Daya Bay RPC Gas Safety System Design

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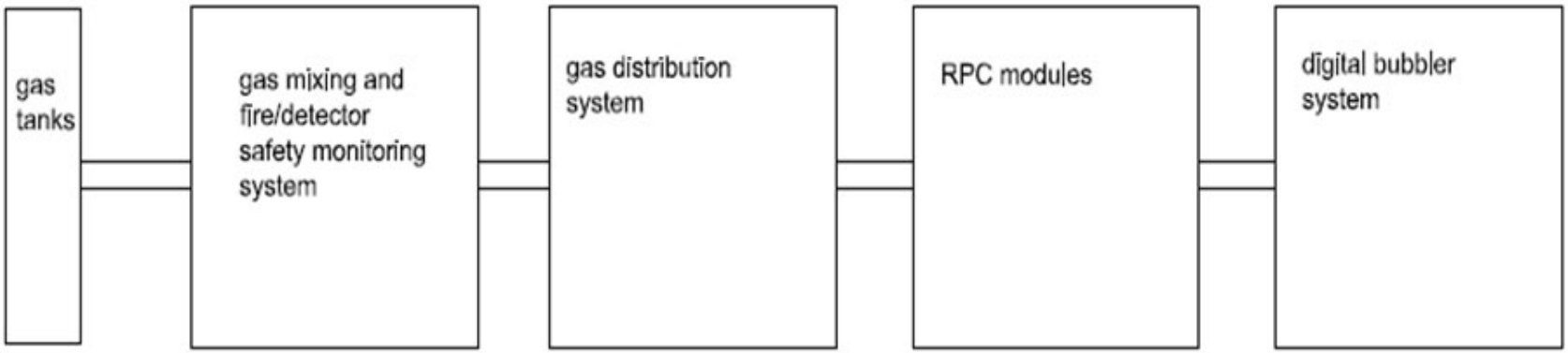
Outline

1. Overview
2. Gas flammability
3. Number of gas cylinders underground
3. Isobutane storage cabinet
4. Isobutane cylinder scale
5. Gas safety interlock system
6. Emergency purging system
7. Cost estimation

Reference: RPC Gas System Final Design Review (April 11, 2008):

http://puhep1.princeton.edu/~mcdonald/dayabay/rpc_fdr_D.ppt

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.

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

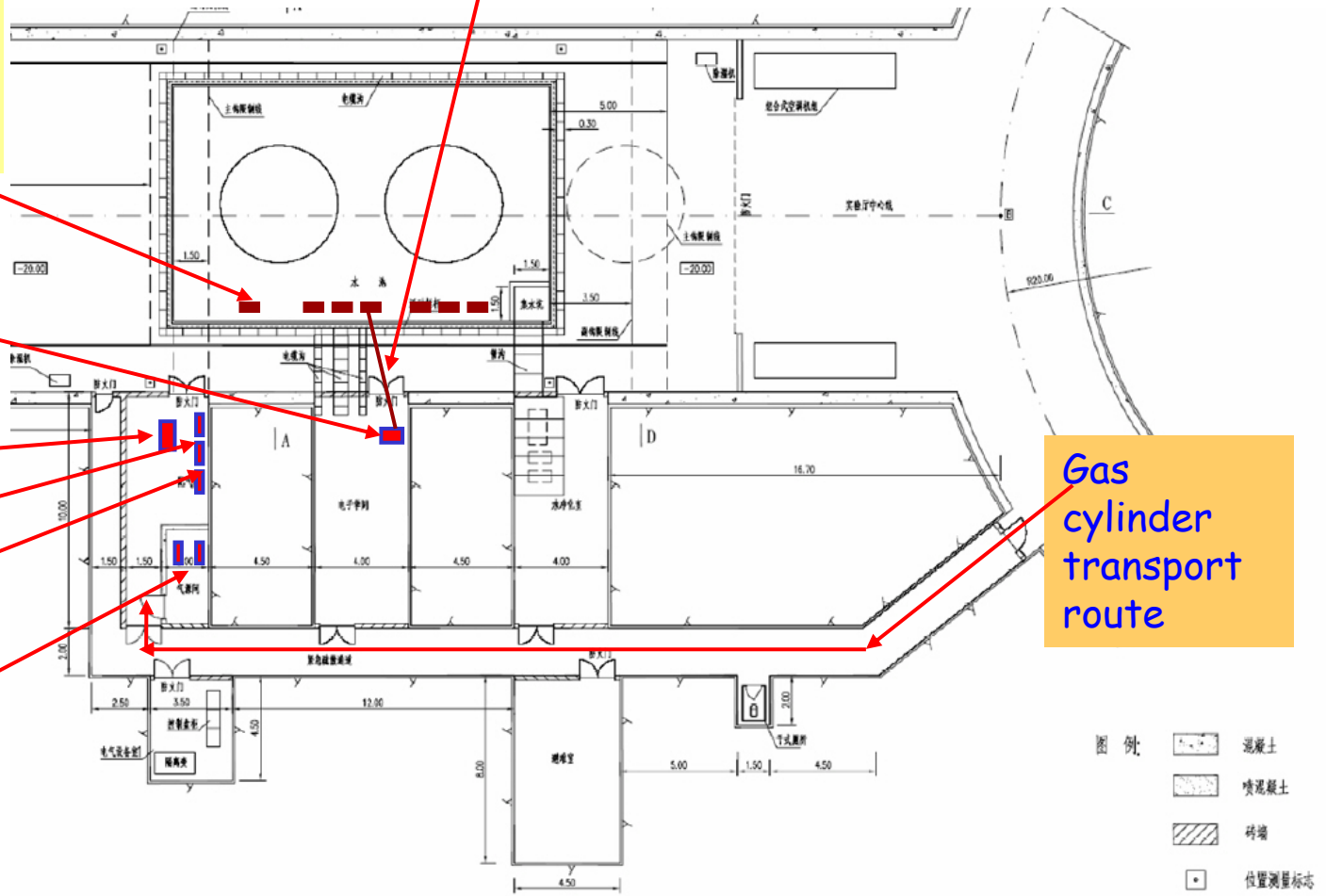
Gas-distribution / digital-bubbler system crates (total 7) on RPC support frame.

Host PC for the digital bubbler system

Gas mixing panel and control system, 2 6-pack Ar cyl stations, Isobutane gas cabinet

SF6, R134A Gas cylinders, ODH & HAD sensors

USB cable



Gas cylinder transport route

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.

http://puhep1.princeton.edu/~mcdonald/examples/detectors/mengucci_nim_583_264_07.pdf

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

Isobutane (C_4H_{10}) 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. Due to flammability concern they are testing an alternative gas mix:

Ar/R134A/Iisobutane/SF_6 (64/32/3.5/0.5).

RPC Gas Flammability Analysis

During the BaBar detector construction SLAC hired Hughes Associates, Inc. to perform an analysis of flammability hazards for the entire detector.

The fire hazard associated with the use of butane (C_4H_{10}) gas mixtures in BaBar was one of the items. (Hughes report: Doc-DB #574)

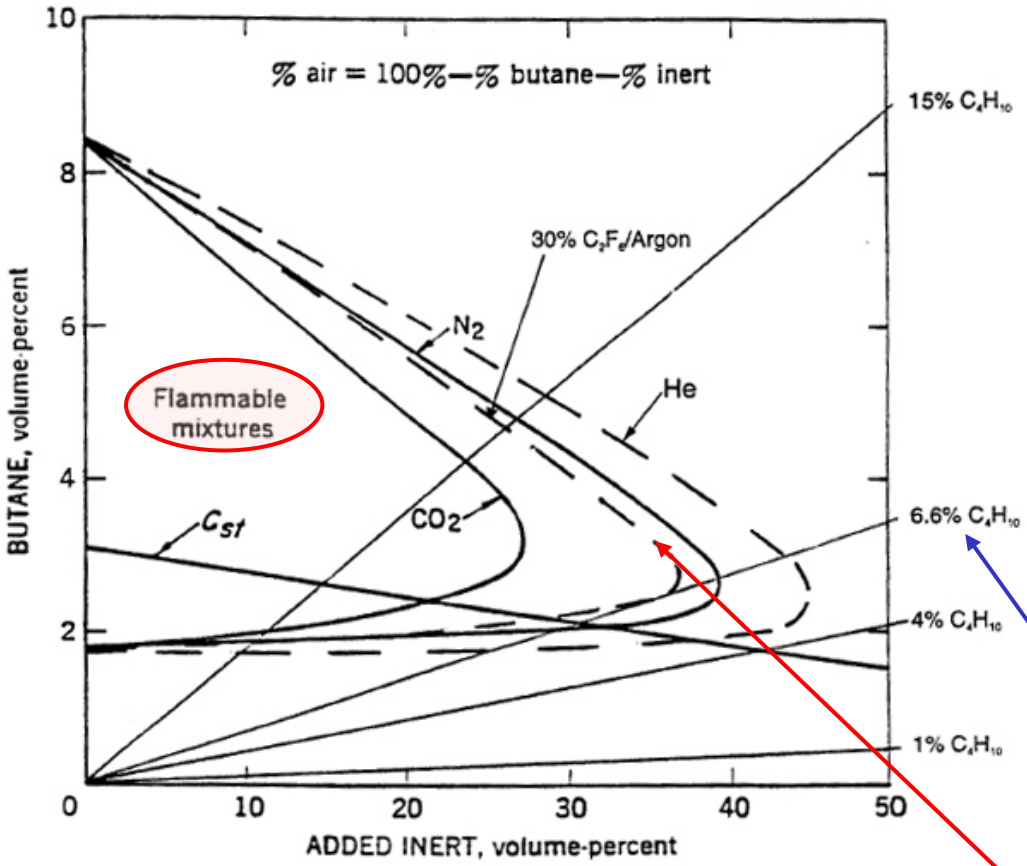
http://puhep1.princeton.edu/~mcdonald/dayabay/BaBar_gas_system/SLAC-FHA.pdf

Here we shall briefly mention the main conclusion that is relevant to our assessment.

Issue beyond the scope of this review:

Should the Daya Bay project commission a fire safety review for the entire experiment by a professional consulting firm?

Flammability Diagram for Butane with Argon/C_2F_6 in Air



The figure shows the flammability regions for several butane/inert gas mixtures in the air.

The curves for butane/N_2 and butane/CO_2 are from lab tests by the, Bureau of Mines (Zabetakis, Bulletin 627).

Any point in the plot corresponds to a gas mixture of **butane/inert gas/air** with the mixing ratio of **y/x/(100-y-x)**.

If the point falls into the corresponding flammable region, this mixture is flammable.

Hughes **calculated** the gas mixture of 30% C_2F_6/balance Ar with Isobutane, because C_2F_6 is very similar to R134A ($C_2H_2F_4$), especially in heat capacity.

The flammability limit of Isobutane in this gas mixture is 6.6%.

OPERA Gas Mixture Flammability Analysis

- The baseline gas mixture is the OPERA RPC gas Ar/R134A/Isobutane/SF_6 (75.5/20/4/0.5). But in a very conservative analysis we couldn't confirm it as non-flammable (DocDB #2000).

  http://puhep1.princeton.edu/~mcdonald/dayabay/Lu/DayaBayRPCGasSafety-06072008.pdf

- To be conservative we could use an alternative gas mixture: Ar/R134A/Isobutane/SF_6 (65.5/30/4/0.5).

  The previous slide shows this to be non-flammable.

  Recent tests done by OPERA RPC group (DocDB #2278) show a very similar gas mix with good performance and ~1000V HV plateau higher than original OPERA gas mix.

  Since our HV supply can provide +/- 4000V, this gas mixture won't call for any modification to the present RPC and HV design.

  http://puhep1.princeton.edu/~mcdonald/examples/detectors/paoloni_lnf-08-14.pdf

- The advantage of this gas mixture is obvious: the RPC system downstream from gas mixing panel won't need to be categorized as a flammable gas control area.

Number of Cylinders Underground

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

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

The following configuration ⇒ 60 bottles underground

[plus 3 more argon bottles for the Emergency Purge System (slides 24-26)].

Exp. Hall	Gas	Cylinder	Location	Days/90% of cylinder used
Near Hall	Ar	6 cyl. @1800psi	Mix. Room	30
	R134A	100kg	Storage Room	39
	Isobutane	9kg	Mix. Room	43
	SF_6	4kg	Storage Room	61
	He	Cyl. 80, 85 ft^3	Mix. Room	➢180 days
	N_2	Cyl. 80, 85 ft^3	Mix. Room	> 1 year
Far hall	Ar	6 cyl. @1800psi	Mix. Room	19
	R134A	100kg	Storage Room	25
	Isobutane	9kg	Mix. Room	27
	SF_6	4kg	Storage Room	38
	He	Cyl. 80, 85 ft^3	Mix. Room	➢180 days
	N_2	Cyl. 80, 85 ft^3	Mix. Room	> 1 year

Isobutane Gas Cabinet

As suggested by D. Beavis, isobutane cylinders will be stored in a gas cabinet, which incorporates have Class I, Div. 1 electrical devices, such as gas sensors, sprinklers, and solenoid valve.

In each gas cabinet we'll install two HAD sensors, two air-flow sensors, an electronic digital scale, a manual scale, and cylinder changeover panel.

In addition, the cabinet volume must accommodate two 9-kg Isobutane cylinders.

Unresolved issue:

Water sprinklers are recommended by the US Fire Safety Code, but are not foreseen in the Daya Bay civil construction.

A minimal solution would be a simple water pipe connected to the water sprinkler in the isobutane cabinet.

Isobutane Gas Cabinet (cont'd)

Features:

- All welded construction using 11-gauge steel, epoxy painted. Texture finish on outside, smooth finish on inside of cabinet.
- Exhaust vent located on top of cabinet is 6" diameter x 3" high.
- 165°F sprinkler head on top of cabinet is coated with bees wax.
- Removable white back panel mounts to inside rear cabinet.
- Cylinder brackets or lecture bottle brackets are adjustable for precise pig-tail alignment.
- Door and window will close and latch automatically.
- Window is 1/4" thick clear wire glass.
- Louvers at bottom of door.
- Flush mounted stainless steel paddle latch.
- All stainless steel fasteners.

Options:

- Dome roof configurations
- Keyed door latch
- Air intake filter
- Custom colors
- Wall mounting brackets
- Full-length back panel

SAFETY EQUIPMENT

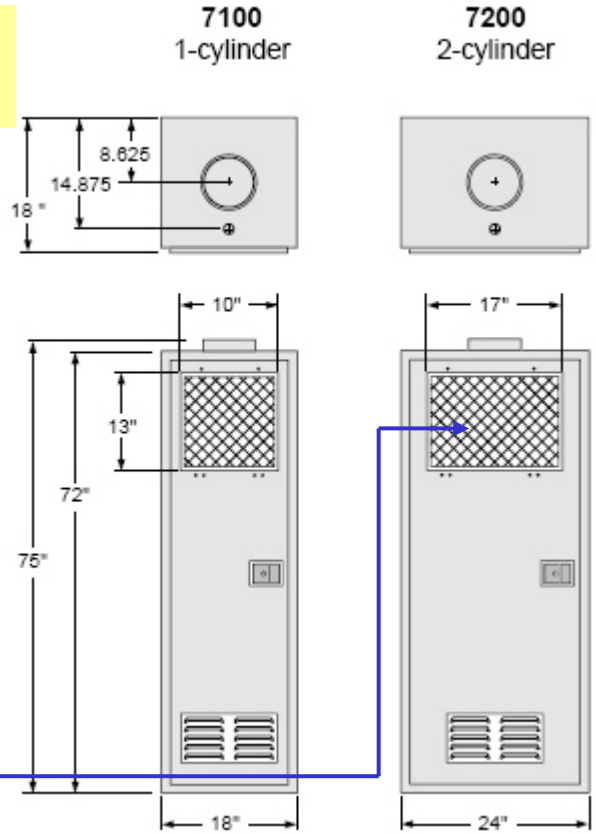
Safety Equipment Corporation
1141 Old County Road
Belmont, CA 94002

(650) 595-5422
Fax (650) 595-0143

E-Mail: Info@SafetyEquipmentCorp.com
Web: SafetyEquipmentCorp.com

ventilation duct

Fresh air in



The Uniform Fire Code requires 150-200 linear ft/min of air through the window opening, that should be provided by the experimental hall ventilation system.

$1300

This is the lowest quote we have obtained to date.

Isobutane Gas Cabinet (cont'd)

GTS-WELCO S5000-2

$1920.

HOW TO ORDER

Model	Description
7100	one cylinder cabinet
7200	two cylinder cabinet

SGD 7200, $2376.

HAD Sensor

One candidate of such HAD sensor is RAEGuard LEL.

The **RAEGuard LEL** is a permanently mounted (fixed) catalytic bead combustible gas transmitter that operates from 9 to 36 VDC power source and provides a 4-20mA analog output in the range of 0-100%LEL combustible gas. The microprocessor based circuit is housed in an explosion-proof enclosure, the **RAEGuard LEL** is equipped with a local digital display of the gas concentration and function keys for performing calibration. The **RAEGuard LEL** is operated with a standard 4-20mA controller or as a stand-alone sensor module.

Key Features

- Highly poison-resistant catalytic bead combustible gas LEL sensor
- 4-20mA analog output of 0-100%LEL combustible gas including methane, acetylene, propane or other combustible gases
- Explosion-proof enclosure for hazardous environment application
- Magnetic key interface eliminates need to open explosion-proof housing when making calibration or other minor adjustments
- Operation at 9 to 36 VDC
- Dry contact output (<30V, 2A)

Applications:

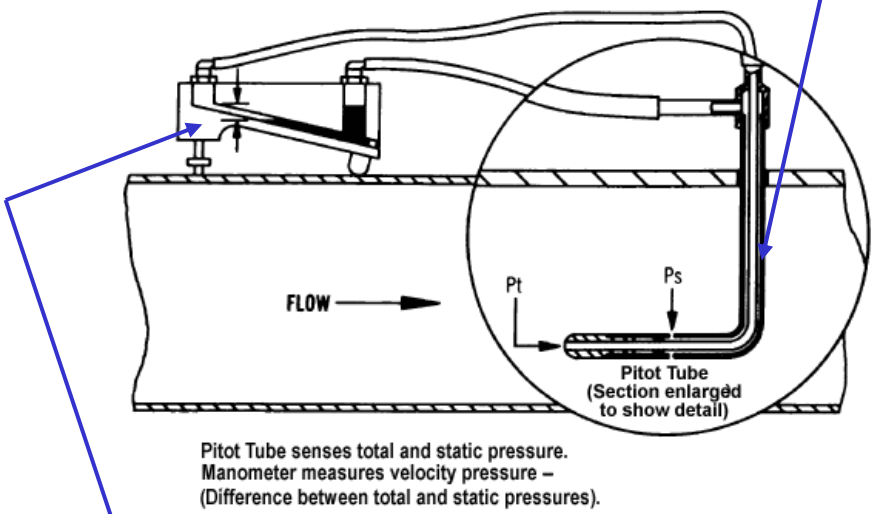
- Refineries
- Oil production
- Chemical plants
- Industrial safety
- Shipyard and maritime
- Power plants
- Steel mills

Hazardous Location Classification:

- UL: Class I, Division 1, Groups B, C and D
- Temperature Code T6

Air Ventilation Sensor and Controller

Working principle: Pitot tube to measure the air velocity.



Pitot Tube senses total and static pressure.
Manometer measures velocity pressure –
(Difference between total and static pressures).

Pt is the total pressure, Ps is the static pressure.
Notice the sensing holes for these two pressures.
The manometer shown on the left can measure the pressure difference between Pt and Ps, this is Pv, the air velocity pressure.

Dwyer model Photohelic 3000SGT pressure transmitter/controller

Isobutane Gas Cabinet Cost Estimate

Purchase of 3 cabinets (+ shipping to Princeton)	$4800
Sensor cost appears in the Gas System Crate budget	
Labor to install sensors, scales, changeover gear	$2400
Shipment to Daya Bay	$5000
Total cost (3 systems)	$12,200

Important issue:

IHEP must specify the dimensions of the isobutane cylinder before we can order a gas cabinet.

Outfitted Gas Cabinet

Cylinder Cabinets
Standard Configurations:

- 1-cyl, [1-process]
- 2-cyl, [1-process, 1-purge]
- 2-cyl, [2-process]
- 3-cyl, [3-process]
- 3-cyl, [2-process, 1-purge]

Gas Panel Purity
Standard Configurations:

- UHP: panels & manifolds are orbitally welded/VCR® construction, 316L SS [20Ra]
- Industrial SS: panels & manifolds are threaded construction [316SS]
- Industrial BP: panels & manifolds are threaded construction [brass or plated]

UHP Gas Panels
Standard Configurations:

- 3-Valve design [HP vent]
- 4-Valve design [adds PURGE]
- 6-Valve design [adds EVAC]

UHP Gas Panels
Options:

- 10Ra surface finish
- Dual stage regulators
- Outlet filters
- DISS cylinder fittings

Industrial Gas Panels
Standard Configurations:

The FlexGas™ Gas Cabinet is designed to cover the widest range of cylinder gas storage & delivery applications. SDC, a time-proven manufacturer of safe, high quality gas cabinets & gas delivery systems for the 1st-Tier semiconductor industry, has seen the need for similarly safe & clean systems in other industries. As codes, local regulations and insurance guidelines tighten, more sophistication and control is required from what was once a *"strap a cylinder to the wall"* philosophy! SDC's modular design concept allows the customer to tailor each system to meet their safety, process, purity AND budgetary goals. The simplest industrial shop system may be configured with a 1-Valve brass gas panel in an exhausted enclosure. More complex

D. Beavis notes that BNL has purchased a FlexGas cylinder cabinet from SDC.

We have contacted SDC, who will quote on a customized cabinet to fit our application.

The "turnkey" cabinet would include a HAD sensor, air flow sensor, digital scale, changeover panel, etc.

We also have asked Praxair to quote on an outfitted cabinet.

Quote from SDC

FlexGas™ Manual/Semi-Auto Gas Cabinets				
Item#	Description	Qty	Unit Price	Extended
1.1	FlexGas™ Gas Cabinet: • Manual 2-Cylinder Independent Out with Onboard Purge configured as [C_4H_{10} – N_2] • Configured with a 4-Valve Process Panel for C_4H_{10} (includes manual PURGE) • Configured with a 2-Valve Purge Panel • Includes *FlexPowr ™ Controller* Option ➢ Touch Screen Display ➢ Eight (8) spare "user configurable" inputs ➢ Eight (8) spare "user configurable" outputs ➢ EMO • (see attached *Product Specification Checklist* for details and *Product Data Sheet* for additional information)	1	$12,430.00	$12,430.00
	(configuration options):			
1.2	• Adjustable Cylinder Shelf (for cyls <51" tall, per cyl.)	1	$165.00	$165.00
1.3	• Integrated Cylinder Scales (per liquefied gas)	1	$960.00	$960.00
1.4	• Onboard Gas Monitoring (combustibles only, per gas type, uses an ALARM INPUT)	1	$595.00	$595.00
1.5	• Onboard Gas Monitoring (non-combustibles, per gas type, uses an ALARM INPUT)	1	$1,730.00	$1,730.00
1.6	• UV/IR Fire Detection Sensor (per cabinet, uses an ALARM INPUT)	1	$2,900.00	$2,900.00
	(gas panel options):			
1.7	• Excess Flow Switch (per panel)	1	$540.00	$540.00
1.8	• Cylinder Pressure Switch (per panel)	1	$295.00	$295.00
1.9	• Dual Stage Regulator (single stage std., per process panel)	1	$350.00	$350.00

Cost ≈ $17k/site, or $51k for three Isobutane cabinets.

Cylinder Scale Safety Issue

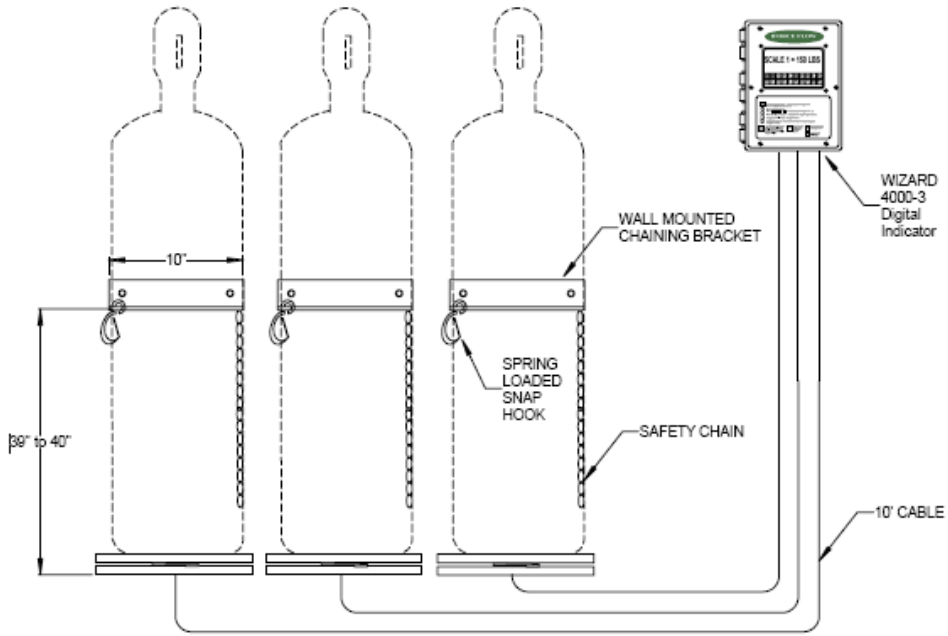
In the RPC gas mixture, the other three gases besides argon are actually in the liquid phase. We will use their vapors.

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.

For isobutane this poses another safety issue: the electronic cylinder scale must meet the Class I, Div 1 standard.



Force Flow model WR200-3HA with Wizard 4000-3 indicator is a candidate: $5150.

INTR-BARR (intrinsic safety barrier) for electronic scale, which is only needed for Isobutane): $1165.

The relays in the indicator will be used in the gas status crate to warn the shift taker to changeover the depleted cylinder when the weight drops below the preset limit.

Standby Cylinder Scale

[Not a safety issue, but a small change to the gas system baseline.]

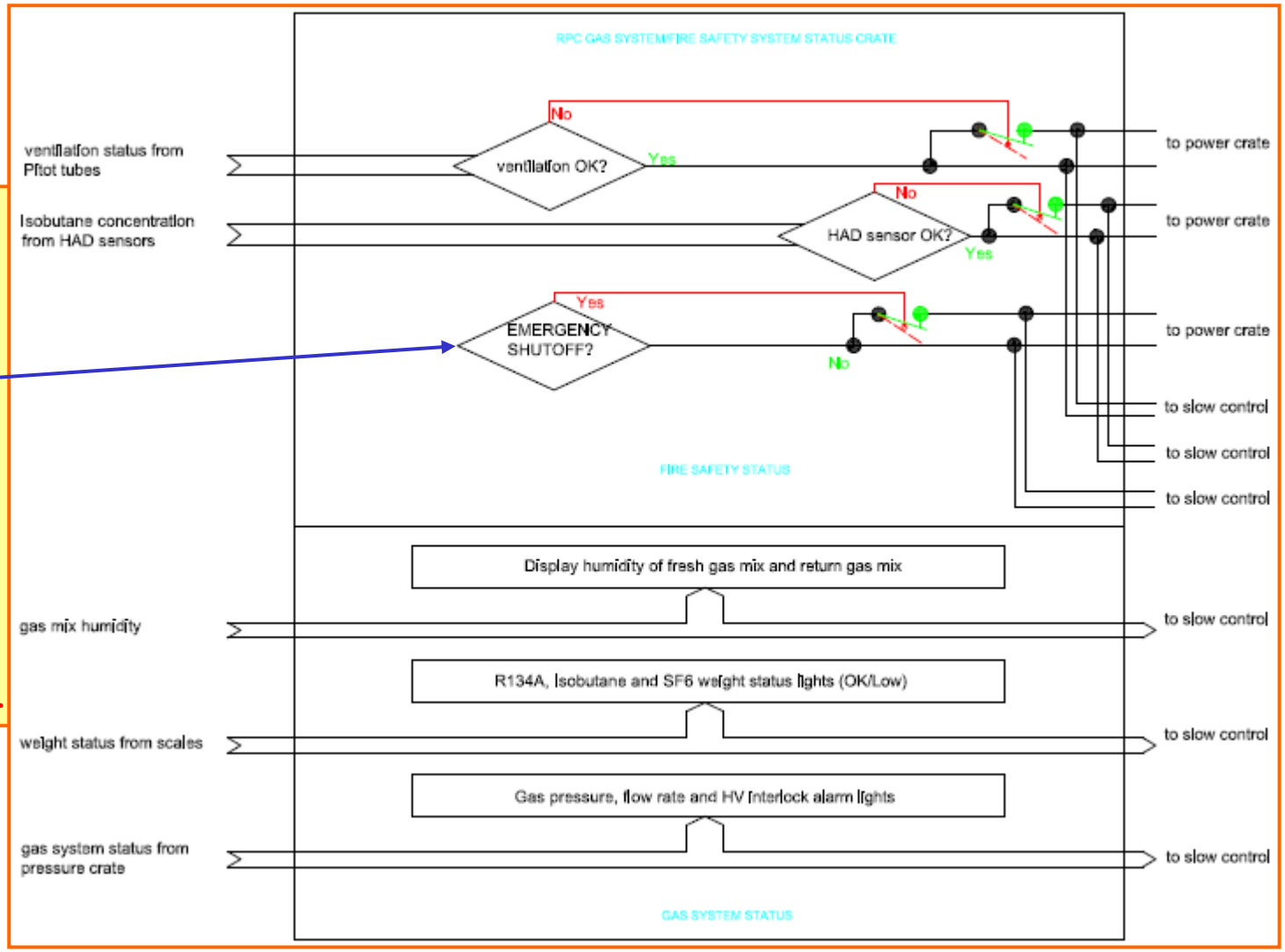
To lower the cost of the cylinder scales, the second cylinder of each pair of R134A, Isobutane and SF6 cylinders will be used only briefly during a changeover; then the new, first cylinder will be brought online.

The standby cylinder can be weighed by a simple mechanical scale.

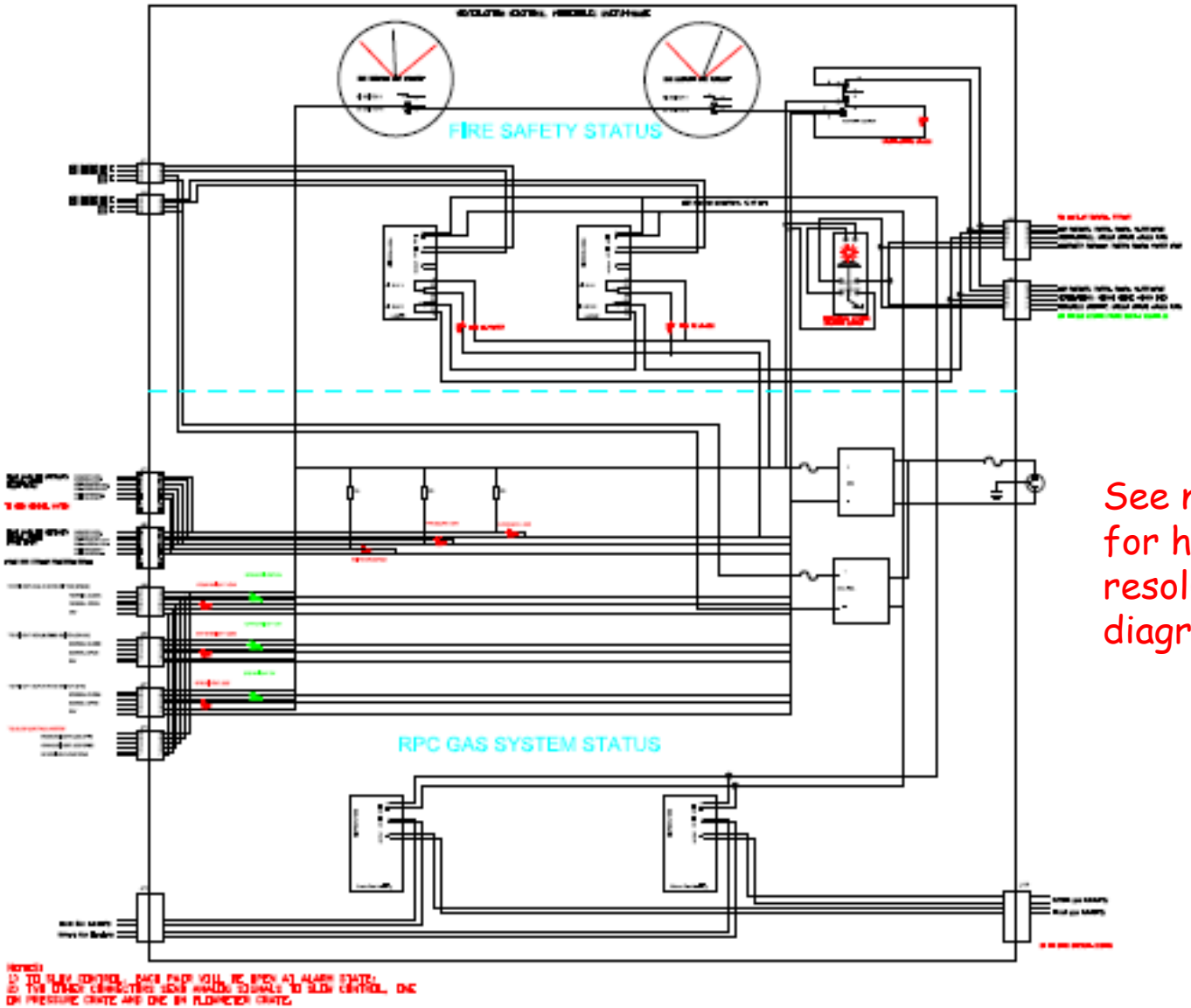
Gas System Status Crate — Logic Diagram

Fire safety interlock function:

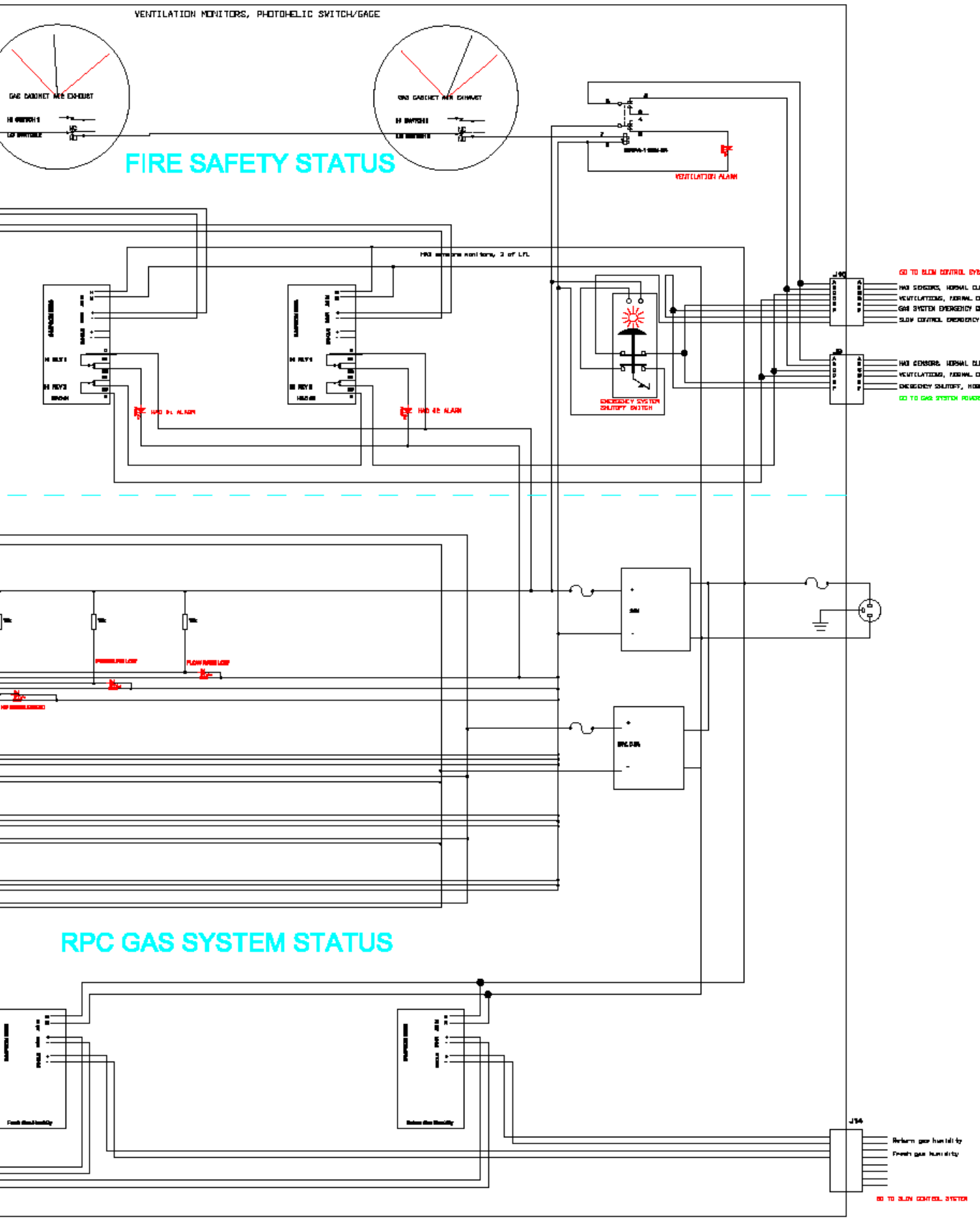
If the Emergency Shutoff button is pushed, all four gases will be shut off simultaneously.



Gas System Status Crate Wiring Diagram



See next slide for high resolution diagram.



TATE)
NTROL, ONE

Cost Estimate of the Status Crate

			GAS SYSTEM STATUS PANEL							
Part Discription	**QTY**	**PRICE ea**	**DISTRIBUTOR**	**DISTRIB #**	**TOTAL PRICE**	**SOURCE OF QUOTE**	**Sub-total**	**# of sets**	**Total**	**Grand total**
24V converter	1	$95.00	Newark	83F2437	$95.00	Lambda kwd15-1212	$5,286.89	3	$15,860.67	$44,466.15
conn 12pin male-female	1	$10.00			$10.00					
conn 4pin male-female	5	$10.00			$50.00					
conn 8pin male-female	3	$10.00			$30.00					
Fuse	4	$5.00			$20.00					
krpa-11dn-24	1	$12.44	Newark	21F1087	$12.44	TYCO_Relay_KHAU_11DN				
LIGHT	14	$2.00			$28.00					
Power Socket	1	$5.00			$5.00					
HAD sensor (EX-5100)	2	$1,145.00	Enmet Corp.		$2,290.00	Email quote from Enmet. Http://www.enmet.com				
Simpson H335	4	$265.00			$1,060.00	Email_quote_Simpson_meter				
Photohelic 3000SGT	2	$418.00	Dwyer Instruments		$836.00	http://www.dwyer-inst.com/htdocs/pressure/Series3000Price.cfm				
Pitot tube (160-8)	2	$46.75	Dwyer Instruments		$93.50	http://www.dwyer-inst.com/htdocs/airvelocity/Series160Price.cfm				
Mounting accessories for Pitot tube	2	$48.50	Dwyer Instruments		$97.00	http://www.dwyer-inst.com/htdocs/airvelocity/Series160Price.cfm				
Humidity sensors w/ Swagelok Tee	4	$100.00	Honeywell HIH-4000-003	ewark SKU 15M02	$400.00	http://www.newark.com/				
Weather Pro Center, WS-2315	1	$259.95	La Crosse Technology		$259.95	http://www.lacrossetechnology.com/2315oak/index.php				
Front Panels 6u (19"x10.5")	1	$42.00	Newark	25B6425	$42.00	BUD PA-1106-BT	$538.00	3	$1,614.00	
Panel Silkscreening	1	$200.00			$200.00					
PCB board (size 150 sq"??)	1	$296			$296.00					
Electric weight scale system	1	$5,150	Force Flow		$5,150.00	http://www.forceflow.cor	$5,150.00	3	$15,450.00	
Mechanical scale	3	$250			$750.00		$750.00	3	$2,250.00	
Intrinsic safety barrier	1	$1,170	Force Flow		$1,170.00		$1,170.00	3	$3,510.00	
HAD sensor calibration equipment	1	$265.00			$265.00	Email quote from Enmet.	$265.00	1	$265.00	
Labor	hours	charge/hour			Total cost					
PCB designs	16	85.82			1373.12		$5,516.48	1	$5,516.48	
panel deigns	8	85.82			686.56					
EP Lab	16	87.32			1397.12					
Assembly	24	85.82			2059.68					

Includes cost of the HAD sensors and air flows sensors for the Isobutane cabinets.

Emergency Purge System

As suggested by D. Beavis, an emergency activation has been added to the RPC gas purging system.

Even though the RPC gas is non-flammable, fire fighters might wish to have the option to purge the RPC gas from the chambers.

Limitations of flow orifices imply that such purging would take 7 hours in the Near Hall and 10 hours in the Far Hall.

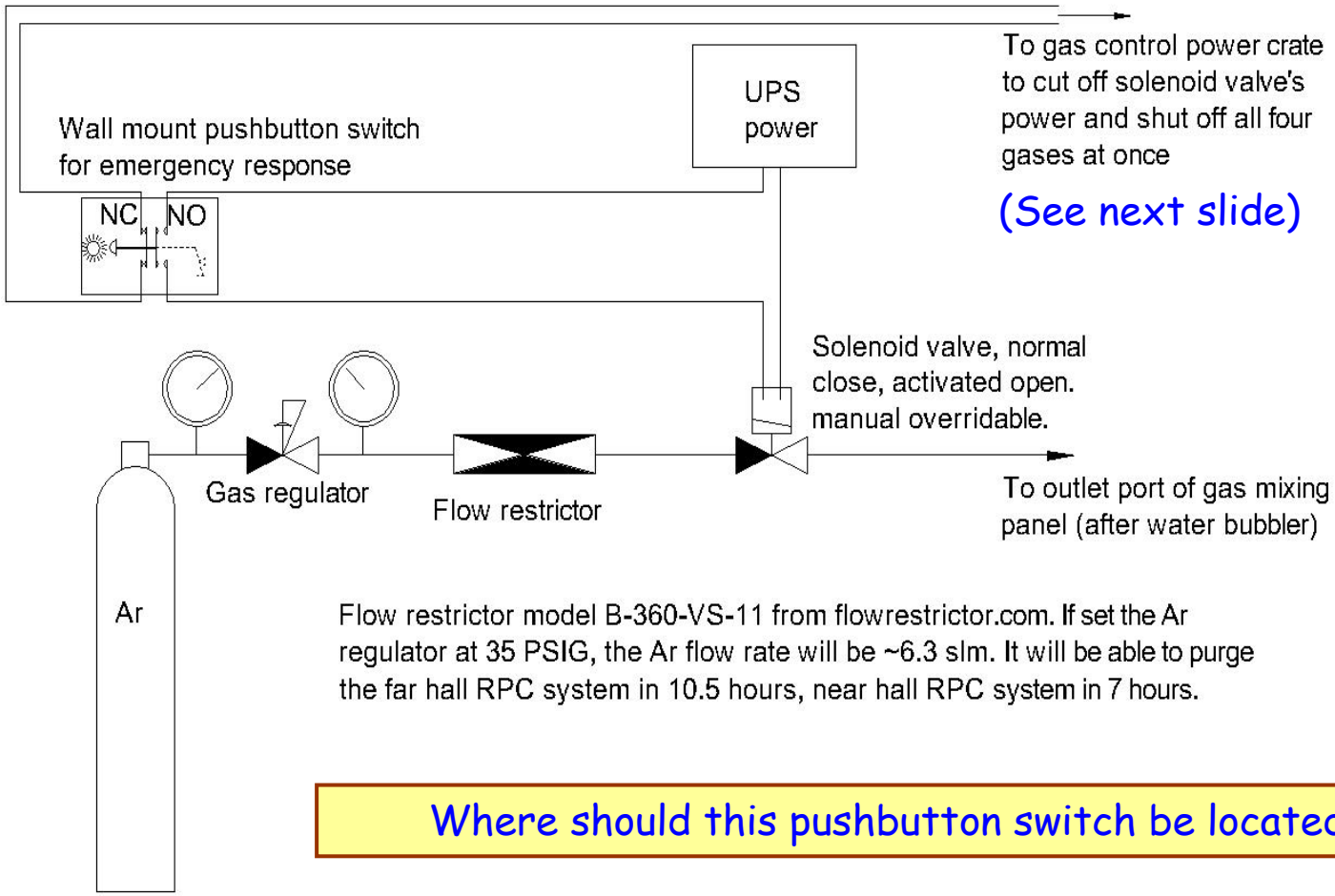
Once the Emergency Purge button has been pushed, the gas cylinders that provide the normal 4-component gas mixture will be shut off immediately. The RPC chambers will enter then a purge mode in which only Ar gas flows into RPC system at the above mentioned rate. Because the overpressure protection bubblers are still functioning, RPCs won't be damaged by this action.

There is a standalone Ar gas cylinder to provide the purging gas. This cylinder will have a gas regulator and a flow restrictor installed. The emergency push button opens a solenoid valve, which controls Ar gas flow to the $\frac{1}{2}$" OD S.S. tubing at the outlet of gas mixing panel.

Since this apparatus should work during an emergency situation, a UPS power supply must be used to provide the power for the solenoid valve.

On slow control system there will be a software button, the shift taker can shutoff (purging as well?) the entire RPC gas system through this button in emergency response.

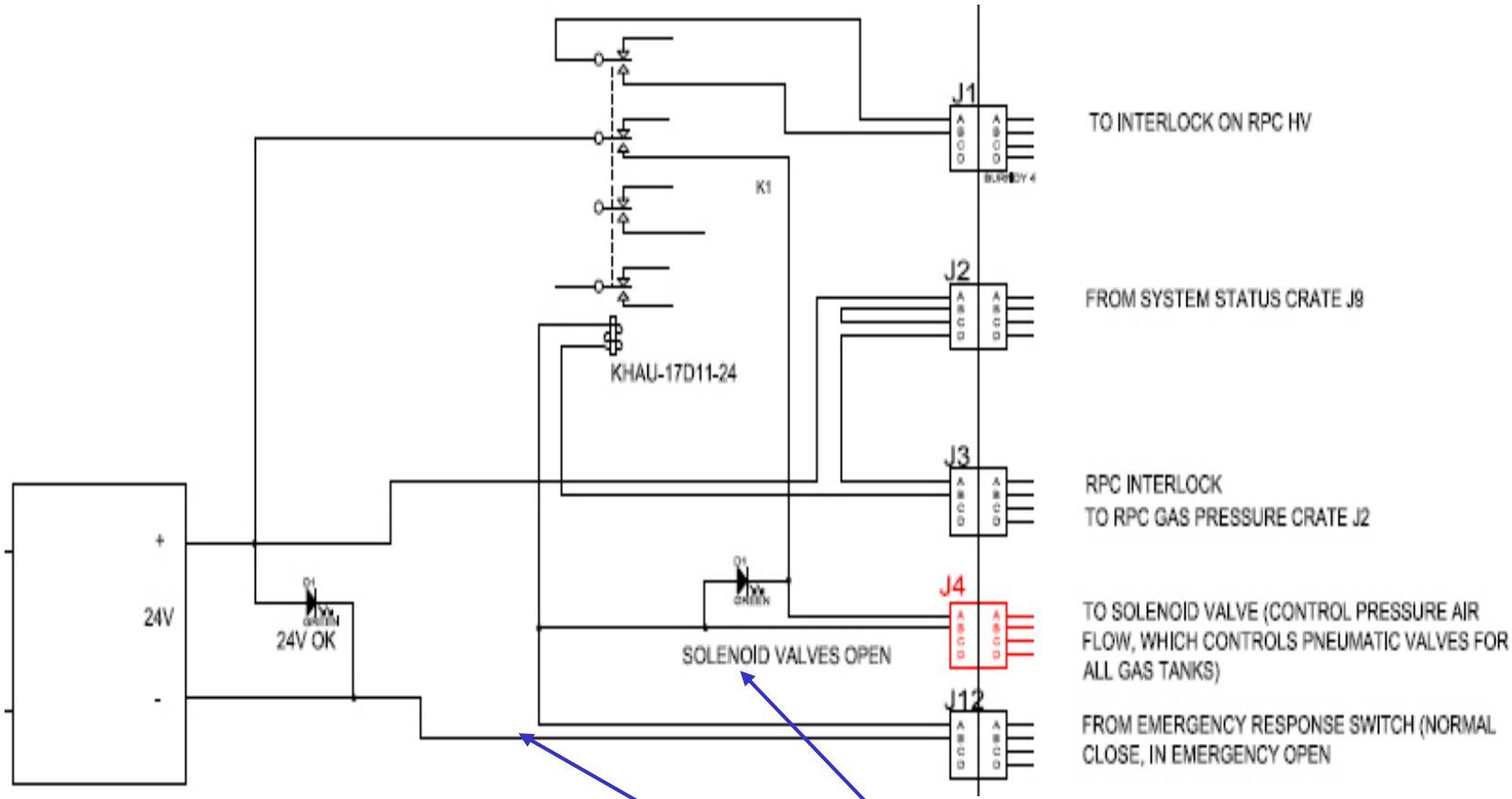
Emergency Purge System



Where should this pushbutton switch be located?

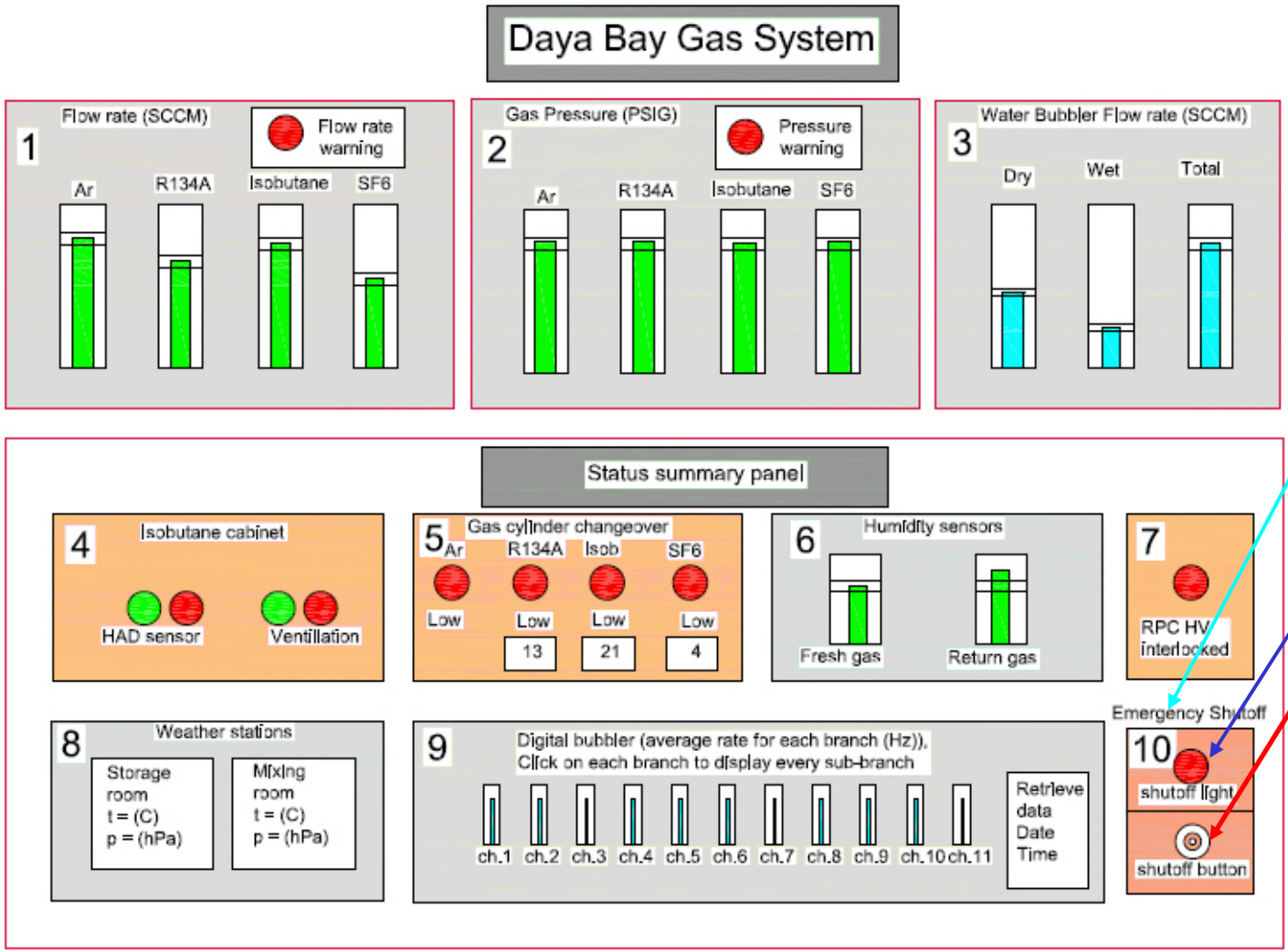
One cylinder of Ar can provide more than 3 volumes for the Far Hall RPCs and almost 5 volumes for Near Hall RPCs, so just one cylinder should be enough for this system in each Hall.

Emergency Purge System (cont'd)



When the emergency button is pushed, the flow of four gas components is halted, and flow of purge argon is initiated.

Gas slow control system GUI



All meters and indicators on screen are passive but this Emergency Shutoff Block.

If this red light is on, it means the hardware shutoff button has been pushed manually.

If for some reason the shift taker needs to push this software button, a warning sign must appear to remind the user the consequence of this action, upon receipt of the confirmation the relevant hardware action takes place.

Cost Estimate of the Emergency Purge System

Description	Price/each	Distributor	Model #	Qty	Total	Total/set	# set	Total cost
Pushbutton switch	13.17	Newark	C&K 1.30.070.121/130	1	13.17	1270.99	3	3812.97
Contact block	13.61	Newark	C&K 1.20122.0210000	1	13.61			
Gas regulator	225.9	GTS-WELCO	S158-1 0-50PSI	1	225.9			
Flow restrictor	100	flowrestrictor.com		1	100			
UPS power	110	APC		1	110			
Solenoid valve	66.75	Peter Paul	22K7YGM-220VAC	1	66.75			
1/4" NPT to Swagelok	25	Swagelok		1	25			
Wall box	30			1	30			
Labor	85.82			8	686.56			

RPC Gas System Cost Summary

Gas system status crates	($44,466)
Isobutane cabinets*	($12,200)
Emergency purge systems	($3,812)
Total cost	$60,478.

* Add $40k if use turnkey Isobutane cabinets.