Daya Bay Reactor Antineutrino Experiment
Resistive Plate Chamber Gas System
Final Design Review

(IHEP, April 11, 2008)

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Overview

- System Requirements
- Proposed Solution
- Budgets, Schedules, and Amendments to the RLS

System Requirements

Provide a system to mix and distribute gas to the three resistive plate chamber (RPC) systems, one in each of the Daya Bay Near Hall, the Ling Ao Near Hall and the Far Hall.

The gas mixture is to be nonflammable.

The gas mixture should permit efficient operation of the RPC at the lowest reasonable voltage.

The gas flow rate is to be approximately one chamber volume per day, with the option to purge the RPCs at five volume changes per day.

The gas supply bottles are to be stored in a designated room in the experimental halls, with monitors for oxygen quality and for flammable gas hazard.

The exhaust gas is to be added to the output stream of the experimental hall ventilation system.

The ambient humidity in the experimental halls should be no more than 60%.

RPC Array Parameters

Individual RPCs are 1 x 2 m^2 with a single gap, and one readout coordinate (x or y).

8 RPCs are grouped into a mechanical module, 2 $\times$ 2 m^2, with 4 layers (gaps).

Each of these modules has 2 input and 2 output gas connections.

The gas system is organized into "branches" and "sub-branches", where one sub-branch $\Rightarrow$ single external input gas connection

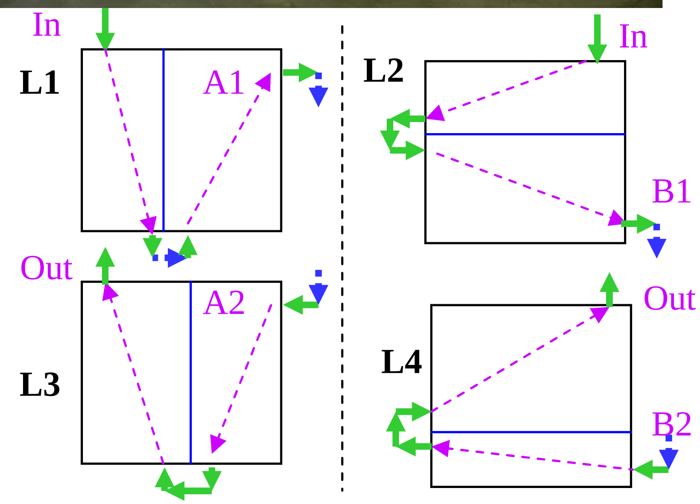
(*i.e.*, 1 sub-branch = 4 RPCs = 1./2 module);

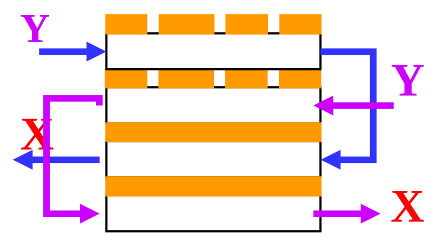
16 sub-branches are combined into 1 branch.

The Near Halls each have RPC arrays 12 $\times$ 18 m^2, comprised of 54 modules, 108 gas sub-branches

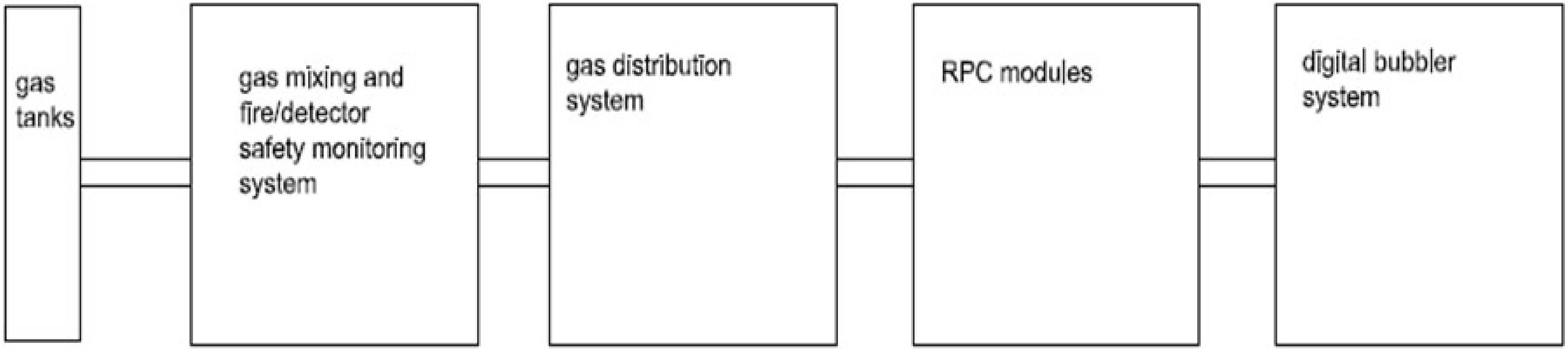
The Far Hall has an RPC array 18 $\times$ 18 m^2, comprised of 81 modules, 162 gas sub-branches.

The chamber volume per sub-branch is 0.016 m^3, $\Rightarrow$ Total gas volume of entire system ~ 6 m^3.





Overview of the Proposed RPC Gas System



The RPC gas system has five major components:

- The gas storage bottles, including the bottle changeover system
- The gas mixing and fire/detector safety monitoring system
- The gas distribution system
- The RPCs
- The gas exhaust system, including the output bubbler system.

The hazardous gas safety system. but not the ODH system, is part of the RPC gas system scope.

Proposed Gas Mixture

The baseline gas mixture is Ar/R134a/Isobutane/SF_6 (75.5/20/4/0.5 volume ratios), as used in the OPERA experiment.

In addition, 0.4% of water vapor will be added to reduce aging of the bakelite RPCs.

Isobutane gas mixtures are nonflammable if the isobutane fraction is lower than certain limit.

75% argon $\Rightarrow$ low operating voltage, but need UV quenching.

R134A = $C_2H_2F_4$ and SF_6 provide the quenching.

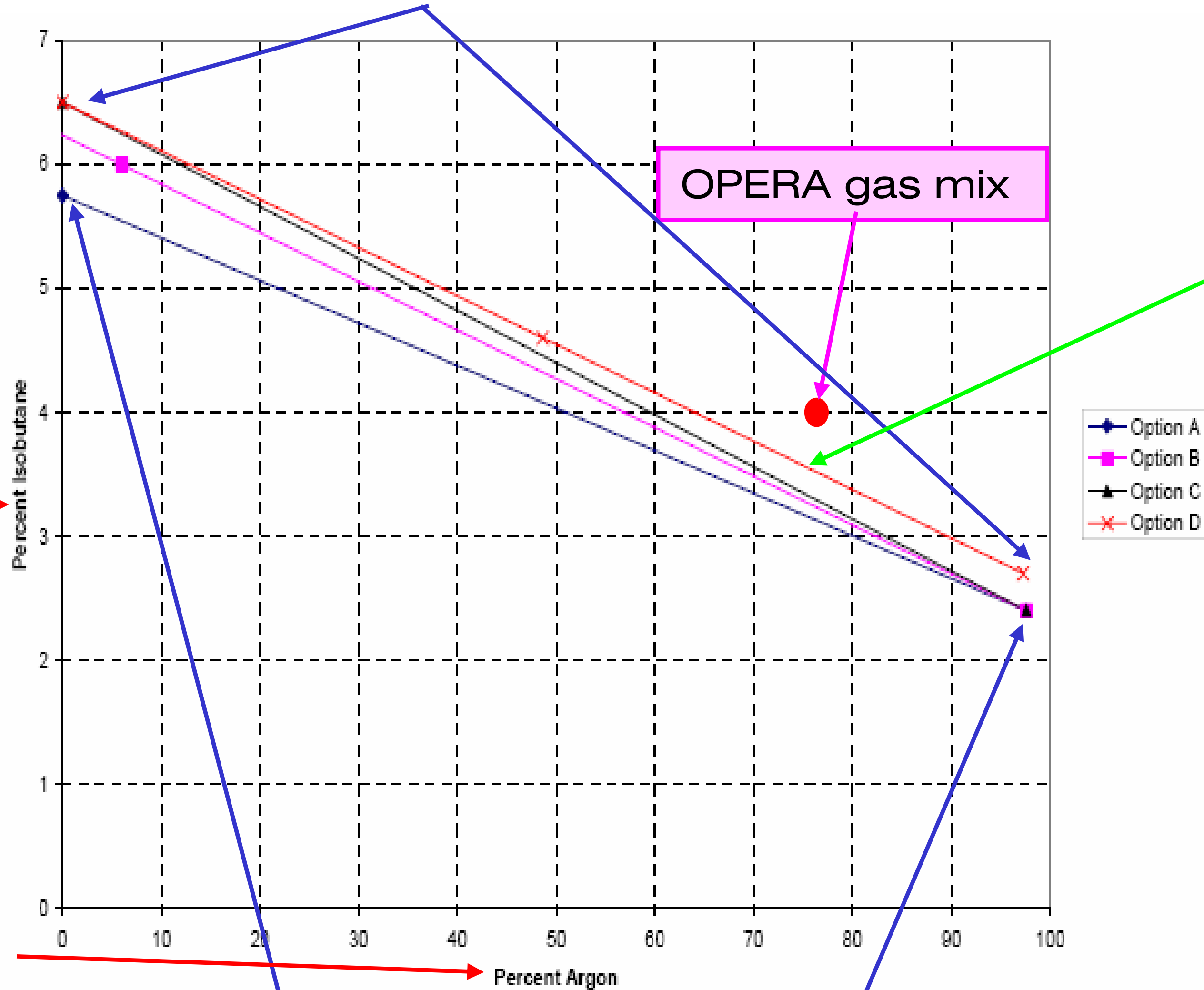
The global-warming-potential index of the OPERA gas mixture is smaller than that of the BaBar mixture (35% R134A) and comparable to that of the Belle mixture (30% R134A).

OPERA has used this mixture at Gran Sasso for several years, which supports the use of 4% isobutane.

Proposed Gas Mixture – Flammability Issue

Multiply by 1.14 to extrapolate CEN's TCi to US flammability.

% of C_4H_{10} in Freon/C_4H_{10} mix

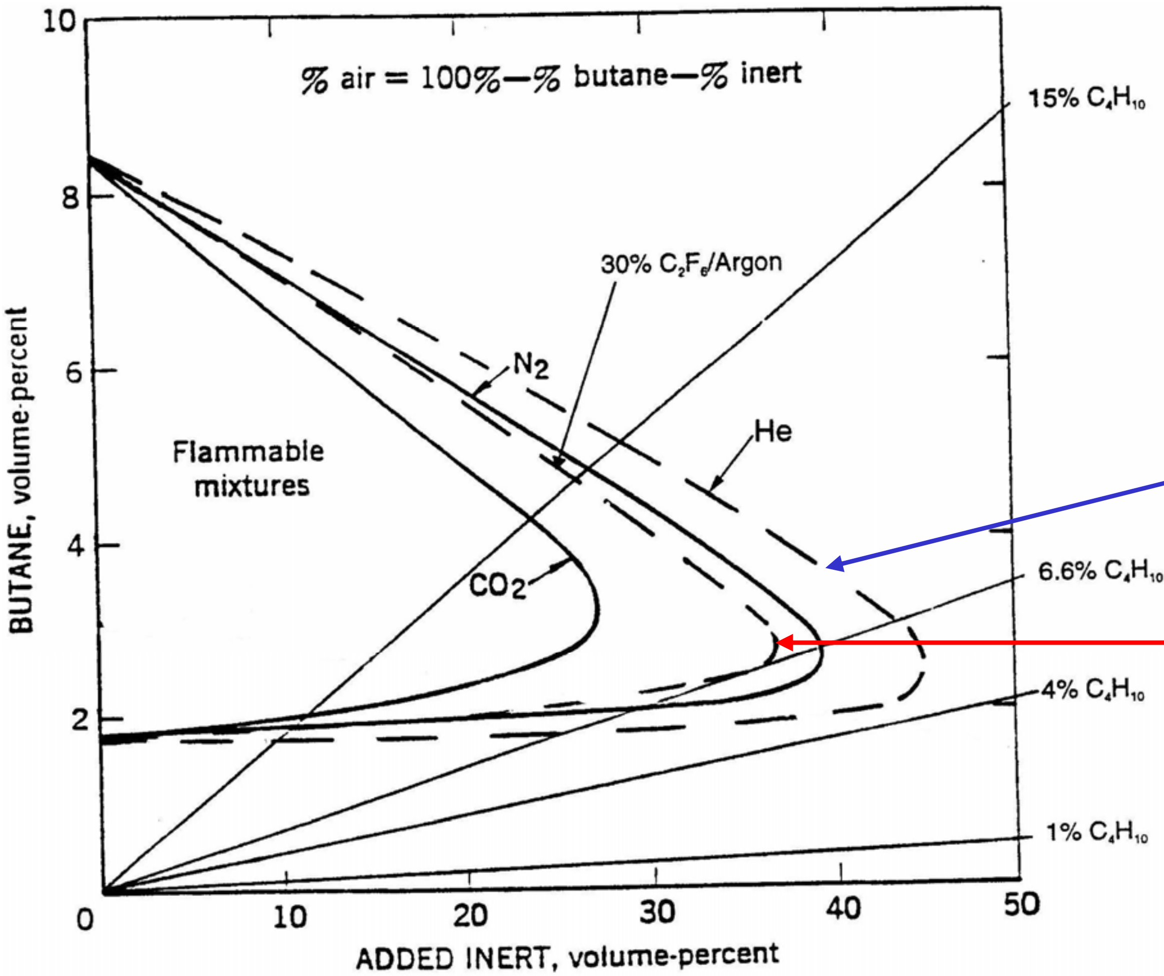


In the most conservative assessment we should reduce isobutane to 3.5% to get non-flammable gas mixture.

% of Ar in Ar/C_4H_{10} mix

CEN's TCi (iginitability limit) values for the mixes of isobutane in Freon and isobutane in argon.

Proposed Gas Mixture (cont'd)



An alternative argument is based on a flammability study of isobutane mixtures for BaBar that was performed by Hughes Associates.

The region of flammability of mixtures of argon and isobutane is larger than that of helium/isobutane (because of the low thermal conductivity of argon).

However, Freons have large heat capacity, so mixtures with 30% Freon + argon + isobutane have a smaller flammability region than helium/isobutane.

This argues that the OPERA gas mixture is nonflammable, but there is no formal certification of this.

A formal certification could be made by Hughes Associates – for a fee.

Proposed Gas Mixture (cont'd)

Why choose the OPERA gas mixture? - cheaper, "greener", HV lower.

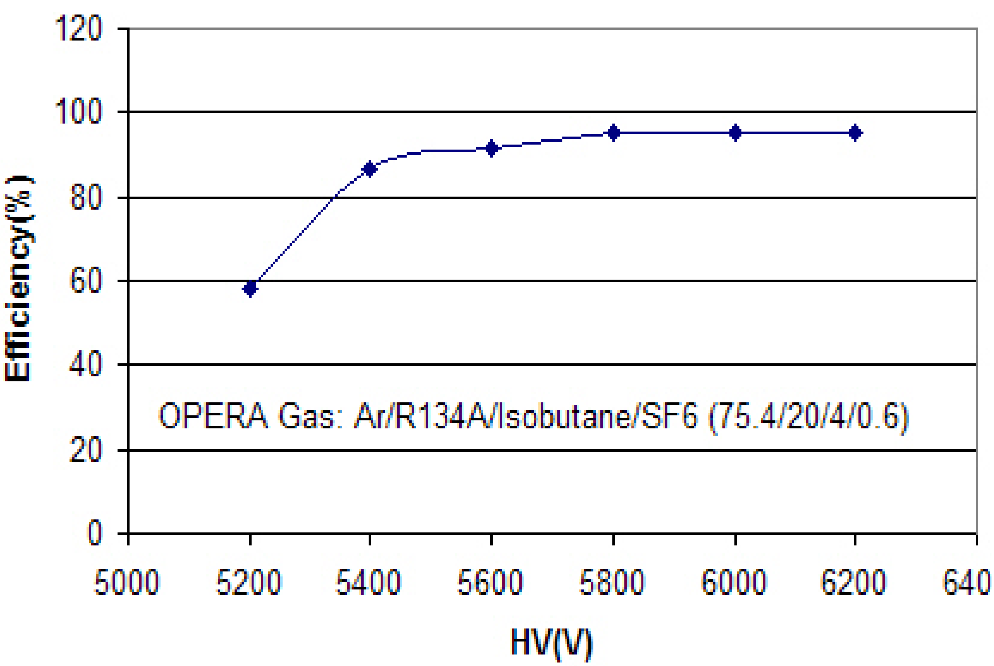
Gas	Weight (LB)	Gas volume (M^3)	Price ($)	% in mix	Cost/day ($)	Cost/year ($)	GWP index	Gas mix GWP
OPERA								
Ar		9.40	72.6	75.5	36.5		1	
R134A	30	2.99	214.5	20	89.8		1300	
Isobutane	17	2.97	145	4	12.2		1	
SF6	35	2.44	366.57	0.5	4.7		22200	
					143.2	52278.7		371.8
BESIII								
Ar		9.40	72.6	50	24.2		1	
R134A	30	2.99	214.5	42	188.6		1300	
Isobutane	17	2.97	145	8	24.4		1	
					237.2	86574.9		546.6
BaBar								
Ar		9.40	72.6	60.6	29.3		1	
R134A	30	2.99	214.5	34.9	156.7		1300	
Isobutane	17	2.97	145	4.5	13.7		1	
					199.8	72909.8		454.4

OPERA gas costs ~ 60% of BESIII, and 72% of BaBar,
OPERA gas Global Warming Potential ~ 68% of BESIII, and 82% of BaBar.

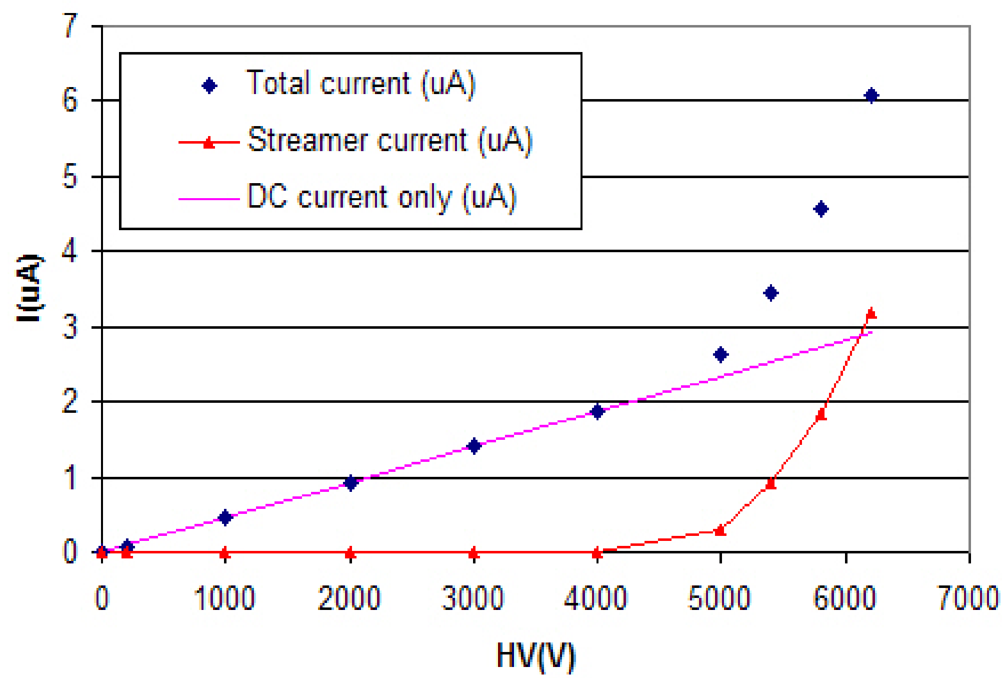
Tests of the OPERA Gas Mixture with IHEP RPC's

OPERA RPC gas mixture: Ar/R134A/Isobutane/SF_6 (75.4/20/4/0.6)

Efficiency plateau curve:



Dark current:



Low HV required: plateau starts at 5400V! Also good plateau length!

How Much Gas Should Be Stored Underground?

Tradeoff between frequency of transport/changeover of bottles *vs.* degree of oxygen deficiency hazard and flammable gas hazard from leaks at bottles.

In the USA, isobutane is available in only two cylinder sizes: 116 lb @ $400, and 17 lb @$145; ⇒ unit price almost 2.5 times higher in the smaller cylinder.

Use of 116 LB cylinders can reduce the gas cost from $52k/year to $48k/year.

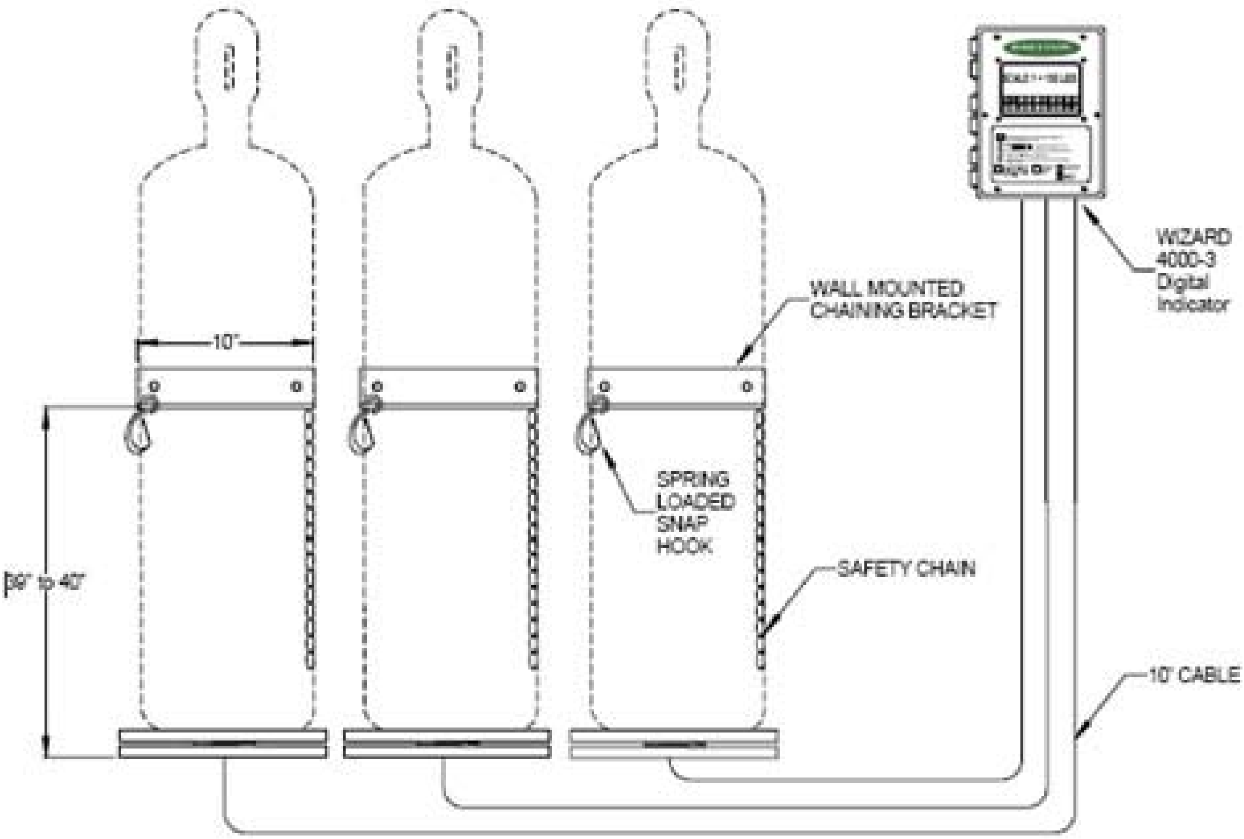
In addition to bottles in use, a second set of bottles should be underground at all times.

In the following configuration, 54 bottles are stored underground.

Exp. Hall	Gas	Cylinder	Days/90% of cylinder used
Near Hall	Ar	6 #300 cyl. @2400psi	35
	R134A	90 lb	24
	Isobutane	17 lb	37
	SF_6	35 lb	243
Far hall	Ar	6 #300 cyl. @2400psi	22
	R134A	90 lb	15
	Isobutane	17 lb	23
	SF_6	35 lb	150

Gas Cylinders

In the RPC gas mixture, the other three gases besides argon actually are in the liquid phase.
We will use their vapors.
The saturated vapor pressure in these cylinders won't change until the last bit of liquid has vaporized
⇒ Monitoring the pressure is not enough.
We have to know how much liquid is left in the tank.

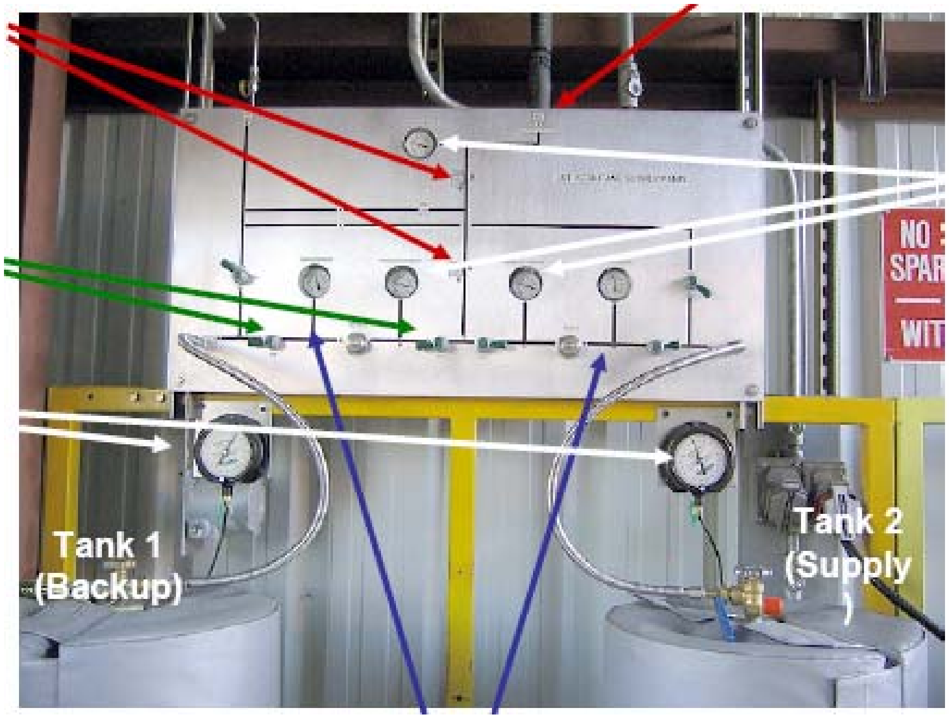


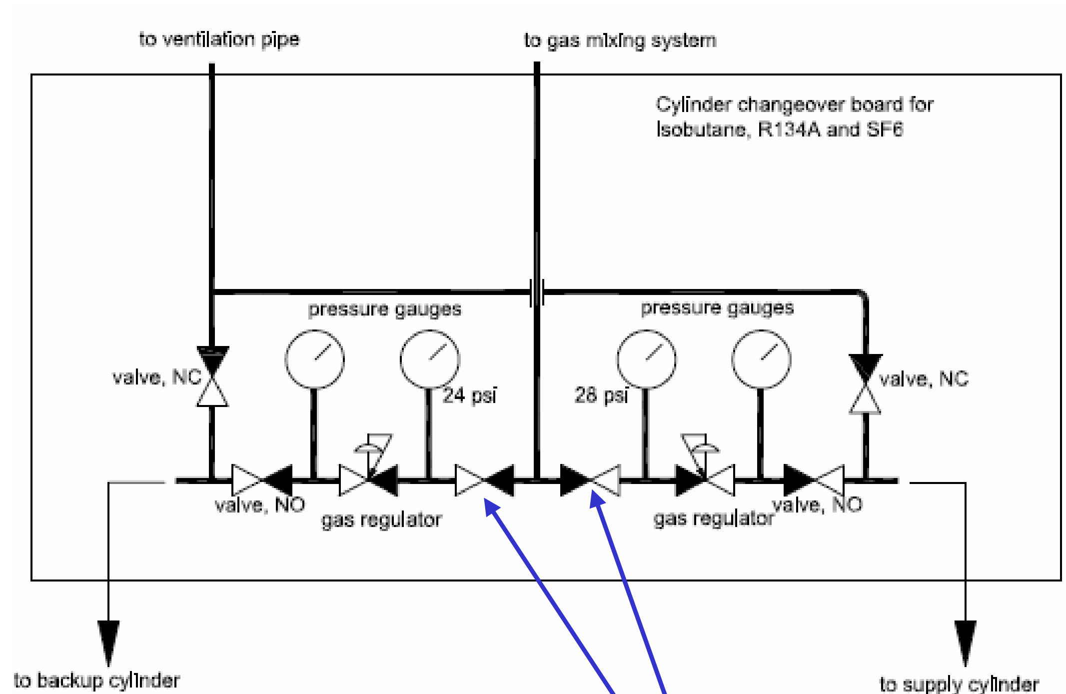
A Force Flow model WR200-3HA electric scale will be used to weigh the cylinders.

Automated changeover of the depleted cylinder when the weight drops below the preset limit.

Gas Cylinder Changeover Panel

To avoid interruption of the gas flow during replacement of depleted gas cylinders, each gas supply line has a changeover panel.





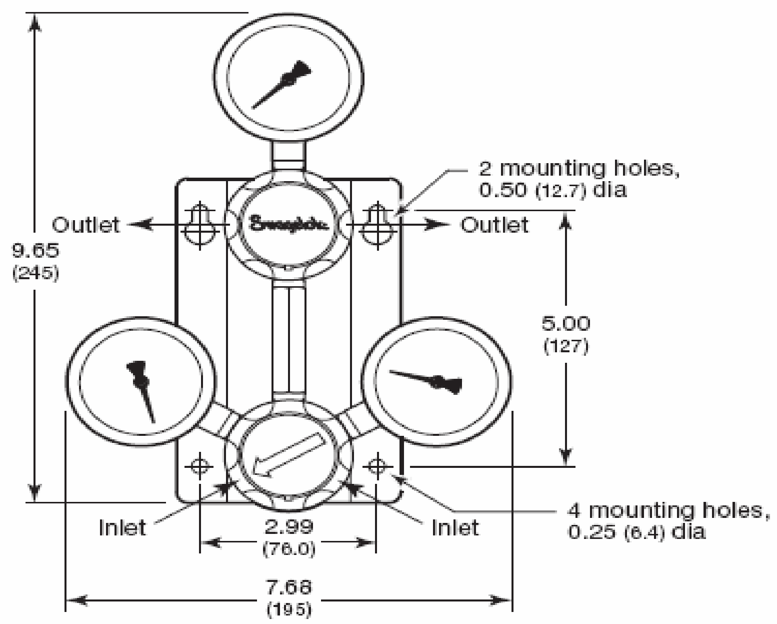
For Isobutane, R134A and SF6.

These two valves are solenoid valves, controlled by the electronic monitor of the cylinder weights.

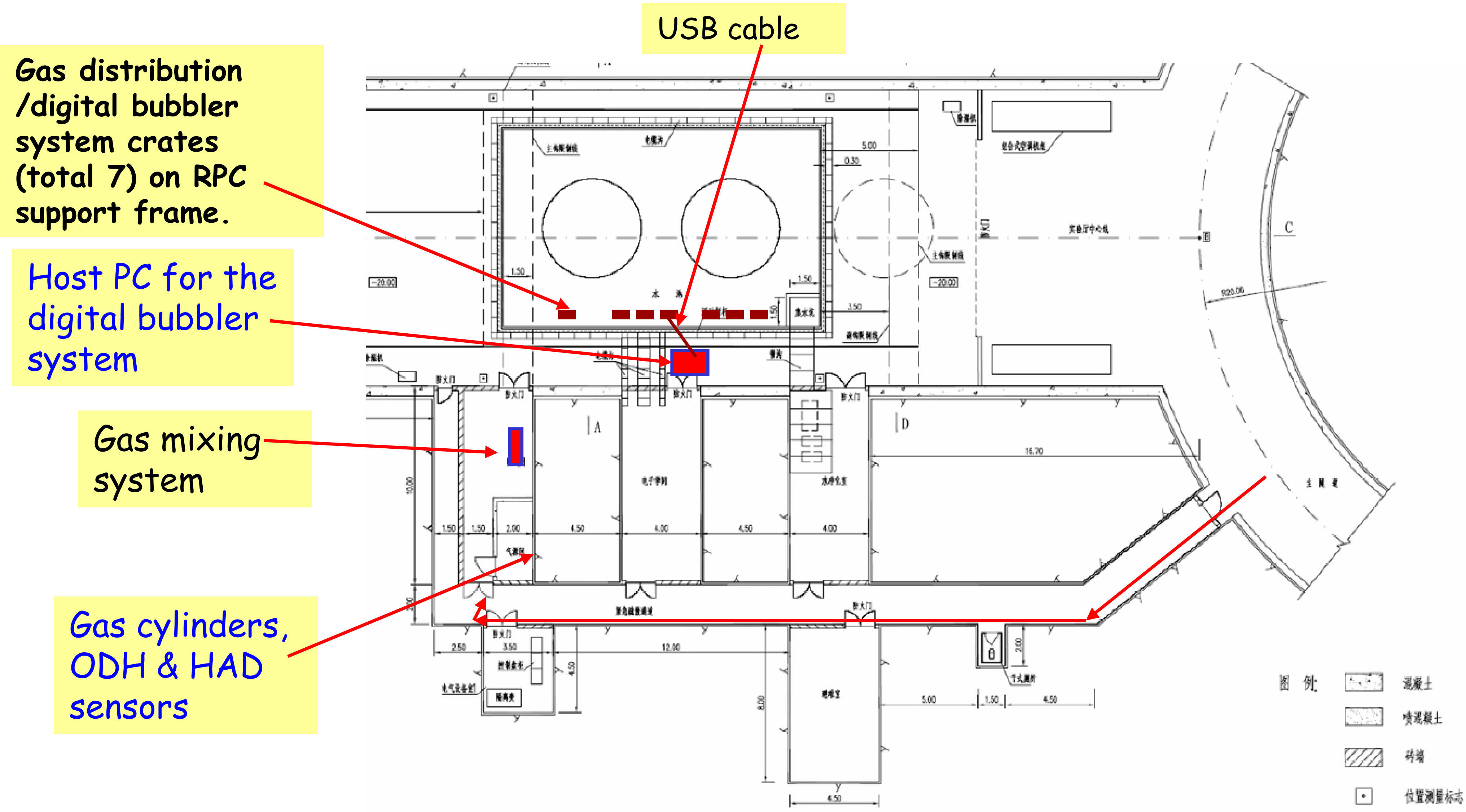
Gas Cylinder Changeover Panel (cont'd)

For argon cylinders this changeover can be done automatically with a commercial changeover regulator (+venting pipe/valves for each 6-pack cylinder farm).

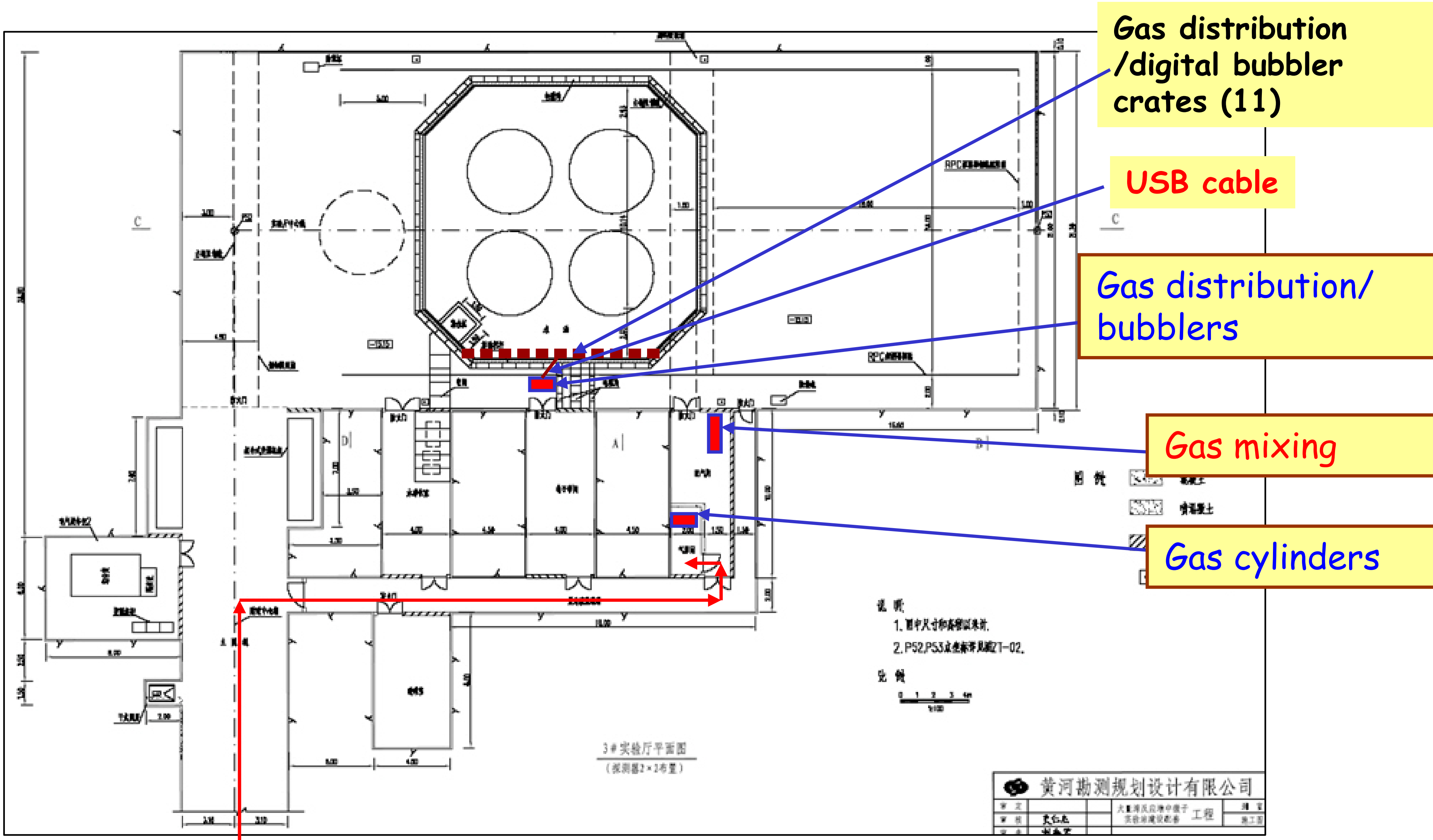
When the pressure of supply side drops to pre-selected changeover pressure, this regulator will automatically switch to the other side of cylinder farm..



Location of the Gas System in the Daya Bay Near Hall (#1)



Location of the Gas System in the Far Hall (#3)



Suggested Ventilation of the Gas Storage/Mixing Rooms

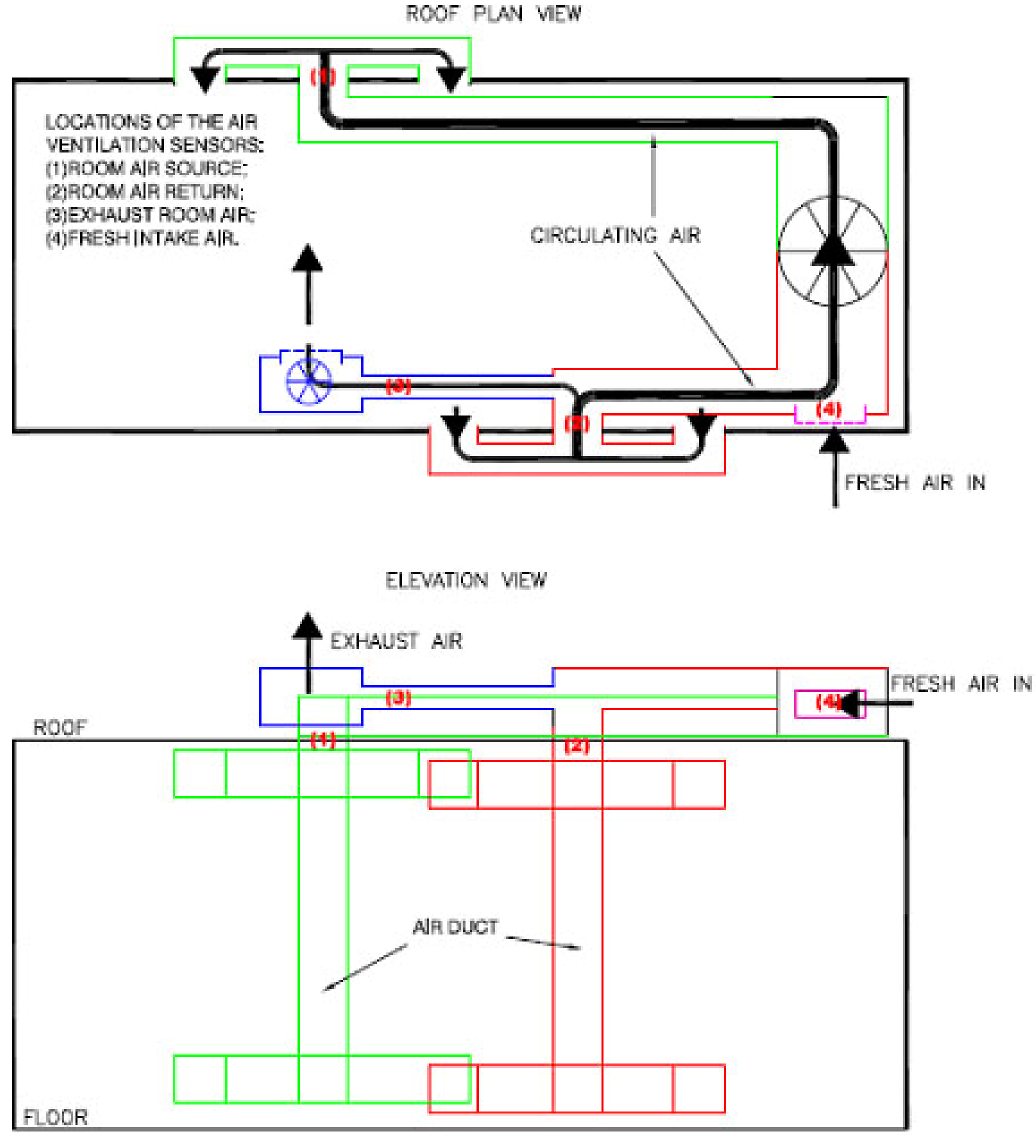
Exhaust of air from the gas storage/mixing rooms should be directly into the exhaust line of the experimental hall ventilation system.

The ventilation system should include 4 air flow sensors: (1) room air source;
(2) room air return;
(3) exhaust room air;
(4) fresh intake air.

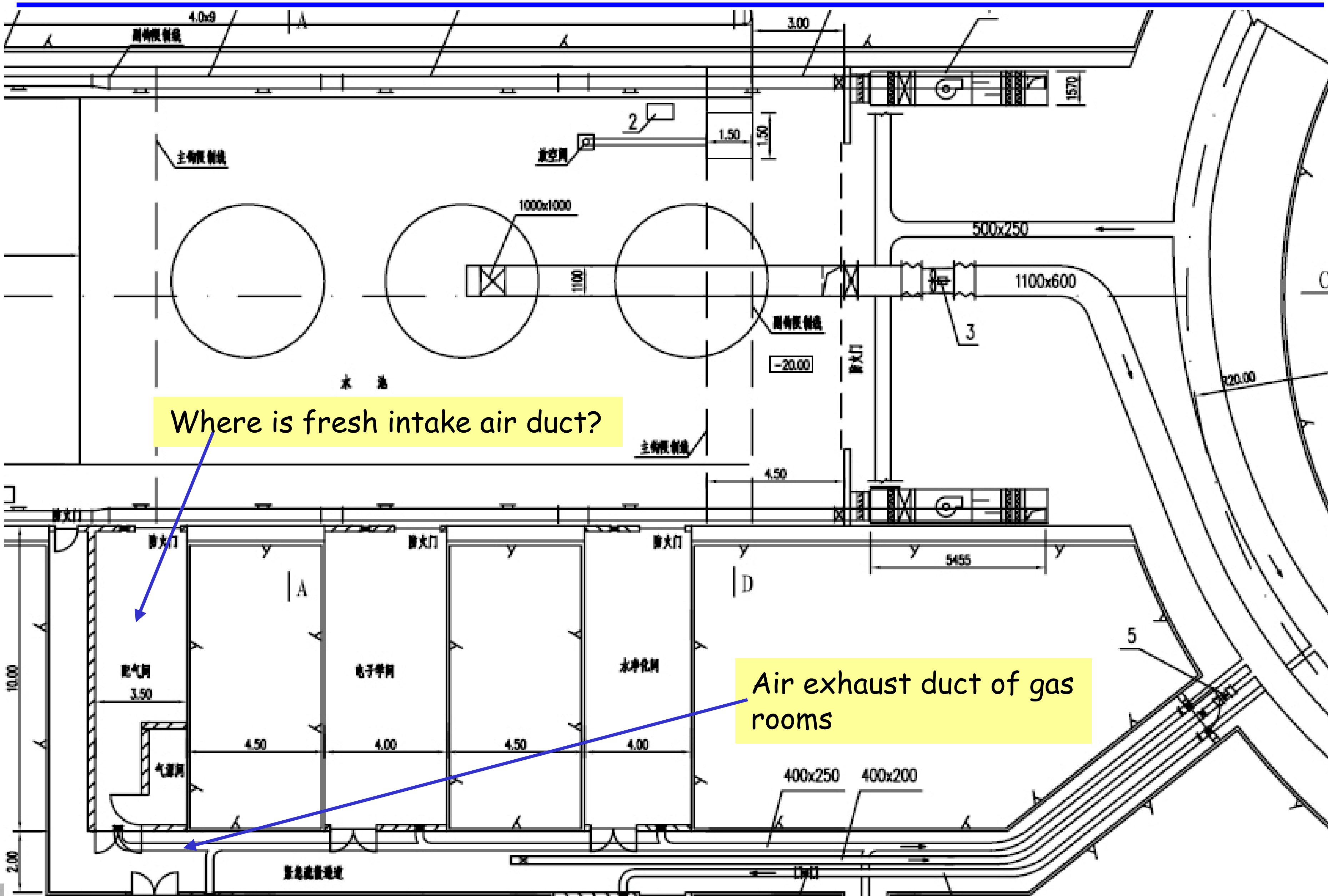
We will provide the sensors (and interface to the gas system status crate).

IHEP is responsible for design, procurement and installation of ventilation ductwork.

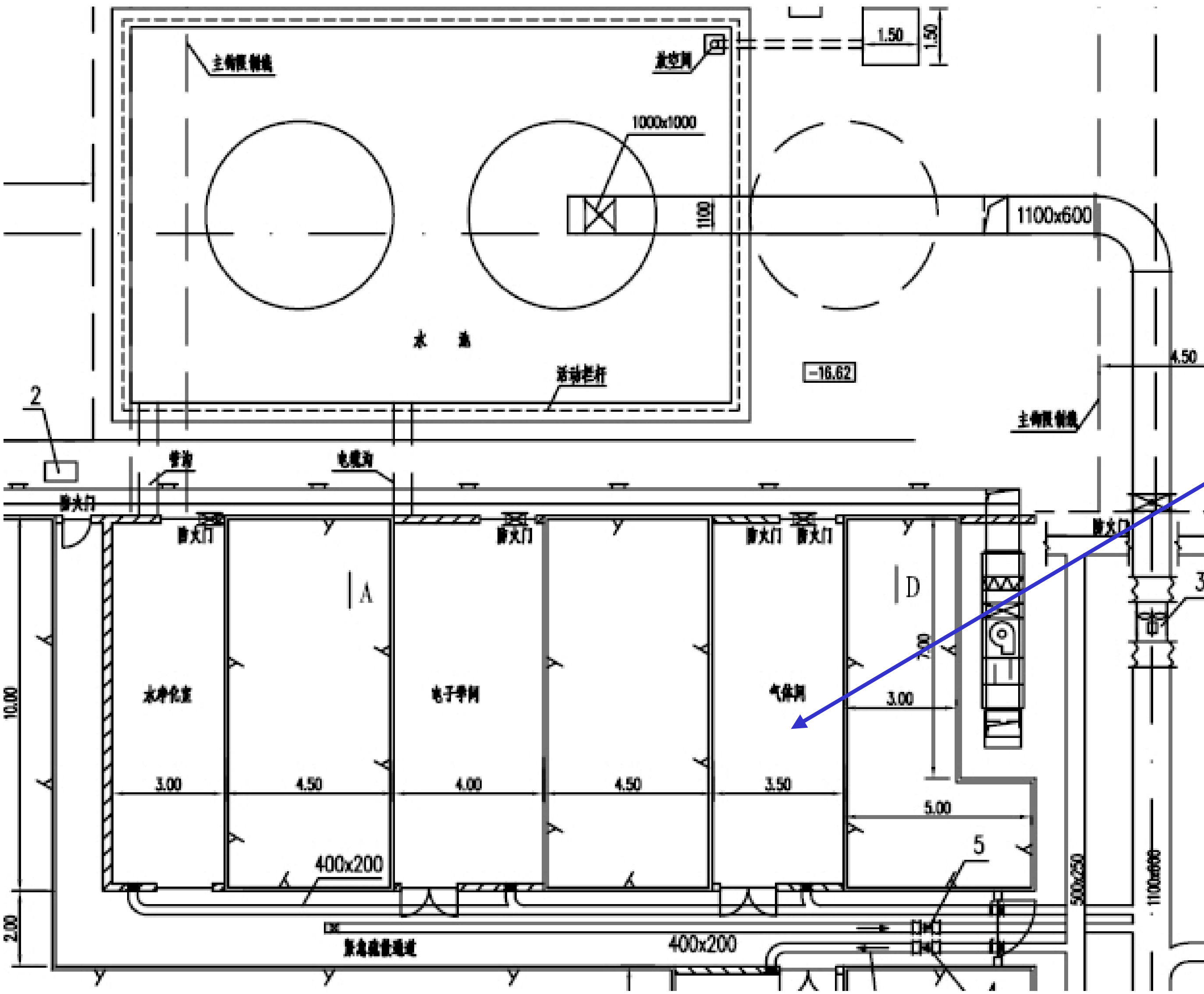
Example: BaBar ventilation system



Ventilation system in the halls – Hall #1

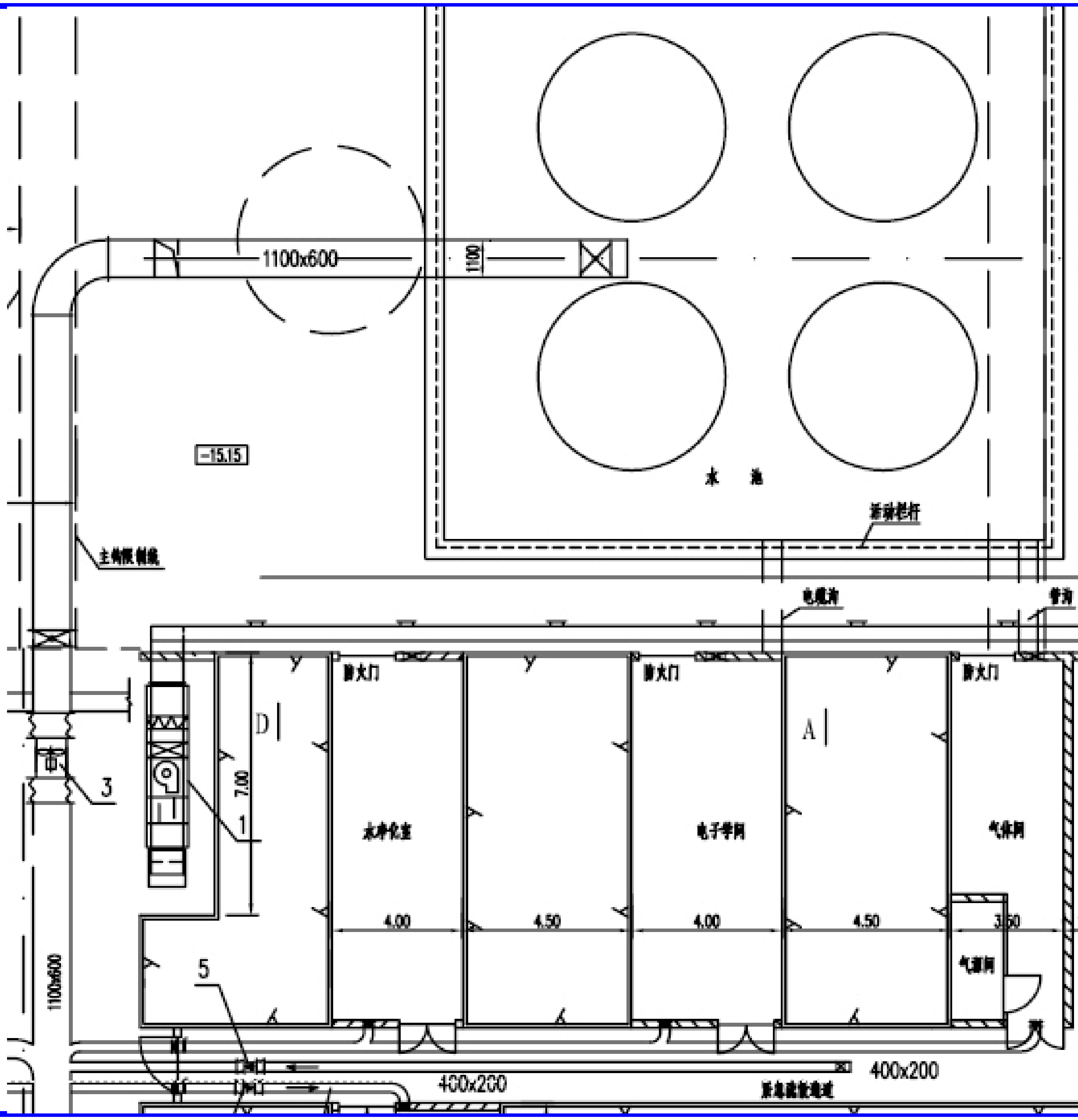


Ventilation system in the halls – Hall #2



No gas storage room in the design?

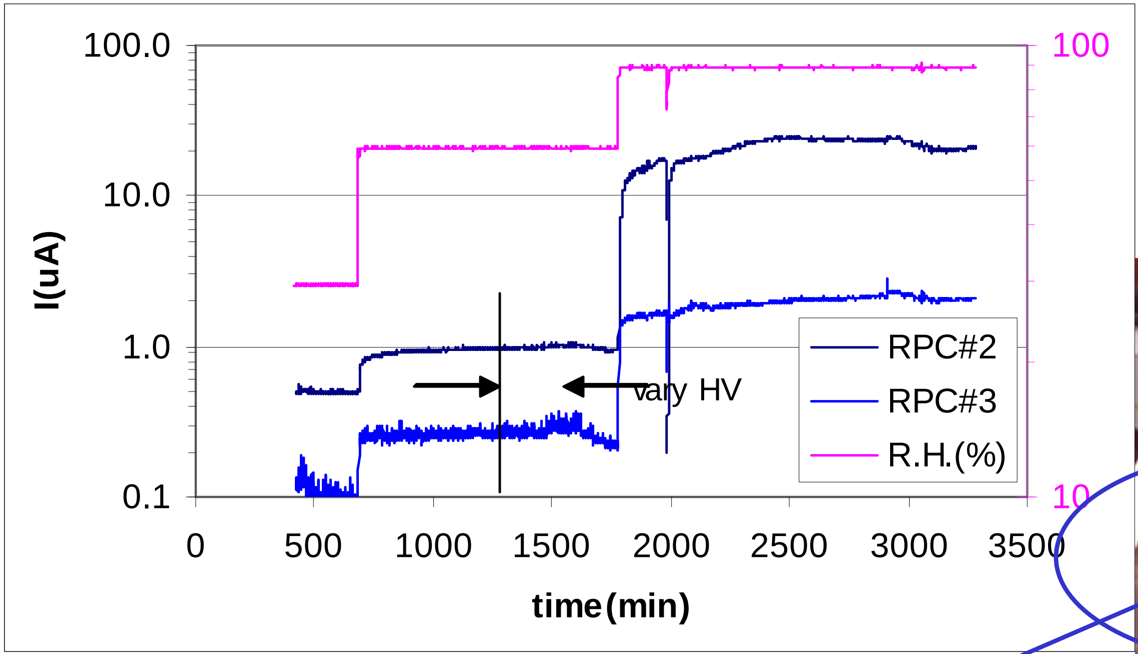
Ventilation system in the halls – Hall #3

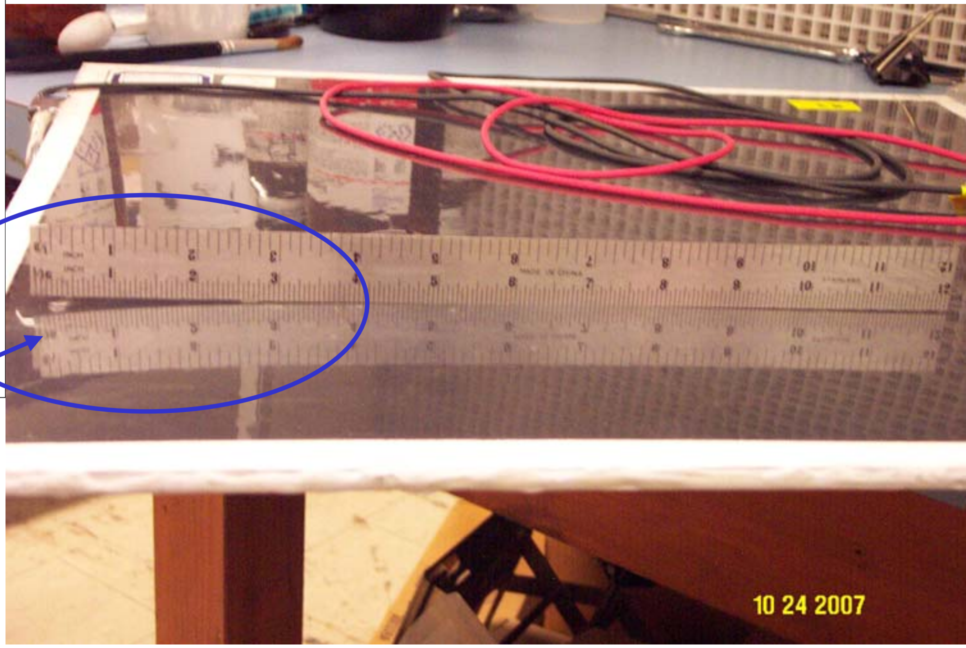


Ambient Humidity Should Be Limited to 60%

The RPC dark current rises rapidly for ambient humidity above 60% (due to leakage currents on the chamber edges).

High humidity results in distortion of the bakelite, possibly leading to failure of the glue joints.





The Bakelite electrode is bulged!

Gas Mixing/Control and Fire Safety Monitoring

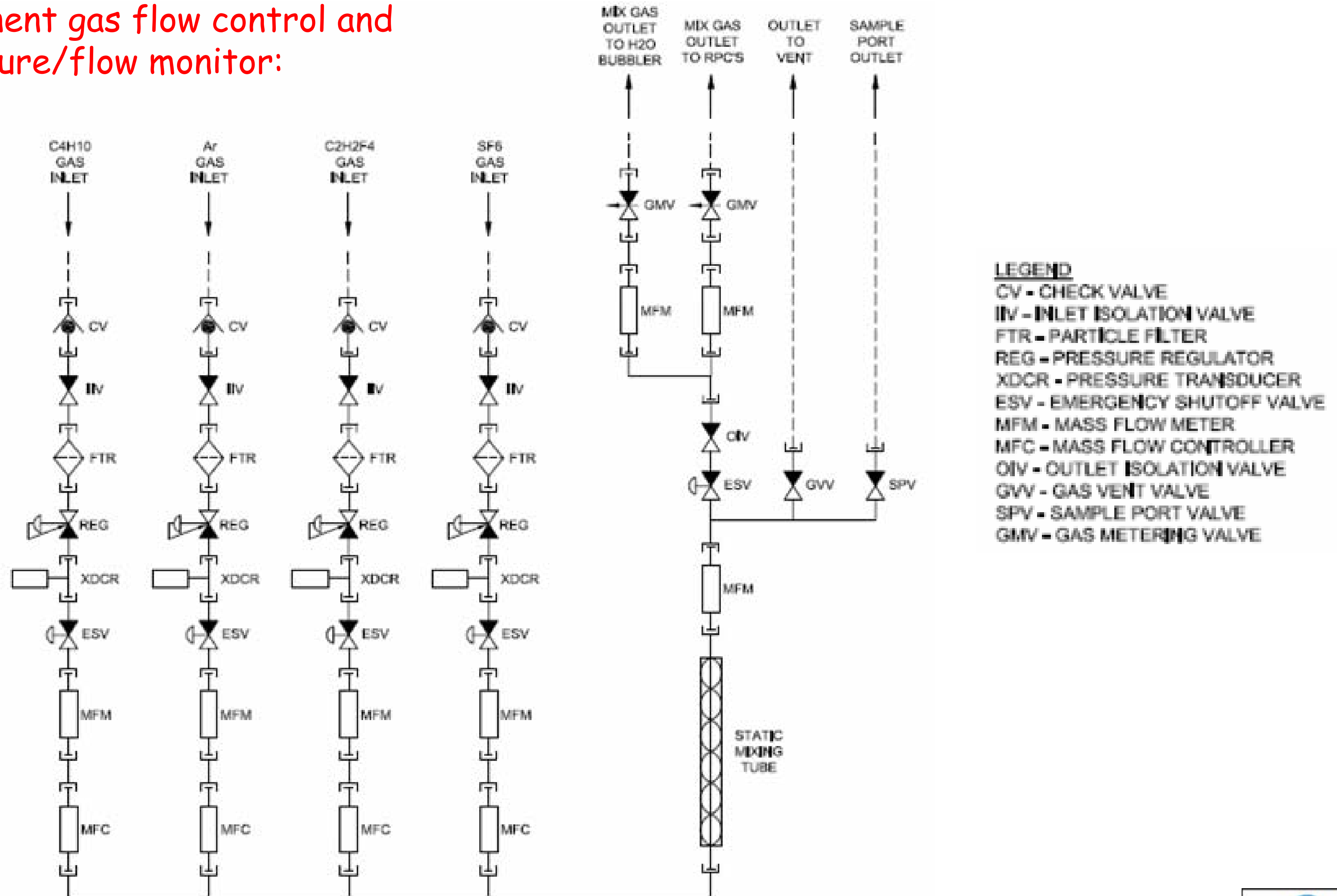
This system consists of

- Gas mixing panel.

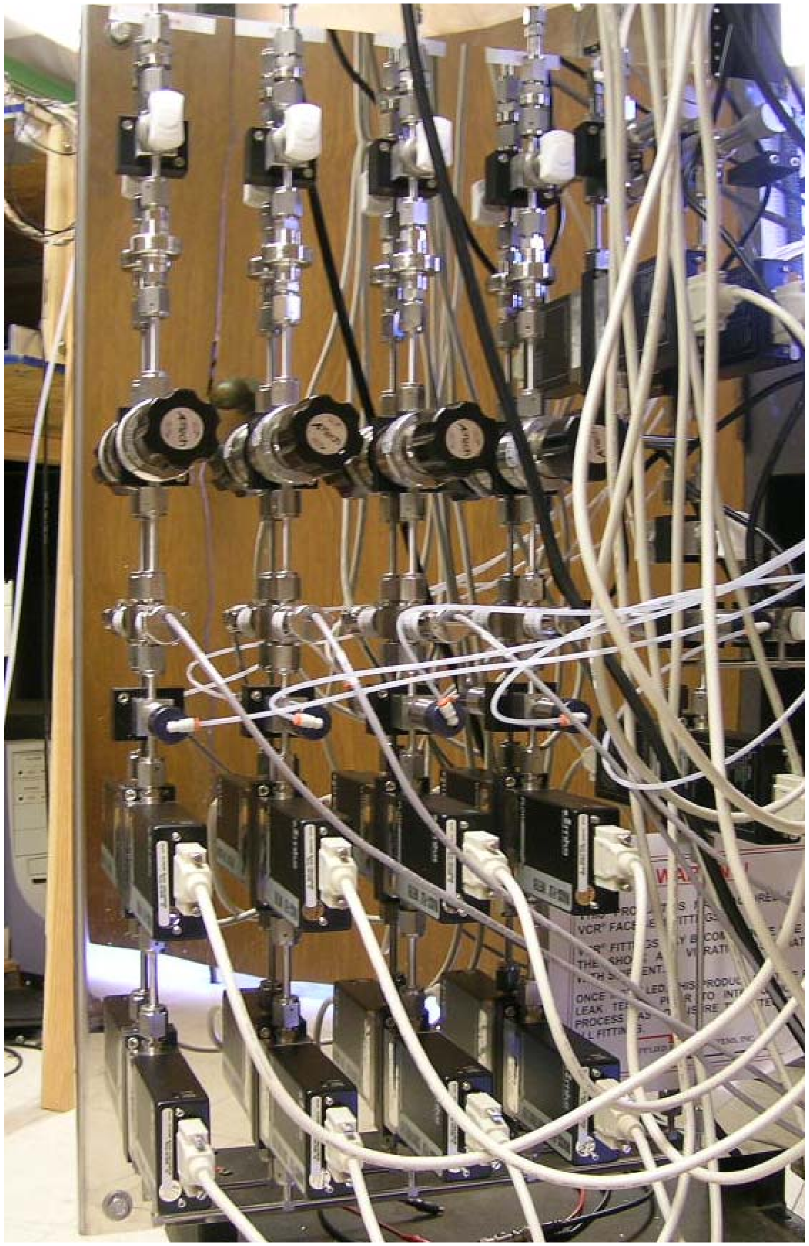
- Four crates:
  System Status crate.,
  Flowmeter crate,
  Pressure crate,
  Power Supply crate.

Gas Mixing Panel

4-component gas flow control and pressure/flow monitor:



Prototype Gas Mixing Panel for RPC QC at IHEP



Applied Energy Systems (AES) fabricated this prototype panel for us.

Main components:

MKS 247D display/power box

Gas filters

Regulators

MKS pressure sensors

Pneumatic valves

MKS flow controllers

MKS flowmeters

Static mixer

Metering/manual valves

Gas Mixing Panel Issues

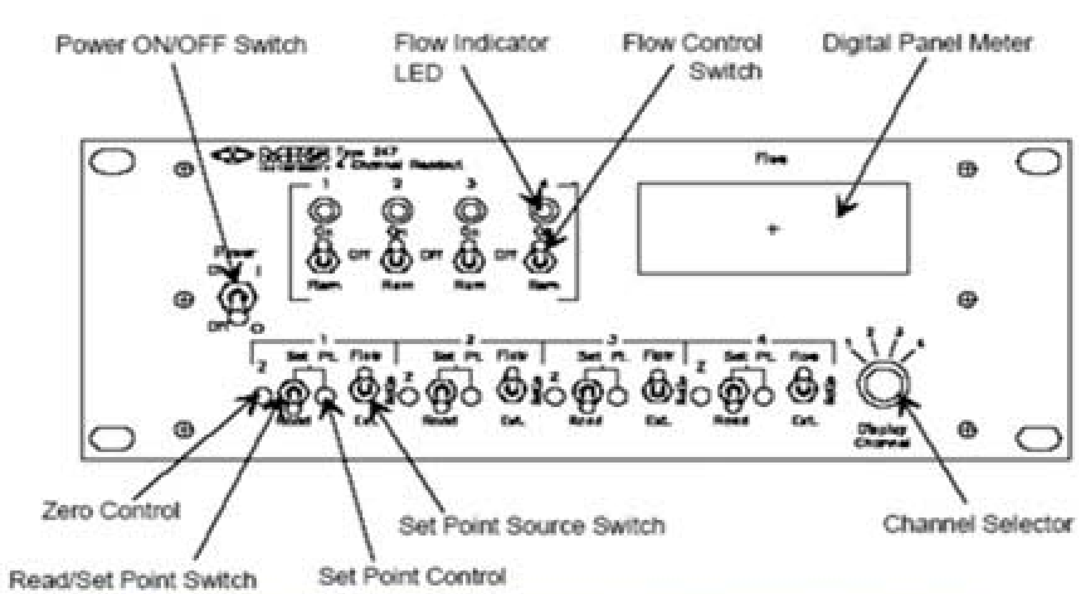
Use of toxic-gas components.

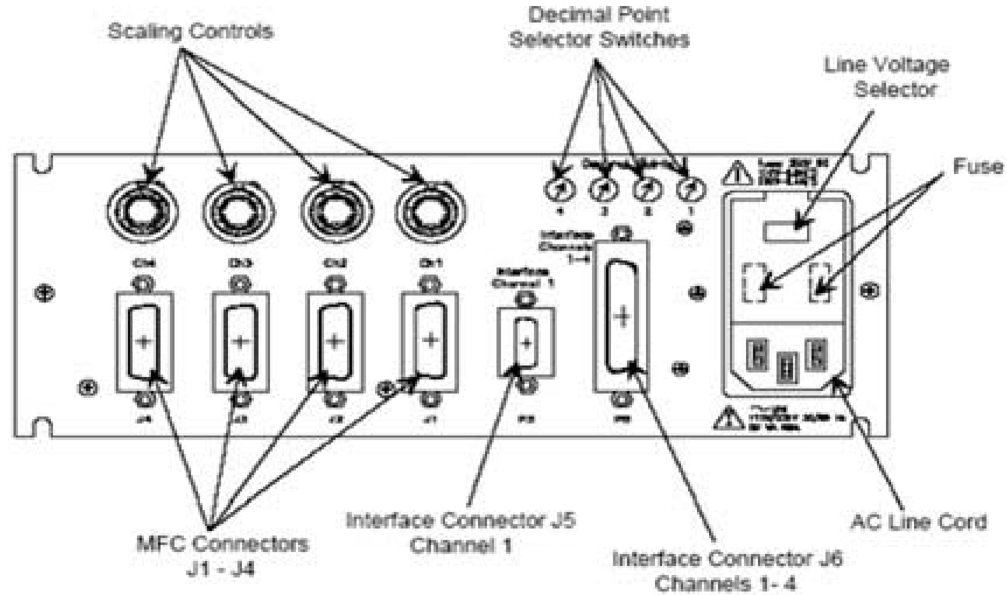
- Somewhat more expensive for all stainless-steel parts.
- Risk of residual toxic gases in commercial gas bottles (BaBar RPC gas system showed some corrosion after several years of use).

Prototype panel flowmeters were sized of use during RPC quality control at IHEP.

- Can replace flowmeters with larger size for use in Far Hall (≈ $10k).
- Prefer to purchase 3 production panels in addition to prototype.
- Prototype was originally agreed to be funded by FY08 R&D funds.

MKS 247D 4-Channel Flow Controller

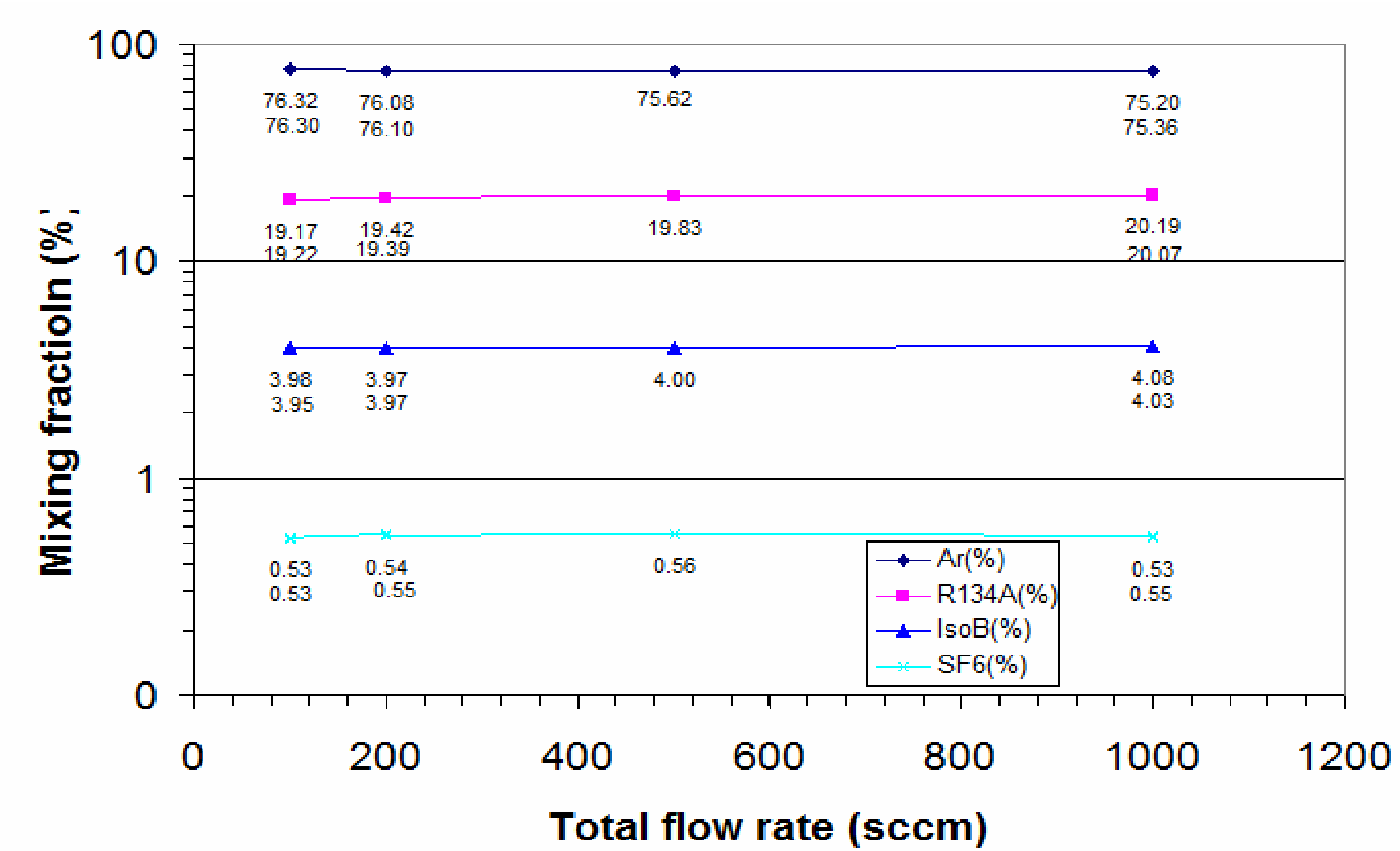




Gas Mixing Panel - Test Results

We tested the gas mixture with a Varian 3900GC Gas Chromatograph system.

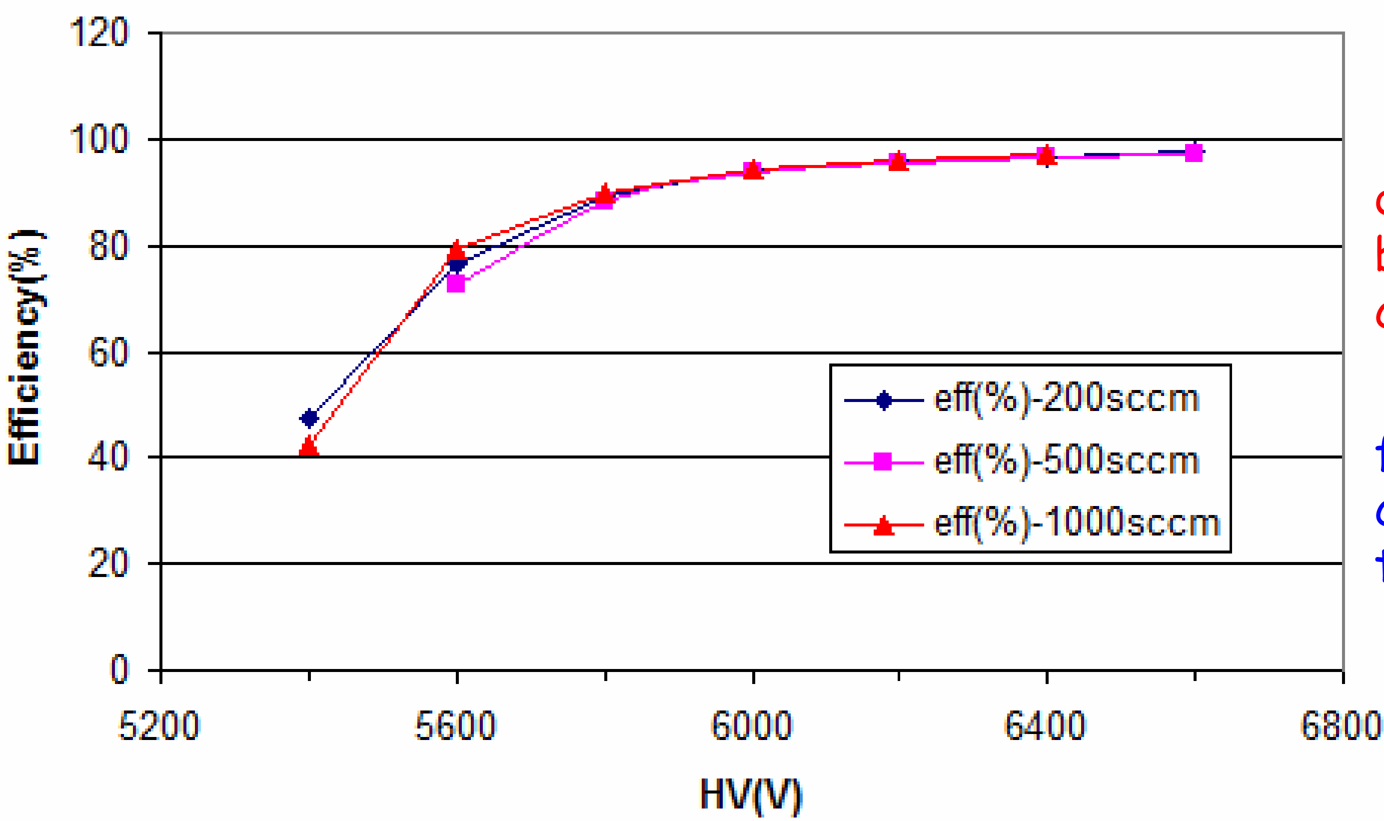
The total flow rate was calibrated at 1000 SCCM, then the mixing ratio was checked at various smaller flow rates.



Gas Mixing Panel - Test Results

We tested the gas mixture with a full size IHEP RPC (1 x 2 m^2).

There was no difference in the efficiency plateau at total flow rates from 200 to 1000 sccm.

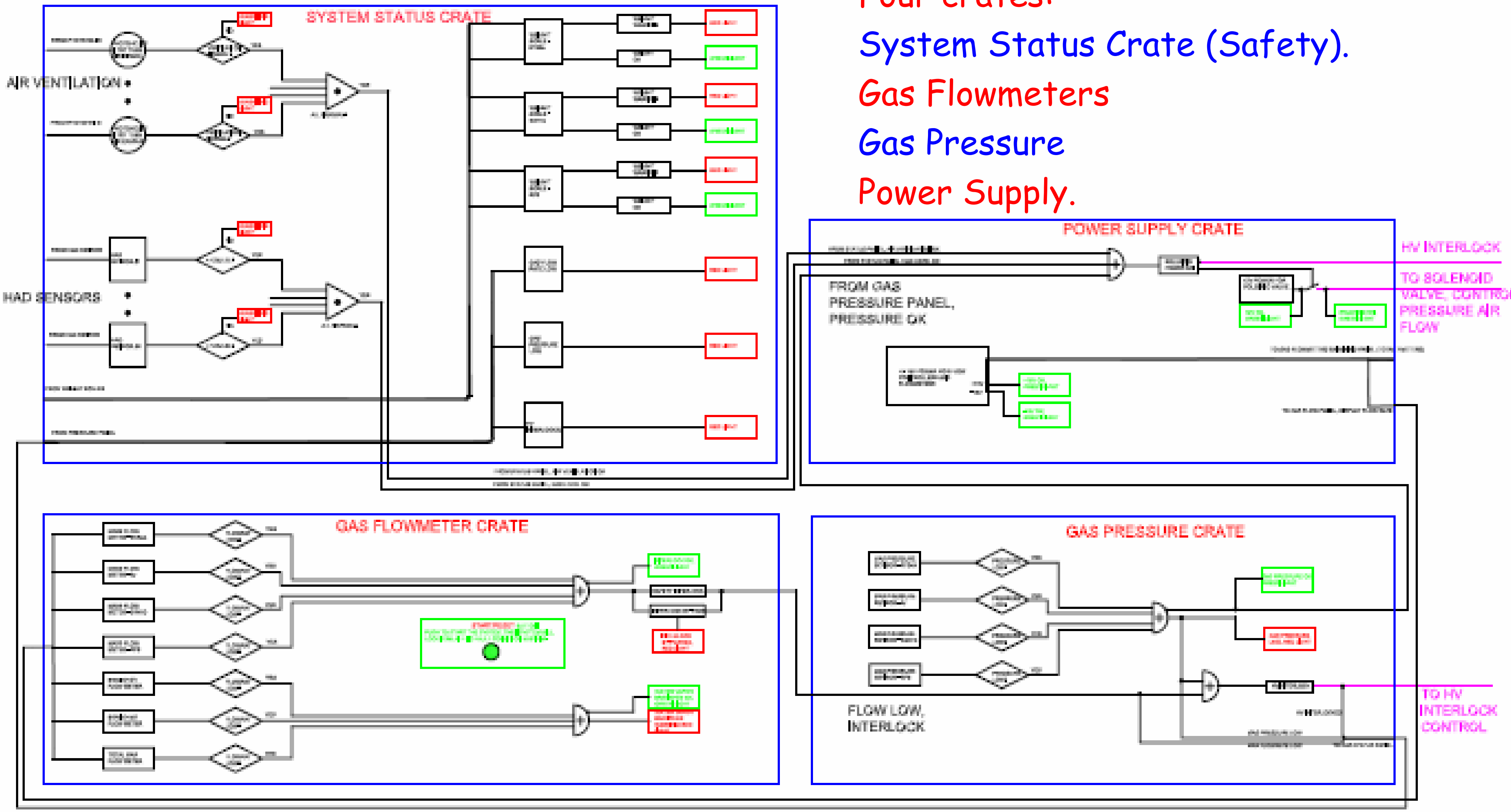


Conclusion

This mixing panel can deliver total flow rates between 100 – 1000 sccm with consistent mixing ratio.

That is quite convenient for Q/C since we do need to change the total flow rate from time to time.

Block Diagram of Gas Control and Fire Safety Systems



Four crates:

System Status Crate (Safety).

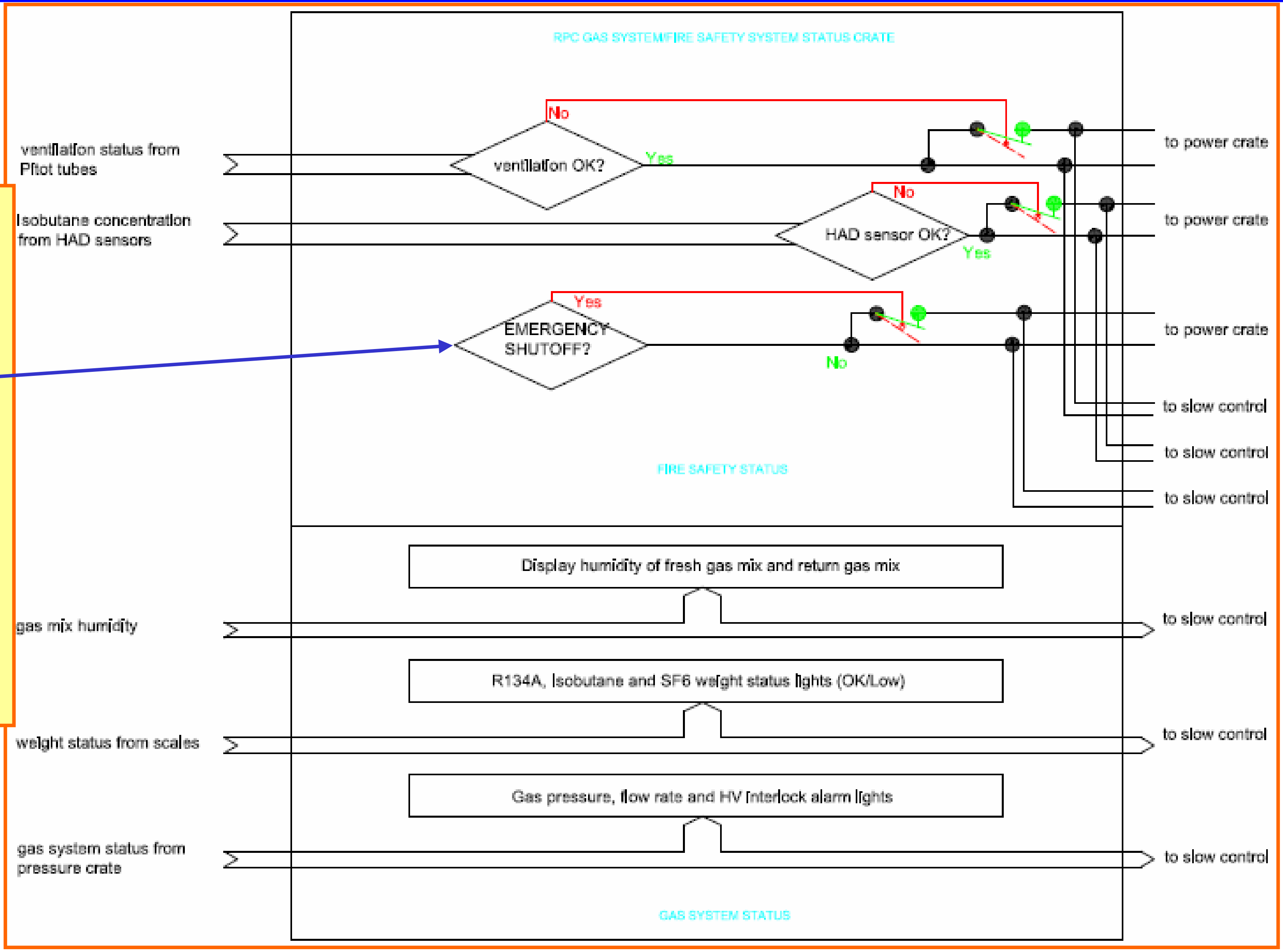
Gas Flowmeters

Gas Pressure

Power Supply.

Fig. 8. Block diagram of the gas mixing and fire/detector safety monitoring system.

Logic Diagram of the System Status Crate



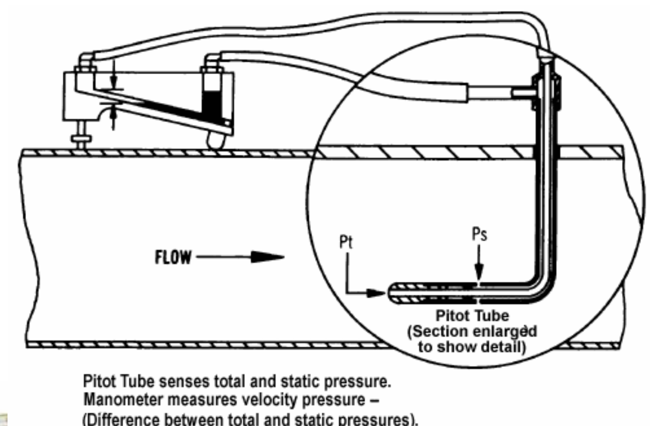
Fire safety interlock function:

If the Emergency Shutoff button is pushed, all four gases will be shut off simultaneously.

Gas System Status Crate

Hazardous Gas Sensors (Rae-Guard):

Ventilation Flow/Pressure Sensors:



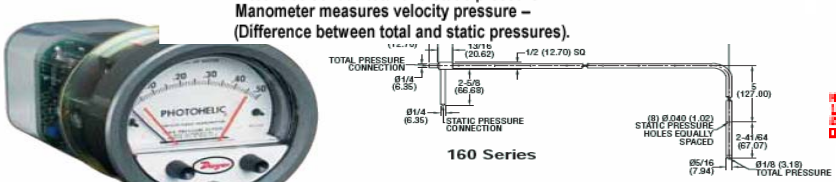
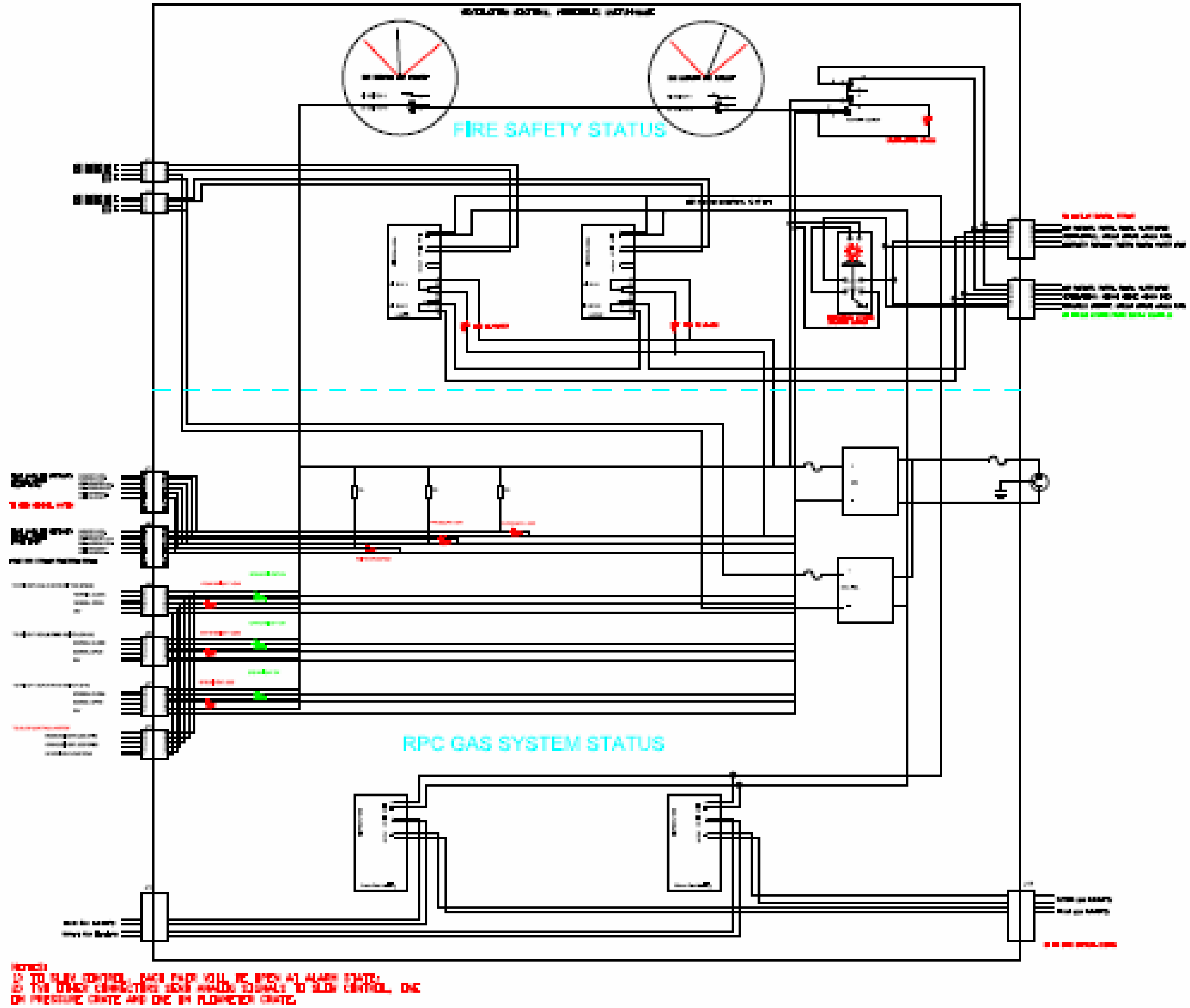
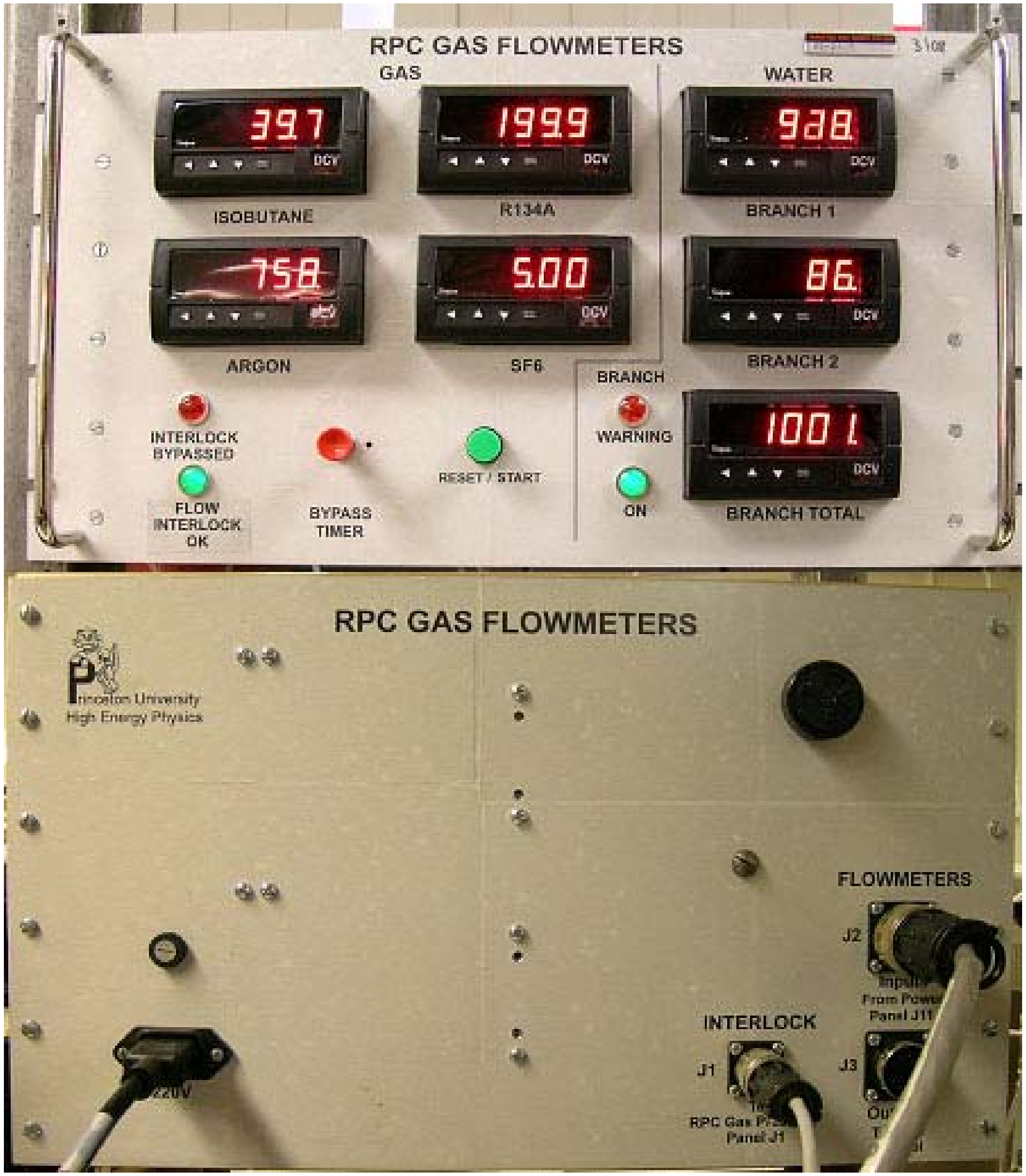


Fig. 24. Dwyer model Photohelic 3000SGT pressure transmitter/controller and 160 series Pitot tube.



Gas Flowmeter Crate

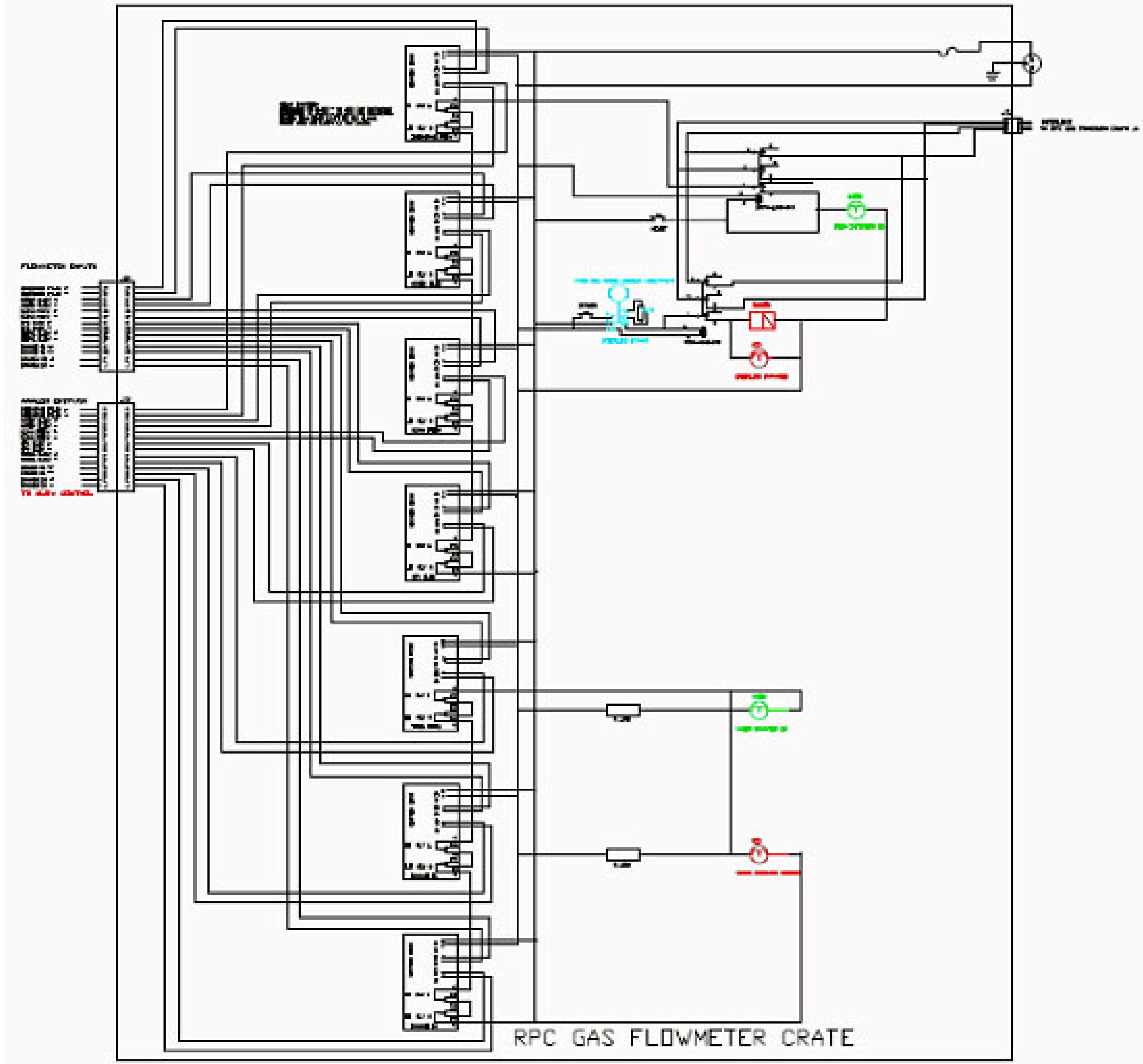


Front Panel

Display is in SCCM unit

Rear Panel

Gas Flowmeter Crate Schematic



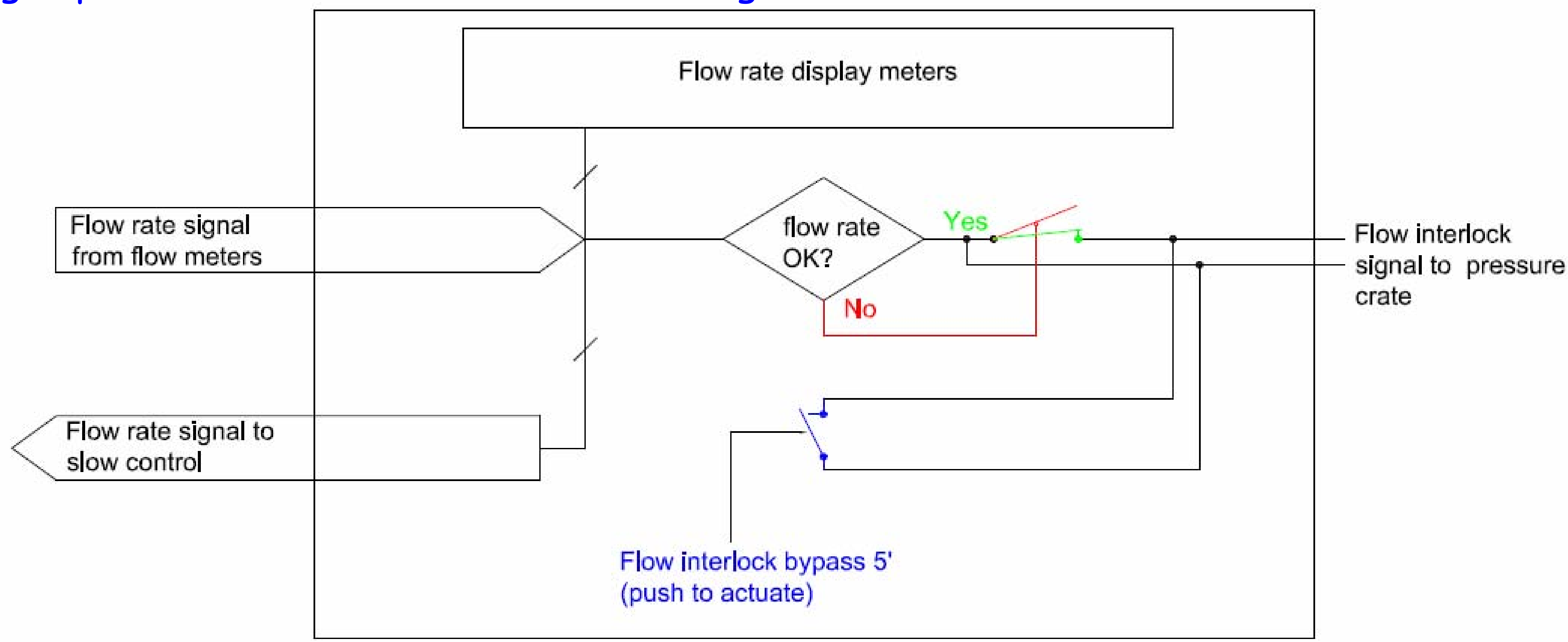
Logic Diagram of the Gas Flowmeter Crate

The gas flowmeter crate displays the gas flow rate from seven mass flow meters: one for each of the four gases, one for each of the three water-vapor-control branches: (total, dry branch, and water-vapor-added branch).

Simpson model H335 controllers are used for the flow-rate display and control.

A normal flow-rate band is defined for each of seven flowmeters.

If the flow rate is out of this preset band, the Simpson controller sends a fault signal to the gas pressure crate, which controls the gas-flow solenoid valves.



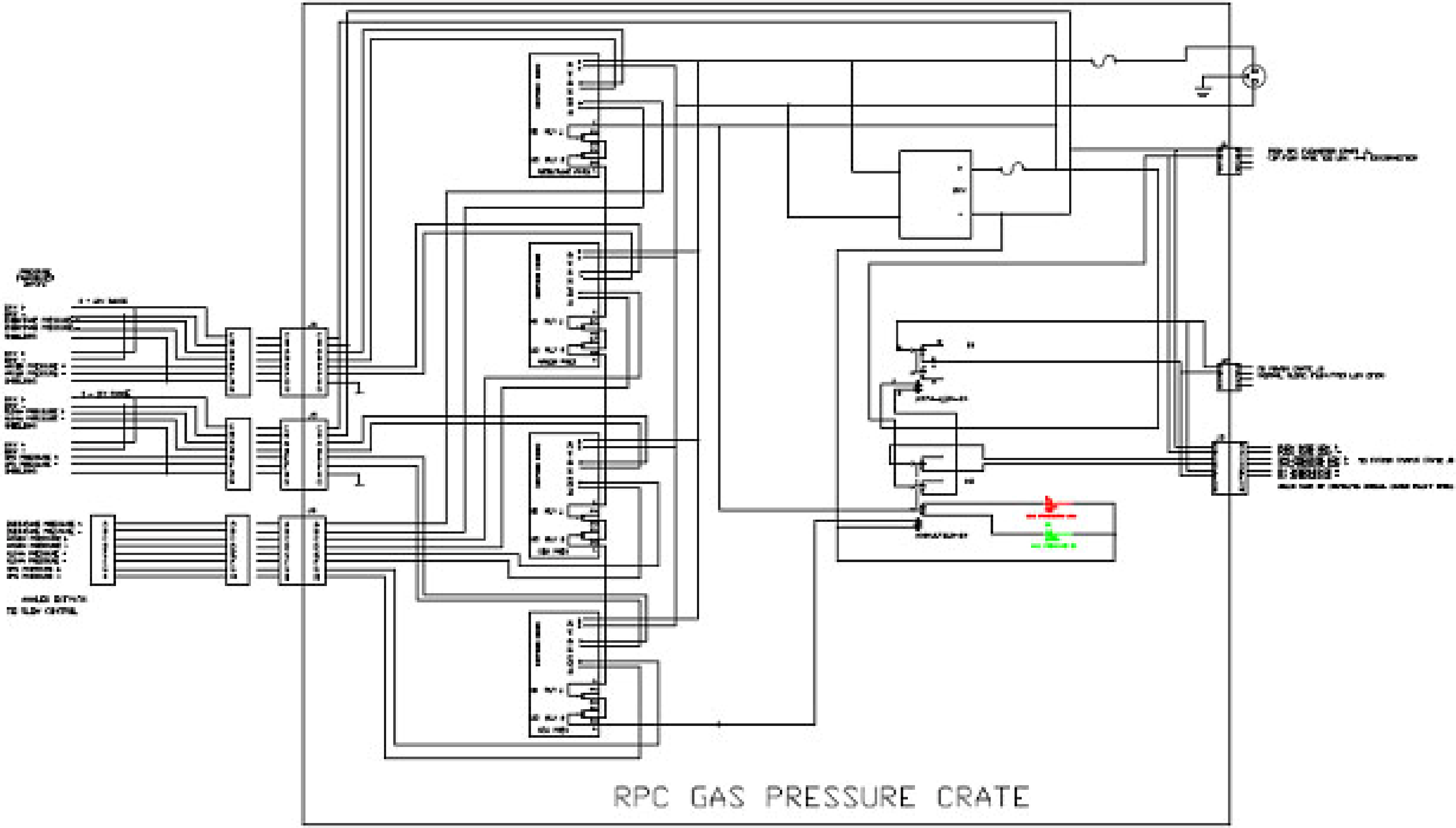
Gas Pressure Crate

Front Panel

Display is in psi unit

Rear Panel

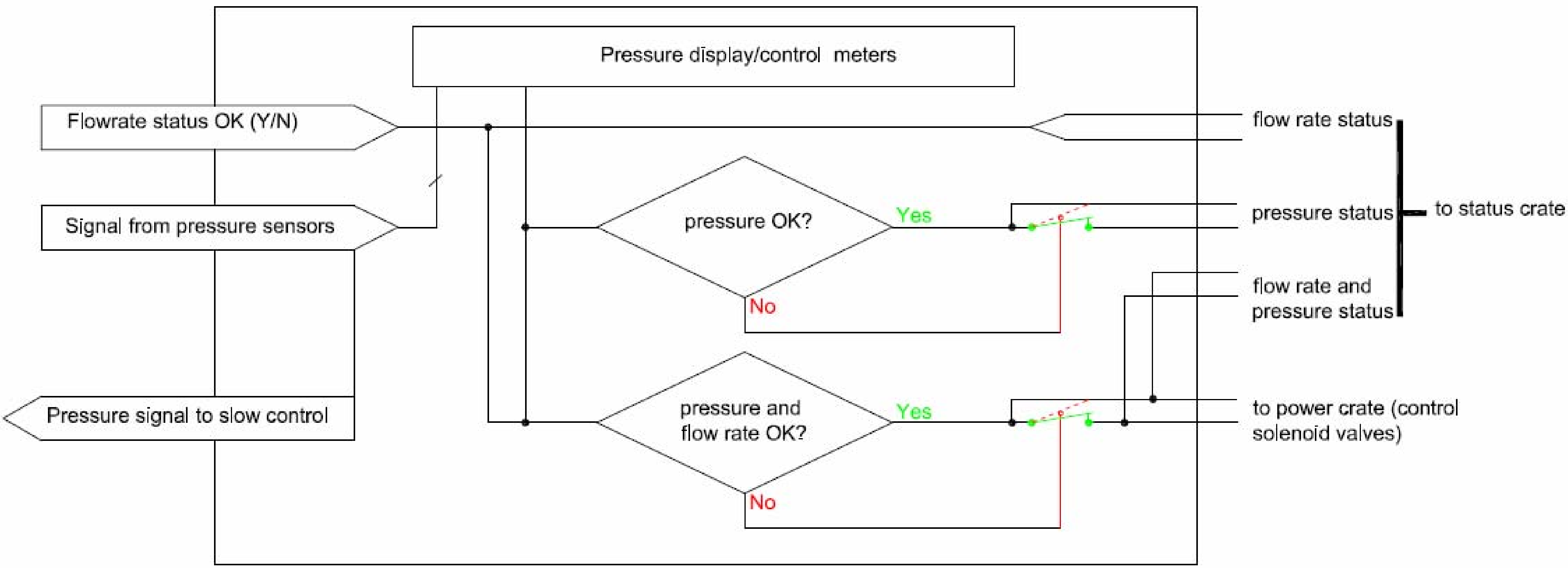
Gas Pressure Crate Schematic



Logic Diagram of the Gas Pressure Crate

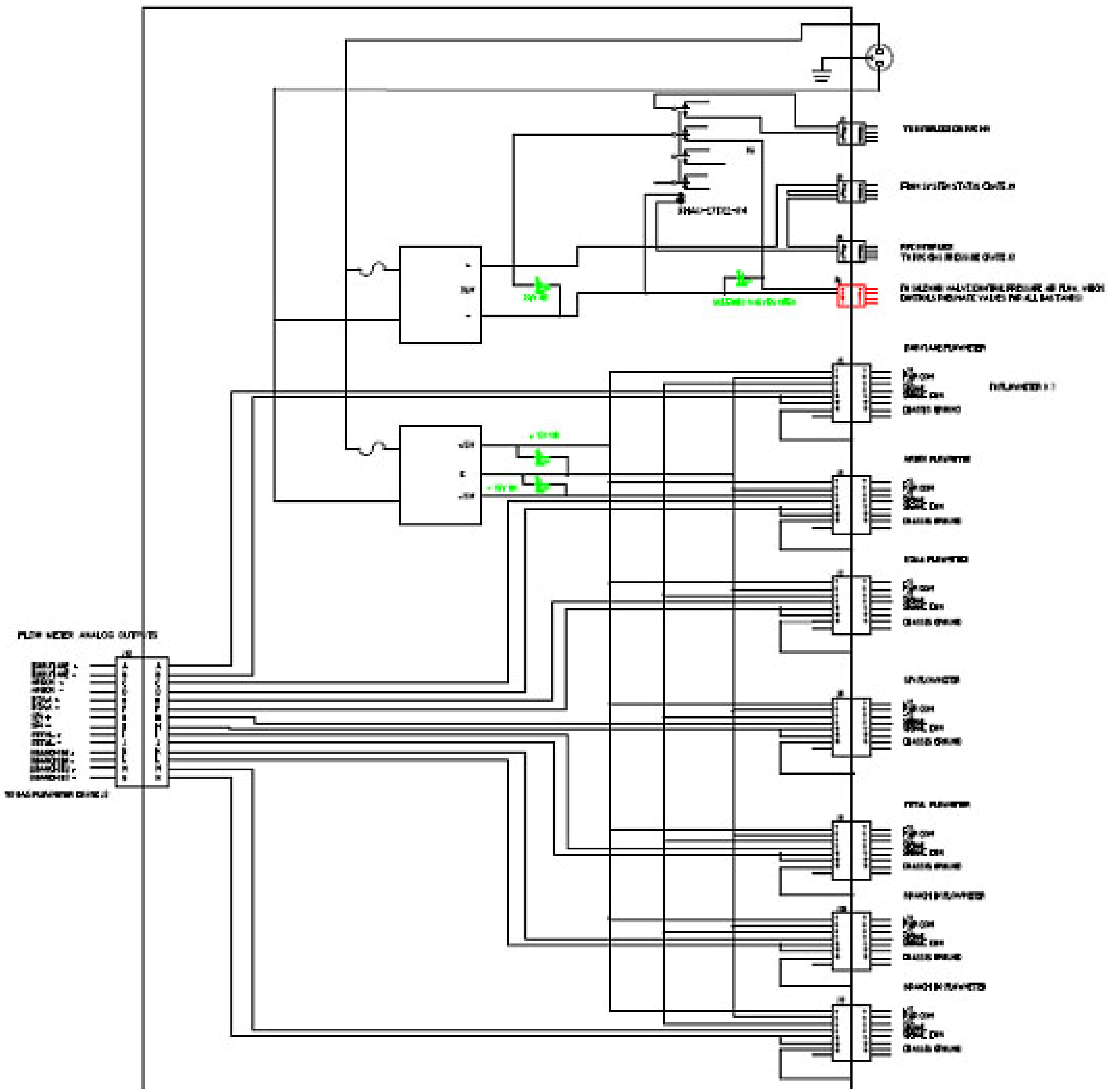
The gas pressure crate displays the gas pressure at the upper stream of the flow controller for each gas.

When any gas goes lower than preset pressure limit, this crate will generate a warning signal, and shut off the inlet solenoid valves to all 4 gas streams so that the gas proportions do not change.



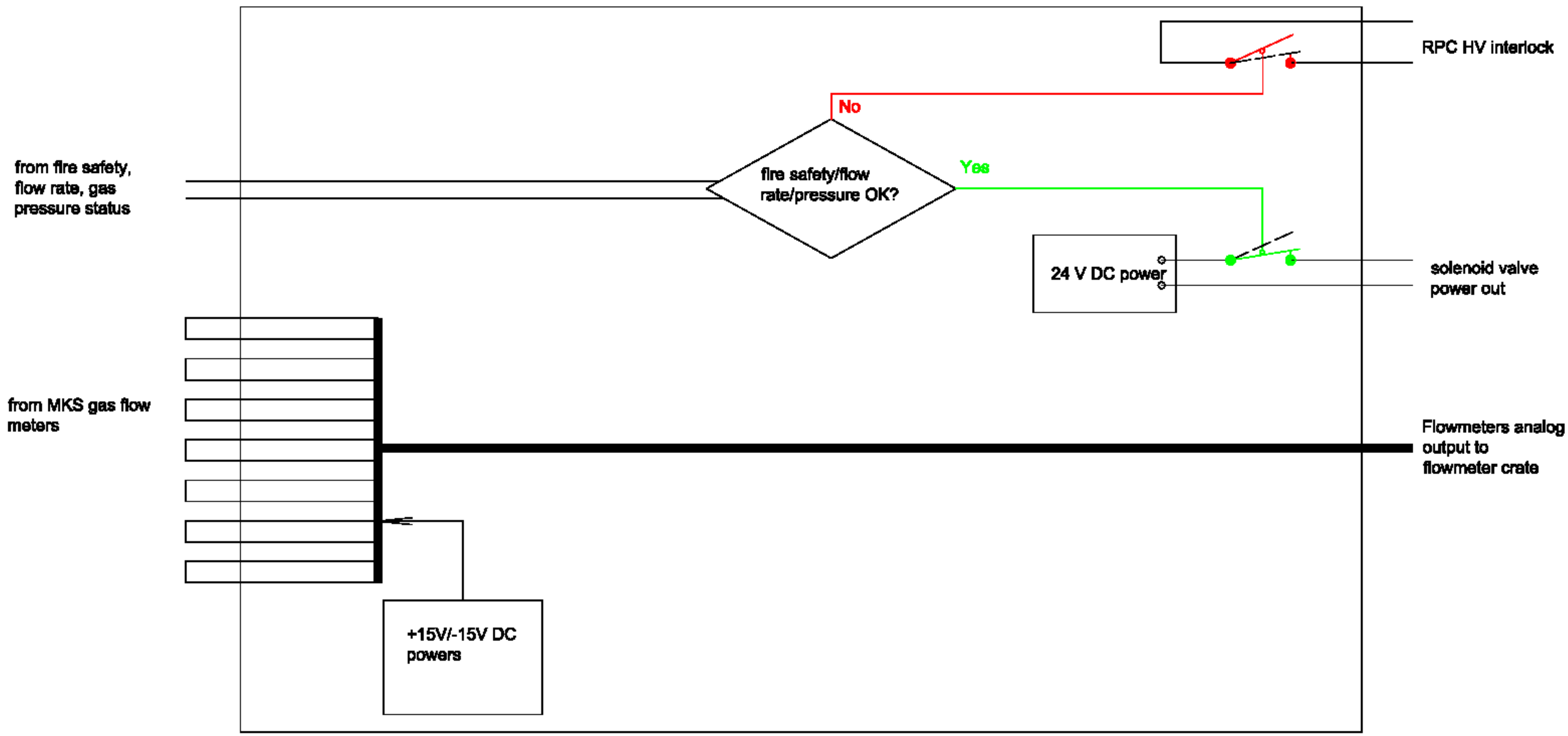
Gas Power Supply Crate

Gas Power Supply Crate Schematic



Gas Power Supply Crate Logic Diagram

This crate powers the gas mixing panel, the gas flowmeter crate and the gas pressure crate.



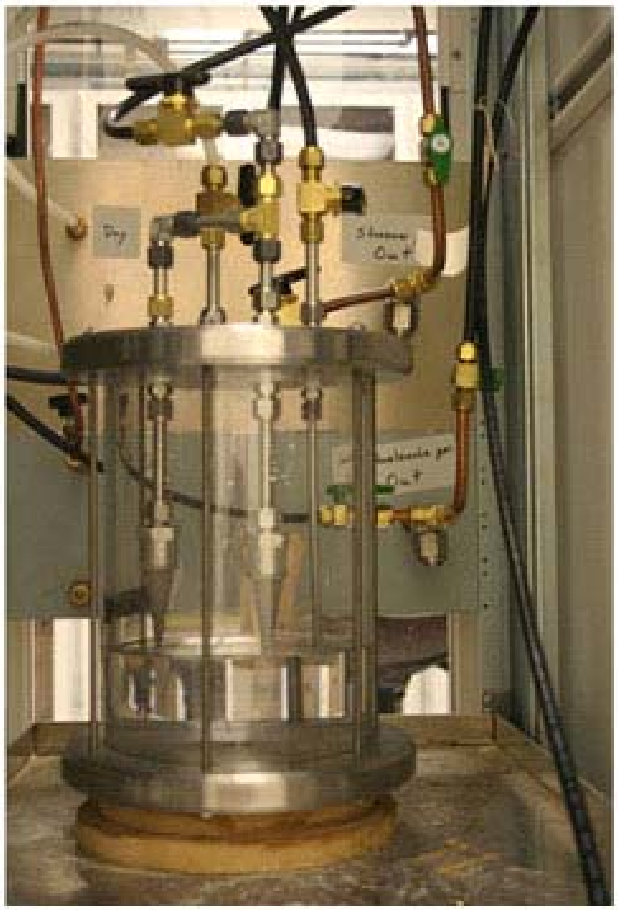
Gas Water Bubbler System

Before delivery to the RPCs, the gas mixture is bubbled through water to add 0.4% water vapor, to reduce aging of the bakelite electrodes, and to maintain good efficiency.

The bubbler system will be modeled on the design of the BaBar experiment.

The relative humidity of the gas after the bubblers will be monitored by inexpensive sensors.

A bypass of the water-bubbler will exist.



Gas Distribution System

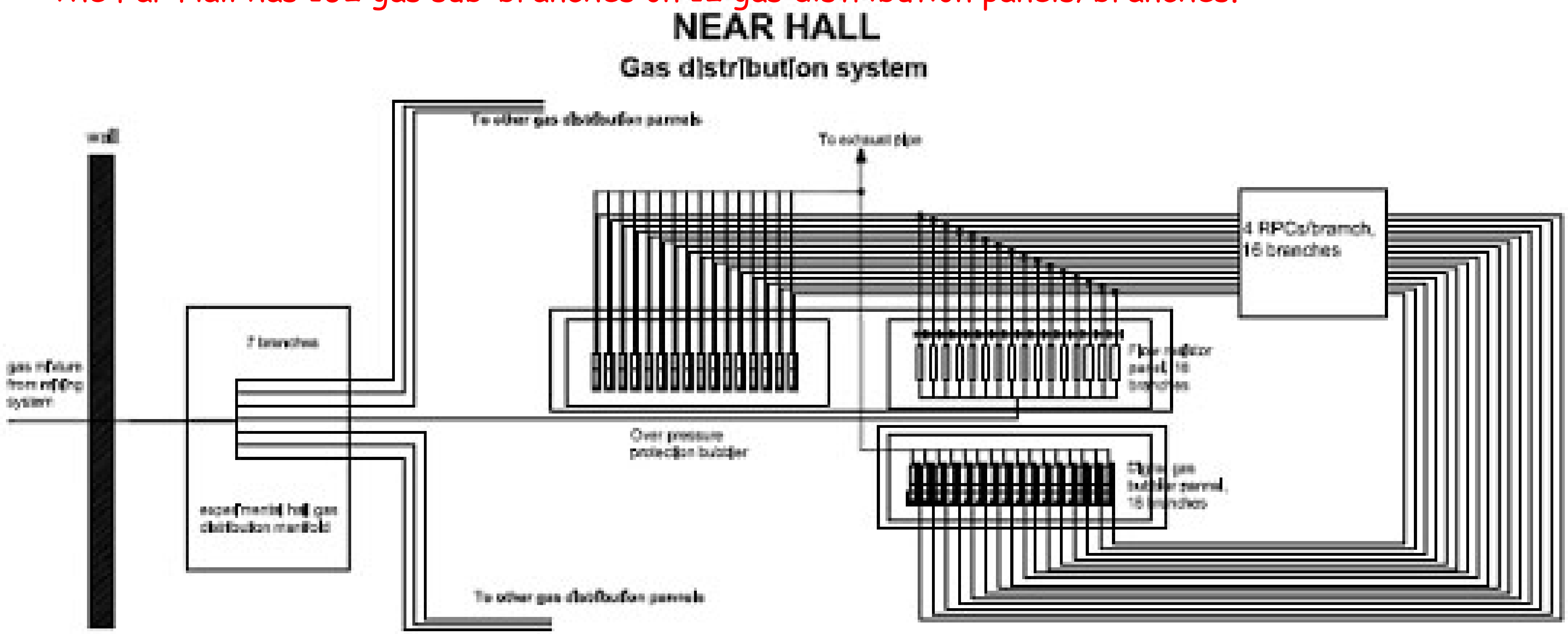
Four 1 $\times$ 2 m^2 RPCs are combined into a single gas "sub-branch".

Each sub-branch has an input gas line which is isolated from other sub-branches by a flow resistor, and protected against overpressure by an input bubbler.

The exhaust line from each sub-branch passes through a digital output bubbler to monitor the flow rate to detect possible leaks.

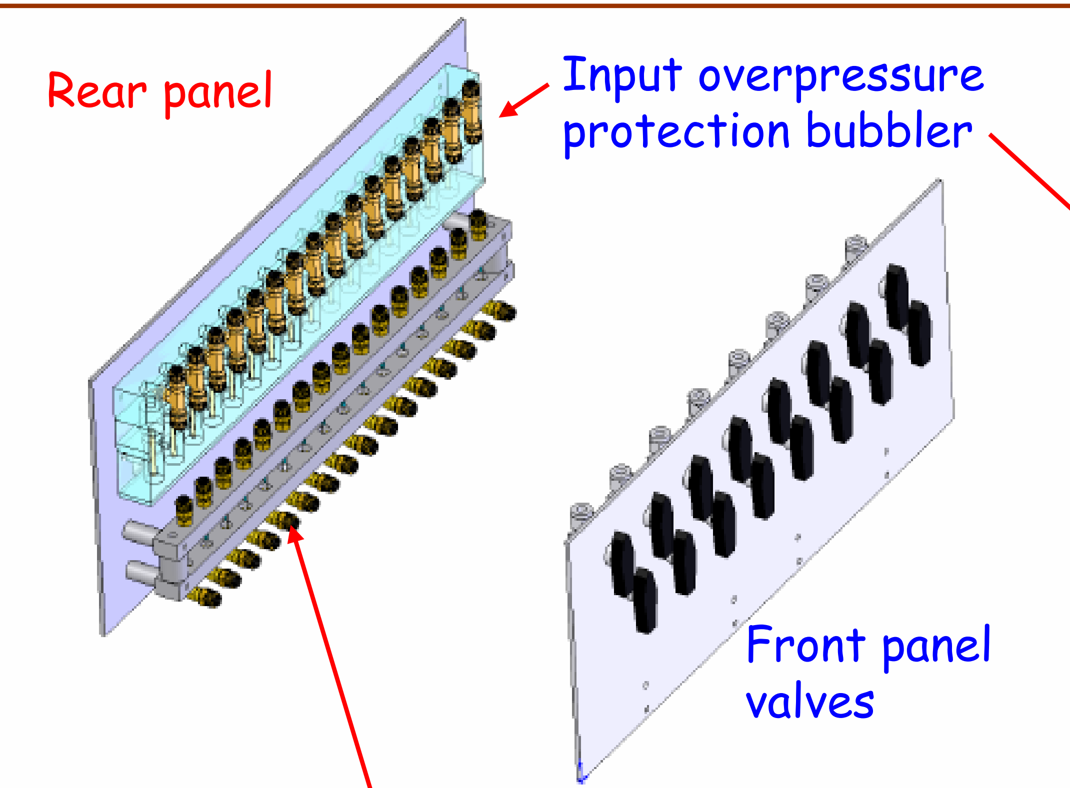
The hardware for 16 sub-branches is grouped onto a gas distribution panel/branch.

- The Near Halls each have 108 gas sub-branches on 7 gas distribution panels/branches.
- The Far Hall has 162 gas sub-branches on 12 gas distribution panels/branches.

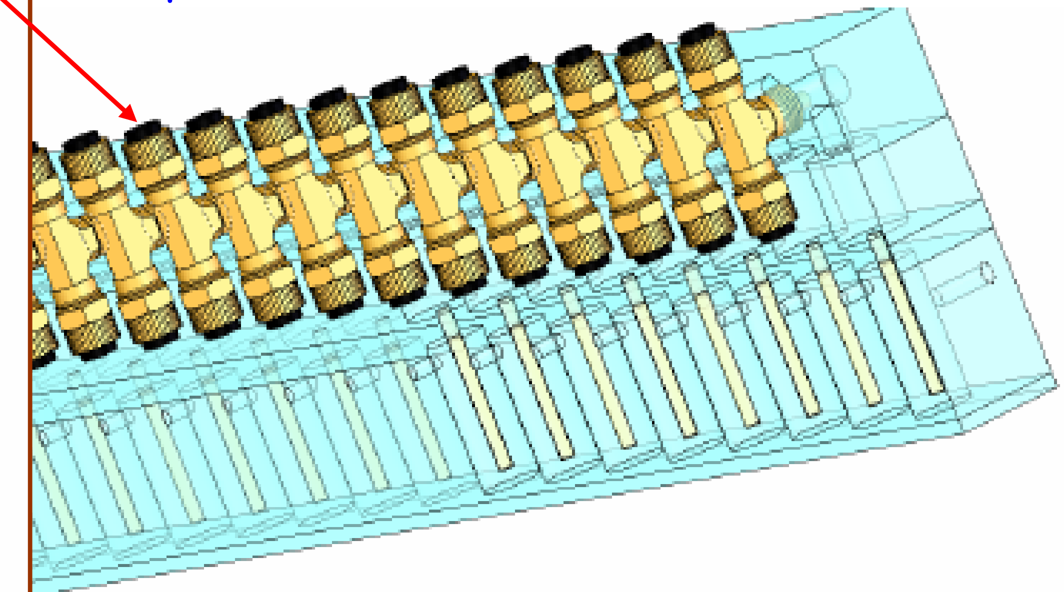


Flow Resistors and Input Protection Bubblers

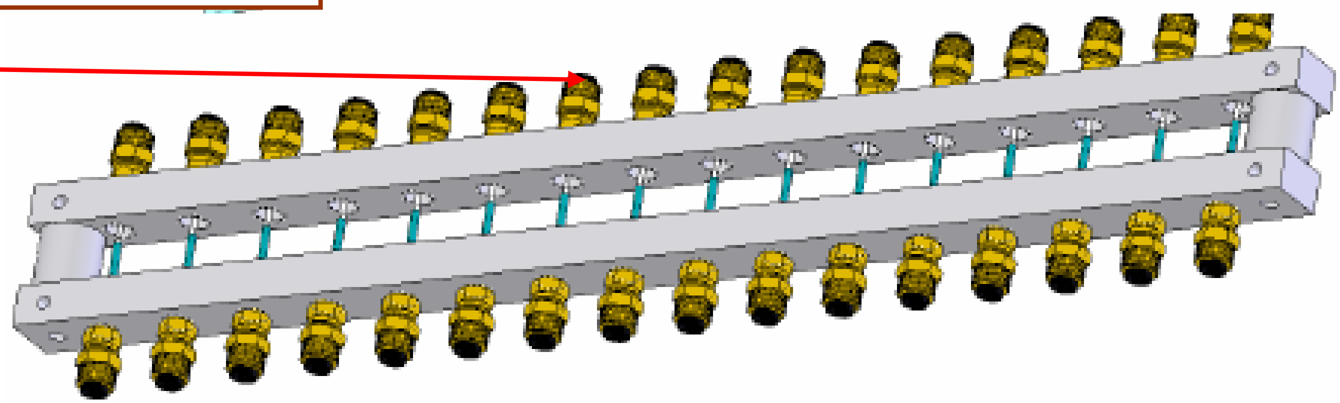
Gas distribution crate



To protect the RPCs against input overpressure, each sub-branch has an oil-filled input bubbler, with relief pressure head set to 2 cm of water.



Flow resistor



The input bubblers are designed to provide protection against overpressure during purging at 5 chamber volumes per day.

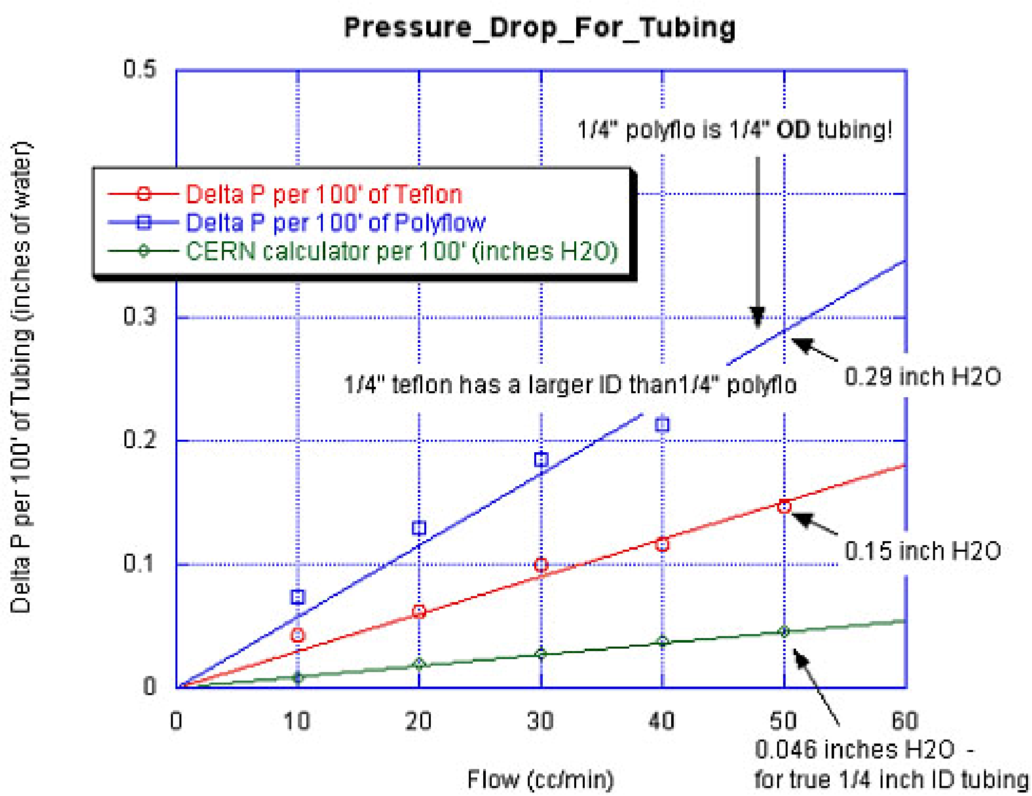
Gas Flow Resistors

One volume change/day in 4 RPCs ⇒ flow rate of = 11 cm^3/m in each sub-branch.

Each sub-branch is fed by a 30-m-long, 4-mm-ID fire retardant PolyFlo tube (or equivalent).

⇒ Pressure drop of 0.15 cm water along this tube.

To prevent disruption of flow to other sub-branches due to leakage in one sub-branch, each input sub-branch includes a “flow resistor” = 5-cm-long, 0.5-mm-diameter SS tube, across which the pressure drop is 1 cm water at the nominal flow rate.



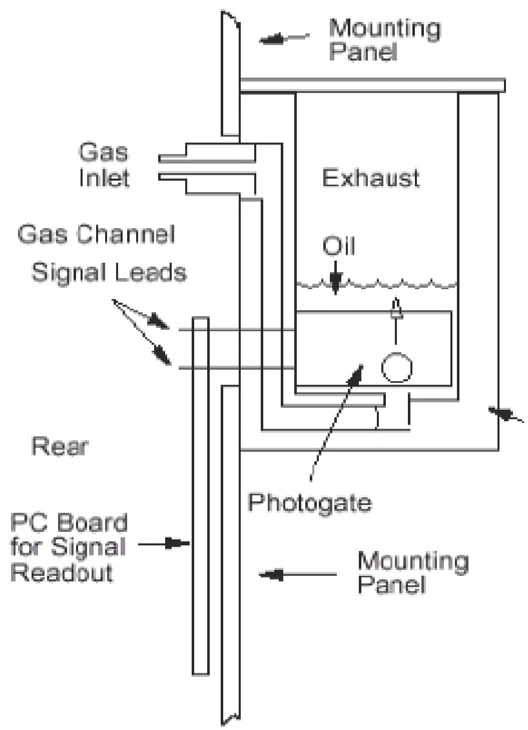
Digital Output Bubblers

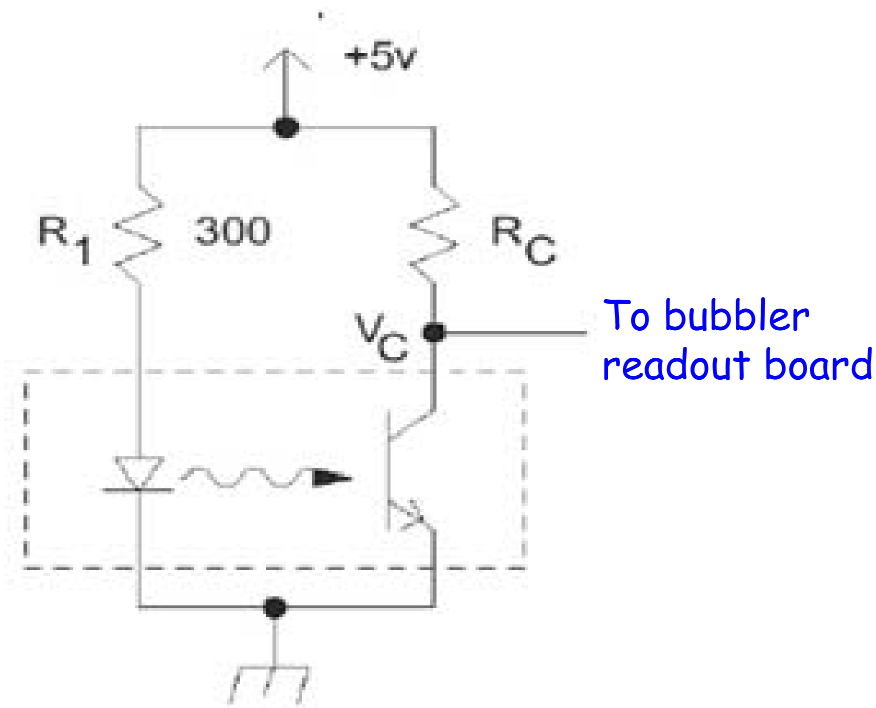
The exhaust line from each sub-branch passes through an oil-filled output bubbler with a pressure head of 0.5 cm water to maintain the RPC pressure relative to that of the atmosphere.

The rate of bubbling in each sub-branch is counted via an optical photogate, which provides a measure of the output gas flow rate.

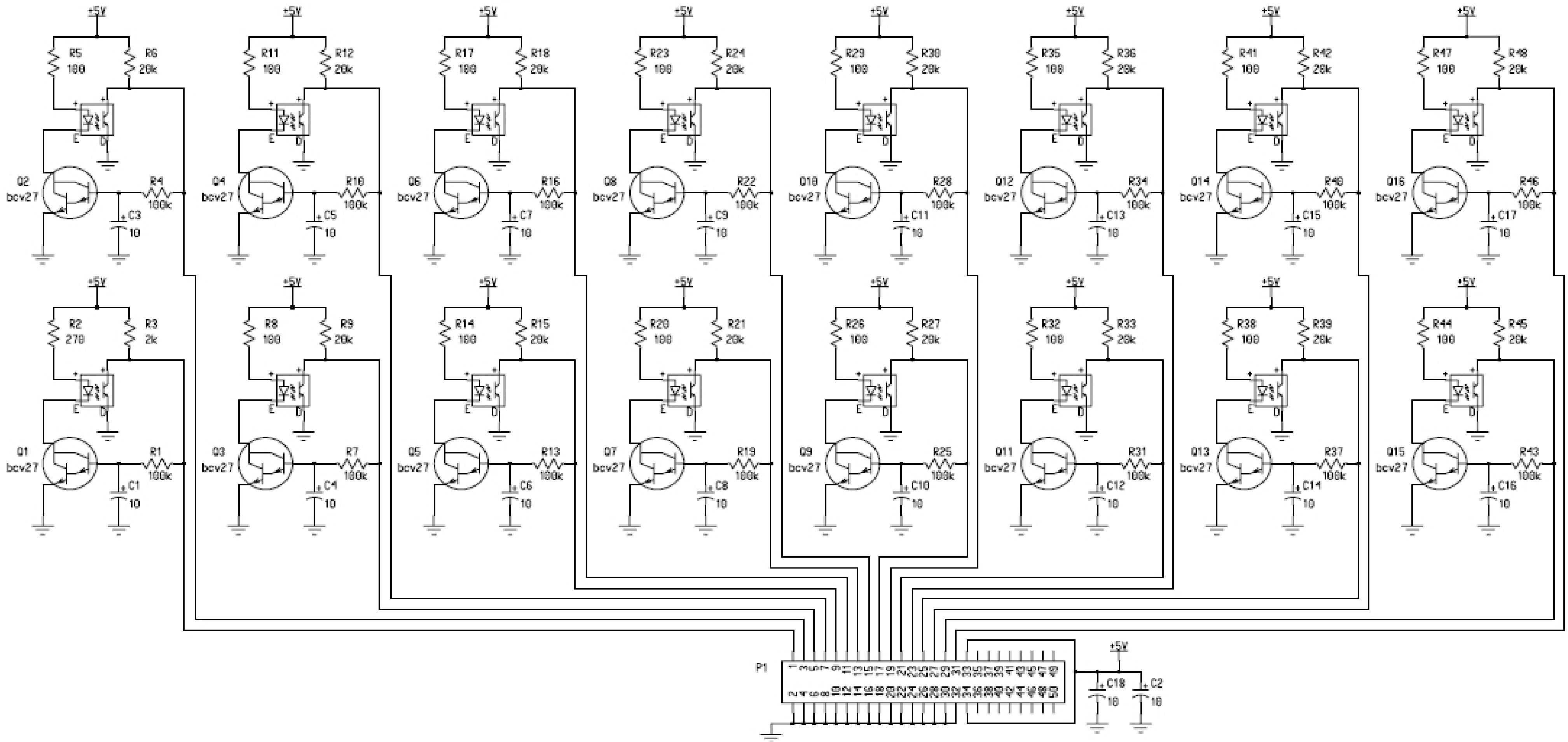
Without gas bubbles, light reaches the photogate through the oil with full intensity.

When a bubble passes, it will partially reflect light, and the reduced light intensity generates a pulse to the photogate PC board.



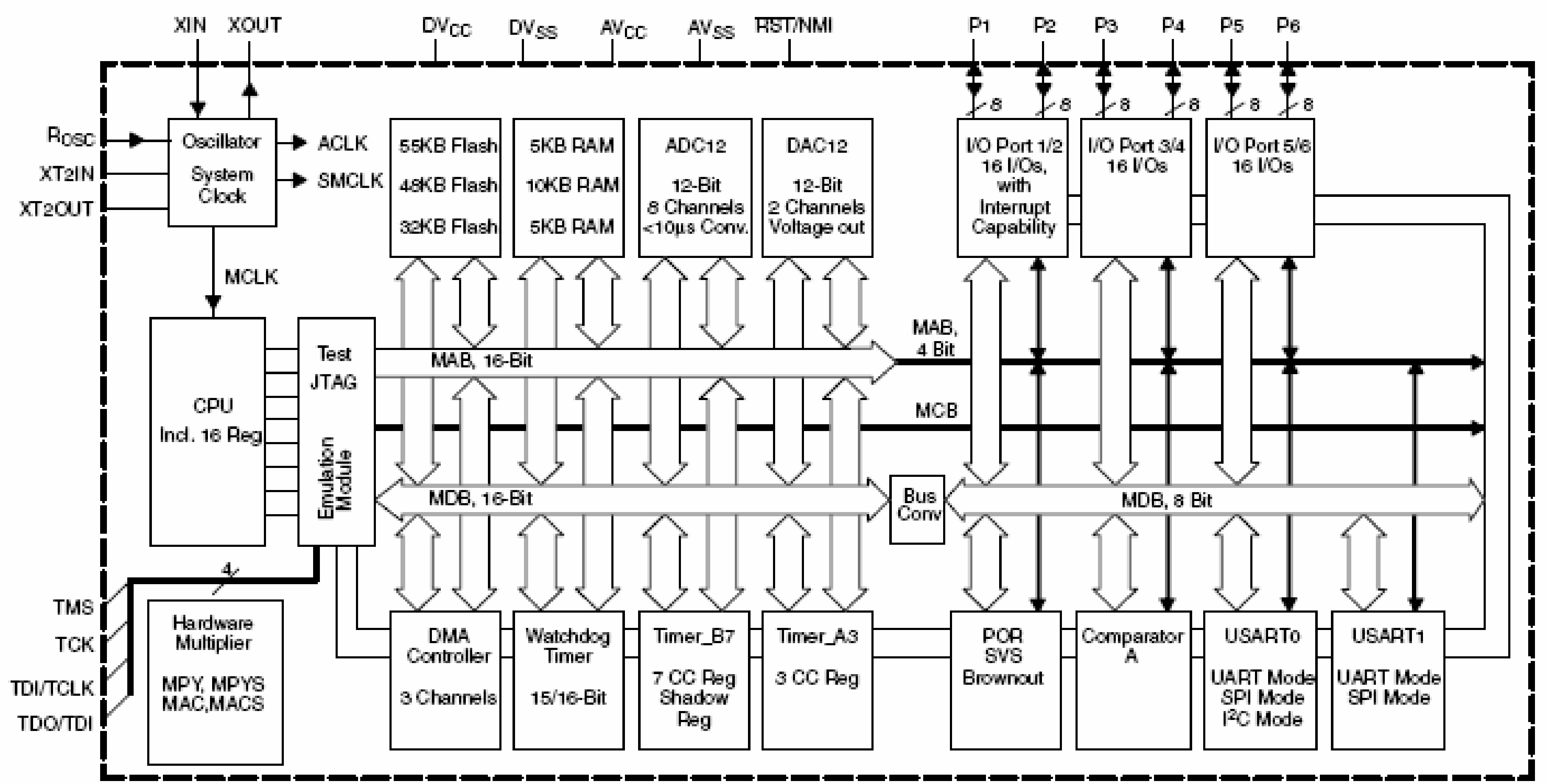


Digital Bubbler Photogate PC board



Digital Bubbler Microcontroller

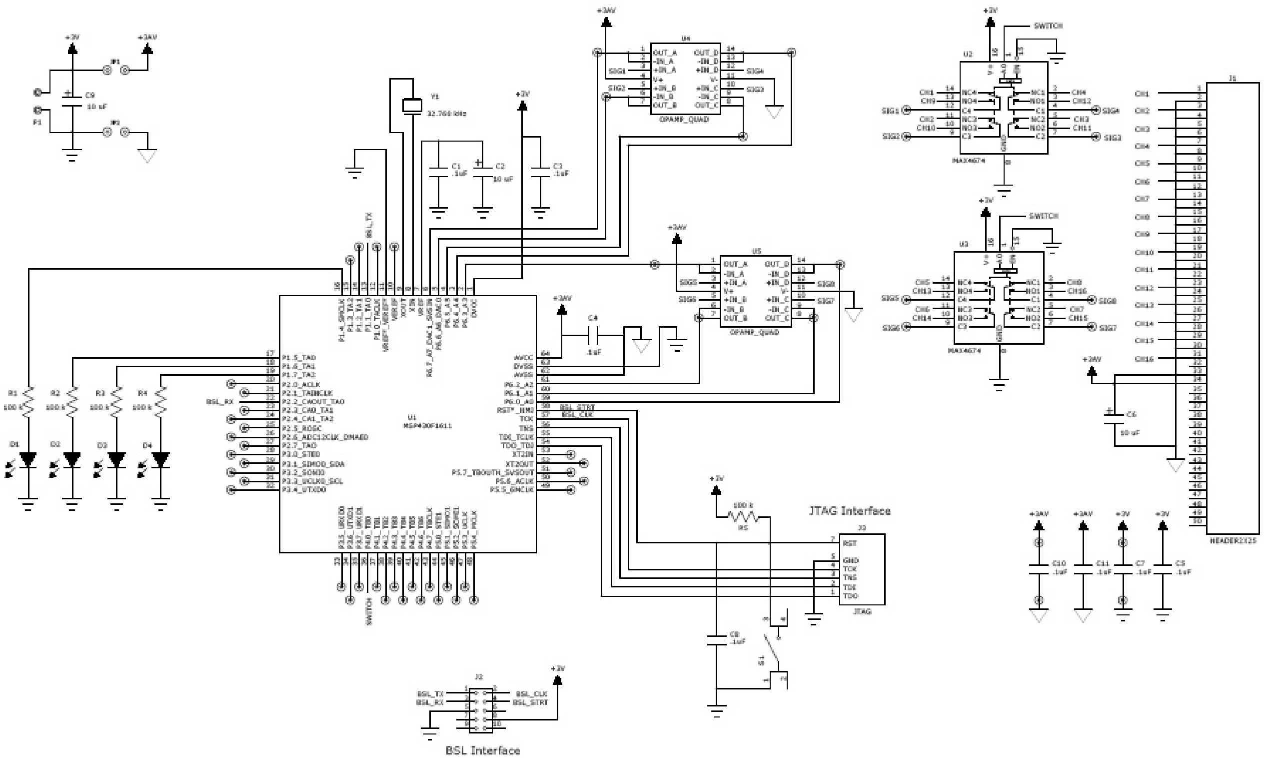
The photogate signals are digitized by a TI MSP430F1611 microcontroller with a 12-bit ADC, MSP430F1611 processor, 10KB RAM, 48KB flash memory, and Universal Synchronous/Asynchronous Receive/Transmit (USART) peripheral interface.



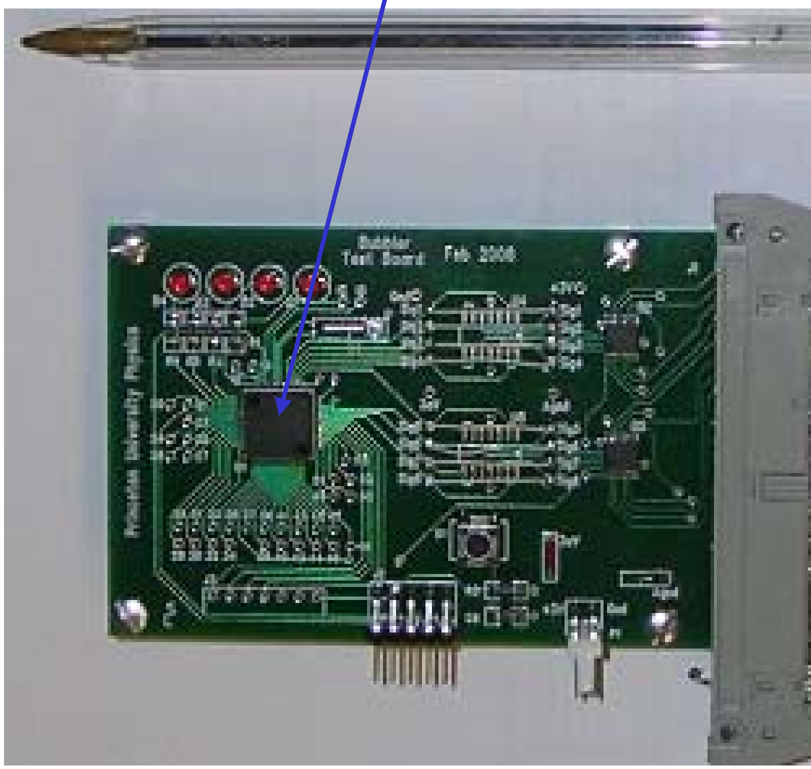
Digital Bubbler Test Board

A 16 channel prototype readout board has been tested with satisfactory results.

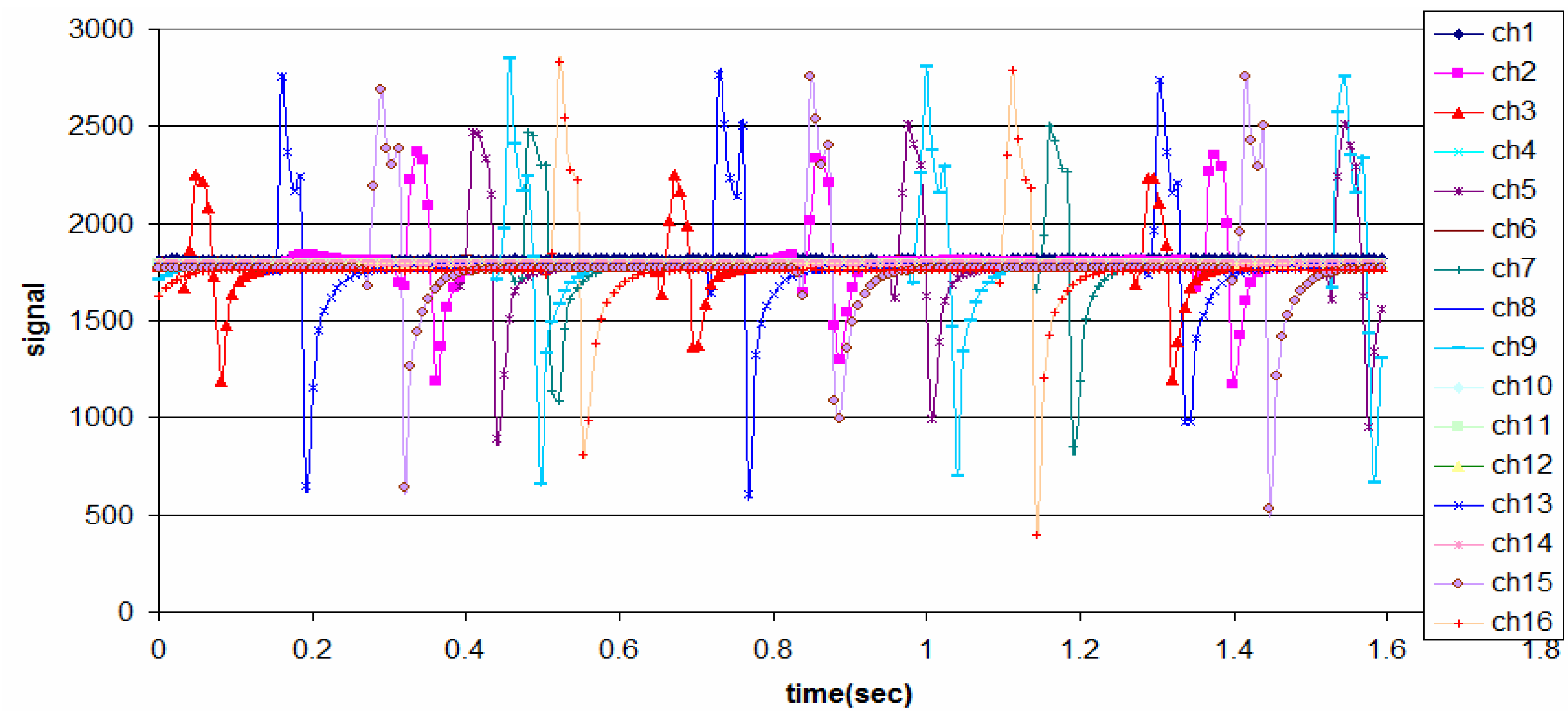
The next step is to integrate the RS232 interface circuit onto the board.



TI microcontroller



Digital Bubbler - Test Results

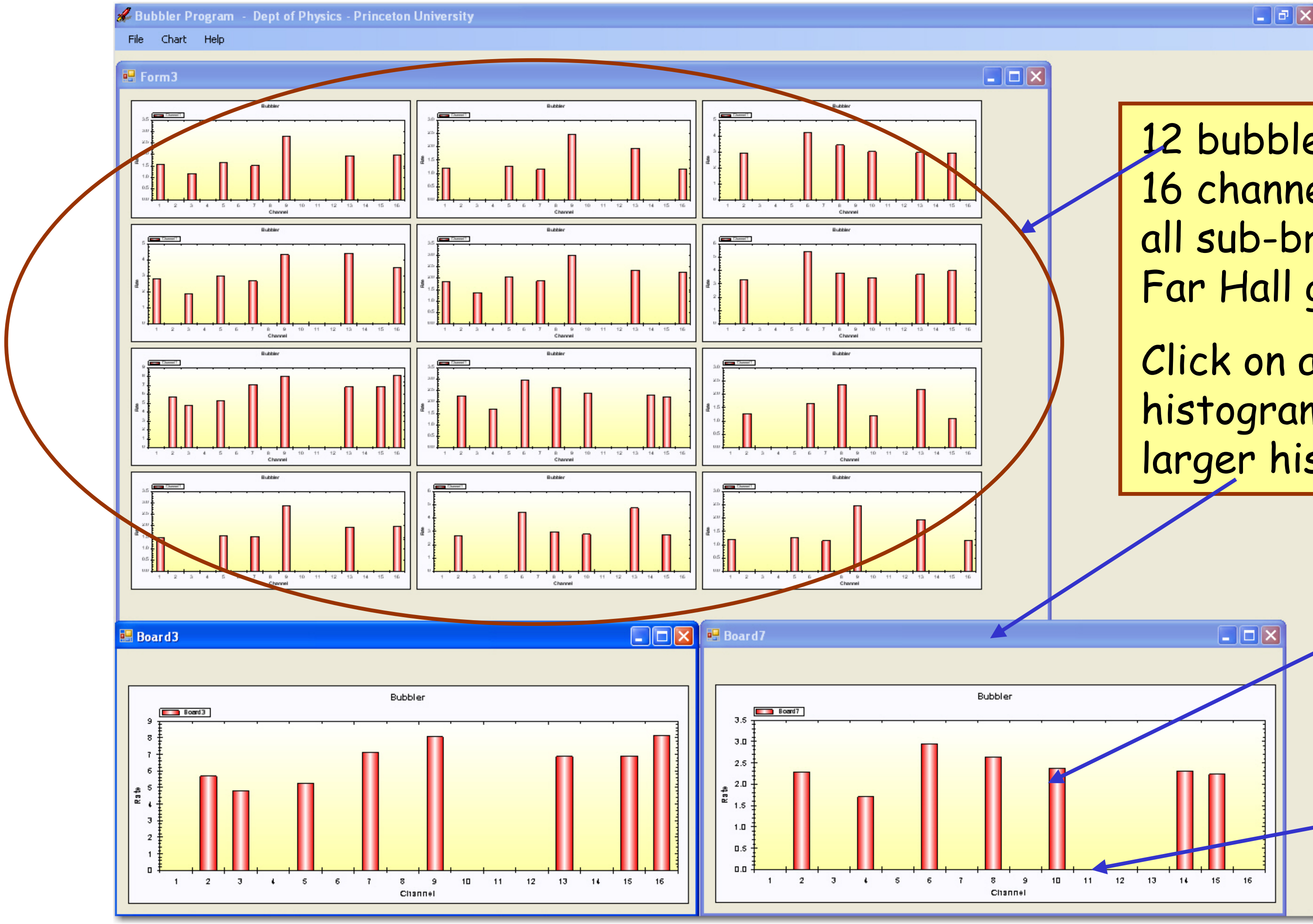


We connected 8 channels to a gas source to generate bubbles

The recorded ADC data show bubbling clearly.

The non-bubbling channels show no pulses.

Digital Bubbler - Graphics User Interface (Far Hall)



12 bubbler boards, 16 channels/each, display all sub-branches for the Far Hall gas system.

Click on any one of the histograms will pop-up a larger histogram window.

Bubbling channel

Non-bubbling channel

Interface to the Slow Control System

The RPC gas system will send signals to the slow control system for on-line monitor and emergency control.

- Gas flow rate for all four components, the total flow rate, and dry/wet branch flow rates for the gas mixture.
- Gas bubbling rate for every sub-branch.
- Gas pressure upstream of the mass flow controllers.
- Gas mixture humidity.
- Ventilation air flow rate.
- HAD sensors.
- Gas cylinder storage room/mixing room temperature/air pressure (a stand-alone Weather Station device in the gas room).

RPC Gas System Signals for the Slow Control System

Source	Name	Type	Range	connector
Flowmeter crate	Flow rate(Isobutane)	DC level	0 – 10V	J3
	Flowr rate(Argon)	DC level	0 – 10V	J3
	Flow rate(R134A)	DC level	0 – 10V	J3
	Flow rate(SF6)	DC level	0 – 10V	J3
	Total flow rate	DC level	0 – 10V	J3
	Branch #1 flow rate	DC level	0 – 10V	J3
	Branch #2 flow rate	DC level	0 – 10V	J3
Pressure crate	Pressure(Isobutane)	DC level	0 – 10V	J6
	Pressure(Argon)	DC level	0 – 10V	J6
	Pressure(R134A)	DC level	0 – 10V	J6
	Pressure(SF6)	DC level	0 – 10V	J6
Gas status crate	HAD sensor status	switch	O(alarm)/C(normal)	J10
	Ventillation status	switch	O(alarm)/C(normal)	J10
	Scale #1(Isobutane)	switch	O(alarm)/C(normal)	J12
	Scale #2(R134A)	switch	O(alarm)/C(normal)	J12
	Scale #3(SF6)	switch	O(alarm)/C(normal)	J12
	Flow rate status	switch	O(alarm)/C(normal)	J11
	Pressure status	switch	O(alarm)/C(normal)	J11
	HV interlock	switch	O(alarm)/C(normal)	J11
Weather station	G.S.R. Temperature	direct read		RS-232
	G.S.R.Air pressure	direct read		
	G.M.R. Temperature	direct read		RS-232
	G.M.R.Air pressure	direct read		
Digital bubbler	bubble rate	Data file	PC Data file/Database	Ethernet
		Database	One PC/each hall	

Budgets and Ammendments

The Present RLS Captures Only Part of the RPC Gas System Cost/Effort

390	**1.02.01**	**⊟ Resistive Plate Chambers**	**$359,891.01**	**Wed 2/28/07**	**Wed 11/25/09**
391	**1.02.01.1**	**⊞ RPC Panels**	**$0.00**	**Wed 2/28/07**	**Wed 11/25/09**
406	**1.02.01.2**	**⊟ RPC Gas System**	**$359,891.01**	**Mon 1/14/08**	**Wed 9/23/09**
407	1.02.01.2.1	Final Spec & Dsgn of RPC Gas sys	$24,800.34	Mon 1/14/08	Thu 2/28/08
408	1.02.01.2.2	FDR/PRR Review of Gas Sys	$0.00	Fri 2/22/08	Tue 2/26/08
409	1.02.01.2.3	Procure compon. For 1st gas sys	$44,960.07	Mon 3/31/08	Tue 7/29/08
410	1.02.01.2.4	Assemble Gas Sys for DB Hall	$16,625.81	Tue 7/29/08	Thu 8/28/08
411	1.02.01.2.5	Pre-Operational Safety Assessm	$0.00	Thu 8/28/08	Tue 9/2/08
412	1.02.01.2.6	Test/Certify Gas System	$22,487.53	Tue 9/2/08	Thu 9/25/08
413	1.02.01.2.7	Package & ship Gas Sys for DB Near	$7,273.46	Thu 9/25/08	Wed 10/22/08
414	1.02.01.2.8	RPC Gas Sys for DB Near arrives at SAB	$0.00	Wed 10/22/08	Wed 10/22/08
415	1.02.01.2.9	Procure remaining components, incl. safety systems	$196,123.55	Mon 3/2/09	Thu 4/9/09
416	1.02.01.2.10	Assemble Gas systems for LA & Far Halls	$28,815.57	Thu 4/9/09	Mon 6/29/09
417	1.02.01.2.11	Test LA and Far Hall Gas Systems	$12,058.73	Mon 6/29/09	Mon 7/27/09
418	1.02.01.2.12	Package & ship Gas System for LA Hall	$3,122.98	Mon 7/27/09	Thu 8/27/09
419	1.02.01.2.13	LA Hall Gas System Arrives at SAB	$0.00	Thu 8/27/09	Thu 8/27/09
420	1.02.01.2.14	Package & ship Gas System for Far Hall	$3,622.98	Thu 8/20/09	Wed 9/23/09
421	1.02.01.2.15	Far Hall gas system arrives at SAB	$0.00	Wed 9/23/09	Wed 9/23/09

Components : $246k; Design/Labor: $105k; Shipping: $14k

Total: $360k

Our Present Budget Estimate

Project Management (W. Sands)	$30k	(red ⇒ NOT in present RLS)
System Design (W. Sands, S. Chidzik)	$25k	(blue ⇒ in present RLS accounting)
3 mixing panels	$75k	
Control boxes for the mixing panels	$25k	
Input bubbler systems	$20k	
Output bubbler systems	$80k	
Water admixture systems	$5k	
Gas bottle switchover systems	$45k	
Conversion of 1st mixing panel from QC to production	$10k	
or 4rth mixing panel		$15k additional
Hazardous gas safety system	$60k	
Installation at Daya Bay	$16k	
Archival drawing sets	$10k	
Test, QC/QA	$35k	
Shipping	$14k	
Total	$450k = $254k + $176k	
or	$465k = $254k + $191k	