RPC Gas Flammability

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Daya Bay

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Daya Bay RPC gas safety issue

Since Daya Bay experiment hall will be located near the nuclear power plant the safety issue should have the highest priority.

The RPC gas mixture needs small fraction of isobutane in it, but the isobutane is a flammable gas, it requires a detailed analysis of flammability hazards associated with the use of isobutane gas mixture.

It should be the best solution if we can hire a local authorized company to do this analysis, that would conform with all local Chinese government fire code.

For the purpose of the internal assessment I have collected some relevant documents from BaBar experiment, and try to understand the flammability issue in more detail.





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BaBar RPC gas flammability analysis

During the BaBar detector construction time SLAC had hired Hughes Associates, Inc. did the analysis of flammability hazards for the entire detector, the fire hazard associated with the use of butane gas mixtures in BaBar was one of the items. (Hughes report: Doc-DB #574) Here we shall briefly mention the main conclusion that is relevant to our assessment.





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Flammability Diagram for Butane with Argon/C2F6 in air.



The flammability regions for several butane/inert gas mixtures in the air: The curves for butane/N2 and butane/CO₂ are from Bulletin 627, Bureau of Mines by Zabetakis. These two curves were the lab test results.

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 Ar/C_2F_6 with Isobutane, because C_2F_6 is very much similar to R134A, especially in heat capacity, it should introduce little error in the analysis.



OPERA gas mixture flammability analysis

OPERA RPC gas mixture is Ar/C2F6/Isobutane/SF6 (75.5/20/4/0.5). Based on (1) SF6 having a higher specific heat than Freon (0.097 kJ/mol-K vs 0.087 kJ/mol-K), and (2) available CEN (European standard, used at CERN) small scale flammability test data that indicates the isobutane Tci (ignitability of a gas instead of flammability, former is more restrictive than the later) value of 19.43% for isobutene/SF6 is significantly higher than the Tci value of 5.75% for isobutene/Freon, we can treat SF6 as Freon (R134A) for the fire flammability analysis. Thus the OPERA gas mixture can be simplified as Ar/C2F6/Isobutane (75.5/20.5/4).





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OPERA gas mixture flammability analysis (contd.)

The TCi values for the mixes of isobutene in freon and isobutene in argon will be used to draw a line that forms a boundary between the non-flammable and flammable regions.



OPERA gas mixture flammability analysis (contd.)

Option D): The CEN tests measure the local ignition of a gas or gas mixture and do not consider flame propagation.

To provide a conservative estimate of the difference between the local ignition of a gas mixture and flame propagation (Bureau of Mines test method), a comparison of known lower flammable limit quantities LFL (Bureau of Mines) to the Tci values (CEN method) was made. These values are shown in Table on next page. According to this analysis Option A value can be increased by fact of 1.14, which is Option D.

Based on the Option D line the nonflammable upper limit for isobutene in gas mixture with 75% of Ar is around 3.5%, therefore 4% of isobutene in the OPERA gas mixture is not in the most conservative nonflammable region. If we want to use the gas mixture without any fire hazardous concern, we have



to lower the isobutene concentration down to less than 3.5%.



Comparison of Bureau of Mines Data to CEN Data

Bureau of Mines	CEN	Ratio
1.8	1.55	1.16
9.5	7.95	1.19
5.4	4,1	1.32
5	4.4	1.14
2.1	1.8	1.17
3	2.4	1.25
1.8	1.45	1.24
4	3.5	1.14
	Bureau of Mines	Bureau of Mines CEN 1.8 1.55 9.5 7.95 5.4 4.1 5 4.4 2.1 1.8 3 2.4 1.8 1.45 4 3.5

Comparison of US Bureau of Mines LFL and CEN TCi data

The ratios vary between 1.14 and 1.32. This indicates that the CEN values can be increased by at least a factor of 1.14 and remain at or below those necessary for flame propagation (Bureau of Mines) for the gas mixtures.



Safe gas for SAB

Since the flammable gas isobutene is not permitted in Daya Bay SAB, we have to find an alternative gas mixture for RPC testing at SAB.

We were thinking about using R417A or R422. Kwong has pointed out the complication of this method:

Raoult's Law: the partial pressure of a given component of the vapor of a multi-component liquid is proportional to the product of the vapor pressure and molar fraction

 $P_A = x_A P_{A0}$

where x_A is the molar fraction of liquid A and P_{A0} is the vapor pressure of liquid A in its own liquid. The three components are consumed at rates not proportional to the initial weight fractions. Thus bring complication to the gas mixing system. But ...





Use liquid phase valve to get the gas mixture

Jiawen mentioned that their refrigerant tank has two valves, one is vapor phase valve, the other one is liquid phase valve (liquid is drawn off the bottom of the cylinder via a dip tube using the pressure in the head space). If we connect our gas tubing to the liquid phase valve, the output vapor composition should depend on the liquid mixing ratio. Jiawen has already purchased a tank of Isobutene/R134A (10/90%) in this type of tank.

Slide 6 points out that Freon/Isobutane (93.5/6.5) is a non-flammable gas mixture. To get the partial vapor pressure ratio in the gas tank as 93.5/6.5 for freon/isobutane, we need to mix liquid of R134A and isobutane according to the molar fraction ratio of 8.55/1(for comparison this ratio is 14.9/1 for R417A).

If we add 50% of Ar with vapor of freon/isobutane(93.5/6.5) the output vapor will have the mixing ratio of 50/46.8/3.2(Ar/R134A/Isobutane), which is similar to the present BESIII RPC gas with half isobutane content.





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Use liquid phase of the gas mixture (contd.)

The gas mixing ratio in such tank is still not absolutely constant when R134A tend to accumulate in the gas head space more than C4H10, thus changes the mixing ratio. The molar mixing ratio changes little:

If we use MG cylinder No. 350, which has internal volume 108 liters. Initially we fill in 414 moles R134A and 47.4 moles isobutane, which is 42.22kg R134A and 2.76kg isobutane. This corresponds to molar fraction of 0.897/0.103. We require at 90% of empty internal volume the molar mixing ratio for the liquid is still meet the safety criteria 8.55/1 (R134A /Isobutane). Because in the cylinder head space (97 liters) according to Raoult's law it will holds 22 moles of R134A and 1.39 moles of isobutane, therefore the left over liquid will have the molar fraction 0.895/0.105 (e.g. (414-22)/(47.4-1.39)), which is not very much different from its initial value.





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Summary

- OPERA gas mix is not in the most conservative nonflammable region. Because this is the most conservative analysis, it does not say OPERA gas is flammable. A reliable test is needed to verify its non-flammability. W/o this test we should reduce the isobutane to 3.5% to guarantee its safety;
- At SAB we can use 50/50 of non-flammable premix of R134A/ Isobutane (89.7/10.3 molar fraction) and Ar, which is similar to the present BESIII mix, but reduce the isobutane to half.





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Compilation of TCi values tested by CERN (B. Messner)



Linearity between TCi and Cp for various inert/flammable gas combinations can be recognized, but R134A deviates from this linearity. It is due to the decomposition of Freon in high temperature. This complication reminds us when we deal with R134A special cautious has to be considered.



