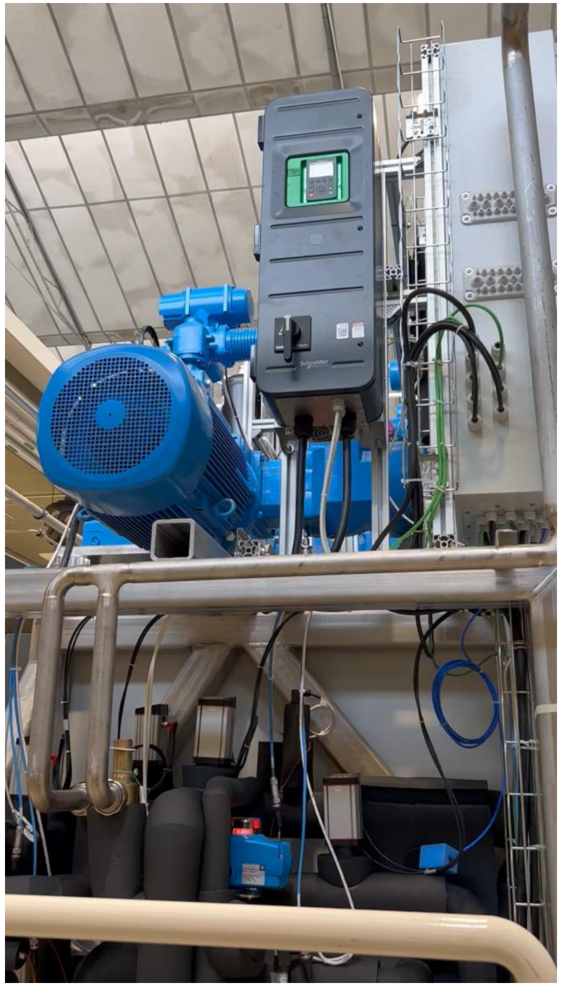
Engine / pump according to ISO10816-7

Fixe

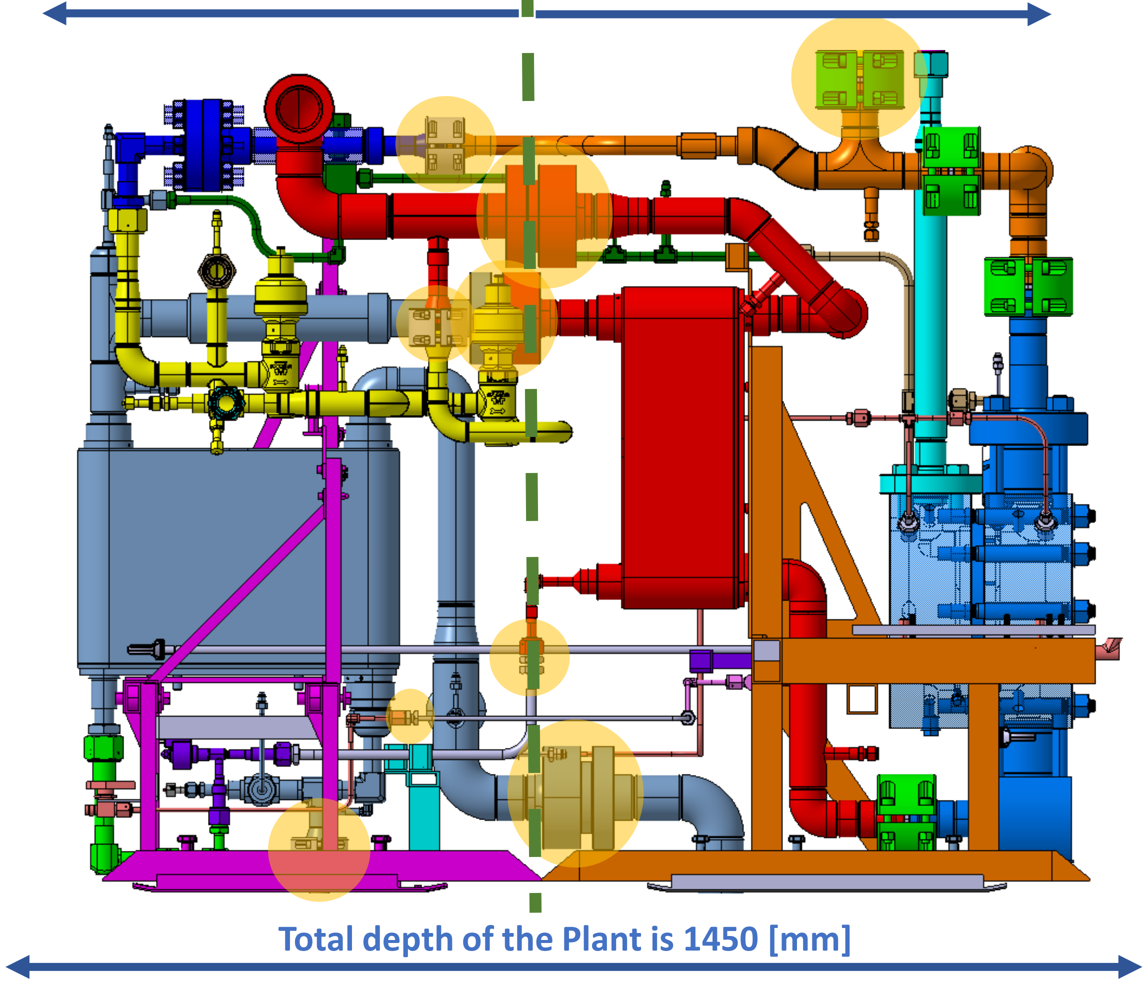


With bumper





2PACL Plant piping - intervention



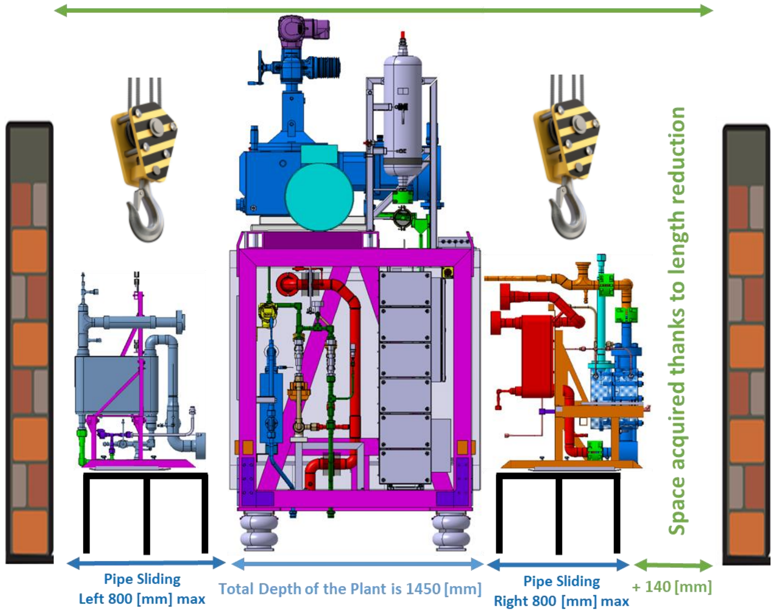
FINAL CO_2 Plant piping redesign aspects:

- Central splitting plane

  Main benefit: we no longer need to slide the entire piping assembly but half of it→ simpler operation and shorter intervention time

- Optimization of pipe routing:
  - More space for maintenance
  - less welds + less connectors
  - Less piping sub-assemblies

Experiments footprint requirements



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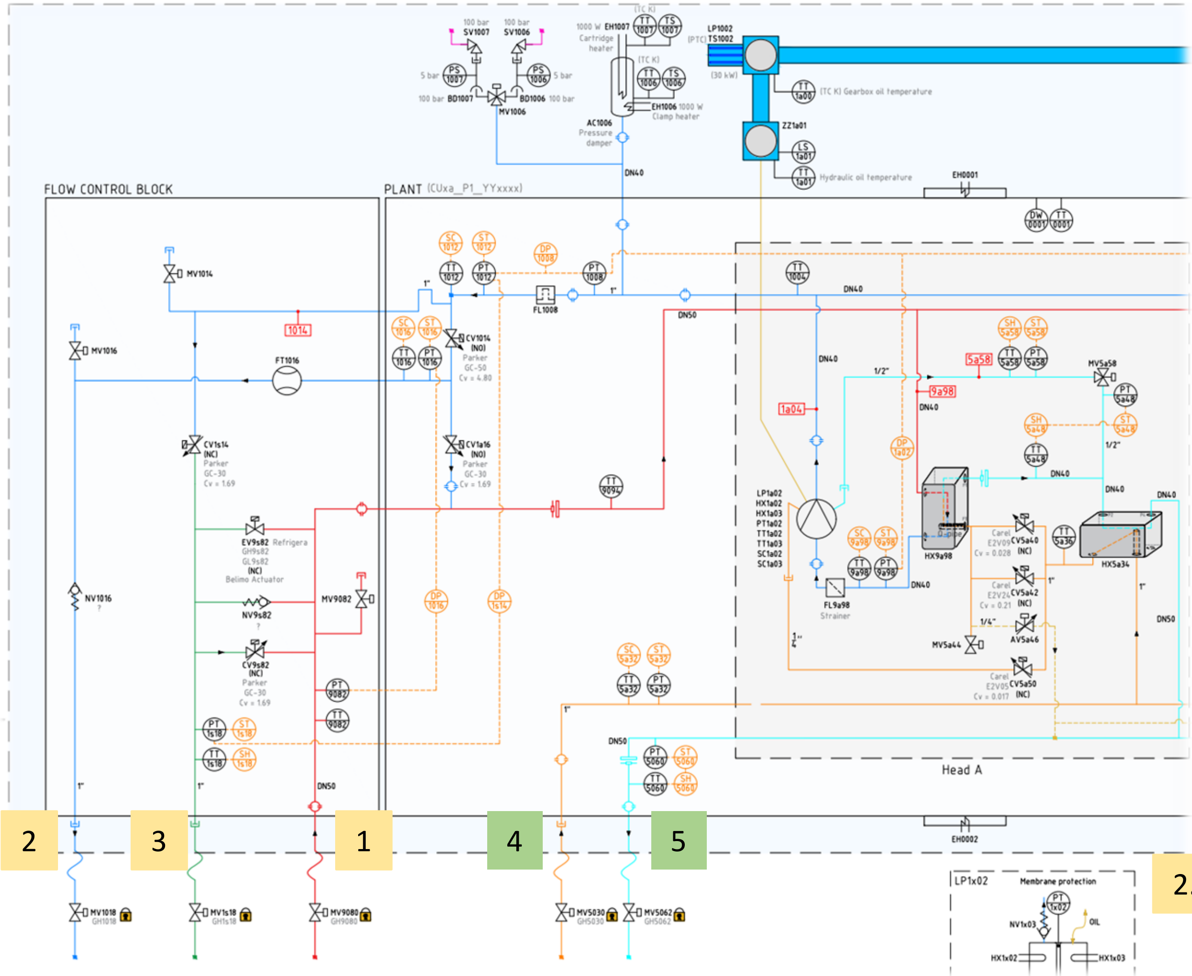
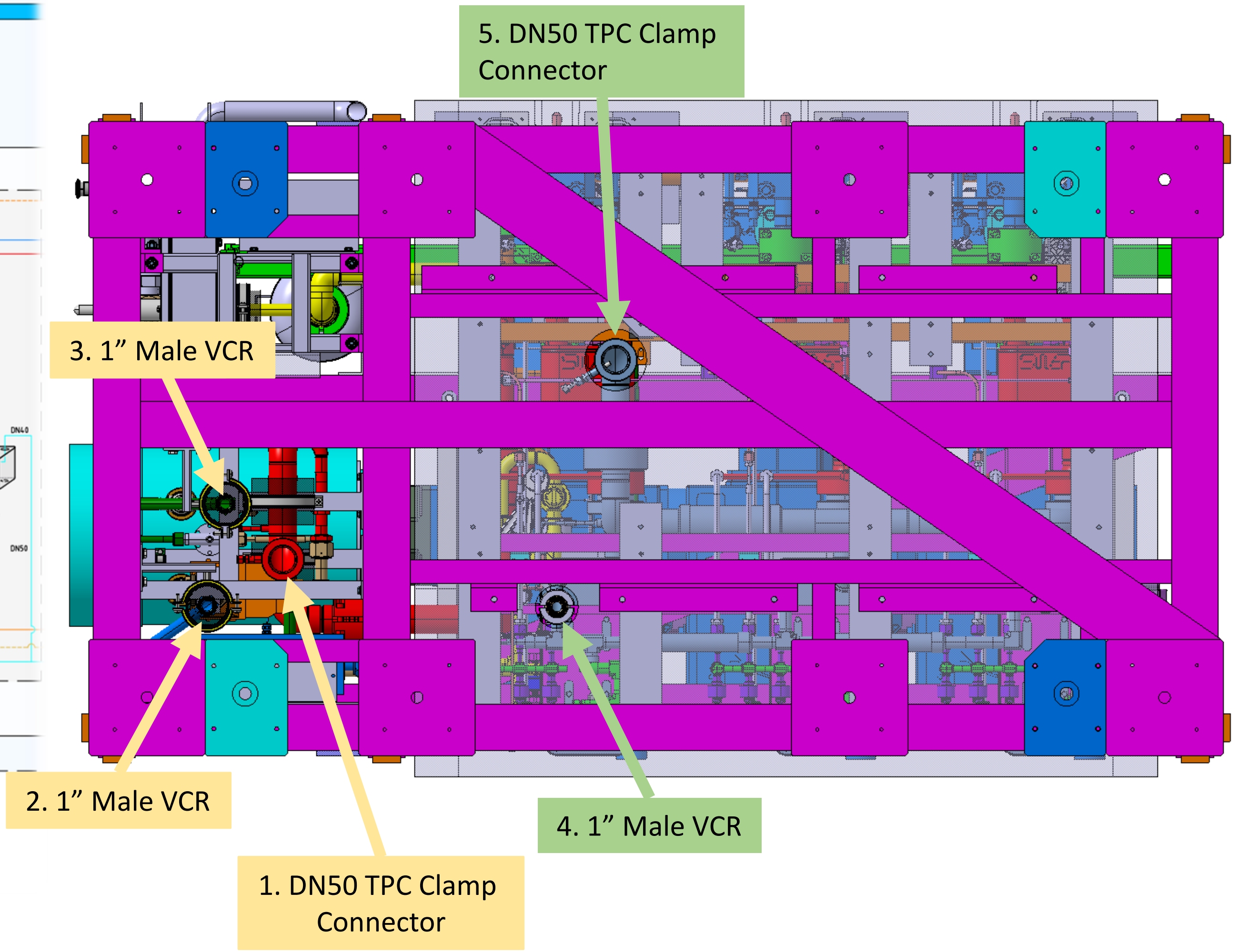
2PACL Plants Connection Interfaces





Piping – fatigue analysis

According to EN 13480 Metallic industrial piping standard:

10.3.2 Simplified fatigue analysis

10.3.2.1 General

Where cyclic loading requiring calculation arises only from variations in pressure, the simplified fatigue analysis shall be permitted.

EN 13480-3:2017 (E)
Issue 1 (2017-06)

It uses the static design criteria and takes into account the relevant fatigue peak stresses by the use of a stress concentration factor η for a range of typical geometries. The method is approximate, and less conservative dimensioning may result from the use of more detailed analysis in accordance with 12.4.

The rules shall apply for pressure containing parts of piping of ferritic and austenitic rolled and forged steels manufactured and tested in accordance with EN 13480-2 and EN 13480-4.

The calculation only applies for components dimensioned on the basis of non-time-dependent strength characteristics and subjected to cyclic loadings only in the form of pressure fluctuations.

NOTE 1 The term « cyclic loading » is the change over time of a load regardless of the magnitude and arithmetic sign of the mean value.

Additional cyclic loads, for example loads due to rapid changes in temperature during operation or from external forces and moments, shall be assessed within the framework of a detailed fatigue analysis (see 12.4).

The rules shall apply if there are no influences from the fluid which will reduce the fatigue life (see 10.3.2.8).

NOTE 2 10.3.2 does not need to be applied if the pressure fluctuations superimposed on the service pressure do not exceed 10 % of the allowable operating pressure.

2PACL Frame FEA

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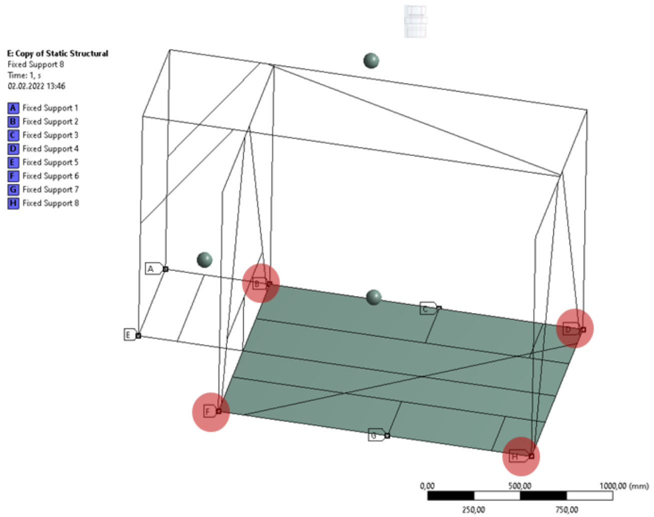
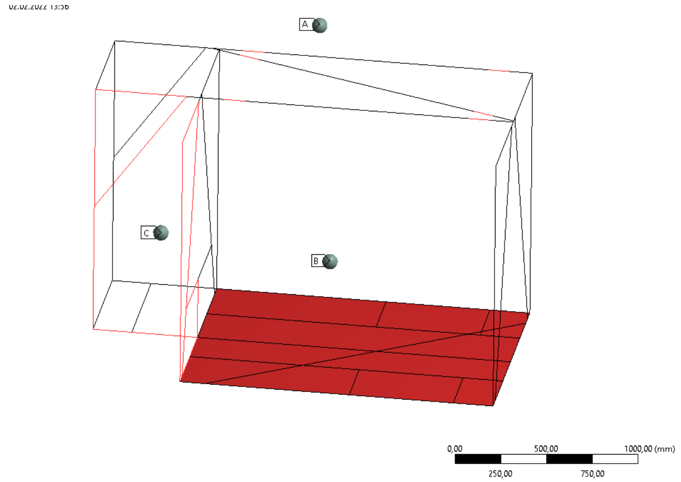
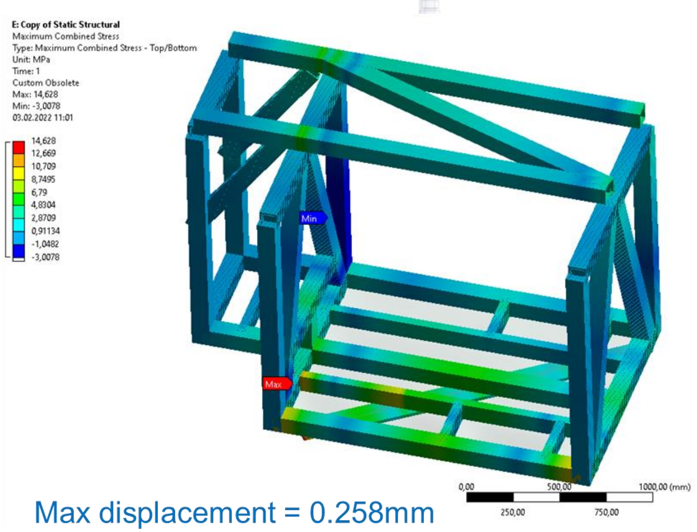
Fixed support on 4 feet (B, D, F, H)

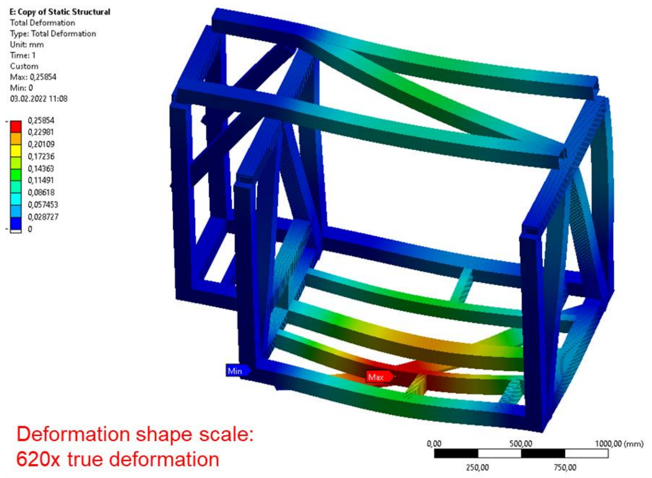




Max stress = 14,6 MPa



Max displacement = 0.258mm



Deformation shape scale:
620x true deformation

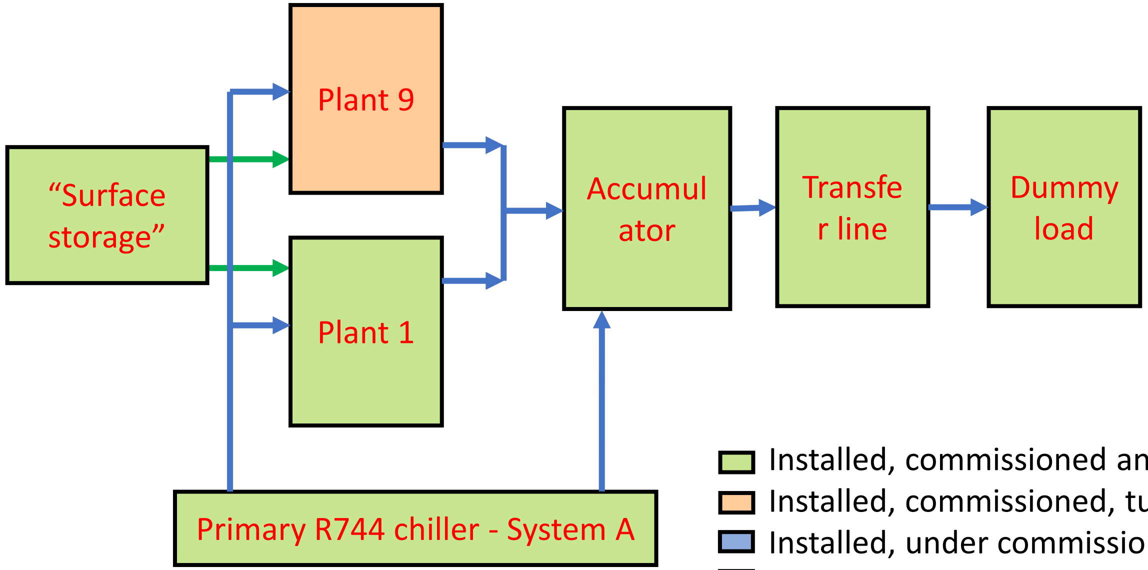
Frame was studied under 3 different fixed supports scenarios. More results are available on request

Maintenance plan

- **Every year:**
  - Pump basic maintenance
    - Replacement of membranes (plus associated gaskets and O-rings), oils (gear box and hydraulic) and pump valves
  - Filters cleaning
  - Valves piloting verification and position switches calibration (if needed)
  - Sensors inspection and calibration (if needed)
  - Verification of electrical connections
    - With thermal camera while system is running before the maintenance
    - Re-torquing of all electrical connections with dynamometric tools when system is OFF
  - Pumps and heaters current measurement (while system is running)
  - Resistance measurements for motors, coils…
  - Heaters insulating resistance measurement up to 1000VDC
  - EMS STOP testing
  - Differential circuit breakers tests
- **Every 2 years:**
  - Safety valves calibration
  - Pump internal safety valve inspection and calibration
  - Valves battery packs replacement
  - Flexible inspection (CO_2 leak test - sniffer)
- **Every 5 years:**
  - Pump in-depth maintenance (performed at the supplier's premises):
    - Membrane replacement (plus associated gaskets and O-rings) + oils replacement (gear box and hydraulic), valves replacement + gear box inspection and replacement of worn parts + piston and hydraulic head inspection and replacement of worn parts
- **Every 10 years:**
  - Burst discs replacement
- **Every 12 years:**
  - Accumulators inspections by HSE

DEMO modular prototype

Each block (Module/subsystem) has its own control cabinet and a dedicate control PCO . Each module can be operated independently and partly tested



- Installed, commissioned and operational
- Installed, commissioned, tuning ongoing
- Installed, under commissioning
- Being installed, not commissioned

Accumulator Safety exhaust Transfer line Dummy load
R744 primary 3H-Plant 1H-Plant

Control cabinets Surface storage simulator

2PACL plant – Vibration campaign

Vibration measurements for 1H 2PACL plant was done as a worst-case scenario with help of EN-MME.

- Before taking measurements EP-DT-FS carefully provide all the inputs regarding the project (technical information about the 2PACL plants, Lewa pumps, their integration in both caverns).
- Test performed:
  - warm and cold saturation temperature on without dummy load (fully liquid worst possible scenario).
  - damping solutions: passive dampers (rubber metal isolators), fixed solution (system fixed to the floor)
- Instrumentation used:
  - 2 seismic accelerometers (impact of the 2PACL plant on the floor)
  - 4 ICP triaxial accelerometers (EN-MME select worst case piping and flanges)