

Creating Safety Cultures in Academic
Institutions: *A Report of the Safety Culture
Task Force of the ACS Committee on
Chemical Safety*

FINAL DRAFT
*(The final report will be available in early
June.)*

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Creating Safety Cultures in Academic Institutions: A Report of the Safety Culture Task Force of the ACS Committee on Chemical Safety is a publication of the American Chemical Society's (ACS) Joint Board–Council Committee on Chemical Safety (CCS). CCS Partnerships Subcommittee (CCS-PS) established the Safety Culture Task Force (SCTF) and developed this report in partnership with these other ACS organizations: the Society Committee on Education (SOCED), the Committee on Professional Training (CPT), the Younger Chemists Committee (YCC), and the Division of Chemical Health and Safety (CHAS). The members of SCTF include:

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Foreword

Devastating incidents in academic laboratories and observations, by many, that university and college graduates do not have strong safety skills, have elevated concerns about the safety culture in academia. Calls for changes in the academic safety educational process and in the academic safety culture are becoming increasingly vocal both within and outside of the academic community.

At the 2011 American Chemical Society (ACS) National Meeting in Anaheim, CA, the Committee on Chemical Safety (CCS) launched an effort to identify ways to assist academia in strengthening and building a strong safety culture. The CCS Subcommittee on Partnerships undertook this effort by collaborating with other ACS organizations that have strong interests in this area. In June 2011, the Safety Culture Task Force (SCTF) held a retreat to discuss and begin efforts to prepare publications that might assist academia in strengthening its safety culture. CCS partners participating in the retreat included the Society Committee on Education, the Committee for Professional Training, and the Division of Chemical Health and Safety. The 2011 ACS president also attended the retreat. Other ACS organizations are also likely to partner in this effort in the future.

The goal of SCTF is to develop guidance, suggestions, and recommendations that can help strengthen the safety culture in two- and four-year undergraduate, graduate, and postdoctoral programs. Specifically, the SCTF's goals are to identify the best elements and best practices of a good safety culture; identify academic institutions that are currently using these best practices, or "bright spots;" identify specific recommendations that could be used by universities and colleges to strengthen their safety culture; and identify tools and resources that would be beneficial to these efforts.

At the retreat, SCTF identified a set of essential elements that are needed in a strong safety culture. The Task Force discussed a number of ideas addressing each of these elements (see Appendix A). These essential elements for a strong safety culture are discussed in more detail in this document.

While the focus of this document is on departments offering chemistry, the safety culture of an institution needs to include all departments and organizations throughout the entire campus. Thus, other departments may find useful parallels in these discussions.

Dedication

Creating Safety Cultures in Academic Institutions is dedicated to those scientists who lost their lives or were injured in laboratory incidents.¹

Executive Summary

Devastating incidents in academic laboratories and observations, by many, that university and college graduates do not have strong safety skills, have elevated concerns about the safety culture in academia. Calls for changes in the academic safety educational process and in the academic safety culture are becoming increasingly vocal both within and outside of the academic community.

This report provides guidance, suggestions, examples, and recommendations that can help strengthen the safety culture in two- and four-year undergraduate, graduate, and postdoctoral programs. Specifically, it identifies the best elements and best practices of a good safety culture, identifies specific recommendations that could be used by universities and colleges to strengthen their safety culture; and identifies tools and resources that would be beneficial to these efforts. While the focus of this document is on departments offering chemistry, the safety culture of an institution should include all departments and organizations throughout the entire campus. Thus, other departments may find useful parallels in these discussions.

The Safety Culture and its Impact on an Organization

The safety culture of an institution is a reflection of the actions, attitudes, and behaviors of its members concerning safety—these members include the managers, supervisors, and employees in the industrial and governmental communities; and the faculty, staff, and students in the academic community. Serious chemical or laboratory incidents within an organization are often thought to be the result of a weak or deficient safety culture—a principal root cause of the incident.

The Need for a Strong, Positive Safety Culture

Safety is a positive value – it prevents injuries, saves lives, and improves productivity and outcomes. When safety is actively practiced and is regarded as a critical core value by organizational leaders, it bestows a sense of confidence and caring in all working there. A strong safety culture is required to protect employees but is especially important in protecting students and in developing students' skills and awareness of safety. It also protects academic institutional reputations. This culture emanates from ethical, moral, and practical considerations, rather than regulatory requirements. Academic administrators, faculties, and staff members have ethical responsibilities to care for their students' safety and to instill awareness about safety. They need to teach students the safety skills required to work in laboratories on campus and in the workplace. In a strong safety culture, students will acquire the skills to recognize hazards, to assess the risk of exposures to those hazards, to minimize the risk of exposures to hazards, and to be prepared to respond to laboratory emergencies.

Elements of Strong Safety Cultures

Leadership and Management of Safety in the Academic Institution

The safety culture of an institution plays a critical role in setting the tone for the importance placed upon safety by its members. Leaders are the key to building a strong culture of safety. Leaders inspire others to value safety, seek open and transparent communications to build trust, lead by example, accept responsibility for safety, and hold others accountable for safety. The direction for and

strength of the safety culture is determined by its leaders. In the academic arena the lines of authority should be clearly flowing from the President and Provost to College Deans, to Department Chairs, to Faculty and Principal Investigators, and staff; however, these lines of authority are not always observed or enforced, especially due to the responsibility for safety being relegated to individual departments. As a result the authority often rests with the departmental chairs; the senior, tenured faculty; and the principal investigators, and they may not always accept responsibility for safety. Nevertheless safety is an educational responsibility.

Teaching Basic Laboratory and Chemical Safety through Continuous Learning and Spiral Education

Within a strong safety culture, safety knowledge should build year after year throughout the undergraduate curriculum and continue into graduate studies, so that upon graduation, chemistry graduates have superior safety skills and strong safety ethics.

Safety concerns apply across all chemistry and related fields. Everyone using chemistry in their careers needs strong knowledge and skills to work safely in a laboratory. A strong safety culture develops superior safety skills and strong safety ethics by building year after year, beginning with the first year undergraduate curricula and continuing through the entire undergraduate experience and into graduate studies and postdoctoral training. Building a strong base of knowledge and skills in laboratory safety throughout the undergraduate course of study requires teaching numerous safety topics. More than 80 suggested laboratory safety topics are presented in this report, as are numerous resources for preparing laboratory safety lessons. Designated staff and faculty, senior undergraduate students, graduate teaching assistants, and postdoctoral scholars who teach laboratory sessions should have a thorough understanding of laboratory safety and know what to teach and how to teach it.

The laboratory is a unique environment. Hazard identification, hazard assessment, and hazard management – collectively known as hazards analysis – in laboratory operations (including research) are critical skills that need to be part of all student and postdoctoral education.

Learning how to prepare for emergencies is also a critical skill. It is important to remember that some hazards may not have been identified, assessed, or managed correctly when the laboratory operation was designed. Safety is an integral part of all laboratory operations but it requires that the laboratory worker consider this every time they start work. In this way, the process of hazards analysis becomes an integral part of the laboratory process, just like the scientific method.

Safety Attitudes, Safety Awareness, Safety Ethics

Solid safety awareness and attitudes are important, and building safety awareness requires a long-term effort—safety is highlighted repeatedly. Teaching safety continuously over the entire undergraduate experience can build positive attitudes and strong safety ethics among students. Faculty and staff members have an ethical obligation to teach students and new employee about the need for a positive, proactive attitude about safety while conducting an experiment in chemistry. Following safety policies and procedures in a lab is just as important as the information the students receive in a presentation or the knowledge a student gains from an experiment. Everyone teaching in chemistry needs to know and follow the appropriate safety practices in the laboratory. The proper attitude for safety is reflected in the “Safety Ethic”—value safety, work safely, prevent at-risk behavior, promote safety, and accept responsibility for safety.

Learning from Incidents

Much of what is known about safety has been learned from mistakes or incidents. Using these incidents and the lessons learned as case studies throughout the undergraduate and graduate learning experience provides an opportunity to capture the interest and imagination of students while forcing them to think about how safety measures could have prevented or minimized these incidents. An important element of a strong safety culture is establishing a system for reporting and investigating incidents, identifying direct and root causes, and implementing corrective actions.

Collaborative Interactions that Help Build Strong Safety Cultures

For a sustainable safety program, the institution must establish an active safety committee system that includes members representing a cross-section of the campus. The committee membership should include safety professionals, faculty and staff members, administrators, and undergraduate and graduate students, who will all be covered and affected by the program. Committees need to be active and productive, and publish informative documents regularly. A critical part of every safety program is to establish collaborative and trusting interactions among members of the institution, especially among faculty, staff, and environmental health and safety professionals. The university or college should establish a close working relationship with local emergency responders, especially fire departments and their hazard materials teams (HazMat Teams).

Promoting and Communicating Safety

Probably the best way to promote safety is through personal example. This is especially important for faculty and staff since students will follow their examples. Selling safety at your institution is, in part, dependent upon a continuous effort to promote the safety program to faculty, staff, and students. Advertising and promoting safety could take many forms. Today, many faculty, staff, and especially students, tend to do everything online and through their cell phones. One way to promote a safety program might be a safety newsletter or weekly bulletin that is distributed via social networks and campus-wide e-mails. Departments may consider having open seminars to discuss topical safety issues or incidents. Recognition of individuals for doing an outstanding job in safety is an important part of a vibrant safety program. Establish a procedure for soliciting suggestions for improving safety and identifying safety concerns.

Encouraging Institutional Support of Safety by Funding Safety Programs and Supplies

Many of the suggestions discussed can be implemented at little or no additional cost. Nevertheless, new and innovative approaches for building a strong safety culture may require funding. The first step in establishing a continuing budget for a safety program is determining institutional needs. Identifying responsibilities for safety and the corresponding staff who will accomplish this is critical in determining budgetary needs. The administration may require EHS support for a safety program. Printing, office and safety supplies, and training materials are recurring expenses that often come from departmental budgets. Report regularly to the administration the progress and accomplishment of the safety program and explain the benefits in terms of how funding your request will benefit the organization, and how funding the program can make the school a leader and a resource to your community.

Recommendations for Creating Safety Cultures in Academic Institutions

To create vibrant, strong safety cultures in academic institutions, the Safety Culture Task Force makes the following recommendations:

1. *Establish the lines of authority for safety, develop a safety policy that includes laboratory safety, and include safety responsibilities in the job descriptions and performance plans of all employees.*
2. *Encourage every leader to become a proponent of safety and safety education, and to demonstrate this care for safety in their actions with other staff members and students.*
3. *Establish a strong, effective safety management system and safety program for the institution, including laboratory safety.*
4. *Ensure graduating chemistry undergraduate students have strong skills in laboratory safety and strong safety ethics by teaching safety lessons in each laboratory session, and by evaluating and testing these skills throughout the educational process (Table 1 within the report).*
5. *Ensure all faculty, staff, and graduate and undergraduate students involved in teaching, managing, or overseeing students in laboratory courses and sessions have successfully completed a course in lab safety.*
6. *Implement hazards analysis procedures in all new lab work, especially laboratory research.*
7. *Build awareness and caring for safety by emphasizing safety throughout the chemistry curricula.*
8. *In the preparation of grant proposal, researchers should include in their plans safety education and training (for undergraduate students, graduate students, and postdoctoral scholars participating in proposed research) and oversight of research for safety.*
9. *Adopt a personal credo: the “Safety Ethic”—value safety, work safely, prevent at-risk behavior, promote safety, and accept responsibility for safety.*
10. *Establish and maintain an Incident Reporting System, an Incident Investigation System, and an Incident Database that includes not only employees, but students also—undergraduates, graduate students, postdoctoral scholars, and other nonemployees.*
11. *Establish an internal review process of incidents and corrective actions with the Departmental Safety Committee (faculty, staff, students, graduate students, and postdoctoral scholars), and provided periodic safety seminars on lessons learned from incidents.*
12. *Publish or share the stories of incidents and the lessons learned (case studies) to an institution’s website, a public website or an appropriate journal where students and*

colleagues from other institutions may also use these as case studies for learning more about safety.

- 13. Establish a series of safety councils and safety committees from the highest level of management to the departmental level or lower. Each of these committees reports, in turn, to a committee that is higher in the hierarchy of the institution.*
- 14. Establish a close working relationship with EHS personnel at every departmental level seeking their advice and experience in safety and offering departmental and faculty advice to EHS based upon their experience with knowledge of chemistry.*
- 15. Establish a close working relationship with local emergency responders so they are prepared to respond to emergencies in laboratories.*
- 16. Establish a system to promote safety in an institution or department that encompasses: electronic communications; printed materials; special seminars or events discussing or promoting safety; a recognition system for good safety performance; and a process to solicit, review, and act on suggestions for improving safety and identifying safety issues.*
- 17. Identify the ongoing need to support a strong safety culture and work with administrators and departmental chairs to establish a baseline budget to support safety activities on an annual basis.*

Looking for the “Bright Spots”: Institutions Worthy of Emulation

The “bright spots” is a term used to describe institutions where efforts toward a goal have been successful and are worthy of emulation. The result of a strong safety culture within an academic institution is evidenced by its prodigy – graduates of that institution who have demonstrated well-rounded safety knowledge and strong safety ethics. The Committee on Chemical Safety seeks those academic institutions that might be deemed bright spots in that they have implemented the elements of safety culture as discussed in this report and are producing graduates who have strong safety skills and strong safety ethics. The recommendations included in this report may be used criteria for recognizing bright spots.

The Safety Culture and its Impact on an Organization

The safety culture of an institution is a reflection of the actions, attitudes, and behaviors of its members concerning safety—these members include the managers, supervisors, and employees in the industrial and governmental communities; and the administration, faculty, staff, and students in the academic community. Serious chemical or laboratory incidents within an organization are often thought to be the result of a weak or deficient safety culture—a principal root cause of the incident.^{2,3,4} A weak safety culture within an organization is usually the result of one or more factors, including:

- No clear commitment of institutional administration to actively promote safety at all levels (weak or deficient leadership in safety);
- Failure to establish accountability for safety among leaders, managers, and supervisors, employees, and students;
- Lack of interest in spending significant time or resources on safety;
- Weak or missing safety management system;
- Failure to adequately educate students in safety and to build strong safety skills;
- Failure to evaluate students' safety knowledge and skills through tests and observations;
- Failure to build and maintain strong safety awareness and interest in safety;
- Failure to learn lessons from past incidents and implement changes (improved safety practices) to prevent future incidents;
- Weak collaborative interactions within the safety program and on safety issues

Defining a Strong Safety Culture

One of the most comprehensive discussions concerning the safety culture is found in a document by the International Atomic Energy Agency.⁵ It provided a simple, clear definition by the U.S. Nuclear Regulatory Commission (NRC) of a good safety culture that is “a reflection of the values, which are shared throughout all levels of an organization, and which are based upon the belief that safety is important, and it is everyone's responsibility.”

On June 14, 2011, the NRC issued its final “Safety Culture Policy Statement,”⁶ which defined a safety culture as: “Safety culture refers to an organization's collective commitment, by leaders and individuals, to emphasize safety as an overriding priority to competing goals and other considerations to ensure protection of people and the environment.” The NRC identified nine traits of a good safety culture:

1. Leadership safety values and actions: Leaders demonstrate a commitment to safety in their decisions and behaviors;
2. Problem identification and resolution;
3. Personal accountability: All individuals take personal responsibility for safety;
4. Work processes: The process of planning and controlling work activities is implemented, so safety is maintained;
5. Continuous learning;
6. Positive, nonpunitive environment for raising safety concerns;
7. Effective safety communication;

8. Respectful work environment; and
9. Questioning attitude.

The U.S. Occupational Safety and Health Administration (OSHA) found that a strong safety culture is the best approach to preventing incidents. OSHA noted organizations that demonstrate the following characteristics in a strong safety culture: few at-risk behaviors, low accident rates, low employee turnover, low absenteeism, high productivity, and success in all aspects of business and excellence.⁷

The National Research Council in its latest edition of *Prudent Practices in the Laboratory*, a well-known reference publication on laboratory safety developed with participation of academic faculty, described the traits of a strong safety culture that should be found in academic institutions.⁸ In the section, titled “The Culture of Laboratory Safety,” the Council reported:

- “The ultimate responsibility... for encouraging a culture of safety rests with the head of the organization and its operating units. Leadership by those in charge ensures an effective safety program is embraced by all.”
- “There should be resolute commitment by the entire faculty to the departmental safety program.”
- “Ensuring a safe laboratory environment is the combined responsibility of laboratory personnel, EHS [Department of Environment, Health, and Safety] personnel, and the management of the organization, though the primary responsibility lies with the individual performing the work.”
- “Teaching safety and safe work practices in the laboratory should be a top priority for faculty as they prepare students for careers. By promoting safety during undergraduate and graduate years, the faculty will have a significant impact not just on their students but also on everyone who will share their future work environments.”
- “A critical component of chemical education at every level is to nurture basic attitudes and habits of prudent behavior, so that safety is a valued and inseparable part of all laboratory activities. In this way, a culture of laboratory safety becomes an internalized attitude, not just an external expectation driven by institutional rules. This process must be included in each person’s chemical education throughout his or her scientific career.”
- “Forming the foundation for a lifelong attitude of safety consciousness, risk assessment, and prudent laboratory practice is an integral part of every stage of scientific education. Teaching and academic institutions must accept this unique responsibility for attitude development.”
- “A strong culture of safety within an organization creates a solid foundation upon which a successful laboratory health and safety program can be built. The ability to accurately identify and assess hazards in the laboratory is not a skill that comes naturally, and it must be taught and encouraged.”

- “[Undergraduate students]... must learn to evaluate the wide range of hazards in laboratories and learn risk management techniques that are designed to eliminate various potential dangers in the laboratory.”
- “A successful... safety program requires a daily commitment from everyone in the organization, and setting a good example is the best method of demonstrating commitment.”

The Need for a Strong, Positive Safety Culture

Safety is a positive value – it prevents injuries, saves lives, and improves productivity and outcomes. When safety is actively practiced and is regarded as a critical core value by organizational leaders, it bestows a sense of confidence and caring throughout the organization.

Most industries learned long ago that safety is critically important because, if ignored, the consequences could affect them financially—even to the point of putting them out of business. Most governmental organizations also learned to manage safety in their operations under the scrutiny of the public eye. Generally, the academic community has not had these pressures on their safety performance.

In 1970, after the passage of the Occupational Safety and Health Act, the U.S. government began to more closely regulate workplace safety by establishing OSHA. In 1990, OSHA recognized that work performed in chemical laboratories differs from industrial operations and issued the “Laboratory Standard” to regulate laboratories.⁹ Many of the academic chemistry communities are covered by this regulation. However, students are not included in this standard. Most universities and colleges have complied with the Lab Standard and other federal regulations, especially those of the Environmental Protection Agency (EPA), which regulates disposal of hazardous wastes.

A strong safety culture is required to protect employees but is especially important in protecting students and in developing students’ skills and awareness of safety. It also protects co-researchers, co-workers, laboratory mates, supporting personnel, vendors, and laboratory visitors. A strong safety culture also protects business, government integrity, and academic institutional reputations. A strong, positive safety culture emanates from ethical, moral, and practical considerations, rather than regulatory requirements. Academic administrators, faculties, and staff members have ethical responsibilities to care for their students’ safety and to instill a strong, positive awareness about safety. They need to teach students the safety skills they need to work in laboratories on campus and in the workplace. In a strong safety culture, students will acquire the skills to recognize hazards, to assess the risk of exposures to those hazards, to minimize the risk of exposures to hazards, and to be prepared to respond to laboratory emergencies.

The barriers that may prevent building and maintaining a strong, positive safety culture include:

1. Safety efforts are highly fragmented resulting in safety being a low priority.
2. The infrastructure necessary for implementing safety is fragmented, generally lacking in overall supervision, and clear lines of responsibility and accountability.

3. Inadequate safety education and training and a lack of instructional materials.
4. Lack of coherence in the presentation of safety considerations as a student advances through the undergraduate program.
5. Safety is regarded as a set of rules and regulations rather than an ethical obligation and an essential part of the chemistry curriculum.
6. Insufficient resources and allocation of time at either the departmental or university level to establish a strong safety management system.
7. Lack of regular, systematic, and comprehensive training of faculty, staff, appointed Chemical Hygiene Officers, and students at higher levels of higher education.
8. Lack of systematic review and discussion of all incidents to learn how future accidents can be avoided.
9. Lack of collaborative interactions with the EHS group.

In the following sections, the elements or components required to build a strong safety culture are discussed. A strong safety culture will have all of these elements. It is hoped that these discussions will be carefully considered and will help in generating new approaches and ideas about safety and developing a strong culture of safety. Following the discussion of each element recommendations are provided to help overcome these barriers and encourage a strong, positive safety culture in academic institutions. The attention given to safety and where safety falls in the priorities of the chemical education process will reflect the importance of safety and the strength of the safety culture of the institution. This report identifies some academic institutions having at least several but not necessarily all of the elements of a strong safety culture. The goal of a strong safety culture in an academic institution is have administrators, faculty and staff who care strongly about safety, who have strong knowledge of safety, who teach safety to their students throughout the curriculum, and who promote safety through their leadership and leading by example.

Leadership and Management of Safety in the Academic Institution^a

The safety culture of an institution plays a critical role in setting the tone for the importance placed upon safety by its members. The direction for and strength of the safety culture is determined by its leaders. In the industrial and governmental sectors, the leader is the president, director, or chief executive officer, where lines of authority are clearly drawn from the managerial ranks to the employees. In the academic arena the lines of authority should be clearly flowing from the President and Provost to College Deans, to Department Chairs, to Faculty and Principal Investigators, and staff; however, these lines of authority are not always observed or enforced, especially due to the responsibility for safety being relegated to individual departments. As a result the authority often rests with the departmental chairs; the senior, tenured faculty; and the principal investigators, and they may not always accept responsibility for safety. Nevertheless safety is an educational responsibility.

Leaders of any institution must demonstrate that they value safety and expect the other members of the institution to follow accordingly. Safety should be guided by principles that are understood

^a Academic institutions include two- and four-year undergraduate, graduate, and postdoctoral programs.

and shared by all members of the institution, rather than focused primarily upon rules or regulations (compliance follows when safety is principle-driven). In any institution, there should be a clear and consistent effort to build and maintain strong safety awareness but in an academic institution, there is an additional requirement to teach students about the importance of safety.

Studies of safety cultures concluded that an effective safety culture starts with leadership and manager involvement from the highest levels of an organization. In organizations with the lowest injury rates, leadership and management demonstrated a commitment to safety, and supervisors were generally responsible for safety goals.^{10,11} Conversely, organizations with the highest injury rates focused on regulatory compliance rather than creating a safety culture. Those organizations also delegated the responsibility to a safety manager, and upper management was not involved in safety issues.

Leaders are the key to building a strong culture of safety. Leaders inspire others to value safety, seek open and transparent communications to build trust, lead by example, accept responsibility for safety, and hold others accountable for safety. In educational institutions they seek to ensure faculty, staff (including non-tenured teaching staff, laboratory supervisors, and non-tenured research staff), students (undergraduates and graduate students), and post-doctoral scholars are protected and trained in the principles of safety. A strong safety culture requires not only leaders but also effective managers. Leaders provide the general direction for the safety program and managers implement the program. Safety managers should share their knowledge and heighten awareness among administrative managers, faculties, and principal investigators to move the organization toward the leader's vision of a strong safety culture.

A strong, positive safety culture in the academic institution includes the highest level of leadership, the president or chancellor, showing an active commitment to safety, including laboratory safety. The president or chancellor establishes a safety policy that broadly addresses all areas of safety and responsibilities for safety. Commonly, the provost, vice president, or vice chancellor (title varies) is assigned responsibilities for broad oversight of the implementation of a safety policy and a safety program.^{b,12} Deans are usually assigned responsibilities for safety in their respective areas. Departmental chairs are assigned responsibilities for the safety program of their particular departments. When building a strong safety culture, deans and chairs should include responsibilities for safety in position descriptions and performance plans of all faculty and staff members.^c The University of California at San Diego and Princeton University have established high level management organizations that provide policy guidance and oversight for the health and safety for their institutions – both of these organizations were recognized by the Division of Chemical Health and Safety (CHAS)/National Institute for Occupational Safety and Health (NIOSH) College and University Health and Safety Academic Safety Award in 2011 and 2010, respectively.

^b See Princeton University's safety policy at: www.princeton.edu/hr/policies/healthsafety/8.0.1/ (accessed Oct 13, 2011).

^c See Appendix B for a list of suggested duties related to safety for members of the institution involved in the leadership and management of the safety program. The University of California, Los Angeles (UCLA) recently developed a similar list of duties and responsibilities discussed in a report on laboratory safety to the chancellor.²

The department's Chair, senior-tenured faculty, research directors, laboratory supervisors, and principal investigators should set the tone for the safety culture in their departments. They are responsible and accountable for the safety of the faculty, staff, students, and postdoctoral scholars, and for ensuring that

- Students are educated in the principles of safety throughout the curriculum;
- Students continuously learn about safety during structured laboratory sessions;
- Students are taught the necessary safety skills to work independently in laboratories;
- Students, who work in research laboratories, are educated and trained in the safety skills they need to conduct research operations safely; and
- Faculty, staff, and postdoctoral scholars who teach or oversee research in laboratories, are educated and trained in safety skills.
- Early-career faculty members are also mentored in safety and in learning how to develop a safety culture within a research group.

Ethics are a set of rules or standards that guide a person or group's conduct and behavior—these are their values or morals. Safety is often seen as the starting place for a leader's ethics.¹³ Ethical leaders value human life, justice, open and honest communications, and excellence in safety—it is their responsibility to keep the people under their purview safe. Ethical and moral considerations should drive departments offering chemistry to place a high value on safety. Developing well-rounded students with strong safety skills should be the practical goal of every department offering chemistry. Achieving this goal is a direct reflection of the safety culture and the value placed upon safety by the department's leadership and management. It is a product of a strong safety program and a curriculum that includes teaching chemical and laboratory safety.

In October 2011, the U.S. Chemical Safety and Hazard Investigation Board (CSB) released its first investigation of a laboratory incident at a large university.¹⁴ The report highlighted the inadequacies of the university's safety management system. The report noted that:

- “Physical hazards inherent to research were not effectively assessed, planned for, or mitigated.”
- “The university lacked safety management oversight and accountability.”
- “Previous incidents with preventive lessons were not documented, tracked, and formally communicated.”

These shortcomings were viewed by CSB as an opportunity for all academic institutions to compare their practices and policies with those that existed at this university at the time of the incident.

The National Research Council described an Environmental Health and Safety Management System in chapter 2 of its publication, titled “*Prudent Practices in the Laboratory*.”¹⁵ OSHA described the components of a Health and Safety Management System, including: (1) management, leadership, and employee involvement; (2) worksite analysis; (3) hazard prevention and control; and (4) safety and health training.¹⁶ While this system is commonly

applied to industry regulated by OSHA, it is relevant to the academic environment also. There are other models for safety management systems.¹⁷ No matter which safety management system is selected or adapted to academic institutions, any safety management system is only as good as its implementation and its continuous sustainment—the leadership and management play essential roles in establishing, implementing, and managing an effective, sustained safety management program.

Many universities and colleges have an environment, health, and safety department (EHS), which is staffed with safety and environmental health professionals, who assist the faculty and administration in building, maintaining, and overseeing the safety program. While the faculty relies upon EHS for support in the management of their safety program, the safety of employees and students is ultimately the responsibility of the faculty and laboratory staff members.

Departments offering chemistry are complex enterprises that not only include teaching and research laboratories, but also include supporting storerooms; shipping and receiving areas; and electronics, wood, metal, and glass shops, where materials are used for laboratory experiments and functions. Safe practices, and safety protocols and rules should be established for these operations, as well as for the laboratories.

Recommendations Concerning Leadership and Management

- 1. Establish the lines of authority for safety, develop a safety policy that includes laboratory safety, and include safety responsibilities in the job descriptions and performance plans of all employees.*
- 2. Encourage every leader to become a proponent of safety and safety education, and to demonstrate this care for safety in their actions with other staff members and students.*
- 3. Establish a strong, effective safety management system and safety program for the institution, including laboratory safety.*

Teaching Basic Laboratory and Chemical Safety through Continuous Learning and Spiral Education

Safety concerns apply across all chemistry and related fields. Everyone using chemistry in their careers needs strong knowledge and skills to work safely in a laboratory. A strong safety culture develops superior safety skills and strong safety ethics by building year after year, beginning with the first year undergraduate curricula and continuing through the entire undergraduate experience and into graduate studies and postdoctoral training. These safety skills, safety education, and safety ethics will serve those students well in future workplaces and research in academic institutions, and enhance opportunities in career progression.

Building Safety Skills in Undergraduate Education

The ACS Committee on Professional Training (CPT) provides guidance to the academic community for bachelor degree programs in chemistry. ACS guidelines indicate that safety education should be an integral part of the chemistry curriculum for undergraduate students, who should develop a strong awareness of safety, build a health and safety information knowledgebase, understand safety procedures and processes, and gain experience in handling hazardous materials.¹⁸ CPT goes on to list major safety topics that chemistry majors should understand, including hazard identification (with specific examples of various hazards), methods to minimize exposure and reduce risk, hazard and risk information, and safety procedures and processes. CPT also identifies “Laboratory Safety Skills” that students should learn and master to become successful professionals.^{19,20} CPT also emphasizes that students should progressively develop the necessary skills to work safely in a lab environment.^{21,22}

The *ACS Guidelines for Chemistry in Two-Year College Programs*, prepared by the Society Committee on Education, provide similar guidance.^{22a} Having the necessary safety resources and promoting a safety conscious culture will help all programs train students in the aspects of chemical safety appropriate to their educational level and scientific needs.

From 1993 until 2006, ACS received grant support to solicit industry input and develop ChemTechStandards – a comprehensive list of knowledge and skills employers expect of chemistry-based technicians.^d These standards have been, and continue to be, successfully used by a number of two-year chemistry-based technology programs, including the Chemical/Environmental Laboratory Technology Program at Texas State Technical College, Waco. The listing of safety knowledge and skills will also be useful to other two- and four-year undergraduate programs whose graduates may be employed in industry.

Continuous and spiral safety education^e reinforces the value and need for safety, and demonstrates to students the high priority that faculty and staff place on safety. Teaching safety over a long period of time builds the knowledge base and safety skills that students will need as

^d The skills related to laboratory safety standards have been excerpted from the ChemTechStandards and are listed in Appendix C. Archive copies of the ChemTechStandards are available upon request from the ACS Office of Two-Year Colleges (2YColleges@acs.org).

^e Spiral education introduces the basics without a lot of details and as the learning process continues more details are added that relate to the basics, thus the topic is reinforced and learned in a comprehensive manner.

they pursue further education and move into the workforce. Continuous safety education may be accomplished by including a relevant safety topic during each laboratory session. Teaching safety in a variety of topics can be challenging at times, since there are many types of hazards, many types of laboratories, and many types of laboratory work. Therefore, building a strong base of knowledge and skills in laboratory safety throughout the undergraduate course of study requires teaching numerous safety topics. Table 1 (see page 15) presents a listing of suggested topics that should be included in the undergraduate student's learning experience.

The goal of teaching laboratory safety is similar to teaching chemistry – to enable students to understand the principles and applications of safety so that they are able to learn to think about safety critically and make decisions that will keep themselves and those around them safe. The topics suggested in Table 1 form a strong base of knowledge in basic laboratory safety for undergraduates, and would go far in helping them develop the safety skills that everyone using chemistry in their careers needs.^{8,23} Teaching each of these topics in each laboratory session over the four-year undergraduate experience provides the knowledge base in safety needed by students upon graduation and the continuous emphasis on safety builds the kind of safety ethic that is evident in a strong safety culture. Wittenberg University's Chemistry Department has used this approach to teach its students safety, including all or most topics in Table 1. During this process, it is essential to frequently quiz and test students' safety knowledge—students are more likely to pay attention to safety if they know it will be on a test. The safety knowledge should be on regular classroom exams and not limited to laboratory quizzes. Instructional and reference resources that can be used in preparing lessons for laboratory safety are listed in Table 2 (see page 16).

The approach that is probably best involves teaching the topics (Table 1) in each lab session throughout the entire four-year curriculum so that students develop strong safety awareness, attitudes, and ethics through constant reinforcement of safety. Some institutions may wish to teach laboratory safety in a stand-alone course that covers topics in Table 1, but deciding when to teach this and what to teach may present challenges since the knowledge of chemistry and chemical terms is limited in the freshman and sophomore years. Safety should be taught as soon as possible. But much of the material that might be taught in a one-semester safety course might be lost on first-year students who are not familiar with terminology or material presented in organic, physical, analytical, and biochemistry coursework. Perhaps a combination of safety lessons in early courses could be used with a more traditional safety course in the junior year and another in the senior year. One concern about a single course is that there is an accompanying sense that education in this topic has finished upon completion of the course—learning safety should be a continuous process. Whatever approach is taken, safety topics in Table 1 should be included for basic laboratory safety knowledge somewhere during the four-year experience.

Who will teach the safety course? Usually, a faculty or staff member who has some expertise or interest in lab safety is assigned. In such cases, the student learns that the designated safety manager is the one who handles safety concerns. There is no motivation for other faculty or staff to learn about safety and teach it to their students. Perhaps an idea to consider is that every faculty member should take their turn in teaching the safety course. If every chemistry class has a safety component, then students will appreciate that safety is an integral part of the science of chemistry.

There may be new, innovative approaches to teaching laboratory safety and building positive attitudes and strong safety awareness and ethics. One reported unique approach to teaching safety and building a strong safety culture is the formation of safety teams in undergraduate chemistry courses, which are used at Seattle University in Washington and the University of California, Merced, as described by Alaimo, Langenhan, Tanner, and Ferrenberg.²⁴ This approach is also being used at the Central Michigan University, Mount Pleasant, and at the University of Iowa, Iowa City.^f

Educating Graduate Students, Teaching Assistants, Postdoctoral Scholars, Laboratory Managers and Coordinators

Designated staff and faculty, senior undergraduate students, graduate teaching assistants, and postdoctoral scholars who teach laboratory sessions should have a thorough understanding of laboratory safety. A stand-alone comprehensive laboratory safety course or capstone course^g would be appropriate for all senior undergraduate and graduate teaching assistants, and laboratory coordinators since they have important responsibilities in teaching safety and overseeing the safety of many undergraduate laboratory sessions. They should know what to teach in safety and how to teach safety. New graduate students should have a course in laboratory safety covering the topics in Table 1 with particular emphasis on safety in research laboratories—the National Research Council’s *Prudent Practices in the Laboratory* would be an effective resource for this group of knowledgeable students.¹⁵ Furthermore postdoctoral scholars who often play major roles in teaching graduate students proper laboratory techniques, and may oversee the day-to-day activities of graduate students should complete a similar course on laboratory safety.

Other efforts to educate and build interest in the topic of safety for graduate students could be used. As part of the educational process in laboratory safety, graduate students could participate with faculty and staff in periodic laboratory inspections or walk-through surveys. Encouraging graduate students to participate in departmental safety committees or allowing them to participate in investigations of laboratory incidents could also contribute to their educational experience. Graduate students may also have informal opportunities to teach safety skills to other students working in the laboratory.

Seminars on safety topics, especially those related to chemical safety could also be used to teach graduate students about more detailed aspects of chemical hazards and methods to minimize exposure to hazards. Current events in laboratory safety such as incidents, or new safety knowledge, could be presented as part of a seminar. Alternatively, faculty could ask graduate students to include aspects of safety which relate to their assigned topic at the beginning of their seminars. During oral defenses of dissertations, a faculty member of the examining committee could ask questions regarding safety concerns in the research covered by the dissertation.

^f Source: Cole, R. University of Iowa, Iowa City. Personal communication, August 2011

^g The capstone is a course that evaluates students’ cumulative knowledge and skills in a given area of study.

Table 1. Suggested Laboratory Safety Topics for Undergraduate Chemistry Programs ^{8,23}	
<i>First- and Second-Year Topics</i>	<i>Advanced Safety (3rd and 4th years) Topics</i>
Principles of Safety: Recognizing/identifying hazards; assessing/evaluating the risks of hazards; minimizing/preventing exposure to hazards; preparing for emergencies; and safety ethics and responsibilities	
Preparing for Emergencies: Responding to emergencies; evacuation actions; fire emergencies; classes of fires; fire triangle/fire tetrahedron; types of fire extinguishers; using fire extinguishers; actions for various chemical spills; using emergency eye washes and emergency showers; elementary first-aid; emergencies with gas cylinders	Preparing for Emergencies: Planning for emergencies; working with outside emergency responders; and drills and exercises for emergencies
Recognizing/Identifying Hazards: Language of safety (terms, signs, labels, symbols; Material Safety Data Sheets (MSDSs); current and Global Harmonization System (GHS) hazard recognition systems; information resources about hazards; introductory toxicology; acute and chronic toxicities; corrosives; flammables, fires, explosions; and incompatibles	Recognizing/Identifying Hazards: Chemical hygiene plans; carcinogens; how the body handles toxic chemicals; sensitizers; irritants; reproductive toxicants; biological hazards; compressed gases; peroxides; reactive/unstable chemicals (explosives, pyrophoric materials; oxidizers; peroxides and peroxide formers; water reactives); pressurized systems; electrical hazards; housekeeping; nonionizing radiation; ionizing radiation; cryogenics; runaway reactions; catalysts; nanomaterials; and laboratory shop hazards
Assessing/Evaluating Risks of Hazards: Routes of exposure; risk assessment; evaluating risks of toxic hazards; and occupational exposure limits	Assessing/Evaluating Risks of Hazards: Assessing chemical exposure; working in a new laboratory; developing a laboratory safety plan for an experiment
Minimizing/Preventing Exposure to Hazards: Managing risk; eye protection, skin protection; laboratory hoods and ventilation; safety standards for safety equipment; handling chemical wastes; and storing flammables and corrosives	Minimizing/Preventing Exposure to Hazards: Safety for common lab procedures; radiation safety; laser safety; biosafety and biological safety cabinets; protective clothing; respirators; safety in research laboratories; process safety; conducting a safety inspection; managing chemicals; chemical inventories and storage; and handling chemical wastes
Cross-cutting and Related Topics: Learning lessons from incidents; and introductory	Cross-cutting and Related Topics: Laws and regulations pertaining to safety; chemical

green chemistry	security; building a strong culture of safety; safety skills for professionals; advanced green chemistry; and the role of institutional environmental, health, and safety professionals
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Table 2. Resources for Preparing Lessons in Laboratory Safety	
<i>Resources</i>	<i>Comments</i>
<i>Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards</i> , Updated Edition, Board on Chemical Sciences, Committee on Prudent Practices in the Laboratory, National Research Council, National Academies, National Academies Press, Washington, DC, 2011	This highly acclaimed publication is an authoritative reference suitable for advanced undergraduates and graduates, and can be used to develop lessons and courses in laboratory safety. It is a very useful reference for teaching assistants and laboratory coordinators. Hard copies must be purchased but it is available free online. ¹⁵
<i>Chemical Laboratory Safety and Security: A Guide to Prudent Chemical Management</i> , Moran, L.; Masciangioli, T. Eds., Committee on Promoting Safe and Secure Chemical Management in Developing Countries, National Research Council, National Academies, National Academies Press, Washington, DC, 2010	An accompanying toolkit (seven components) is available for use with this manual; the toolkit is published in English, French, Arabic, and Indonesian. ^{26,27} This is designed for use in developing countries.
<i>Handbook of Chemical Safety and Health</i> , Alaimo, R. J. Ed., Oxford University Press, Washington, DC, 2001	A very good reference book for chemists and health and safety professionals. ²⁸
<i>Safety in Academic Laboratories</i> , Vol. 1 (Student Ed.), Vol. 2 (Teachers Ed.), 7th ed., ACS Joint Board–Council Committee on Chemical Safety, American Chemical Society, Washington, DC, 2003	This publication has been used by hundreds of colleges and universities as a general guide to laboratory safety for undergraduates. ^{29,30}
<i>Laboratory Safety for Chemistry Students</i> , Hill, R. H.; Finster, D. C. John Wiley and Sons, Inc., Hoboken, NJ, 2010	This is a textbook written for chemistry undergraduate students; it is designed to be used throughout the four years of undergraduate study. ²³
<i>Journal of Chemical Health and Safety</i> , Elsevier Science and the ACS Division of Chemical Health and Safety, New York	This journal is a publication by the ACS Division of Chemical Health and Safety. It is included in a membership to the division. ³¹
<i>Journal of Chemical Education</i> , American Chemical Society and the Division of Chemical Education, Washington, DC	This journal is a publication of the ACS Division of Chemical Education. It has occasional contributions about laboratory safety but may soon include a laboratory safety

	section in future issues. ³²
ACS Joint Board–Council Committee on Chemical Safety, American Chemical Society, Washington DC	This ACS Committee serves as a resource to ACS and the public on chemical and laboratory safety. It develops and publishes booklets and presentations on chemical safety. ³³
ACS Division of Chemical Health and Safety, American Chemical Society, Washington, DC	This ACS Division offers membership to ACS and non-ACS members. It promotes health and safety through: (1) symposia at ACS national and regional meetings; (2) publication of its <i>Journal of Chemical Health and Safety</i> ; (3) its listserv where members discuss questions with EHS professionals. ³¹
<i>CRC Handbook of Laboratory Safety</i> , 5th ed., Furr, A. K., CRC Press, 2000	While this reference is somewhat dated, it can be used as a resource in developing safety lessons for students. ³⁴
<i>Princeton University Laboratory Safety Manual</i> , Princeton University, Environmental Health and Safety Department, Princeton, NJ	Its web-based lab safety manual is available. ³⁵
Chemical Engineering 5310, Laboratory Safety Course Resource, Dan Crowl’s course page, Michigan Technological University, Houghton, MI	This is a safety course for new graduate students; it contains course syllabus, lecture notes, homework, and a list of resources provided on compact disc (CD). ³⁶
<i>Bretherick’s Handbook of Reactive Chemical Hazards</i> , 7th ed., Urban; P. G., Ed., Elsevier Science, 2007	This is an authoritative reference on hazardous chemical reactions and hazardous reactive properties of chemicals. ³⁷ This book is incorporated into an online hazardous chemical database <i>Hazmat Navigator</i> . ^{37,38}

The Role of Hazards Analysis in Developing and Sustaining a Strong Safety Culture

The CSB found in its investigation of a laboratory accident that the assessment of hazards in research laboratories was inadequate or missing.²⁵ The CSB recommended that tools be developed for students working in research to help them assess the risk of hazards in their laboratory work. This is explained below.

The scientific method is a foundational principle used for centuries to impress upon young scientists the need to methodically plan for, perform, and evaluate the results of experiments. Organizations with a strong safety culture also find ways to integrate the process of identifying, evaluating, and mitigating the hazards of the experiment to be performed into the experimental

design process. This interaction is illustrated with the most basic elements of the scientific method represented within the circle and the basic elements of a hazards analysis process in the corresponding boxes (Fig. 1).

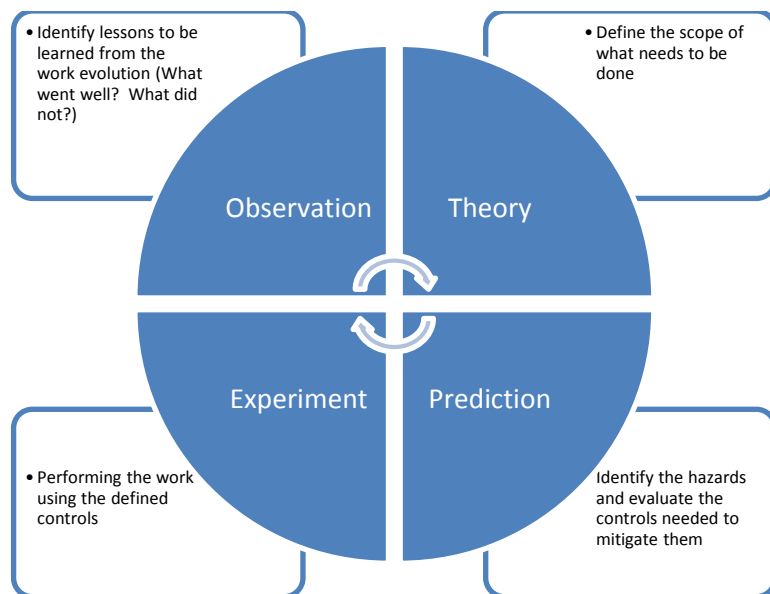


Figure 1: Integration of Hazards Analysis with the Scientific Method

Individuals who are part of an organization where this process is highly valued, as demonstrated in a strong safety culture, exhibit certain characteristics throughout this process.^h

Defining the Scope of Research

- Ascertain published information on the reactivity and toxicity of the chemicals used or generated in the proposed experiment. For novel preparations or those having unstable reactants/products, determine appropriate safe approaches to carry out operations, such as running reactions on a small scale. Identify emergency procedures and equipment needed for this proposed work.

Identifying and Evaluating Hazards

- Hazards to the investigator and risks to the environment and the success of the experiment are identified and evaluated. Material Safety Data Sheets (MSDSs) should be utilized for reagents, especially for new reagents.
- Routes of potential exposure are identified; these routes may include exposure to hazards through skin or inhalation but they may be other hazards that result from handling or processing chemicals, such as being hit by flying objects (from explosions), receiving

^h See the section, titled “Defining a Strong Safety Culture,” for traits of a strong safety culture on p 5.

cuts (preparation steps with sharp objects), or adverse contact with equipment (contact with moving parts, pinching, burns, pressure, or electrical shocks). Eliminating or minimizing potential routes of exposure is a critical component of hazards assessment and management.

- A questioning or challenging attitude is welcomed to ensure the best analysis possible.
- Potential, credible accident or event scenarios are hypothesized and discussed.
- Controls are identified that will eliminate the hazard, control it, or protect the investigator in the event the thinkable or unthinkable happens.
- Regulatory requirements, which are often hazards-based, are identified.
- Tools are used to facilitate a thorough review and to lend a reasonable consistency across the organization. These tools may take a number of forms (for example, checklists, what-if analyses, barrier analyses, failure modes analyses, control banding, and so forth).ⁱ
- While the experiment may be completed by an individual, this investigator should call upon others to help or advise with the process, deferring to those who may have more experience. This could be a senior investigator, a health and safety professional, or another student. The expertise of others is valued.

Performing the Work with the Identified Controls and Protective Measures in Place

- Confirm that the agreed-upon controls and protective measures are in place and functioning before the work begins. This includes a conscious evaluation of the skills and capabilities of the individuals who will complete the work.
- Conduct the experiment with the identified controls in place. If unexpected conditions are found, the investigator pauses and ensures the scope of the work or the necessary controls have not changed significantly enough to warrant additional analysis.
- Question or remind investigators about their controls, especially if they suspect a necessary control is not in place or is not being used.
- Seek to avoid at-risk behavior in your work and help others recognize risky behavior in their work, as needed. At-risk behavior, a leading cause of incidents, results when personnel bypass safe practices to reduce the time or level of effort. Examples of at-risk behavior include: not wearing personal protective equipment; not using hoods; skipping safety plans or steps; poor housekeeping; and scaling up a reaction without adequate planning. Prevention of at-risk behavior is a key component of safety.

Identifying Lessons to be Learned

- The investigator approaches the end of an experiment the same way he or she began and asks even more questions. For example, “Did a hazard manifest itself that was not previously identified? Did a control perform the way it was expected to or do I need

ⁱ More information about these tools is forthcoming in an ACS publication.

another option if I repeat this experiment? Did something go really well that others can learn from? Did I recognize any close calls that can serve as a warning for identifying areas of needed improvement?

- Hazards analysis documents are continually improving and not something that are created once and never looked at again.
- If an incident occurs, students and investigators could learn how to conduct investigations and root cause analyses, and then communicate the lessons learned to others.

The laboratory is a unique environment. Hazard identification, hazard assessment, and hazard management – collectively known as hazards analysis – in laboratory operations (including research) are critical skills that need to be part of all student and postdoctoral education. Learning how to prepare for emergencies is also a critical skill. It is important to remember that some hazards may not have been identified, assessed, or managed correctly when the laboratory operation was designed. Safety is an integral part of all laboratory operations but it requires that the laboratory worker consider this every time they start work. In this way, the process of hazards analysis becomes an integral part of the laboratory process, just like the scientific method.

Recommendations Concerning Teaching Laboratory Safety

4. *Ensure graduating chemistry undergraduate students have strong skills in laboratory safety and strong safety ethics by teaching safety lessons in each laboratory session, and by evaluating and testing these skills throughout the educational process (Table 1).*
5. *Ensure all faculty, staff, and graduate and undergraduate students involved in teaching, managing, or overseeing students in laboratory courses and sessions have successfully completed a course in lab safety.*
6. *Implement hazards analysis procedures in all new lab work, especially laboratory research.*

Safety Attitudes, Safety Awareness, Safety Ethics

Solid safety awareness and attitudes are as important to chemistry as are following experimental procedures and keeping good recordkeeping of conducted experiments. Building safety awareness requires a long-term effort—safety is highlighted repeatedly. Faculty and staff members have an ethical obligation to teach students and new employee about the need for a positive, proactive attitude about safety while conducting an experiment in chemistry.

When teaching someone how to drive a car these days, it would be remiss in our role as instructor if no one mentioned the need to wear seatbelts and to avoid the use of alcohol or other drugs, and refrain from using cell phones, especially sending text messages, while driving. To carry the driving analogy one step further, demonstrating by personal example is as important to the student as what their instructor says.

Following safety policies and procedures in a lab is just as important as the information the students receive in a presentation or the knowledge a student gains from an experiment. Thus, everyone who teaches or trains others in chemistry has to know and follow the appropriate safety practices in the laboratory.

Safety should be a focus for all students – chemistry majors as well as non-chemistry majors – and all chemistry-based science courses. It will benefit the chemical enterprise, if all students grow to understand and appreciate that working safely without injuring themselves or the larger environment is an essential career goal. Every member of the organization must share in the safety vision and demonstrate a high level of safety awareness, especially toward laboratory safety.

Everyone involved in the teaching or learning process must be convinced of the necessity of good safety practices and a strong safety culture. Members include faculty, instructors, academic staff, teaching assistants, and stockroom personnel. In addition, maintenance, shipping and receiving, and facility management personnel must contribute to the safety culture. Professional training, education, and development of these individuals will require varying approaches and task-appropriate content.

A driving force for safety in the research environment can be found in the requirements of the National Science Foundation's (NSF), *The Responsible Conduct of Research*.^{38a} Under the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (COMPETES) Act (42 U.S.C. 18620-1), the responsible and ethical conduct of research (RCR) is essential for excellence and for the public's trust in science and engineering. Our future scientists and engineers should be able to conduct research responsibly and ethically. The NSF requires a plan to provide appropriate training and oversight in the responsible and ethical conduct of research to undergraduate students, graduate students, and postdoctoral scholars that participate in proposed research. Safety should play a significant and substantial role in this plan. Faculty and staff applying for financial resources from NSF (and other organizations, such as NIH) should include safety education and training, and oversight of research for safety, as a basic and integral part of their plan to conduct responsible and ethical research.

The proper attitude for safety is reflected in the “Safety Ethic”—value safety, work safely, prevent at-risk behavior, promote safety, and accept responsibility for safety.³⁹

- **Value safety:** Safety is an integral part of what one does, its automatic, and it does not change its priorities—it is never questioned and never compromised.
- **Work safely:** One continues to learn about safety, learns to recognize hazards, assesses the risks of hazards, manages the risks of hazards, and prepares to handle emergencies.
- **Prevent at-risk behavior:** One does not cut corners or bypass safety measures in the laboratory and shares this information with others, as needed.
- **Promote safety:** One encourages and acknowledges others for working safely.
- **Accept responsibility for safety:** One takes steps to work safely, setting a positive example for others, and being accountable for safety.

Teaching safety continuously over the entire undergraduate four-year experience can build positive attitudes and strong safety ethics among students. The University of Wittenberg is using this approach. Another approach to positive attitudes and safety ethics found in a strong safety culture may be the formation of safety teams in undergraduate chemistry courses as used at the Seattle University in Washington and the University of California, Merced, and described by Alaimo, Langenhan, Tanner, and Ferrenberg.²⁴

Recommendations Concerning Safety Attitudes, Awareness, and Ethics

7. *Build awareness and caring for safety by emphasizing safety throughout the chemistry curricula.*
8. *In the preparation of grant proposal, researchers should include in their plans safety education and training (for undergraduate students, graduate students, and postdoctoral scholars participating in proposed research) and oversight of research for safety.*
9. *Adopt a personal credo: the “Safety Ethic”—value safety, work safely, prevent at-risk behavior, promote safety, and accept responsibility for safety.*

Learning from Incidents

Most people in our world love stories – they often ignite our interest in something, inflaming our imagination, our awe, and sometimes our humor. Most chemists have experienced memorable incidents and want to do a little one-upmanship with their own thrilling story. This high interest in these stories can be used to build stronger safety cultures by turning accounts of laboratory incidents into learning experiences about safety.

Each laboratory incident should be investigated so that direct, indirect, and root causes can be identified and measures can be devised to prevent or minimize future incidents. In strong safety cultures the stories of these incidents and the lessons learned are collected and then publicized or shared with colleagues and students. For example Princeton University posts these kinds of stories on their EHS website. These are accessible to the public.

Using these incidents and the lessons learned as case studies throughout the undergraduate and graduate learning experience provides an opportunity to capture the interest and imagination of students while forcing them to think about how safety measures could have prevented or minimized these incidents.

Sharing lessons learned through incidents is an important step in building a strong safety culture. This may seem difficult at time since in today's world incidents, especially those involving calls for emergency services attract media attention. Most companies or institutions, including universities and colleges may be embarrassed by these “public” media events and may seek to limit coverage by issuing statements that minimize the incident and report that an investigation will be conducted. Often the report of this investigation is not made readily available to the public.

There needs to be a public outlet that will post these lessons learned so that they are available for all to share. The ACS Division of Chemical Health and Safety has applied for an innovative grant to develop a database of incidents with lessons learned that can help prevent future incidents – if ACS can find a way to support this activity this could lead to a new resource of materials for learning about safety. Those interested in this kind of sharing should send a note to secretary@dchas.org or to safety@acs.org.

A recent string of incidents in laboratories has raised questions about the safety culture in academic laboratories. The CSB expressed its concern about safety management practices in academic labs. In 2010, an explosion occurred at a Texas university and the CSB then-Chairman John Bresland said, “We see serious accidents in high school and university labs every year... it is time to begin investigating these accidents to see if they can be prevented through... rigorous safety management.”²⁵ The CSB issued a report of this incident in October 2011.⁴⁰

Most of what is known about safety has been learned from mistakes or incidents. Investigations of incidents can be key tools in helping to build a strong culture of safety by identifying direct and root causes, so that action can be taken to prevent future incidents. Direct causes are the immediate causes of the incident. For example, a fire resulted from using a flammable material close to an ignition source. Root causes are the underlying causes. For example, the individual

was not educated in fire safety because it was not taught. Often a key root cause of an incident is a weak or missing safety culture—leadership says safety is important but places little value on it, as evidenced by the failure to invest significant time, effort and resources, and by the avoidance of taking responsibility for safety.

An important element of a strong safety culture is establishing a system for reporting and investigating incidents, identifying direct and root causes, and implementing corrective actions. The components of an incident investigation system are:

- **An incident reporting system** that includes students. An OSHA-required incident reporting system is in place for employees. Incidents should be reported within 24–48 hours, so that facts are easily remembered. Furthermore near-misses and non-reportable incidents should be included in this incident system.
- **An incident investigation system** that collects reports of incidents, conducts investigations of incidents, and reports lessons learned to faculty, staff, and students. The extent of an investigation is determined by the seriousness of the incident, but all incidents should be investigated as soon as possible and serious incident scenes (injuries or serious damage) should be preserved until released by investigators. This system includes an investigation reporting system, so that lessons learned may be shared and appropriate actions can be taken to prevent future incidents.
- **An incident database** that contains incident and investigation reports, including those of near misses. This database is used to look for tracking, trends analysis, and systemic problems, and to track implementation of corrective actions. This information should be used to teach lessons through proactive communications to others to prevent or minimize future incidents.

Incident investigations can be used as safety education and training tools in classrooms, group discussions, or seminars. They should be topics of discussion in departmental safety committees, as well as at higher levels in the institution. The focus of incident investigations should always be on learning the direct and root causes of the incident, so that corrective actions can be determined and implemented. Investigations should not focus on affixing blame or assessing penalties. Punitive actions will drive the faculty and staff to stop reporting incidents. OSHA prohibits retaliation for reporting safety issues. In a truly strong safety culture, incidents are effective learning tools and information is freely shared without fear of retaliation.

Incidents will never be eliminated but in a strong safety culture, serious incidents are rare. Most serious incidents are the result of a series of bad decisions and steps that ignore proper safety measures. In a strong safety culture, it is much more likely that fewer poor decisions and missteps will take place, so that serious incidents are avoided.

Incident Reporting System

There should be a reporting system for students and postdoctoral scholars who are paid by stipends or grants as teaching assistants, lab assistants, or researchers but who may not be considered employees, per se. There is already an OSHA requirement for employees to track and

report incidents. It is understood that this is an internal reporting system, which should be used as a tool for improving safety, not reporting incidents to the public or government agencies.

In larger institutions, these reporting systems are maintained by the EHS office. In smaller institutions, the chair should maintain them. Incidents involving undergraduate and graduate students, or postdoctoral scholars should be reported to the lab supervisor, lab instructor, teaching assistant, or principal investigator—they should be responsible for recording and reporting the incident, usually within 48 hours. These incident reports should be reviewed by faculty and staff, or by a safety committee composed of faculty, staff, students, and postdoctoral scholars.

It would be more effective to use one system, but concerns for not counting students as employees may lead to establishing a separate system for students. Some universities have a “Safety Concerns Report” for nonemployees for this purpose, such as the one at the University of California, San Diego.⁴¹

Incident Investigation System

All incidents should be investigated. However, the depth of investigation depends upon the seriousness of the incident. Incidents are often examined by the lab supervisor or manager to determine causes and corrective actions. These incidents may be teachable moments for the student or the entire laboratory class—lab supervisors or instructors may want to review the incident, ask what caused the incident, and ask what corrective actions might be taken.

More significant incidents may be investigated by the EHS office, principal investigators, or faculty. If there is no EHS office or personnel, then it will fall to the faculty to investigate. Incidents involving only superficial injury or damages may use a simple investigative approach, such as the “5-Why?”⁴² The 5-Why approach is only approximate and is subject to bias and is less reproducible than a more formal method. Nevertheless, this is a quick-and-easy method that often produces reasonable results, particularly for learning purposes. More complex and more serious incidents require more formal investigations based upon data and observations, using a “root cause analysis” approach. These kinds of investigations are usually conducted by EHS professionals or staff trained in the investigative process.^{43,44,45,46,47}

An Incident Database

This database contains all incidents and near misses involving employees and nonemployees. EHS or designated staff should use the database to look for trends and systemic problems and track the implementation of corrective actions, which should be done at least annually. It is important to not only report all incidents, but also near misses that are often precursors to incidents. Frequent database analysis is particularly important since corrective actions are either not taken or are only partially implemented, and a follow up may prevent future incidents. Safety committees or EHS personnel can use the database to call up incident investigation reports to assess the status of corrective actions or determine where weaknesses are in the safety program.

Hearing stories about incidents usually peaks students’ interest, as they are likely to remember these stories. The stories of incidents can be useful for teaching about safety generally, as well as

a particular area of safety. Students can learn safety from examining these incidents. The ACS Division of Chemical Health and Safety maintains, as a service to its members, a listserv that provides weekly reports of chemical incidents.⁴⁸ A number of publications and Web sites describe laboratory incidents, some of which provide a lessons learned analysis of each incident.^{23,49,50,51,52,53,54,55}

Recommendations Concerning Learning from Incidents

10. *Establish and maintain an Incident Reporting System, an Incident Investigation System, and an Incident Database that should include, not only employees, but students also—graduate students, postdoctoral scholars, and other nonemployees.*
11. *Establish an internal review process of incidents and corrective actions with the Departmental Safety Committee (faculty, staff, students, graduate students, and postdoctoral scholars), and provide periodic safety seminars on lessons learned from incidents.*
12. *Publish or share the stories of incidents and the lessons learned (case studies) to your institution's website, a public website or an appropriate journal where students and colleagues from other institutions may also use these as case studies for learning more about safety.*

Collaborative Interactions that Help Build Strong Safety Cultures

The formation of a campus-wide safety program does not happen overnight, and it is not something that an individual or a single department can develop alone. To create a sustainable safety program, the institution must establish an active safety committee system that includes members representing a good cross-section of the campus. The membership of such a committee should include safety professionals, faculty and staff members, administrators, and undergraduate and graduate students and postdoctoral scholars, who will all be protected and affected by the program.

Developing a program is more than a set of regulations and standard operating procedures (SOPs). In order for it to succeed, a safety program will require cooperation across departmental lines and the support of all people associated with the organization. When looking for faculty liaisons, recent hires who transferred from institutions with a strong safety program could be useful allies. The committee needs to be active and productive, and publish informative documents regularly. Safety is a team endeavor—it takes everyone working as a team to keep everyone safe. A critical part of every safety program is to establish collaborative interactions among members of the institution.

One approach to establishing a strong and vibrant safety program starts with the leaders of the institution—the chancellor or president.⁵⁶ Leaders assign responsibilities for oversight to the vice chancellor or vice president who, in turn, might establish a health and safety council. The University of California at San Diego and Princeton University have established high level management organizations that provide policy guidance and oversight for the health and safety for their institutions. This council is usually composed of appointed faculty to conduct the following activities:

- Oversee development and implementation of health and safety policies;
- Oversee the campus network of safety committees;
- Monitor the effectiveness of the institutions' health and safety programs, including a review of incidents and trends; and
- Oversee compliance with regulatory requirements, which is usually done through the institutions' EHS office.

These institutions also have special safety committees that report to the chancellor or president, or their appointed representative.⁵⁷ For example, these committees oversee some aspects of safety, such as laboratory safety, and their members are appointed faculty representatives. These committees provide:

- Provide advice on all matters related to the laboratory (their area of responsibility)
- Develop checklist of safety activities for use across the department – individual research groups supplement these checklists to address specific areas relevant to their group's activities
- Reduce risk of laboratory exposure;
- Establish policies and procedures for laboratory safety; and
- Impose disciplinary actions for willful or negligent violations of policies, practices, and procedures.

Additionally, departments offering chemistry may establish an active safety committee with members from faculty, staff, undergraduate and graduate students, EHS staff, maintenance engineers, and administrators. A designated faculty member or EHS representative could act as chair and ensure the committee meets on a regular basis. Safety committees should meet on a periodic schedule—this is often monthly. Faculty members should serve on the safety committee for a designated term and participation should rotate among all members of the faculty. The committee is responsible for any number of duties, such as the following:

- Deal with current or newly recognized safety issues;
- Review or investigate incidents and safety complaints;
- Sponsor special seminars or safety programs;

- Assist with prioritizing budget needs for safety;
- Recognize members for significant contributions to safety;
- Participate in safety surveys and inspections;
- Review the safety program;
- Make recommendations to improve the safety program; and
- Distribute an e-newsletter to all departmental members.

The safety committee could establish its duties in the form of a charter that details the terms of membership, and explains the duties and responsibilities. Departmental leaders should work to ensure recommendations generated from safety committees are addressed and carried out promptly. Recognize that your faculty, staff, and students may not be experts in safety, and that your EHS personnel may not be experts in chemistry, but an extensive knowledgebase of safety information is freely available from other academic institutions throughout the country.

If universities or colleges have an EHS Department, it is important to establish a close partnership with these professionals. EHS personnel have expertise in health and safety issues, such as a radiation safety officer, and their knowledge can be of invaluable assistance in solving health and safety issues and helping to ensure regulatory requirements are met. EHS personnel may not have the expertise in chemistry, so faculty or staff may have to help them understand chemical issues. It takes teamwork to make this relationship a strong one. Since it is often the EHS Department that leads or conducts periodic inspections and requires departmental chairs to enforce regulatory requirements, adversarial relationships between EHS and departments may occur. It is critical that EHS personnel become a valued part of the safety program. Because EHS staffing is relatively small, they often include department faculty and staff in conducting inspections – this can be a team building opportunity where value on is realized by EHS and faculty.

Another opportunity for collaboration on issues of safety and ethics exists across departments, for example, the chemistry, biology, health sciences, and engineering departments, could share information in these areas or work collaboratively with departments, such as philosophy or psychology, that might have more expertise.

The university or college should establish a close working relationship with local emergency responders, especially fire departments and their hazard materials teams (HazMat Teams). This should include active liaisons with EHS and departments that handle and store chemicals and other hazardous materials. Visits by emergency responders to laboratories can provide valuable information for both responders and institution administrators and managers. Faculty should take the time to explain the kinds of hazardous materials being used so that they build bridges of understanding and cooperation and can better prepare emergency responders so that they know what to expect and will more comfortable in responding to emergencies. This takes some effort

because emergency response organizations have multiple shifts and responders may move to other locations.

Not all emergency response organizations have HazMat teams, but if they do, it is important to especially prepare them to respond to the institution's emergencies. Most emergency responders will want to have accurate and up-to-date inventories of chemicals being stored and used in the institutions laboratories (this is part of the community right-to-know) so that they may better plan for emergencies. Providing accurate maps and locations of buildings and emergency cut offs is an important part of this effort – this is most frequently provided by the institutions facility engineers. Knowing the names of key contacts in the institution and in the local emergency response organizations can lead to a trusting relationship that will benefit all parties.

Recommendations Concerning Collaborative Interactions

- 13. Establish a series of safety councils and safety committees from the highest level of management to the departmental level or lower. Each of these committees reports, in turn, to a committee that is higher in the hierarchy of the institution.*
- 14. Establish a close working relationship with EHS personnel at every departmental level seeking their advice and experience in safety and offering departmental and faculty advice to EHS based upon their experience with knowledge of chemistry.*
- 15. Establish a close working relationship with local emergency responders so they are prepared to respond to emergencies in laboratories.*

Promoting and Communicating Safety

Probably the best way to promote safety is through personal example. Always following safety procedures, protocols, and rules that are required of everyone. Most labs require eye protection, lab coats, closed toed shoes, long pants or skirts, and no drinking or eating in the lab – complying with these requirements sends a message to others that you really do care about safety. This is especially important for faculty and staff since students will follow their examples.

Business and service organizations know that the key to building a successful consumer following is advertising. Selling safety at your institution is, in part, dependent upon a continuous effort to promote the safety program to faculty, staff, and students. Advertising and promoting safety could take many forms.

Today, many faculty, staff, and especially students, tend to do everything online and through their cell phones. One way to promote a safety program might be a safety newsletter or weekly bulletin that is distributed via social networks and campus-wide e-mails. Departments may consider having open seminars to discuss topical safety issues or incidents; this might involve an

open conversation that focuses on how safety issues might be addressed. Another approach to highlighting safety is to have a “Safety Week” that features various activities associated with safety. Celebrating a “Safety Day” could also become an important event. Some organizations have “safety stand down days” when the time is dedicated toward safety issues – special safety training, chemical and waste disposal, lab reorganization and cleanup, etc.

Printed information sheets and appropriate signs and posters may be displayed on campus billboards, in science department hallways, as well as inside elevators when allowed. However, campuses are often covered with many of these types of printed materials, so safety materials could be lost unless they are very memorable. Other promotional approaches might involve placing safety articles in campus newspapers, or including inserts in orientation packets for incoming students, and newly hired faculty and staff.

Recognition of individuals for doing a good job in safety is an important part of a vibrant safety program. This recognition usually does not involve any type of monetary award, but rather an acknowledgement in a public meeting. Send out special postings if there are opportunities to recognize a colleague or student organization for doing a good job in safety. An effective way to recognize people is by personally thanking them for doing some particular safe action. A handshake or a personal note is a great way to thank people—recognition does not always have to be in the public eye and is often more effective if it is done privately.

Establish a procedure for soliciting suggestions for improving safety and identifying safety concerns; ideally, this will be an online form, but suggestion boxes are also a great advertising tool when placed in high-traffic areas.

Recommendation Concerning Promoting Safety

- 16. Establish a system to promote safety in an institution or department that encompasses: electronic communications; printed materials; special seminars or events discussing or promoting safety; a recognition system for good safety performance; and a process to solicit, review, and act on suggestions for improving safety and identifying safety issues.*

Encouraging Institutional Support of Safety by Funding Safety Programs and Supplies

Many of the suggestions described in this document can be made at little or no additional cost. Nevertheless, new and innovative approaches for building a strong safety culture may require funding. Bringing in expert safety consultants to assist with developing improvements in the safety program may also incur some costs. Establishing an information technology system for incident tracking, chemical waste management, and chemical inventory may have some additional costs, but many of these systems are likely to be in place. Upgrading and maintaining safety equipment is an essential part of any strong safety program, as are the people involved in

the program. Expenses for seminars and short courses for faculty and staff designated as Chemical Hygiene Officers should be included. This is especially important since some Chemical Hygiene Officers may have little or no background in chemistry. All of these recurring expenses support an institution's safety program and require annual financial support from top leadership.

The first step in establishing a continuing budget for a safety program is determining institutional needs. Identifying responsibilities for safety and the corresponding staff who will accomplish this is critical in determining budgetary needs. Safety is often assigned as a collateral duty to many university staff. It is often possible that departments can collaborate and lend each other support on special projects. The administration may require EHS support for a safety program. Printing, office, and safety supplies, and training materials require sufficient funding to sustain the program annually—these items often come from departmental budgets. Gather allies for support. Allies include departmental chairs, faculty, staff, students, campus physicians and nurses, Human Resources, Risk Management, and select community leaders, such as emergency management personnel and first responders. Advise the administration of a proposed safety program and explain the benefits in terms of how funding the request will benefit the organization, and how funding the program can make the school a leader and a resource to the community.

Recommendation Concerning Institutional Support

- 17. Identify the ongoing need to support a strong safety culture and work with administrators and departmental chairs to establish a baseline budget to support safety activities on an annual basis.*

Looking for the “Bright Spots”: Institutions Worthy of Emulation

The “bright spots” is a term used in a book, titled *Switch: How to Change Things When Change Is Hard*, by Chip Heath and Dan Heath, in bringing about change in cultures.⁵⁸ These are places where efforts toward a goal have been successful and are worthy of emulation. The result of a strong safety culture within an academic institution is evidenced by its prodigy – graduates of that institution who have demonstrated well-rounded safety knowledge and strong safety ethics. As expected by their employers these graduates are fully prepared to work as professional chemists using the safety skills they have learned as undergraduates and graduates. These graduates will need these safety skills as secondary school teachers, chemists working in industry or government, or as graduate students studying and conducting research safely.

The Committee on Chemical Safety seeks those academic institutions that might be deemed bright spots in that they have implemented the elements of safety culture as discussed in this report and are producing graduates who have strong safety skills and strong safety ethics.

The recommendations included in this report may be used criteria for recognizing bright spots. Thus bright spots will likely share most of these traits:

1. *Established the lines of authority for safety, developed a safety policy that includes laboratory safety, and included safety responsibilities in the job descriptions and performance plans of all employees.*
2. *Encouraged every leader to become a proponent of safety and safety education, and to demonstrate this care for safety in their actions with other staff members and students.*
3. *Established a strong, effective safety management system and safety program for the institution, including laboratory safety.*
4. *Ensured graduating chemistry undergraduate students have strong skills in laboratory safety and strong safety ethics by teaching safety lessons in each laboratory session, and by evaluating and testing these skills throughout the educational process (Table 1).*
5. *Ensured all faculty, staff, and graduate and undergraduate students involved in teaching, managing, or overseeing students in laboratory courses and sessions have successfully completed a course in lab safety.*
6. *Implemented hazards analysis procedures in all new lab work, especially laboratory research.*
7. *Built awareness and caring for safety by emphasizing safety throughout the chemistry curricula.*
8. *In the preparation of grant proposal, researchers included in their plans safety education and training (for undergraduate students, graduate students, and postdoctoral scholars participating in proposed research) and oversight of research for safety.*
9. *Adopted a personal credo: the “Safety Ethic”—value safety, work safely, prevent at-risk behavior, promote safety, and accept responsibility for safety.*
10. *Established and maintained an Incident Reporting System, an Incident Investigation System, and an Incident Database that includes not only employees, but students also—undergraduates, graduate students, postdoctoral scholars, and other nonemployees.*
11. *Established an internal review process of incidents and corrective actions with the Departmental Safety Committee (faculty, staff, students, graduate students, and postdoctoral scholars), and provided periodic safety seminars on lessons learned from incidents.*
12. *Published or shared the stories of incidents and the lessons learned (case studies) to an institution’s website, a public website or an appropriate journal where students and*

colleagues from other institutions may also use these as case studies for learning more about safety.

- 13. Established a series of safety councils and safety committees from the highest level of management to the departmental level or lower. Each of these committees reports, in turn, to a committee that is higher in the hierarchy of the institution.*
- 14. Established a close working relationship with EHS personnel at every departmental level seeking their advice and experience in safety and offering departmental and faculty advice to EHS based upon their experience with knowledge of chemistry.*
- 15. Established a close working relationship with local emergency responders so they are prepared to respond to emergencies in laboratories.*
- 16. Established a system to promote safety in an institution or department that encompasses: electronic communications; printed materials; special seminars or events discussing or promoting safety; a recognition system for good safety performance; and a process to solicit, review, and act on suggestions for improving safety and identifying safety issues.*
- 17. Identified the ongoing need to support a strong safety culture and work with administrators and departmental chairs to establish a baseline budget to support safety activities on an annual basis.*

The Committee on Chemical Safety seeks nominations for “bright spots”. Persons considering nominating organizations for this recognition should contact the Committee on Chemical Safety at safety@acs.org.

Appendix A: Brief Summary of the Discussions of the Elements of a Safety Culture from the June 2011 Retreat of the Safety Culture Task Force

During the June 2011 retreat, SCTF began to identify elements that are critical in strengthening safety cultures, such as:

- Leadership;
- Teaching basic laboratory and chemical safety (shop safety included);
- Safety ethic, attitude, and safety awareness;
- Learning lessons from laboratory incidents;
- Collaborative interactions;
- Promoting and communicating safety; and
- Encouraging institutional support of safety by budgeting for safety programs and supplies.

SCTF considered several ideas addressing these elements and best practices, including:

- **Leadership:** Identify the chain of command and line of authority within the academic institution and seek strong safety policies and support from the top down—identify leaders, inform leaders of the issue. Include safety as an element in all faculty and staff performance evaluations. Identify major points in a form letter to be sent to the principal administrator. Identify a model safety policy. Seek administration support and commitment of funding resources. Identify “bright spots”—these could be past recipients of the CHAS/NIOSH College and University Health and Safety Award. Examine the ACS Chemist Code of Conduct and ACS Academic Professional Guidelines. Identify organizations that can provide evaluations of the institution’s safety program. Partner with other departments to assist with developing and teaching safety and ethics.
- **Teaching basic laboratory and chemical safety:** Identify safety topics that could be taught to undergraduates in each and every laboratory session. Assess safety skills by testing knowledge of safety frequently. Ensure all faculty and staff overseeing laboratory operations have safety education. Consider a capstone course or examination to demonstrate proficiency in safety, especially for teaching assistants and laboratory coordinators. Consider a laboratory safety course for all graduate students. Identify resources and instructional materials for developing and implementing safety lessons. Re-examine CPT resources for evaluating safety skills, safety equipment in facilities, and safety programs at colleges and universities. Develop an ACS Chemist Standard (four-year study plan) for safety using the ACS two-year Technician Standard as a model.
- **Safety ethic, attitude, and safety awareness:** Teach safety lessons throughout the entire four-year undergraduate program. Students should learn about ethics, including focus on

attitude and responsibilities for safety—these ethics should be integrated into the educational process. Provide a capstone course on ethics. Hold an open forum to get ideas and suggestions from the academic community about how to improve safety education and safety culture in academia. Identify resources for faculty and staff about safety. Ensure all faculty, lab coordinators, instructors, and teachers take a comprehensive course on lab safety. Each organization should conduct a “consumer reports” type of evaluation of their safety program. Hold periodic safety seminars or discussions of lab incidents with undergraduate and graduate students, faculty, and staff.

- **Learning lessons from incidents:** Develop and maintain a system for reporting all incidents—set a timeline for expected reporting (such as 48 hours). Maintain a database of all incidents. Analyze the incidents and seek to learn lessons that can be used for preventing future incidents—do not seek to affix blame or assess penalties. Use these incidents as a training tool, and discuss them in safety meetings and seminars.
- **Collaborative interactions:** Faculty and staff should partner with EHS staff—avoid adversarial roles. Recognize that faculty and staff may not be experts in safety, and EHS personnel may not be experts in chemistry. Designate a faculty liaison with EHS and fund, or support, their development in safety. Establish an active safety committee with faculty, staff, EHS personnel, and undergraduate and graduate students. Develop recommendations with assistance from EHS staff. Faculty and staff, or health and safety professionals, should inspect lab facilities at least annually, preferably more often.
- **Promoting and communicating safety:** Identify appropriate signs and posters. Develop a safety newsletter. Recognize colleagues for doing a good job in safety. Have Safety Day celebrations (could incorporate with other celebrations). Establish a procedure for soliciting suggestions for improving safety and identifying safety concerns.
- **Budgeting for safety:** Establish a budget for safety—not an ad hoc response to problems. Solicit support from the administration for permanent safety funding for the Chemistry Department.

SCTF seeks: (1) input, suggestions, and recommendations for strengthening the safety culture in academia; (2) “bright spots”—those places within academia that provide textbook examples of one or more of these safety culture elements; and (3) good resources and instructional materials that can be used to build a strong safety culture. Send your comments and suggestions to: safety@acs.org.

Appendix B: Suggested Duties of Institutional Personnel

President or Chancellor

- Establishes a safety policy that supports the administration's commitment to faculty, staff, and student safety (including laboratory safety)
- Assigns responsibility for oversight of the implementation of the safety policy and the institution's safety program to the Provost, Vice President, or Vice Chancellor
- Provides resources and financial support for the institution's safety program, according to the recommendations of the manager responsible for oversight of this program
- Communicates to the entire institution about the importance of safety and expectations to establish and maintain a strong safety program that continually improves and protects all faculty, staff, and students
- Reviews safety reports from Provosts, Vice Presidents, Vice Chancellors, Deans, and Administrators

Provost, Vice President, or Vice Chancellor

- Responsible for oversight of the implementation of the institution's safety program, including laboratory safety programs
- Establishes responsibilities of Deans and other Administrators for safety programs within their areas of oversight
- Allocates resources and financial support for safety programs
- Establishes a system for providing safety training to high-level managers within the institution
- Establishes a system to address institutional safety concerns
- Maintains a system of oversight of safety programs through periodic reports from Deans and other Administrators
- Establishes faculty and manager safety committees to cover all areas of safety within the institution and receives reports about the status of safety from those committees

Deans and other Administrators

- Ensures safety programs are established and maintained for each department within their areas of responsibility
- Provides oversight for incorporation of ethics and safety into the curriculum
- Provides resources to accomplish the objectives of the safety program
- Provides and receives training for managers and supervisors that emphasizes health and safety leadership responsibilities
- Establishes lines of responsibility for safety
- Reports safety results to the President or Chancellor, or their designee
- Reviews reports from Department Chairs about the status of their safety programs, including the safety curricula

Department Chairs

- Identifies a Chemical Hygiene Officer or Departmental Safety Officer
- Establishes safety responsibilities for faculty, staff, and students
- Establishes curricular goals for safety education

- Ensures faculty, staff, laboratory supervisors, and teaching assistants involved in teaching and overseeing laboratory operations have attended a principle-based safety course
- Establishes a budget for the health and safety program to ensure the safety of employees, visitors, and students
- Establishes a safety committee and appoints safety committee members
- Ensures the development and implementation of safe practices, safety protocols, and safety rules for undergraduate and graduate laboratories and other affiliated shops, storerooms, stockrooms, and corridors within their purview
- Ensures that all safety training is documented
- Ensures that all safety practices, protocols, and safety rules are enforced and responsible employees are held accountable
- Establishes a system for reporting safety problems and issues
- Conducts regular faculty and staff reviews on meeting safety goals
- Reports safety program results to the Dean or Administrator
- Works with EHS to establish regular inspections of both teaching and research laboratories

Faculty

- Implements the curricular goals for safety education
- Ensures principle-based safety education and safety training is provided to students and staff within their laboratories
- Ensures safety is discussed at the beginning of each research group meeting
- Ensures new graduate students have received a principle-based safety course and specific safety training relating to their areas of research
- Participates in the development of the Chemical Hygiene Plan (CHP)
- Works with the Chemical Hygiene Officer (CHO) in documenting the safety training of laboratory members
- Documents all safety training that individual employees and students receive
- Serves as a safety advisor and mentor for staff and students who work and study under their supervision
- Enforces all health and safety practices, protocols, and rules within his or her laboratory space
- Ensures the appropriate personal protective equipment is available and used by all personnel in the laboratory
- Reviews new laboratory procedures for potential risks
- Ensures all visitors (including vendors and contractors) follow the safety rules
- Ensures all laboratory incidents are reported to the Chair
- Reports promptly any facility problem or improperly functioning equipment to the appropriate office or individual

Staff

- Receives safety training courses
- Develops with the Departmental Safety Officer safe practices, safety protocols, and safety rules for areas under their purview
- Ensures students understand and follow safety practices, safety protocols, and safety rules and institutes disciplinary measures for students who repeatedly violate these rules
- Reports unresolved, unsafe practices to managing faculty and the Chair
- Receives and reports all safety incidents to managing faculty and the Chair
- Ensures new safety measures are implemented within the safety program
- Reports safety issues, including unresolved safety equipment malfunctions, to managing faculty and the Chair
- Conducts periodic safety inspections of laboratories and shops under their purview

Chemical Hygiene Officer, Departmental Safety Officer

- If the institution has an EHS Department (or equivalent), works with that office as a safety resource for all departmental personnel and students
- Works with the Chair, faculty, and staff on enforcing safety requirements
- Oversees recordkeeping of safety-related training records, incident reports, MSDSs, inventories, and so forth
- Assists with developing a CHP, and distributes and establishes universal distribution of the CHP
- Monitors procurement, usage, storage, and disposal of all chemicals
- As members of the safety committee, conducts laboratory and departmental safety inspections, and evaluates departmental compliance with applicable regulations and rules
- Working with the department chair, ensures all employees and students receive safety training
- Provides for forklift training and other specialized-equipment training, as needed
- Provides for Personal Protective Equipment (PPE) training and fit testing

Safety Council (campus-wide)

- Advises the vice president or vice chancellor on policies relating to health and safety
- Ensures effectiveness of programs to implement policies
- Provides policy guidance on all matters related to health and safety
- Reviews activities of institutional health and safety committees for effectiveness and coordination
- Monitors effectiveness of the institution's health and safety program through periodic review of incident reports and other activities
- Reviews institution's health and safety activities for compliance with local, state, and federal laws and regulations

Safety Committees

- Comprises faculty, staff, and students
- Serves as a resource
- Helps enforce requirements
- Works with the Department Chair and CHO to ensure an effective program
- Reviews all incident reports
- Participates and reviews all laboratory inspections
- Provides the Department Chair regular reports
- Develops an Emergency Evacuation Plan and conducts evacuation drills

Appendix C. Safety Knowledge and Skills for Chemistry-based Technicians

ChemTechStandards for chemistry-based laboratory technicians lists the following knowledge and skills under the standard for maintaining a safe and clean laboratory adhering to environmental health and safety regulations.^j

ACS Chemical Technician Standards—Safety-Related Competencies

MAINTAINING A SAFE AND CLEAN LABORATORY ADHERING TO ENVIRONMENTAL HEALTH AND SAFETY REGULATIONS

Overview of the Impact of Federal, State, Local, and Company Regulations

- Use computers to access information about procedures for chemical safety, environmental protection, and health preservation
- Identify the agencies (federal, state, and local) that develop and enforce regulations pertaining to chemical and related industries
- Describe the purpose of the Responsible Care Code developed by the American Chemistry Council
- Specify three to five OSHA regulations that are directly applicable to the health and safety of workers
- Specify three to five EPA regulations that directly affect the work of the laboratory technician; special attention should be paid to the regulations regarding the handling and disposal of hazardous wastes
- Describe the Department of Transportation (DOT) regulations for labeling and shipping hazardous wastes; include the possibility of personal liability and an explanation of the manifest system
- Recognize companies have specific safety, health, and environmental (S/H/E) rules and regulations; review several examples from local industry
- Identify specific state and local regulations that affect operations at local industries
- Specify regulations that apply to consumer protection
- Read a variety of clean-up and emergency response procedures and determine how to implement the procedures
- Describe procedures used to respond to a spill or release of different kinds of chemicals
- Categorize regulations according to those that impact each environmental area (air, water, and noise)
- Prepare and present to lay community members clear information about how the industry implements its responsibilities as a good neighbor in the area of S/H/E issues
- Use library and online sources to prepare a report for oral presentation on the impact of major regulations, such as OSHA, the Food and Drug Administration (FDA), the Resource Conservation and Recovery Act, the Clean Air Act, and the Clean Water Act on industry

^j Developed by ACS from 1993 to 2006 with grant support and industry input, ChemTechStandards contain a comprehensive list of knowledge and skills employers expect of chemistry-based technicians. Archive copies are available upon request from the ACS Office of Two-Year Colleges (2YColleges@acs.org).

The Chemical Technician's Role in Implementing Regulations, Policies, and Practices

- Categorize common hazardous materials as corrosive, flammable, and so forth
- Identify the conventions and symbols used for labeling chemical materials; include Hazardous Material Identification Symbols (HMIS) and the National Fire Protection Association (NFPA) guidelines
- Apply, by example, the Responsible Care Codes as it relates to the laboratory
- State the responsibilities and rights of the technician under the Hazardous Communication Standard of OSHA; explain right-to-know; emphasize the importance of PPEs
- Identify the responsibilities of the technician for applying regulatory guidelines in a variety of typical laboratory situations
- Read and interpret hazard data associated with chemicals that are presented in MSDSs and other chemical data reference documents; explain Threshold Limit Values (TLVs), Permissible Exposure Limits (PELs), and so forth
- Access S/H/E regulations and data regarding chemicals using references, such as CRC Press handbooks, the Merck Index, the Chemical Technician's Ready Reference Handbook, and MSDSs, as well as conducting online searches
- Describe appropriate storage and disposal techniques required for each of the categories of common hazardous materials
- Demonstrate the ability to convert chemical concentrations to different units so that comparison can be made with MSDS safe levels
- Visit a local industry and describe the policies and programs that are in place to ensure worker safety
- Identify the requirements for effective response teams and describe the role of such teams in handling emergencies

Developing and Executing a Safety Plan

- Participate in an evacuation procedure
- Test safety equipment in laboratories and maintain a log
- Specify components of an effective chemical hygiene plan
- List elements of a safety plan for general laboratory safety
- Access an emergency response procedure plan from a local industry and discuss the implications for workers
- Develop and deliver a safety awareness session for fellow technicians
- Identify and describe components of a safety plan for emergencies, including fire, spills, gas release, bomb threats, and inclement weather
- Identify and describe components of an Emergency Response Plan, and per OSHA 1910.120, Hazardous Waste Operations and Emergency Response (HAZWOPER); 1910.38, Employee Emergency Action Plans; and Fire Prevention
- Use a building plan of an existing facility with an on-site water treatment system using chlorine cylinders and develop an evacuation and response plan addressing a leaking cylinder evolution
- Conduct a safety review and audit of a school laboratory by identifying the regulations for the laboratory as if it were in industry, developing or participating in a review team,

conducting an audit, identifying areas of noncompliance, and reporting to the group; work with the school staff to correct the items of noncompliance according to a timetable

Personal and Coworker Safety

- Demonstrate good housekeeping by maintaining a clean and safe workplace
- Demonstrate the proper lifting techniques
- Demonstrate the proper use of hand tool
- Demonstrate the ability to perform basic first-aid skills
- Demonstrate the appropriate use of safety equipment including, but not limited to, safety glasses, showers, respirators, eyewashes, and blankets
- Participate in a fire safety activity that includes an explanation of how to use different classes of extinguishers to put out a variety of fires
- Prepare and lead a short safety meeting for classmates appropriate to the school setting
- Select and demonstrate the use of appropriate PPE for a variety of situations involving hazardous chemicals including, but not limited to, corrosive, explosive, biological, and volatile materials
- Participate in a simulated emergency, both as a leader and as a victim
- Participate in an evacuation procedure
- Describe causes of sight and hearing loss in the laboratory environment and identify noise-level thresholds requiring protection

Fire Safety

- Explain the importance of reporting even small fires that can be extinguished quickly
- Describe the characteristics of fires that occur in chemical laboratory environments, including electrical, hydrocarbon, wood, paper, and chemical fires
- Describe the environmental conditions (fire triangle) required to support combustion
- Define the term “flash point” and explain the importance of knowing the flash point of a specific hydrocarbon
- Describe fire potential information in an MSDS.
- Select the correct fire-fighting equipment to use based upon the type, size, and conditions of a fire
- Demonstrate proper selection and use of fire-fighting and suppressant equipment, such as fire extinguishers type A, B, C, and D (mounted, cart, and hand-held halon, carbon dioxide, and powder), deluge systems, fire turrets, and nozzle operations
- Describe the difference between flash point and auto ignition
- Define the terms “upper and lower explosive limits” and explain the importance of knowing the actual values in a potentially hazardous situation

Handling Chemicals Safely

- Prepare the paperwork to replenish the stock of chemicals
- Clean laboratory glassware and equipment made of other materials, using appropriate solvents, detergents, and brushes or devices

- Read and interpret SOPs and MSDSs
- Use a chemical reference handbook to identify hazards associated with handling and storing chemical materials
- Classify chemicals according to health and safety hazards (flammables, corrosives, oxidizers, and carcinogens)
- Recognize and handle corrosive materials properly
- Store chemicals appropriately, recognizing the compatibility of the material being stored and the container in which they are being stored
- Handle and dispose of hazardous materials safely and according to regulatory guidelines
- Use mixing techniques appropriate for the materials, specifically when handling acids, bases, oxidizers, and strong reducing agents
- Assess safe handling procedures for a variety of volatile chemicals on the basis of vapor pressure
- Use appropriate techniques to transfer gases, liquids, and solids from storage containers to equipment used in the laboratory
- Identify the heating and ventilation systems used in chemical storage areas and compare their appropriateness for the groups of chemicals being stored
- Develop a chemical inventory system for a stockroom that includes all pertinent information regarding stability, hazards, and sensitivity

Handling and Working with Radioactive Materials

- Apply the appropriate special requirements for the handling and disposal of radioactive materials
- Apply the concept of half-life to predict potential hazards of radioactive materials
- Compare the hazards associated with various modes of radioactive decay
- Calculate the half-life of radioactive material using the first-order decay equation
- Choose the proper equipment for monitoring radioactive materials
- Calibrate equipment used for monitoring radioactive materials

Handling Laboratory Equipment Safely

- Describe the purpose of common chemical laboratory equipment and safe handling
- Demonstrate a basic awareness of electrical safety and its application to the work environment
- Manipulate and care for glassware and other apparatus safely, including making connections, cleaning, and storing
- Store, transport, and change compressed gas cylinders correctly and safely
- Choose the proper regulators for gases and other materials under pressure or under vacuum
- Describe how maintenance programs for equipment and laboratory facilities relate to safe and efficient laboratory operations
- Identify common components of electrical and electronic circuits that may frequently be maintained by laboratory technicians

- Use autoclaves, pressurized reactors, vacuum reactors/separators, closed systems, and a variety of valves for several chemical systems

Glossary of Acronyms

ACGIH	American Conference of Governmental Industrial Hygienists	FR	<i>Federal Register</i>
AHERA	Asbestos Hazard Emergency Response Act	HAZWOPER	Hazardous Waste Operations and Emergency Response
AIChE	American Institute of Chemical Engineers	HEPA	High-Efficiency Particulate Air (filter)
AIHA	American Industrial Hygiene Association	HMIS	Hazardous Materials Identification System
ALARA	As Low As Reasonably Achievable	IARC	International Agency for Research on Cancer
ANSI	American National Standards Institute	IDLH	Immediately Dangerous to Life and Health
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers	ISO	International Organization for Standardization
ASTM	American Society for Testing and Materials	MSDS	Material Safety Data Sheet
ATSDR	Agency for Toxic Substances and Disease Registry	MSHA	Mine Safety and Health Administration
BEI	Biological Exposure Index	NAS	National Academy of Sciences
CAA	Clean Air Act	NCI	National Cancer Institute
CAS	Chemical Abstracts Service	NEC	National Electrical Code
CCS	Committee on Chemical Safety	NFPA	National Fire Protection Association
CDC	Centers for Disease Control and Prevention	NIEHS	National Institute of Environmental Health Sciences
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act	NIH	National Institutes of Health
CFR	Code of Federal Regulations	NIOSH	National Institute for Occupational Safety and Health
CGA	Compressed Gas Association	NOAEL	No-Observed-Adverse-Effect Level
CHAS	Division of Chemical Health and Safety	NOEL	No-Observed-Effect Level
CHEMTREC	Chemical Transportation Emergency Center	NRC	Nuclear Regulatory Commission
CHO	Chemical Hygiene Officer	NRCC	National Registry of Certified Chemists
CHP	Chemical Hygiene Plan	NSF	National Science Foundation
CIH	Certified Industrial Hygienist	NTP	National Toxicology Program
CMA	Chemical Manufacturer's Association	OEL	Occupational Exposure Limit
CPSC	Consumer Product Safety Commission	OSHA	Occupational Safety and Health Administration or Act
CPT	Committee for Professional Training	OTA	Office of Technology Assessment
CSB	U.S. Chemical Safety and Hazard Investigation Board (a.k.a. Chemical Safety Board)	PEL	Permissible Exposure Limit
CSHEMA	Campus Safety, Health, and Environmental Management Association	PEL	Personal Exposure Limit
CSP	Certified Safety Professional	PPE	Personal Protective Equipment
CWA	Clean Water Act	RCRA	Resource Conservation and Recovery Act
DOE	Department of Energy	REL	Recommended Exposure Limit (NIOSH)
DOL	Department of Labor	SARA	Superfund Amendments and Reauthorization Act
DOT	Department of Transportation	SC3	EPA Schools Chemical Cleanout Campaign
EHS	Environmental, Health, and Safety	SCBA	Self-Contained Breathing Apparatus
EPA	Environmental Protection Agency	SCTF	Safety Culture Task Force
EPCRA	Emergency Planning and Community Right-to-Know Act	SOCED	Society Committee on Education
FDA	Food and Drug Administration	SOP	Standard Operating Procedure
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act	STEL	Short-Term Exposure Limit
		TLV	Threshold Limit Value
		TSCA	Toxic Substances Control Act
		TWA	Time Weighted Average
		VOC	Volatile Organic Compound
		WHO	World Health Organization

Bibliography

- ¹ Laboratory Safety Institute. The Lab Safety Memorial Wall. <http://labsafetyinstitute.org/MemorialWall.html> (accessed Sept 25, 2011).
- ² University of California, Los Angeles. Report to the Chancellor on UCLA Laboratory Safety, July 2009. <http://www.ovcr.ucla.edu/labsafety/july2009report.pdf> (accessed Oct 13, 2011).
- ³ Kemsley, J.; Baum, R., Ed. Texas Tech Lessons. *Chemical & Engineering News*. Aug 23, 2010, Vol. 88, No. 34, pp 34-37.
- ⁴ Van Noorden, R. A. Death in the Lab: Fatality Adds Momentum to Calls for a Shakeup in Academic Safety Culture. *Nature*. April 18, 2011, Vol. 472, pp 270-271.
- ⁵ International Atomic Energy Agency, Operation Safety Section (IAEA-TECDOC-1329), December 2002. Safety Culture in Nuclear Installations: Guidance for Use in the Enhancement of Safety Culture. http://www-pub.iaea.org/MTCD/publications/PDF/te_1329_web.PDF (accessed Feb 14, 2012).
- ⁶ Nuclear Regulatory Commission. Final Safety Culture Policy Statement (NRC-2010-0282). *Federal Register*. June 14, 2011, Vol. 76, No. 114, p 34773. Washington, DC: Government Printing Office.
- ⁷ Occupational Safety and Health Administration. Safety and Health Management System eTool, Module 4. Creating a Safety Culture. http://www.osha.gov/SLTC/etools/safetyhealth/mod4_factsheets_culture.html (accessed July 27, 2011).
- ⁸ Committee on Prudent Practices in the Laboratory. Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards: An Update. Washington, DC: National Research Council of the National Academies, National Academies Press, 2011.
- ⁹ Occupational Safety and Health Administration. Occupational Safety and Health Standards. Occupational Exposure to Hazardous Chemicals in Laboratories. http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=10106 (accessed Oct 13, 2011).
- ¹⁰ Hewitt, M. Vice President, Global Workplace Safety Practice. Strategies for Creating and Sustaining a Culture of Safety, 2008. http://www2.dupont.com/Consulting_and_Safety_Training_Campaign/en_US/content/CultureOfSafetyPresentation.pdf (accessed July 27, 2011).
- ¹¹ —. Relative Culture Strength: A Key to Sustainable World-Class Safety Performance, 2009. http://www2.dupont.com/Sustainable_Solutions/de_DE/assets/downloads/A_Key_to_Sustainable_World_Class_Safety_Performance.pdf (accessed July 27, 2011).
- ¹² Princeton University, Environmental Health and Safety. Laboratory Safety Manual. Policy Section: Workplace Health and Safety. www.princeton.edu/hr/policies/healthsafety/8.0.1/ (accessed Oct 13, 2011).
- ¹³ Krause, T. The Ethics of Safety. http://ehstoday.com/safety/best-practices/ehs_imp_67392/ (accessed Nov 30, 2011).
- ¹⁴ U.S. Chemical Safety and Hazard Investigation Board. Chemical Safety Board. <http://www.csb.gov>. (accessed Oct 23, 2011).
- ¹⁵ National Academies Press. Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards, Updated Version, 2011. http://www.nap.edu/catalog.php?record_id=12654 (accessed Aug 15, 2011).

- ¹⁶ Occupational Safety and Health Administration. OSHA Safety and Health Management Systems eTool. <http://www.osha.gov/SLTC/etools/safetyhealth/comp1.html> (accessed Oct 25, 2011).
- ¹⁷ International Labour Organization. Guidelines on Occupational Safety and Health Management Systems (ILO-OSH), 2001. International Labour Organization. http://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/publication/wcms_110496.pdf (accessed Feb 14, 2012).
- ¹⁸ American Chemical Society, Committee on Professional Training. Laboratory Safety Supplement to CPT Guidelines, Jan 2012. http://portal.acs.org/portal/PublicWebSite/about/governance/committees/training/acsapproved/degreeprogram/CNBP_029139 (accessed January 31, 2012).
- ¹⁹ —. Undergraduate Professional Education in Chemistry: ACS Guidelines and Evaluation Procedures for Bachelor's Degree Programs, Spring 2008. http://portal.acs.org/portal/PublicWebSite/about/governance/committees/training/acsapproved/degreeprogram/WPCP_008491 (accessed Feb 14, 2012).
- ²⁰ —. Development of Student Skills in a Chemistry Curriculum, Supplement to CPT Guidelines, March 2009. http://portal.acs.org/portal/PublicWebSite/about/governance/committees/training/acsapproved/degreeprogram/CNBP_025490 (accessed Feb 14, 2012).
- ²¹ —. Rigorous Undergraduate Chemistry Programs, Supplement to CPT Guidelines, Jan 2010. http://portal.acs.org/portal/PublicWebSite/about/governance/committees/training/acsapproved/degreeprogram/CNBP_024263 (accessed July 11, 2011).
- ²² —. Excellent Undergraduate Chemistry Programs, Supplement to CPT Guidelines, Jan 2010. http://portal.acs.org/portal/PublicWebSite/about/governance/committees/training/acsapproved/degreeprogram/CNBP_024262 (accessed July 11, 2011).
- ^{22a} American Chemical Society, Society Committee on Education. ACS Guidelines for Chemistry in Two-Year College Programs, Spring 2009. <http://www.acs.org/2YGuidelines> (accessed February 15, 2012).
- ²³ Hill, R. H.; Finster, D. *Laboratory Safety for Chemistry Students*. New York, NY: John Wiley and Sons, 2010.
- ²⁴ Alaimo, P. J.; Langenhan, J. M.; Tanner, M. J.; Ferrenberg, S. M. "Safety Teams: An Approach to Engage Students in Laboratory Safety." Division of Chemical Education, 2010, *Journal of Chemical Education*, Vol. 87, No. 8, pp 856-861.
- ²⁵ Chemical Safety Board. CSB to Investigate Laboratory Explosion at Texas Tech University Chemistry Department, Jan 19, 2010. <http://www.csb.gov/newsroom/detail.aspx?nid=301> (accessed July 27, 2011).
- ²⁶ Moran, L.; Masciangioli, T., Eds. *Chemical Laboratory Safety and Security: A Guide to Prudent Chemical Management*. National Academy of Sciences, 2010. <http://dels.nas.edu/resources/static-assets/bcst/miscellaneous/Chemical-Laboratory-Safety-and-Security.pdf> (accessed Aug 15, 2011).
- ²⁷ —. *Chemical Laboratory Safety and Security: A Guide to Prudent Chemical Management*, 2010. <http://dels.nas.edu/global/bcst/Chemical-Management> (accessed Aug 15, 2011).
- ²⁸ Alaimo, R. J., Ed. *Handbook of Chemical Health and Safety*. Washington, DC: Oxford University Press and American Chemical Society, 2001.

- ²⁹ American Chemical Society, Committee on Chemical Safety. *Safety in Academic Chemistry Laboratories: Accident Prevention for College and University Students*, 7th ed.; Washington, DC, 2003; Vol. 1.
- ³⁰ —. *Safety in Academic Chemistry Laboratories: Accident Prevention for Faculty and Administrators*, 7th ed.; Washington, DC, 2003; Vol. 2.
- ³¹ American Chemical Society, Division of Chemical Health and Safety. *Journal of Chemical Health and Safety*. Netherlands: Elsevier, Inc.
- ³² American Chemical Society, Division of Chemical Education. *Journal of Chemical Education*. <http://pubs.acs.org/journal/jceda8> (accessed Aug 15, 2011).
- ³³ American Chemical Society, Committee on Chemical Safety. http://portal.acs.org/portal/acs/corg/content?nfpb=true&pageLabel=PP_TRANSITIONMAIN&node_id=2228&use_sec=false&sec_url_var=region1&uuid=4126fb61-bd87-4ef8-a6c7-575620b4f887 (accessed Aug 15, 2011).
- ³⁴ Fur, A. K. *CRC Handbook of Laboratory Safety*, 5th ed.; 2000. ISBN: 9780849325236.
- ³⁵ Princeton University, Environmental Health and Safety. Laboratory Safety Manual. <http://web.princeton.edu/sites/ehs/labsafetymanual/index.html> (accessed Aug 15, 2011).
- ³⁶ Crowl, D. Laboratory Safety Course Resource. Department of Chemical Engineering, Michigan Technological University, Houghton, MI. <http://www.chem.mtu.edu/~crowl/LabSafetyResource.htm> (accessed Feb 14, 2012).
- ³⁷ Urban, P. G., Ed.; *Bretherick's Handbook of Reactive Chemical Hazards; Two Volume Set*, 7th ed.; Burlington, MA: Academic Press; 2006.
- ³⁸ Elsevier. *Hazmat Navigator*. http://www.elsevier.com/wps/find/electronicproductdescription.cws_home/724147/description#description (accessed Feb 14, 2012).
- ^{38a} The National Science Foundation, Responsible Conduct of Research, <http://www.nsf.gov/bfa/dias/policy/rcr.jsp> (accessed March 8, 2012)
- ³⁹ Hill, R. The Safety Ethic: Where Can You Get One? *Journal of Chemical Health and Safety*, 2003, Vol. 10, No. 3, pp 8-11.
- ⁴⁰ U.S. Chemical Safety Board Home Page. <http://www.csb.gov> (accessed Oct 25, 2011).
- ⁴¹ University of California, San Diego. Report a Safety Concern to Environment, Health, and Safety, 2011. <http://blink.ucsd.edu/sponsor/EHS/report-concern.html> (accessed July 27, 2011).
- ⁴² Hill, R. H.; Finster, D. C. Section 1.2.1 Rethinking Safety: Learning from Lab Incidents. *Laboratory Safety for Chemistry Students*. Hoboken, NJ: John Wiley and Sons; 2010, pp 1-21.
- ⁴³ U.S. Department of Energy. DOE Accident Investigation Program Electronic Reference Tool, Jan 2011. http://www.hss.doe.gov/sesa/corporatesafety/aip/docs/AI_Electronic_Toolbox_2011.htm (accessed Feb 14, 2012).
- ⁴⁴ Ferry, T. S. *Modern Accident Investigation and Analysis*, 2nd ed.; New York, NY: John Wiley and Sons, 1955.
- ⁴⁵ American Institute of Chemical Engineers, Center for Chemical Process Safety. *Guidelines for Investigating Chemical Process Incidents*, 2nd ed.; New York, NY: John Wiley and Sons, 2003.
- ⁴⁶ ABS Consulting, Inc. *Root Cause Analysis Handbook: A Guide to Effective Incident Investigation*. Brookfield, CT: Rothstein Associates, Inc.; 2005.

- ⁴⁷ Rooney, J.; Heuvel, L. V. Root Cause Analysis for Beginners, July 2004.
<https://webspace.utexas.edu/mae548/www/research/digital%20forensics/qp0704rooney.pdf>
(accessed July 11, 2011)
- ⁴⁸ Division of Chemical Health and Safety (DCHAS-L). American Chemical Society Division of Chemical Health and Safety.
http://www.dchas.org/index.php?option=com_content&view=article&id=31&Itemid=68
(accessed Feb 14, 2012).
- ⁴⁹ Mojtabai, F.; Kaufman, J., Ed. *Learning by Accident*. Natick, MA: Laboratory Safety Institute; 1977, Vol. 1.
- ⁵⁰ —. *Learning by Accident*. Natick, MA: Laboratory Safety Institute; 2000, Vol. 2.
- ⁵¹ Robertson, T.; Kaufman, J., Ed. *Learning by Accident*. Natick, MA: Laboratory Safety Institute; 2003, Vol. 3.
- ⁵² American Industrial Hygiene Association, Laboratory Health and Safety Committee. Laboratory Safety Incidents.
<http://www.aiha.org/INSIDEAIHA/VOLUNTEERGROUUPS/LABHANDSCOMMITTEE/Pages/LaboratorySafetyIncidents.aspx> (accessed Feb 14, 2012).
- ⁵³ Princeton University, Environmental Health and Safety. Laboratory Safety Manual Section 11: Anecdotes. <http://web.princeton.edu/sites/ehs/labsafetymanual/sec11.htm> (accessed Oct 10, 2011).
- ⁵⁴ University of Arizona, Risk Management and Safety. Chemical Safety Bulletins.
<http://risk.arizona.edu/healthandsafety/chemicalsafetybulletins/> (accessed Oct 10, 2011).
- ⁵⁵ U.K. Chemical Reaction Hazard Forum. Incidents. <http://www.crhf.org.uk/index.html>
(accessed Oct 10, 2011).
- ⁵⁶ University of California, San Diego. Health and Safety Coordinating Council. Vice Chancellor–Resource Management and Planning Departments.
<http://blink.ucsd.edu/sponsor/VCRMP/health-safety.html> (accessed Feb 14, 2012).
- ⁵⁷ University of California, San Diego. Chemical Safety and Surveillance Committee. Vice Chancellor–Resource Management and Planning Departments.
<http://blink.ucsd.edu/sponsor/VCRMP/chemical.html> (accessed Feb 14, 2012).
- ⁵⁸ Heath, C.; Heath, D. *Switch: How to Change Things When Change Is Hard*. New York, NY: Crown Publishing, 2010.
- ⁵⁹ University of California, San Diego. Blink Safety Topics. <http://blink.ucsd.edu/safety/>
(accessed Oct 25, 2011).
- ⁶⁰ Alaimo, P. J.; Langerhan, J. M.; Tanner, M. J.; Ferrenberg, S. M. “Safety Teams: An Approach to Engage Students in Laboratory Safety.” *J Chem Ed*. 2010, Vol. 87, No. 8, pp 856-861.
- ⁶¹ Kemsley, J., *Undergraduate Laboratory “Safety Teams,”* The Safety Zone. CEN Blog.
<http://cenblog.org/the-safety-zone/2010/07/undergrad-laboratory-safety-teams/> (accessed Nov 30, 2011).
- ⁶² Princeton University, Environmental Health and Safety. Laboratory Safety Manual Section 11: Anecdotes. <http://web.princeton.edu/sites/ehs/labsafetymanual/sec11.htm> (accessed Feb 14, 2012).
- ⁶³ Princeton University, Environmental Health and Safety. Laboratory Safety Manual Section A2: Accident Investigation Procedure.
<http://web.princeton.edu/sites/ehs/healthsafetyguide/a2.htm> (accessed Nov 30, 2011).

⁶⁴ Texas State Technical College, Waco. Chemical Technology. <http://chemtech.org/> (accessed Oct 25, 2011).