Laboratory Safety

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Introduction

EHS Professionals face some unique challenges in laboratory environments. When I took a job last March at a research and technology center, I found myself having to reference new standards relative to laboratory operations, and change my approach to basic EHS processes. Traditional EHS tools and processes could take longer to run through than it would take a chemist to run an experiment. This can make it very difficult to have laboratory personnel accept valve in safety processes and, more importantly, take time to complete these processes.

Although this paper could not possibly cover all the unique aspects that a laboratory can offer an EHS professional, the intent is to capture lessons learned from someone that has recently been assigned responsibility in this type of facility. Discussed below are laboratory issues regarding codes and standards, ventilation, environmental concerns, chemical management and inventory, and process safety.

Codes and Standards

Laboratories are not immune from following basic EHS regulations, such as lockout/tagout or hazard communication. However, as with all industries, one must become familiar with codes and standards unique to the operation.

OSHA Regulations

For those regulated by OSHA, the first regulation EHS professionals should be aware of is 29 CFR §1910.1450, Occupational Exposure to Hazardous Chemicals in Laboratories. More commonly referred to as "The Lab Standard," it provides specific guidance on protecting laboratory workers.

A large part of the Lab Standard is based on the need to evaluate chemical exposures to laboratory workers and mitigate those exposures by developing a chemical hygiene plan. This plan should contain elements such as employee exposure determination, information and training, medical surveillance, personal protective equipment (PPE), equipment, work practices, and hazard identification. Appendix A of the Lab Standard gives EHS professionals a model program, complete with an example table of contents and applicable content. Although this appendix provides some very specific information such as ventilation rates, it should be noted that Appendix A of this standard is non-mandatory.

Industry Standards

On the non-regulatory side, there a several industry standards that are extremely useful. The National Fire Protection Association (NFPA) 45, *Standard on Fire Protection for Laboratories Using Chemicals,* is very helpful on issues such as ventilation rates for rooms and chemical fume hoods, and chemical inventory. Both of these issues will be discussed in further detail later.

Another consensus standard that is useful for EHS professions is ANSI/AIHA Z9.5, *Laboratory Ventilation*. This document contains recommendations on the design and operation of laboratory ventilation systems. This standard references other applicable standards such as the aforementioned NFPA 45 standard and additional lab design standards from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). Like NFPA, good guidance is given on ventilation rates and face velocity standards on fume hoods.

Local Codes and Standards

EHS professionals must always consider local codes and standards. City, county, or state codes can place additional requirements on any number of laboratory safety issues, such as storage quantities of chemicals, design of flammable/combustible gas distribution systems, and ventilation. If your local government does not have developed or adopted codes and standards, a good reference is the International Code Council (ICC). Many local governments incorporate ICC codes, such as the International Fire, Building, and Mechanical Code. In Houston, as well as other cities, all of these ICC codes have been adopted, and can include city amendments to these requirements. City amendments, along with the ICC codes, can be found on their website www.iccsafe.org.

Ventilation

Ventilation in laboratories can be broken down into two major components: general ventilation and local ventilation. General or room ventilation has to do with ventilation of the entire room. Local ventilation is ventilation at the point of exposure. Fume hoods are usually the most common local ventilation. EHS professionals need to know some basics about each of these engineering controls.

General Ventilation

Some basic design principles apply when it comes to general or room ventilation. Specifically, lab areas need to maintain a negative pressure to adjoining work areas. In other words, the room should be in a “suction-mode” compared to the hallway or adjacent offices. This insures that, if a spill or leak occurs in the lab, nothing harmful escapes into public areas. General ventilation should also not re-circulate in a lab. Again, this requirement exists to protect workers in the event of an accidental spill or release.

There are no definitive federal regulatory guidelines on general ventilation rates. Table 1 shows several recommendations from various sources on general ventilation rates. The first three codes deal with local codes specific to the City of Houston. As previously mentioned, it is imperative for EHS professionals to investigate all codes and standards.

Table 1. Ventilation Codes and Standards

Code/Standard	Section	Rate	Comments
International Building Code (IBC) - 2003	415.9.2.6	1 CFM/ft^2	Required for H-5 occupancies[1]
Uniform Fire Code (UFC) with City of Houston Amendments - 2000	2704.3.1	1 CFM/ft^2	Ventilation requirements are for indoor hazardous material storage
International Mechanical Code (IMC)	502.8.1.1.2	1 CFM/ft^2	Code unknown[2]
ACGIH – Industrial Ventilation – 24th Ed. – 2001	7.5.1	None specified	"Air changes per hour/minute" is a poor basis for ventilation criteria. The impact of the lab's ceiling height is identified as one reason why "air changes" does not adequately address the required contamination control.
ANSI/AIHA Z9.5 - 2003	2.1.2	None specified	The specific room ventilation rate shall be established or agreed upon by the owner or his/her designee.
ASHRAE Lab Guide - 2001	Ch. 3 – Lab Planning	4-12	Minimum Outdoor Air Changes section (pg. 32) simply points to OSHA guidance in Lab Safety Standard
NFPA 45 – 2004	Annex A8.2.2	4 ACH unoccupied; >8 ACH occupied	
OSHA 29 CFR §1910.1450 (Lab Safety Standard)	§1910.1450 Appendix A - C.4.f	4-12 ACH	"4-12 room air changes/hour is normally adequate general ventilation if local exhaust systems such as hoods are used as the primary method of control." Located in a non-mandatory section of the Lab Standard

ACGIH – American Conference of Governmental Industrial Hygienists
ACH – Air changes per hour
ANSI – American National Standards Institute
AIHA – American Industrial Hygiene Association
ASHRAE – American Society of Heating, Refrigeration, and Air-conditioning Engineers
CFM – Cubic feet per minute
NFPA – National Fire Protection Association
OSHA – Occupational Safety & Health Administration

[1] If occupancies stay below quantity limits outlined in table 307.7(1) in the 2003 International Building Code, they are considered a Group B occupancy. If not, occupancy could be considered H-5 occupancy.

[2] City of Houston has only adopted the 2000 Uniform Mechanical Code. However, the City of Houston Amendments to the Uniform Fire Code requires adherence to the International Mechanical Code.

Local Ventilation

The fume hood is one of the best engineering controls in a lab. However, workers can be overconfident when it comes to these controls. If a chemist or researcher is asked about potential exposures of running an experiment, this issue may be discounted and met with the statement, "But I'm doing it in a hood." Unfortunately, lab workers will rely on these engineering controls without necessarily knowing minimum air flow standards or maintenance schedules of the equipment. If the hood alarm is not going off then it should be safe to use, right?

Various sources list that acceptable face velocity rates range anywhere from 60 feet per minute (cfm) to 150 cfm. Most publications discourage face velocities greater than 150 cfm, as these rates can cause turbulent flow or eddy currents in the fume hood that could actually result in fumes being pushed out of the hood in the direction of the lab worker. Unfortunately, there is no single solution when it comes to fume hood face velocities. Fume hoods simply vary too much in size configuration and usage to give a single ventilation rate that works for all. Industrial hygiene sampling and smoke tests can help EHS professionals determine if ventilation rates are adequate for their use.

Laboratories also utilize "elephant trunks" or "snorkels exhausts" for local ventilation. These devices are typically small ducts that can be easily maneuvered over work areas or experiments. Again, the dangers with this type of ventilation primarily deals with overconfidence in their ability to adequately displace harmful vapors. The device should be on a regular maintenance schedule and verified through industrial hygiene sampling to be adequate for its intended use.

Additionally, it is not uncommon for these systems to be tied together or into other exhaust systems, such as general room ventilation or even fume hoods. EHS professionals should be cautious of this practice, as vents can easily be tied together with little or no regard for the compatibility of the chemicals being vented.

Maintenance and Monitoring

Both general and local ventilation systems must be placed on a routine maintenance schedule. Ventilation rates in the lab should be checked at least annually and preferable by a National Environmental Balancing Bureau (NEBB) certified contractor. This ensures that established standards on room air changes per hour or fume hood face velocities are being maintained. To instill confidence in your lab workers, all tests and certifications should be posted in laboratories or on the equipment. NFPA 45 provides guidance on inspection, testing, and maintenance on local exhaust systems.

Hopefully, a good preventative maintenance program will be able to keep hoods and other ventilation systems running; however, this is rarely the case. As such, other protective measures should be in place. Each hood should have an air flow monitor and alarm to alert laboratory workers that hoods or general ventilation has fallen below acceptable standards. It has been my experience that most ventilation issues typically occur with broken motor belts. As such, EHS professionals should scrutinize air flow protective systems and alarms by asking facility maintenance personnel what ventilation monitors are monitoring. For instance, if monitoring is set up to simply monitor if a fan motor is running, then this system will be of little use in the event of a fan motor belt breaking. The motor will still turn, but a broken belt will not be moving air.

Environmental Concerns

EHS professionals should be aware of numerous unique environmental concerns. Typically, these concerns are on a smaller scale compared to a petrochemical plant, but must be monitored and handled per EPA and state guidelines.

Energy Usage

According to the Environmental Protection Agency (EPA), ventilation accounts for 44% of energy costs for a typical laboratory (Geoffrey C. Bell, 2008). In short, lab ventilation systems can be considered energy hogs. The challenge here is to conserve natural resources, but never at the expense of employee safety.

In most office environments air is brought in from the outside and is initially conditioned. This conditioning can be heating the air on cold days or cooling the air on hot days. Conditioning the air requires a great deal of energy, such as electricity or gas. As such, most office building re-circulate this conditioned air in the building to lessen the burden on conditioning units and to save energy costs.

In a lab, air is brought in from the outside, conditioned to keep workers comfortable, and then immediately vented outside the lab. This proves to be especially challenging in some areas, as EHS professionals will need to balance being good environmental stewards and maintaining confidence in lab workers that lowering ventilation rates can be accomplished safely. A variety of strategies exist to keep workers safe, and lower energy costs. For instance, ventilation motors can have variable speed drives where ventilations rates drop during unoccupied times. Hoods can also have variable speed drives, which can operate at a higher setting when lab workers are standing and working at the hood, and lower ventilation rates when no one is standing there or while the hood is fully closed.

Hazardous Waste

With several chemicals onsite and the nature of experimental research in labs, hazardous waste concerns can vary greatly. Labs can have established waste streams in their operations, such as spent solvents used for cleaning. However, new chemicals are being introduced into labs all the time. Researchers may try one chemical this week, and want to switch to a different chemical the next. This variability can create large amounts of waste in small quantities.

Lab packs typically become a catch-all for small containers of hazardous chemicals. Labs should consult with or contract with a firm that specializes in packing lab pack containers. Most lab packs are handled by packing similar containers in drums with absorbent materials. This way, small containers can be transported and disposed of safely.

Water Issues

EHS professionals should consider the possibility of laboratory operations polluting public water sources. This concerns spans from obvious incidents, such as spills, to less obvious issues, where processes are tied to public water systems. Labs can easily tie into public water systems for operations such as chilled water or flushing vessels. These systems can easily be protected by installing check or one-way valves that prevent process chemicals from back-flowing into water lines.

Air Emissions

Although laboratories can deal with lots of hazardous chemicals, personnel typically deal with small quantities. Nevertheless, EHS professionals should evaluate air emissions coming from general and local ventilation. Vent hoods can be used to store containers of volatile organic chemicals and/or waste containers. Although venting hazardous vapors is a necessity for worker protection, it should not be overlooked as a potential source of air pollutants.

Chemical Management and Inventory

Chemical inventories in labs can easily reach tens of thousands of chemicals. If no processes are put in place to manage chemical procurement, labs can be overrun with unnecessary inventories.

Chemical Procurement

In addition to basic procurement requirements, companies should implement a chemical management of change (MOC) process. This puts parameters on lab personnel to consider chemicals they are procuring, and brings in outsiders to help them evaluate additional requirements or safety concerns. This simple paper process can be setup as a checklist, requiring that several people or departments sign-off before procuring a new chemical. These sign-offs can be the researcher's supervisor, who checks requests against established lists of extremely hazardous chemicals such a teratogens, mutagens, or poisons. The next approver can be the safety or industrial hygiene professionals, who evaluate the need to perform chemical exposure monitoring. Lastly, the environmental department should evaluate a chemical to see that disposing of the chemical as waste will not be an issue.

A well-established procurement process helps to prevent problem chemicals from entering the facility, or can allow extremely hazardous chemicals to enter the facility under certain conditions. EHS professionals should evaluate how researchers are allowed to procure chemicals, and work with procurement groups to establish basic rules of ordering. For example, it may be necessary to ban the purchase of chemicals with company credit cards. This makes it more difficult for an individual to place an order over the phone or internet.

Chemical Inventories and Storage

Chemical inventories in any facility should be monitored, but in labs it can be very daunting. Tracking inventory levels at other facilities could be easier to manage if chemicals are purchased and stored in established stockrooms. Also, if hazardous or flammable materials are stored in large containers, they can be easily tracked by inventorying fire cabinets. Laboratories, on the other hand, typically deal with numerous hazardous chemicals in numerous small containers. These containers could be stored in fire cabinets, hoods, dry boxes, lab benches, not to mention the chemicals that are in use during experiments.

In addition to a strong chemical procurement process, inventories must be managed within the laboratory itself. Prudent practices in the lab should include the following: all chemicals must be labeled or bar-coded; all chemicals should have an owner; and some type of inventory system should be in place with annual checks on inventory levels. During annual inventories, lab workers should evaluate the need to keep chemicals that have not been used for some time.

Special processes should also be in place for any unique inventory. For example, if your lab stores chemicals that can degrade over time or form peroxides, a system should be in place to check these chemicals periodically. In the instance of peroxide formers, this check could be as frequent as quarterly.

<u>Chemical Storage</u>

In laboratories, storage of chemicals can be challenging, given the large number of small containers. A lab can easily find itself over regulatory limits when the aggregate of hundreds of containers is calculated. Lab personnel should look at chemical storage in compliance layers. In other words, all chemicals should be compliant within its container, the cabinet or hood, and the room or control area. Figure 1 shows a depiction of how a chemical has many layers of compliance.

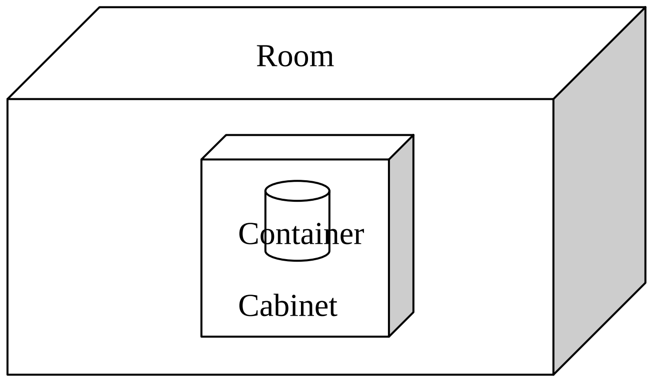

Figure 1. Chemical Storage Compliance Layers

OSHA and NFPA 45 have established tables on maximum allowable container capacities by container type for flammable and combustible liquids. Per the tables, you should not store an IA Flammable Liquid in a glass container larger than one pint. Laboratory workers can easily order chemicals in containers that are larger than OSHA and NFPA standards. If not informed of these standards, chemists could be trying to save the company money by buying a class IA Flammable Liquid in bulk, not realizing they have exceed allowable container capacities. OSHA's Table can be found in 29 CFR §1910.106 Table H-12 (see Table 2).

Table 2. OSHA's Table H-12 – Maximum Allowable Size of Containers and Portable Tanks

Container Type	Flammable Liquids			Combustible Liquids	
	Class IA	Class IB	Class IC	Class II	Class III
Glass or approved plastic	1 pt	1 qt	1 gal	1 gal	1 gal
Metal (other than DOT drums)	1 gal	5 gal	5 gal	5 gal	5 gal
Safety Cans	2 gal	5 gal	5 gal	5 gal	5 gal
Metal Drums (DOT specifications)	60 gal	60 gal	60 gal	60 gal	60 gal
Approved Portable Tanks	660 gal	660 gal	660 gal	660 gal	660 gal

As with chemical containers, EHS professionals must educate lab workers on quantity limits of fire cabinets and rooms. Cabinets are simple in that all flammable cabinets have a maximum storage capacity labeled on the front. If this label is missing, the manufacturer should be contacted to obtain these limits.

As far as room limits, EHS professionals can reference OSHA's Flammable and Combustible Liquids standard, but local codes and standards should also be researched. The International Building and Fire Code has established maximum allowable quantities per control area of hazardous materials. Control areas can be one or several rooms, as defined by the

International Building Code. These tables, which are codified by numerous cities, go into quantities limits of not only flammable and combustible liquids, but also oxidizers, explosives, organic peroxides, and several others.

Process Safety

Although most labs do not have to comply with OSHA's Process Safety Management (PSM) Standard, there are some great resources and tools that can be utilized from prudent process safety practices.

The first one that comes to mind is the process hazards analysis (PHA). The real challenge for EHS professionals is to incorporate meaningful PHA tools and processes, while keeping in check the inherent need for a research chemist to hurry up and just perform their experiment. Laboratory experiments can range from simple glassware setups with minimal equipment to very complex pilot plant operations. The complexity of these experiments and the hazards associated with them should be evaluated so as to apply the right tools for the job. Below is a simplified matrix (Table 3) to determine what level of analysis should be used.

Table 3. PHA Process Decision Matrix

	Low Probability	**Medium Probability**	**High Probability**
High Severity	PHA Teams Discretion	HAZOP/LOPA Analysis	HAZOP/LOPA Analysis
Medium Severity	PHA Teams Discretion	PHA Teams Discretion	HAZOP/LOPA Analysis
Low Severity	What-If Checklist	What-If Checklist	PHA Teams Discretion

HAZOP/LOPA analyzes consequences of various potential undesirable process-related events, and evaluates safeguards to determine if the mitigated risk meets risk-ranking matrix criteria. This level of analyses is primarily reserved for large chemical processes and would be rarely utilized in a lab. However, labs that have larger scale pilot plants may find the need to use this tool.

Smaller lab operations or experiments can utilize a What-If Checklist to evaluate potential process safety issues. This analysis can be constructed by putting together a simple series of questions. Table 4 below shows an example of a simple What-If Checklist. These checklists can be easily constructed for general purposes, as well as specific hazards in labs or processes. Whereas a HAZOP/LOPA analysis can take several multi-hour sessions to complete, a What-If analysis can typically be completed in a single session.

Table 4. Sample What-If Checklist

Question	**N/A**	**Y/N**	**Comments**
1. Have the consequences of flow stoppage been evaluated?			
2. Have the consequences of significant increases in pressure been evaluated?			
3. Have the consequences of significant increases in temperatures been evaluated?			
4. Are all pieces of equipment visibly labeled?			

When using either analysis tool, it is important to have cross-functional PHA team evaluate processes safety issues. These teams can be constructed using lab workers from other areas, EHS personnel, engineers, technicians, etc. This gives each experiment or process a fresh set of eyes. Documents from these analyses should be maintained with other experiment or process documents, such as SOPs, process descriptions, MSDSs, or other relevant materials.

Conclusion

The dynamic nature of laboratories presents many unique challenges for EHS professionals. Standard EHS tools can be utilized to help lab workers perform their job safely, but it is up to EHS professionals to develop these tools to bring value to lab workers, while maintaining compliance. Hopefully, this brief collection of unique laboratory information can help EHS professionals to meet this challenge.

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