Possible Operation with Fluorocarbon blends of C_3F_8/C_2F_6

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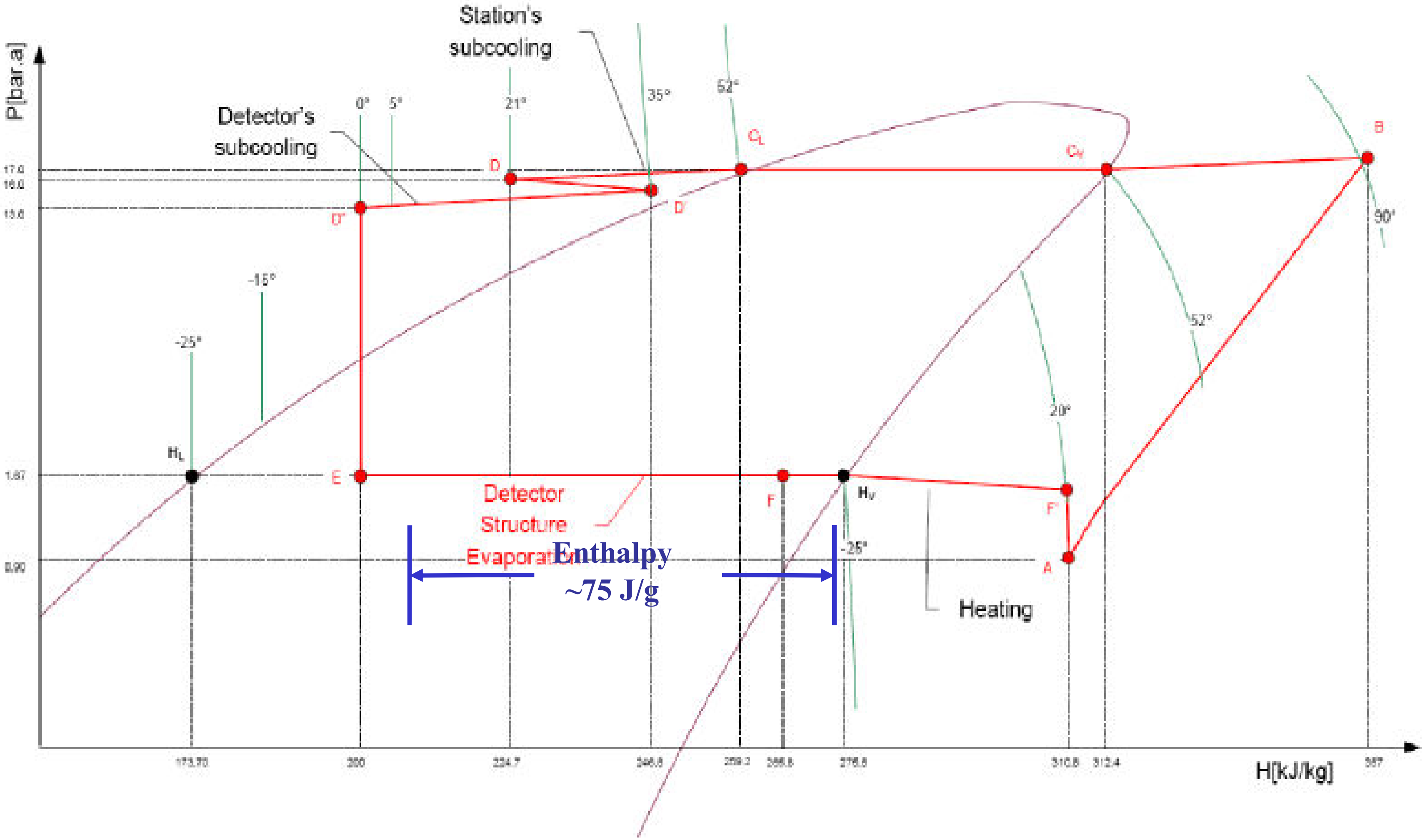
Thermosyphon workshop, CERN, July 6, 2009

Possibilities for operation with C_3F_8/C_2F_6 blends

INITIAL MOTIVATION:

Exhaust pressure drop problem
(heaters, HeX and return tubing)
will not allow present C_3F_8 compressor system to maintain
an evaporation temperature of -27ºC
(to operate silicon below -7°C (TDR spec.)
after significant irradiation (increased I_{leak}))

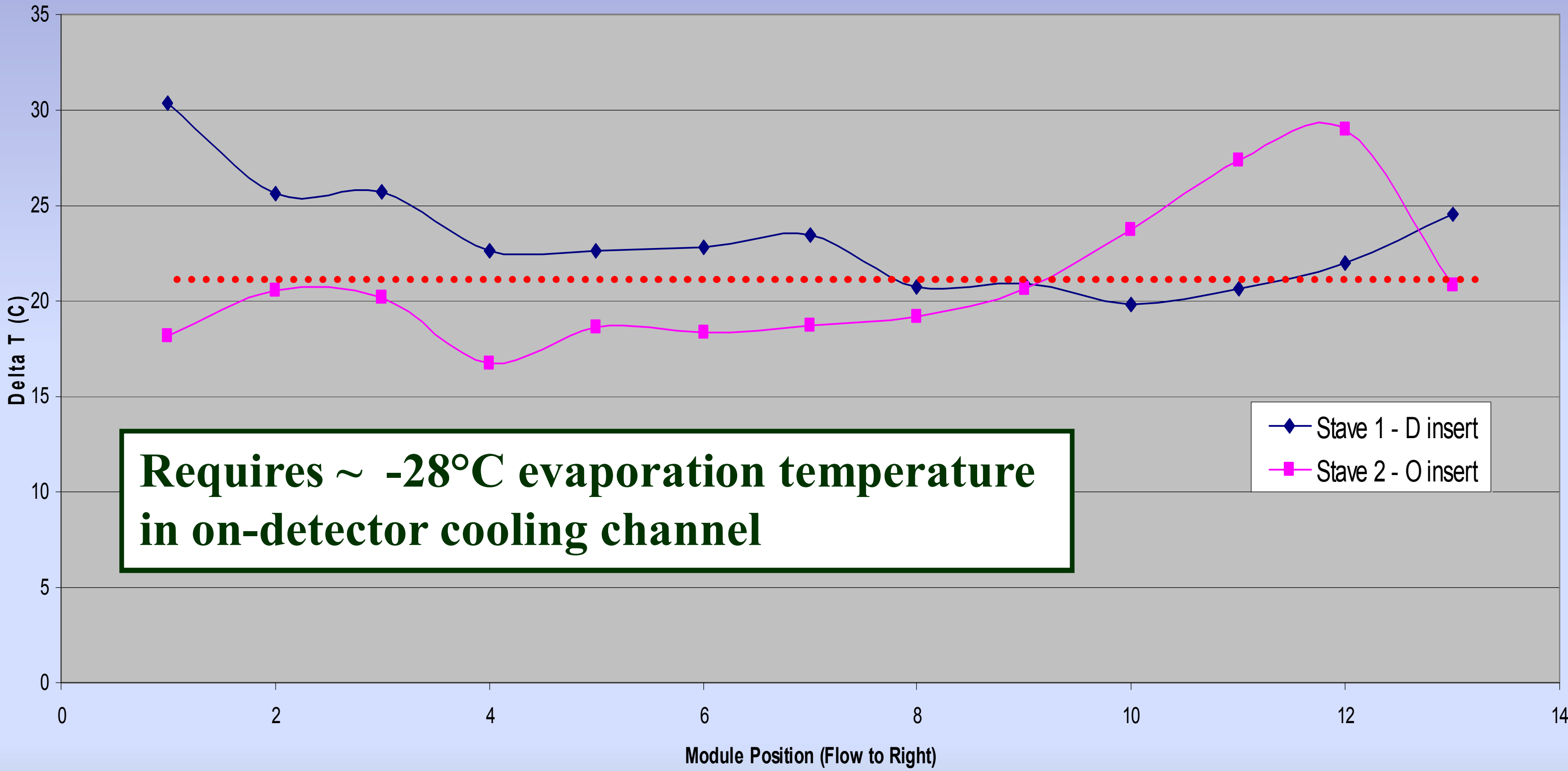
Present C_3F_8 implementation (from evaporative cooling paper)



Enthalpy ~75 J/g

Example of temperature gradients across (pixel) cooling & support structures.

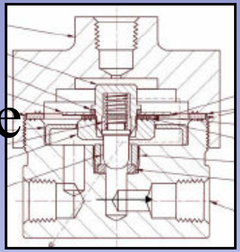
(Temperature differences to be *subtracted* from -7°C to get in-tube evaporation temperature: mass flow ~4.7 $g.s^{-1}$, enthalpy ~50 $J.gm^{-1}$)

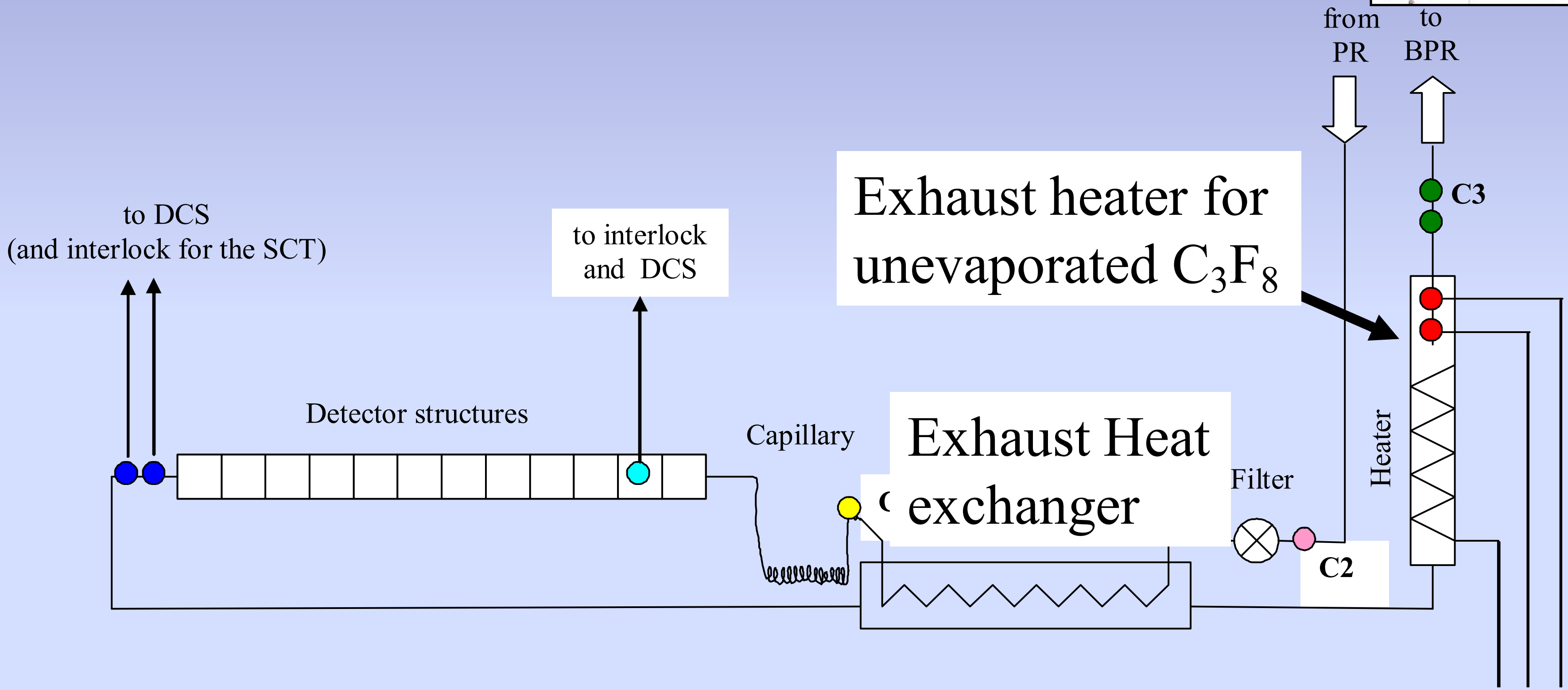


Requires ~ -28°C evaporation temperature in on-detector cooling channel

So where are the actual pressure drops?

Backpressure regulator





Exhaust heater for unevaporated C_3F_8

Exhaust Heat exchanger

Original exhaust ΔP budget (Olcese): 350mbar

- More recent estimates for SCT barrel @ 8.9 gm.s^{-1} (exhaust hex, heaters, 'internal' tubes, BPRs, tubes to compressor) suggest 520 mbar as a more reasonable figure

- However, including the losses in SCT end-of-barrel exhaust manifolding, and losses along staves pushes this to 1190mbar!

➔ T_{Si} +2°C (Spec +9°C!)

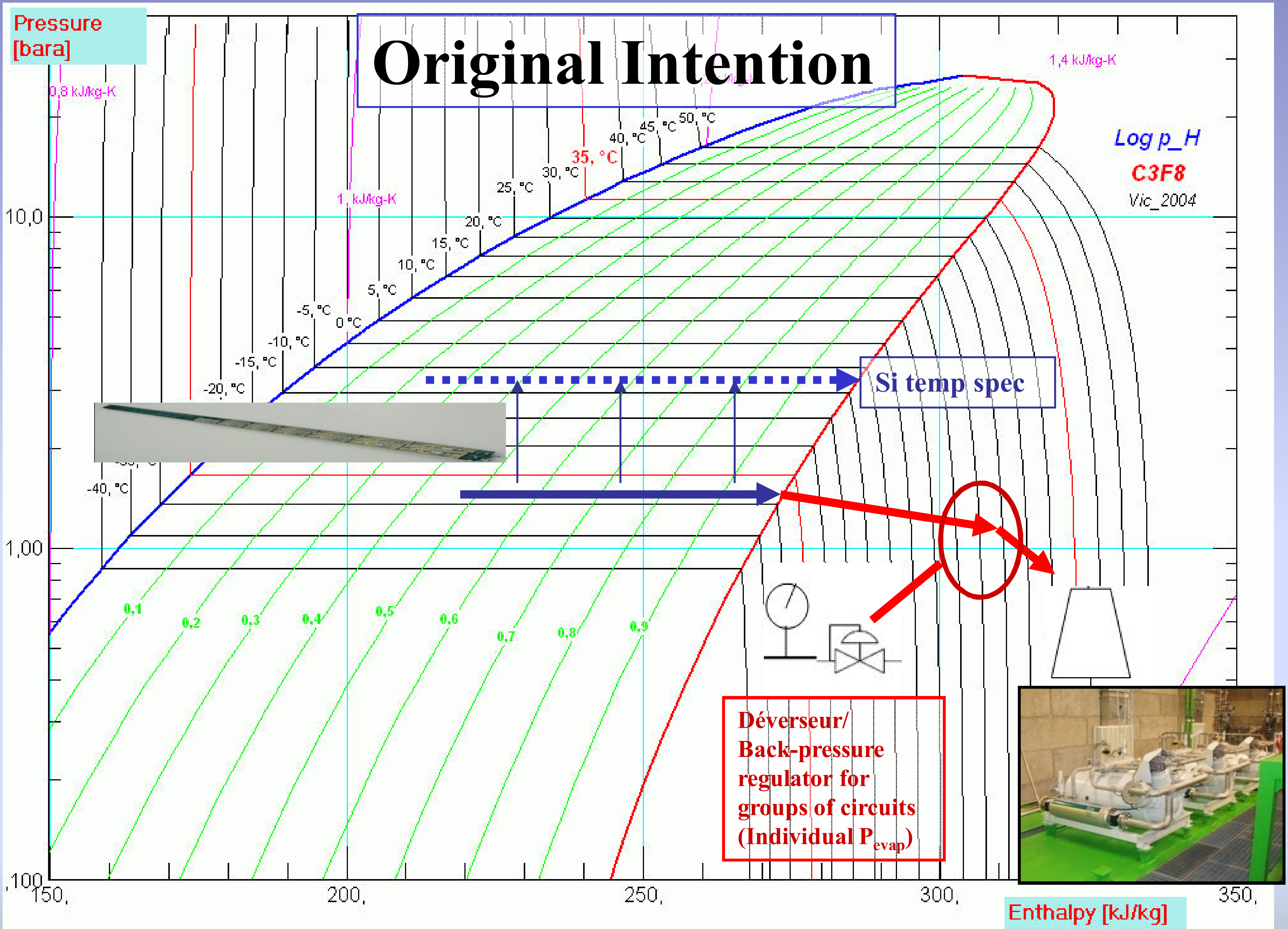
- Far from TDR specification on T_{Si} post-irradiation…

AND THIS WAS BEFORE 'FAR HEATER' PROPOSAL STARTED TO BE CONSIDERED, WHICH ADDS ~220 mbar

➔ T_{Si} +4°C (Spec +11°C!!)

WHAT TO DO??

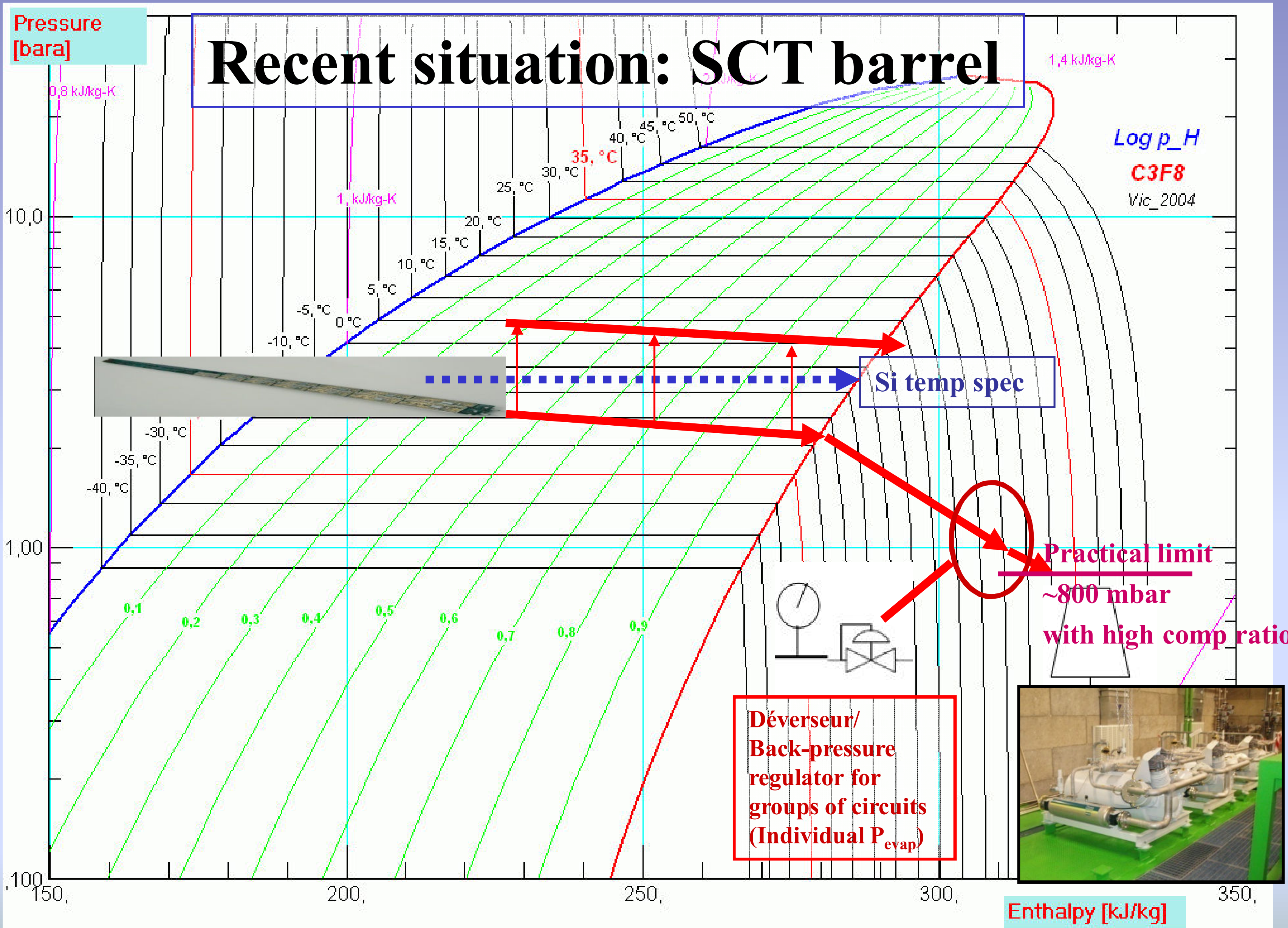
Original Intention



Si temp spec

Déverseur/
Back-pressure regulator for groups of circuits
(Individual P_{evap})

Recent situation: SCT barrel



Si temp spec

Practical limit

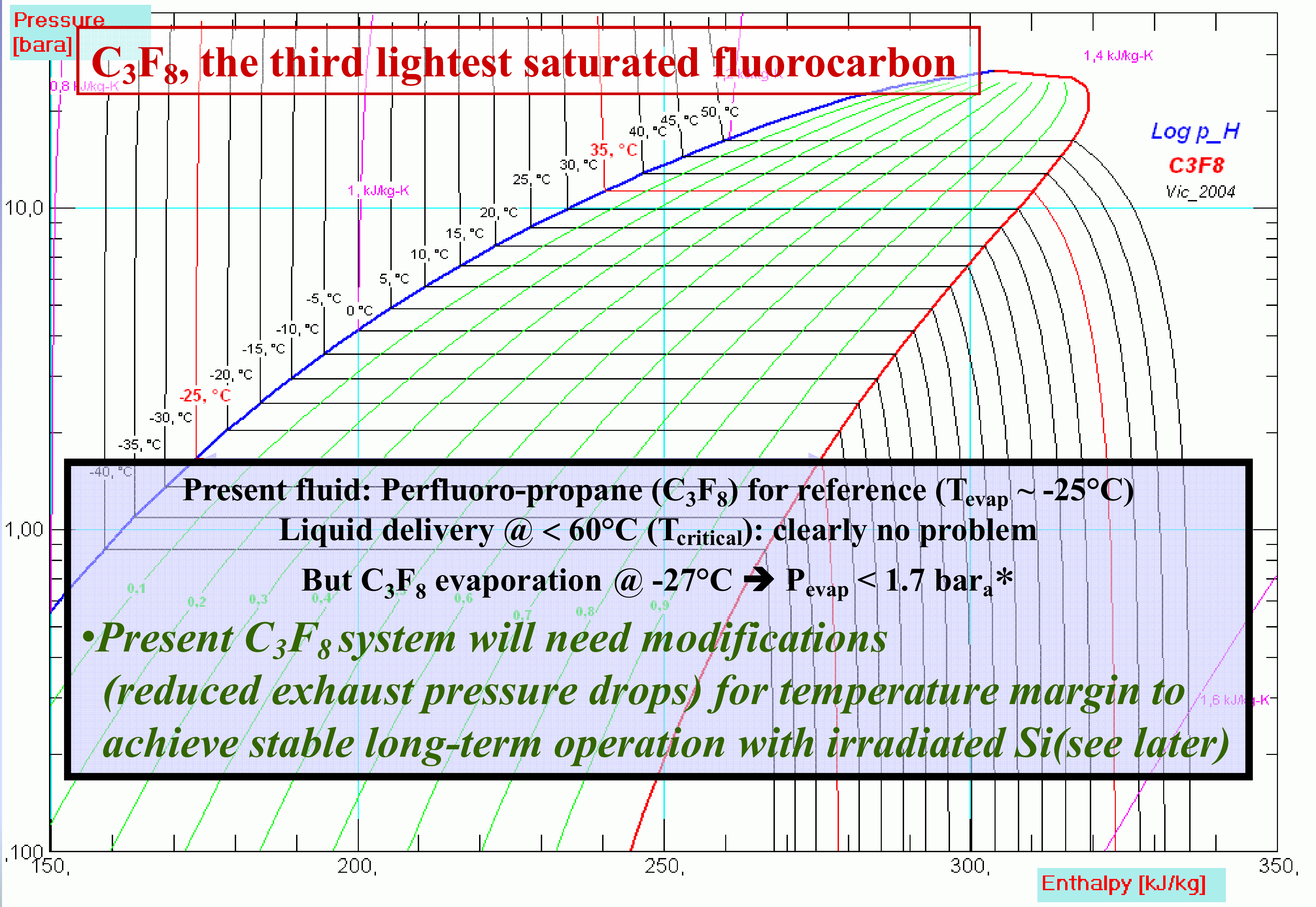
~800 mbar

with high comp ratio

Déverseur/
Back-pressure
regulator for
groups of circuits
(Individual P_{evap})

Fluorocarbon blending

Already experience with C_3F_8/C_4F_{10}



C$_3$F$_8$, the third lightest saturated fluorocarbon

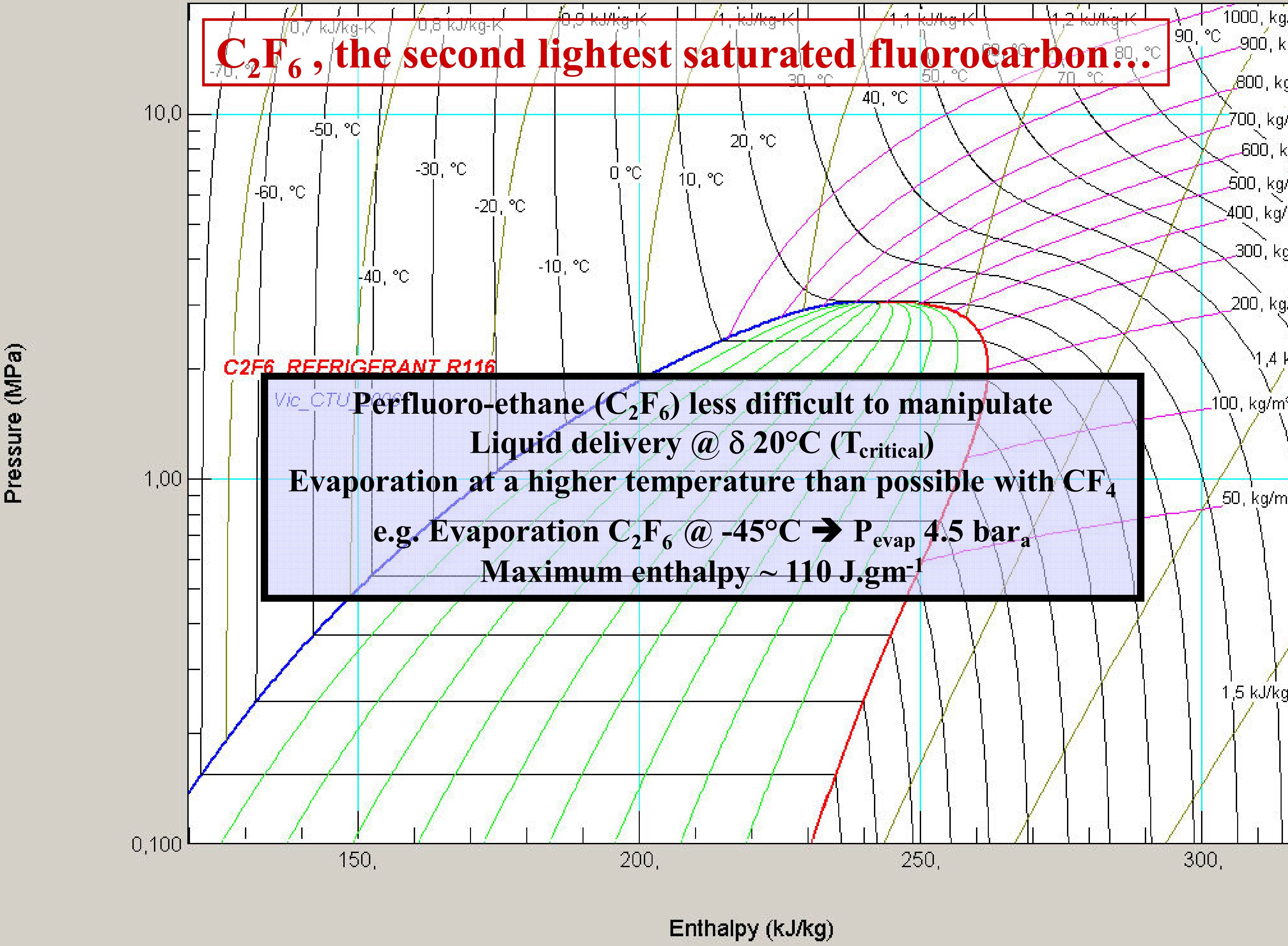
Present fluid: Perfluoro-propane (C_3F_8) for reference (T_{evap} ~ -25°C)

Liquid delivery @ < 60°C ($T_{critical}$): clearly no problem

But C_3F_8 evaporation @ -27°C ➔ P_{evap} < 1.7 bar$_a$*

- ***Present C_3F_8 system will need modifications (reduced exhaust pressure drops) for temperature margin to achieve stable long-term operation with irradiated Si(see later)***

C_2F_6 , the second lightest saturated fluorocarbon…



Perfluoro-ethane (C_2F_6) less difficult to manipulate

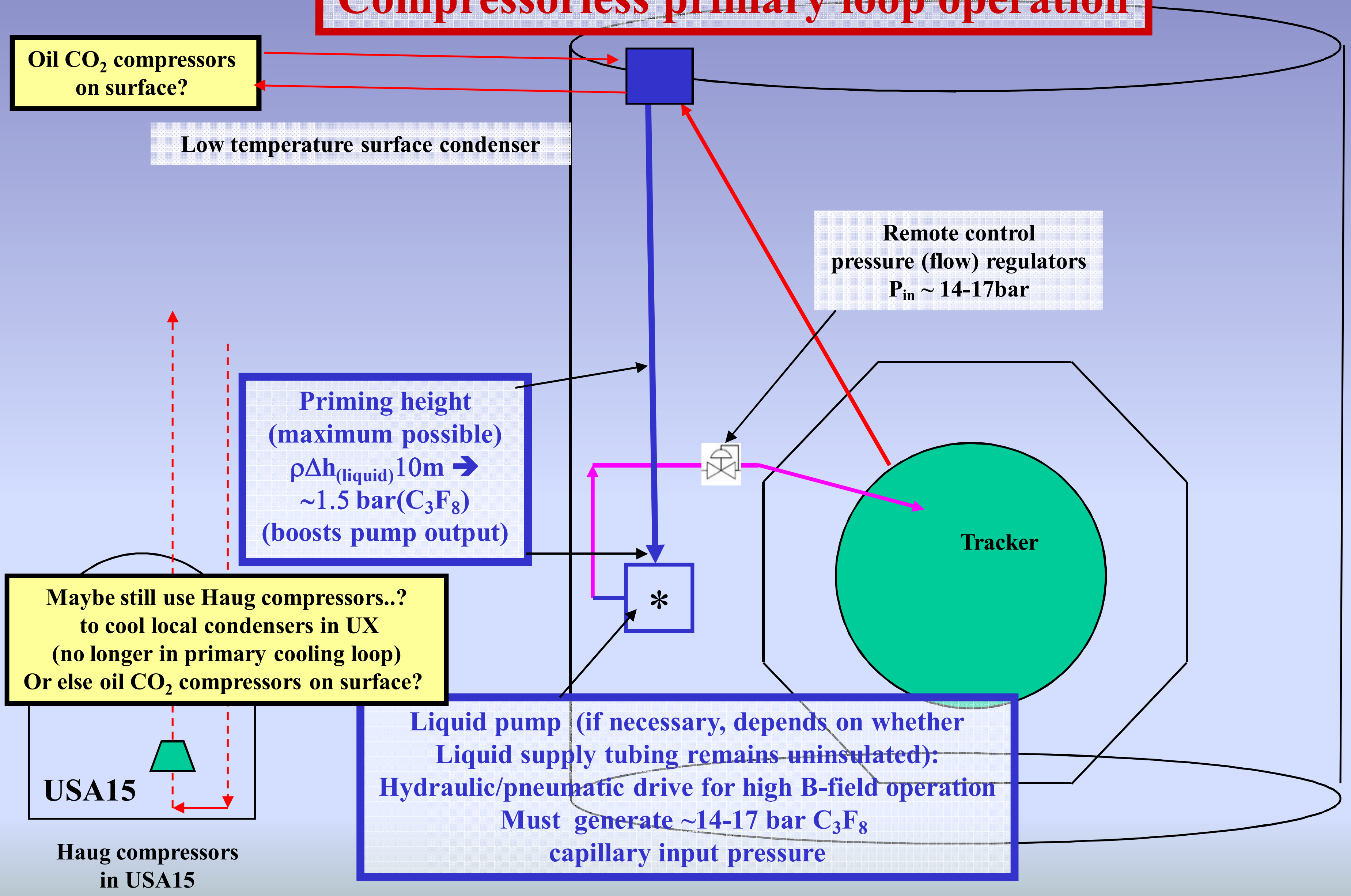
Liquid delivery @ δ 20°C ($T_{critical}$)

Evaporation at a higher temperature than possible with CF_4

e.g. Evaporation C_2F_6 @ -45°C ➔ P_{evap} 4.5 bar_a

Maximum enthalpy ~ 110 $J.gm^{-1}$

Compressorless primary loop operation



Oil CO_2 compressors on surface?

Low temperature surface condenser

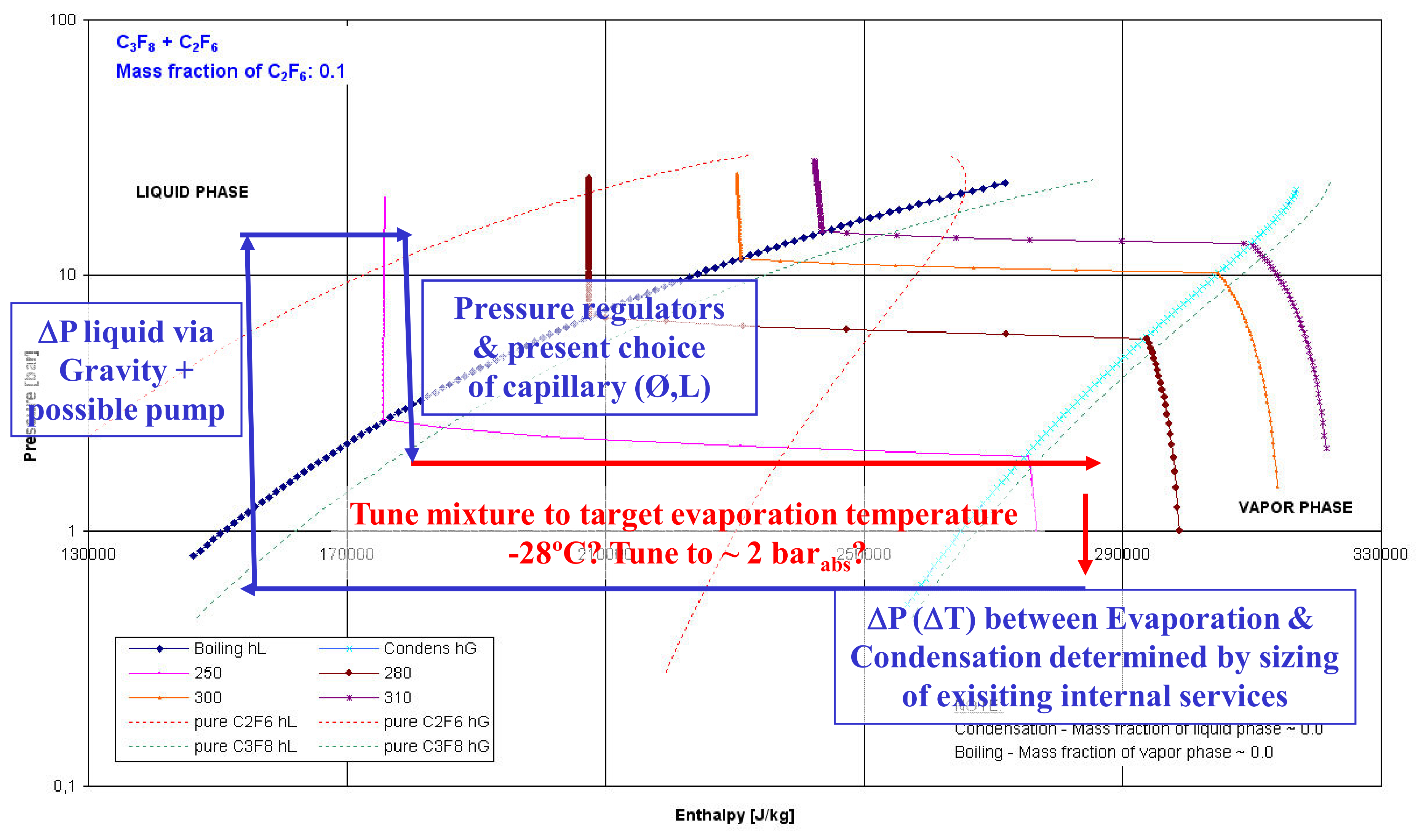
Remote control pressure (flow) regulators P_{in} ~ 14-17bar

Priming height (maximum possible) $\rho\Delta h_{(liquid)}$10m ➔ ~1.5 bar(C_3F_8) (boosts pump output)

Maybe still use Haug compressors..? to cool local condensers in UX (no longer in primary cooling loop) Or else oil CO_2 compressors on surface?

Liquid pump (if necessary, depends on whether Liquid supply tubing remains uninsulated): Hydraulic/pneumatic drive for high B-field operation Must generate ~14-17 bar C_3F_8 capillary input pressure

Haug compressors in USA15

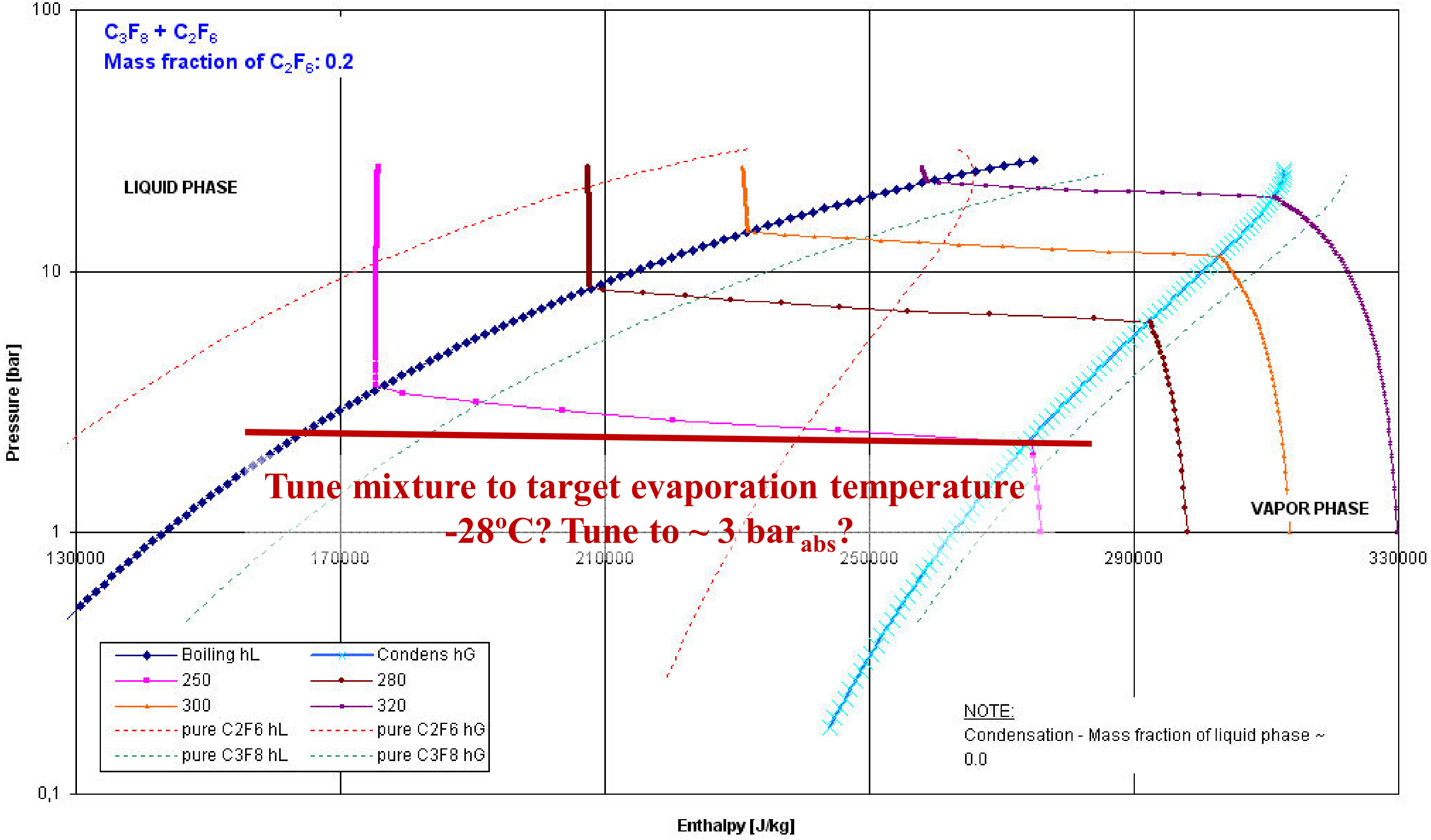


ΔP liquid via Gravity + possible pump

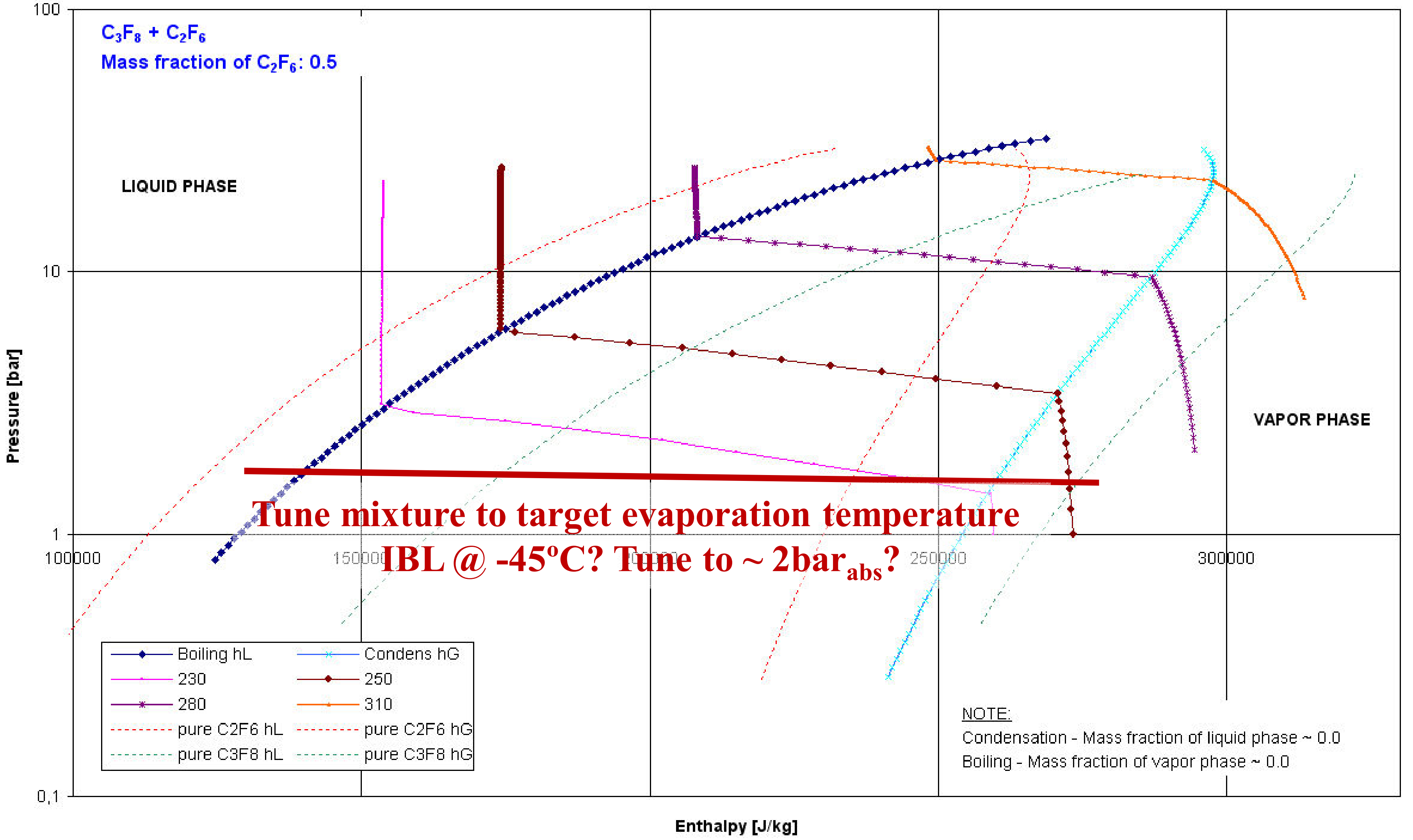
Pressure regulators & present choice of capillary (Ø,L)

Tune mixture to target evaporation temperature -28°C? Tune to ~ 2 bar_{abs}?

ΔP (ΔT) between Evaporation & Condensation determined by sizing of exisiting internal services



Tune mixture to target evaporation temperature -28ºC? Tune to ~ 3 bar$_{abs}$?



NOTE:
Condensation - Mass fraction of liquid phase ~ 0.0
Boiling - Mass fraction of vapor phase ~ 0.0

Tune mixture to target evaporation temperature

IBL @ -45°C? Tune to ~ 2bar$_{abs}$?

Fluorocarbons can be mixed (blended) to arrive at compromise thermodynamic properties

(many modern refrigerants are blends)

- This was tested with C_3F_8/C_4F_{10}

(2 papers in Fluid Phase Equilibria 2000-2001)

Mixture thermodynamic, transfer properties calculated & set up as ‘temporary’ folders in NIST database

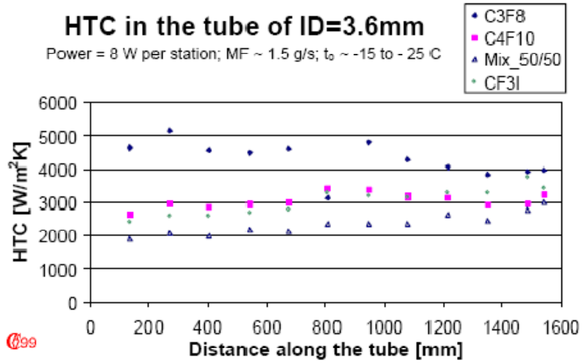


Fig. 4. Heat Transfer Coefficients in a 3.6mm ID tube: C_4F_{10}, CF_3I, C_3F_8 and 50%C_4F_{10}/50% C_3F_8 mixture at similar power and flow rate.

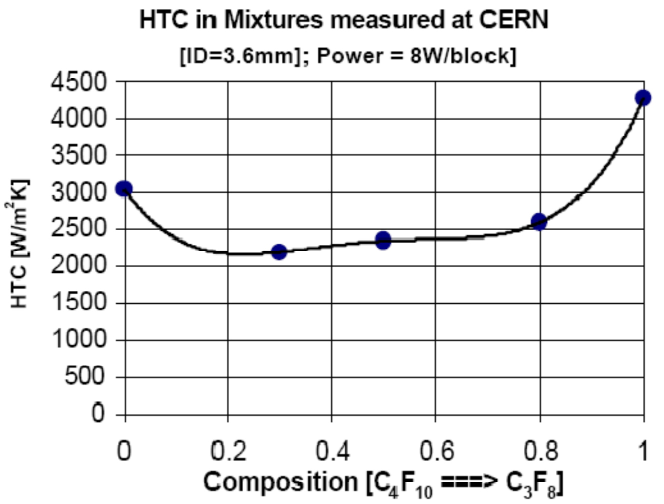
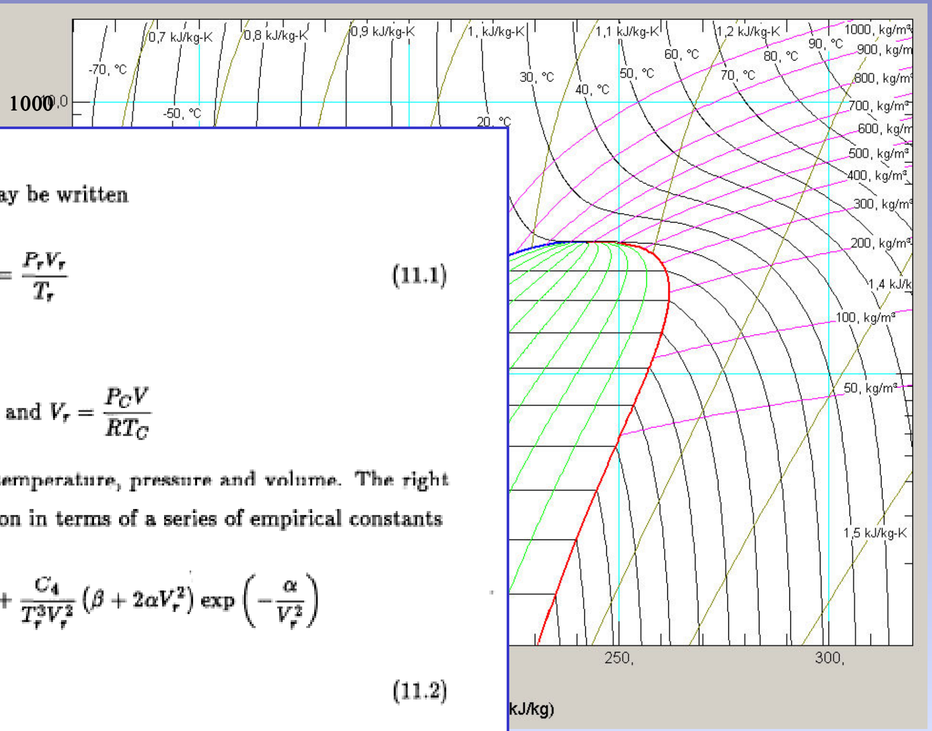
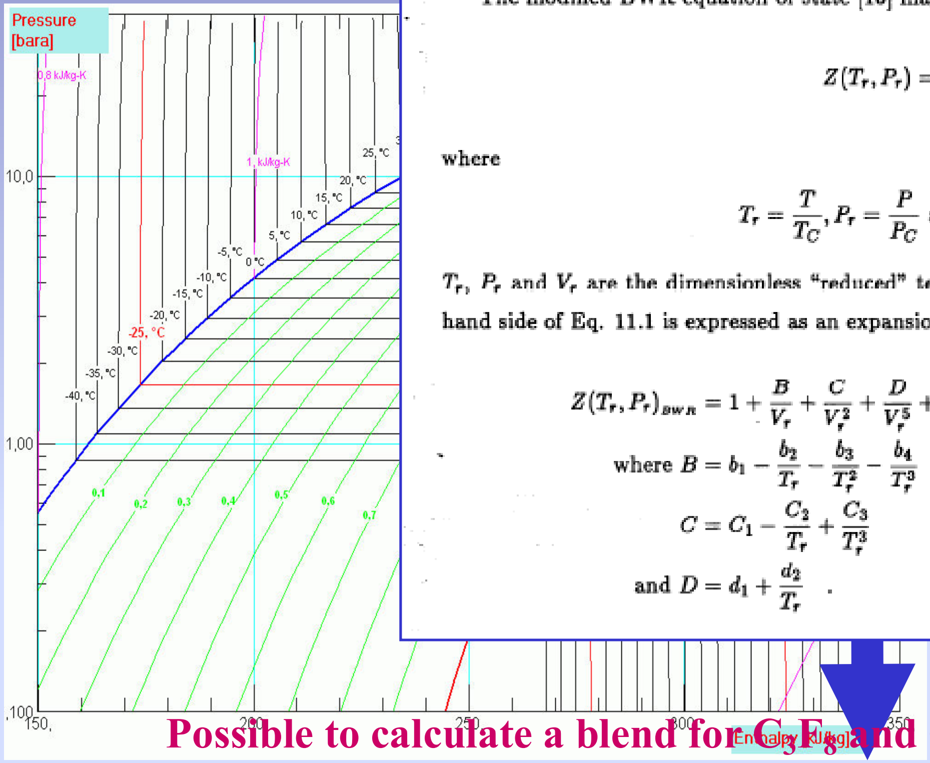


Fig. 5. Measured variation of the Heat Transfer Coefficient in a 3.6mm ID tube with changing C_4F_{10}/C_3F_8 mixture composition.





The modified BWR equation of state [13] may be written

$$Z(T_r,P_r)=\frac{P_rV_r}{T_r} \tag{11.1}$$

where

$$T_r=\frac{T}{T_C},\ P_r=\frac{P}{P_C} \text{ and } V_r=\frac{P_CV}{RT_C}$$

T_r, P_r and V_r are the dimensionless "reduced" temperature, pressure and volume. The right hand side of Eq. 11.1 is expressed as an expansion in terms of a series of empirical constants

$$\begin{aligned} Z(T_r,P_r)_{BWR} &= 1+\frac{B}{V_r}+\frac{C}{V_r^2}+\frac{D}{V_r^5}+\frac{C_4}{T_r^3V_r^2}\left(\beta+2\alpha V_r^2\right)\exp\left(-\frac{\alpha}{V_r^2}\right) \\ \text{where } B &= b_1-\frac{b_2}{T_r}-\frac{b_3}{T_r^2}-\frac{b_4}{T_r^3} \\ C &= C_1-\frac{C_2}{T_r}+\frac{C_3}{T_r^3} \\ \text{and } D &= d_1+\frac{d_2}{T_r} \ . \end{aligned} \tag{11.2}$$

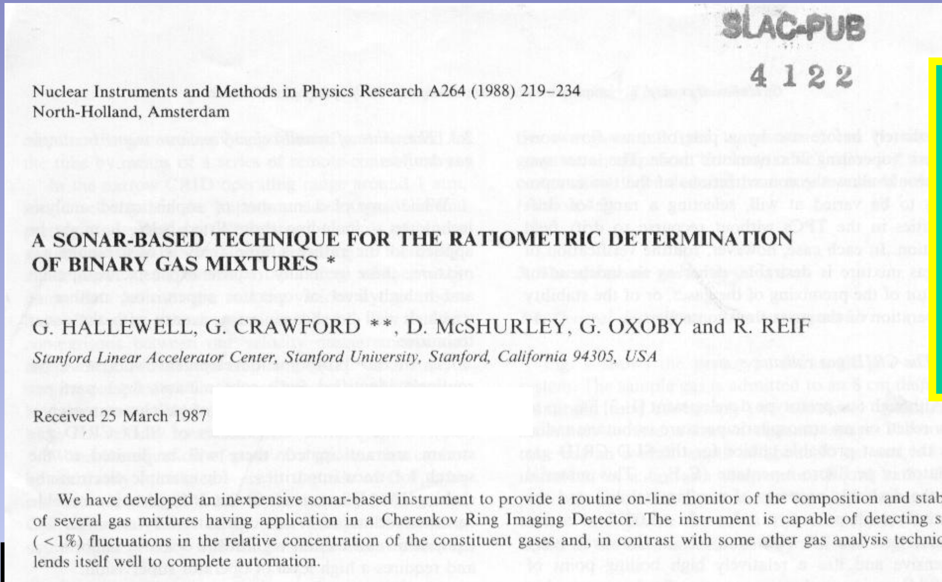
Possible to calculate a blend for C_3F_8 and C_2F_6 having P_{evap}= 3 bar_{abs} @ -25°C
Using molecular dynamics (vacek, Prague) or modified Benedict-Webb-Rubin equation of state, and avoiding low critical temperature problem of pure C_2F_6

(Sidesteps pressure drop problem and raises aspiration pressure)

But needs mixing set-ups and batch assay (ultrasonic or GC…)

Question of heat transfer coefficient: measurements needed

Not a new idea: C5F12/N2 mixed for SLD RICH and analysed by sonar (1988➔)



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Nuclear Instruments and Methods in Physics Research A264 (1988) 219–234
North-Holland, Amsterdam

A SONAR-BASED TECHNIQUE FOR THE RATIOMETRIC DETERMINATION OF BINARY GAS MIXTURES *

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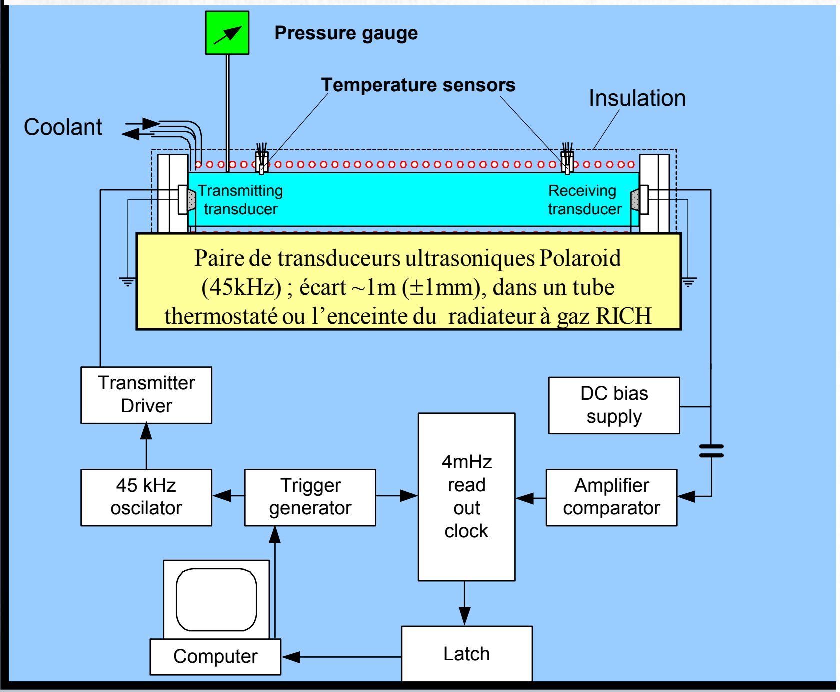
Received 25 March 1987

We have developed an inexpensive sonar-based instrument to provide a routine on-line monitor of the composition and stability of several gas mixtures having application in a Cherenkov Ring Imaging Detector. The instrument is capable of detecting small (<1%) fluctuations in the relative concentration of the constituent gases and, in contrast with some other gas analysis techniques, lends itself well to complete automation.



Paire de transducteurs ultrasoniques Polaroid (45kHz) ; écart ~1m (±1mm), dans un tube thermostaté ou l'enceinte du radiateur à gaz RICH

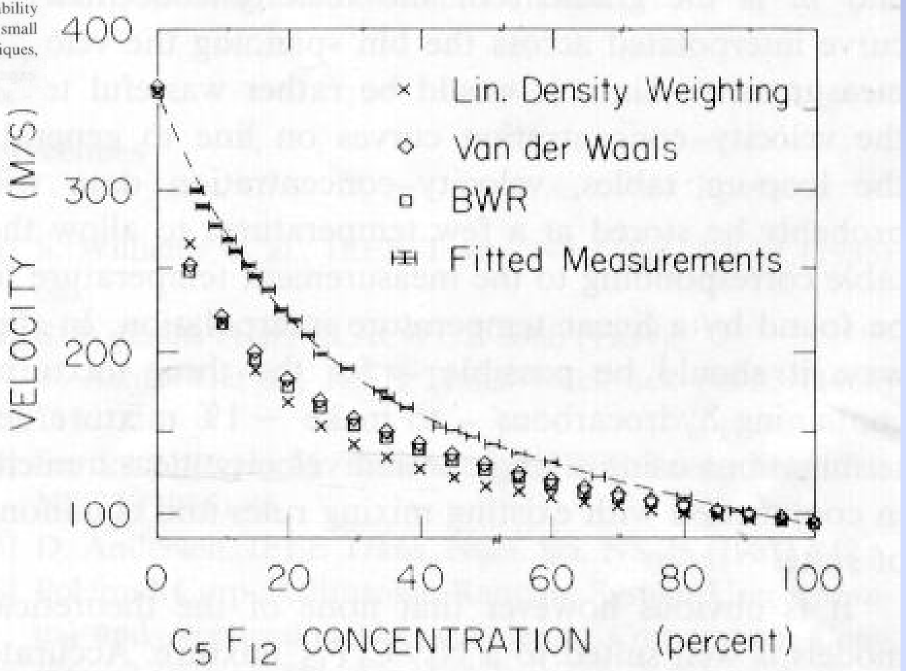
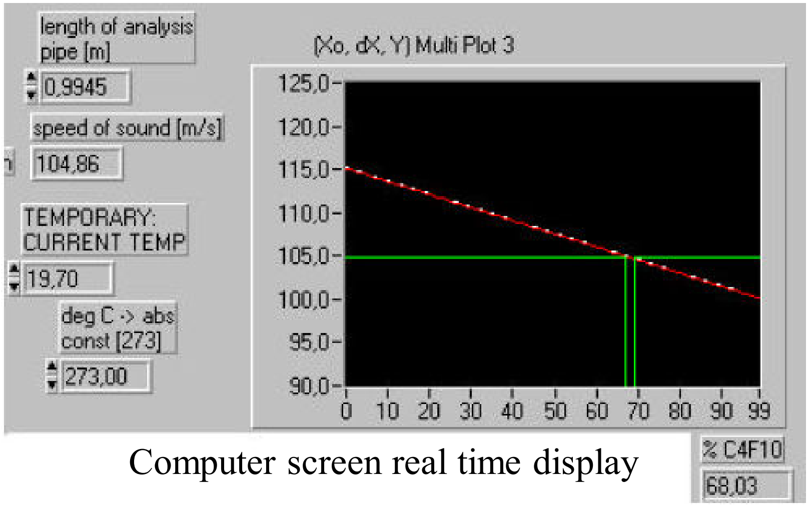


Fig. 16. Variation of sound velocity with concentration of C_5F_{12} in N_2 at 41°C: comparison between fitted measurements and predictions.



length of analysis pipe [m]: 0,9945

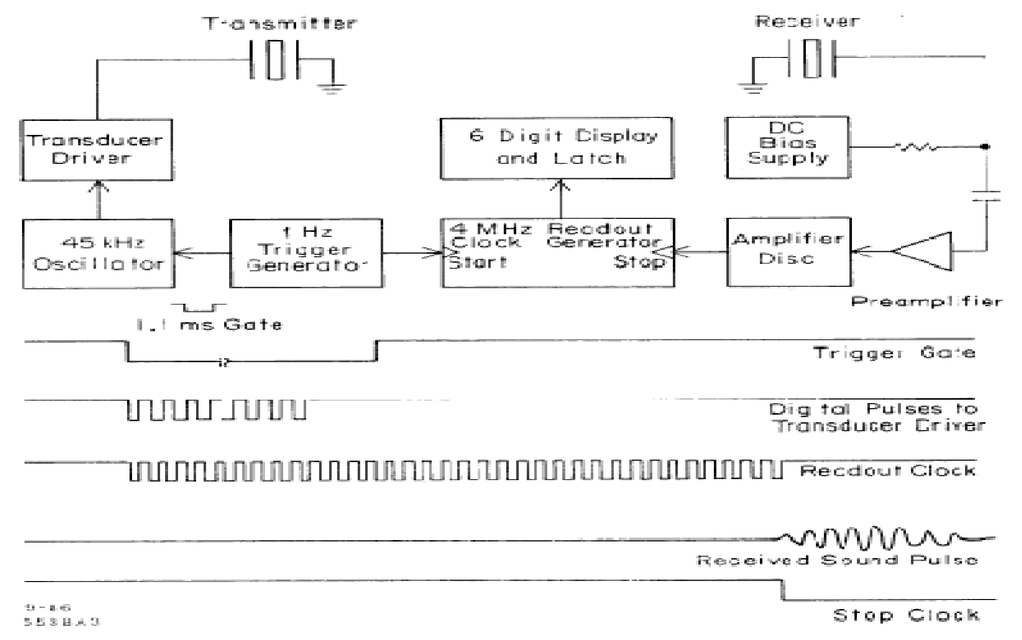
speed of sound [m/s]: 104,86

TEMPORARY: CURRENT TEMP: 19,70

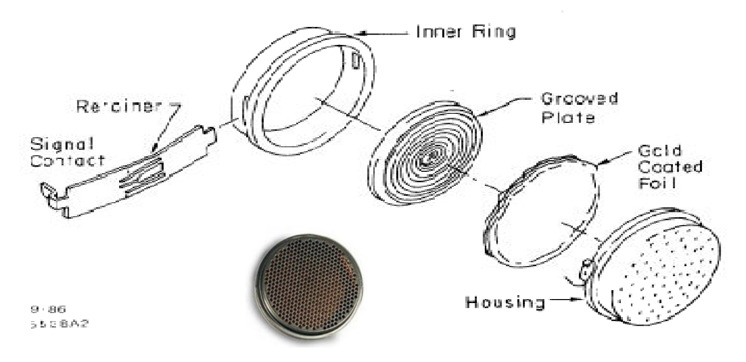
deg C -> abs const [273]: 273,00

% C4F10: 68,03

Computer screen real time display



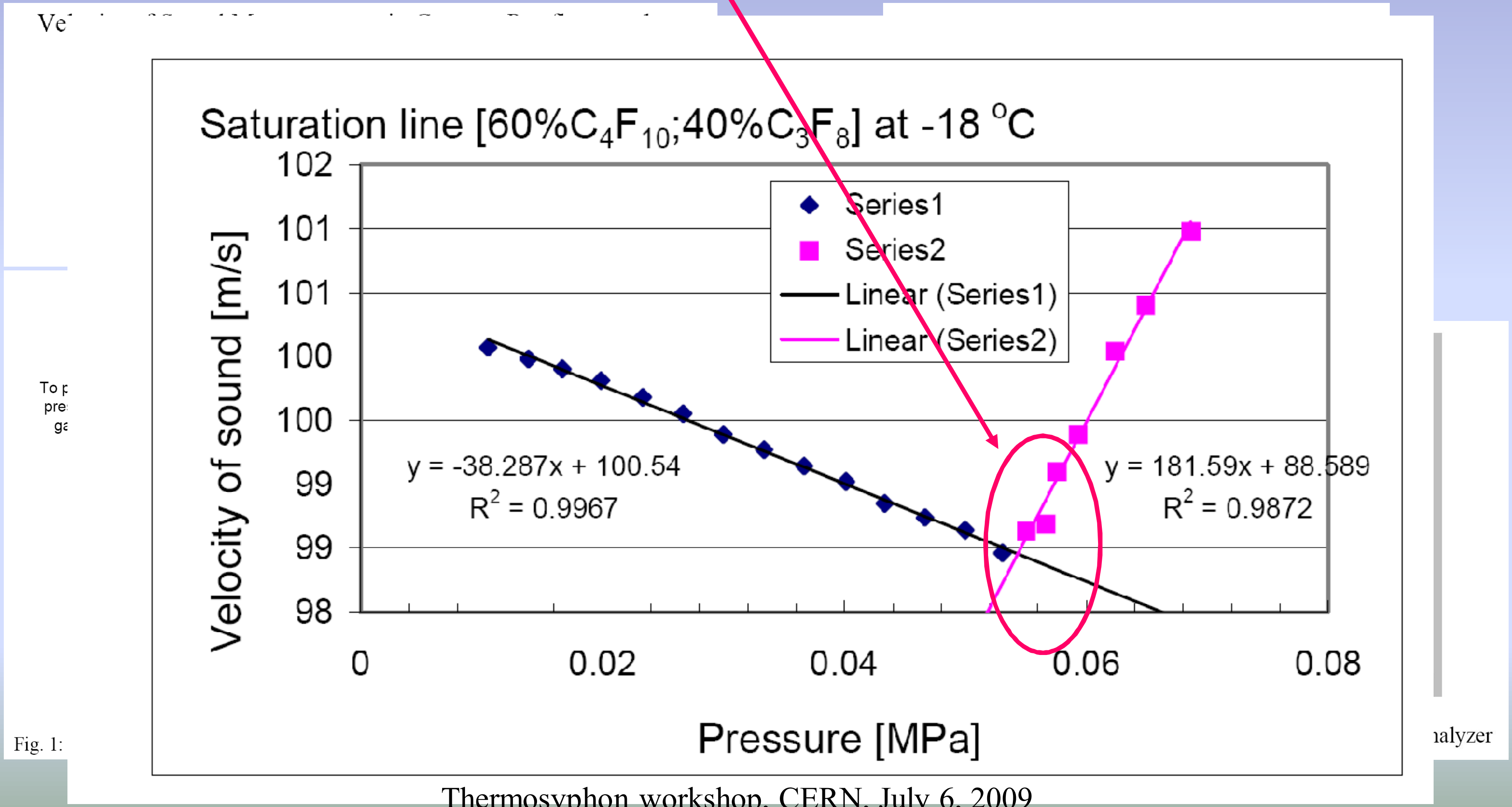
Polaroid camera
ultrasonic transducer



Real time ultrasonic Gas Analyzer

Demonstatration (measurement) of differential condensation of the heavier component with increasing pressure:

- Test of NIST database prediction (~ 2%):
- Sound velocity increases once C_4F_{10} concentration in superheated phase starts to decrease (@ saturated liquid line)



C_2F_6 / C_3F_8 Fluorocarbon Blending

- **Thermodynamic cycle calculations on good theoretical basis (Vacek, Prague)**
- **Have ideas on how to mix small samples and measure mixture by ultrasound but these need more work**
- **Extensive HTC measurements will be needed in trial blends of C_2F_6/C_3F_8 @ realistic power loads and evaporation temps -25°C → -45°C (IBL?)**