Lessons Learned (Round 2)

Executive Summary

In early 2011, an extensive review was conducted on operating labs and a number of concerns about lab design and construction were identified. This resulted in the first series of “Laboratory Design Lessons Learned” which had been summarized and communicated to SAPMT in May 2011.

Following on this path, the second round of “laboratory design lessons learned” aims to streamline laboratory design by identifying area of improvement to simplify over-engineered and unnecessary features in existing LFOs which had made the design, commissioning and operation cumbersome with little or no gain in safety or functionality.

Moreover, research needs are changing all the time, and labs must allow for a flexible design that accommodates for easy and reasonable modifications. In today's lab, the ability to expand, reconfigure, and permit multiple uses has become a key concern. Research institutions are expected to make physical changes an average of 25% of their labs each year.

As a continuation of the “Laboratory Design Lessons Learned” issued in May 2011, KAUST recommends implementing the following criteria for immediate execution in the design and construction of all new LFOs:

1. Gas cabinets to be selected for types of gases specified under NFPA 45. Unless specifically required by KAUST for justifiable reasons.
2. Performance specifications of gas cabinets shall be simplified in accordance with 6.17.1 of NFPA 55. Additional features in gas cabinets must be justified and deemed necessary.
3. Toxic Gas Monitoring (TGM) Systems must be justified and designed with greater emphasis on simplicity and reliability
4. Extensive manifolds and pipework must be justified and designed with greater emphasis on simplicity and reliability
5. Locations of service cutoffs (such as chilled water, power etc.) shall be at readily accessible with easy connects/disconnects at walls to allow for fast hook up and relocation of lab equipment
6. Lab equipment exhaust manifold design shall be simplified and flexible that allows for easy modifications.
7. Noise attenuators in ventilation ducts to be critically reviewed and, where required, lighter and less bulky alternatives be considered.
8. Consider the use of materials other than stainless steel for laboratory exhaust ducts
9. Ventilation of lab equipment and storage cabinets to be optimized Hazardous exhaust hoods and ventilated cabinets to be evaluated by industrial hygienist.

Lessons learned and Recommendations:

1. Gas cabinets installed for gases that do not require this level of control

1.1 Applicable standard: Section 11.1.4, NFPA 45 – 2004 , Design guideline of University of California, Prudent Practices in Labs , KAUST Lab Safety Manual.

The types of gases listed above shall be kept in mechanically ventilated gas cabinets:

a) all gases that have health hazard ratings of 3 or 4,
b) all gases that have a health hazard rating of 2 without physiological warning properties, and
c) pyrophoric gases,

1.2 Practice in existing LFOs

In existing LFOs, gas cabinets were provided for gases other than those listed above. Examples include NF3, CF4, CH4, C2H4, C2H6, C3H8, H2, N2O, as well as dilute mixtures (ppm levels) of various gases. All of these have a health hazard rating of 1.

1.3 Recommended Changes:

a) Gas cabinets shall be provided ONLY for types of gases specified under NFPA 45.
b) If gas cabinets are proposed for housing other types of gases, the reasons must be justified and approved by KAUST LDD.

1.4 Benefits of applying these changes:

a) Focus safety and security features at locations where they are actually needed
b) Reduce the number of unnecessary gas cabinets
c) Reduce project complexity, cost and construct time
d) Reduce space requirement
e) Reduce exhaust airflow (the exhaust flow of each two-cylinder gas cabinet is more than a standard fume hood)

Fig.1 Gas cabinets provided for non-toxic gases

2. Gas Cabinets functionality simplification (provided with too many optional features)

2.1 Applicable Standard: Section 6.17.1 of NFPA 55 Design guide of University of California, Prudent Practices in Labs , KAUST Lab Safety Manual.

Section 6.17.1 of NFPA 55 specifies construction and ventilation of gas cabinets, essential requirements include: constructed with min. 12 gauge steel, self-closing doors, limited access ports, continuously exhausted by mechanical ventilation; 200 fpm face velocity at the access port, internal sprinkler for toxic, highly toxic and pyrophoric gases.

Additional features such as automatic operation, various sensors and interlocks, detection systems, alarms, as well as integration with external system, if proposed, shall be provided only if they are justified and the overall design is approved by KAUST LDD.

2.2 Practices in Existing LFOs

May gas cabinets in existing LFOs have numerous additional features such as fully automatic operation, gas detection sensors and alarms, remote alarm triggers, excess flow sensors, pressure sensors, automatic shutoff valves, automatic switch over manifolds, exhaust failure interlocks, co-axial pipes and associated monitoring and interlocks, integration with external system such as TGM, LCS, auto-dialers that were supposed to send e-mails, SMS and recorded phone messages in case of cabinet alarms. While many of these features are appropriate when highly toxic and pyrophoric gases are involved, they are not needed for routine use of less hazardous gases. In addition to cost implications, these over-complicated systems required longer times to be designed, manufactured, installed and commissioned properly. Researchers often found them too complicated to operate and maintain. Excessive layers of sensors and safeguards also increase the frequency of false alarms and service interruptions, which further degrade researchers' confidence in these systems.

2.3 Recommended Changes:

a) Performance criteria of gas cabinets for toxic, highly toxic and pyrophoric gases shall be in accordance with Section 6.17.1 of NFPA 55.
b) Additional features such as automatic operation, various sensors and interlocks, detection systems, alarms, as well as integration with external system, if proposed, shall be provided only if they are justified and the overall design is approved by KAUST LDD.

2.4 Benefits of applying these changes:

a) Focus safety resources at locations where they are actually needed
b) Reduce project complexity, cost and construct time
c) Reduce frequency of false alarms and service interruptions
d) Simplify and reduce cost of operation and maintenance

3. Complex toxic gas monitoring (TGM) systems provided in situations that do not require them

3.1 Applicable standards: Good Industrial Hygiene Practice, Threshold Limit Values by ACGIH, Emergency Response Planning Guideline(ERPG) values by AIHA, Design guide of University of California

When hazardous gases are used, a hazard evaluation should be conducted to establish whether there is a credible scenario where significant quantities might be released and present dangers to people, and whether a TGM system is important for detection and mitigation of this release. Such a system should then be carefully designed, commissioned, operated and maintained.

A TGM system is NOT always necessary whenever hazardous gases are in-use. In many situations, a combination of different strategies, such as quantity minimization, use of continuously exhausted gas cabinets, use of restrictive flow orifices, the negative pressure and single-pass nature of the laboratory ventilation is sufficient to limit the dangers of accidental releases to acceptable levels. With these controls already provided, a TGM system might have very little additional value in terms of safety but it adds heavily to the complexity in design, installation, operation and maintenance. As a general rule, when considering suitable control measures for hazardous gases, the most effective strategies should be considered first. Preventive measures such as limiting quantities and pressures, restrictive flow orifices, ventilation, are among the most effective controls..

3.2 Practice in existing LFOs

In existing LFOs, toxic gas sensors are provided for many gases the do not require them. Examples include NF3 and CF4 in LFO7 as well as N2O in LFO 29. These gases are very low toxicities; the utility of gas sensors for these gases is highly questionable. The oxygen monitoring system in the NMR Core Lab was unable to record data in the event of a magnet quench, which severely limited its usefulness. The TGM system in LFO 9 and LFO29 include many sensors and they have been installed for a long time but the associated gas cabinets were still not fully commissioned. Even in the complete absence of these target gases, TGM systems in LFO 9 and LFO 29 produce frequent false alarms, which further erode researchers' confidence in these systems.

3.3 Recommended Changes

a) It is recommended that the justification, design and performance criteria for TGMs be established and reviewed in each case by KAUST LDD.
b) The design of TGM system must put greater emphasis on simplicity, economy, reliability, ease of operation, ease of maintenance as well as adaptability for future changes.

3.4 Benefits of applying these changes:

a) Provide and focus important safety systems at locations where they are actually needed
b) Ensure TGM system designs are reviewed by health and safety professionals
c) Reduce project complexity, cost and construct time
d) Reduce frequency of false alarms and service interruptions

e) Simplify and reduce cost of operation and maintenance

4 Extensive ducts and air-valves provided do not match exhaust requirements

4.1 Acceptable standards: NFPA 45, ANSI Z9.5, and manufacturer's recommendations

As mentioned in the previous "lab Design lessons learned" dated 11 May 2011, ventilated cabinets should have roughly 10 air changes per hour, or as specified by the manufacturer. Exhaust for other miscellaneous lab equipment should be in accordance with manufacturer's recommendations. In accordance with NFPA 45, flammable storage cabinets shall not be required to be ventilated for fire protection reasons and if provided, shall be in accordance with relevant fire protection standards.

4.2 Practice in existing LFOs

In their response to the previous "lessons learned" dated May 2011, HOK maintained that 24 l/s was the minimum flowrate which can be balanced on site and where 24 l/s are inappropriate, exhaust would not be provided at all. To achieve their "minimum" flow rate which is 10 times more than appropriate, much larger ducts and associated air-valves and noise attenuators were specified in the design. This adds substantially to cost, construction time and cluttering of the interstitial space. The increased exhaust volume also adds unnecessary burden to building exhaust system. Chemical storage cabinets continue to be provided with at least 24 l/s exhaust or none at all. In many cases, a dedicated phoenix valve, noise attenuator, long lengths of stainless steel ducts and multiple turns are installed to serve each fume hood, cabinet or piece of lab equipment that requires exhaust.. The extra hardware increase costs and construction time, and severely clutters the interstitial space.

4.3 Proposed Changes

1) Exhaust flow rates for storage cabinets need not be highly accurate and there are many simple methods for estimating flow rates on site. The designer must not omit these small but important exhaust requirements.
2) Small rate exhausts do not require dedicated Phoenix Valves. They should be connected to exhaust manifolds or share tap into nearby exhaust lines, similar to the exhaust line of the under fume hood cabinets which are tied to the fume hood exhaust with a flexible duct.

4.4 Benefits of applying this standard:

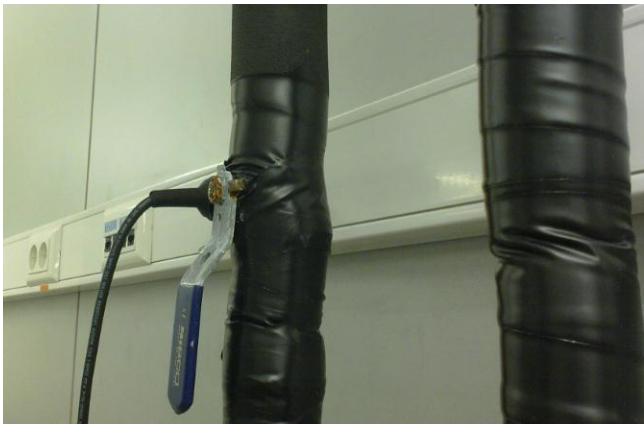
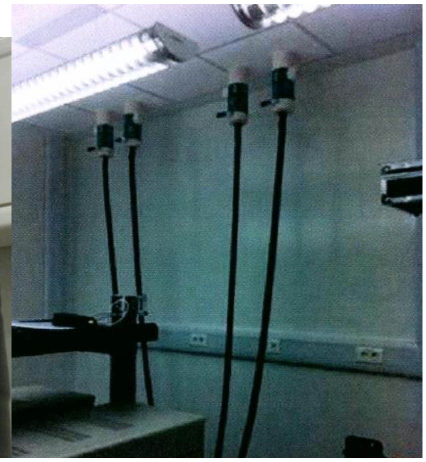
1) Minimize researcher exposure to chemical vapors and odors
2) Greatly simplify exhaust duct work
3) Reduce burden on exhaust capacity
4) Simplify design and construction,
5) Reduce cost
6) Increase flexibility for future changes

Fig.1 Phoenix valve and attenuator provided for single cabinet

5 Location of service cutoffs and connection points

Applicable standard:

Cooling by chilled water is often required for high-powered laboratory equipment such as power supplies for high power lasers. Isolation valves and connection points of the chilled water supply should be readily accessible. In some labs, such as LFO 43A, the valves and connection points were installed just below the ceiling, approximately 3m above the floor, which made them un-reachable by a standing person. Even a small leak from these connections could cause water to spray onto high voltage equipment below.   All these valves in LFO 43A had to be moved to more suitable locations. Locate shutoff valves where they are accessible and easily understood. Labs should have easy connects/disconnects at walls and ceilings to allow for fast and affordable hook up of equipment

(6) Over-engineered exhaust manifolds

Equipment exhaust manifolds in exist LFOs are constructed with exceedingly heavy-duty components. Most of them are not in use in fully operating labs. **<u>A much simpler design should be provided for general equipment exhaust needs.</u>**   If a constant flow is desired through the manifold system for ventilation balancing, a non-return bypass can be incorporated.


(7) Noise attenuators for lab exhausts to be reviewed

Applicable Standard: Reasonable practice

Apparently, all supply and exhaust ducts in existing lab areas have in-line sound attenuators typically next to the air valves. The purpose of attenuators is to suppress acoustic noise transmitted through the ventilation ducts. The attenuators in existing LFOs are heavy, bulky rectangular objects which take up a lot of space in the interstitial level. Very often, their installed locations and orientation were limited by their bulk. The ductwork would then have to be rerouted extensively to their installed location. This extra ductwork again adds to the complexity and cluttering of the interstitial space and substantially increase pressure drop in the system. While there may be reasons for sound attenuators in supply air ducts and room exhaust ducts because these ducts open more or less directly into the room so any noise that exists in the duct may be transmitted relatively easily into the room. Fume hoods, storage cabinets and equipment exhaust are connected to enclosures which function as effective sound dampers. For example, if noise is transmitted from the exhaust duct to a fume hood, closing the sash would effectively dampen the noise – fume hoods are meant to be used with the sash down most of the time. Similarly, if noise is transmitted from the exhaust duct to a chemical storage cabinet, the doors of the cabinet would effectively dampen it. In existing LFOs, even pump cabinets (C3) and storage cabinets have sound attenuators in their exhaust ducts; the attenuators in these ducts are almost certainly unnecessary. Moreover, even if attenuators are effective in reducing the noise generated by the phoenix valve in the interstitial space, they cannot not dampen the noise generated at the manual dampers installed near the equipment. The overall benefit of these attenuators is questionable. The corridor is design for supporting equipment such as pumps, power supplies, coolers, refrigerators and ice makers, many of them produce noticeable noise. They are placed there because the corridor is not design for continuous occupancy and therefore a higher noise level is acceptable. Because of this, sound attenuators for ventilation ducts serving the service corridors have little or no benefit.

<u>It is strongly recommended that the need for these sound attenuators be critically reviewed.</u> A test-case can fitted out to demonstrate in one of the up-coming labs, by omitting the attenuators and then conducting background sound measurements and subjective appraisals. (Since nuisance noise is very difficult to quantify by instrumental measurements, it should be supplemented by subjective appraisals.) If the sound level is found acceptable without the attenuators, they should be deleted from the design

(8) Use of approved PVC exhausts ducts

Applicable standards: FM Approval Class 4922, Approval Standard for fume exhaust ducts and fume or smoke exhaust ducts.

The exhaust ducts in existing KAUST LFOs are all made of type 316 Stainless Steel. In other universities, fume hood exhaust ducts are more often made of PVC (or uPVC). PVC ducts are corrosive resistant, lighter, much easier to work with (hot air thermal welding) and much cheaper than ducts made of 316 Stainless Steel. The disadvantage of PVC ducts compared to metal ducts is their properties under high temperatures and fire conditions. NFPA 45 section 8.5.2 permits fume hood exhaust ducts to be made of combustible material if the flame spread index of the material is 25 or less. Some duct manufactures have products that meet and exceed these requirements and their products are FM-approved to be used as industrial fume exhaust without internal sprinkler systems. As these ducts and fittings are readily available, pre-fabricated and much easier to work with (modified and adapted on site using relatively simple hot-air welding technique), substantial saving in design and construction time as well as cost reductions can be realized without compromising safety. **<u>It is recommended that, where applicable, PVC ducts of suitable fire resistant rating be used for lab exhaust including all general purpose fume hoods</u>**. Suitability of these ducts in special high-risk exhausts, such as high concentration of organic vapors or high temperature exhausts shall be examined case by case.