Magnet test at LNF/FNAL: preparation, cryogenics, and compliance

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KLOE Magnet: 20 years of operation

The magnet was designed, in conjunctio
long 4.8 m diameter volume.

KLOE magnet in numbers	
Central magnetic field	0.6 T
Vacuum case length	4.4 m
Vacuum case inner diameter	4.86 m
Vacuum case outer diameter	5.76 m
Coil shell inner diameter	5.19 m
Cold mass	10 tonnes
Vacuum case mass	26 tonnes

KLOE to SAND: Superconducting magnet activities

Scope:

1. Revamping of aged subsystems in order to provide to the Collaboration a reliable detector that guarantees years of efficient operation
2. Test the magnet before the shipment in order to guarantee a proper hand-off of the system including the compliance with FNAL internal regulation on Pressure Vessels
3. Preparing the magnet for the handling and the shipment
4. Test the magnet before its re-insertion in the yoke at FNAL, in order to check for any damage possibly suffered during the travel from Italy

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KLOE Magnet Revamping

- KLOE has been operated almost continuously from 1998 to 2018 at LNF showing excellent performance in terms of the reliability of the magnet and its subsystems.
- Nonetheless, in the last years of operations, the hydraulic circuit of the PS showed signs of “natural” aging. For this reason, the procurement of a new PS is in progress
- The original control system (developed on LabView platform) must be migrated to a more recent version of the software for obvious reasons (compliance with present OS and integration with FNAL supervisor). A reconfiguration of the CS HW architecture will be evaluated to increase the robustness of the subsystem
- All the consumable parts will be serviced as well as the vacuum pumps

KLOE Magnet test @ LNF and FNAL

Test of the magnet will be performed to put it back to service. Tests can be divided in two sections

1. Warm test
2. Cold test

Warm test - will check the electrical, mechanical, fluidic and control operational status of all the subsystems at 300 K: vacuum, temperature sensors, pressure sensors, valve leaks, actuators, PS interlocks, heaters, CS etc.

Cold test – will check the previous list at 4.4 K in addition to all the test that must be performed on the PS and the quench detector with the coil energized to a limited current

Tests at LNF will be repeated at FNAL, and both performed in presence of FNAL representatives as part of training program and compliant hand-off

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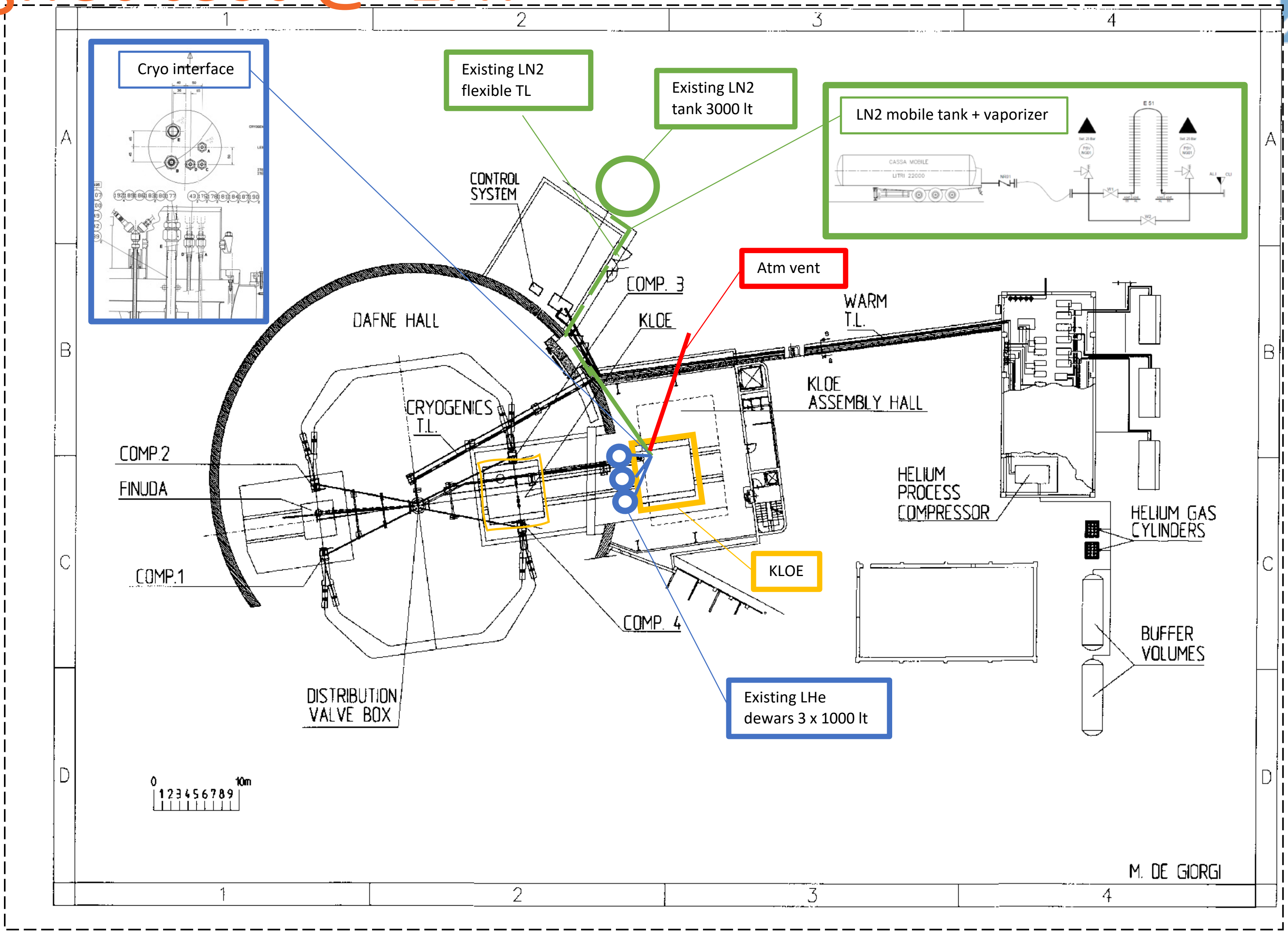
KLOE Magnet test @ LNF



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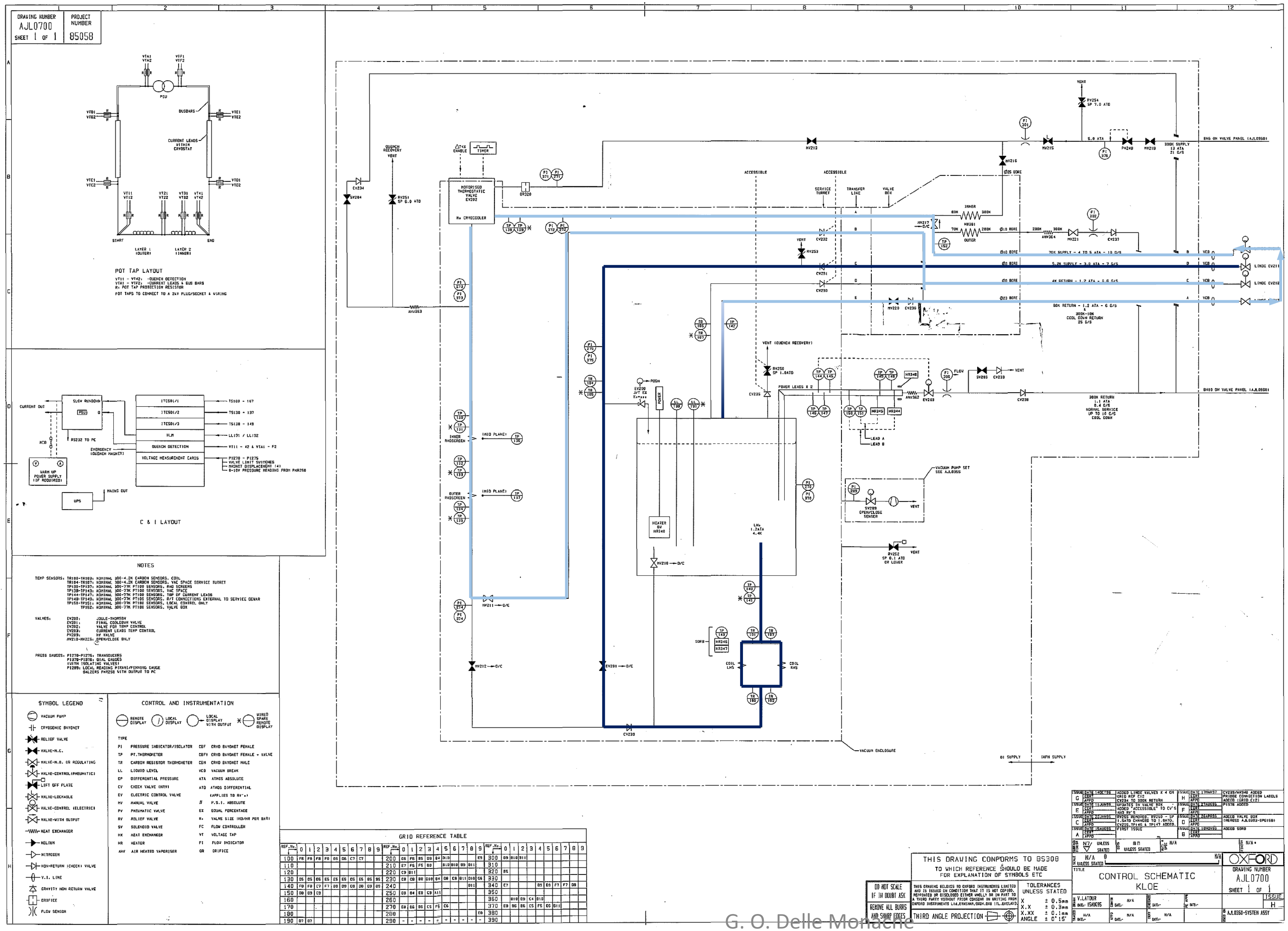
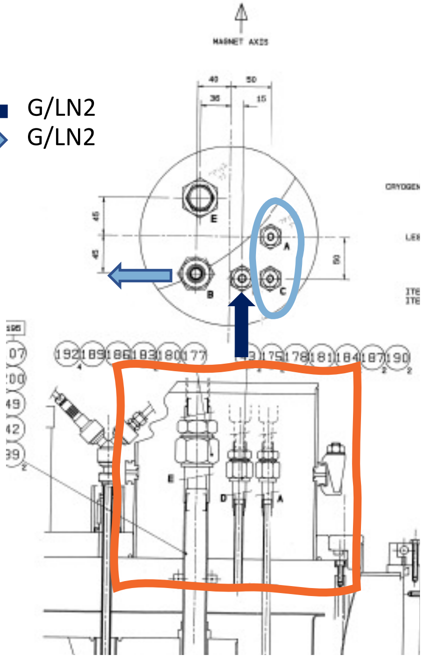


Cool Down

100 – 4.4 K

G/LN2
G/LN2



G. O. Delle Monache

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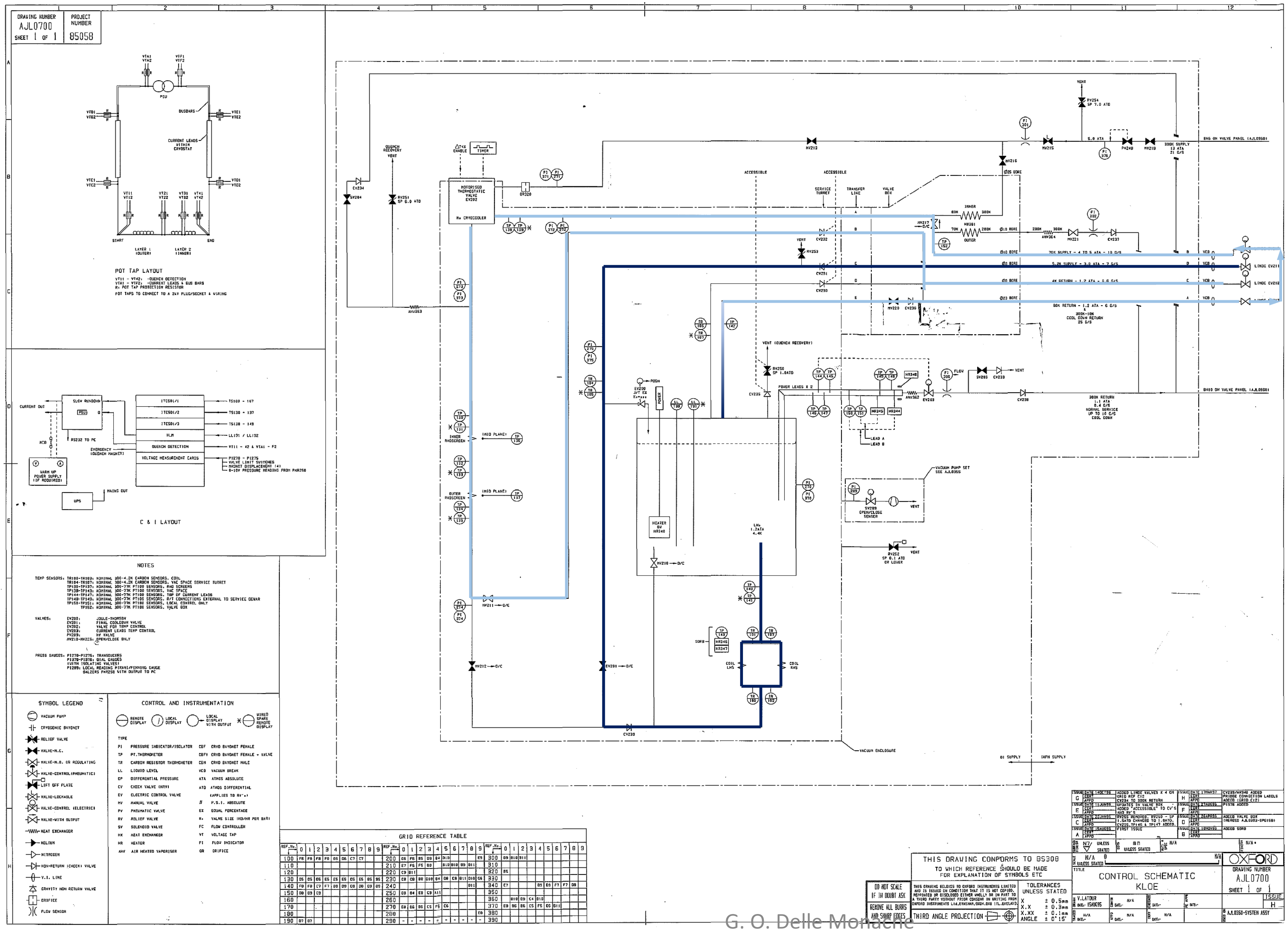
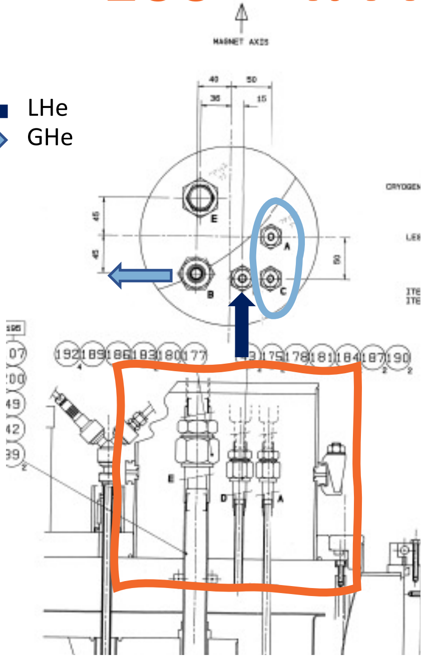
Cool Down

100 – 4.4 K



LHe
GHe



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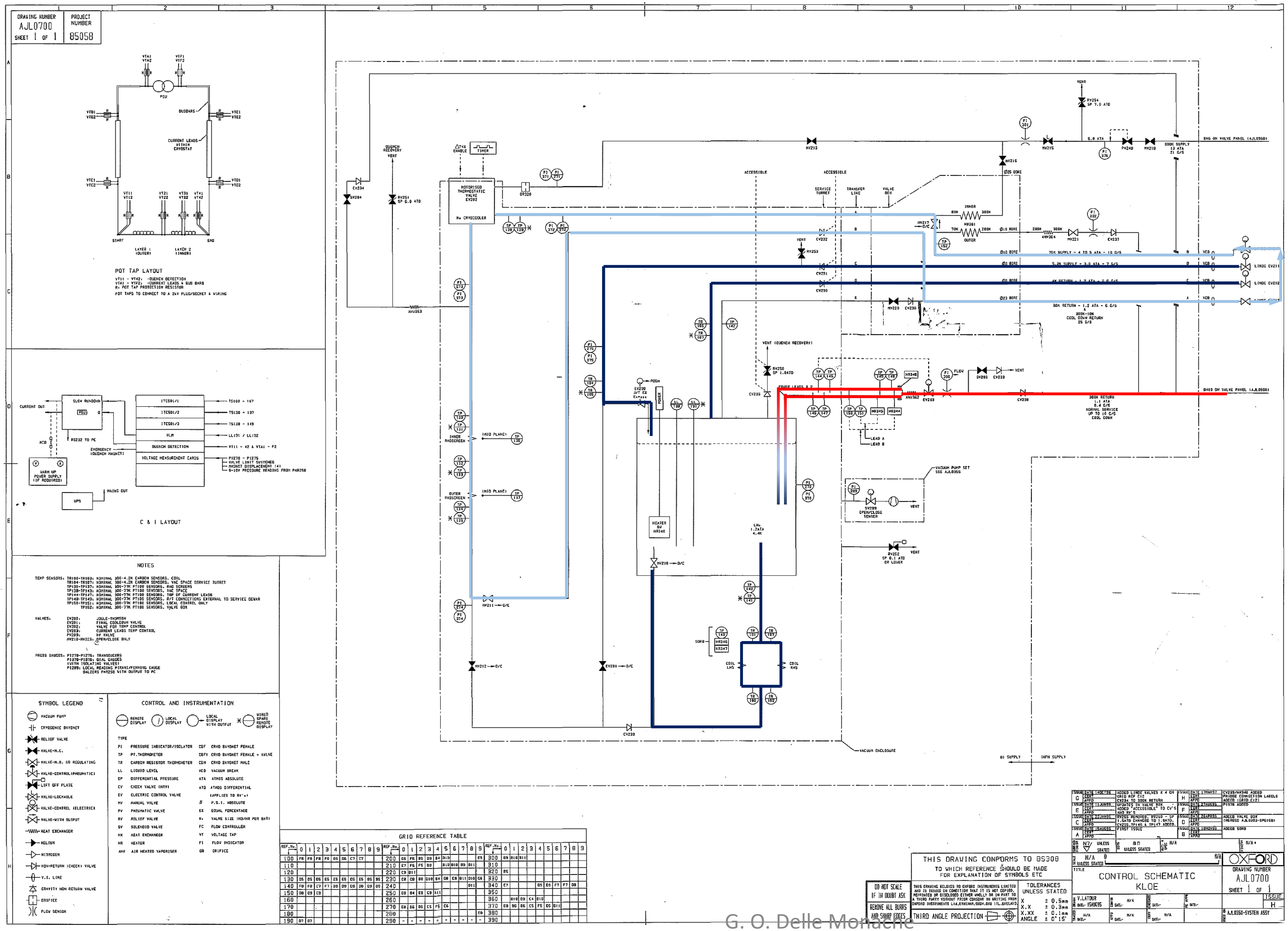
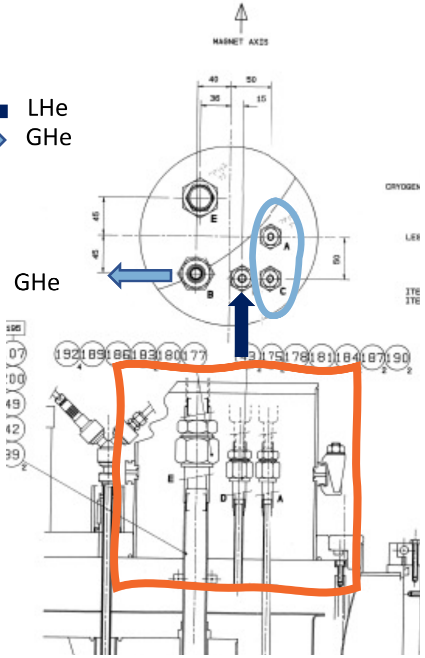
Magnet @ 4.4 K



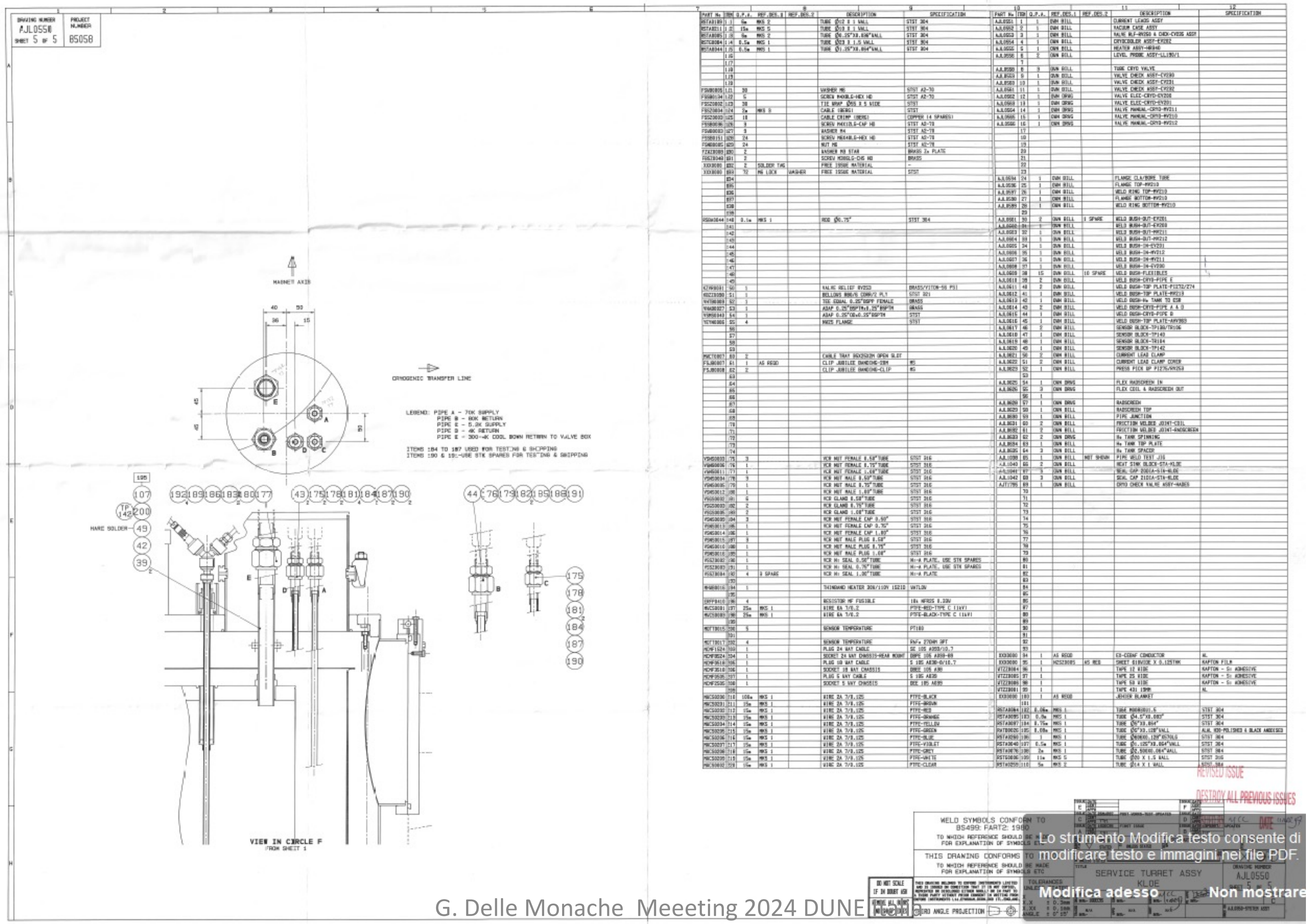
LHe

GHe

GHe



KLOE Magnet test @ LNF and FNAL



Magnet Cool Down with LN2 and LHe

- Requires very limited re-installation of the original fluidic subsystems
- LN2 flexible TL already in place (with 3000 lt LN2 tank for preliminary test)
- LHe dewars available in house (3x1000 lt) already PED re-qualified
- Requires the manufacturing of noncomplex cryogenic interfaces
- The HW is self consistent to repeat the test “keys in hand” @ FNAL before magnet re-integration in the yoke

Procurement and costs estimate

PO for most part of the HW and services for the cold test has been emitted to the suppliers, in details:

- All the cryo components connecting the LN2 and LHe lines to the magnet turret + exhaust He and N2 lines
- 36.000 liters of LN2 + 4/6 weeks of renting LN2 mobile thank + manufacturing of evaporator to control the LN2 T inlet to the magnet
- Interface for the connection of the DAFNE compensator TL to the mobile thank + its redeployment

LHe will be procured near the test date for commercial reasons.

KLOE Magnet handling: Service Turret Removal

After the tests before the shipment FNAL the service turret must be removed because of the interference with the hall door. The reverse process has been performed by OI in 1997 at magnet delivery. The main operations can be summarized as in the following:

1. Disconnection of the signal sensors cable (air side)
2. Removing of the cylindrical shell of the vacuum case
3. Removing of the MLI
4. Disconnection of the signal sensors cable (vacuum side)
5. Disconnection of the coil terminals
6. Cutting of the 4 cryogenic lines

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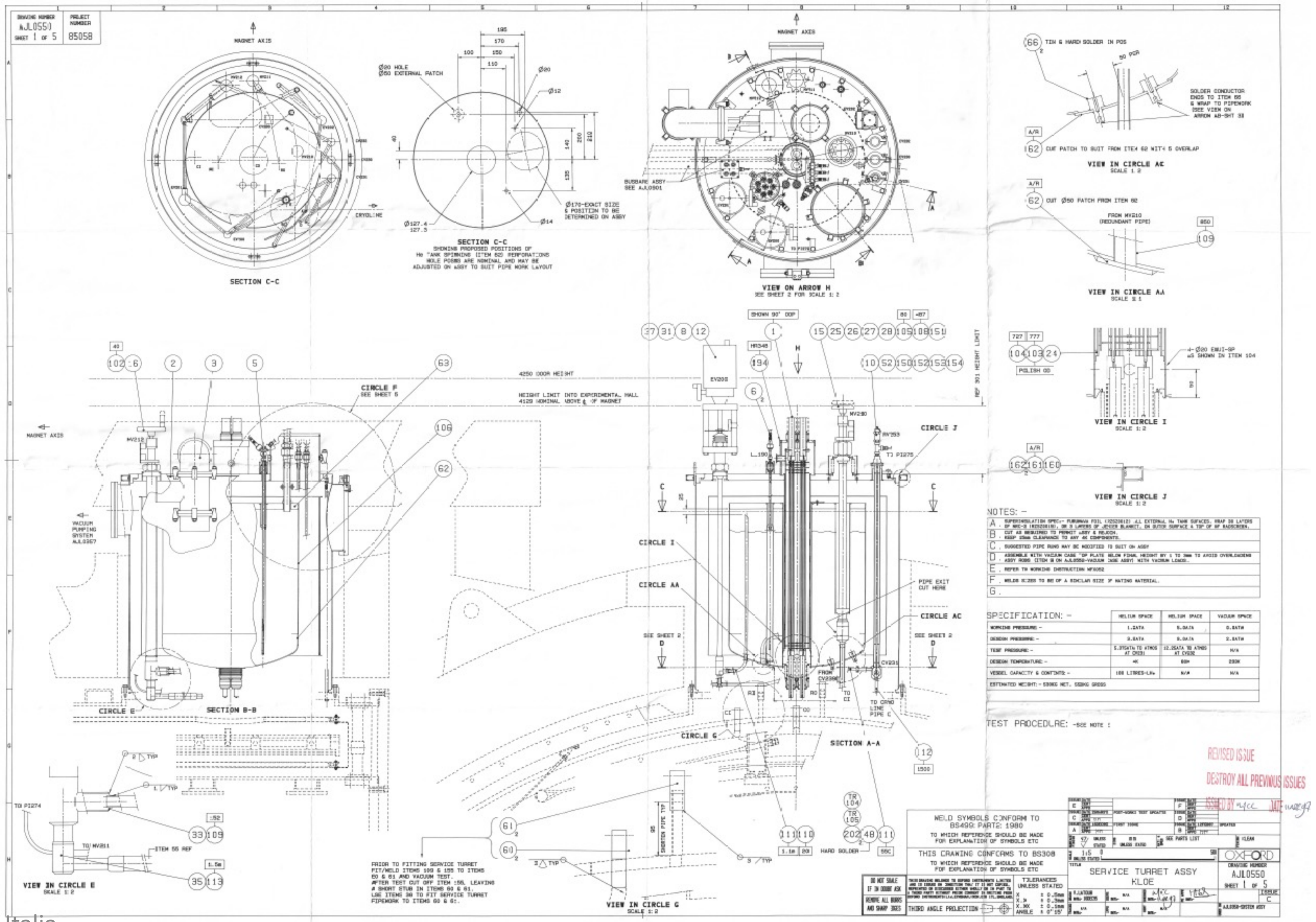
KLOE Magnet handling: Service Turret Removal

The turret will be reconnected at FNAL and the procedure (to be used in the reverse sequence for the turret removal) is described in the drawing from Oxford Instrument AJL0550 "Service Turret Assy KLOE sheet 1 to 5.

Working Instructions (OI internal procedures) obviously are not available, for this reason due to the nature of this operation INFN will award a contract to ASG Superconductors to perform the entire process of removal and reconnection at FNAL of the service turret.

KLOE Magnet handling: Service Turret Removal



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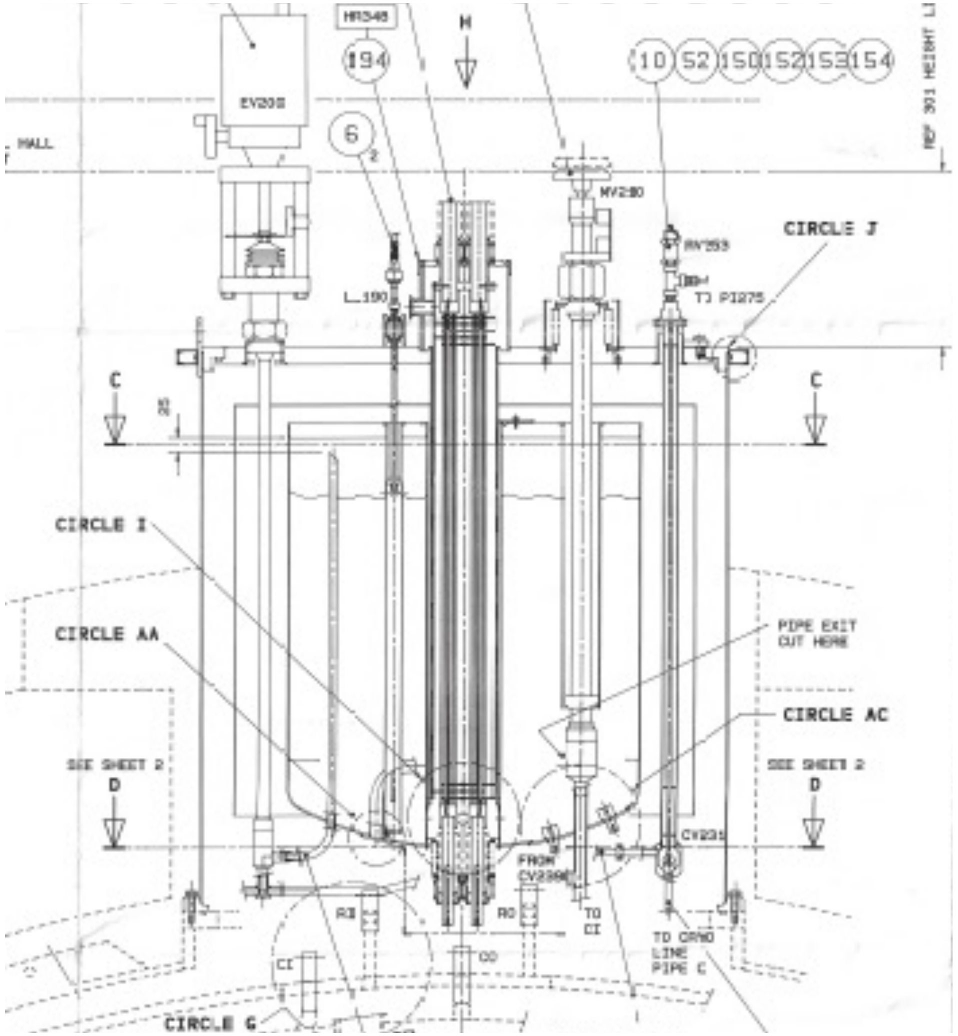
KLOE Magnet handling: Service Turret Removal



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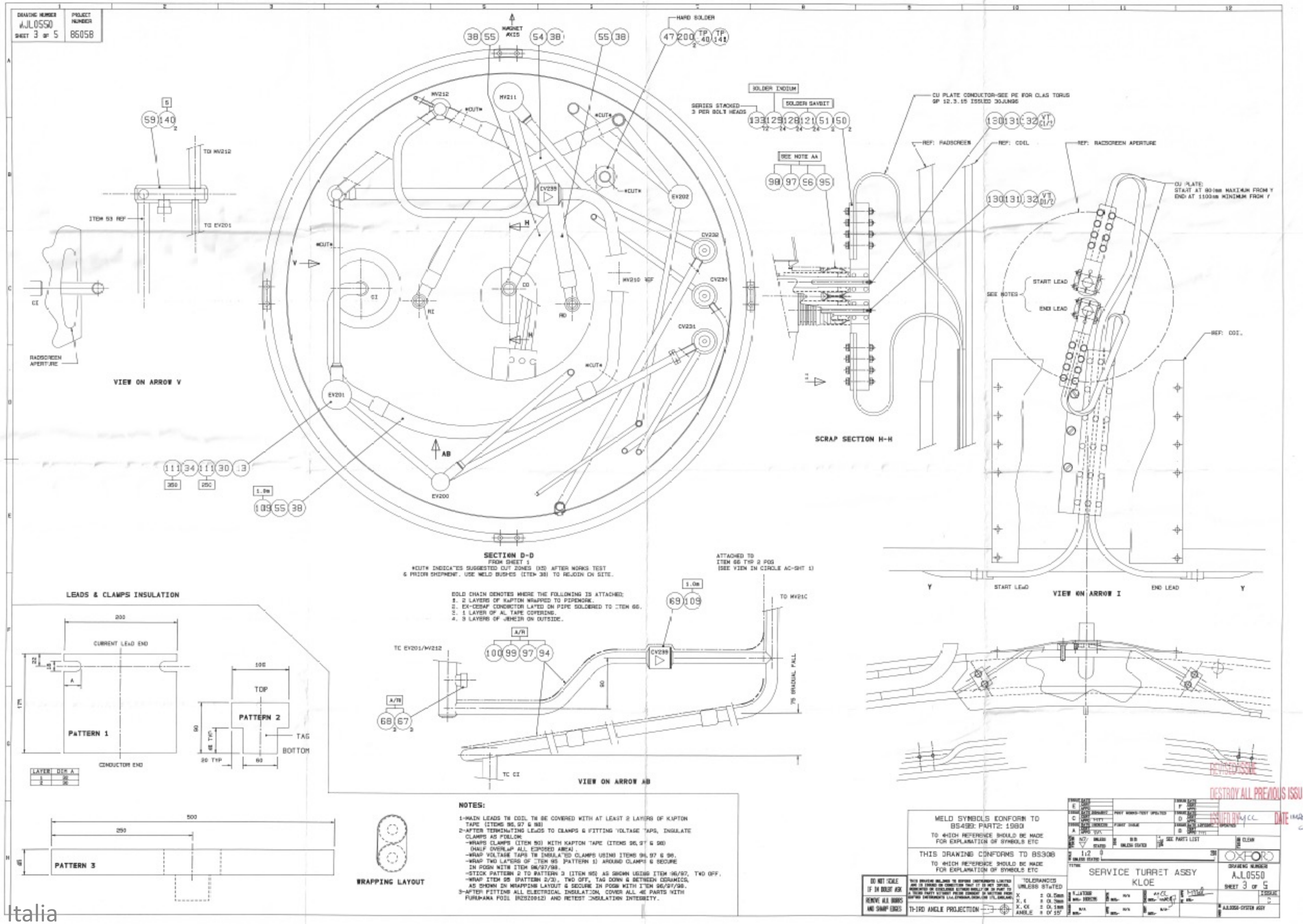
KLOE Magnet handling: Service Turret Removal



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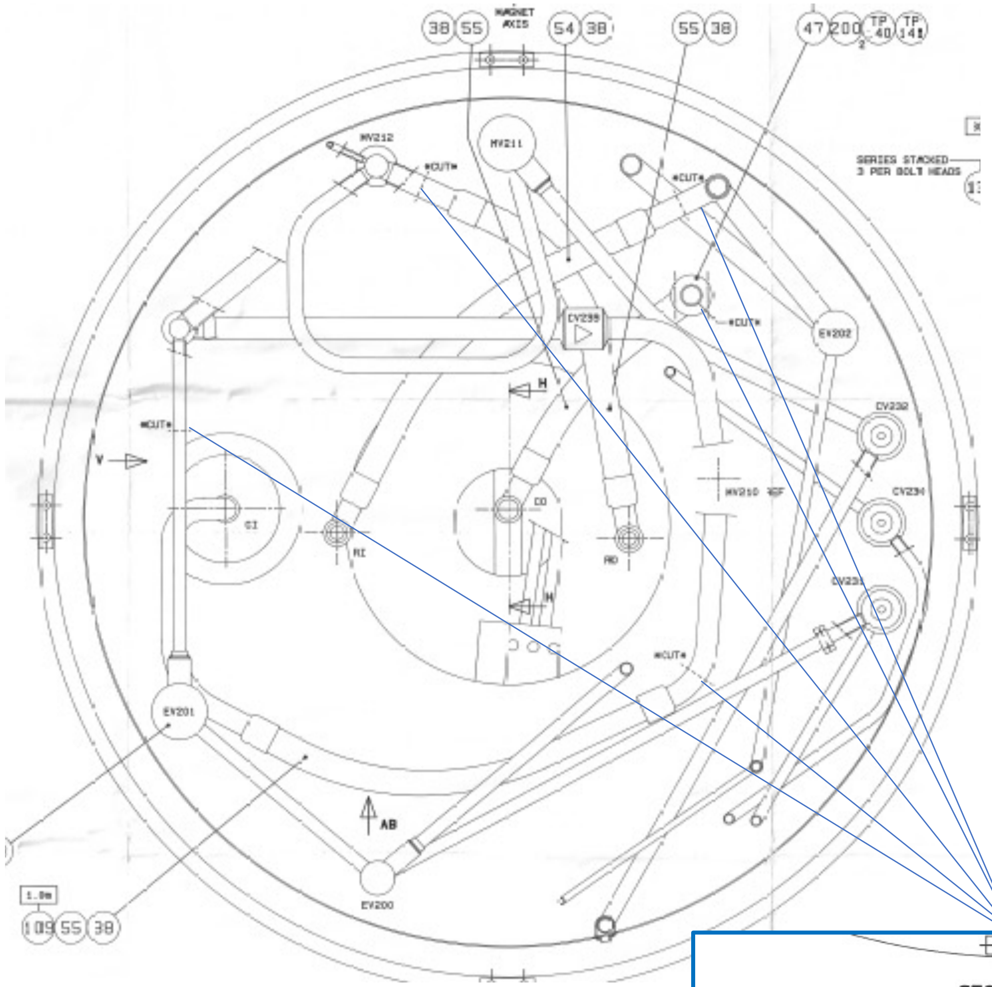
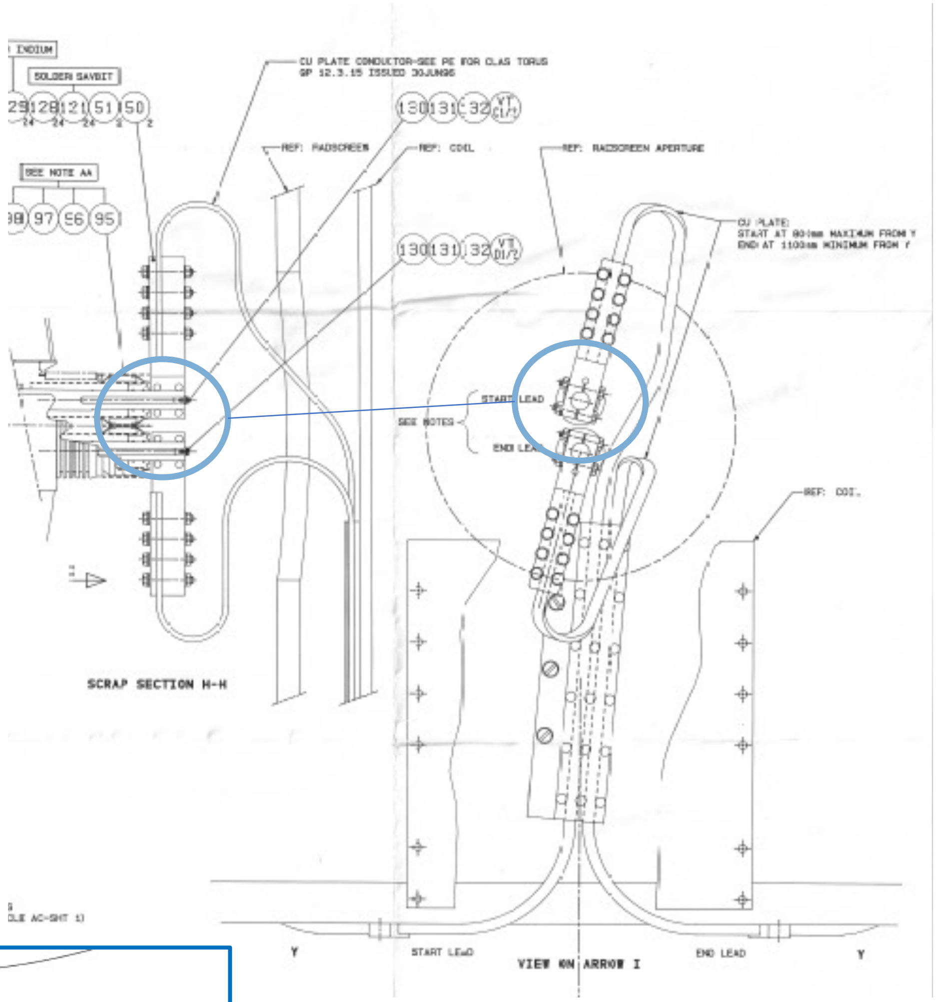
KLOE Magnet handling: Service Turret Removal





SECTION D-D
FROM SHEET 1
CUT INDICATES SUGGESTED CUT ZONES (X5) AFTER WORKS TEST
& PRIOR SHIPMENT. USE WELD BUSHES (ITEM 38) TO REJOIN ON SITE.

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DAFNE Cryo Plant Linde TCF 50

LINDE KRYOTECHNIK AG

2. PLANT & PROCESS DESCRIPTION

2.1. Plant performance

2.1.1 Normal operation mode

The total performance supplied to the 6 magnets is:

Liquefaction rate:	1.14	g/s
Refrigeration capacity at 4.45 K, 1.22 bar	99	W
Shield cooling capacity below 80 K	800	W

2.1.2 Refilling the compensator magnets

The four compensator magnets are refilled periodically with a fixed time interval of 24 hours, all 6 hours an other magnet. The quantity of liquid helium which is used to cool down the transfer line and to fill the compensators is produced continuously and stored in the phase separator of the refrigerator. This quantity is included in the liquefaction rate above.

2.1.3 Cool down of the refrigerator

The time to establish liquid Helium level from turbine start will be 3 hours (or less), with LN2.

2.1.4 Cool down mode for Kloe

During this operating mode the refrigerator is supplied with LN2. Finuda is out of operation, but it is kept cold. The compensators are not refilled. The total cool down time takes less than 10 days.

Capacity available for Finuda:

Liquefaction rate:	0.2	g/s
Refrigeration at 4.45,1.22 bar	44	W
Shield cooling capacity below 80 K	270	W

Capacity for Kloe while warmer than 80 K.

Source	Nominal HL (guarantee)	Measured HL @ 1000 A
Current Leads	0.6 g/s	0.12 g/s
coil	55 W	27.6 W
Radiation screen	530 W	62.6 W

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Cold gas (3bar,4.5 K)	4.6	g/s
Shield cooling capacity below 80 K	530	W

2.1.5 Cool down mode for Finuda

During this operating mode the refrigerator is supplied with LN2. Kloe is out of operation, but it is kept cold. The compensators are not refilled. The total cool down time takes less than 10 days.

Capacity available for Kloe:

Liquefaction rate:	0.3	g/s
Refrigeration at 4.45,1.22 bar	55	W
Shield cooling capacity below 80 K	530	W

A FEW SPECIFIC POWERS

- Carnot at 4,2 K   70.43 $W_{300\,K}$ / W
- Carnot at 80 K   2.75 $W_{300\,K}$ / W
- Carnot for 1 g/s LHe (for LHe at 1,2 b)   6852 $W_{300\,K}$

Theoretical equivalence liquéfaction/refrigeration :
1 g/s ⟺ about 100 W

Guy Gistau Bauger

Istituto Nazionale di Fisica Nucleare

Cryo plant Linde LR 140 vs TCF 50

Linde Kryotechnik AG

5 INDICATIVE PRICE

132 kW

Main Scope

Pos No	Description	Price
1.	LR140 Helium Refrigeration System including scope of supply as per item 3	EUR 6.5 Mio
2.	Technical assistance during Instal Practical instructions – Including travel, overnight allowances	

Note:

[1] May be subject of separate order.

The prices referred to herein include delivery standard packing for sea transport. The prices not include any Value Added Tax (VAT), sales Any additional taxes and/or duties have to be b

If any taxes/duties become applicable, then th submission of documentary proof by the Selle USA as well as any Tax Deducted at Source (T

The prices are indicative prices and an estimate factors change, we reserve the right to adjust t based on Seller's standard Terms & Conditions or contract conditions are excluded.

Linde Kryotechnik AG

2 REFRIGERATION CAPACITY

The following refrigeration capacities can be provided with the proposed LR140, without LN2 pre-cooling:

Expected Performance Data [1,2,3]	Cooling Power	Pressure supply-return	Temperature supply-return	Mass Flow
	W	bar(a)	K	g/s
Refrigeration at 4.5K [4]	55	3.0 – 1.2	4.45 – 4.45	(4.5)
Shield capacity at 70K	530	5.0 – 1.2	40 – 80	(3.3)
Liquefaction LHe [5]	-	1.25 – 1.05	4.45 – 300	0.73

Notes:

[1] Cooling water supply < 21°C; He gas temperature at Coldbox inlet < 303K

[2] for pure, dry He gas (99.999%)

[3] Expected refrigeration/liquefaction rates, measured in the distribution/test box with the installed equipment.

[4] Pressure in phase separator

[5] Return purity to compressor inlet >99.999%

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2

The price break down below is indicative only and shall not be used for separated line item procurement:

250 kW

	with recovery system		without recovery system	
Refrigeration System	CHF	1'234'000.–	CHF	1'234'000.–
Cryogenic Distribution System	CHF	831'000.–	CHF	831'000.–
Recovery System	CHF	509'000.–	CHF	–.–
Process control system	CHF	176'000.–	CHF	156'000.–
Installation and Start Up	CHF	316'000.–	CHF	306'000.–
Acceptance tests without and with magnets	CHF	363'000.–	CHF	343'000.–
Total	CHF	3'429'000.–	CHF	2'870'000.–

According to INFN's request, Linde Kryotechnik AG is ready to grant on the above mentioned prices a maximum discount of 3 (three) %, arriving to the following net final totals:

Price for the system and services with recovery system CHF 3'326'000.–

Price for the system and services without recovery system CHF 2'783'000.–

3.850.000.000 di Lire in 1995

for a double power plant

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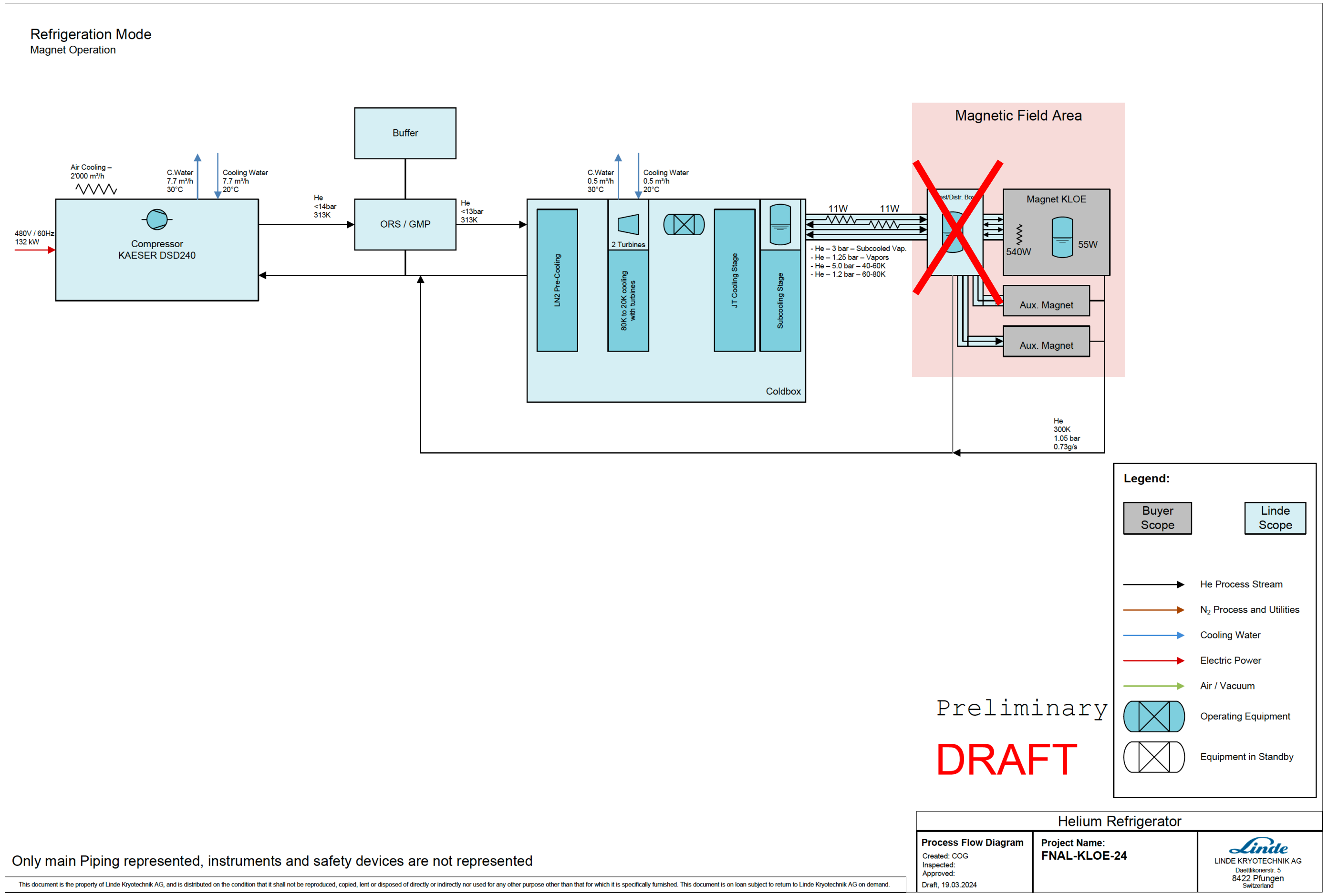
Cryo plant Linde LR 140



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KLOE Magnet Compliance

- KLOE is provided with 150 liters of LHe reservoir aimed to limit its temperature below 20 K in case of a quench, so it must comply FNAL internal regulation for pressure equipment.
- In the past, the safety protocol and methodology described in Fermilab ESH Manual allowed Fermilab Director to accept pressure equipment as “exceptional” after the production of an Extended Engineering Note in case of non compliaces.
- Recently DOE is reconsidering the methodology for operating FNAL equipment built in periods where ASME and PED code did not require data recording of production processes (e.g. design calcs per ASME, FEA, verification of thicknesses, radiography, additional pressure testing, etc.), so it most likely that **FFT “Fitness For Service”** methodology will be applied

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KLOE Magnet Compliance

For the **FFS assessment** ***if the in-service equipment cannot be linked to a construction Code, then the pedigree of the in-service equipment (materials, design, fabrication, over-pressure protection) will have to be established by:***

Inspections, design re-constitution, operating history, tests, risk analysis etc.

<u>We have collected most part of relevant documentation needed to be ready when DOE will fix the procedure:</u>

1. Drawings
2. User Manuals
3. Final Design (and test) report