Daya Bay RPC gas system design report

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The RPC gas system will be similar to that used in the BELLE [1] and BABAR [2] experiments, in which a gas mixing systems distributes gas to the individual RPCs through simple "flow resistors", with the output flow from each chamber separately monitored by a low-cost electronics bubbler [3]. A high-level diagram of the system is given in Fig. 1.

Mixing of the chamber gases is performed with mass flowmeters, as sketched in Fig. 2. It will be advantageous to use "drop-in" modular mixing components recently developed for the semiconductor processing industry, such as the Integrated Gas System of Fujikin [5].
The electronic bubbler system [3] monitors the chamber gas flow by counting gas bubbles in a small oil bubbler as they pass a photogate, as indicated in Fig. 3. Detailed histories of the input and output gas flow will be available via the online slow-control system. The gas will be input from multiple, switchable sources to minimize interruptions of the gas flow during chamber operation. However, the gas flow rate will be only 1 volume per day, so that short interruptions of the flow will be of little consequence.

An extensive safety system with status monitors and interlocks will be implemented via the slow-control system. For a recent example of a muon-chamber-gas safety system, see [4].

1. Major gas system parameters

Daya Bay neutrino experiment has three experimental halls, two near halls and one far hall. The near hall RPC system will cover an area of 12 x 18 m^2 with four layers of 1 x 2 m^2 RPC chambers, and the far hall will cover larger area of 18 x 18 m^2.

The basic design assumption is the normal gas flow rate at 1 volume change/day. When we choose the gas flow controllers we put the possible 3 times larger gas flow rate into consideration. The major gas system parameters are listed below:

Common to both near and far halls:
Number of RPCs/Gas branch $N_b = 4$,
Gas volume/branch $V_b = 0.016$ m^3, 1 volume/day = 0.016/(3600*24) = $1.85*10^{-7}$ m^3/sec,
RPC module size $A_m = 4$ m x 6 m,
Number of RPCs/module = 48,
Gas branches/module $B_m = 12$,
Number of branches/gas distribution panel = 16,

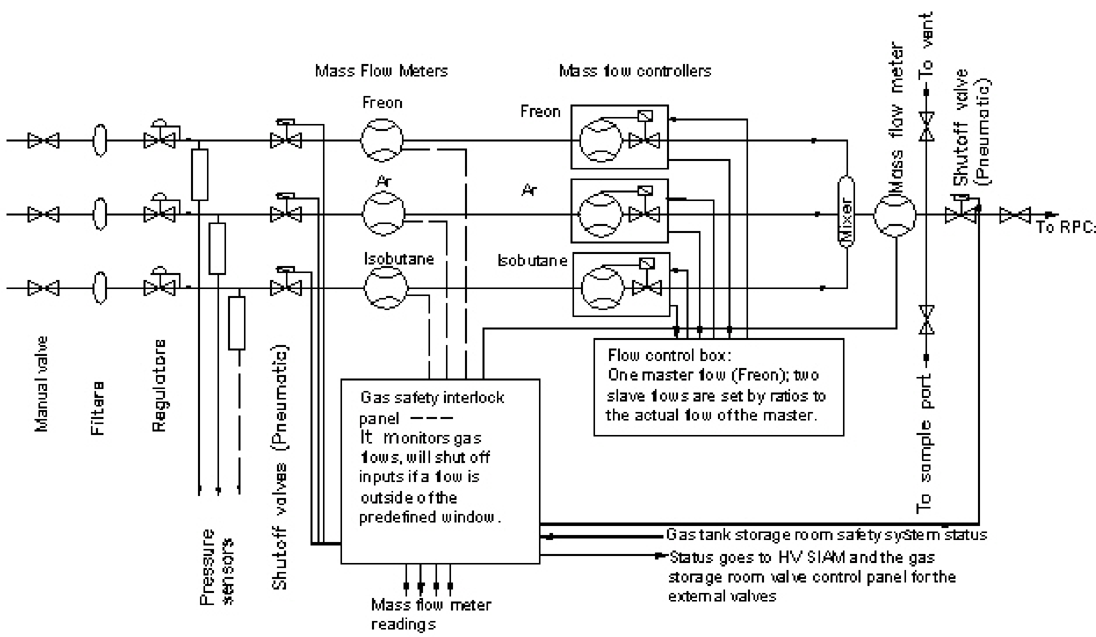
Far hall:
Total number of RPC = ~700,
Total gas volume = 2.8 m^3,
Total number of modules (4 x 6 m^2) in far hall = 3 x 5 = 15,
Total number of gas distribution panel = 12.

Near hall:
Total number of RPC/near hall = ~432,
Total gas volume/near hall = 1.73 m^3,
Total number of modules/near hall = 3 x 3 = 9,

Total number of gas distribution panel/near hall = 7.
Total number of gas distribution panels for one far hall and two near halls is 12+14 = 26.

2. Gas mixing system

The gas mixing system diagram is shown in fig. 1. We have incorporated the BaBar RPC/LST gas system experience and Daya Bay RPC system's requirement to design our own gas system. We are still facing two possible options: conventional gas mixing system panel construction and a new breed of Integrated Gas System (IGS) solution. The finished system may look similar as shown in Fig. 2 for conventional panel and Fig. 3 for IGS panel.



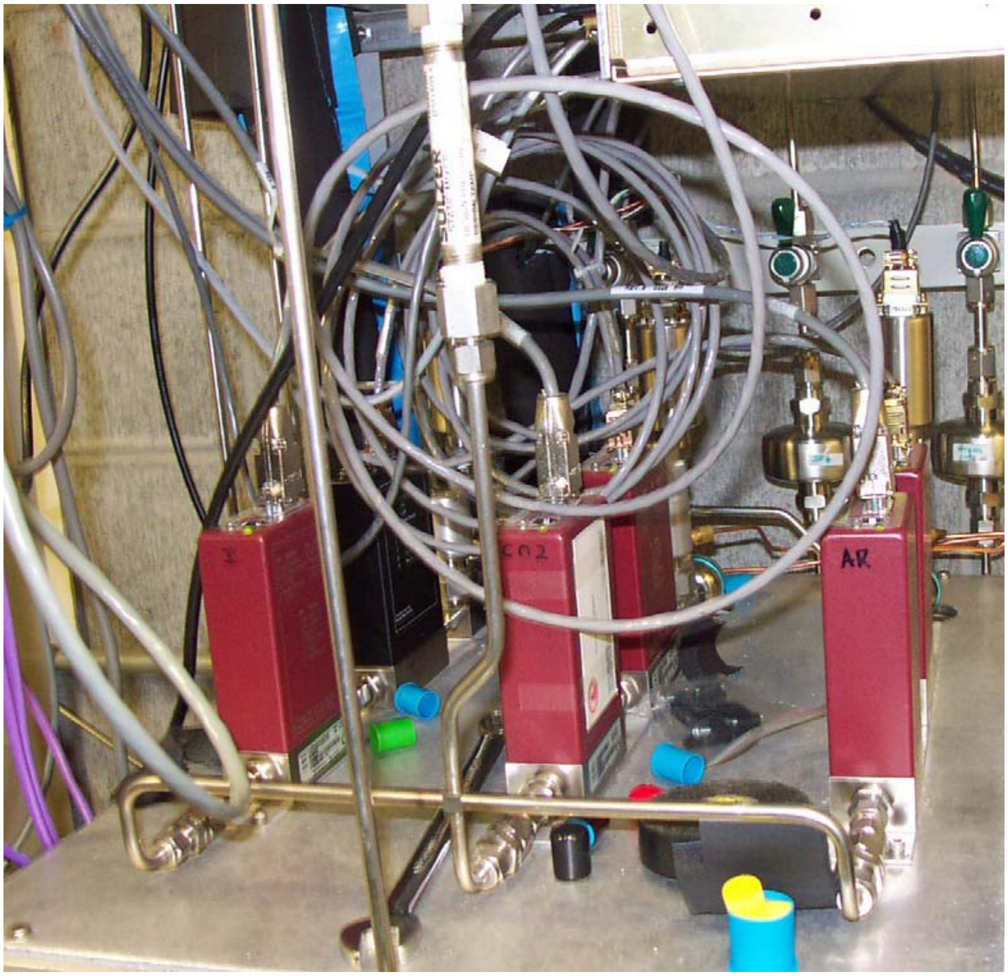


Figure 2. Conventional gas system panel.

Figure 3. Gas system panel constructed with IGS technology.

Budget for gas mixing system

We list the material cost for one such mixing system in the Table 1. The labor cost is not included. To construct one of such system, the panel design and assemble need 100 hours of our machine shop. The main components for two construction options are the same. The additional cost for the standard building blocks needed in IGS is used to trade the labor cost and fittings in the conventional option. The overall cost should be more or less the same.

Table 1. Budget estimation for one gas mixing system with conventional building technology (labor cost not included).

Subsystem	Item	Specs	Price/unit	# of unit	Cost/item	Subsystem
Gas mixing Rack						19058
Components						
	1479 Mass Flow Controller	Full range 3.0	1503	1	1503	
	1479 Mass Flow Controller	Full range 1.0 SLM	1503	1	1503	
	1479 Mass Flow Controller	Full range 0.5 SLM	1503	1	1503	
	179A Mass Flow Meter	Full range 3.0 SLM	983	1	983	
	179A Mass Flow Meter	Full range 1.0 SLM	983	1	983	
	179A Mass Flow Meter	Full range 0.5 SLM	983	1	983	
	Gas Pressure Sensor	Type 890 single-ended, absolute	556	3	1668	
	247D four channel Power Supply/Readout		1482	1	1482	
	Line gas regulator		400	3	1200	
	Line gas filter		200	3	600	
	Manual shutoff valve		150	3	450	
	Solenoid shutoff valve		150	4	600	
	Gas mixer		600	1	600	
	Heaters(isobutane and Freon)		400	2	800	
	Gas regulator for gas tank		400	3	1200	
	Valve power supply		100	1	100	
	Line check valves		150	3	450	
Rack construction						
	Swagelok/VCR fittings ($10-20/fitting)				1500	
	S.S. tubing ($8/ft)				750	

3. Gas distribution system

The gas mixture after the mixing system needs to be distributed to every RPC in an experimental hall. The design goal can be summarized as following:

- Uniformly distribute the gas mixture to every RPC in the system;
- Divide the entire RPC system into branches that should be isolated from each other. In case of one branch has leaky RPC the rest of the system should not be affected;
- The RPCs in the same branch are better to be in parallel, not in series, to prevent the poison gas produced in upper stream polluting the down stream chambers;
- At the end of each branch should implement a monitoring device to check if there is any leaky RPC.

A sketch diagram of the gas distribution system is shown in figure 4.

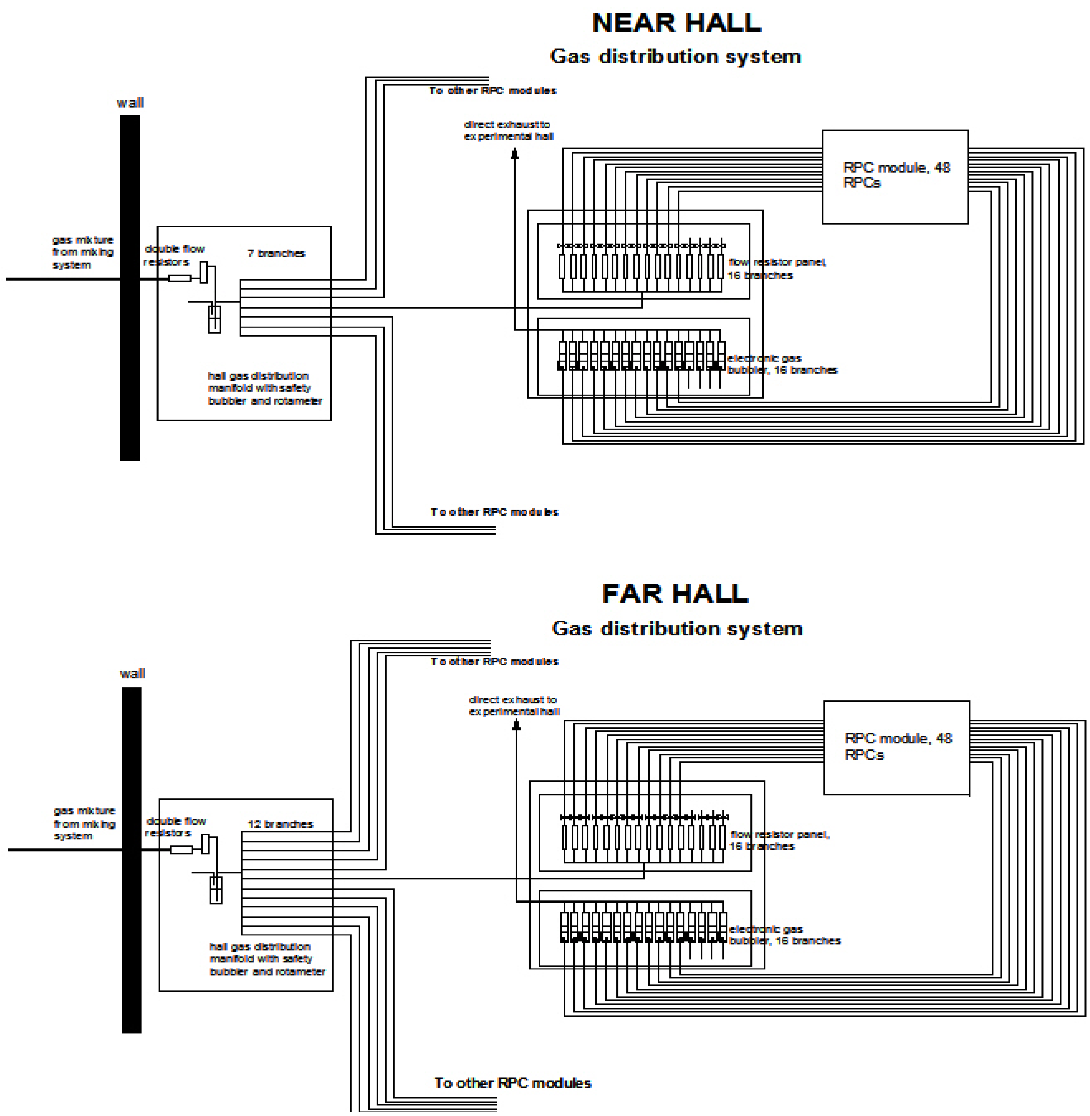


Figure 4. Daya Bay near and far hall RPC gas distribution system sketch diagram.

In far hall the main gas manifold provides 12 branches, each of which will come to a 16-channel flow resistors panel. A S.S. capillary with 0.01" diameter bore and 5cm length serves as flow resistor. Because the flow resistance of this capillary is much higher than the rest in the gas path, even there is a leaky RPC in the down stream, it will not affect the overall flow resistivity for this branch. 12 out of 16 flow resistors on the panel will be connected to an RPC module, which consists 48 RPCs. Each flow resistor provides gas mixture to 4 RPCs. To ease the gas tubing interconnection these 4 RPCs are connected in series. The gas outlet from this sub-branch will return to a digital bubbler panel, which is mounted on the same rack as flow resistor panel. The digital gas bubbler can count the rate of the output bubbles, therefore can record the returning gas flow rate. The detailed structure and circuit diagram of this digital gas bubbler can be found in [6].

In near hall the main gas manifold provides 7 branches. The rest of the system is just the same as far hall's.

The double flow resistors in front of the gas manifold is used to keep the gas pressure in the input gas tubing higher, therefore the whole long tubing can be served as an input gas buffer.

Budget for gas distribution system

The construction of gas distribution system includes two main tasks: 1, Installation of gas transporting pipe from gas control room to the experimental hall, 2, manufacture of the flow resistor's panels and digital bubbler's panels.

According to the source loaded DB Integrated Schedule (see Appendix 3) the first task will be constructed by IHEP. The second task is Princeton's responsibility. Main expense will be the labor cost. All parts need to be made at Princeton machine shop, and the whole system will be assembled at Princeton. Total we need to build 26 gas distribution panels, each of which includes one 16-channel flow resistor panel and one 16-channel digital bubbler panel.

4. Hazardous Atmosphere Detection (HAD) System

We will use the same hazardous atmosphere detection system for BaBar as our Daya Bay safety system.

All HAD sensors are connected to their display/controllers on the HAD control panel as shown in figure 5 (4).

We use VME Summary Interlock and Alarm Module (SIAM) as the interface of its gas safety hardware system to the slow control system. The SIAM is a VME compatible module which can generate an output signal (trip) based on the latched state of eight input conditions (faults). Several modules can be daisy-chained to form a larger set of input conditions. Detailed description of SIAM can be found from this link http://www.slac.stanford.edu/BFROOT/www/Detector/DAQ/Det_Cntrl_Monitor/siam/siam.html

Since this gas safety system need involve the effort from several different institutions and subsystems, it is pending for the collaboration wide discussion.

5. Slow control of the gas system

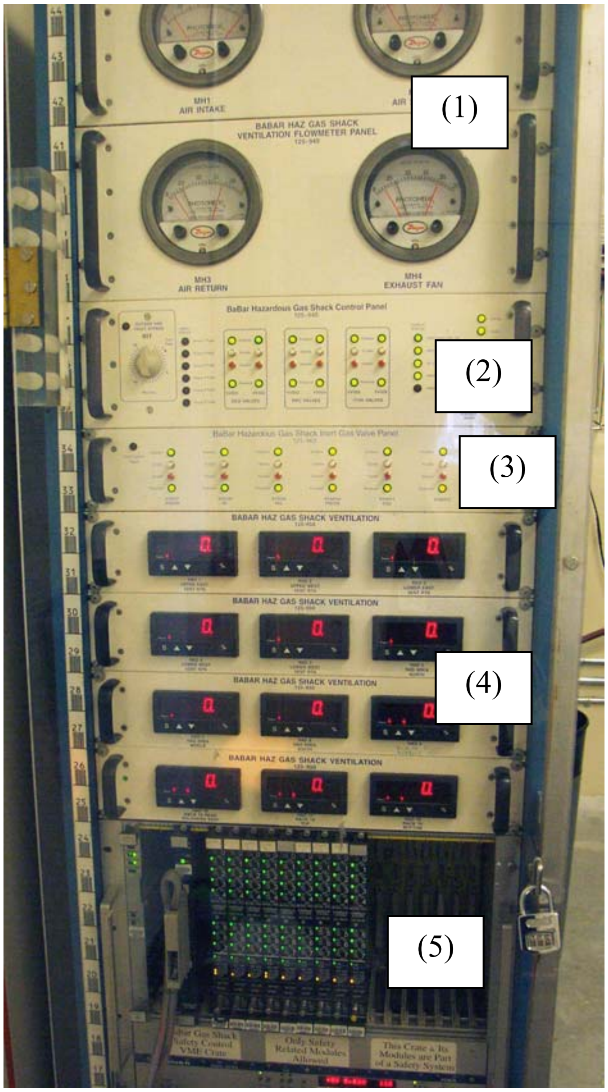


Figure 5. BaBar gas safety display/interlock panel.

(1) Ventilation flowmeter panel;

(2) Gas storage room hazardous gas control panel ;

(3) Inert gas valve panel;

(4) HAD sensor display/control panels;

(5) SIAM modules.

For the Daya Bay RPC detector we need slow control system for gas status monitor and on-line emergency control, HV monitor/control and on-line RPC performance. monitoring. Here we only consider the gas slow control part.

What need to be monitored and controlled for the RPC gas system?

- Gas flow rate for three or four components and the total flow rate for the gas mixture;
- Gas pressure at the gas supply end to avoid running out of the gas without noticed;
- Ventilation air flow rate monitoring;
- HAD sensors monitoring;
- Gas tank storage room temperature monitoring.

References

1. A. Abashian *et al.*, Nucl. Instr. Meth. **A449**, 112 (2000).
2. S. Foulkes *et al.*, Gas system upgrade for the BaBar IFR detector at SLAC, Nucl. Instr. Meth. A **538**, 801 (2005).
3. M. Ahart *et al.*, Flow Control and Measurement for RPC Gases, Belle Note 135 (Aug. 26, 1996), http://wwwphy.princeton.edu/ ~ marlow/rpc/gas/flow.ps
4. R. Messner, The LST Gas Mixing System(Oct. 4, 2004), http://puhep1.princeton.edu/ ~ mcdonald/dayabay/BaBar gas system/messner LST gas system.pdf
5. Fujikin Integrated Gas System Brochure, http://www.technofittings.com/pdf/igs/igsbroc.pdf
6. C. Lu, Proposal for making a prototype of the Daya Bay RPC gas system, DYB-doc-743-v3.

Appendix

1, Pressure drop in 10m long ¼" tubing

The general formula of gas flow (full developed laminar flow) Poiseuille's law:
$Q=(\pi*D^4/(128*\mu))*(P1-P2)/L$,
where
D (diameter of the tubing) = 0.17"=0.004318m, (1/4" OD tubing, 0.17" ID)
μ(viscosity of the air) = 1.85*10^(-5) (N*s/m^2), our gas mix may be different, but should in same order of magnitude,
P1-P2 = ΔP(N/m^2), pressure difference between gas inlet and outlet,
L (length of the tubing) = 10m, actually the flow resistance of the RPC system is mainly due to the long gas tubing, chamber itself has much larger cross section,
Q = 0.008m^3/day (four 2m×1m RPCs in series, 1 volume change/day) = $9.2*10^{-8}m^3$/sec, thus
$\Delta P=Q*L*128*\mu /(\pi *D^4)$ = 9.2*10^(-8)*10*128*1.85*10^-5/(3.1416*0.004318^4)
≅ 2N/m^2 = 2Pa = 0.2mm WC.

For the gas flow rate at 1 volume change per day for 4 RPCs it will produce ~0.2mm water overpressure inside the RPC due to the flow resistance of 10m long ¼" polyflo tubing, even ten times higher flow rate the overpressure would be only 2mm water. Therefore it should pose no any threat to the safety of RPC. In the case of rapid atmospheric pressure swing, 10% of atmospheric pressure/3hours, the additional flow rate due to the pressure swing is similar to the regular flow rate, so RPC should be quite safe in this situation.

2, Pressure drop in a flow resistor

If we use the capillary with 0.01" ($2.54*10^{-4}$ m) bore diameter, 0.05 m length, the pressure drop through the capillary:
$\Delta P=Q*L*128*\mu /(\pi *D^4) = 1.85*10^{-7}*.05*128*1.85*10^{-5}/(3.1416*(2.54*10^{-4})^4)$
≅ 1675 N/m^2 = 1675 Pa = 1.68% of atm = 16.7 cm WC.
We can see that the pressure drop through a capillary is much higher than 10 m long ¼" tubing.

3, Source loaded DB Integrated Schedule (the gas system schedule)

	2007	2008	2009
Final Spec & Dsgn of RPC Gas sys		600 hrs	
Princeton Sr-Tech		160 hrs	
Princeton-Grad-Student		120 hrs	
Princeton-Postdoc		120 hrs	
Princeton-Physicist		200 hrs	
FDR/PRR Review of Gas Sys			
Procure compon. for gas sys		240 hrs	
Princeton Sr-Tech		40 hrs	
Princeton-Grad-Student		40 hrs	
Princeton-Physicist		40 hrs	
Princeton-M&S		120 hrs	
Assemble Gas Sys for DB Hall		614 hrs	
Princeton Sr-Tech		60 hrs	
Princeton-Mech-Tech		90 hrs	
Princeton-Elec-Tech		24 hrs	
Princeton-Grad-Student		160 hrs	
Princeton-Postdoc		160 hrs	
Princeton-Physicist		120 hrs	
Pre-Operational Safety Assessm			
Test Gas System		80 hrs	240 hrs
Princeton Sr-Tech		6 hrs	18 hrs
Princeton-Mech-Tech		10 hrs	30 hrs
Princeton-Elec-Tech		4 hrs	12 hrs
Princeton-Grad-Student		20 hrs	60 hrs
Princeton-Postdoc		20 hrs	60 hrs
Princeton-Physicist		20 hrs	60 hrs
Package & ship Gas Sys			66.67 hrs
Princeton-Mech-Tech			32 hrs
Princeton-Grad-Student			32 hrs
Princeton-M&S			2.67 hrs
RPC Gas Sys for DB Near arrives at SAB			
Design RPC gas safety system		560 hrs	
Princeton Sr-Tech		320 hrs	
Princeton-Grad-Student		80 hrs	
Princeton-Physicist		160 hrs	
Procure RPC gas safety system components		65 hrs	
Princeton Sr-Tech		10 hrs	
Princeton-Physicist		30 hrs	
Princeton-M&S		25 hrs	
RPC gas safety system fabrication & testing		630 hrs	
Princeton Sr-Tech		150 hrs	
Princeton-Mech-Tech		160 hrs	
Princeton-Grad-Student		160 hrs	
Princeton-Physicist		160 hrs	
Ship RPC gas safety system to SAB		4.43 hrs	28.77 hrs
Princeton-Mech-Tech		2.13 hrs	13.87 hrs
Princeton-Grad-Student		2.13 hrs	13.87 hrs
Princeton-M&S		0.17 hrs	1.03 hrs
RPC gas safety system elements arrive at SAB			
Assemble Gas systems for LA & Far Halls		75 hrs	975 hrs
Princeton Sr-Tech		7.15 hrs	92.85 hrs
Princeton-Mech-Tech		10.72 hrs	139.28 hrs
Princeton-Elec-Tech		2.85 hrs	37.15 hrs
Princeton-Grad-Student		20 hrs	260 hrs
Princeton-Postdoc		20 hrs	260 hrs
Princeton-Physicist		14.28 hrs	185.72 hrs
Test Gas Systems			544 hrs
Princeton Sr-Tech			40 hrs
Princeton-Mech-Tech			60 hrs
Princeton-Elec-Tech			24 hrs
Princeton-Grad-Student			140 hrs
Princeton-Postdoc			140 hrs
Princeton-Physicist			140 hrs
Package & ship Gas System for LA Hall			49 hrs
Princeton-Mech-Tech			24 hrs
Princeton-Grad-Student			24 hrs
Princeton-M&S			1 hr
LA Near Hall Beneficial Occupancy			
LA Hall Gas System Arrives at SAB			
Package & ship Gas System for Far Hall			49.5 hrs
Princeton-Mech-Tech			24 hrs
Princeton-Grad-Student			24 hrs
Princeton-M&S			1.5 hrs
Far Hall gas system arrives at SAB			