PDSG – COOLING

Prepared by Vic Vacek

Requested Items for Talk to be Addressed [by Leo Rossi]:

- 1. Status of evaporative cooling
- 2. Planning for phase 2
- 3. Compressor vs condenser
- 4. Maximum pressure risk analysis

• 1. Status of evaporative cooling:

Experimental Setups

1) Big Cooling Circuit

- Originally designed for C4F10, then expanded for use to test variety of the fluids
- Most of the pixel structures have been measured in the circuit

2) Small Cooling Circuit

- Originally designed for HTC measurement
- Staves can be measured in this installation at the moment

Both circuits are able to cool down OLD POWER BUDGET SPECs

Both installations have to upgraded for increased values of power dissipation

[details to come later in this presentation]

Basic Properties of the Candidates - Fluorinerts for Atlas Pixel and SCT Cooling System – *"EVERGREEN PROBLEM"* - WHAT TO CHOOSE?

				Molar fraction	Molar fraction	Molar fraction
				C3F8[35%]	C3F8[50%]	C3F8[70%]
				C4F10[65%]	C4F10[50%]	C4F10[30%]
				Mix 3_7	**Mix 5_5**	**Mix 7_3**
Fluorinert >>>>>>	**C3F8**	**C4F10**	**CF3I**	Mass fraction	Mass fraction	Mass fraction
				C3F8[30%]	C3F8[44%]	C3F8[80%]
Name	octafluoropropane	decafluorobutan	trifluoroiodomethane	C4F10[70%]	C4F10[56%]	C4F10[20%]
Molar mass	188.2	238.03	195.91	220.4	213	200.7
Triple point temperature [C]	-160.15	-84.15	-153.15	-	-	-
Boiling point temperature [C]	-36.6	-2.09	-22	-	-	-
Critical temperature [C]	71.87	113.18	122.22	98.65	92.52	82.32
Critical pressure [bar]	26.8	23.23	38.82	25.24	25.77	26.18
Critical density [kg/m^3]	628	599.8	874	608	611.9	619.3
Accentric factor [-]	0.325	0.374	0.1796	-	-	-
Dipole at NBP [debye]	0.014	0	0.92	-	-	-
Range of applicability						
Minimal temperature [C]	-160.2	-84.2	-93.2	-89	-95	-100
Maximal temperature [C]	226.9	226.9	146.9	130	125	120
Maximal pressure [bar]	300	300	200	280	285	290
Maximal density [kg/m^3]	2049	1823	2614	1900	1950	2000

Performed measurements with refrigerant candidates

- Temperature profiles along *[NEARLY ALL]* SCT and Pixel structures were measured
- HTC were measured for all fluids&various technological parameters

- Procedure of mixture preparation and its composition check was verified

  - Different geometries [I.D. or I.D_h.]
  - Different heat fluxes
  - Different mass flows
  - Different sub-cooling

- Needle valve, ruby injectors and capillaries were tested in the BOTH evaporative circuits

Mixture issue

- **Nearly all new refrigerant alternatives are mixtures [binary, ternary ..]**
- **Studies were driven by "fixed" demand" for temperature and pressure SPECs by Pixel community [respecting the baseline of C4F10 low pressure limit in the structure – below 1 bar and looking for possible alternative ➔➔ CF3I at the beginning of 1999]**
- **CF3I did not fail from the thermophysical properties point of view but "unlikely" did not fulfill expectations during irradiation tests**
- **Respecting "fixed" demand", there was no other alternative than custom mixtures of C4F10 and C3F8**
- **NOTE concerning pressure limits:**
- Eric Perrin and myself raised question of pressure limit value in the structures up during the Cooling review in May. NOBODY, I REPEAT **NOBODY** WANTED TO TAKE RISK and decide it
- As stated during the Cooling review in May by the Cooling team members - any single fluid is easier to handle in principal.

Conclusions

• From the point of HTC values [averages]:

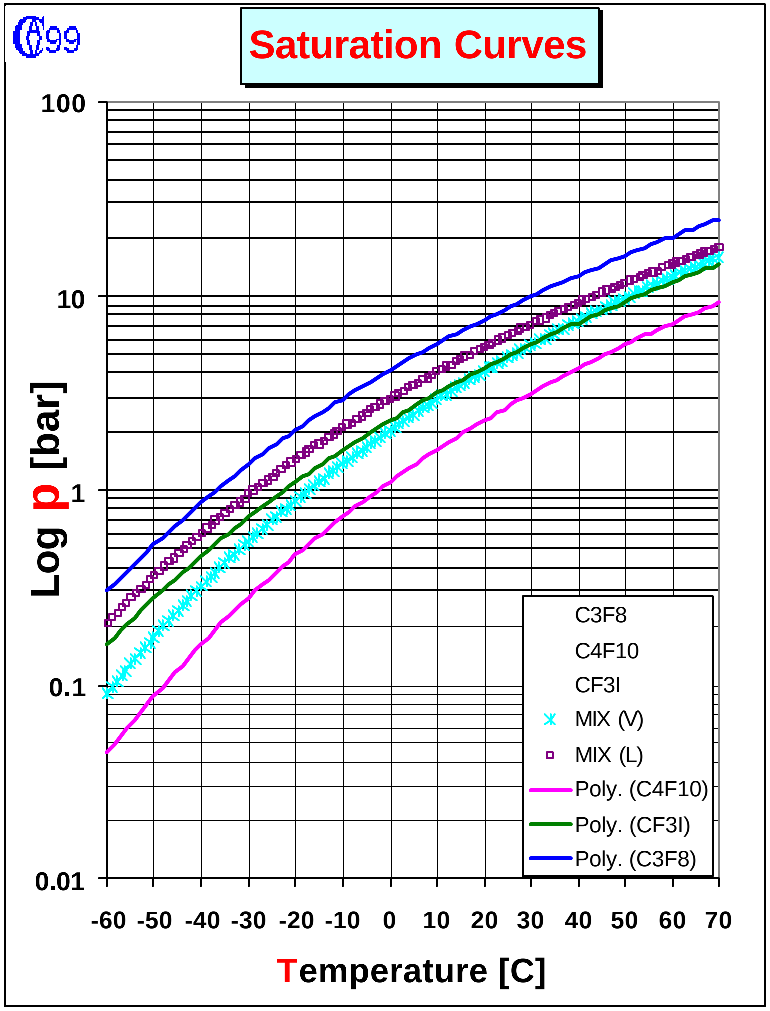
- In the tube of ID = 3.6 mm

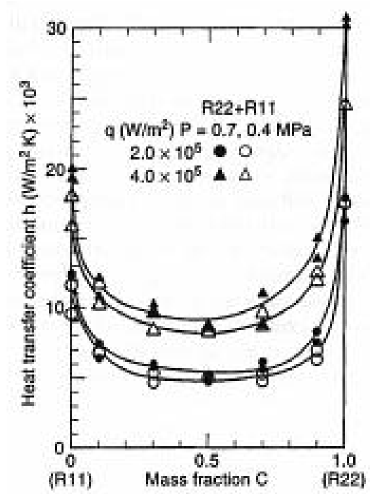
Tube _ I.D. =3.6 mm		HTC [W/m^{2}K]		
FLUID	**C3F8**	**C4F10**	**MIX_ 50/50**	**CF3I**
AVERAGE	4284	3047	2350	3024
RATIO	**1.8**	**1.3**	**1.0**	**1.3**

- In the Genova Stave Prototype

Stave _ I.D$_h$. =3.4 mm		HTC [W/m^{2}K]		
FLUID	**C3F8**	**C4F10**	**MIX_ 50/50**	**CF3I**
AVERAGE	6759	4881	3232	4892
RATIO	**2.1**	**1.5**	**1.0**	**1.5**

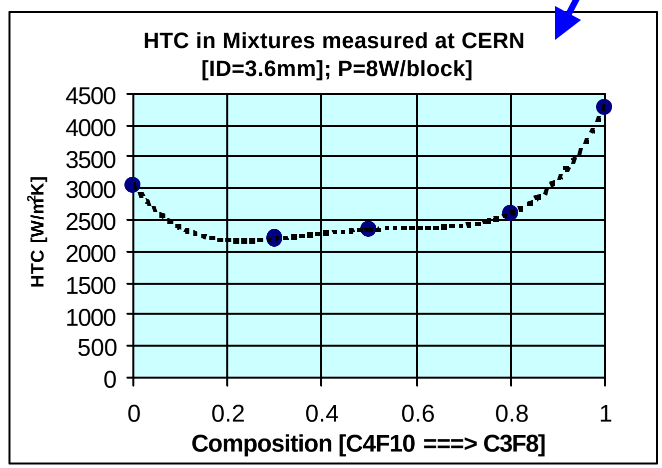
Some additional and "hopefully" useful INFO's:





See my presentation for Cooling Review – part References: *Heat and Mass Transfer, 33, 1998*

From our HTC measurements



• Other aspects are to be considered:

- Pressure limits for the structure
- Material budget
- Pressure losses within the stave and connecting pipes

  [Reference =➔ M. Olcese two presentations from our measurements, LHC review; PixMech]

  [D. Cregg ➔ Working on pipe dimensions and pressure losses for all fluid "menu"]
- Temperature ranges [i.e. line insulation matters etc.]
- Availability of the other components of the cooling circuit for certain fluid
- Compatibility with used materials
- Safety margins

  [Reference =➔ M. Olcese two presentations from our measurements, LHC review; PixMech]
- Safety and environmental aspects
- Etc.

HTC coefficient is not the only priority!!!

• 2. Planning for phase 2

- **Project for the Phase 2 [JAN 2000]**

  [Slides from Cooling review, presentation for LHC, …..]

  - **1/8 of the ID mockup [SCT+Pixel] outlined by G.H.** *[Approved by May99 C.R.]*
    [possibly integrated with mockup for services]
  - Cooling system setup [first by M.B.; then revised by M.B.&cooling team]
    [Approved by May99 C.R.]
    - Based mostly on commercial parts [most of them available]
    - Safety issues for this setup under study
      [---> results to be submitted at the end of October 99]
    - Place for the installation – still under considerations [more than 1 year]

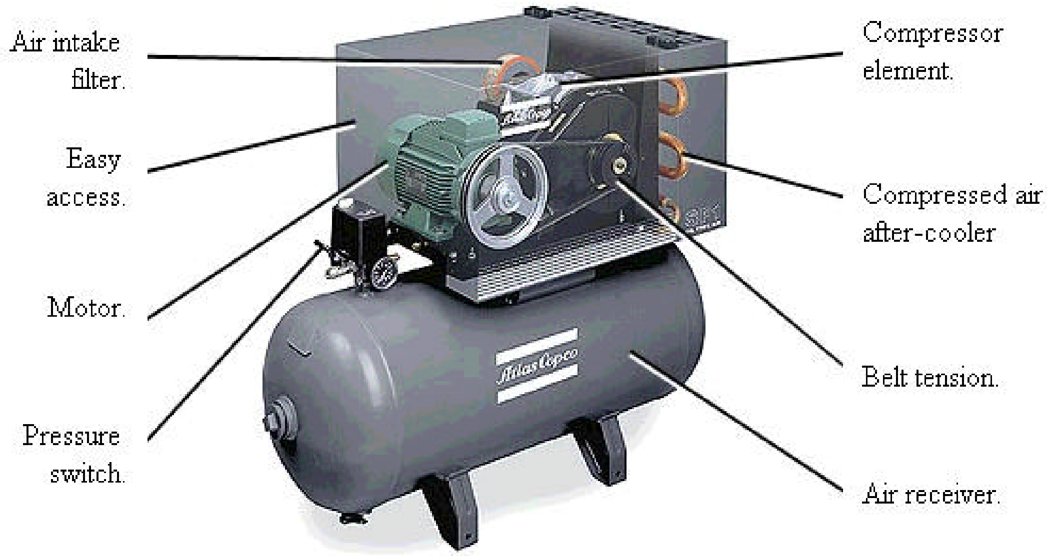
- **Changes in the lab related to Phase 2 [going on since May99 C.R.]**

  - **Higher power budget is not the only reason for modification**
  - **Many partial tests of technology and equipment for the Phase 2 are included:**
    - Scroll compressor [modification; performance tests …]
    - Pressure and back pressure regulators [see demonstrator …]
    - Safety aspects [handling ….]
    - DAQ system development, control system, etc. ….

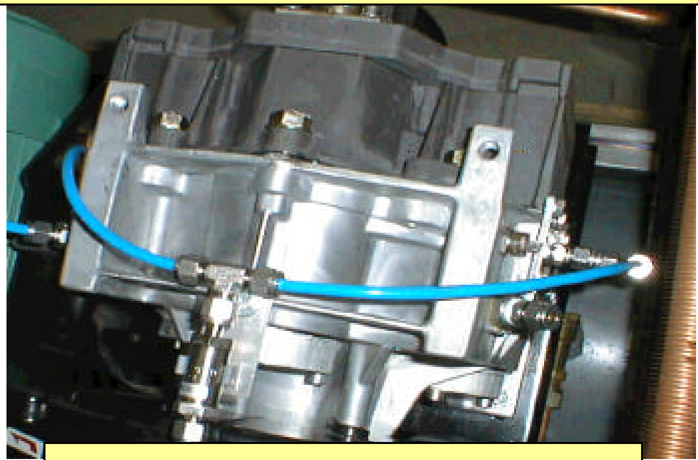
• Compressor studies for fluorocarbon vapors.

Dry scroll compressor Atlas Copco SF4-8-120

Main modifications ↓



Performance test with modified Scroll compressor



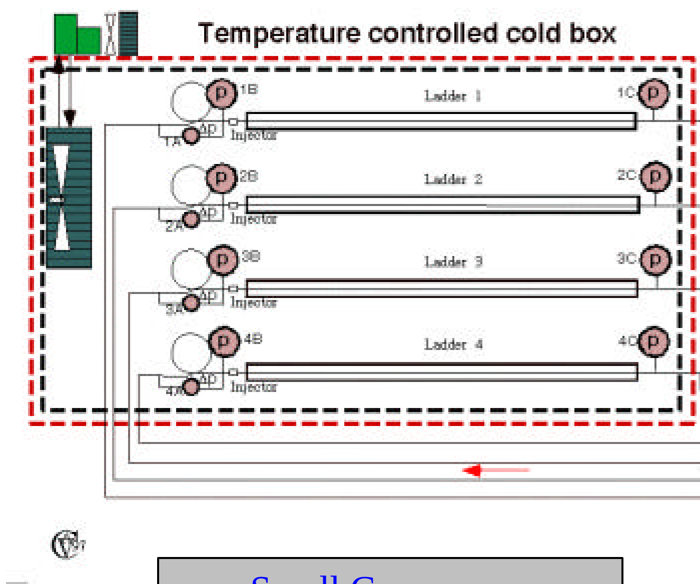
Internal cooling loop implementation

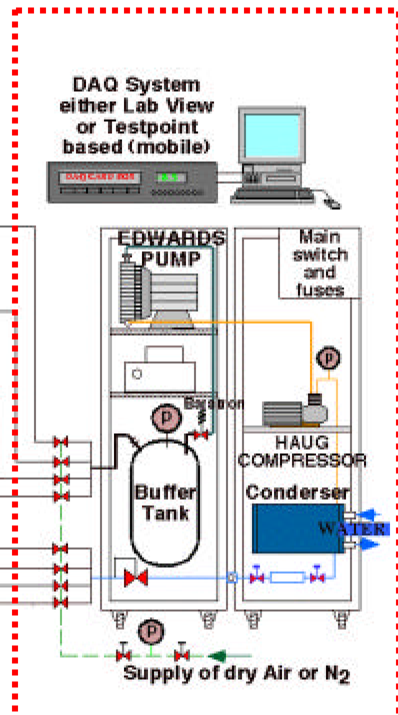
- **Completed:**
- Leak-tightness [He], Internal cooling loop implementation, Frequency regulator device implementation, Buffer tank modification
- **Performance test have been done with following fluids:**
- Air [initial test], Fluorinert vapors: **C_4F_{10}, C_3F_8**

[With an average measured flat pumping speed of ~20 m^3hr^{-1} for both C_4F_{10} (P_{in} = 0.25, P_{out} = 4 bar abs) and C_3F_8 (P_{in} = 1.4, P_{out} = 8 bar abs)].

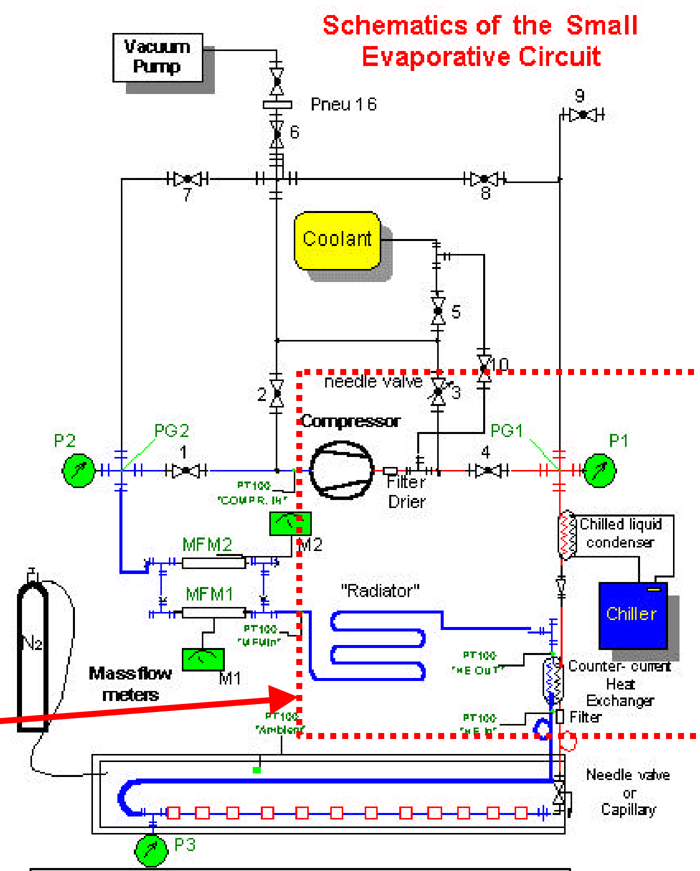
- Scroll compressor is ready for an installation into the main cooling system circuit and necessary workshop actions are under way.
- Other technology under consideration [**Screw compressors** – SIZE ???]

Cooling circuit modifications [big&small installation]





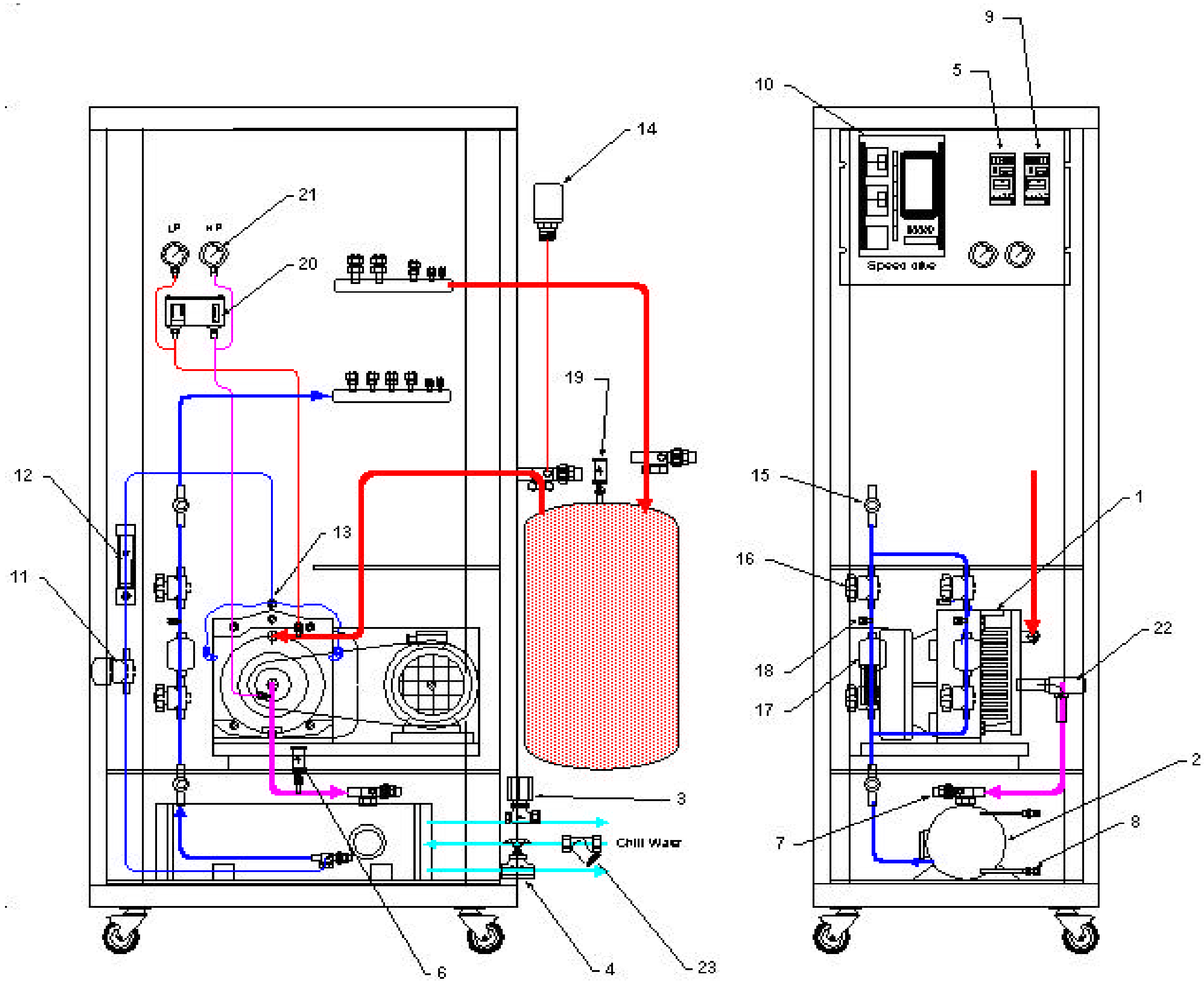
Scroll Compressor unit [Compressor and new condenser] will be installed



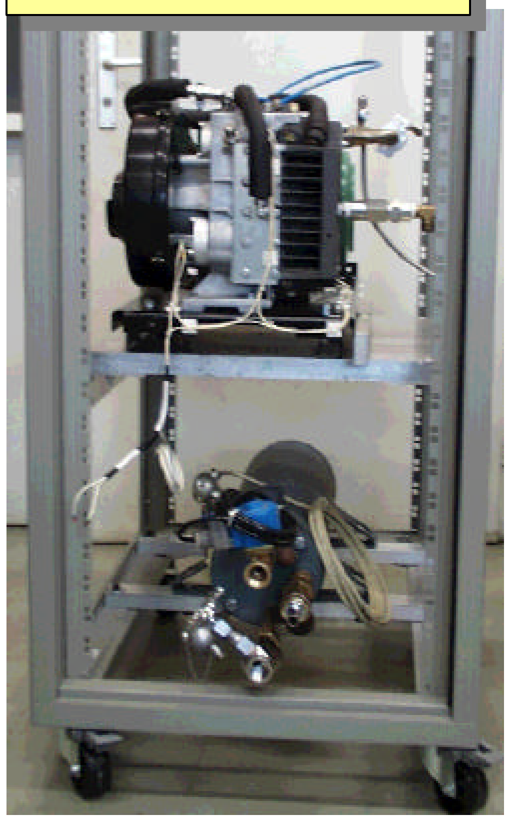
What is going to be changed ?????

Haug Compressor unit will substitute membrane compressor and a small Danfoss condenser

New Scroll compressor unit



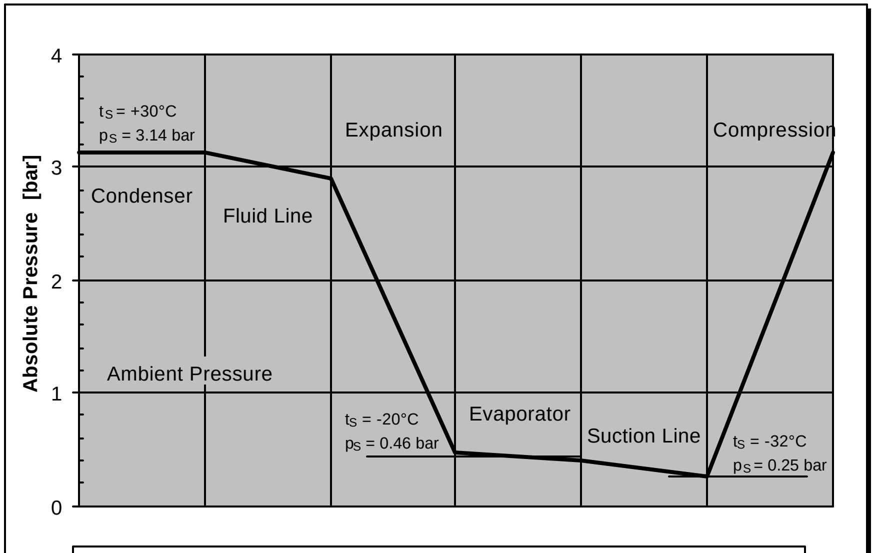
Situation in the workshop on 21/09/99



- **3. Compressor vs condenser – other cooling system studies [no recommendation from *May99 Cool.Rev*.]**

- ***Short-loop circulation system [condenser] study [C4F10]***

[S. Grohmann, ST/CV, M. Olcese, EP/HC, G. Hallewell, V. Vacek, EP/ATI] the first draft submitted for discussion – in early 1999

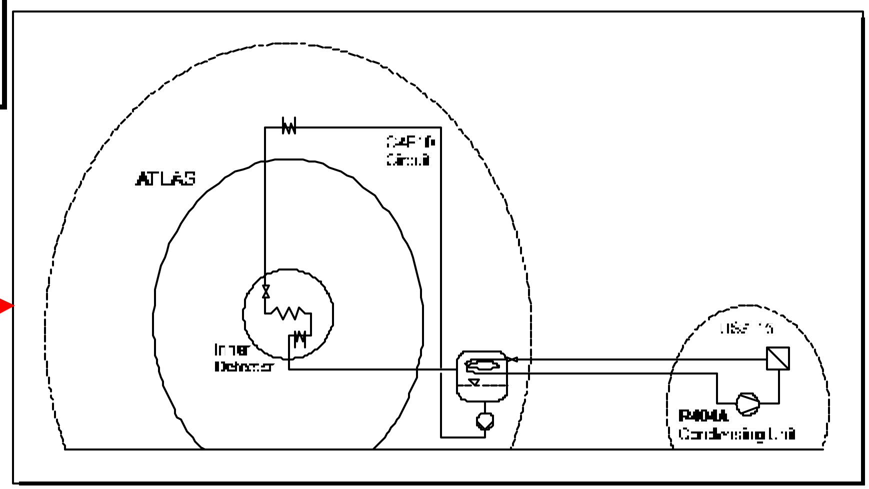


C4F10 at operating temperatures t_C/t_0 = 30/-20°C

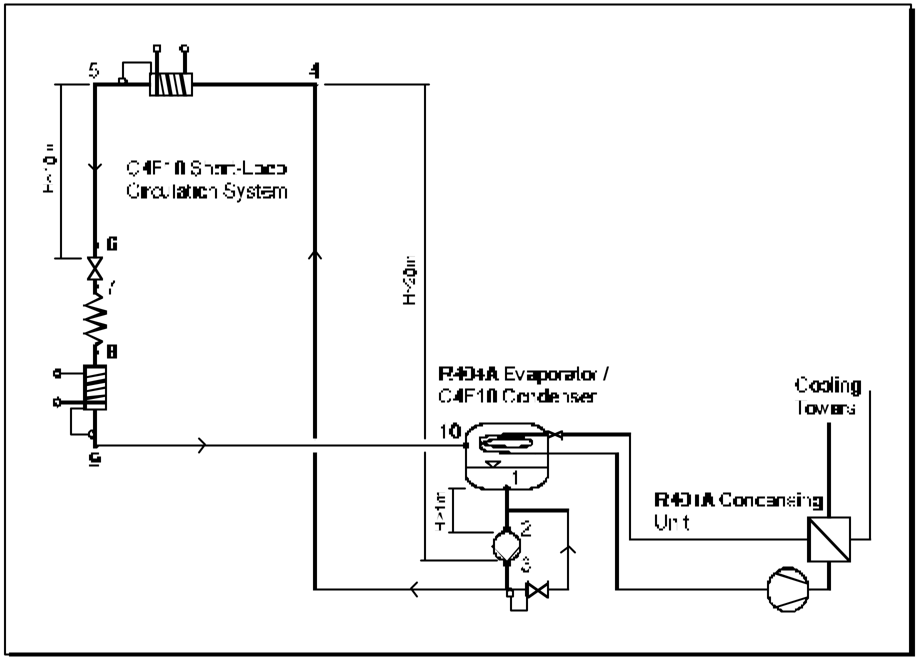
There is only a pressure drop of roughly 200mbar available to assure favorable heat transfer and flow conditions in the evaporator and suction line

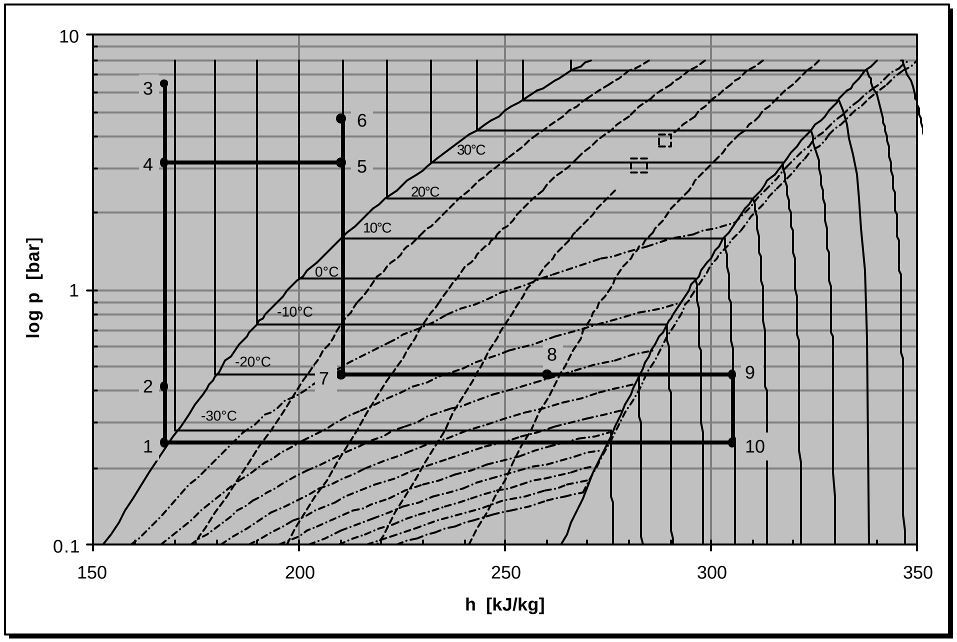
One could therefore propose also a 'short-loop circulation system' using a refrigerant supply pump. The idea is basically derived from so-called 'flooded systems'

The circuit design of the 'Short-Loop Circulation System' for the ATLAS Pixel Detector cooling



• Possible implementation





C4F10 'Short-Loop Circulation System' for ATLAS Pixel cooling

C4F10 lg p,"h" diagram, operating conditions

- **Main parts for the short-loop circulation system are available in the lab [from latter study & development at CPPM]**

AVAILABLE IN THE LAB
Condenser and Compressor unit with R 404 [Danfoss]

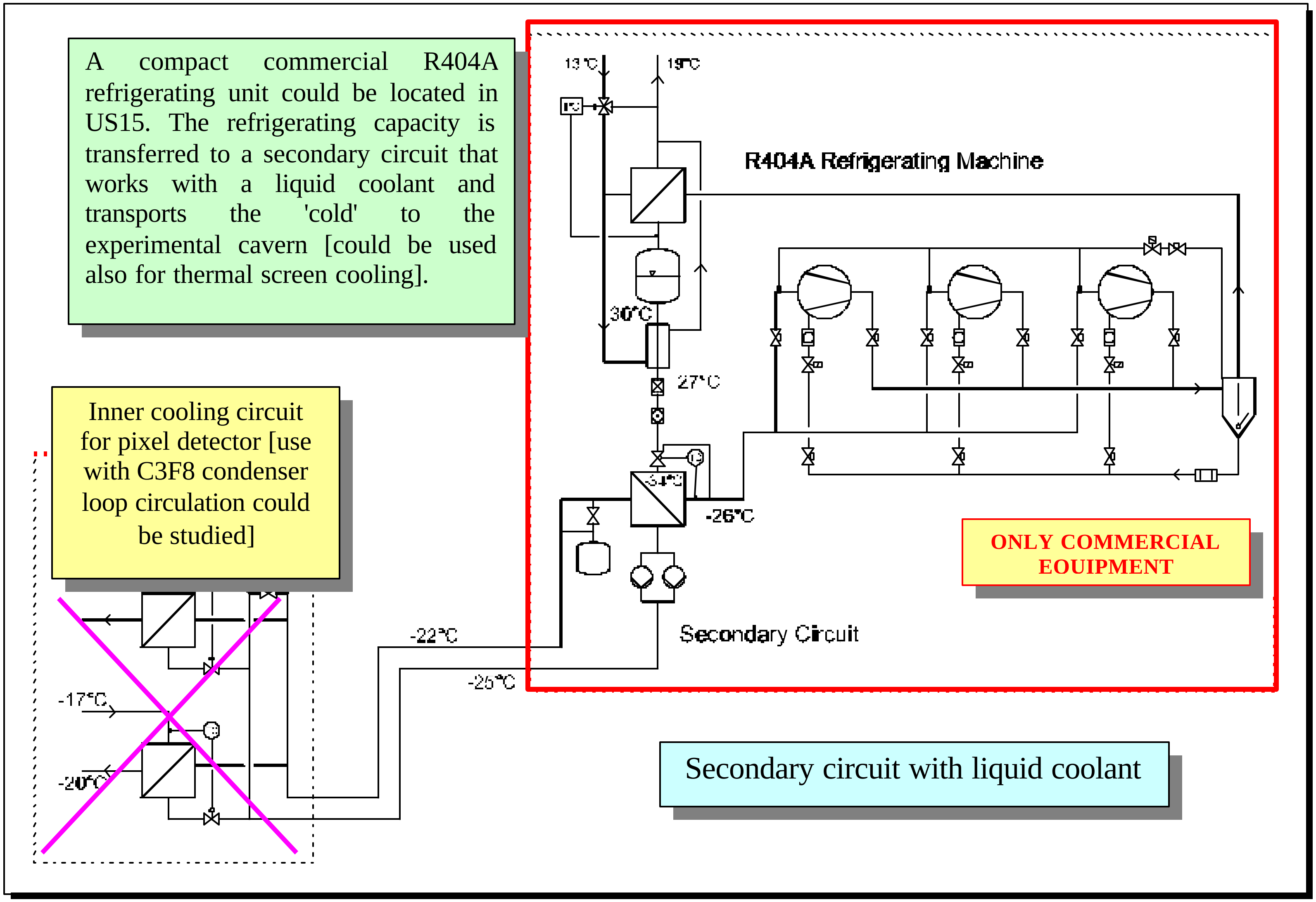
Side Channel Pump would be needed to purchase!

Offer - Pump:

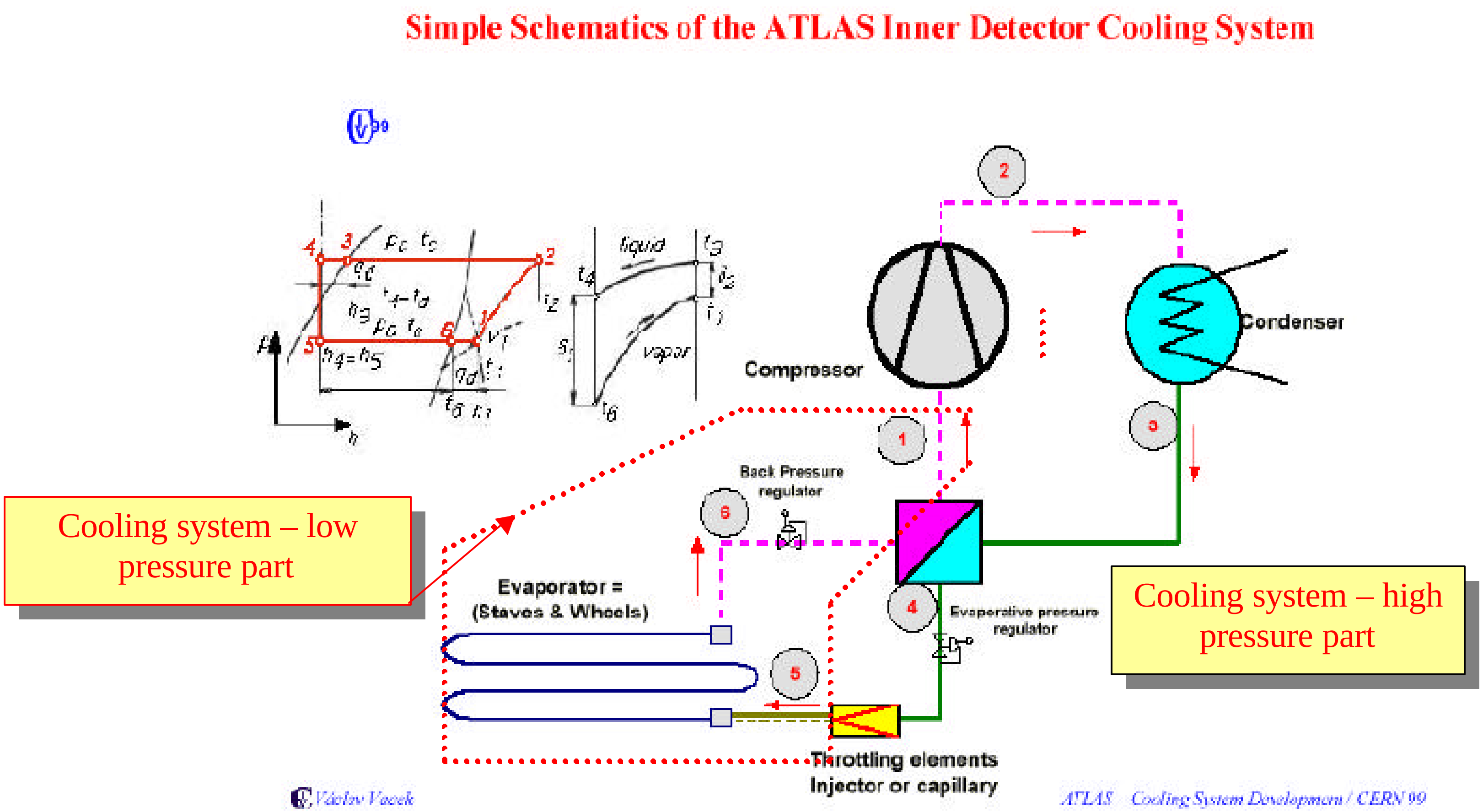
Medium:	C4F10
Temperature:	-30 °C
Density:	1.7 kg/m^3
Viscosity:	0.27 mm^2/s
Delivery Capacity:	0.12 m^3/h
Delivery Head:	54 m
NPSH:	1.45 m

Price: <u>3960 CHF</u>

- Other options: *[see CMS Tracker Cooling - one out of the three alternative technical proposals]*



• 4. Maximum pressure risk analysis & SAFETY ISSUES



• Status of the analysis so far:

- **Safety and control issues were always analyzed and addressed [and never neglected] within the cooling system development reports and presentations [referring to TDR reports and number of G.Hallewell's presentations]**

- **Number of tests have been done on existing cooling circuits**

    - **Start up of the system**
    - **Shut off of the system [regular and also accidental]**
    - **Changes of technological parameter during the cooling system operation [sudden pressure changes, failure of the heating elements control ….]**

- **So, always a few steps ahead *[we can verify the options only on existing cooling circuits with real components]***

    - **Interlock box development and tests**
    - **Shut off valve tests**
    - **Heater control**

• S.I. & Cooling system setup for Phase 2
• to “drive” 1/8 of the ID Mockup [SCT+Pixel]

- outlined by G.H. [first by M.B.; then revised by M.B.&cooling team] based mostly on commercial parts [most of them already available]
- *Safety failure issues for the whole setup under study*
    - [---> results to be submitted at the end of October 99]
- **Intermediate steps** – going on in accordance with parts delivery and reconstruction of the Cooling circuits in the lab:
- Ready at the moment:
    - DAQ + Control system development for Phase 2
    - Pressure control demonstrator setup

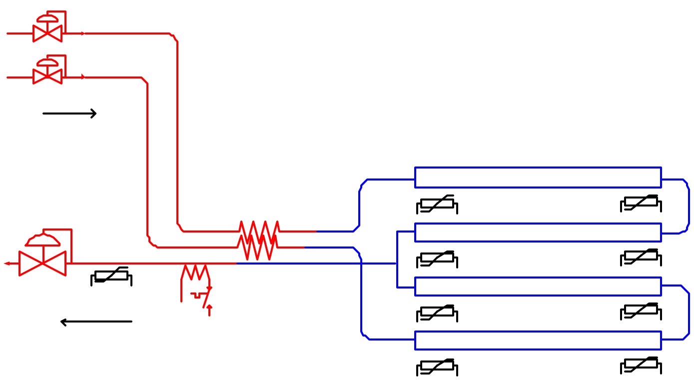
• Introduction of the new DAQ system with control functions for the big Cooling circuit

Sensor type	No	Type	Name	LMB	V range (V)	I (A)	Comments
Temperature	64	AI	Pt-100	PT-100	+/-0.1	100p	4 wire read ou
Pressure	0-8	AI	RS	ADC+ V div.	0-10	100ì	Max current
		AI	ST	ADC+ V div.	0-10	100ì	Max current
Mass flow	0-8	AI	BH	ADC+ V div.	0-10	ins.	For big rig
		AI	S	ADC	0-5	ins.	For little rig
Isolation valve control	4	DO	HW	WAGO	5 (TTL)	5m	Controlling pressurised ai
Heater Control	4	DO	Custom (TTL)	WAGO	5 (TTL)	5m	Turns heaters On/off
Isolation valve status	8	DI	Custom (TTL)	ADC	0-5 (TTL)	5m	Using AI
Heater status	0	DI	Custom (TTL)	ADC	0-5 (TTL)	5m	Using AI

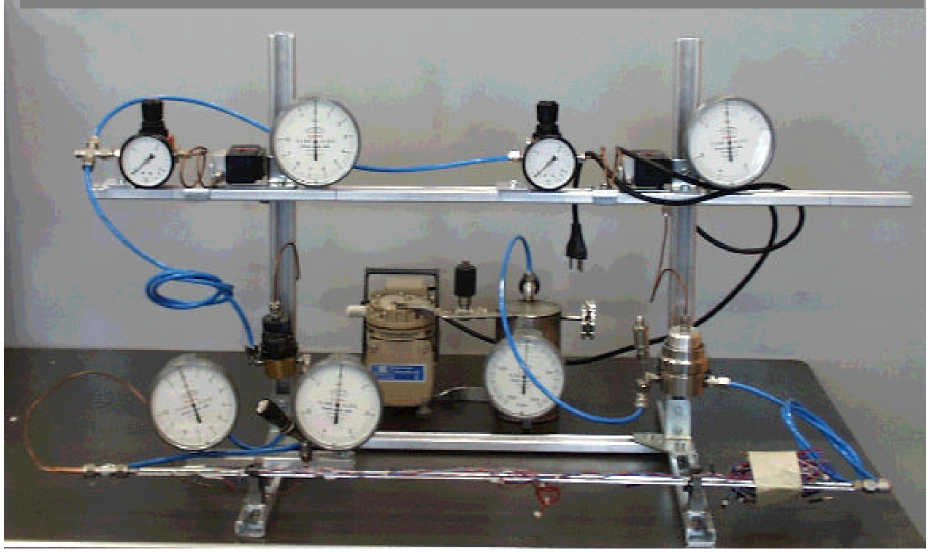
System is being used for temperature monitoring of the SCT test structure [RAL] – 20-30/09/99

• The demonstrator to test pressure and back pressure regulator system has been prepared

One of the possible solution



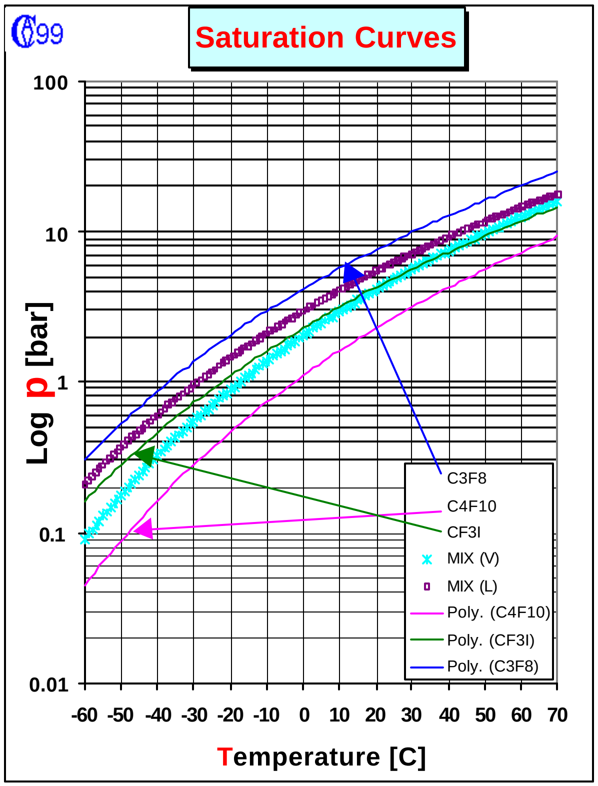
Setup with pressure regulators and dummy pixel stave



- **Pressure control system and pressure fault conditions will be simulated with real components [already in the lab]**
- Verified solution is going to be implemented into both circuits [for additional tests in the small circuit {to save fluid and protect environment} and for pressure control in the big circuit]

Summary:

- **1. Status of evaporative cooling was described**
  - Possibility of the common cooling system and common coolant - **C_3F_8** for the SCT and pixel should be considered at the pixel stave and wheel design sites



Selected Refrigerant Properties (-15° C)

Fluid *[ref for calcn]*	L (Jg^{-1})	$Vol_{(vap)}$/ $cm^3_{(liq)}$	S.V.P (bar a) @ -15° C
C_3F_8 *[5],[7]*	97.0	71.4	2.46
C_4F_{10} *[5],[7]*	101.1	242.6	0.58
CF_3I *[7]*	100.8	176.3	1.33
C_3F_8/ C_4F_{10} (50/50) *[8],[9]*	98.3	147.6	$1.01P_{SV}$ → $1.65\ P_{SL}$

- **SPECs** for temperature **[-7 °C]** on silicon and also pressure in the staves [around **1 bar_{abs}** or below] and discs did not changed since Binary-Ice and Liquid cooling system considerations
- We have never heard objections against lower temperatures on silicon **[what could be the lowest limit ???]**
- To achieve a lower pressure with C_3F_8 means to lower the temperature of evaporation – see graph and table!

- **2. Planning for Phase 2 was reviewed shortly:**
  - Phase 2 cooling system project – expected to begin JAN 2000
  - Upgrade of the existing cooling systems due to:
    - Higher power dissipation in the cooled down structures
    - Possibility to test components and verify technology for Phase 2

- **3. Compressor vs condenser - discussed:**
  - Two alternatives under study presented
    - Still evaporative system
    - Originally for C4F10 to over come limited pressure “drop stock”, now difficult or impossible with this fluid and new power SPECs
    - Replacement with C3F8 possible – needs to be studied IN DETAILES
  - Basic components for setup of this kind in the lab
    - R404 Danfoss compressor unit with control system and condenser with ALFA LAVAL heat exchangers inside
    - ALL OF THOSE FROM UNCOMPLETED STUDIES OF THE SYSTEM AT CPPM
    - [except side channel pump]
  - MANPOWER, SOME FUNDING AND TIME NEED TO BE ALOCATED - **NOW!** **“IF”**

- **4. Maximum pressure risk analysis were outlined:**
    - Final results for Phase 2 prototype [end of October 99]
    - Basic tests already performed on existing circuits
    - Demonstrator for pressure regulators and safety valves ready
    - Important control features implemented into new DAQ system

Closing remarks:

- **Announced pixel prototype measurements until December 99**
    - **LBL Disc sector (AL tube in the structure);** *[already in the lab]*
        - But needs work
            - *Frame to hold structure,*
            - *RTD sensor connectors, and some more gluing*
            - *Tube connectors*
    - **New Genova stave prototypes;** *[end of October]*
        - *Two staves*
        - *To be tested in parallel and series*
    - **Other prototypes** *[CPPM stave expected]*
- **Kind request from the Cooling team *[to speed up measurements of YOUR Prototypes]***
    - **Pay attention to the proper sensor cabling [flat cables; 34 wires with Screw terminal interface assemblies; RS stock No. 424-462 *{English catalog}*] !**
    - **Equip your structures with adequate tube connectors - Swagelok!**
- ***Note:*** *All C.S. installations are also used for SCT prototype tests*

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