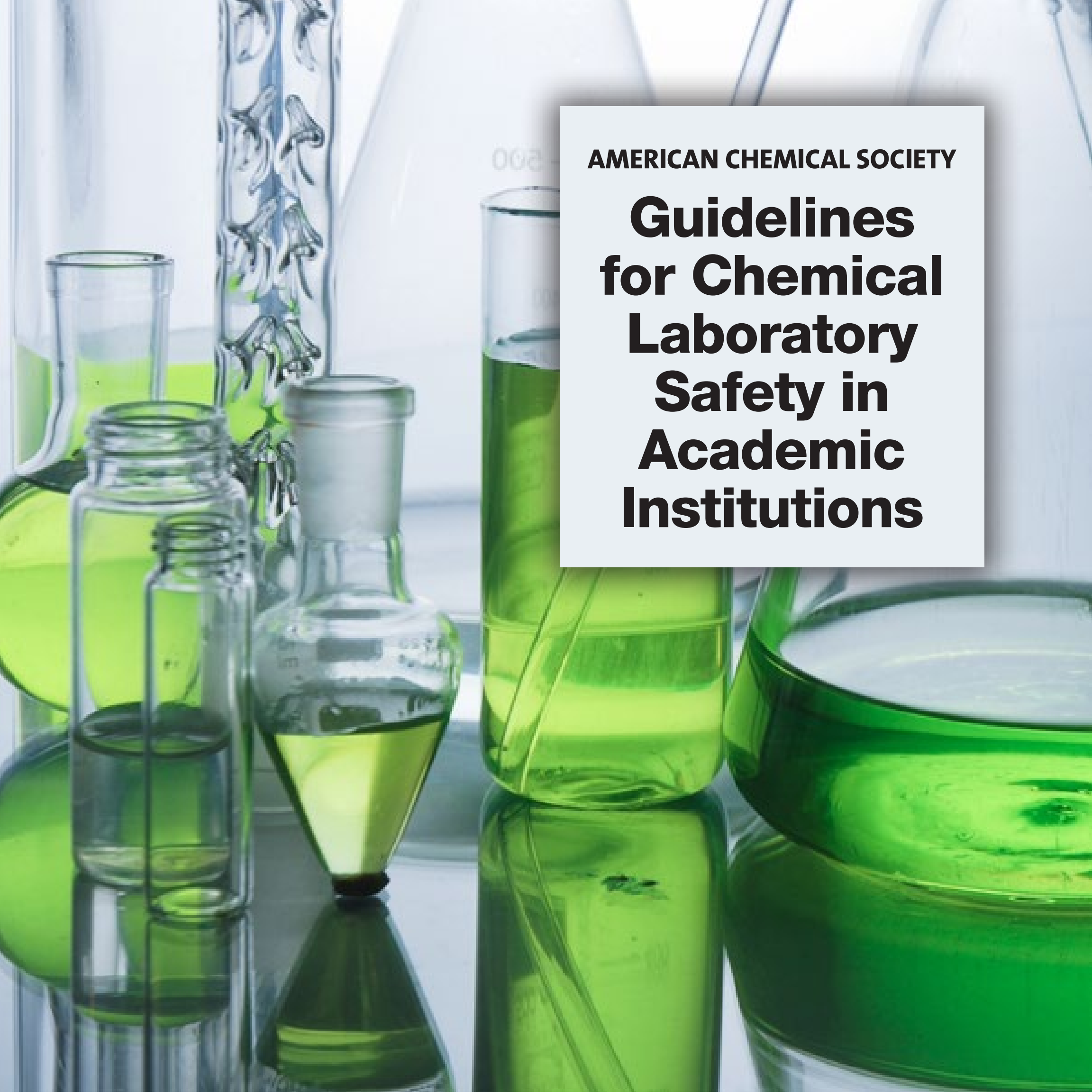

AMERICAN CHEMICAL SOCIETY

Guidelines for Chemical Laboratory Safety in Academic Institutions

Published by
American Chemical Society
1155 Sixteenth Street, NW
Washington, DC 20036

AMERICAN CHEMICAL SOCIETY

Guidelines for Chemical Laboratory Safety in Academic Institutions

Disclaimer:

The guidance contained in this publication is believed to be reliable but is not intended to specify minimal legal standards or to represent the policy of the American Chemical Society. No warranty, guarantee, or representation is made to the American Chemical Society as to the accuracy or sufficiency of the information contained herein, and the American Chemical Society assumes no responsibility in connection therewith. Users of these guidelines should consult pertinent local, state, and federal laws and legal counsel prior to initiating any accident prevention program.

Guidelines for Chemical Laboratory Safety in Academic Institutions

TABLE OF CONTENTS

Acknowledgments

This guide was produced by the ACS Committee on Chemical Safety (CCS) Task Force for Safety Education Guidelines.

TASK FORCE MEMBERS

TASK FORCE CO-CHAIRS

Kirk Hunter, *Texas State Technical College, Waco, TX*

W.H. "Jack" Breazeale, *Francis Marion University, Florence, SC*

Secondary Education

Jennifer Panther Bishoff
Southern Garrett High School, Mountain Lake Park, MD

Regis Goode
Ridge View High School, Columbia, SC

Karlo Lopez
California State University Bakersfield, Bakersfield, CA

Patricia Redden
Saint Peter's University, Jersey City, NJ

Two- and Four-Year Undergraduate Education

Georgia Arbuckle
Rutgers University, Camden, NJ

Edgar Arriaga
University of Minnesota, Minneapolis, MN

Joe Crockett
Bridgewater College, Bridgewater, VA

Julie Ellefson
Harper College, Palatine, IL

Ken Fivizzani
RETIRED
Nalco Company, Naperville, IL

Steven Fleming
Temple University, Philadelphia, PA

Frank Torre
Springfield College, Springfield, MA

Graduate and Postgraduate Education

Dom Casadonte
Texas Tech University, Lubbock, TX

Anna Dunn
University of Michigan, Ann Arbor, MI

Scott Goode
University of South Carolina, Columbia, SC

Robert H. Hill
PAST CHAIR (2012–2014)
COMMITTEE ON CHEMICAL SAFETY (CCS)
Battelle Memorial Institute, Atlanta, GA

Neal Langerman
Advanced Chemical Safety, Inc., San Diego, CA

In addition to the Task Force members, the contributions of the following people and groups to this document are gratefully acknowledged.

David C. Finster
Wittenberg University, Springfield, OH

Elizabeth M. Howson
2015–2017 CCS CHAIR
Morristown, NJ

ACS Committee on Chemical Safety (CCS)

ACS Committee on Professional Training (CPT)

ACS Division of Chemical Health and Safety (CHAS)

Marta U. Gmurczyk
ACS STAFF LIAISON TO THE CCS
ACS, Washington, DC

Raihanah Rasheed
ACS ASSISTANT STAFF LIAISON TO THE CCS
ACS, Washington, DC

INTRODUCTION

Laboratory work is a critical component of all chemistry programs, beginning with introductory-level undergraduate classes. Therefore, students need to develop a solid foundation in the basic principles and procedures of laboratory safety and to deepen their knowledge as they progress through their academic career. To care about safety and develop a safety ethic, students need to learn the "why" behind safety so that they can identify safety issues and can make decisions that reflect their personal safety values and knowledge.

These guidelines are intended to assist faculty and staff as they develop, enhance, and assess the safety education of their students. The statements that follow are intended to be suggestive as a department establishes its own academic laboratory safety program. Faculty and staff may select those statements that are relevant to their institutional environment, and they may add others. The overarching goal of these guidelines is to enable students to develop an understanding of the principles of chemical safety and to enable them to apply these concepts when working in a laboratory.

Many students begin pursuing their academic goals at two-year colleges with the intent of transferring to a four-year institution, and some students continue beyond the undergraduate degree to earn a graduate degree. Use of the same safety education guidelines across the full educational spectrum will enable students to understand the expectations with respect to laboratory safety throughout their educational career, with an increasing depth of knowledge as their education progresses. For example, students in upper-division classes will have exposure to advanced chemical principles, such as kinetics, mechanisms, and thermodynamics, and should begin to develop a deeper understanding of the underlying science and applications of chemical safety. Students entering into undergraduate research should be prepared, under the guidance of their mentor, to assess the hazards associated with their specific research area and to conduct laboratory activities safely.

While these safety education guidelines are focused on students who complete a bachelor's degree in chemistry, they also cover those students who take chemistry courses as a support for other majors or specialties, such as biology, physics, engineering, medicine, or nursing. Also, these students may go on to become science teachers in the K–12 grades, and so it is crucial for them to know the basics of chemical safety.

For students who plan to continue to a graduate program, a broad background in safety education and basic familiarity with common laboratory hazards are expected.

Special Considerations

Some two-year institutions may also prepare students to work in industrial settings through a chemistry-based technology program. These programs may have additional chemical safety practices that are recommended by their industry partners, such as wearing special clothing and personal protective equipment, and special emergency response procedures. Chemistry-based technology programs should incorporate these guidelines into their safety education along with the additional recommendations from their industry partners.

Undergraduate Laboratory Safety Learning Objectives

The learning outcomes in these guidelines were developed using the RAMP concept for scientific safety, developed by Robert H. Hill and David C. Finster in their textbook *Laboratory Safety for Chemistry Students*.[a] The goal is to help those working in a laboratory environment keep chemical safety a top priority. RAMP stands for:

R **Recognize the hazards**

A **Assess the risks of the hazards**

M **Minimize the risks of the hazards**

P **Prepare for emergencies from uncontrolled hazards**

[a] *Source*: Hill, R. H.; Finster, D. C. *Laboratory Safety for Chemistry Students;* John Wiley & Sons, Inc.: Hoboken, NJ, 2010; p 1-7.

Recognize the Hazards

Students should be able to recognize common laboratory hazards, to explain why these are hazards, and to have some familiarity with hazard rating systems. These are outlined in the learning objectives below and in Table 1.

Assess the Risks of the Hazards

Students should be able to assess the risks of specific hazards. Risk is the probability of suffering injury or harm from exposure to a hazard. Students should be able to determine the relative severity of a specific hazard and to give an estimate of the likelihood of exposure under certain circumstances.

Minimize the Risks of the Hazards

Students should be able to identify ways in which the risk can be lowered. This may involve using appropriate engineering controls (equipment such as hoods, ventilation systems, and safety interlocks), administrative controls (procedures, processes, and training), and personal protective equipment (PPE) to reduce or mitigate the hazard. Students should know common methods to minimize hazards and the limitations of those protective measures. Students must be aware that all laboratory research has risks and that careful planning and preparation can reduce those risks to acceptable levels.

Prepare for Emergencies from Uncontrolled Hazards

Students should prepare for emergencies by being able to explain how to respond to common emergencies that could occur in laboratories, such as fires, explosions, chemical exposures, injuries, and chemical spills. Students should be able to explain the selection and proper use of emergency equipment such as fire extinguishers, eyewash stations, safety showers, spill kits, first aid kits, fire alarms, and fire blankets. Students should know the importance of reporting laboratory incidents and the lessons that can be learned from the incidents. Training, walking to locations of all emergency equipment, and considering what one would do should occur BEFORE an incident or emergency occurs.

Use of these safety education guidelines should help foster a culture of safety, in which students apply the RAMP concept to their laboratory experiences and continue to keep safety a high priority throughout their education and their professional lives.

By the time they complete their undergraduate education, students should have acquired specific safety knowledge and skills. The following learning outcomes provide a framework (or basis) for the safety knowledge and skills.

Learning Objectives

Below are the outcomes that faculty and staff should expect of undergraduate students. They should be integrated and assessed throughout the curriculum.

Students should be able to define, explain, and understand the following terms and concepts at a basic level.

RECOGNIZE THE HAZARDS

Terms to Define or Explain

- Acute toxicity
- Asphyxiant
- Autoignition temperature
- Biological hazards (infectious agents, blood-borne pathogens)
- Boiling liquid expanding vapor explosion (BLEVE)
- Carcinogen
- Chemical Abstracts Service (CAS)
- Chronic toxicity
- Compressed gas
- Corrosive
- Cryogen
- Electrical hazard
- Environmental Protection Agency (EPA)
- Explosives
- Fetotoxicant
- Flammability
- Flash point
- Globally Harmonized System (GHS)
- Halogen
- Hazard
- High- and low-pressure systems
- Immediate danger to life or health (IDLH)
- Incompatible chemicals
- Lachrymator
- Lethal concentration, 50% (LC_{50})
- Lethal dose, 50% (LD_{50})
- Long-term exposure limit (LTEL)
- Mutagen
- National Fire Protection Association (NFPA)
- Organ toxicant

- Occupational Safety and Health Administration (OSHA)
- Occupational exposure limit (OEL)
- Permissible exposure limit (PEL)
- Peroxide
- Personal protective equipment (PPE)
- Pyrophoric
- Radioactive and radiological hazards
- RAMP system
- Reactive/unstable chemicals
- Risk
- Runaway reaction
- Safety Data Sheet (SDS)
- Sensitizers (allergens)
- Short-term exposure limit (STEL)
- Sublimation
- Teratogen
- Threshold limit value (TLV)
- Time-weighted average (TWA)
- Toxicity
- Ultraviolet radiation

Basic Terminology and Concepts

1. Differentiate between hazard and risk.
2. Define acute and chronic toxicity and cite some examples of each.
3. State the general effects that corrosives have on the skin.
4. State the general hazards associated with flammables commonly used in the laboratory.
5. Correlate a compound's structure and properties with potential flammability.
6. Explain the statement "The dose makes the poison."
7. Explain why reducing the scale reduces the risk.
8. Describe the different classes of lasers.

Labels, SDS, and PPE

9. Explain the components of the GHS labeling system, including pictograms, signal words, hazard statements, hazard categories (ranking), and precautionary statements.
10. Interpret information given on an NFPA diamond.
11. Given an SDS, identify the substance, the hazards, and the appropriate PPE.

Basic Laboratory Safety

12. State the general rules for working safely in a chemical laboratory.
13. Describe the possible routes of exposure for a hazardous material.
14. Explain why food and drinks are not permitted in a chemical laboratory.
15. List the general considerations for appropriate waste disposal.
16. State the general hazards associated with mercury, mercury compounds, and pyrophoric compounds.
17. Identify potential unusual situations or unplanned events in the laboratory (e.g., chemical spills, odors).
18. Explain why long hair that is not tied back, neckties, jewelry, and loose articles of clothing are considered hazards.

Regulatory Agencies and Regulations

19. State the purpose of regulatory agencies (e.g., OSHA, EPA).
20. State the purpose of the Chemical Hygiene Plan.
21. Identify the components of a Chemical Hygiene Plan.

Labels

22. Interpret the information given on a manufacturer's label or an in-house prepared label for a chemical substance.
23. Use hazard information to prepare labels, as per GHS 2012, for secondary containers.

Information from SDS

24. Locate the CAS Registry Number for a chemical.
25. Locate an SDS for a chemical.
26. Identify the occupational exposure limits (OELs) using TLV and PEL values.
27. Differentiate between flash point and autoignition temperature.
28. Define and explain the relevance of upper and lower explosion limits for a substance.

Inspections

29. Conduct a laboratory safety inspection.
30. Identify common safety concerns upon casual examination of a laboratory.

Risk Assessment

31. Explain the process of assessing the risks from chemicals and chemical procedures.
32. Prepare and explain a general risk assessment matrix.

General Concepts

33. Explain why the “buddy system” is used in laboratory environments.
34. Explain why various flammable and combustible materials should be available in limited quantities in laboratories.
35. Discuss the considerations that must be taken into account when measuring flammable materials and transferring them from one container to another.
36. Explain the reasons for following established and written protocols and/or standard operating procedures (SOPs) for laboratory activities and experiments.
37. Explain the reasons for good housekeeping in the laboratory.
38. Demonstrate good housekeeping by maintaining a clean and orderly workspace.
39. Identify and demonstrate the appropriate use of PPE for a given laboratory activity.
40. Identify and demonstrate the appropriate use of common laboratory safety equipment (e.g., safety shower, eyewash station, fire blanket, fire extinguisher).
41. Describe and demonstrate methods to prevent spills, including situations involving falling containers, or when transferring and transporting chemicals.
42. Describe and demonstrate the appropriate use of common laboratory devices for heating (e.g., Bunsen burners, hot plates, alcohol burners, candles, heat guns, laboratory ovens).

43. Describe the precautions for using the following equipment: microwave ovens, ultrasonic cleaners, centrifuges, vacuum pumps, refrigerators, and freezers.
44. Describe the precautions needed when using any electrical equipment, including inspection of cords and connections, grounding, and switches.
45. Describe the basic precautions for the following laboratory operations: chromatographic techniques, distillations, refluxing, recrystallization, extraction, and stirring.
46. Describe the basic precautions for working with reactive materials, peroxides, and other high hazard chemicals.

Planning

47. Prepare a safety checklist for experiments using the RAMP concept.
48. Describe how to plan experiments in order to minimize the use and generation of hazardous materials.
49. Prepare and lead a short safety meeting appropriate to the laboratory setting.

PPE

50. Describe the various types of eye protection and the specific protection that each provides.
51. Describe and discuss skin protection measures (e.g., clothing, gloves, tools).
52. Describe the appropriate materials and construction for a laboratory coat.
53. Explain why glove material and construction must be considered when selecting proper PPE.

54. Given a glove selection chart, select the proper glove material and construction for a laboratory operation or potential chemical exposure.
55. Select and wear appropriate PPE while in the laboratory.
56. Describe the proper care of PPE.

Ventilation

57. Differentiate between a chemical hood and a biological safety cabinet.
58. Describe the proper use and operation of chemical hoods and ventilation systems.
59. Describe the use of a “snorkel” exhaust system.

Lasers

60. Describe the precautions to take when using a laser.

Sharps

61. Demonstrate the proper disposal of “sharps”.
62. Demonstrate proper procedures to prevent lacerations while handling glassware, either intact or broken.

Inventory, Storage, and Security

63. Explain how a chemical inventory management system may assist in minimizing laboratory hazards.
64. Describe the appropriate storage protocols for laboratory chemicals.
65. Describe methods to ensure the security of laboratory chemicals.

66. Describe the proper use of safety cabinets for the storage of corrosives and flammables.
67. Explain why incompatible chemicals must be separated when being stored.
68. Describe the steps needed to prevent incompatible chemicals from coming into contact with each other.
69. Describe the appropriate storage procedures for flammables and corrosives.
70. Describe the considerations to be taken into account, including the quantities on hand and needed, when ordering and receiving chemicals.
71. Describe the general considerations and physical requirements for storing chemicals.
72. Describe measures that should be taken to prevent theft of chemicals and equipment.
73. Describe measures that should be taken to secure high hazard materials in the laboratory.
74. Given a list of chemicals commonly found in an undergraduate laboratory, describe the proper storage location for each chemical.

Chemical Wastes and Disposal

75. Describe the appropriate protocols for handling and disposing of chemical wastes.
76. Describe the appropriate disposal methods for damaged glassware.
77. Explain why disposal of chemical wastes by pouring them down the drain or placing them in the trash can is generally not appropriate.

78. List the two main responsibilities of laboratory personnel in hazardous waste disposal.

Chemical Demonstration Safety

79. Outline the appropriate safety measures that should be taken for any classroom or public chemical demonstration.

Spills and Spill Prevention

80. Demonstrate the appropriate use of bottle carriers.
81. Use appropriate techniques to transfer gases, liquids, and solids from storage containers to laboratory equipment.
82. Describe and demonstrate how spills of solids and liquids can be minimized and contained during weighing operations.

High Hazard Materials

83. Describe safety concerns and controls for the use of compressed gases.
84. Describe safety concerns and controls for the use of cryogens.
85. Describe safety concerns and controls for the use of lasers, pyrophorics, and other high hazard materials.
86. Describe safety concerns and controls for the use of radioactive materials.
87. Describe safety concerns and controls for the use of infectious biological materials.

General Preparation

88. Access the Chemical Hygiene Plan.
89. Identify the location of all exits and laboratory safety equipment (e.g., safety shower, eyewash station, fire extinguisher, first aid kit).

Emergency Response

90. Respond appropriately per institutional policies to emergency situations in the laboratory (e.g., spills, fires).
91. Describe emergency exit procedures and specific locations of emergency equipment in the laboratory.
92. Participate in an emergency exit procedure for the laboratory.
93. Outline the appropriate response per institutional policies to various laboratory hazards, including chemical hazards (e.g., corrosives, poisons, flammables) and physical hazards (e.g., sharps, electrical circuits, wet floors).

First Aid

94. Describe institutional policy related to providing first aid for laboratory accidents.
95. Demonstrate basic first aid procedures for common minor laboratory accidents.
96. Demonstrate the proper use of a safety shower and an eyewash station.

Fires

97. Describe the components of the fire triangle and the fire tetrahedron.
98. Describe the classes of fires and the appropriate class and use of fire extinguishers for each class of fire.
99. Describe the result of flammable vapors catching fire and expanding according to the gas equation.

Spills

100. Demonstrate proper techniques for cleaning up incidental (small or minor) spills.
101. Demonstrate the appropriate use of PPE in responding to a minor chemical spill.
102. Demonstrate the proper use of a spill kit in response to a minor acid, base, or organic spill in the laboratory.
103. Describe the appropriate action to take in the case of a large (or major) chemical spill.
104. Describe the proper protocol for cleaning up a mercury spill from a broken thermometer.

Graduate Student and Postgraduate Safety Education

Graduate students are those students who have chosen to continue their education in order to obtain an in-depth knowledge of and experience in chemistry and related sciences. They do this through additional learning opportunities, including conducting original research. Since most physical scientists will be involved in some level of laboratory work or research, laboratory safety must be a critical component of their academic preparation. In addition, those with advanced degrees are very likely to be overseeing the safety of others and offering experimental advice during and after graduation, making safety awareness a requirement throughout their professional lives.

Graduate students need to be able to synthesize all the pieces of safety education they acquired during their undergraduate experience and extend the application of that knowledge to new situations. During their graduate education, they will move to a new level of understanding. They will be developing processes and synthesizing compounds that have never before existed, and therefore need to be able to extrapolate the likely hazards and risks and identify and use appropriate precautions.

Prerequisites

New graduate students should come to their respective graduate schools with a basic education in laboratory safety, as described earlier in this document. Their education should be based on physical, chemical, and toxicological principles of safety as summarized by the RAMP concept: Recognize the hazards; Assess the risks of the hazards; Minimize the risks of the hazards; Prepare for emergencies from uncontrolled hazards. At a minimum, graduate students should be able to do the following.

RAMP

Recognize the Hazards

Recognize the Hazards

Graduate students should be able not only to recognize common laboratory hazards but also to explain why these are hazards (see Tables 1 and 2 for methods of hazard classification). This involves using hazard rating systems, including but not limited to the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) and National Fire Protection Association (NFPA) 704: Standard System for the Identification of the Hazards of Materials for Emergency Response. Familiarity with hazard rating systems will help graduate students characterize the relative severity of a hazard, which is required in order to assess the risk.

Table 1. Common Laboratory Hazards

Laboratory Hazard	Explanation or Specific Examples
CHEMICAL HAZARDS	
Corrosive chemicals	Typically, strong acids and bases, solutions with a pH < 2 or a pH > 12, and some solvents, such as formic acid, glacial acetic acid, and trifluoroacetic acid, which are particularly aggressive against tissue.
Flammable chemicals	Chemicals that are easily ignited or explode under usual laboratory working conditions, such as low-molecular-weight alcohols, aldehydes, ketones, and hydrocarbons.
PHYSICAL HAZARDS	
Incompatible chemicals for storage or handling	Storing strong oxidizers, such as nitric acid, with reduced compounds, such as hydrocarbons. Reactants that react with air or water, such as alkyl metals or acid halides.
Compressed gases and high-pressure systems	This includes both the chemical hazard of the gases and the physical hazard of all parts of the system subjected to greater than 1 bar (>100 kPa).
Low-pressure and vacuum systems	This includes any system that operates at less than 1 bar (<100 kPa), including rotary evaporators.

Electrical hazards	All electrical equipment and energy sources.
Radiation hazards	Both ionizing and non-ionizing radiation, including lasers and ultraviolet lamps.
Cryogenic hazards	Any system operating below 0 °C. Examples are dry ice (solid CO_2), liquid nitrogen (LN_2), liquid oxygen (LOx), liquid hydrogen (LH_2), and liquid helium (LHe). Any system operating at greater than 90.1 K (the boiling point of O_2) will condense oxygen and create a potentially highly flammable environment.
HEALTH HAZARDS	
Toxic substance classifications	Students should be able to explain terms such as “highly toxic”, “acutely toxic”, “chronically toxic”, carcinogens, allergens, mutagens, and teratogens.
Acute chemical exposures	Students should recognize that brief exposures to highly toxic or allergenic chemicals can have a significant impact on health, and should be able to identify chemicals with these properties. Biological chemicals can also have significant effects, such as biological enzymes that can produce allergic reactions.
Chronic chemical exposures	Students should recognize that extended exposure to chronically toxic chemicals can result in cancer or other organ-specific damage, and should be able to identify such compounds.
Nanomaterials	The small size of nanomaterials allows these materials to enter deeply into the respiratory tract or to penetrate unprotected skin. Currently, there is very limited information about the health impact of nanomaterials, so strict handling precautions are required.
REACTION HAZARDS	
Scale-up and potential runaway reactions	During a research career, the need to synthesize larger quantities of a specific chemical is likely. This scale-up may alter reaction kinetics unpredictably and may create conditions under which a reaction vessel can self-heat more than passive cooling can dissipate away, creating a thermal runaway reaction.

Catalyst effects on reactions	Whenever a catalyst is added to a reaction, the reaction rate changes, as does the rate of generation of heat and byproducts. Separating some catalysts from reaction mixtures may cause fires.
Reactive and unstable chemicals	Students should be able to explain what makes chemicals reactive or unstable, including both explosive chemicals and reactions that could lead to explosions. Pyrophoric chemicals require special techniques for handling, and students must be trained specifically in these techniques if they are to use these chemicals. Chemicals that react with air or water, such as phosphorus oxychloride ($POCl_3$), sodium metal (Na), or acetic anhydride (Ac_2O), require special handling to address their reactive hazards. Also included are chemicals that become unstable over time, such as cyclic polyenes or some alkyne structures.
Peroxides and peroxide-forming chemicals	Students should be able to explain peroxide reactivity and the types of chemicals that form peroxides spontaneously at varying rates. Most –C–O–C– compounds that contain an activated α-hydrogen will slowly react to form the corresponding peroxide –C–O–O–C–, which may be violently unstable.

Table 2. Examples of Hazards Commonly Identified for Research Activities

Hazard Type	Examples
Agent	Carcinogenic, teratogenic, corrosive, pyrophoric, toxic, mutagenic, reproductive hazard, explosive, non-ionizing radiation, biological hazard/pathogenic, flammable, oxidizing, self-reactive or unstable, potentially explosive, reducing, water-reactive, sensitizing, peroxide-forming, catalytic, or chemical asphyxiant.
Condition	High pressure, low pressure, electrical, uneven surfaces, pinch points, suspended weight, hot surfaces, extreme cold, steam, noise, clutter, magnetic fields, simple asphyxiant, oxygen-deficient spaces, ultraviolet radiation, or laser light.
Activity	Creation of secondary products, lifting, chemical mixing, long-term use of dry boxes, repetitive pipetting, scale-up, handling waste, transportation of hazardous materials, handling glassware and other sharp objects, heating chemicals, recrystallizations, extractions, or centrifuging.

RAMP

Assess the Risks of the Hazards

Assess the Risks of the Hazards

Graduate students should be able to accurately assess the risks of specific hazards. As discussed previously, risk is the probability of suffering injury or harm from being exposed to unsafe chemicals, processes, or equipment. Graduate students should be able to use various hazard rating systems to determine the relative severity of the hazards of a specific process, and to provide an accurate probability of exposure to these hazards under specific conditions. Graduate students should be able to determine whether probability of exposure or severity of hazard is more important in a specific situation. For example, the probability of exposure might be considered first if there are no controls or protective measures — in this case, many hazardous chemicals can cause serious harm, injury, or even death.

RAMP

Minimize the Risks of the Hazards

Minimize the Risks of the Hazards

Graduate students should be able to identify how the risk level can be lowered by using appropriate engineering controls (equipment such as hoods, ventilation systems, and safety interlocks), administrative controls (training, methods, procedures, and processes), and personal protective equipment (PPE). They should be able to extrapolate from known compounds and processes to new experimental situations where the compounds and processes being proposed have never before existed.

Risks of hazards can be minimized by using appropriate equipment, methods, and procedures to protect the researcher and others during laboratory work. These measures should include laboratory hoods, shielding, restraints, interlocks, other equipment, standard operating procedures (SOPs), and appropriate PPE, designed to minimize exposures to hazardous chemicals. Students should be able to explain the basics of these protective measures and the advantages and disadvantages of different measures through personal inquiry or discussion with their research principal investigator and their research group. Students should know that PPE is not the primary method for protection — rather, engineering controls, equipment, administrative controls, and laboratory procedures are always considered first and are supplemented with necessary use of PPE. Some institutions may have laboratory manuals and technique-specific SOPs, which should be critically reviewed on a regular basis. Students should also know the limitations or shortcomings of these measures.

This combination of recognizing hazards, assessing the risks of those hazards, and identifying ways to minimize the risks of hazards is called “risk analysis” or “process hazard analysis” and should be routinely practiced by every graduate student. Students should be able to explain the most relevant hazard rating systems and hazard analysis techniques. They should know common and specific methods to minimize hazards, and should also know the limitations of those protective measures.

It is also important for students to understand that all laboratory research has risks. They can do their best to minimize these risks by using appropriate protective measures, BUT research often involves working in areas where one does not have previous experience, and incidents can happen. Using the best protective measures will likely reduce the risks of incidents, but it will not eliminate the risks completely.

RAMP

Prepare for Emergencies from Uncontrolled Hazards

Prepare for Emergencies from Uncontrolled Hazards

Graduate students should be prepared for emergencies by practicing how to respond to various common emergencies that could occur in laboratories, such as fires, explosions, chemical exposures, injuries, and chemical spills. Students should be able to explain the selection and use of emergency equipment such as fire extinguishers, eyewash stations, safety showers, spill kits, first aid kits, fire alarms, and fire blankets.

Students should recognize the importance of reporting laboratory incidents, as well as "near misses", and the lessons that can be learned from these incidents. This information should be shared with others in their laboratory, department, and elsewhere. Students should know that the focus of incident investigation and reporting is to prevent future incidents.

Continuing Safety Education

Throughout graduate school, students are expected to build up and develop a deeper knowledge and understanding of chemistry. They will likely be participating in independent research, which may require the use of hazardous chemicals or conducting hazardous operations. In conjunction with this effort, students should be increasing their knowledge of safe operating procedures, especially in their particular areas of study. New graduate students should have mentors to help explain safe procedures and processes needed in their work, and as their experience grows, they should become the mentors for other new graduate students.

During this time, graduate students will learn more about standard and specialized laboratory operations and techniques, the associated hazards, and the safest ways to conduct these operations. For example, students may learn more about the properties and uses of pyrophoric materials and how to safely handle these materials.

Graduate students should also be learning about risk assessment and the use of risk assessment tools for research laboratories, such as those published by the American Chemical Society in *Identifying and Evaluating Hazards in Research Laboratories*.[b]

As students develop their research proposals, they should also include detailed standard operating procedures, which include operational safety, that are submitted for review and approval by principal investigators, research advisors, or other faculty.

---

[b] *Identifying and Evaluating Hazards in Research Laboratories;* American Chemical Society: Washington, DC, 2015. www.acs.org/content/dam/acsorg/about/governance/committees/chemicalsafety/publications/identifying-and-evaluating-hazards-in-research-laboratories.pdf (accessed Sept 21, 2015).

Hazard and Risk Analysis

Graduate students should be exposed to the hazard analysis tools commonly used by practicing chemists. Several are described in the American Chemical Society document *Identifying and Evaluating Hazards in Research Laboratories* and are summarized below.

CONTROL BANDING

Chemical Safety Levels (CSL) 1 to 4 are assigned to hazards that are found in the laboratory. CSL 1 applies to relatively benign materials or processes, such as consumer products or working with dilute aqueous solutions. Typical PPE usually includes a laboratory coat, lightweight eye protection, full-length leg covers, and closed-toe shoes. CSL 4 refers to high hazard chemicals or procedures, such as the transfer of pyrophoric and highly toxic materials. Training and a standard operating procedure are required, working alone is disallowed, engineered controls such as fume hoods or glove boxes are required, and activity-specific PPE such as eye protection, a flame-proof laboratory coat, and activity-specific gloves are specified.

JOB HAZARD ANALYSIS

This analysis focuses on the relationship between the researcher, the task (or job) to be done, the tools needed to complete the task, and the work environment. The method can be used to identify the hazard(s) associated with a job, a task, each reaction, or complex situations. Potential failures, contributing factors, consequences, and the likelihood of those failures are identified. A task or job is first defined by a description statement – what is being done and why. Next, the job or task is divided into steps, and the potential hazards for each step are identified. These potential hazards are researched and analyzed for risk using data from accident and "near miss" history, literature searches, and organizational safety documentation. Once the hazards are identified, controls are suggested that mitigate the risk.

WHAT-IF ANALYSIS

A what-if analysis is a structured way to anticipate what might go wrong, and then judge the likelihood of occurrence and the harm that might result from each possible scenario. This technique can be used to analyze existing or new processes or procedures. The analysis team will often divide the problem into human error and process failures. What might happen if the material is too concentrated, is too dilute, or is present in the wrong amount, if a valve is not opened or is opened in the wrong sequence, or if a purge gas is omitted? What might happen if there is a loss of electrical power, purge gas, laboratory temperature control, or ventilation?

After risks are identified, solutions such as automatic shutdowns or adding emergency power circuits might be suggested and evaluated.

CHECKLISTS

Checklists have been implemented in many fields. For example, in the health care profession, implementing the relatively simple checklist of washing your hands, cleaning the patient's skin, using sterile clothing and drapes, and checking to see whether a sterile dressing was in place after the procedure decreased the 10-day infection rate from 11% to zero within a year.

Checklists can be simple or complex. *Identifying and Evaluating Hazards in Research Laboratories* has a checklist for making checklists.

STANDARD OPERATING PROCEDURES (SOPS)

Developing SOPs for high hazard materials or processes involves identifying hazards, assessing risks, conducting literature surveys, and developing strategies to minimize risk. *Identifying and Evaluating Hazards in Research Laboratories* provides a template for developing SOPs, and Internet resources contain SOPs for thousands of substances and processes. Online material varies widely in quality and must be analyzed with as much care as if the procedure were being developed for the first time.

Teaching Assistants

Teaching assistants (TAs) often have responsibilities for operating and overseeing undergraduate students and laboratories. Typical expectations are listed below. Additional topics may be added as needed by a specific institution. *Safety in Academic Chemistry Laboratories*[c] should be used jointly by TAs and faculty to identify specific learning objectives for the students under the supervision of TAs.

TYPICAL EXPECTATIONS OF TEACHING ASSISTANTS

- Understand the organizing principles of safety—RAMP—and how these apply to each experiment.
- Read and sign the Chemical Hygiene Plan for their assigned teaching laboratories.
- Know the location of the SDS information for their assigned laboratories.
- Know the underlying chemistry for each experiment being taught.
- Demonstrate proper laboratory techniques for each experiment to the students.

---

[c] *Safety in Academic Chemistry Laboratories*, Vol. 1, 7th ed.; American Chemical Society: Washington, DC, 2003. www.acs.org/content/dam/acsorg/about/governance/committees/chemicalsafety/publications/safety-in-academic-chemistry-laboratories-students.pdf (accessed Sept 21, 2015).

- Demonstrate appropriate procedures for operation of common laboratory equipment, such as burners and hot plates.
- Provide appropriate laboratory safety instruction to students, including explaining the health hazards and risks associated with each experiment.
- Manage the setup and cleanup of laboratory experiments.
- Follow appropriate safety and PPE protocols during laboratory preparation activities, such as making solutions and preparing student samples.
- Maintain good housekeeping in assigned laboratories.
- Know, follow, and enforce the institutional policies and procedures for the following:
    - Appropriate use of PPE and laboratory clothing
    - Responding to students or staff who have mental health problems
    - Administering basic first aid to students and staff for injuries, fainting, or other physical health problems
    - Generation and disposal of hazardous waste.
- Know, follow, and enforce institutional procedures and reporting protocols for emergencies, including:
    - Incidental and major spill
    - Building evacuation
    - Loss of ventilation
    - Loss of electrical power
    - Fire and fire alarm
    - Natural disaster, such as a hurricane, tornado, volcano, or earthquake
    - Active shooter alert.

Building Strong Safety Cultures

Strong safety cultures will evolve only if leaders in the institution, as well as throughout the department, are fully and visibly committed to safety. Below are a few suggestions that may help strengthen and build strong safety cultures.

MISSION, VISION, AND VALUES

The institution's Mission, Vision, and Values statement should place equal value on safety and productivity. This value should be reflected in the behavior and statements of the senior institutional management.

MENTORING SYSTEMS

Departments should assign a more experienced graduate student as a mentor to a less experienced student, but the overall safety of the laboratory is the responsibility of the principal investigator (PI). The mentors can teach their protégés the laboratory safety policies, including specific laboratory safety protocols, the location of safety equipment, and the location of the Chemical Hygiene Plan and SDS. The PI must be responsible for assessing the mastery of laboratory procedures and techniques by less experienced students.

The experienced graduate student will be able to build effective communication and teaching skills and establish expectations and accountability. The less experienced student will benefit by having a peer to ask questions and discuss safety issues. The involvement of the PI helps to reinforce the importance of the laboratory's safety culture.

SAFETY PRESENTATIONS AND DISCUSSIONS

Including safety topics in each laboratory session and/or in weekly research group meetings will reinforce the importance of safety. Some institutions already begin each laboratory session or meeting with a brief discussion of safety as applied to the group's research. The use of case studies or incident reports is an effective method of evaluating the root cause of an incident and applying those lessons to the current laboratory activities.

INCLUDE HAZARD ANALYSIS IN RESEARCH PROPOSALS

Hazard analysis is the process of recognizing hazards, assessing the risks of those hazards, and identifying ways to minimize the risks of those hazards. Research proposals could include a hazard analysis. This will help the student consider the potential hazards and consequences of their work should an incident occur. This hazard analysis could include a checklist of items to consider and the necessary controls needed to prevent or minimize exposure and injury, damage to apparatus, and property damage.

INCLUDE SAFETY ASSESSMENTS IN CUMULATIVE EXAMINATIONS

Safety is an integral part of all chemical operations. Safety knowledge and its application by graduate students should be evaluated in cumulative or comprehensive examinations.

A Note to Faculty, Staff, and Supervisors

Chemical safety is an integral part of an education in chemistry. Both undergraduate and graduate students must be able to recognize hazards, assess risks, minimize risks, and prepare for proper execution of potentially hazardous processes. Safety considerations should be woven into every part of the chemistry curriculum, from basic familiarity with common hazards for undergraduate students to the ability to predict and prepare for hazards of unknown materials at the graduate and professional level. Assessing student mastery of chemical safety learning objectives should be a component of all laboratory experiences, including being a component of cumulative comprehensive examinations. Safety training should be treated as a critical component of preparing students to be successful as chemical professionals.

Faculty and staff who supervise students in chemistry laboratories at all levels in higher education must themselves be familiar with chemical safety and safe laboratory procedures. They must know their institutional requirements for safety training and monitoring and the protocols for responding to emergencies. They must also know their institutional protocols for managing the safety of students with disabilities.

This document is a tool for the development and strengthening of chemical safety awareness and a safety culture at an academic institution. Safety in the laboratory does not happen by accident. It is the result of careful planning, recognizing the inherent hazards of working in a chemical laboratory environment, managing those risks, and being prepared for unexpected events. Students will carry these experiences and practices for chemical safety with them far beyond their institutions and into the workplace and into their public life.

Resources

Creating Safety Cultures in Academic Institutions: A Report of the Safety Culture Task Force of the ACS Committee on Chemical Safety; American Chemical Society: Washington, DC, 2012. **www.acs.org/content/dam/acsorg/about/governance/committees/chemicalsafety/academic-safety-culture-report-final-v2.pdf** (accessed Sept 21, 2015).

Doing Things Safely: Safety for Introductory Chemistry Students; American Chemical Society: Washington, DC, 2010. **www.acs.org/content/dam/acsorg/about/governance/committees/chemicalsafety/publications/doing-things-safely.pdf** (accessed Sept 21, 2015).

Hazard Assessment in Research Laboratories website: **www.acs.org/hazardassessment** (accessed July 25, 2016).

Hill, R. H.; Finster, D. C. *Laboratory Safety for Chemistry Students*, 2nd ed.; John Wiley & Sons, Inc.: Hoboken, NJ, 2016.

Identifying and Evaluating Hazards in Research Laboratories; American Chemical Society: Washington, DC, 2015. **www.acs.org/content/dam/acsorg/about/governance/committees/chemicalsafety/publications/identifying-and-evaluating-hazards-in-research-laboratories.pdf** (accessed June 7, 2016).

Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards; National Academies Press: Washington, DC, 2011. **www.nap.edu/catalog/12654/prudent-practices-in-the-laboratory-handling-and-management-of-chemical** (accessed Sept 21, 2015).

Safety in Academic Chemistry Laboratories, Vol. 1, 7th ed.; American Chemical Society: Washington, DC, 2003. **www.acs.org/content/dam/acsorg/about/governance/committees/chemicalsafety/publications/safety-in-academic-chemistry-laboratories-students.pdf** (accessed Sept 21, 2015).

NOTES

NOTES

NOTES

NOTES

EMERGENCY TELEPHONE NUMBERS

Fire Department/Ambulance/Police: **911**

Campus Health Center: ______________________________

Poison Control Center: ______________________________

Security Office: ______________________________

Faculty Advisor/Research Director: ______________________________

____

____

____

____

ACS

Chemistry for Life®

1155 Sixteenth Street, NW
Washington, DC 20036
www.acs.org