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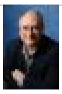
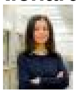
Good Practices for Managing a Safe Chemical Laboratory Part 3: Safety Administration and Facilities

By  **Richard C. Wedlich**,  **Ulyana Matyugicheva**

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ABSTRACT

The overall activity of the laboratory should be considered in terms of smaller pieces or unit operations and these should be organized around workflow and the circulation of personnel through the lab, to the extent that the facility design permits. Each unit operation should be designed to be as inherently safe as possible. Each should be well-defined and the steps for carrying out the operation should be documented in an SOP (Standard Operating Procedure). The design of the lab e.g. floor plan, location of safety showers, etc. and the controls that are put into place e.g. engineering controls, administrative controls, etc. must be well conceived and documented and changes must be controlled. Safety oversight must have a view of individual activities, unit operations and the laboratory operation as a whole. Decisions on how resources are to be applied for the organization, operation and monitoring of the lab should be made from a safety and risk-based perspective. The Chemical Hygiene Officer must play an active role and have a strong presence in the lab, providing feedback and expertise and keeping lines of communication open between lab workers and management.

INTRODUCTION

The size of the laboratory facility and amount of work and organization required to administer the safety program in the facility go hand in hand. To a large extent, this consists of determining how resources are to be applied for the organization, operation and monitoring of the lab from a safety and risk-based perspective. It is not possible in this article to discuss all the elements, unit operations and engineering controls of a typical lab facility nor is it our intention to inform the reader of how frequently they should calibrate their chemical fume hoods or how long they can safely store peroxide-forming chemicals or how to create and maintain a chemical inventory, etc. While these are all very important considerations, they are better addressed elsewhere by persons truly expert in the area and the reader is referred to reference [1]. Rather, we must be contented to take a high-level view and put forward some good practices that work in both large and small facilities. The efficient facility run with good administration reflects a superior understanding of division of labor and conflict of interest. Although the operation may be seen from the outside as a large, well-lubricated machine, it is made up of many smaller parts and "safety" is one of the key lubricants. In fact, to many outsiders, the face of the laboratory is the facility and the safety administration.

PRINCIPLES OF SAFETY ADMINISTRATION

A "divide and conquer" strategy for administrating the safety program is recommended. The activity of the lab is "divided", at least conceptually, into unit operations, which are sets of smaller activity that can be well-defined. Weighing out a white powder on an analytical balance, spinning down a mixture on a centrifuge and preparing a mobile phase in a fume hood are all examples of unit operations. As work progresses through the lab, it goes through these unit operations. The unit operation is "conquered" by studying it: The hazards associated with it are identified, a plan to mitigate the hazards is put into place, a standard operating procedure (SOP) is written that lab workers are trained on.

Appropriate records are kept that show how the operation has performed over time. Such a record might be the instrument logbook for the balance, centrifuge or fume hood. These records are reviewed and used to provide feedback so that improvements can be made. The unit operation is a part of a larger objective, namely the labor of the lab. Making each unit operation as inherently safe as possible by design and integrating the lab operations are key goals. Of course, this is only one model for laboratory activity. It makes us think about the planning, managing and administering of a safety program. The principles of safety administration, as we see them, are given in Table 1.

Table 1: Safety Administration Principles

Principle	Description
Organize	Understand the workflow through the lab and organize facilities (e.g. safety stations), eq personnel circulation and materials circulation around it with a view towards safety. Ap planned changes. Decide what records e.g. floor plan to keep that will show on paper h organized. Develop a Chemical Hygiene Plan (CHP) and a Business Continuity Plan (BCP
Operate	Put controls in place. Conduct lab activity following approved written procedures such a Operating Procedures (SOPs), Test Methods and Experimental Protocols. Use a safe-by- strategy to "write safety into the procedure". Identify required Safety SOPs at all points a workflow. Take a risk-based approach.
Monitor	Take an active role in the lab. The Chemical Hygiene Officer (CHO) actively oversees the conducts regular walkthroughs and inspections. Decide what records to keep at points (points) along the workflow for tracking safety performance.
Feedback	Communicate and provide feedback. Include results from inspections, audits and invest reviews of incident, accident &near-miss reports, review safety policies& written safety p review case studies, etc. Use a team approach. Feedback is both negative and positive.
Document	Document performance.

RISK ANALYSIS

The Lab Manager must determine whether proposed work is suitable for the lab. In the second of these articles we described a way (called system safety analysis) to do this on a project-specific basis. Here we take a higher level view. The lab capabilities are limited by design and perhaps also by regulations, the environment and the level of expertise of personnel and these limitations must be understood and applied in making a determination. For example, a contract analytical lab may consider providing support to an EPA worker risk exposure program. It anticipates performing extractions of biocides with acetone from clothing worn by workers that have been exposed to the biocide. The lab stores and handles acetone routinely and has expertise with biocides and validated analytical methods already in place for the anticipated analysis.

All those working in the lab know that acetone and acetone-based wastes are flammable and have been trained on how to handle them. The lab is under local regulation as to how much flammable liquid can be in the facility at any given time (based on a number of parameters including whether a sprinkler fire-suppression system is in place, whether approved flammables cabinets are in place, etc.). An estimate is made on the maximum quantity of acetone/acetone waste to be in the lab at any given time based on the proposed (written) experimental protocol. This value is added to the total flammables liquid inventory that the lab typically maintains, and the sum is compared to the allowed limit. It is determined that some changes must be made in how the lab handles flammable liquid waste before this kind of work may be done. There are costs associated with making these changes. In determining whether or not to allocate the resources to this project, Management will use a risk-based approach. This involves making a risk assessment and performing risk management. The former involves the collection of data (facts) to ascertain the hazard to an individual, facility or environment posed by exposure to hazardous materials and situations. The latter involves rolling that assessment into the decision making process.

Part of the risk assessment will be an impact assessment to determine how the course of action may impact upon workflow, existing regulatory status, existing safety status (e.g. is there adequate ventilation in the lab) and many other things. We chose a very simple example. More challenging cases will bring in many more concerns that must be addressed to go forward safely. A number of common questions and concerns that come up in the risk analysis are listed in Table 2. Some may pose serious challenges for the lab.

Consider again the hypothetical example we used in our two earlier articles, namely the proposal to prepare and store in the lab a nearly stoichiometric mix of H2-O2-CO2 gases in a 50L metal tank to 8 standard atmospheres of pressure: The process can be done safely with minimal risk to personnel, the facility and the environment, however, the cost to do so is probably prohibitive for the lab. Included in the cost will be “opportunity costs” associated with disruption of the work environment, the cost of the required lab renovations, the cost of the required safety review and many other costs. These will all come out in the risk analysis.

Lab Management is under constant tension between meeting financial goals and safety goals and must be guided by input from the risk assessment and management process to keep the correct balance. Managing risk is really tantamount to managing conflicting interests. Next, we take up good practices for the organization and operation of the lab as well as for monitoring lab activity and providing feedback

Table 2: Partial Listing of Questions to Arise in a Risk Analysis

1	Are we at risk to be in violation of a regulation (e.g. building or fire code regulation)
2	Is the emergency response program adequate (e.g. to a large spill)
3	Are we likely to bring in an audit from a regulatory agency (e.g. EPA)
4	Do we require any special licensing (e.g. fish and wildlife permit, DEA license, etc.)
5	Must we put additional security into place (e.g. to get a DEA license)
6	Do we require renovations to the lab (e.g. more flammables storage)
7	Are additional monitoring capabilities required (alarms, etc.)
8	Are adequate engineering controls in place (e.g. ventilation)
9	Must additional safety SOPs be written
10	Must we hire and train additional personnel
11	Is the required PPE on hand or can we get it

ORGANIZING AND OPERATING THE LABORATORY

The Chemical Hygiene Plan (CHP)

The CHP is a comprehensive program, typically written by the Chemical Hygiene Officer (CHO) that provides details for how the lab will perform most activities including peripheral ones such as procurement of chemicals. It must put forward procedures, equipment, PPE and work practices capable of protecting employees from the health hazards presented by hazardous chemicals used in the workplace. It is a controlled document that is approved at the highest level and is to be reviewed and revised at least annually. It is readily available to all lab workers (employees) at all times and is part of their mandatory initial new employee safety training. The OSHA Laboratory Standard requires the lab develop a CHP that is specific to their facility and contains certain mandatory elements. These are discussed in references [1 -3]. In Table 3 and Table 4, mandatory elements and some optional elements are listed, respectively.

Table 3: Mandatory CHP Elements

1	SOPs for Handling Hazardous Chemicals
2	Criteria to be used for Implementation of Control Measures to Reduce Exposure
3	Requirements that Control Measures (hoods, respirators and all other protective equipment) Functioning Properly
4	Employee Information and Training (including emergency procedures)
5	Requirements for Prior Approval of Laboratory Activities
6	Medical Consultations and Medical Examinations
7	Designation of Responsible Personnel (e.g. Chemical Hygiene Officer)
8	Special precautions for Working with Particularly Hazardous Substances
9	Designated Areas
10	Containment Equipment
11	Procedures for Safe Removal of Contaminated Waste
12	Decontamination Procedures

Table 4: Additional (Optional) CHP Elements

1	Laboratory Safety Policies
2	Safety Inspection Program
3	Chemical Procurement, Distribution and Storage
4	Labeling Chemicals and Secondary Storage Containers
5	Maintaining a Chemical Inventory
6	Reporting Accidents, Incidents and Near-misses
7	Keeping Records
8	Meeting Requirements of Local Authorities
9	Other Prudent Practices as Deemed Appropriate

Business Continuity Plan

Safety must integrate with other programs such as the program to ensure continuity of business in the event of a disaster, pandemic, etc. In light of the international struggle in the fight against the Covid-19 coronavirus pandemic presently ongoing, the Business Continuity Plan (BCP) is getting particular attention. The Center for Disease Control (CDC) provides guidance for small businesses through their website (www.cdc.gov) as well as emergency response protocols for laboratories. A model BCP can be had through the International Organization for Standardization (ISO) standard entitled "Societal security business continuity management systems" and identified as ISO 22301:2012.

The Business Continuity Plan (BCP) is developed in order to establish procedures to follow upon the occurrence of a severely-adverse event. The BCP is created by a team that will include representatives from the Safety group and will contain sections that also appear in the CHP such as "Emergency Response."

At Pine Lake Laboratories, we include in the BCP those elements listed in Table 5. In developing the plan, the first step is to decide what is meant by an "adverse event" then identify all such adverse events. The next step is to decide on what it is you want to protect in such an event. For example, you want to protect personnel from an adverse event such as a pandemic. In detailing how to do this, include (a) how you will be prepared for such an event (b) how you will minimize the impact (c) how you will ensure continuity of business throughout the event and (d) the steps you will take to shorten the time to recovery. Referring to Table 5, under each "Protection" header we treat (a) through (d).

Table 5: Recommended BCP Elements for a Laboratory Business

1	Definitions of terms used in the BCP
2	Scope of the BCP and methods for Implementing the BCP
3	Roles and Responsibilities of Persons Covered by the BCP
4	Planned Changes that may impact Business Continuity
5	Notifications: Personnel, Safety Department, Agencies (Local, State and Federal)
6	Protection of Personnel from Adverse Events
7	Protection of the Environment from Adverse Events
8	Protection of Experimental Studies from Adverse Events
9	Protection of Computer Servers from Adverse Events
10	Protection of other Establishment Resources from Adverse Events
11	Keeping Critical Lab Functions Operating
12	Implementing the BCP
13	Process Documentation: Document each time you implement the BCP
14	Continuous Improvement
15	Change Control (History of Changes to the BCP document)
16	Approvals

CONTROLS

Administrative Controls

Administrative a.k.a. Procedural Controls are one of three strategies for reducing exposure to hazardous chemicals: The other two are Engineering Controls such as fume hoods and Personal Protective Equipment (PPE) such as respirators.

A typical Administrative Control is requiring that lab equipment be labeled as per its intended use. This can be done reliably and in a timely fashion following a procedure agreed upon by the lab and procurement and safety groups. The procurement of a commercial metal tank, for example, should be made following a specification issued by the person requesting the equipment (the user) such as "wish to purchase a tank for use with compressed air at 8 atm total pressure". Other specifications of course can be made on the tank. A suitable tank is purchased. Upon receipt of the tank, the user would check that the tank received does in fact meet all the specifications used to procure it and then label the tank appropriately. To override this label and to label the tank, for example, "for use with H_2-O_2-CO_2 gas mixtures only" would be a deviation from procedure and require prior approval. The Hazard Review detailed in the first two articles of this series is another example of an Administrative Control. The "Do Not Work Alone in the Lab" policy is another example and to emphasis the importance of this, we point to one of the most famous examples in the history of modern chemistry: In 1946, the extraordinary chemist, G.N. Lewis, nominated 41 times for the Nobel Prize was found dead in his UC Berkeley lab. He had been working alone in the lab with liquid hydrogen cyanide. Since he was alone, the details of the moments leading up to his death are unknown.

An instruction such as may be found in an SOP or Test Method that calls for the work to be done in the Fume Hood is an Administrative Control. The SOP too is another Administrative Control as are written and approved Test Methods, Experimental Study Protocols and Safety Policies. Administrative Controls are kept turned “on” all the time, unlike an Engineering Control such as a Fume Hood.

Personal Protective Equipment

Minimizing risk of exposure should first be done through engineering and administrative controls. PPE is a last resort. Rules and guidance on selection and use of PPE can be found in OSHAs PPE Standard (29 CRF 1910.132) and in the American National Standards Institute PPE guidance (ANSI/ISEA 105-2016), respectively. On a daily basis, lab workers must select and properly use gloves. The importance of this cannot be overemphasized, and so we point to the tragic loss of Chemistry Professor Wetterhahn, a brilliant researcher at Dartmouth College, who was poisoned in 1996 when 1 or 2 drops of dimethylmercury fell onto her gloved hand. The compound permeated through the latex glove onto her skin and after extensive chelation therapy, she died less than a year after her exposure.

Facilities and Engineering Controls

In the previous two articles of this series, we approached safety on an individual level, looking at what the individual was proposing to do in the laboratory as they move their experimental project forward and what we all must do to keep them safe. In the present article, we zoom out. We consider the ideal laboratory workplace, where a qualified worker can expect to work safely and specifically, the facilities and engineering controls that must be in place to ensure that. Engineering controls are the first line of defense and represent the most important level of protection. Facilities vary widely with age, geographic location, building codes, type of laboratory operation, chemical inventory, etc. Those persons lucky enough to build the laboratory from the ground up will do so in a way that accommodates workflow through the lab and in anticipation of growth. Most of us have to work with a facility we inherited, but still must consider workflow and growth. Older facilities are more likely to present problems such as the presence of asbestos, inadequate ventilation and many others.

The design, installation, operation and maintenance of facilities and engineering controls are vast subjects. We can do no more here than to present some of the considerations (Table 6) that normally go into the Chemical Hygiene Plan under “Criteria to Be Used for Implementation of Measures to Reduce Exposures” and direct the reader to references [1-4] where they can learn more.

Table 6: Considerations for Facilities and Engineering Controls

1	Location	Consider: Goodness of neighborhood (low crime), adequate parking, indigenous pests, proximity of local emergency services
2	Facilities Design Considerations	Do facilities match up with present and future lab capabilities? Do they accommodate anticipated workflow and growth?
3	Facility Security System	Employee scan card system, motion detectors to alert local police department of an intruder
4	Fire Alarm System	Internal alarm with automatic call out to local fire department
5	Fire Suppression System	Sprinkler (water) system or dry powder system
6	Back-up Power Generation	To support critical systems in the event of a power outage
7	Computer Servers	Data storage and backup
8	Exit Lights	To illuminate exits to safety in the event of fire, power outage or chemical release
9	Explosion Proofing	Consider wall receptacles, lighting fixtures, refrigerator motors
10	High-pressure gas cylinder storage	As needed
11	Facility HVAC system	Consider that laboratory instrumentation and particularly freezers and refrigerators dissipate a lot of heat to the lab.
12	Environmental Chambers	Providing controlled temperature and/or humidity for sample, reagent and specimen storage, these need room to breathe.
13	Environmental monitoring and controls	Temperature and relative humidity monitoring in lab rooms
14	DEA Safe (Drug Enforcement Agency)	For storage of DEA-controlled substances
15	Storage Rooms designed to house the Archives	Protect documents, specimens, samples, etc. against fire, water damage, mold, theft, pests, etc.
16	Chemical Fume Hoods	As many and wherever needed. These are noisy.
17	Dedicated ventilation for select instruments	For example, venting GC effluent to an elephant trunk drop
18	Safety (drench) Showers	Located no more than 100 feet (or less than 10 seconds travel time) from the furthest distance in the lab.
19	Eyewash Stations	As many and wherever needed
20	Flammables Cabinets	As many and wherever needed
21	Fire Extinguishers	As many and wherever needed
22	Safety Equipment Stations	For keeping fire blankets, first aid kits and spill cleanup kits
23	Break-rooms and Bathrooms	To promote good personal hygiene

The senior author at one time owned and operated a chemical laboratory. Starting out with a single lab, he expanded to renovate seven labs in an older (early 1950s) facility, until finally relocating to a relatively modern (late 1990s) facility. The older facility was plagued with difficulties. Originally, the labs had floor drains, and these had to be permanently covered so that the floors could be mopped without concern that waste water would go down the drain into the municipal sewer. They had drop ceilings that obscured the sprinkler heads, which had to be extended; the safety showers were not located less than 100 feet (or less than 10 seconds traveling time) from the furthest point in the lab nor were they positioned well away from instruments and other electrical sources, noise from an air compressor made it impossible to work in one of the offices while vibrations from the same compressor made it impossible to situate a mass spectrometer on a nearby lab bench.

The older facility was rented, and although a card-scan security system was installed to limit access, the landlord was permitted access and he would walk through the facility with his dog during normal business hours. Without a break-room, people may try to use the lab refrigerator and desk as places to keep and eat their lunch. Probably the most horrendous issue was discovered during renovation of the lab, when it was found that kick-out panels that were installed in offices to provide the employee a means of egress in the event of a fire, were installed directly in front of steel I-beams, making it impossible for any adult to pass through. All of these things and more had to be corrected. The reader may wish to use Table 6 as a sort of checklist as they walk through their own laboratory facility.

Monitoring Lab Activity and Providing Feedback

"Safety" must be an integral part of everyone's daily activity in the lab. Safety "awareness" is increased by maintaining a presence. Safety signage helps. OSHA requires the poster known as "Job Safety and Health: It's the Law" (poster 3165) to be posted in plain view along with the evacuation routes and location of emergency exits, fire extinguishers, fire alarms, drench showers and eyewash stations. The lab must post emergency contact phone numbers. Signage is used to mark entrances to labs to identify the nature of the work in the lab. These may include signs such as "Authorized Personnel Only" and "Biohazard" and "Radiation Hazard" and "Safety Glasses Required in this Area." Other useful signs tailored to the individual lab may include: location of Safety Stations (Fire Blanket, First-aid kit, Spill Clean-up kits, etc.), glove selection posters, the GHS symbols poster, the NFPA diamond poster, Listing of Peroxide Forming Compounds, Ergonomics in the Workplace poster and other labels, posters or signs to warn workers where there is a "safety area of concern" such as a requirement to have the fume hood sash at the correct level.

Internal safety inspections are another important way to maintain a presence. It is common for the inspection to be conducted monthly by the CHO and a peer, who may be a qualified volunteer from the safety steering team, for example. Unannounced lab walkthroughs by senior management is yet another way. To facilitate the safety inspection, a checklist is used (Figure 1).

Figure 1: Example of a Safety Inspection Checklist

Monthly Facility Safety Inspection Checklist				
Name & Title of Inspector				**Date of Inspection**
Safety Signage		Good Housekeeping		Pest Control
Proper Chemical storage & Chemical Labeling & Secondary Containers		Monthly Fire Alarm Check & Quarterly Fire Drill Check		Slip, Trip and Tip (drop we Hazards
Proper Flammables Storage & Inventory		Safety Stations: Fire blankets, first-aid kits, spill clean-up kits		Proper Use of Fume Hooc Biosafety Cabinets
Proper Use of PPE		Glassware and Sharps		Electrical Hazards Check
Fire Extinguishers, Safety Showers, Eyewash stations		New Employee Training Records (if applicable)		Bench-top Use & "six-inch violations
Storage and use of Compressed Gases		Proper Handling of Lab Waste		Proper Handling of BioHa Waste

The results of the monthly lab inspection are summarized in the Safety Inspection Report and posted in plain view (Figure 2). These results form the basis for discussion in the monthly safety meeting attended by all. Feedback (both positive and negative) is provided in the monthly safety meeting. Agenda items will come from the monthly report, results from any outside audit/inspection and results from any accident/incident/near-miss report generated that month. In addition to agenda items that are issued in advance of the meeting, participants are free to bring up any item they see fit for discussion. A constructive and positive approach is taken. The meeting is intended to solve problems, ward off potential problems and nurture the growth of a good safety culture.

Figure 2: Example of a Safety Inspection Report Template

Date:	20 May 2016
Inspector (s)	R. C. Wedlich (Chemical Hygiene Officer) and Z. Miller (scientist)
A facility-wide inspection was conducted on the dates below using the Safety Inspection Checklist a The following observations were made:	
List any outstanding work orders:	None.
Proper Use of PPE:	No issues. All lab personnel were found to be wearing proper PPE.
Housekeeping:	A few issues were found: Box clutter on the loading dock, dirty glassware an eyewash station in lab 121. These were corrected on the spot.
Pest Control:	No issues. Pest inspection reports for the past 2 months were reviewed.
Fire Extinguishers:	No issues. All are in place and fully charged.
Safety Showers:	No issues. All were tested and "passed"
Eyewash stations:	No issues. All were tested and "passed"
Flammable Liquids:	No issues.
Compressed Gases:	No issues.
Fume Hood Use:	No issues.
General Issues:	No issues.
Observations made:	The labs are neat and well-organized, proper chemical labeling is being fo solvents and reagents not in use are stored properly.
Comments:	Commend the lab on a very positive outcome for this safety inspection.
Respectfully submitted by:	Sign: Date:
Reviewed and Approved by:	Sign: Date:

Figure 3: Example of an Accident Report Template

Name (Worker):
Name of Worker's Supervisor:
Names of All Witnesses:
Check one (required) ▫ Accident ▫ Incident ▫ Near-miss
Date of occurrence: Time of occurrence: Location of occurrence:
Provide a detailed account or description of what happened and attach any supporting documentation if necessary (e.g. drawing).
Was worker treated in an emergency room? ▫ yes ▫ no
Was worker hospitalized overnight as an in-patient? ▫ yes ▫ no
If treatment was given away from the worksite, where was it given? Facility: Street Address: City: State: Zip:
Name of the attending physician or other health care professional:
Describe the activity worker was doing just prior to the occurrence (Include tools, equipment and materials you were using at the time).
Describe the injury:
What object or substance directly harmed worker:
What immediate actions were taken following the occurrence?
What preventative measures must be, or already have been taken to prevent reoccurrence?
Completed by (Print): Sign: Title: Phone: Date:

Accidents, incidents and near-misses must be documented. The report (Figure 3) is to be completed by the lab worker and/or their supervisor within 24 hours of receiving information of an occurrence (accident, incident or near-miss).

CONCLUSION

Establishing and maintaining a safe chemical laboratory is a lot of work. Surely, the lab wants to expand its capabilities while at the same time it is operating under constraints. Safety is not a constraint. Safety is a product. It is the outcome of performing careful risk assessment where constraints such as budgets and regulations and technical "know-how" figure into planning and design and execution of laboratory activities and the laboratory itself. Safety is also an expectation. As we endeavor to improve, always learning how to do things better, our facilities and controls improve as does our ability to successfully administer a major safety program. In the end, everyone, our laboratory students, our professional lab technicians, chemists, engineers and managers, our academic researchers and our industry, is better for it.

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