

Final acceptance tests of Helium Refrigerator for Wendelstein 7-X

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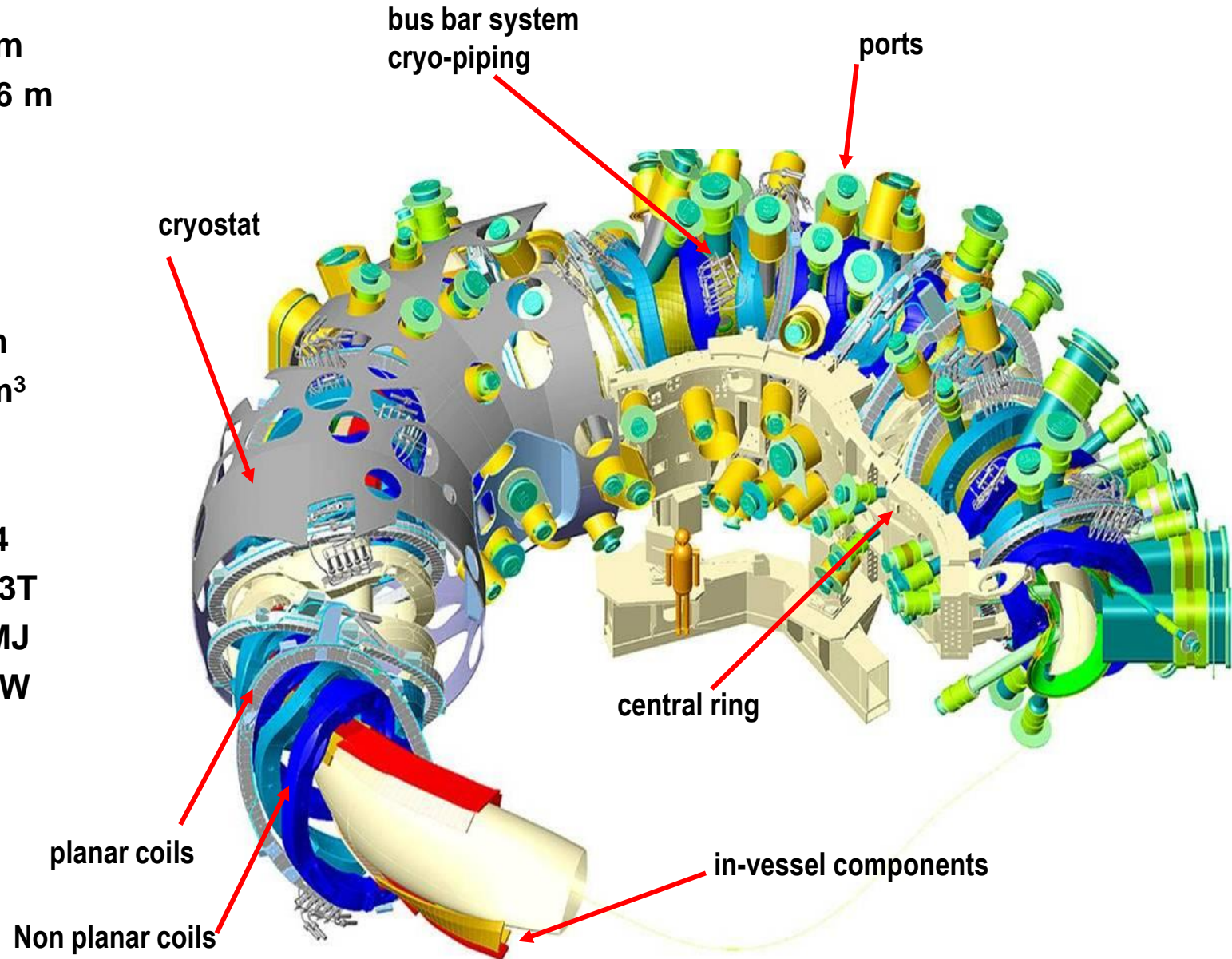
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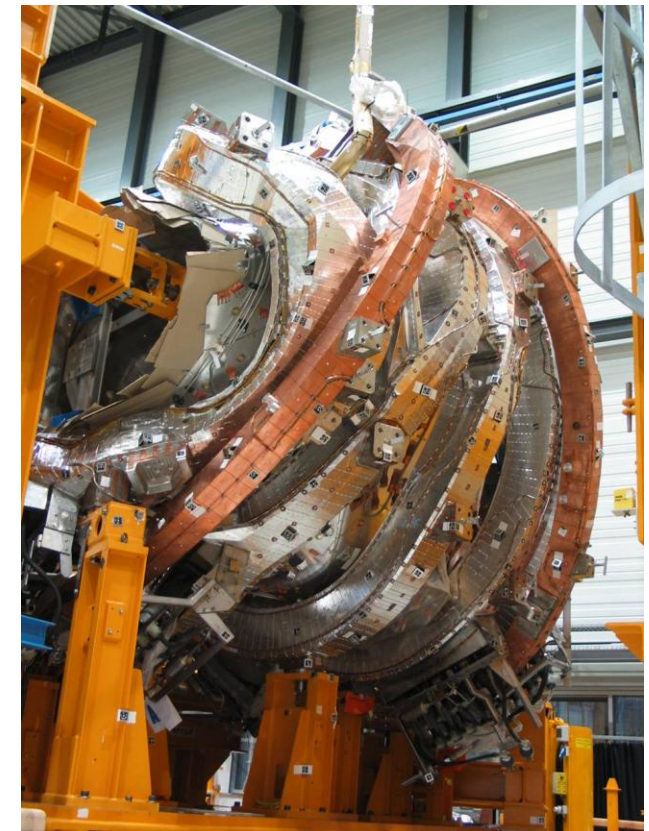
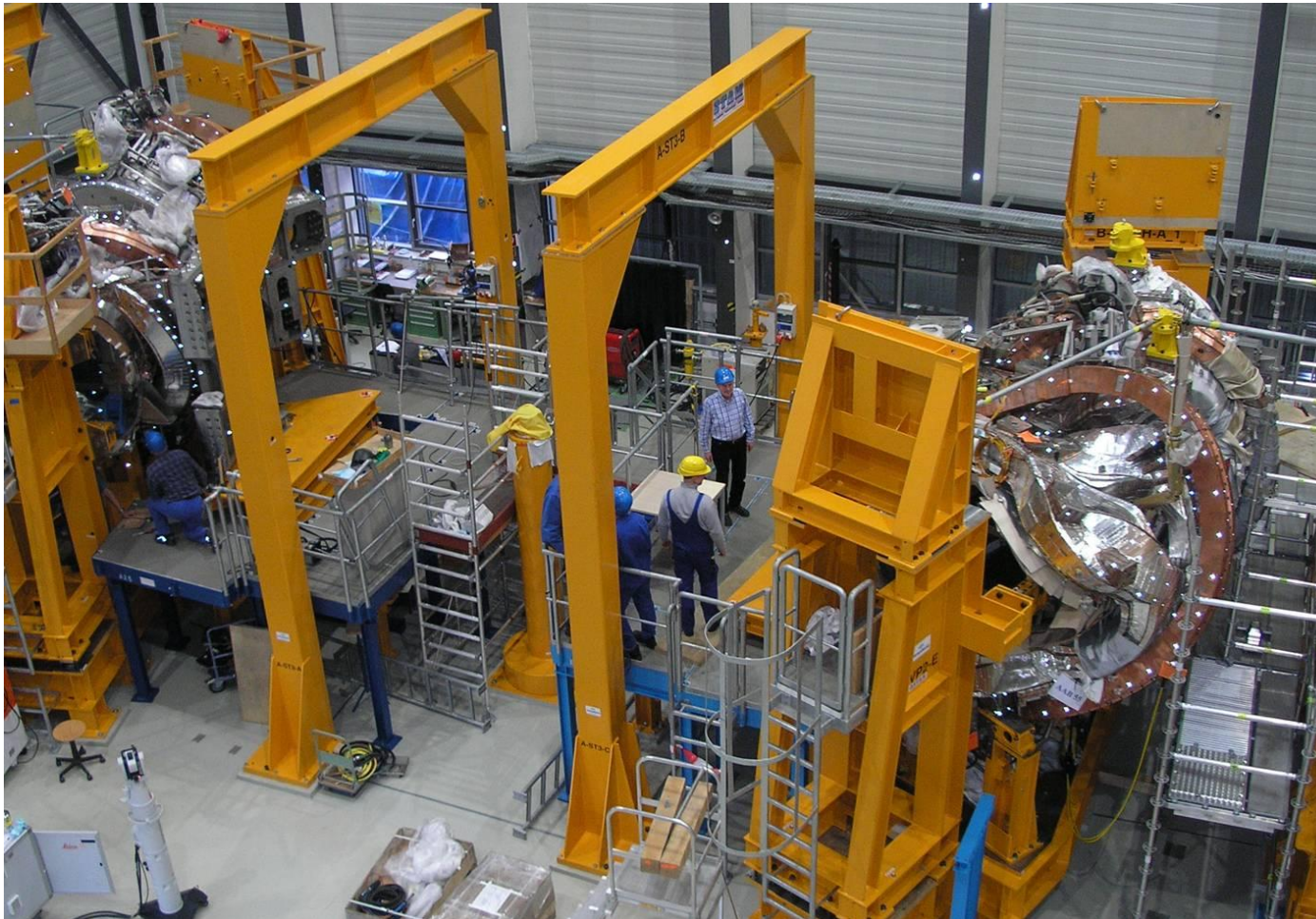
**Linde Kryotechnik AG
Daettlikonerstrasse 5, CH-8422 Pfungen, Switzerland**

Machine height: 4.5 m
Machine diameter: 16 m
Machine mass: 725 t
Cold mass: 425 t

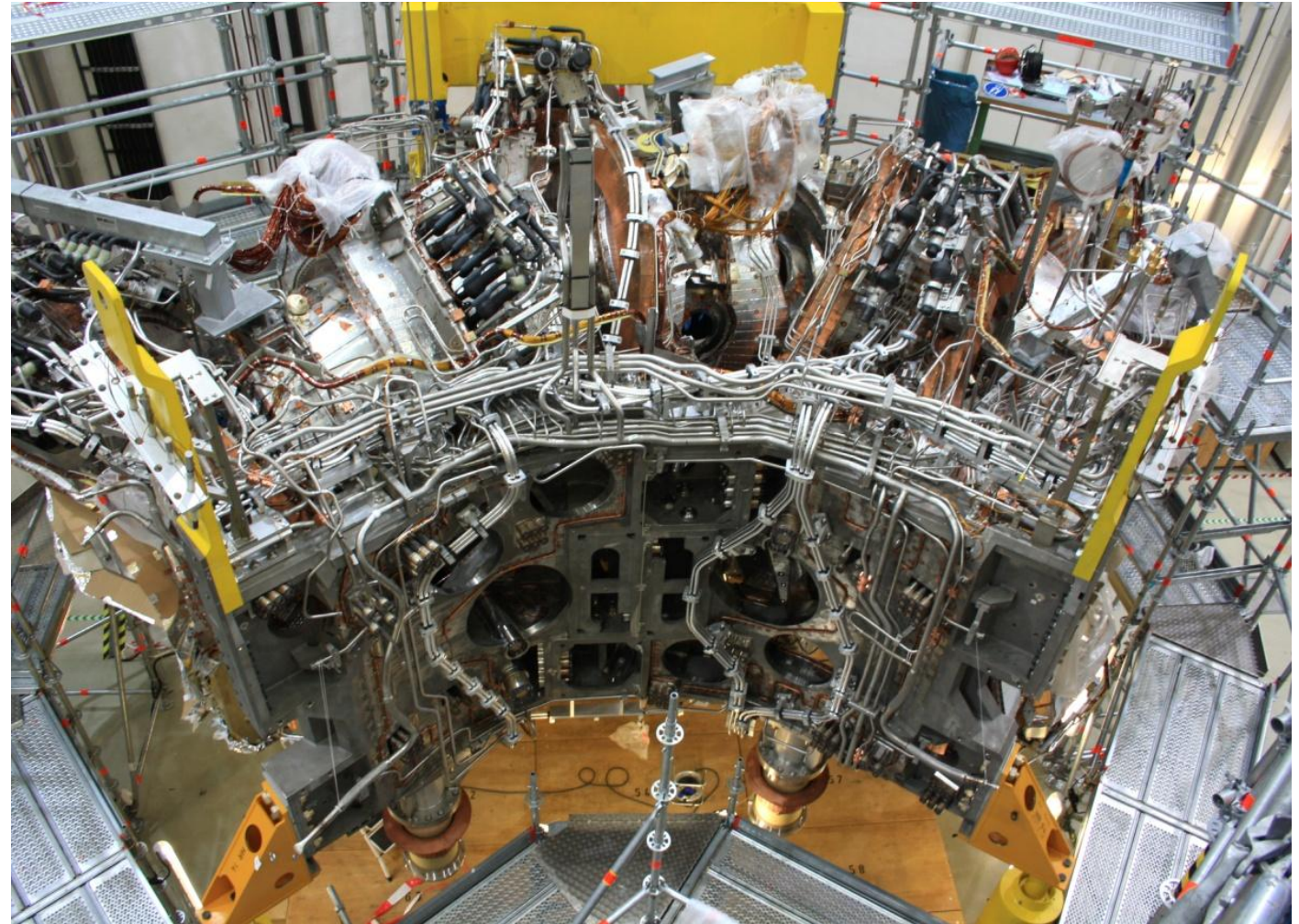
Major radius: 5.5 m
Minor radius: 0.53 m
Plasma volume: 30 m³
Non-planar coils: 50
Planar coils: 20
Number of ports: 254
Induction on axis: < 3 T
Stored energy: 600 MJ
Heating power: 10 MW
Duration: 30 min



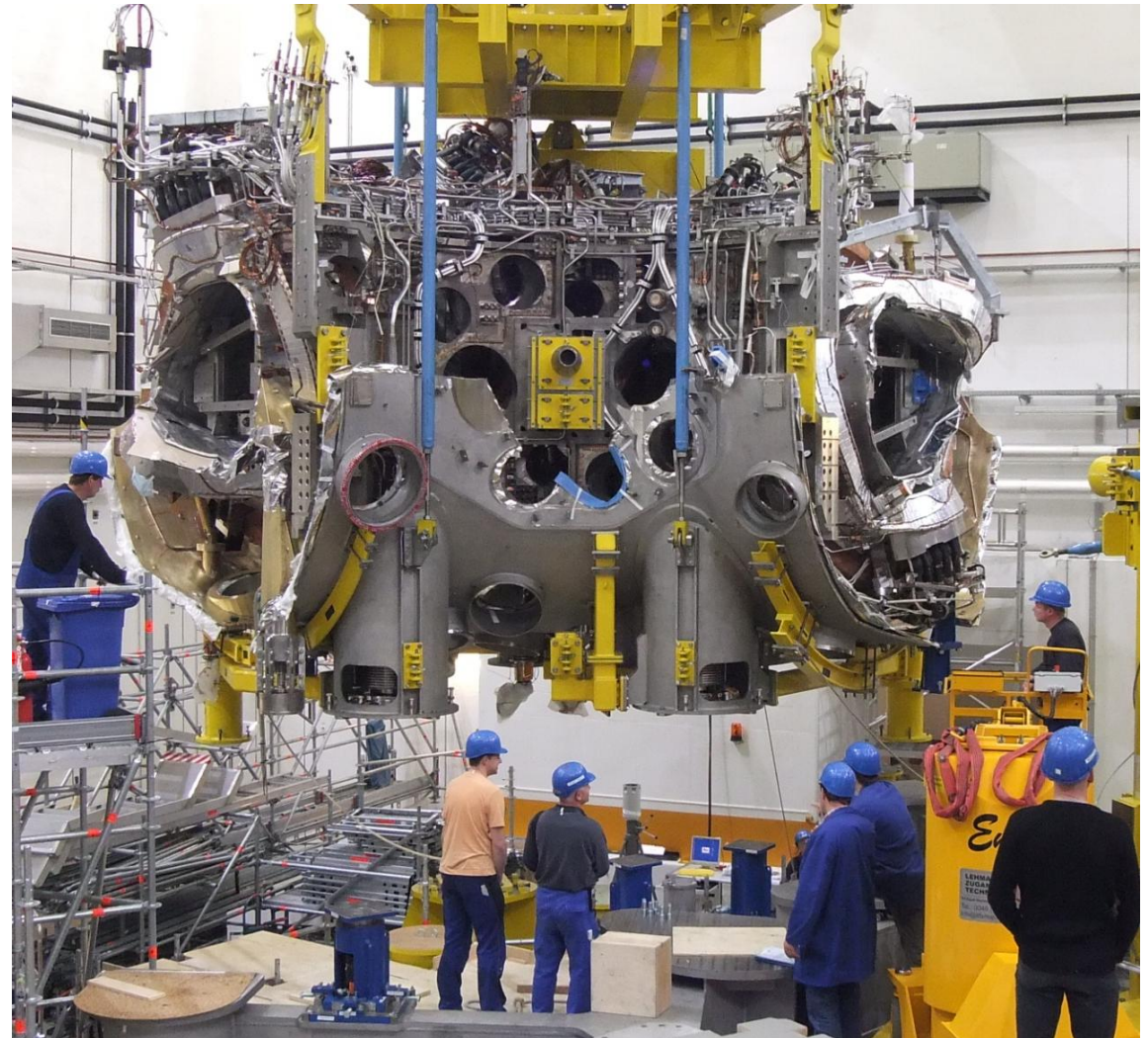
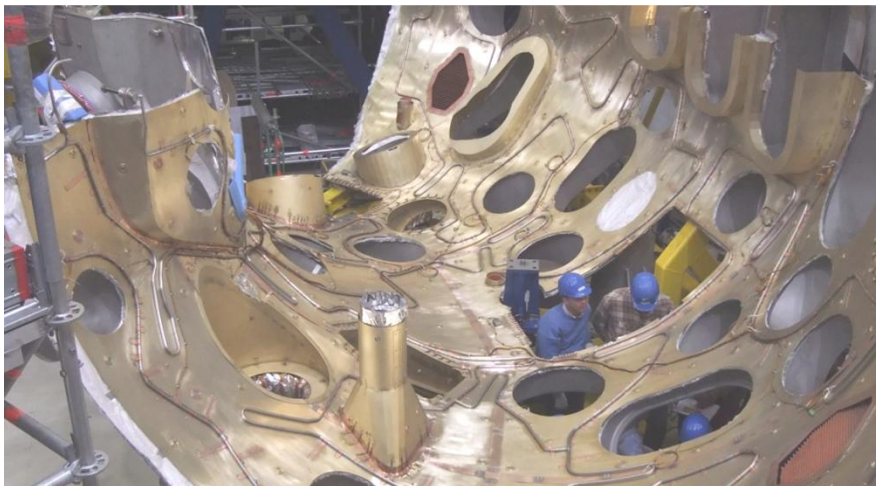
- Two assembly stands next to each other
- Volume of half module
 $4 \times 5 \times 4 \text{ m}^3$
- Max. height over ground:
6m

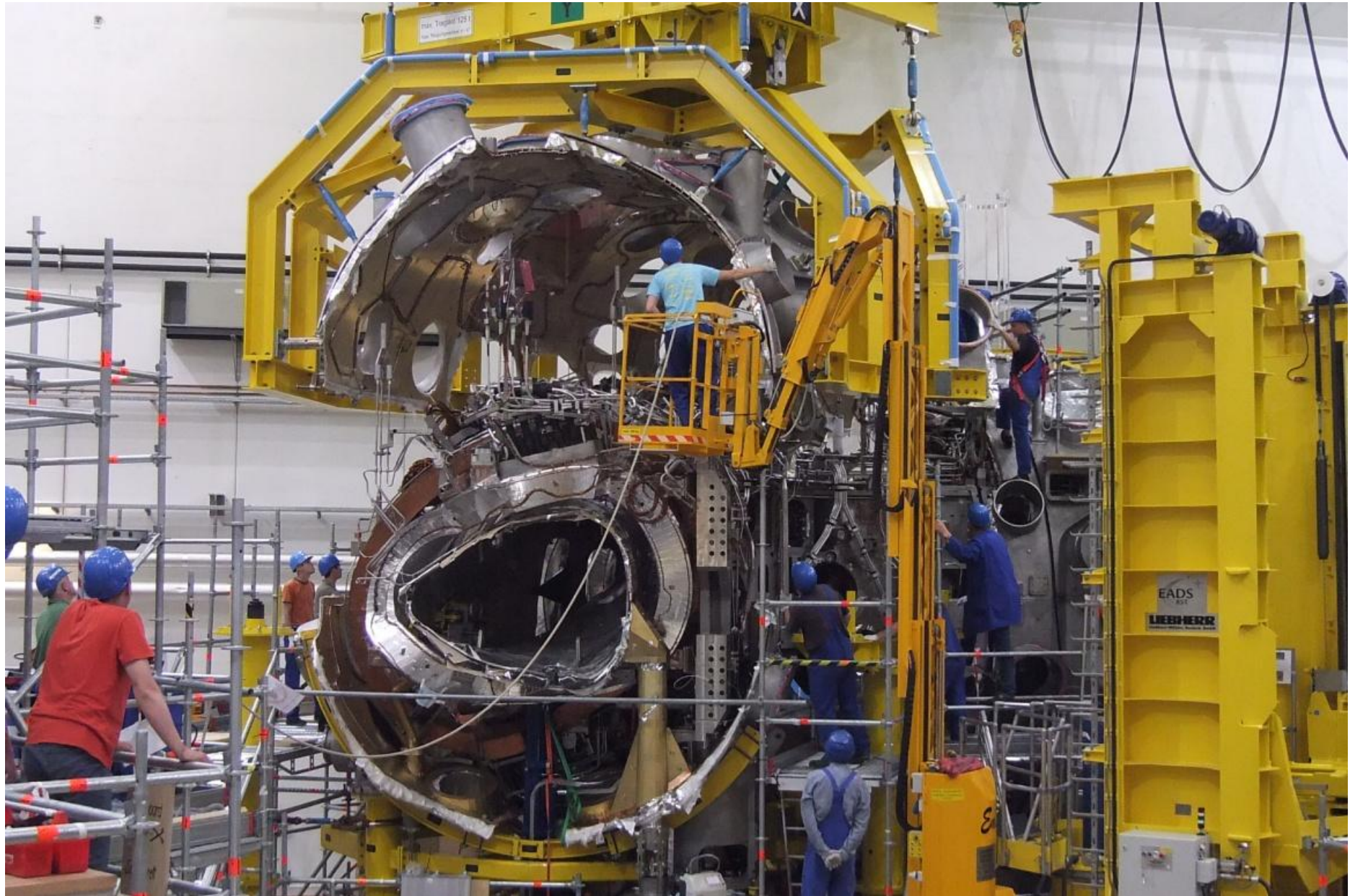


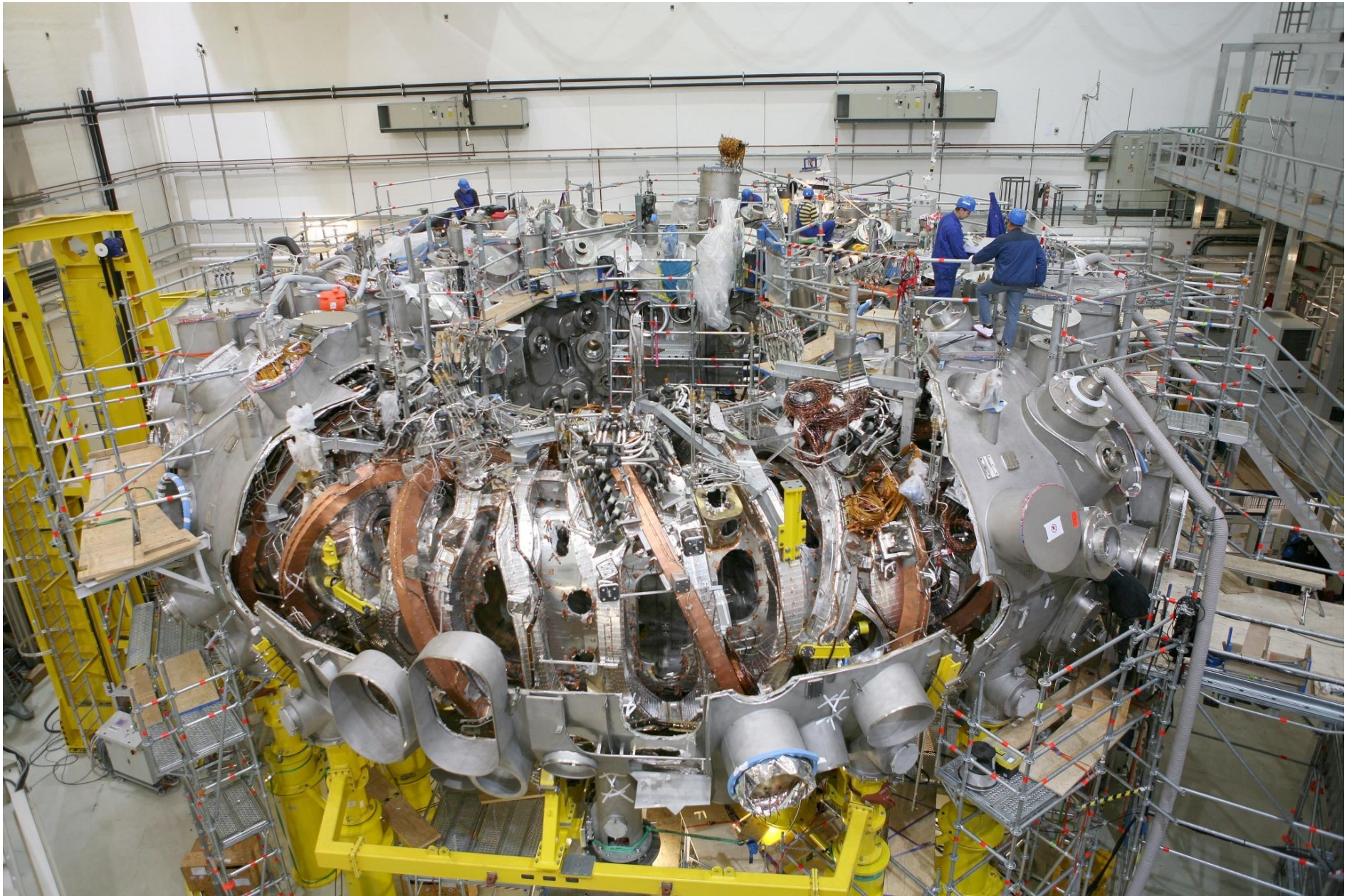
- After connection of 2 half modules installation of pipes and super conductor is performed
- For each superconductor or pipe at least two supports have to be adjusted
- Installation of sensors and cables
- assembly of joints between superconductor and coils

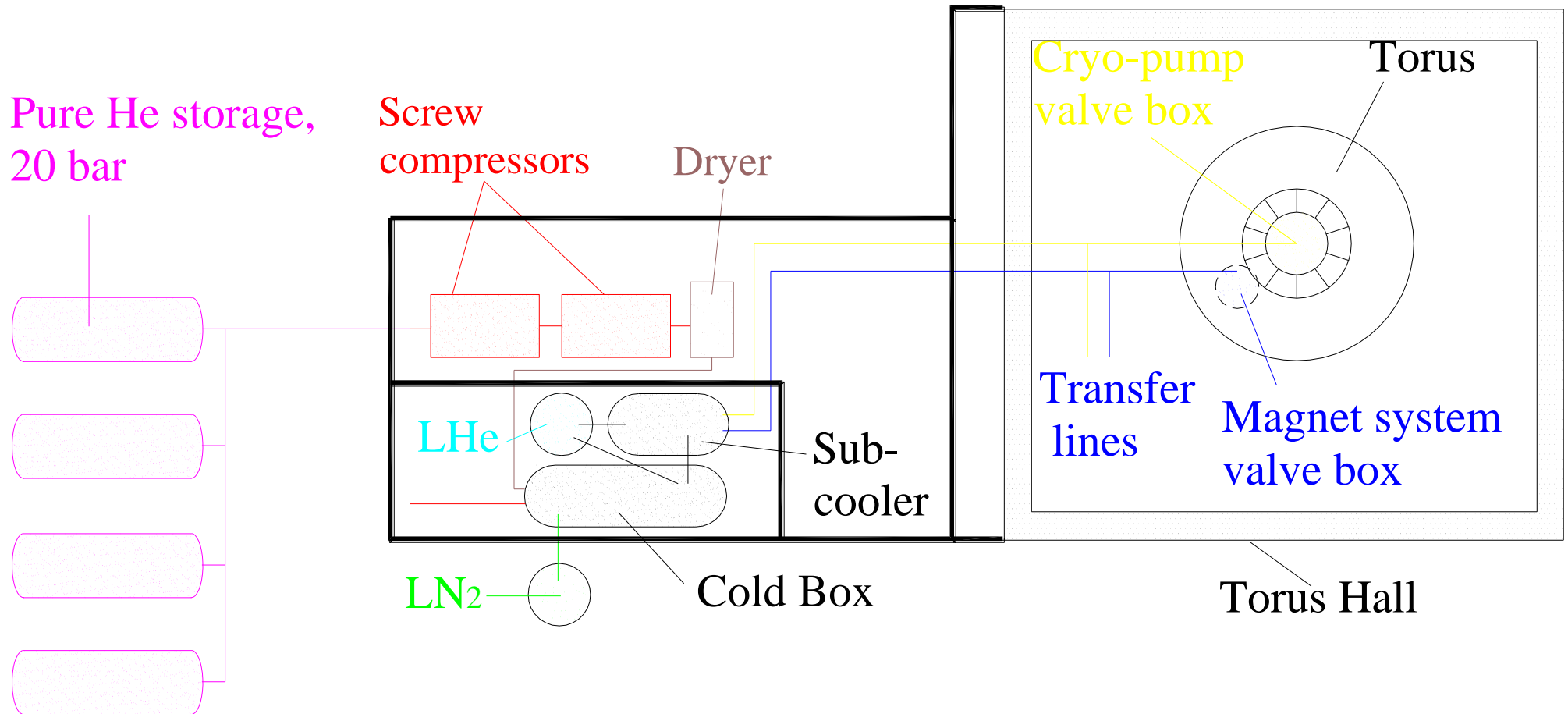


- Lifting of magnet module into empty lower shell of cryostat
- Moving of magnet module and lower shell to their final position on machine table
- Adjustment tolerance $r < 1.5\text{mm}$

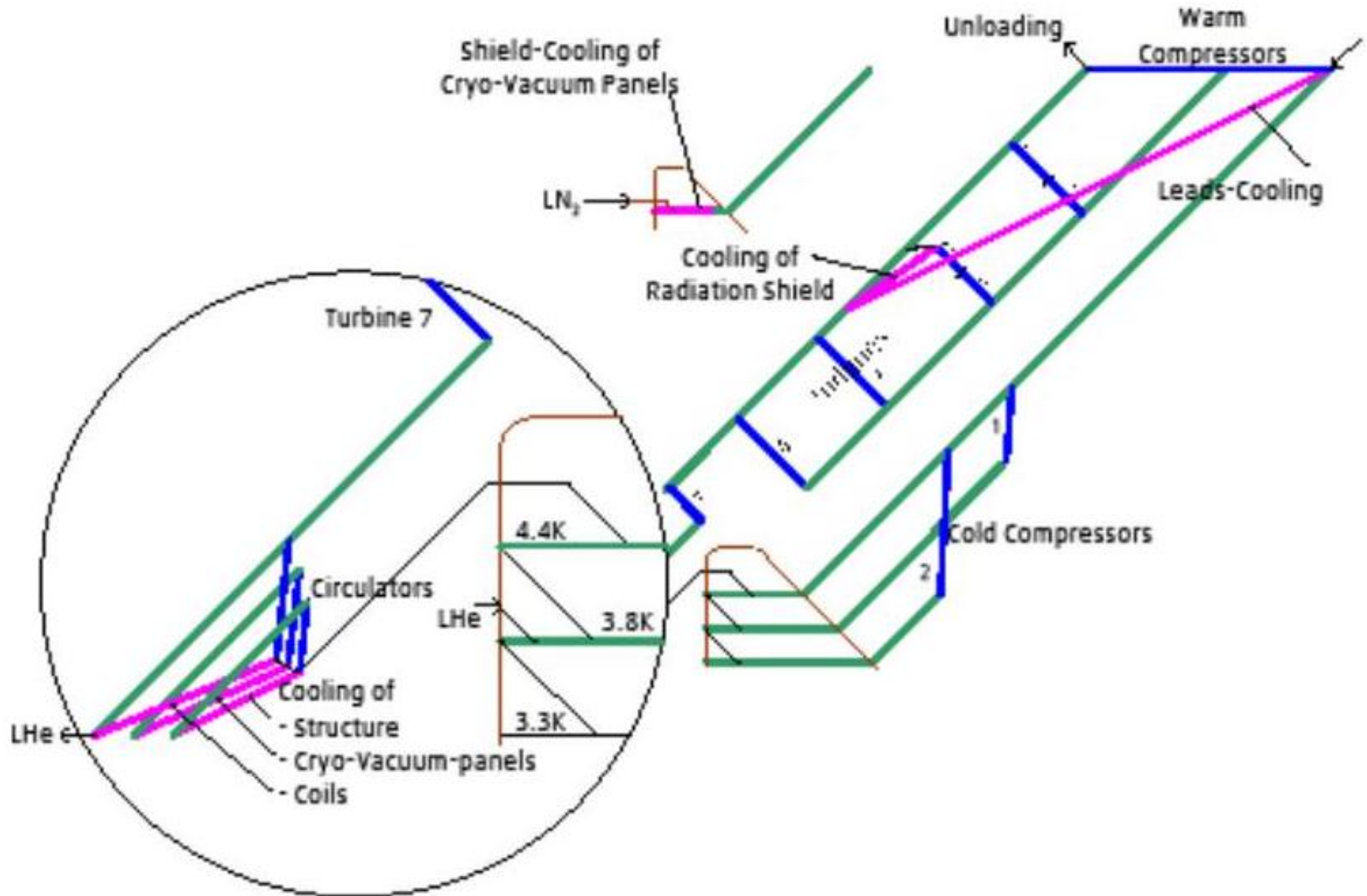




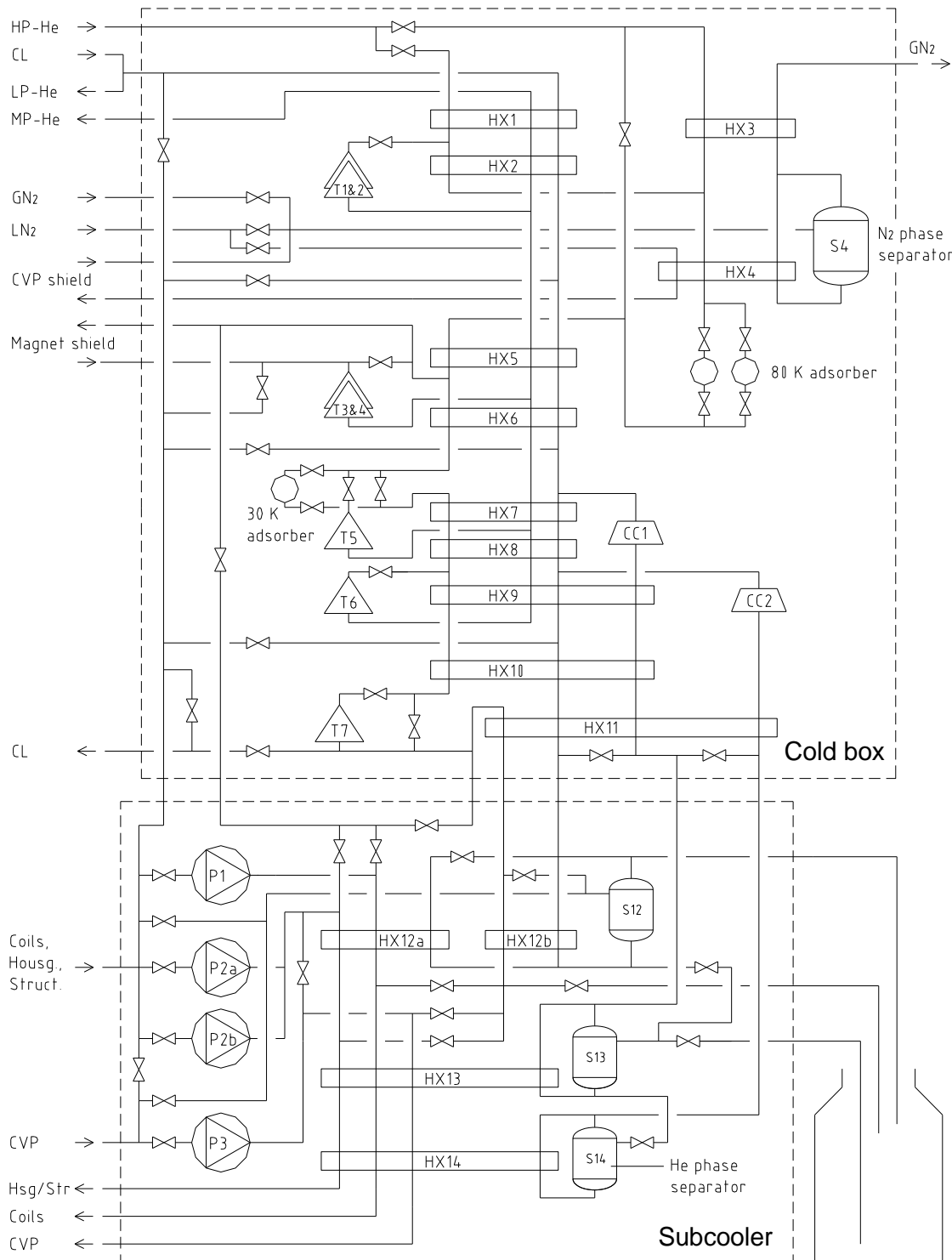




Refrigerator supplied by Linde Kryotechnik AG



Proceedings of ICEC22 (2009) 655 Kuendig, Dhard et al



1. Short standby mode

- PV Baking
- CVP regeneration (ambient & LN2 temp.)

2. Standard mode

3. Peak-power mode

4. Long standby mode

5. Auto mode change over

6. Emergency signals

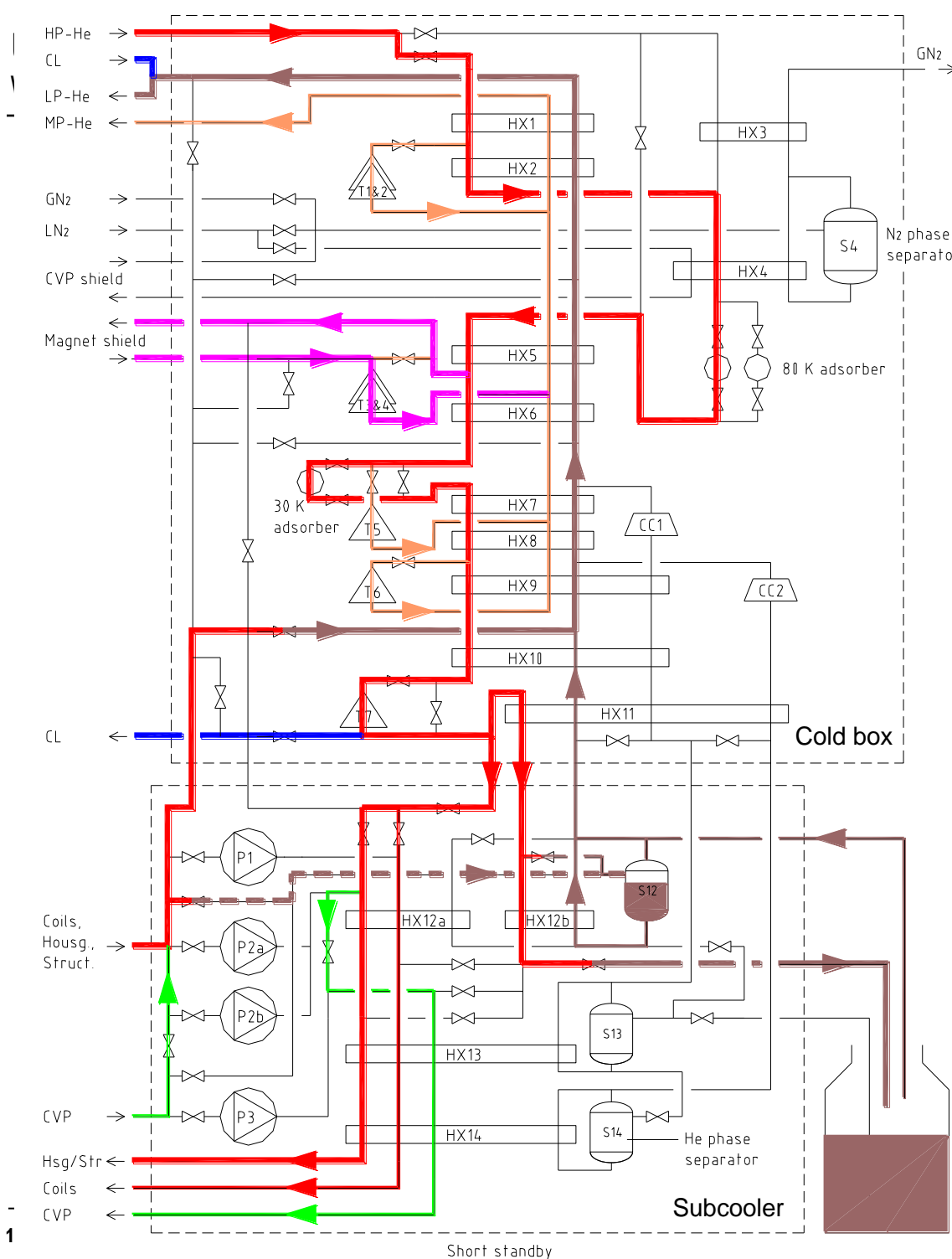
Modes with / without

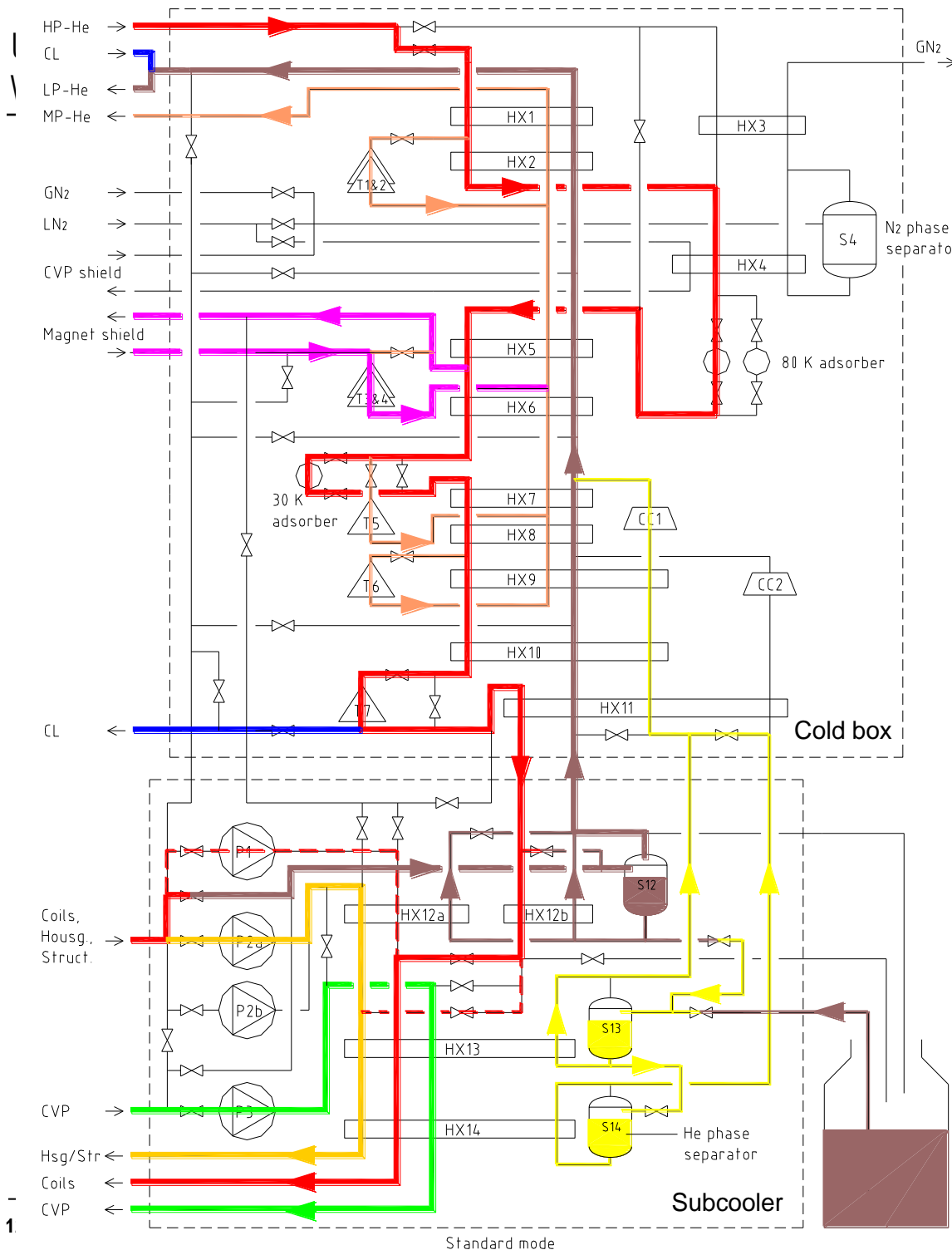
- Liquefaction of He
- LN2 precooling

Short standby mode

Guarantee value and (measured average value)

<u>Appl.</u>	<u>Heat load</u> W	<u>T_{op}</u> K
Casing	1800 (1853.6)	<10K (5.6K)
Coils	250 (259.7)	<10K (5.3K)
CVP	450 (513)	<10K (5.3K)
Shield:	14000 (14400)	<70K (68.1K)
PV baking	28000 (28526)	<100K (91.3K)
Leads		5 g/s ~4.5K (5.33g/s ~4.5K)
LHe		9 g/s (18.7g/s)
LN2 + LHe		-103 g/s (-115.2g/s) 21 g/s (31.84g/s)
LN2 +LHe	PV baking	-126g/s (-91.1g/s) 11g/s (20.4g/s)



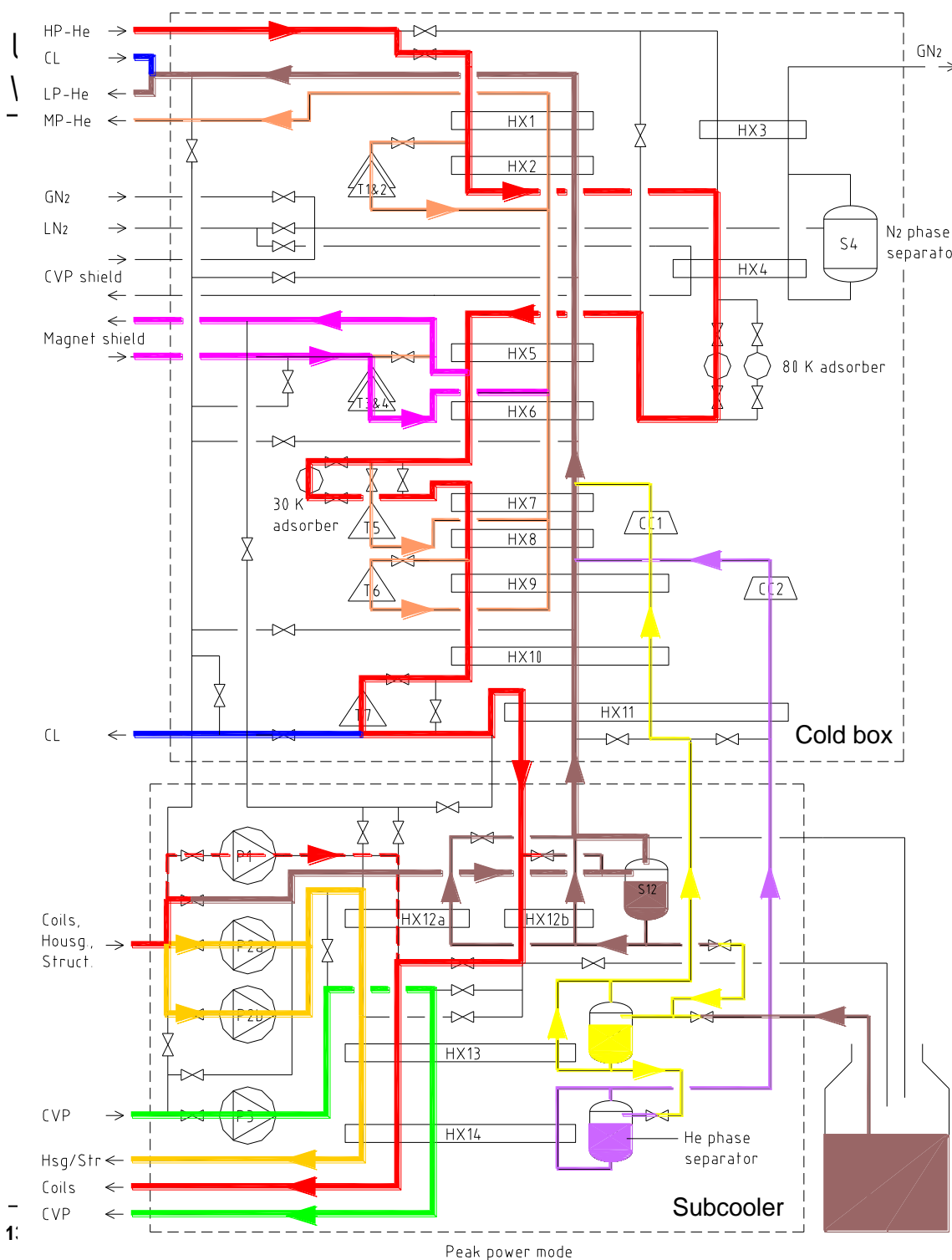


Standard mode (3.9 K, 2.5 Tesla)

Guarantee value and (measured average value)

Appl.	Heat load W	Mass flow g/s	ΔP Bar
Casing (3.87K)	1800 (1835)	300 (307)	0.1 (0.2)
Coils (3.84K)	800 (808.6)	200 (216)	0.7 (0.8)
CVP (3.86K)	450 (508.5)	250 (255)	0.6 (0.53)
Shield	14000 (14553)		<70K (61K)
Leads		15 (15.43)	~4.5K (~4.5K)
LHe		-22.5 (18.65)	
LN2+ LHe		-31.5 (27.4) -15 (14.35)	

Peak power mode (3.4 K, 3 Tesla)
 Guarantee value and (measured average value)



<u>Appl.</u>	<u>Heat load</u> W	<u>Mass flow</u> g/s	<u>ΔP</u> Bar
Casing (3.37K)	1800 (1835)	800 (808)	0.4 (0.5)
Coils (3.35K)	1100 (1110.4)	450 (455)	2.3 (2.4)
CVP (3.38K)	450 (508.5)	250 (253)	0.6 (0.5)
Shield	14000 (14570)		<80K (62)
Leads		25 (25.6)	~4.5K (~4.5)
LHe		-69 (54)	

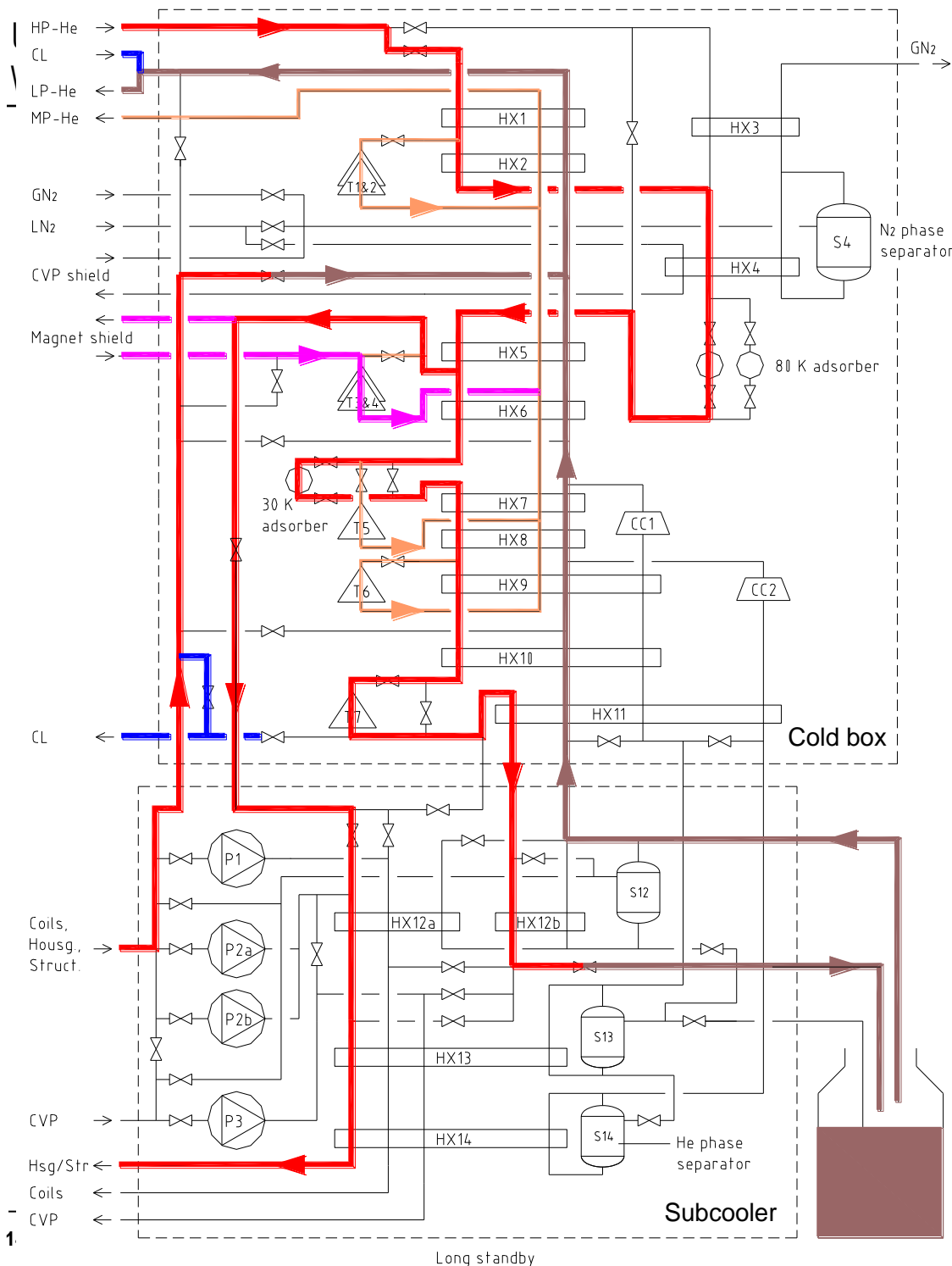
Turbine 1 & 2 not in operation

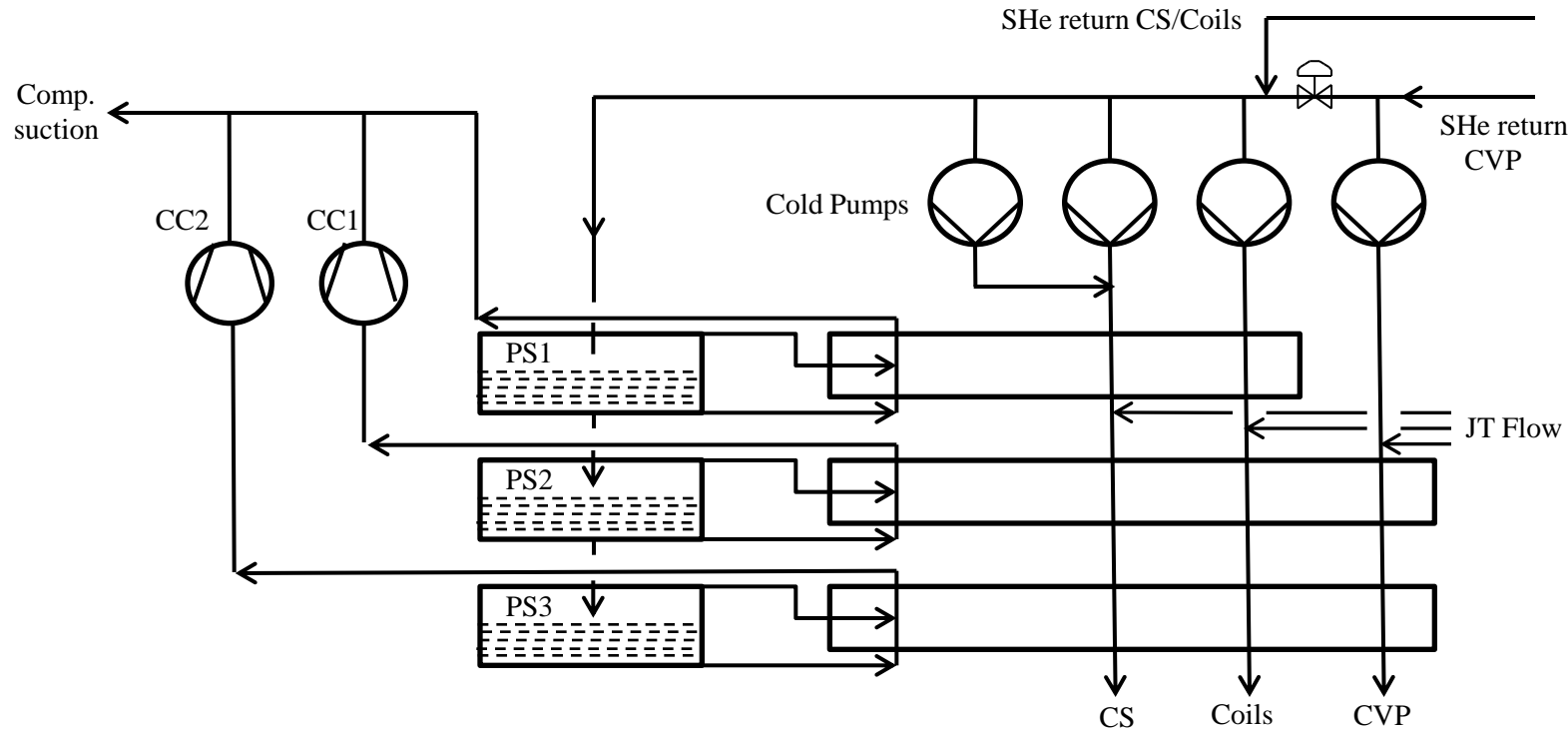
Peak power mode

Long standby mode

Guarantee value and (measured average value)

Appl.	Heat load W	T_{op} K
Casing+	520 (527)	<100K (72.9K)
Coils+		
CVP		
Shield	10000 (10450)	
Leads		5 g/s <105K (5.33g/s 79.6K)
LHe		20 g/s (26.9g/s)
LN2		n.a.
+ LHe		n.a. (37.75g/s)



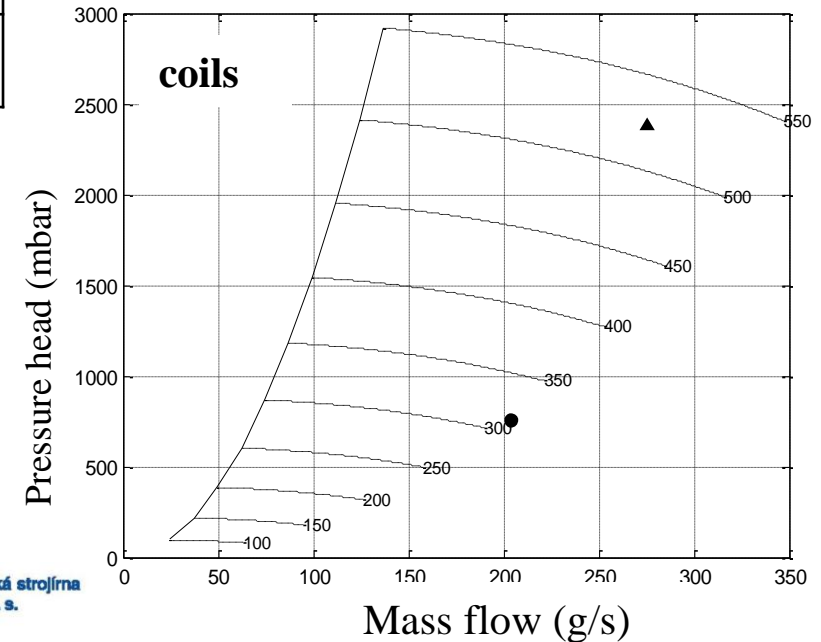
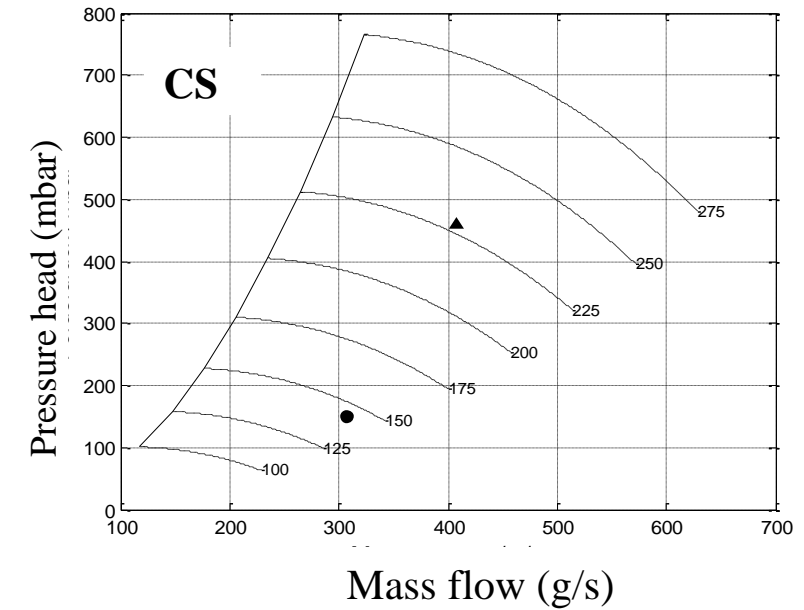


Challenges

Cold pumps: Parallel configuration, start-up & continuous operation

- The cold pumps can be started individually or together
- 2 pumps were started at the same time without troubles
- 4 pumps were operated together
- Cold compressors were started individually
- Cold compressors were operated together continuously

Parameters	Units	Pumps for casings & structure (CS)		Pump for coils		Pump for CVP	
		SM	PPM (2 pumps)	SM (Not operating)	PPM	SM	PPM
Mass flow	g/s	306	816	--	275	255	255
Suction pressure	bar	3	3	3	3	3	3
Suction temperature	K	5.09	4.3	5.09	4.3	4.5	4.14
Discharge pressure	bar	≥ 3.15	3.46	--	5.38	3.66	3.66
Discharge temperature	K	5.2	4.38	--	4.74	4.61	4.26
Efficiency Isentropic	%	≥ 55	≥ 55	≥ 55	≥ 55	≥ 55	≥ 55



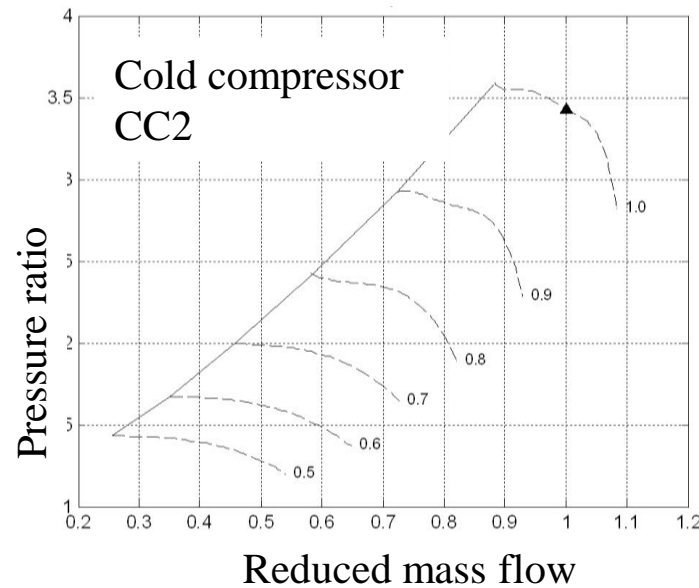
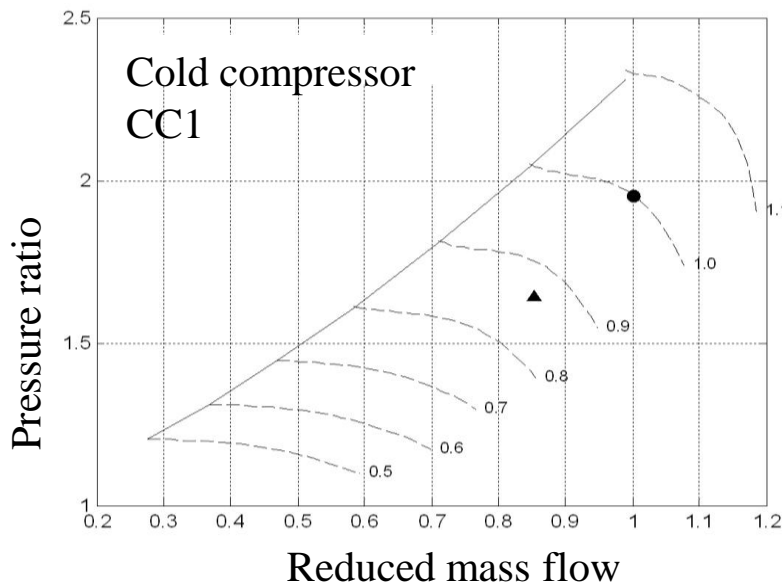
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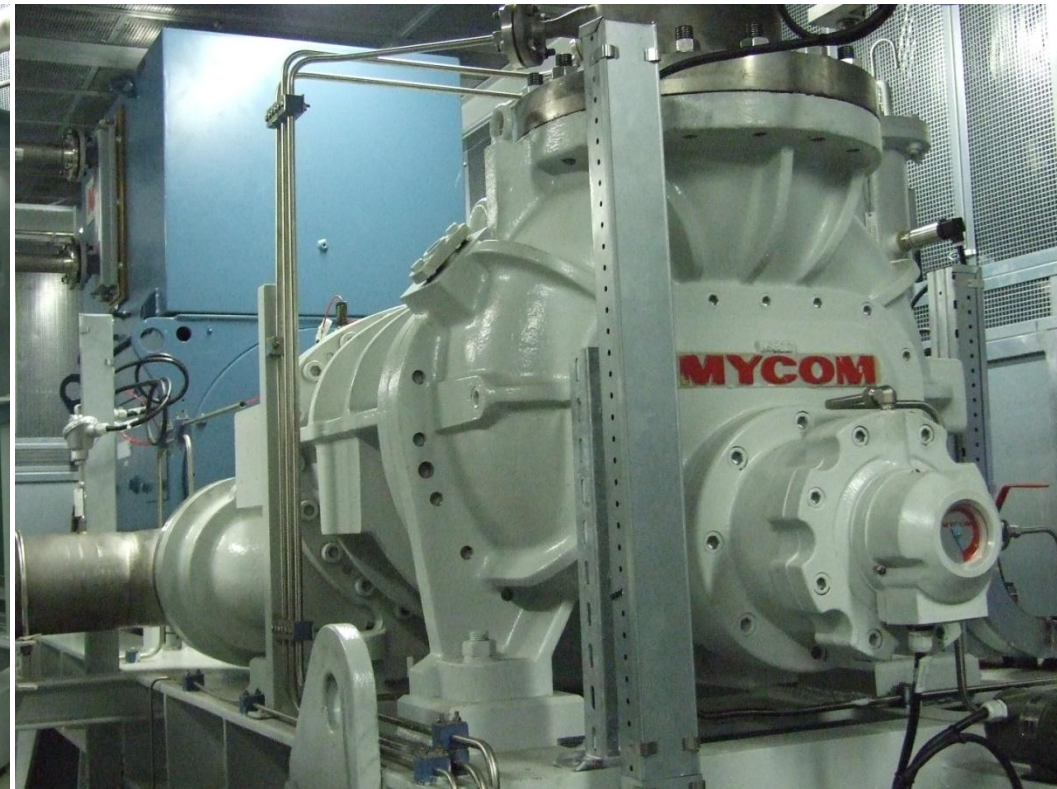
Parameters	Units	Cold compressor (CC1) (3.9K operation)		Cold compressor (CC2) (3.4K operation)	
		SM	PPM	SM (Not operating)	PPM
Mass flow	g/s	102.8	113.3	--	126.6
Suction pressure	mbar a	640	760	1250	350
Suction temperature	K	12.8	10.8	6	5.25
Discharge pressure	bar a	1.25	1.25	1.25	1.25
Discharge temperature	K	18.4	14.2	--	10.2
Efficiency Isentropic	%	≥ 70	≥ 70	--	≥ 70
Heat leak with intercept cooling	W	≤ 50	≤ 50	≤ 50	≤ 50



První brněnská strojírna
Velká Bíteš, a. s.



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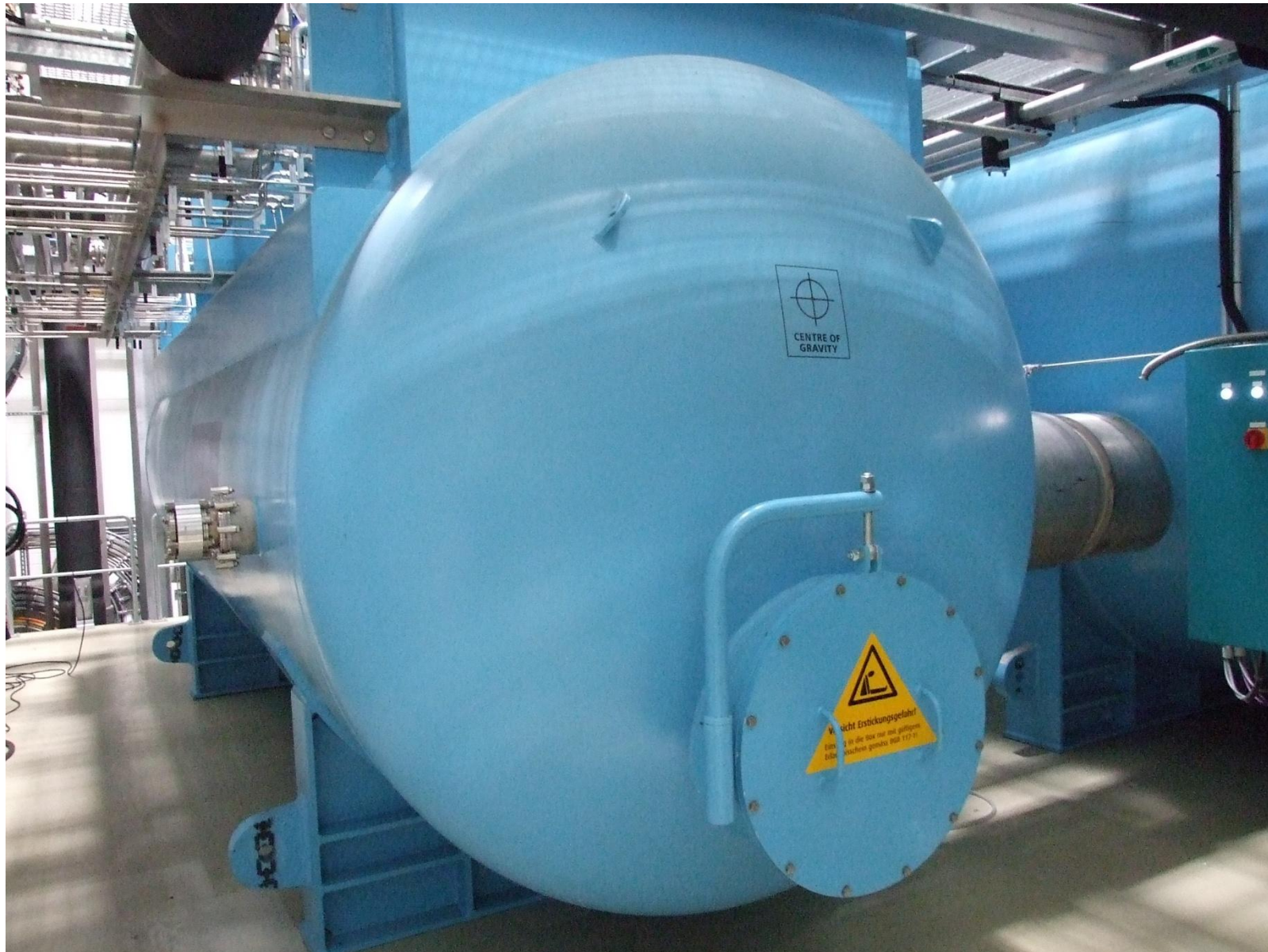


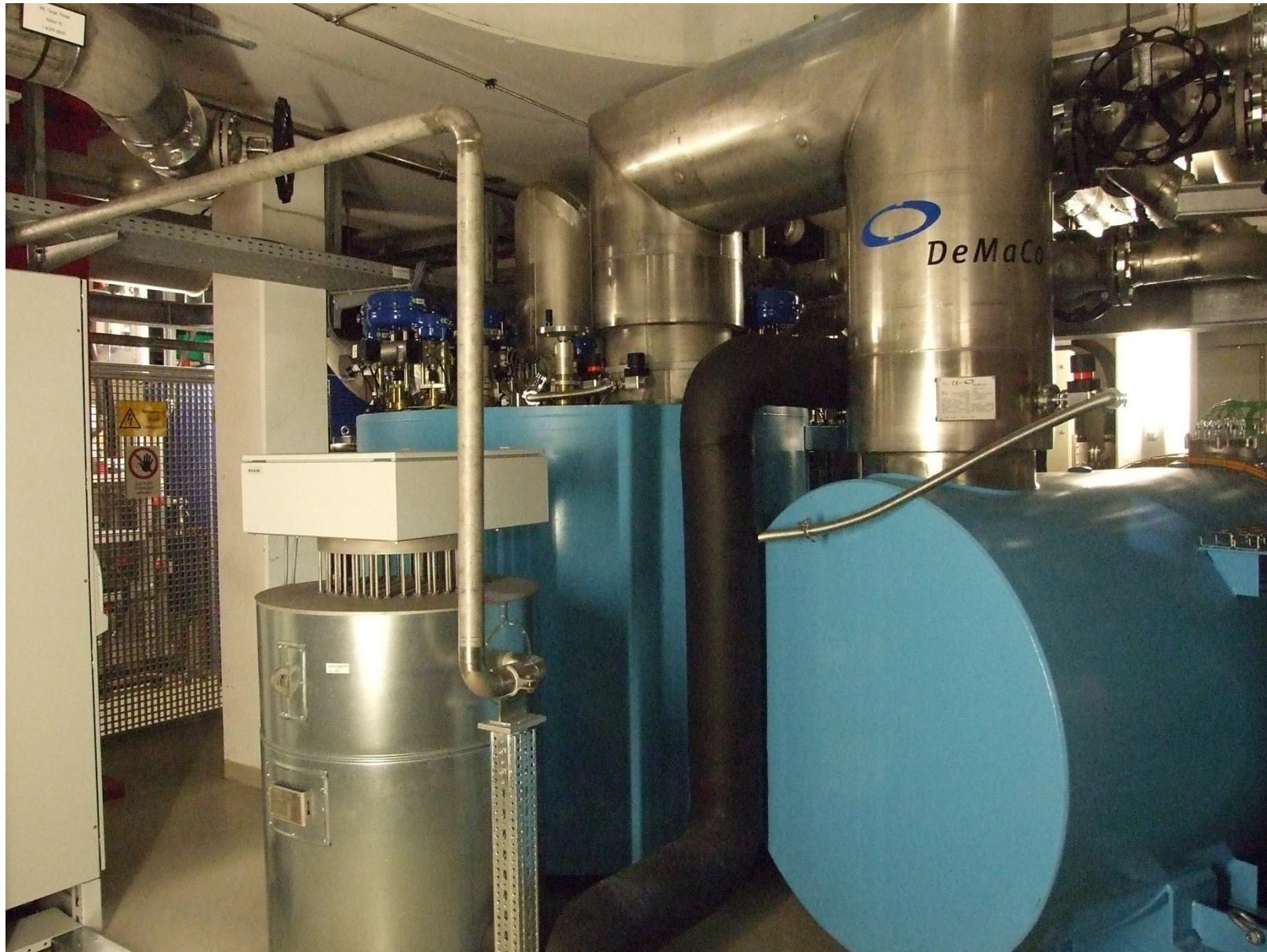
Operation mode	Unit	PPM		SM		SSM		SSM-LN2	
		1 st stage	2 nd stage	1 st stage	2 nd stage	1 st stage	2 nd stage	1 st stage	2 nd stage
P_suction	bara	1.02	4.80	1.02	3.85	1.02	4.20	1.02	3.90
P_discharge	bara	5.35	15.5	4.40	16.3	4.75	17.1	4.45	17.5
T_suction	K	296	302	306	308	309	309	308	308
T_discharge	K	356	360	351	363	346	364	348	364
Mass flow	g/s	273	693	241	627	187	670	210	646
Speed	rpm	3600	2850	3300	3050	2950	3050	2950	3100
El. Power input (drive)	KW	552.4	977.2	434.8	1067.8	367	1121.6	393.3	1155.9
Total: 1640kW			(1554.2)		(1521)		(1614.6)		(1585.8)
Coolant power	KW	493	864	396	973	335	1026	359	1055
Total: 1500kW			(1349.9)		(1362.2)		(1447)		(1485.7)

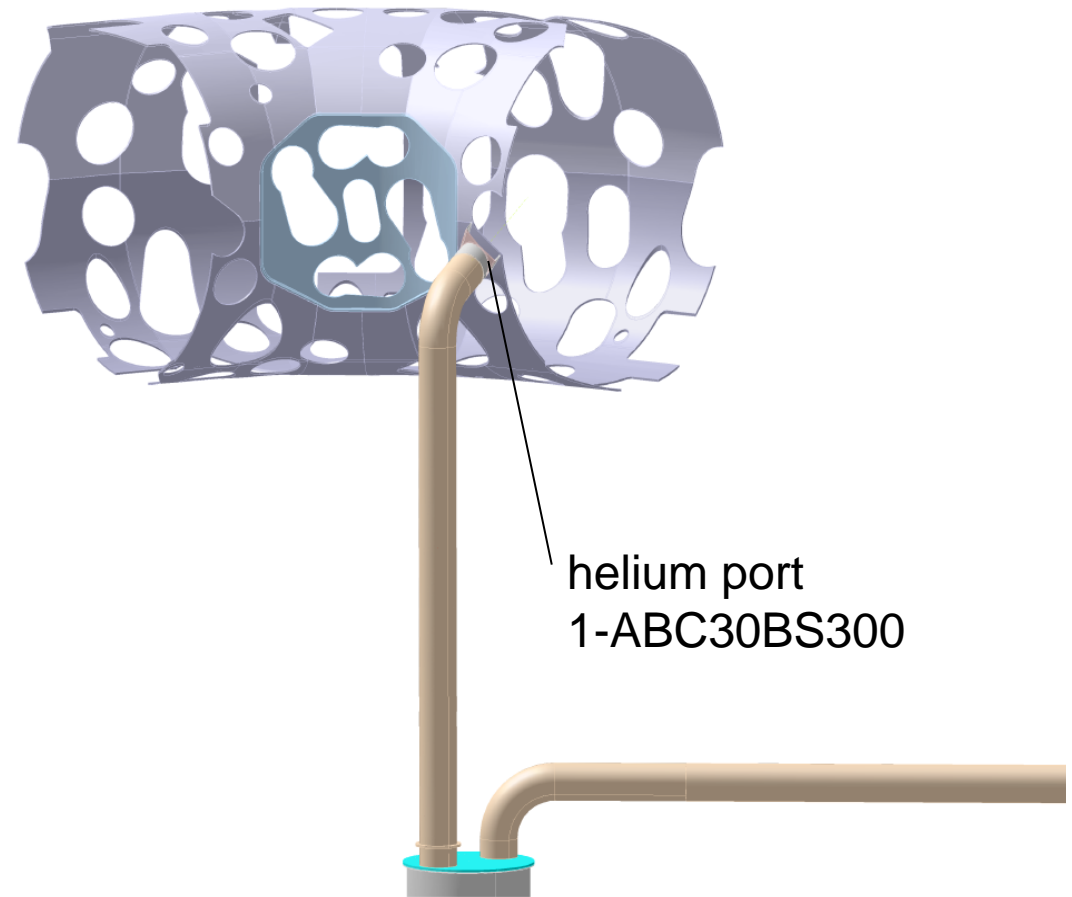
The values shown in colour are the total (HP+LP) guarantee value and (measured average value)











1. The final acceptance tests have been completed successfully
2. All the normal operating modes and emergency operations were demonstrated
3. The list of open items has been fulfilled
4. Refrigerator has been handed over to IPP
5. Operation by IPP team has begun
6. W7-X cool-down planned to start in October 2014

Thank you very much for your kind attention

Assembly overview:

<http://www.youtube.com/watch?v=MJpSrqiSMQ&list=UUJYBq24FIHN9gONdauS6gMw>

<http://www.youtube.com/user/plasmaphysik>