Commissioning of the Super-3HC Cryogenic System

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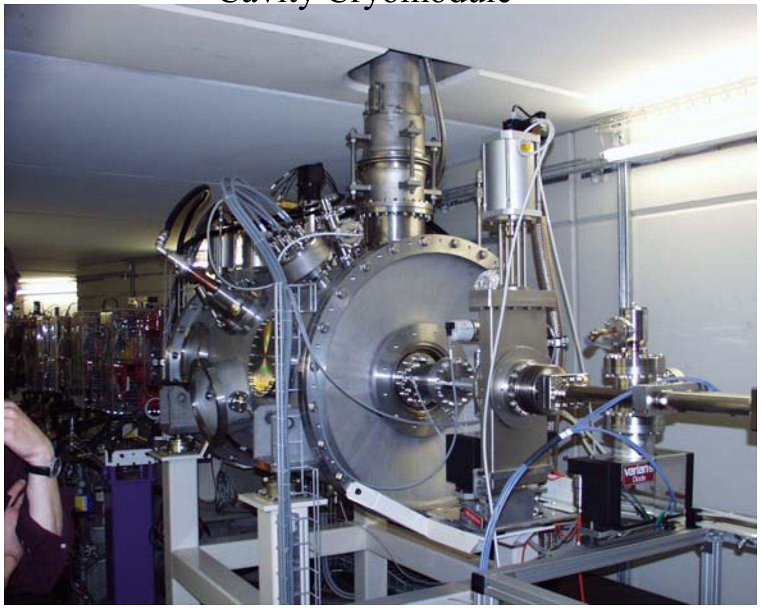
Layout of the presentation

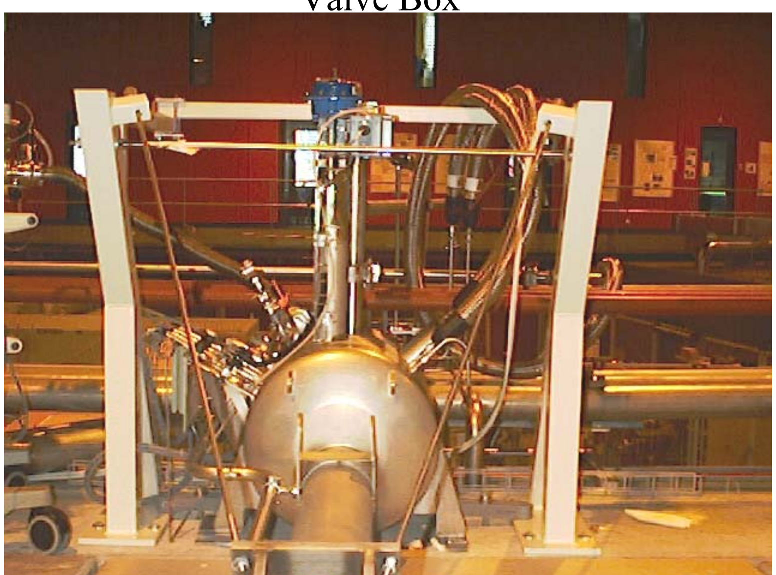
- Cryogenic system
- Cryogenic scheme
- Control system
- Comissioning
  - Cryomodule Test at Saclay
  - Refrigerator FAT at SLS
  - System Test at SLS
- Conclusions

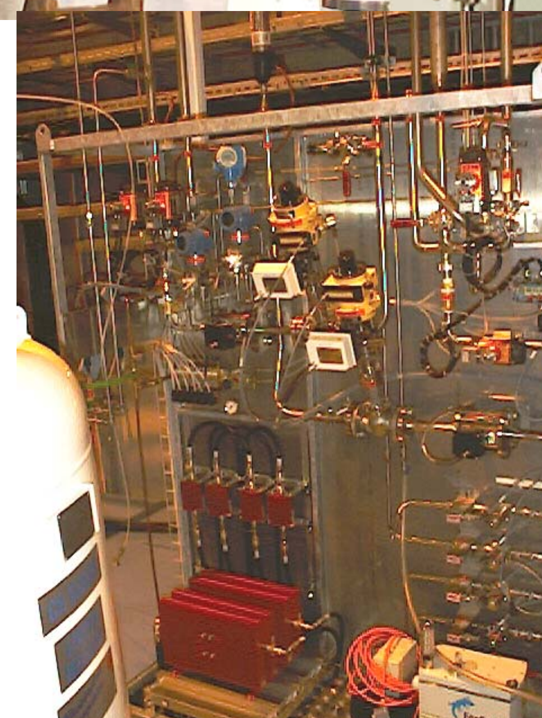
Cavity Cryomodule



Transfer line and Dewar

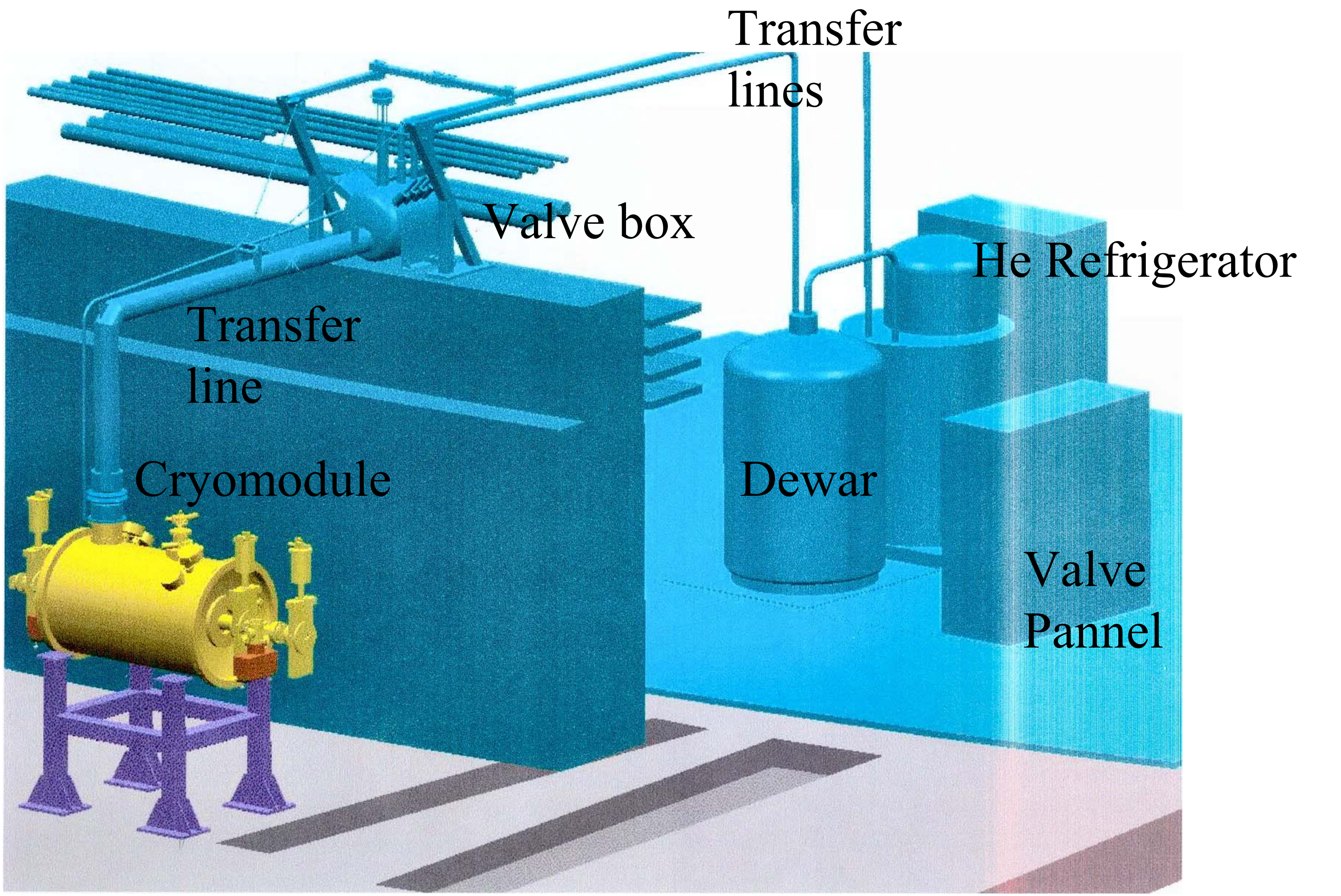
Valve Box

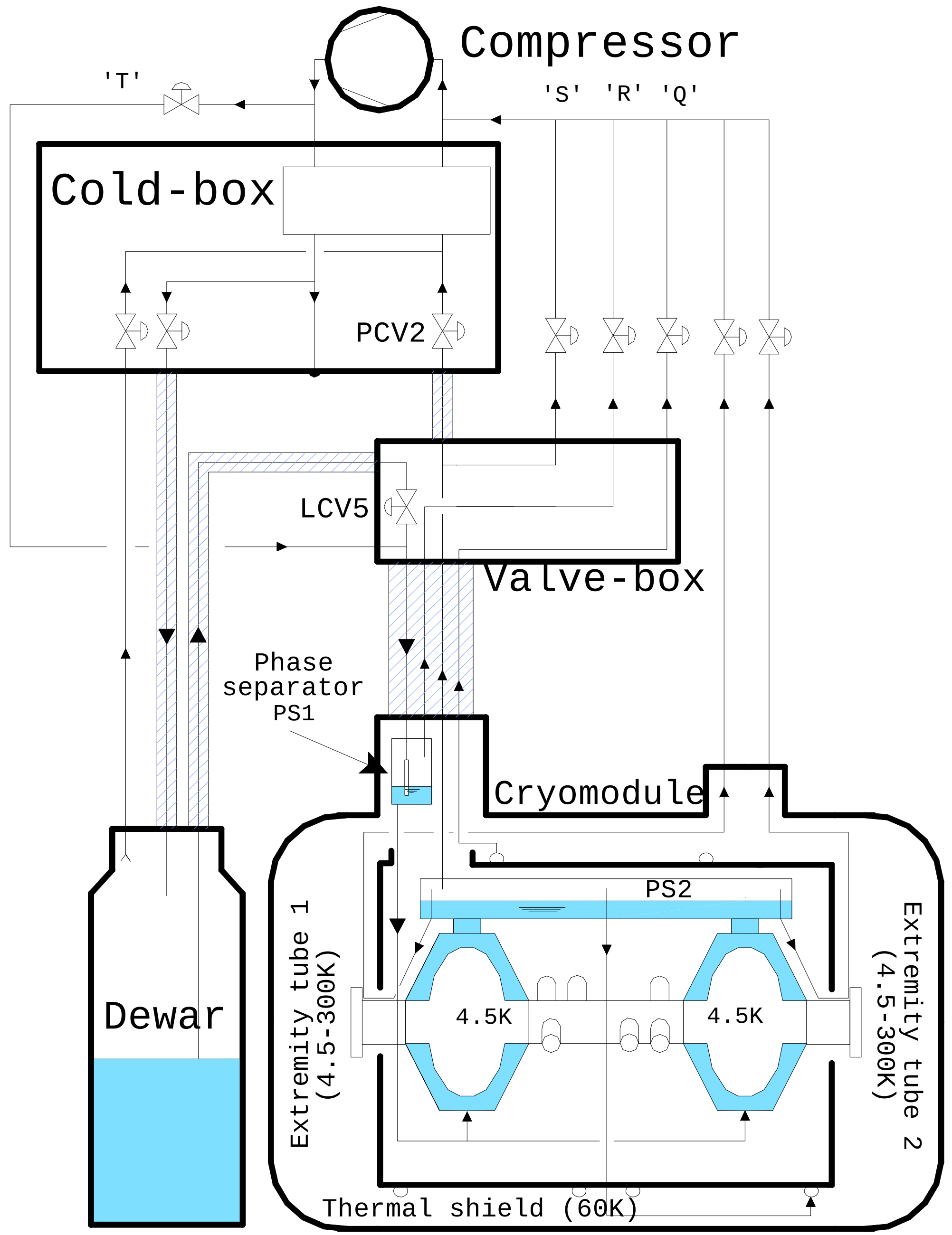




Valve pannel

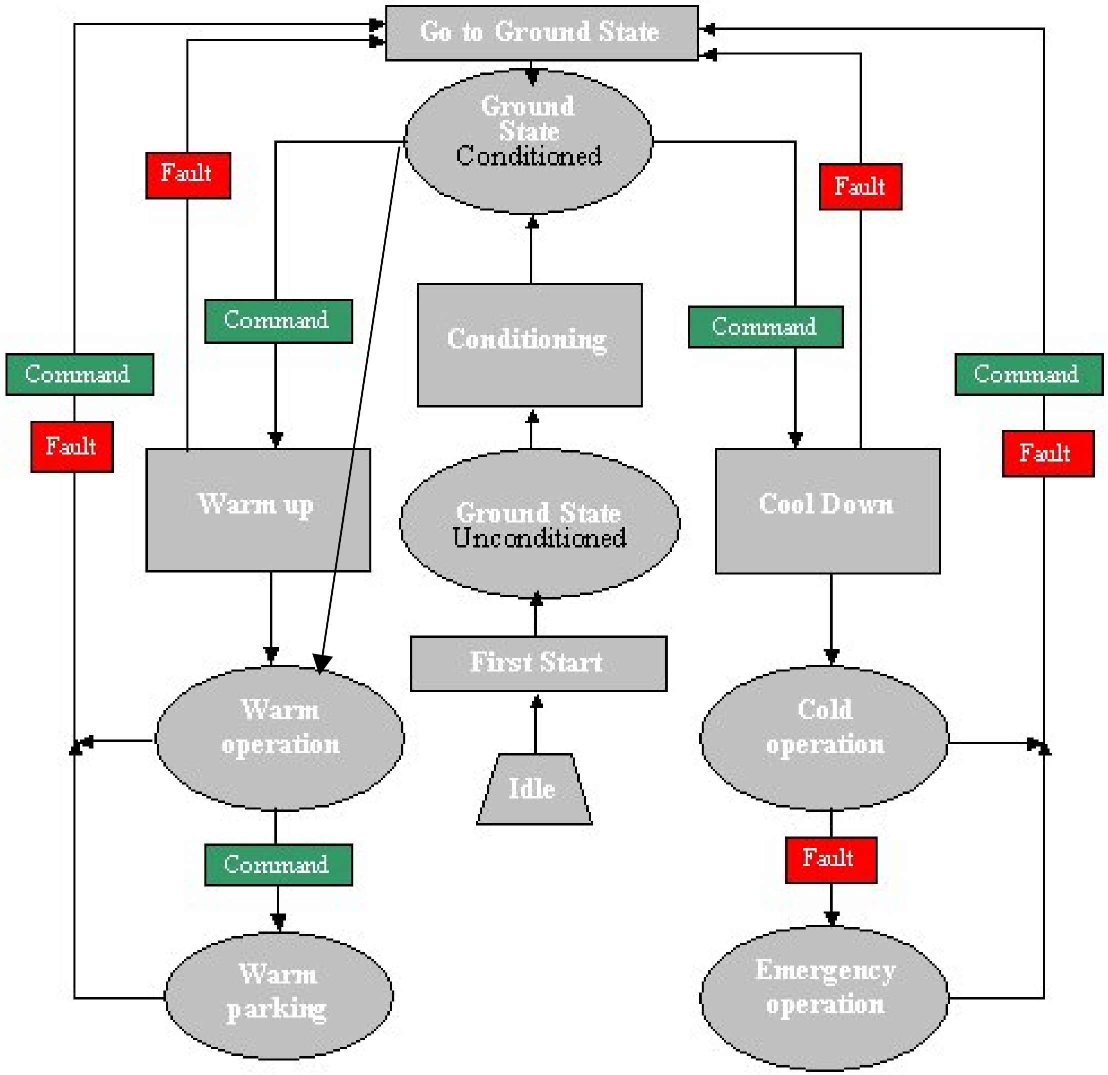
Layout of the cryogenic system

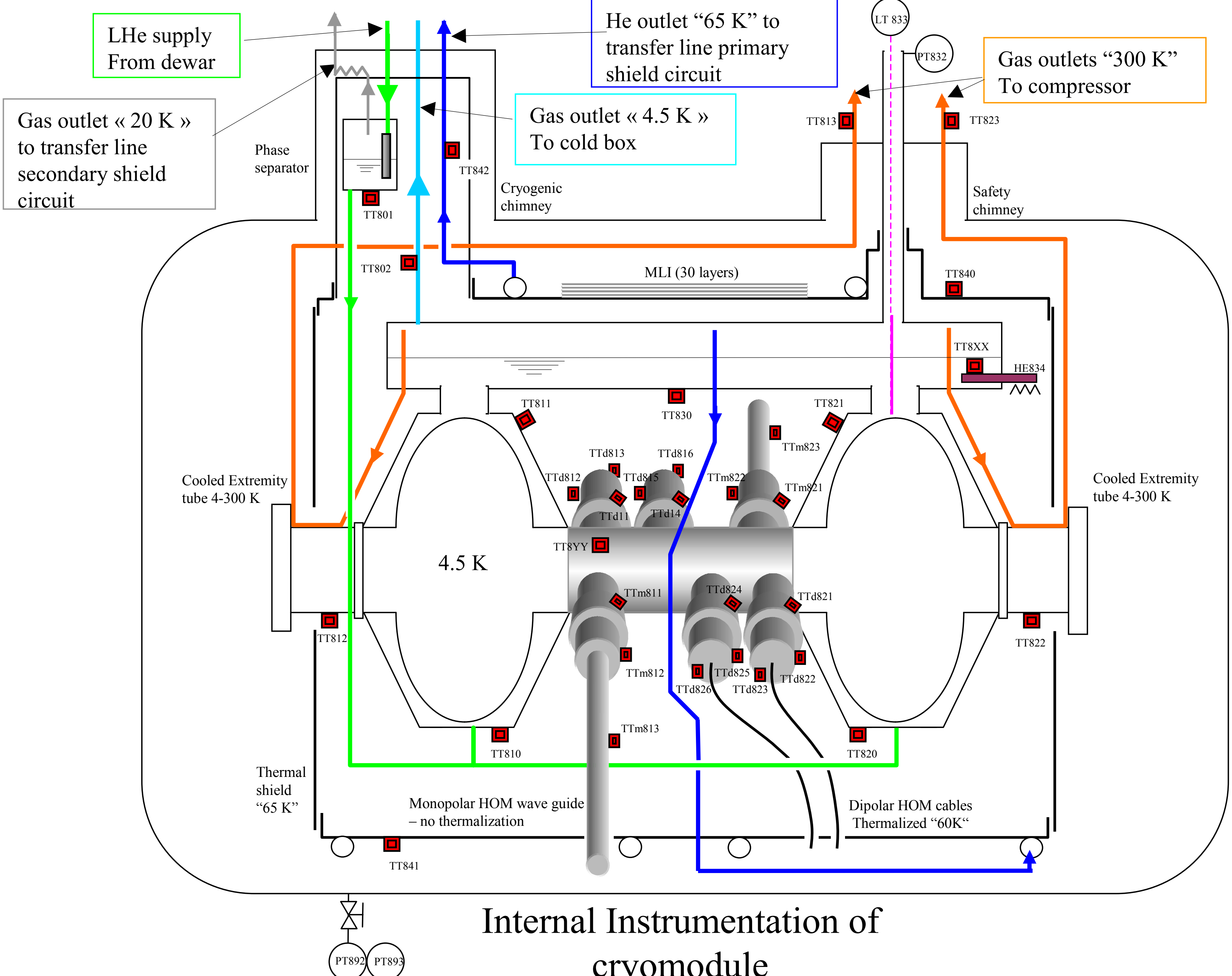




Cryogenic scheme (symplified)

Control Logic





Internal Instrumentation of cryomodule

Activities

- **First cold test of cryomodule (performed at CEA Saclay)**
  - Measurement of static losses — as specified
- **Factory acceptance test of refrigerator (performed at SLS)**
  - Measurement of refrigeration power and liquefaction duty — more than specified
- **Commissioning of the whole system (performed at SLS)**
  - Automatic Conditioning — test OK
  - Warm operation with Air and GHe cooling — test OK
  - Cool down — test OK
  - Cold operation — test OK
  - Stop and restart, interlock check (water/power failure, etc.) — partly tested OK
  - Emergency operation — not yet tested
  - Warm up — not yet tested

Cryogenic test at Saclay(1)

- Fast cool-down: 5th april 2002
- Slow cool-down: 7th april 2002
- Static heat loss measurements: 11th april 2002
- Nominal condition run: 4th june 2002

Fast cool down: dewar pressure=1300mbar,

cryomodule pressure=1200mbar

mass flow=3g/s, later reduced to 1.25g/s

shield cooling=0.25g/s (measured) later bypass added (estim. 0.5-1g/s)

cooling rates: cold mass=>400K/hr @3g/s 100K/hr @1.25g/s

shield=>10K/hr @0.25g/s later 100K/hr @0.75g/s

After two hours the cold mass temperature was 5K and the shield temperature 125K

After 3 hours fiest LHe appear in the cryostat (shield @ 70K) but the level could not be increased above 70mm with 3g/s of mass flow.

The reason was: imperfect thermalization of HOM and tuning system and mass flow in the extremity tubes 5mg/s (the correct value was found later, 25mg/s)

The test was stopped after 4 hours.

Cryogenic test at Saclay(2)

Slow cool-down:

The cryomodule was cooled-down slowly , during one night with less than 500L of LHe. The start condition was 200K instead of 300K due to the previous cooling test.

Thermal shield was cooled with 0.25g/s (decreased one hour later to 0.175g/s) and the cooling rate was 20K/hr. The nominal temperature of 70K was reached after 7hr.

The cold mass was cooled with 0.8g/s during the first hour later with 0.6g/s. It reached 20K after 3hr and 5K affter 9hr. First liquid appeard 16hr after the start.

Static heat loss measurement:

The cryostat was filled wit LHe at 125mm, then the cryomodule was separated from dewar. Cryomodule pressure was regulated at 1100mbar. Boil-off mass flow, liquid level and pressure were monitored

Results:

Total loss=10.7W (with provisory RF cabling) as compared to the estimated value of 8.2W

The difference was due to the variation in the thermal properties of the cables and the unknown thermalizartion points. (ex. Axon cables for incident couplers and cable shields of copper instead of stainless-steel)

Cryogenic test at Saclay(3)

Test at nominal conditions:

The RF cabling was modified. Axon cables with large copper cross-section and coaxial lines for monopolar HOM were removed and replaced by cables similar with the pick-up cables to be used later in operation.

Conditions:

Mass flow from phase separator=71mg/s

Thermal shield=70mg/s, 105mg/s

Extremity tube=27.5mg/s, 37.5mg/s

Nominal level=125mm

Cryostat pressure 1100mbar, Dewar pressure=1200mbar

Measured:

Lhe flow=29L/hr (including the transfer line loss) [1.2L/hr (4.2% pressure drop flash) + 8.7L/hr (thermal loss)=9.9L/hr

Total loss=15W @4.5K (including transfer losses)

Thermal shield thermalized between 67K and 72K, outlet at 74K, heat load on shield=24W (estim. 18W @ 4.5K)

Extremity tubes thermalized at 115K with 27.5mg/s

Static loss: (with 105mg/s in the shield and 37.5mg/s in extremity tubes)

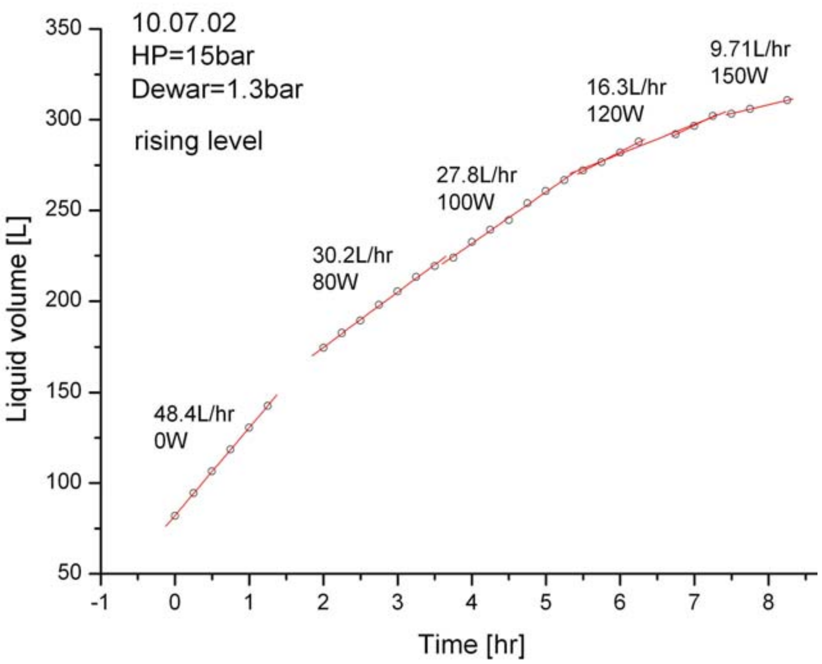
Total boil-off=0.4g/s representing 8W at 4.5K

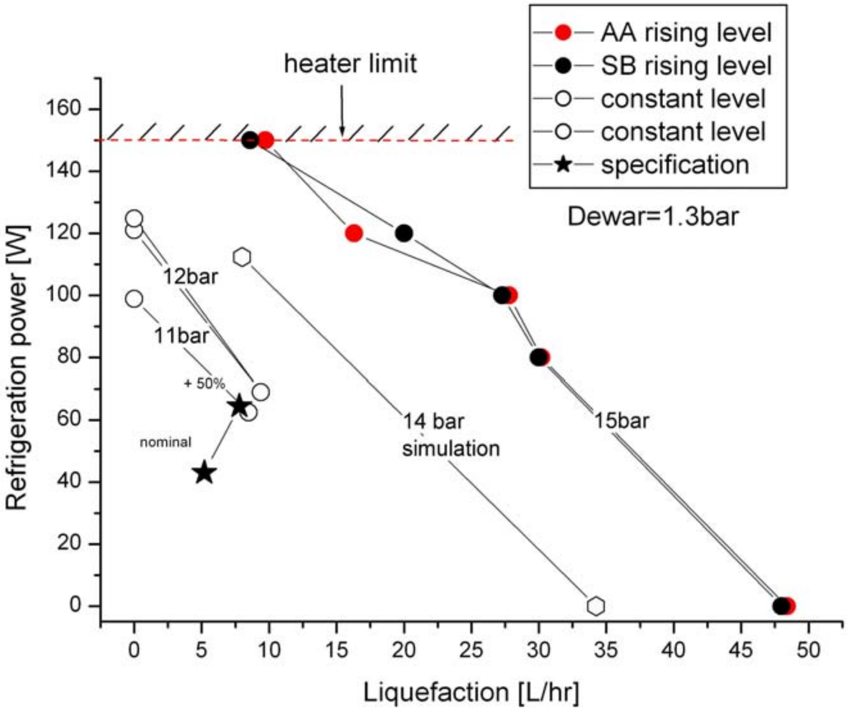
Cryogenic test at Saclay (conclusions)

- Important information concerning the operation of the cryomodule have been obtained
  - The shield cold mass is higher than initially assumed. Increase the shield mass flow during cool-down
  - But...the shield can be operated in steady-state at the nominal massflow of 70mg/s.
  - During cool-down the shield should be cooled simultaneous with the cavity cold mass
  - The extremity tubes can be cooled as soon as the cryomodule temperature is below 100K
  - Cold mass temperartures are consistent with He temperature (wire thermalization and contacts are OK)
  - Homogeneity in temperature distribution shows a good thermalization of different cold parts of the six HOM‘s
  - Thermal balance is in good agreement with the calculation
  - But....
    - Measured static losses are 2.5W higher than calculated (8W instead of 5.5W)
    - An extra load of 7W is measured during LHe transfer (15W instead of 8W). Probably bad transfer line used at Saclay.
    - Nb loops temperatures on both monopolar HOM couplers were at higher temperature than the dipolar ones. Probably higher thermal conductivity in coaxial lines in KAMAN cables.
    - Rapid cooling is not efficient. High LHe consumption and thermalization problems

FAT at SLS (26.06.02-10.07.02)

The factory acceptance test was performed at SLS becouse the first attempt at AL-Sassenage failed due to a turbine failure. In order to keep with the time schedule, the cold box was moved to SLS, installed and the spare turbines were inslalled on the spot.





At HP pressures >12bar enough and more than enough performance is available

Test at SLS(19.08.02-23.08.02)

19.08.02
The conditioning sequence is tested by performing 5 automatic cycles. Again the quality of He in the system after conditioning could not be measured because the PSI analyser does not work properly at pressures below 1.5bar. A previous measurement at 1.45 bar showed 5vppm N2 and 35vppm H2O but these values are uncertain. An analysis with a mass spectrometer is proposed for the future (PSI). Based on simple estimation it was decided that in principle 3 conditioning cycles are enough since the vacuum level in the pumping phase was as low as $3x10^{-1}$mbar (the partial pressure reduction factor per cycle is $3x10^{-1}$mbar/1400mbar=1/4667).

20.08.02
The cooldown sequence is started for the first time. In Step 1102 an offset opening of the TCV706 at 1% was added in order to have some small mass flow to help in the pressure regulation by PCV707+PT702.

The SP of CL7_PCV708 was set to 1250mbar because the actual Dewar pressure was 1300mbar. It was assumed that 50mbar pressure difference between Dewar and cryomodule is enough to promote liquid transfer.

A first problem with LCV705 is observed. The valve does not close at 4mA signal. PSI decides to readjust the zero point of the valve. The system was put in the Ground State.

During the work on the valve LCV705, AL changes the PLC by adding a transition sequence to the Ground State, which can be issued by the operator (Force Ground State), which was overviewed by PSI and considered necessary after the practical experience with the system. This sequence will be available during the cooldown and warm up transitions.

PSI reports that the I/P transmitter is not working properly and proposes to exchange it with a new one from another manufacturer. After installing this it was observed that the valve stem cannot be moved continuously indicating that the valve stem is sticked in the valve body. It was decided to stop the refrigerator in order to be able to reduce the Dewar pressure at 1bar and to dismantle the valve. After the valve stem was extracted, deep wear traces were observed on the valve plug. Also a small but visible bending (misalignment) of the valve stem and valve pug was observed.

Test at SLS(19.08.02-23.08.02) cntd.

21.08.02

After long discussions on how to proceed, AL and PSI agreed to try to repair the existing stem (no spare part could be found by PSI) by machining 0.5mm on the diameter of the valve plug. After machining, the valve stem could be easily reinserted in the valve body. The valve was remounted with its original I/P transmitter and worked properly. AL agreed that if this measure will somehow influence the heat leak of the valve, it would replace the valve plug or the complete valve stem at a later time with a new one.

During the following night (around 23pm) while the He compressor was still running, the buffer pressure started to decrease down to 2bar and the compressor was stopped. The helium in the buffer was release into the PSI recovery system. There was no rational explanation for this problem. The parts agree to investigate this problem. **Remained a mystery**

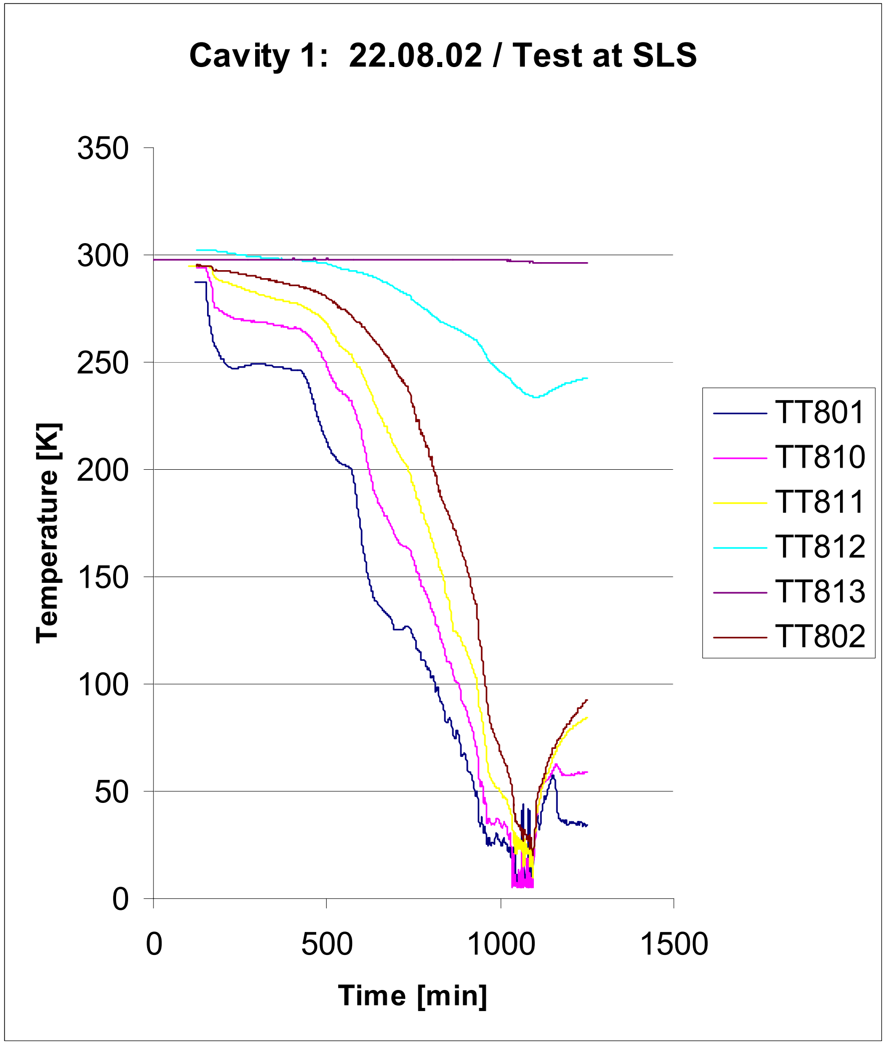
22.08.02

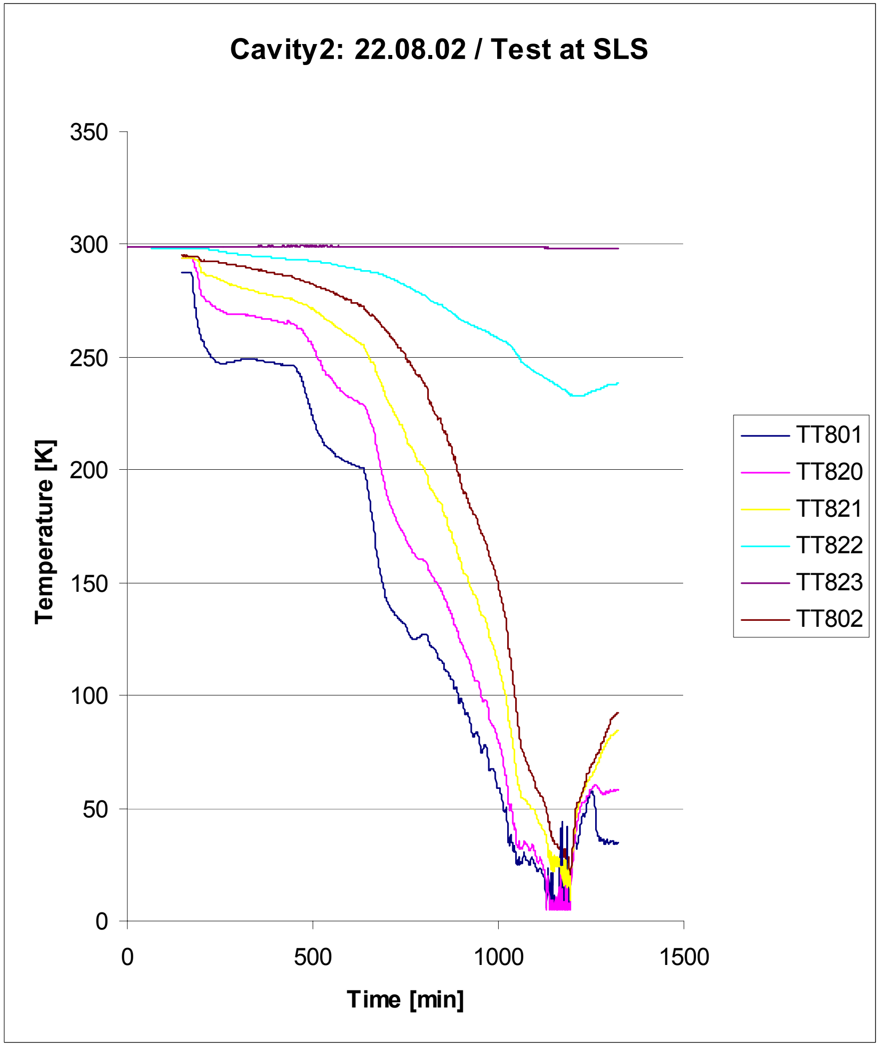
The buffer is refilled with clean He from PSI and the refrigerator (compressor + cold box) was restarted.

The flow meters readings were added to the archive system. The heaters were checked and it was found that the polarity of the thermo elements for the temperature regulation was reversed.

At 9am the cool down procedure was started with a cooling offset of 50K as specified. The set point for the CL7 was 1200mbar. At 11:27am the cooling offset was increased to 60K because there was the feeling that the cooling down was too slow. Later on it was increased to 80K and finally to 100K (13:10pm).

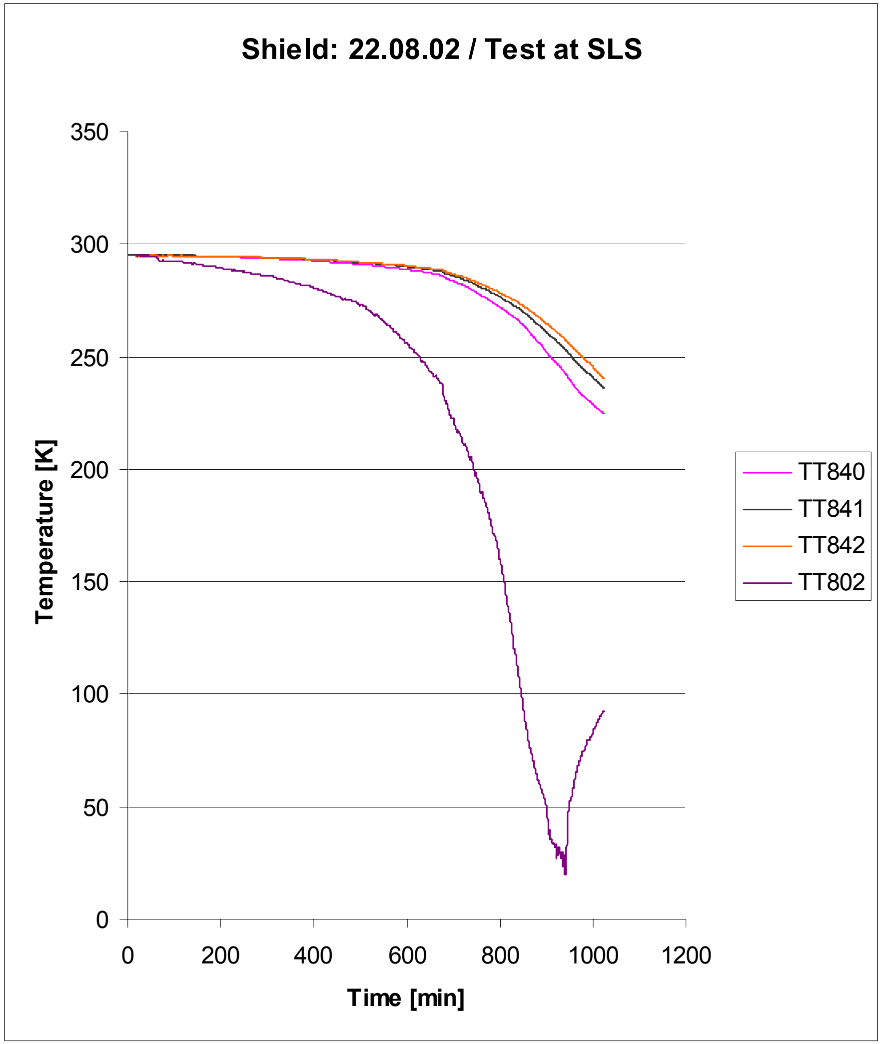
Results of first cool-down





the right sequence: the lowest temperature is TT801 followed by TT810 the bottom of the cavity then by TT811 at the top of the two cavities and finally TT802 which is the outlet temperature from the cryostat. The extremity tube temperatures (TT812 and TT813) are rather high but the cooling is only by conduction since down to the step 1107 the active cooling of the extremity tubes is not yet started.

Shield cooling

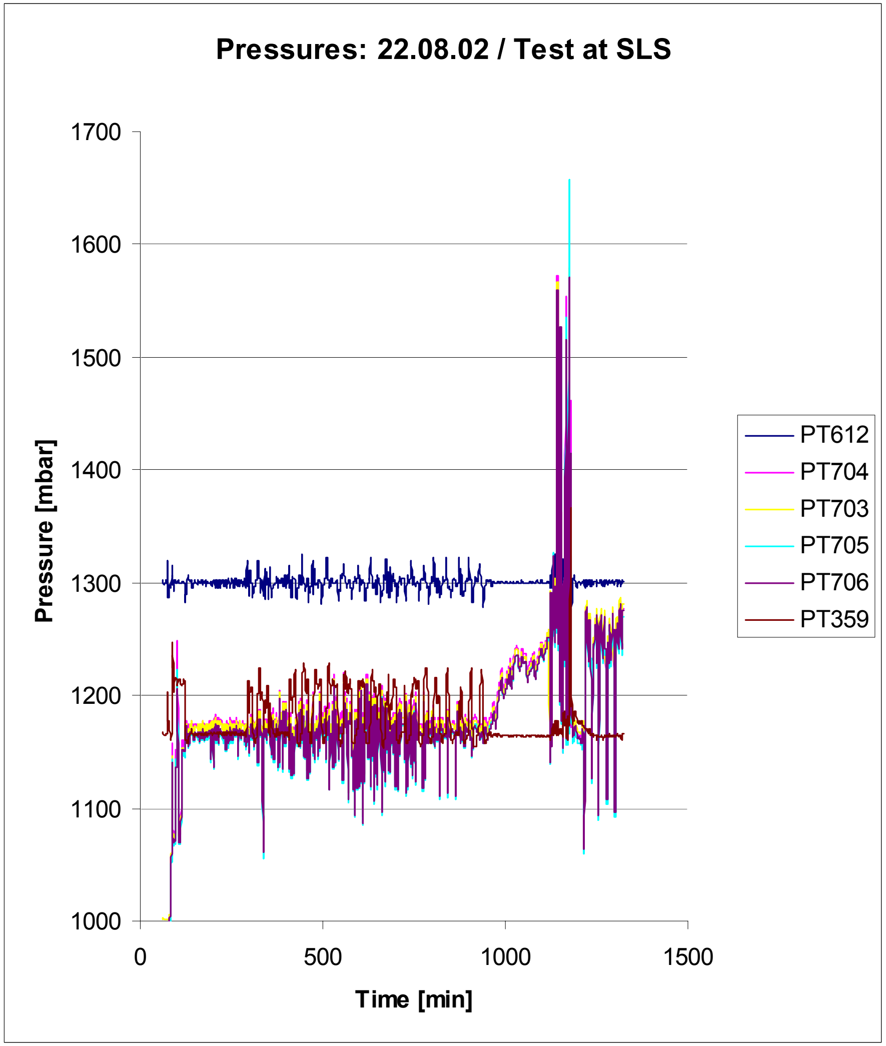


A problem was with the shield cooling. As can be seen in Fig.4 the shield could not be cooled over the whole sequence bellow 230K. The mass flow in the shield was 70mg/s as specified. The temperature gradient between the inlet and outlet from the shield increased during the cool down up to about 200K. Previous cooldown at CEA Saclay has shown the mass flow in the shield circuit was as large as 250-300mg/s in the steady state and surely larger (a by-pass circuit was installed there to cope with the problem but the mass flow could not be measured) during the cooldown. PSI will install a larger valve on this circuit by providing a new module for FT703+TCV703.

Pressure oscillations

The PLC has worked its way through all steps pretty nice until 80K were reached at TT802. Pretty large pressure oscillation are observed all the way to 80K in the pressure of the cavity and valve box but since the amplitude of the oscillations was such that the cavity peak pressure was lower than the Dewar pressure the cool down could be continued. The period of these oscillations was around 3 min. A possible explanation for these oscillations is the mixing process, which is known to induce such instabilities.

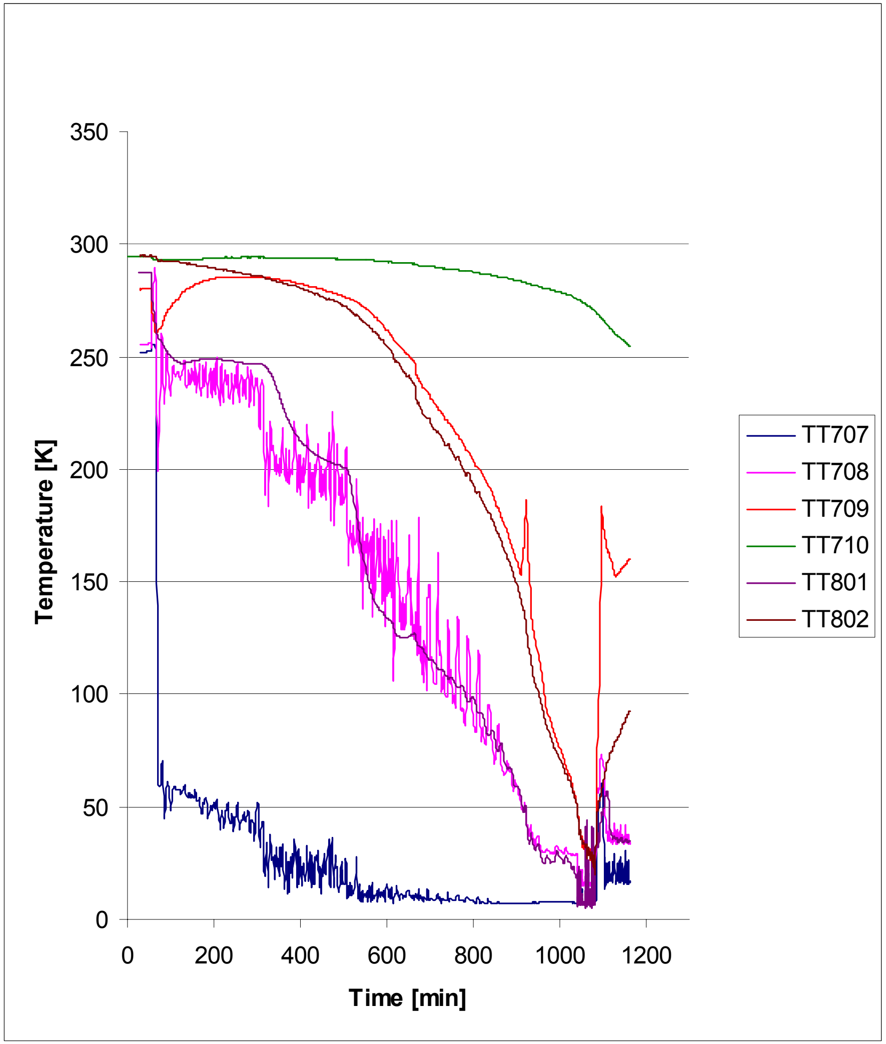
Once in step 1105, were CL5 is deactivated and TCV706 is closing, the pressure oscillations in the cavity disappeared for a while as shown but then appear again with much larger amplitude and a higher frequency after the cavity presure was increased.



Temperature oscillations

The evolution of the temperature at different position of the valve box in illustrated in Fig.8 and compared with the temperature in the cryostat: TT801 and TT802. Illustrative for the instabilities in the mixing process are the traces TT708 (the mixing temperature) and TT801 (cryostat inlet temperature). While at the mixing point there are large oscillations, at the outlet of the cryostat they disappear completely.

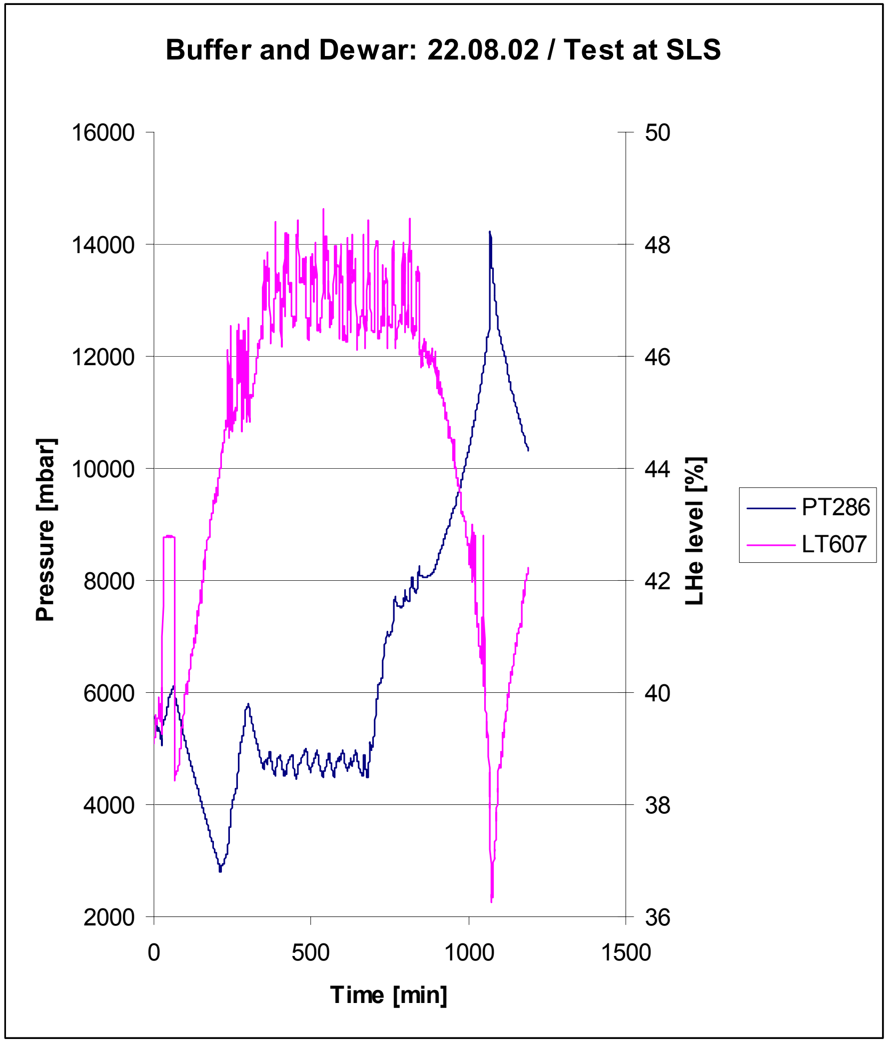
Later on it was observed that two lines (T and S) on the valve box were fully covered with ice and that this situation persist even after we have reached 30K (Step 1107) where the system switches to cold gas return. The warm gas for mixing, flowing through line T, has been already stopped at 80K.



Refrigeration power

The refrigeration/liquefaction power of the refrigeration decreases also dramatically as indicated by the rapid decreasing of the liquid level in the Dewar. The buffer pressure also increases drastically up to about 14bar (Fig. 9).

The 22.08.02 test was stopped.



Conclusions of first cool-down test

Based on the observation made during the previous test it was decided to restart the cooldown with CV481 open from the beginning.

The HP of the refrigerator will be increased increase to 13bar in order to have more refrigeration power.

It is by now clear, that with a mass flow of 70mg/s we are not able to cooldown the shield in a reasonable time. PSI will replace the flow meter-valve module 703 with a new one of larger range. According to a last minute report from CEA, they had 70mg/s in steady state and a much higher mass flow during the cool down: 250-300mg/s during a slow cool down and up to 750mg/s for a fast cooldown.

It is clear from the two tests performed so far that there is a problem with the valve box. The fact that the two connections “T” and “S” on the valve box are massively covered with ice even after the mass flow through these two circuits is stopped indicates a big heat leak into the valve box.

Two hypotheses are available. a) That the heat leak is by conductions in the two pipes which are too short or too thick-walled or both and b) we have thermal-acoustical oscillation (Taconis).

Measures

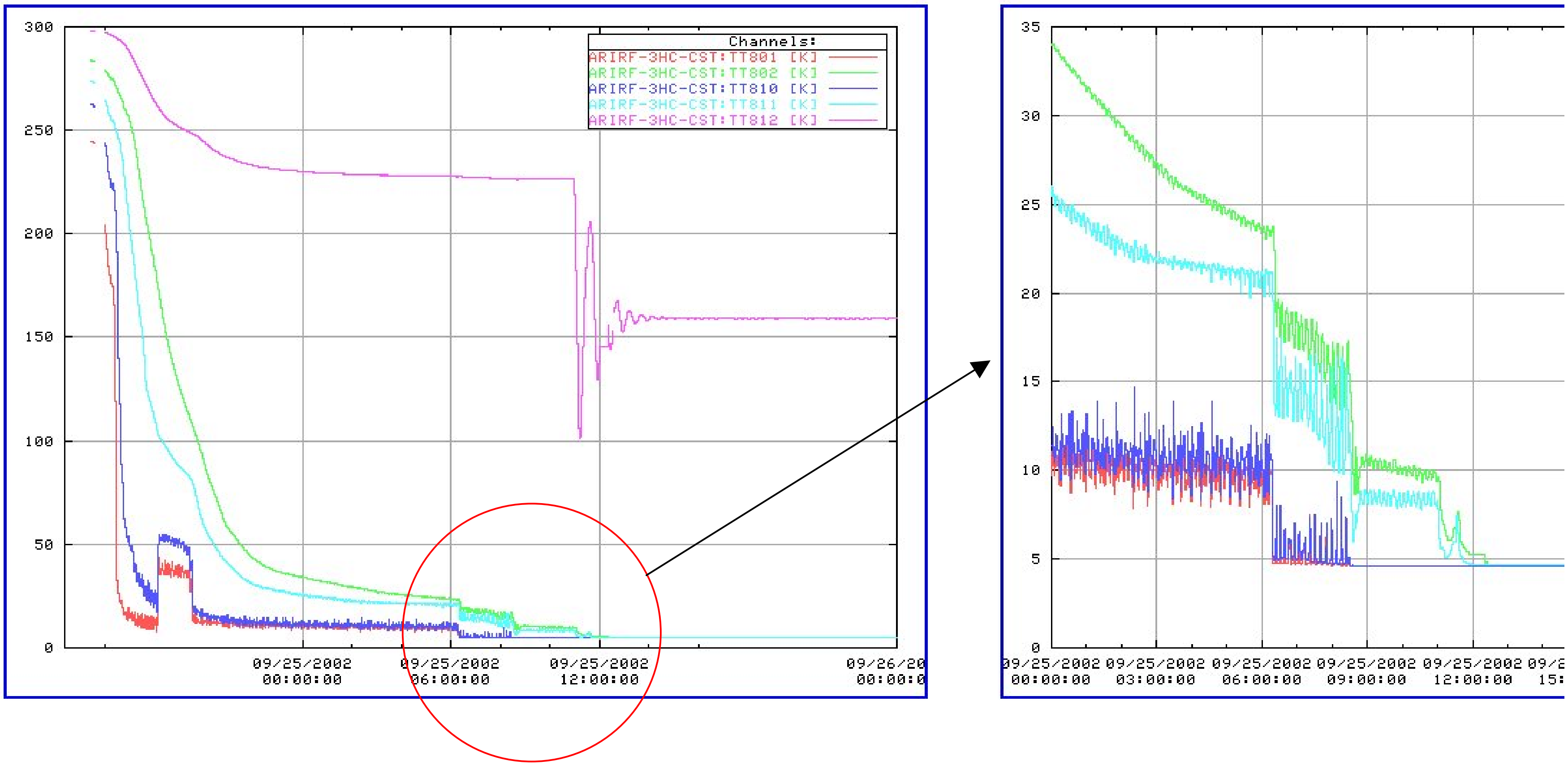
1) It is necessary to be able to discern between a conduction and a thermal oscillation effect. AL will send to PSI a complete set of the original drawings (including all details) of the valve box and will check with their own cryogenic engineering the heat leaks by conduction in all the piping (connections) of the valve box. PSI will provide the “T” and “S” lines with non-return valves in order to eliminate the possibility of thermal oscillations. It was found later that the cryogenic design of these pipes was OK.

2) PSI will provide a new module for TCV703 with a range 0-750mg/s or will provide a by-pass line on the shield circuit.

Second attempt(24.09.02-25.09.02)

Settings: HP=12bar, Buffer=2.6bar, Dewar=1400mbar, Cryomodule 1300mbar, shield circuit open, cooling offset=-100K

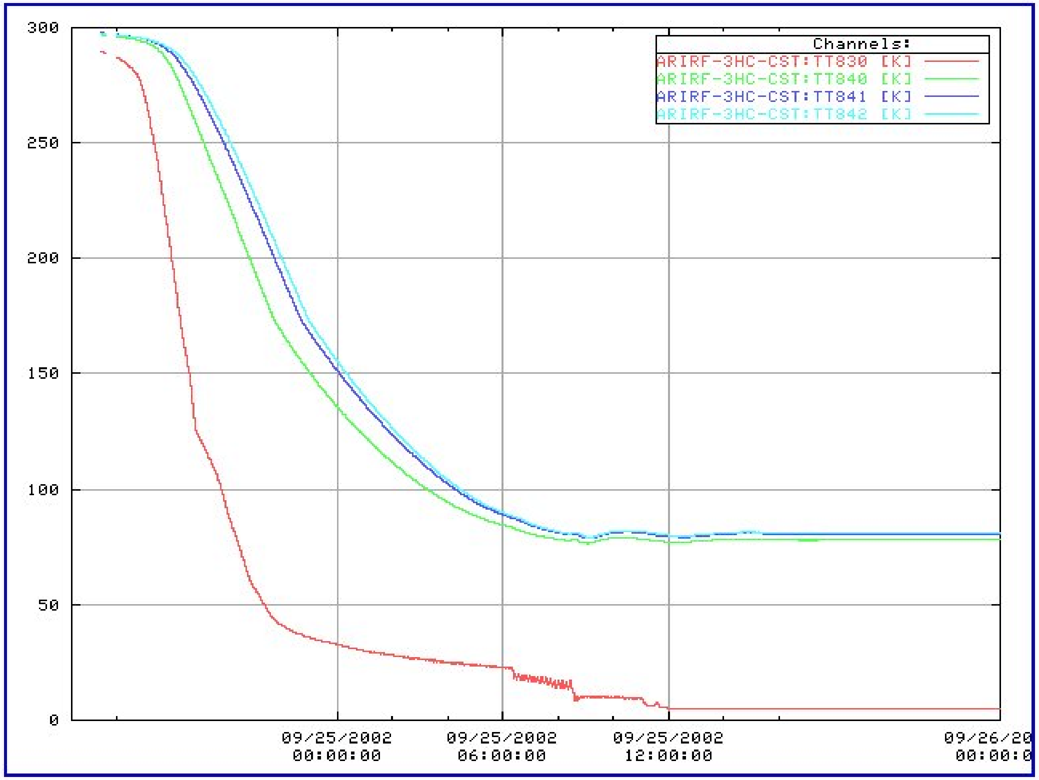
24.09.02 15:00 ->25.09.02 23:59:59



Start: 11:00 on 24.09, first LHe at 12:11 on 25.09 (from 20:18 to 06:30 i.e. Over night no action)

Total cool-down time 25hr, effective 15hr)

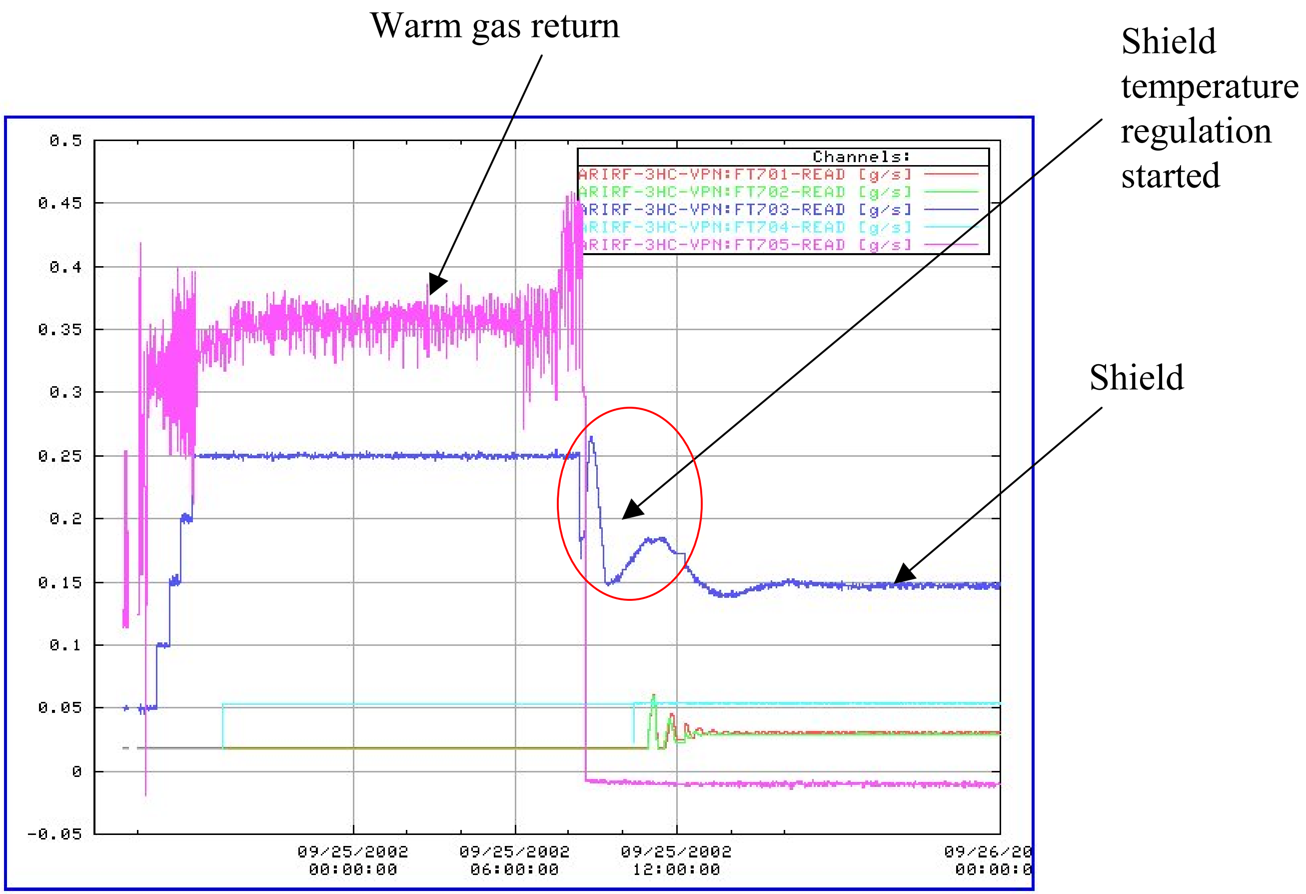
Shield



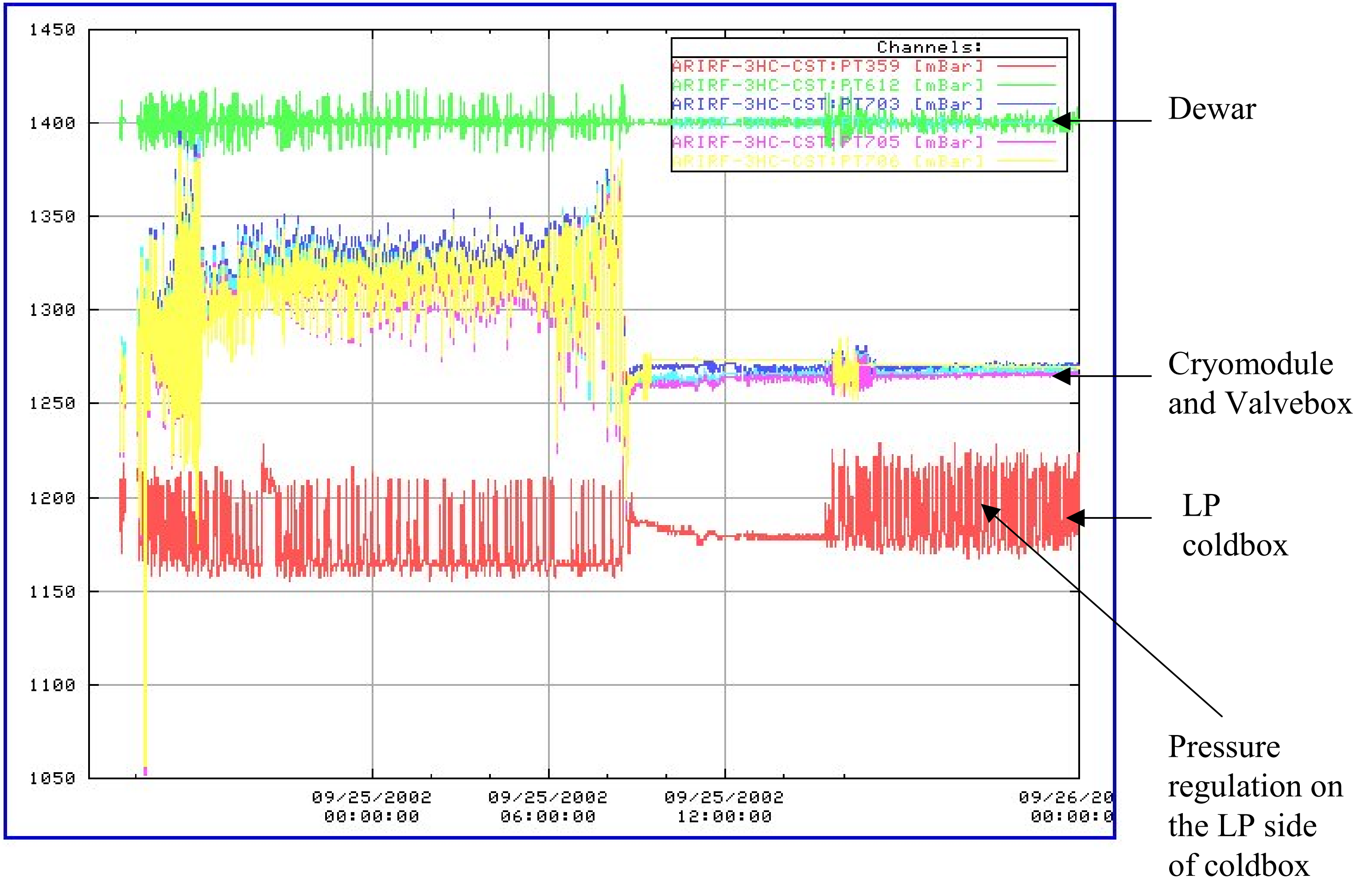
The shield cooling was perfect this time, massflow=250mg/s

24.09.02 15:00 ->25.09.02 23:59:59

Mass flows


Warm gas return
Shield temperature regulation started
Shield
Channels:
ARIRF-3HC-VPN:FT701-READ [g/s]
ARIRF-3HC-VPN:FT702-READ [g/s]
ARIRF-3HC-VPN:FT703-READ [g/s]
ARIRF-3HC-VPN:FT704-READ [g/s]
ARIRF-3HC-VPN:FT705-READ [g/s]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
09/25/2002 00:00:00
09/25/2002 06:00:00
09/25/2002 12:00:00

Pressures



The non-return valves on S and T lines eliminate the thermal oscillation at low temperature

Refrigeration

(calculation based on theoretical Cv of LCV705)

With HP=13bar, no beam

Inlet: LCV705=36% ->1.26g/s->38.11L/hr

FT701=30.7mg/s
FT702=29.4mg/s
FT703=147.5mg/s
FT704=53.5mg/s

} Warm gas

Total warm return=261.1mg/s ->7.9L/hr

Cold gas return=1.26g/s-0.261g/s=1g/s -> On transfer Q_{module}=18.84W

Q_{dewar}=69W

At Saclay:

Inlet: 29L/hr

On transfer Q_{module}=15W

Static Q_{module}=8W

With HP=13bar, 300mA beam

Inlet: LCV705=40% ->1.4g/s->42.35L/hr

FT701=36mg/s
FT702=34.2mg/s
FT703=152mg/s
FT704=53.5mg/s

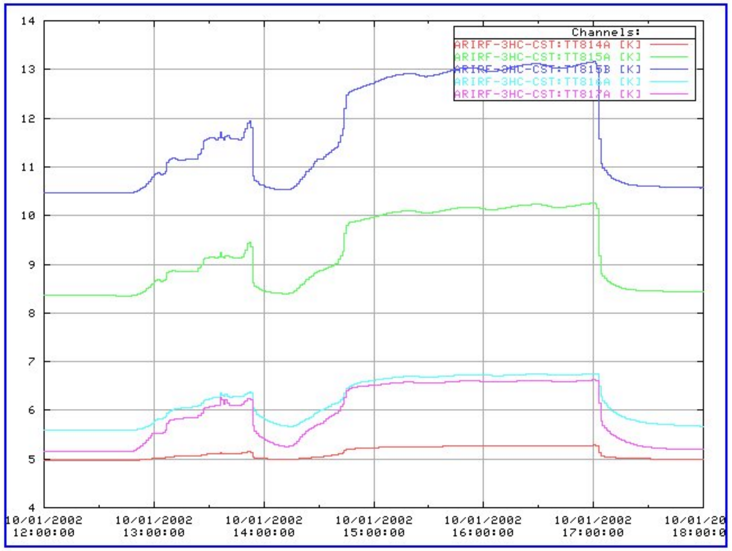
} Warm gas

Total warm return=276mg/s ->8.35L/hr

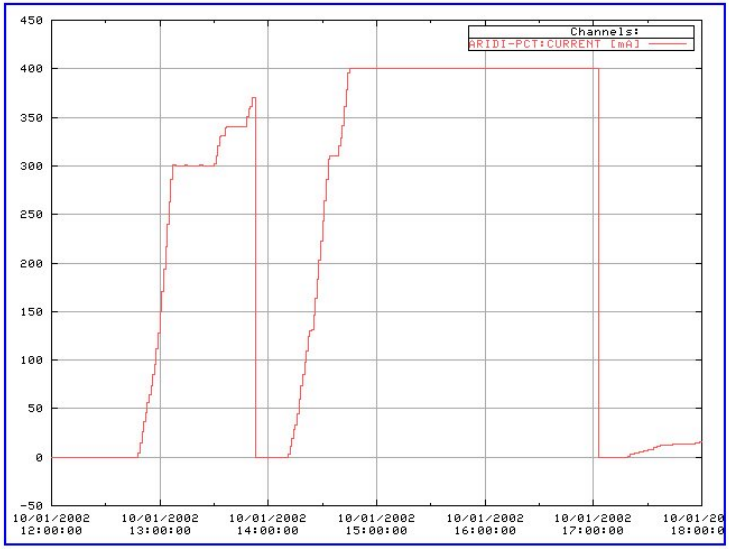
Cold gas return=1.4g/s-0.276g/s=1.124g/s -> On transfer Q_{module}=21.2W

Q_{dewar}=58.6W

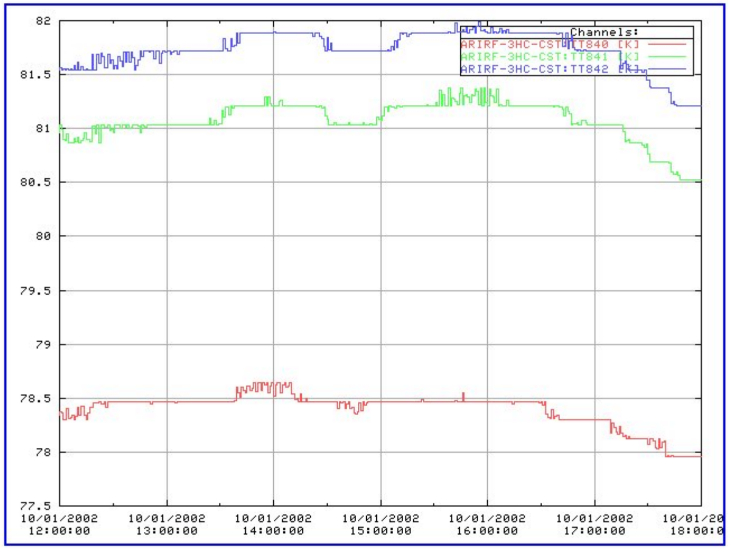
Operation with beam



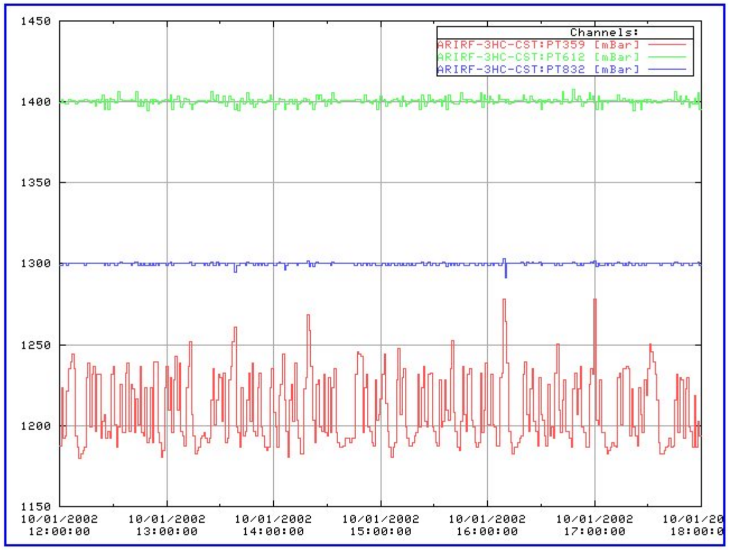
HOM temperatures



Beam current



Shield temperatures



Pressures: Dewar,cryomodule, LP coldbox

Conclusions

- The Super-3HC cryomodule was successfully commissioned
- The cavity can be stable operated up to 400mA beam
- The refrigerator has fulfiled the specification
- The control logic has been proven to be flexible enough to cope with the on site problems. (enough engineering values)

What we have learned:

- Cryogenic needs patience
- Take care of thermal acoustic oscillation. They realy exist! Avoid large volumes at room temperature
- The problems are more on the side of instrumentation, data aqusition, communication, cooling water, power supply
- Avoid testing and/or commission a cavity directly on the operating ring.

Shut-down times are to short