MARY KAY O'CONNOR PROCESS SAFETY CENTER
TEXAS A&M ENGINEERING EXPERIMENT STATION

19th Annual International Symposium
October 25-27, 2016 • College Station, Texas

Challenges in applying Process Safety Management at a University Laboratories

Tomasz Olewski[1], Mike Snakard[2] and Luc Vechot[1]
[1]Mary Kay O'Connor Process Safety Centre – Qatar, Texas A&M University at Qatar, PO Box 23874, Doha, Qatar
[2]Snakard Group, Inc., PO Box 86, Gainesville, Virginia, 20156, USA
Corresponding author: tomasz.olewski@qatar.tamu.edu

Abstract
Risks associated with academic research are often perceived as being much lower than risks within large-scale process industry operations. While the inventories of hazardous materials are generally lower within an academic environment and the number of other hazards may be lower, factors such as materials of construction typically used in laboratories, and the proximity of researchers to their equipment push risks to the individual disproportionately higher. The number of reported lab accidents worldwide that have resulted in fatalities, severe personnel injury, and financial loss demonstrates that there is a need to better risk management practices within academic teaching and experimental research labs. This need was very strongly emphasized by the US Chemical Safety Board following their investigation of major fatal laboratory accidents in the previous years.
Risk management within academic laboratories starts with developing a solid understanding of the concepts of *Hazard* and *Risk.* For people outside the safety and process safety industry, there is a lack of distinction between these two terms. While *Hazard* corresponds to the potential for harm (usually independent of scale), *Risk* is related to the combination of the likelihood of a hazard scenario occurring and the severity of the consequence, should the scenario occur and is typically expressed in terms of impacts to People, Assets, Environment, and Company Reputation. The more layers of protection (controls, prevention measures and mitigations methods) in place to prevent and manage the hazard scenario and the higher the reliability of each layer, the lower the likelihood, and / or severity and thus the lower the risk.
A variety of different hazards exist within university academic and research laboratories, and the risks associated with the experiments being undertaken within these labs can be significant if not properly managed. Yet, the misperception that university labs are "low risks" and "inherently safer" still remains within and outside academia, in part due to a lack of hazard awareness.
This work discusses a proven approach to applying the principles of process safety management, widely used in the process industry, to teaching and research laboratories within an academic environment through selected challenges and examples.

Introduction

Implementing a risk management system within universities is a fairly uncommon concept and unfortunately rose after a series of high-profile serious and fatal accidents that happened at the universities over the past few years. Sadly, history has shown that universities are not exempt from catastrophic accidents involving process operations and the lack of process hazards awareness has led to financial losses, property damage, environmental disasters, injuries and, most important, fatalities. The U.S. Chemical Safety and Hazard Investigation Board (CSB) identified 120 university laboratory incidents between 2001 and 2011 (CSB 2011). The Lab Safety Memorial Wall collected by Lab Safety Institute summarizes some of the reported fatal accidents at laboratories all over the world. Since 2000, there were 49 fatalities reported in 34 accidents in laboratories, of which 23 accidents were in US and 11 at universities (Lab Safety Institute 2015). Still, the risks associated with academic research are often perceived as being much lower than risks within large-scale process industry operations. While it might be true that number of hazards or quantity of hazardous materials is smaller at the universities, the number of reported lab accidents worldwide that have resulted in fatalities, severe personnel injury and financial loss demonstrates that there is a need to better hazard identification and risk management practices within academic teaching and experimental research labs. These risk management practices must go beyond the traditional management of chemical exposure or slip, trip and fall hazards and need to include the identification and management of hazards from the process. Academic institutions need to learn from industry and incorporate process safety management into the teaching and research lab environment. In other words, academic and research laboratories and universities must develop and implement an Occupational Health and Safety Management System (OHSMS) covering the elements recognized as industry best practice, adjusted to fit the local environment, verified and continuously improved. This need was very strongly emphasized by the U.S. Chemical Safety and Hazard Investigation Board (CSB) following their investigation of major fatal laboratory accidents in the previous years (CSB 2011) and also recognized by some universities as the response to CSB reports (Mulcahy et al. 2013).

There is little doubt that universities have been slow to apply process safety management principles to manage the risk of experimental processes, and at the same time, focusing on quality accreditation or environmental management. However, once one realizes that many of the same processes are present within an industry, where they are managed by the process safety management principles, the concept becomes much more logical. It is at this time that the gap resulting from the absence of process safety management practices is so evident that addressing the risk becomes the highest priority in the lab. The risk management should be a definitely higher priority than the environmental or quality management, production, operation, teaching, and research, above any other management system, and actually, it goes together with others, to help them and make them exist. In fact, international standards for an OHSMS, such as the British Standard OHSMS 18001 (British Standards Institution 2007) or American National Standards Institute Z10 (American National Standards Institute (ANSI) 2012), are aligned with well-known quality or environmental management international standards (Manuele 2014; British Standards Institution 2008; Toy & Dotson 2013) and thus these systems can be easily integrated to manage environmental, health and safety risks.

Philosophy of the Safety Management Systems

Safety Management System (SMS) is often confused with occupational safety regulations developed to protect personnel against work place injuries. One of the elements of these regulations is the provision for personnel protective equipment, which within the lab, is directly linked to wearing safety glasses, lab coats, and gloves. The focus of traditional SMS is on personal protective equipment, which is important for protecting personnel in the event of an accident, but does nothing to reduce the likelihood of the incident occurring nor does it reduce the magnitude of the event. This focus on occupational safety can lead to a false sense of security and does not engage the lab personnel in a critical assessment of hazards within the laboratory process; a critical first step in managing risk at any level. The elements of a Safety Management System cover an extensive spectrum of safety, occupational health hazard identification and risk management practices designed within an integrated program for the prevention of major accidents. History has shown many times that organizations may be excellent at occupational safety, showing millions working hours without injuries, and yet experience a major accident. This distinction has been recognized in the industry and must now be recognized within research laboratories and universities. Continuous identification of hazards, risk analysis and control of major accident hazards, is required within universities to implement inherently safer designs when possible, implement engineering and administrative controls designed to prevent process safety accidents from occurring and reducing the consequence of such events, should they occur. It is also important to understand that process safety review is not a one-time activity. Process safety is rather about combining the operation of our labs with the developed safety systems in a way the distinction between operations and safety is forgotten and replaced the concept of safe-operation. When this concept of safe-operation is applied, it is not possible to do one without the other.

All the elements of process safety should be integrated into our normal operating practices and continuous safety improvement is not only seen as a way to avoid accidents and losses but as a way of improving the quality and repeatability of experimentation process. Safety measures are implemented for their benefits to the experimentation process and not solely in response to a regulatory requirement. This is when we know that we are on a path towards the zero accident goal.

Safety Management System may be, and perhaps should be, built based on the concept of a Plan-Do-Check-Act (PDCA) model. PDCA is a well-known business method for the control and continuous improvement of processes and products and utilized in existing Occupational Health and Safety Management System (OHSMS), and other “non-safety” related standards such as:

- British Standard 18001 (British Standards Institution 2007)
- American National Standards Institute Z10 (American National Standards Institute (ANSI) 2012)
- International Organization for Standardization: quality ISO 9000 (International Organization for Standardization (ISO 9001) 2008)
- Environmental ISO 14000 (International Organization for Standardization (ISO 14001) 2004),

OHSMS 18001 and ANSI Z10 are system-oriented, rather than compliance-oriented, standards. They do not focus nor give details of the solutions and rather provide a framework to be implemented in an organization. The organization can demonstrate its adherence to the standard through the processes it develops and implements across the organization to manage safe-operations and control residual risks to acceptable levels. In a sense, the mentioned OHSMS share the philosophy of European Seveso directives (European Union 2012) for the prevention of major accidents in the industry.

"Plan" means that the objectives and the whole system, all processes have to be carefully developed and there is no action at the organization without planning, meaning there is no ad-hoc solution. Planning also needs to include the commitment of the top management to go beyond compliance to legal requirements, describe all personnel roles and responsibilities, and involve employees into safety related activities emphasizing that everybody is responsible safety.
Once all planning is ready, all plans have to be implemented and performed, which is the "Do" part. At university, it corresponds to all actions undertaken to execute and perform teaching and research activities in laboratories. The system has to ensure that measurement and collection of useful and meaningful data to be subsequently used. Data collection should not only include incident and close-call investigations but also early detection of deviation from normal operation and other safety performance indicators, which can be used for further analysis.
The next step is to "Check", which means to perform inspections at the operation, review the system and analyze all data, compare them against expected outcome and learn from those.
The following step is to "Act", which does not necessarily mean to immediately correct the deviation, but consist in proposing changes, adjustments, and corrections and then go for planning ("PLAN") before they can be implemented and done ("DO").

Process Safety management challenges at the university

As discussed above, the general perception is that risks associated with the operation of university research labs are lower than the risks associated with the operation of large-scale process plants. This general perception typically comes from the belief that university labs contain fewer and smaller inventories of hazardous materials, university processes operate on a smaller scale and thus are more simple and easier to operate. While many of these beliefs may be true, there are numerous other lesser understood factors that lead to many high risks to the individual. These include, but are not limited to the following:

- Close proximity to the operating equipment. Often researchers are within a few meters of the operating equipment and typically closer than that when collecting experimental data, industry personnel are typically several meters away or housed in a control;
- Researchers in close proximity to the operating equipment for longer periods of time, more so than is typical for industry;
- University research labs are often involved in the development of new technologies and do not have proven designs to build from; and
- Due to the nature of using students to operate the research laboratories, the turnover of operating personnel is frequent and the sharing of process safety knowledge during a formal handover often does not exist.

All of these issues must be identified and managed in a structured way and the development of an OHSMS will provide a mechanism through which employees and students know the system that they have to follow. Circumstances within the university create a complex system that can lead to many challenges. The sections below provide a high-level summary of some of the key issues identified in building an effective safety management system at the university.

Leadership commitment

The key to an effective safety management system (SMS) is the presence of a strong safety culture and a strong safety culture cannot be present without leadership commitment to safety. At the university level, this means a commitment from the dean's office as well as the program chairs. Without this commitment, the effectiveness of the safety management system will be limited. The leaders have to recognize the need to apply SMS as the structured way to run the hazardous operations and, equally important, they must provide necessary resources to run the system and ensure safe operation. If adequate resources cannot be provided the risk cannot be managed to an acceptable level. The need for SMS may be sometimes hard to understand, providing resources may meet financial limitations, but even harder is to understand that overall the leaders are responsible for safety at the university laboratories, not the HSE office only, and if we cannot operate safely, at broadly acceptable risk levels, we should not be operating at all. Frequent safety meetings, discussions about safety and one on one discussions with students asking about the hazards of their experiments and the safeguards they put in place to manage those hazards are excellent ways management can demonstrate the organization's commitment to safety.

Leadership is not only the top management, deans or program chairs. The leaders are also all faculties as they almost all represent separate research group, with different goals and many times different hazards, which may cross from chemicals, high pressures, temperatures, through moving parts up to research on the human subject. All faculties and principal investigators have to recognize that they are not only responsible for their research outcome, but also for the safety of the research operations. To emphasize, the principal investigators, usually professors, are operators of the research and thus has responsibility for research outcomes. Their role is also to ensure that all operations are conducted safely. While the professors are very highly educated and experts in their respective research areas, they may have a limited knowledge of safety and process safety principles, and may correlate safety to regulatory compliance or wear the personal protective equipment (PPE) only. Thus they need support and training.

Unfortunately, many times principal investigator may not feel to be responsible for the safety and tend to believe that the Safety department of the organization bears the full responsibility for lab safety. The Health, Safety and Environment (HSE) department personnel often has the right level of expertise in safety management, hazards identification, risk assessment, safety regulations and PPE, and these are areas where can and have to support researchers. However, HSE experts usually cannot have the same detailed scientific or technical knowledge about the design or reliability of a research setup as a principal investigator or researcher. Therefore, it is necessary to establish a close cooperation between safety departments and principal investigators/researchers/professors to merge and exchange the knowledge. The principal investigator can provide the knowledge about the design and potential hazards of the operation and have to learn how to assess the associated risks and control them at the acceptable level. The HSE department can provide the knowledge about hazards identification and risk assessment methodology, help to establish the risk acceptance criteria and evaluate it, and have to learn about the design and technical specification of the equipment to understand and assess the resilience of the research setup to failure. All are responsible for safety, together. Only such good symbiosis ensure reliable and safe systems and reduce the risk to acceptable level.

There is one more, and very important, the benefit of such close collaboration: the leaders, the faculties, and HSE experts give good examples to younger, less experienced researchers, conveying the message that safety matters, which greatly increase safety culture of the organization and develop the safety culture of the younger generation.

Faculty members could also share good safety practices through participation in safety training together with young researchers and discussion of safety issues. Safety related discussion can be short, but their frequency is of central importance. For example, a good practice would be to start every research group meeting with a short safety discussion.

Risk Assessment

An important element of safety management system (SMS) planning is to develop the hazard identification and risk assessment methodologies to be used and establish corresponding risk acceptance criteria at the organizational level. It seems to be necessary that risk assessment at such complex organization like a university or research laboratory has to be done utilizing a structured method rather than an ad-hoc expert evaluation. Once developed, staff and students must be trained to identify potential hazards within their labs and understand how best they can mitigate the risks following the concepts of the hierarchy of risk control.

A variety of different hazards exist within university academic and research laboratories, and the risks associated with the experiments being undertaken within these labs can be significant if not properly managed. The risk is the product of likelihood and severity, and while this seems to be a very straightforward concept, its implementation requires a lot of thoughts. What experience should a student or a faculty member draw on to predict consequence and likelihood of an incident they never thought possible? Given this possible lack of process safety knowledge, it is important to provide a prescriptive solution.

The severity of the consequences seems to be straight forward, however, the key and the challenging element are to correctly recognize how severely the hazard can potentially harm: small amount of highly toxic chemical may potentially harm as much as the big amount of less toxic or high pressure. Unfortunately, history has shown many times that small amount of chemical or "small hazard" killed or seriously injured people (CSB 2011). The "amount" of hazard is usually not important and one should focus on the identification of the severity of the consequences, and at the university, the consequences to people are the most important.

The second term, the frequency or likelihood of a potential accident scenario can be, and often is, closely related to a number of barriers that minimize the likelihood of the hazardous event. The common mistake is to assume that we do not need barriers because such accident never happened or is very rare at our organization and outside. It has to be understood and agreed that "*never happened*" does not mean "*will not happen*". Starting from this clarification, the need for safety barriers and the layers of protection becomes clear. The more layers of protection (controls, prevention measures and mitigations methods) in place and the higher the reliability of each layer, the lower the likelihood of the potential accident. Although it should be noted that in some cases the protection layer can also reduce the severity of the consequences, for instance, application of safer design such as working at lower pressure may reduce, both, the severity as well as the likelihood of a potentially hazardous event.

Researchers, inexperienced in process safety, who are required to perform a risk assessment, require a simple and easily understandable risk assessment tool. The tool must provide clear instructions and require a low level of resources to be used. As far as hazards identification is considered, it seems that most of the laboratory cases can be effectively covered by what-if/checklist or preliminary hazard analysis methods. Both of them can be prepared with the list of potential issues or list of hazards that help in a systematic way to go through potential accidents scenario. More sophisticated methods like HAZOP may be required on a case by case basis when a research setup involves complex processes and equipment.

Considering risk assessment, it is obvious that fully quantitative risk assessment is too sophisticated and unrealistic to be performed for the vast majority of research laboratories due to limited human resources, lack of consequence's models to simulate small releases and lack of information on equipment and setup reliabilities. The authors suggest a simple 4x4 or 4x5 risk matrix supported by simple definitions for severity and a likelihood definitions utilizing layers of protection approach to be the suitable methodology at the university level.

Procurement and Contractors

Procurement is very important part of safety management system as the first step of the cycle to handle any chemical or equipment. Monitoring of the procurement is a good measure to identify incoming hazardous chemicals, equipment or experimental setup being built. At university, experimental setup may be built for short term use only, at a pace set by the frequent change in research topics. This is a common characteristic in many research laboratories. Unfortunately, this need for the short-term usage of some experimental setup may lead a researcher to buy cheap, low-quality material or equipment which may generate higher risk or unsafe conditions. In fact, the lowest price is many times a determining criterion for the equipment or contractor selection at many organizations (industry and academia). Whereas an equipment has to usually meet minimum technical requirements, it seems to be uncommon that the defined requirements include reliability or safety criteria. One should make sure that purchased equipment meet minimum safety technical requirements following current safety standards. When off the shelves equipment are bought from recognized and well-known vendor with a good reputation, it is usually expected that the equipment meets the adequate safety requirements. When equipment or experimental setup are custom built or “home-made” ensuring that the final product meets minimum safety requirements is more challenging.

Using the lowest price criterion in the case of custom built equipment may be very risky. Instead, the price criterion, vetting, and selection of the vendor/contractor should be carefully done based on the company quality and, very important, safety reputation of the company. These could be potentially vetted considering the vendor’s experience in manufacturing similar equipment, the opinion of previous investors, the review of vendor’s quality and safety management system and its safety performances, and finally by onsite inspection of the vendor’s manufacture or workshop. The contracting authority could audit the vendor’s safety management system and assess its personnel safety awareness during this inspection. The contractors, especially contractors performing critical operations should be required to have quality and safety management system and shall demonstrate quality and safety performance, which should be at least as good as the one of the investor.

Although it is understandable that the investor’s budget is limited, especially at the universities, it should be recognized that the cost of the equipment or service is also correlated to the cost of the maintenance and to the decommissioning cost. A low initial purchasing price does not necessarily mean a lower long-term price considering the entire lifecycle of the equipment or experimental setup. A problem arises when the researchers are not certain about the duration of the research or when “temporary” set or equipment become “permanent” ones, not to mention that the decommissioning cost is usually not considered at all, at the time of procurement. It seems that regarding the prediction of the equipment usage, maintenance and decommissioning, planning can be improved at the university as well.

The development of an equipment specification prior to the placement of an order set the minimum requirements of the equipment against which competing bids can be compared and evaluated to eliminate those that are not technically acceptable. Furthermore, the establishment of procurement procedures that require vendors to submit equipment data sheets, technical specifications, and when applicable, operating procedures for all equipment will help ensure that equipment is operated within acceptable limits.

Safety competence, awareness, and training

One of the issues that have to be taken care of at university is a very high turnover of personnel / students employed for short term only. This may be the case of personnel involved in experimental work and directly exposed to the hazards, for instance, post-doctoral researchers working for a year or two, student workers working for a maximum two to three semesters. The situation tends to be better with faculty members who usually stay with the university for many years. Although, in some instances, frequent turnovers within the faculty population or within the leadership of a university may occur. Short term employment and high turnover rate reduces the capacity of an institution to develop and safety corporate memory, knowledge and experience and can thus potentially weaken the reliability of the safety system to prevent incidents and the resilience of the organization. Short term employment often means that by the time an employee is properly trained and develop experience in safety working practices the employee has to leave the organization.

In addition, usually for relatively young and inexperienced employees (new postdoctoral researchers, new students) the expectations for safety competence at the time of employment cannot be high, thus even more appropriate education and training is required. The verification of experience and the quality of education and training becomes very critical. The employer should identify the training needs of new employees at the time of the appointment of the new employee. In class, practical education, learning by doing, should be in favor over very convenient and, unfortunately, popular in recent days, on-line training. While the authors are not claiming that online training are not good, they see them as lower quality than training and discussion in class. Perhaps the good balance between on-line and in-class the number of training needs to be found. It is understandable that on-line training may reduce costs (at least in the short term as safety training related costs are a long term investment) and can be applied to the large number of employees in a relatively short time, which is an advantage over a class one. However, it should be clear that they are in many instances less effective and may never substitute in-class experience, face to face interaction with a qualified trainer and learning via practical exercises and by doing. Some good discussions and good examples of practical safety training and education at universities can be found in the literature (Véchot et al. 2014; Shallcross 2014; Olewski et al. 2015).

There is one observation noted during the training that is worth to share. Performing in-class training in front of an audience composed of a technical specialist in specialized areas (e.g. recognized professors, experienced technical staff and researchers) may be a challenging activity particularly when the expectation is that the same level of technical knowledge from the safety specialist/trainer is necessary to discuss safety issues in their respective areas.

Sometimes, very knowledgeable and experienced people may hardly accept weaknesses and recognize the need to learn and may resist changes. Sometimes the message is better communicated to them and a better quality training is achieved when the training is provided by senior personnel.

Closing remarks

For universities, embarking on the safety journey through the development and implementation of safety management systems, under the impulse and with the strong commitment of the university leadership, can lead to a significant improvement of safety culture and safety performances.

Top leadership at the university has a key role to play in conveying the message that safety is not the sole responsibility of a safety department but a truly shared responsibility. Major efforts must be made by the top leadership to establish a working environment where safety goes beyond compliance and where everyone has a clearly defined role to play in the safety system.

The improvement of competences through extensive and adapted hazard awareness and risk assessment training programs is key to ensure that university personnel has the necessary tools to identify the hazards, evaluate the risks, and reduce the risk to acceptable level. Risk tolerance criteria need to be clearly defined at the university level. Upgrading procurement processes based on accepted process safety management practices is a significant contributor to the control and reduction of risks in the laboratories.

There are no doubts that there are more challenges to the development and application of safety management system principles to university laboratories than listed and discussed in this paper. The ones mentioned here were identified by the authors as some of the key factors in the successful implementation of safety management systems at university, that, they feel, need to be shared with others.

References

American National Standards Institute (ANSI), 2012. *Occupational Health and Safety Management Systems*, USA: American Society of Safety Engineers (ASSE).

British Standards Institution, 2008. *Occupational health and safety management systems - Guidelines for the implementation of OHSAS 18001:2007* 2008th ed.,

British Standards Institution, 2007. *Occupational health and safety management systems - Requirements* 2007th ed., BSI Standards Publication.

CSB, 2011. *Texas Tech University Laboratory Explosion*, Washington, DC: Office of Congressional, Public, and Board Affairs.

European Union, 2012. *Seveso III Directive: DIRECTIVE 2012/18/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC* 2015th ed.,

International Organization for Standardization (ISO 14001), 2004. *Environmental management systems - Requirements with guidance for use*,

International Organization for Standardization (ISO 9001), 2008. *Quality management systems - Requirements*,

Lab Safety Institute, 2015. The Lab Safety Memorial Wall. *webpage*. Available at: http://labsafetyinstitute.org/MemorialWall.html [Accessed July 22, 2015].

Manuele, F.A., 2014. ANSI / AIHA / ASSE Z10-2012. An Overview of the Occupational Health & Safety Management Systems Standard. *Professional Safety*, 59(4), p.44.

Mulcahy, M.B. et al., 2013. College and university sector response to the U.S. Chemical Safety Board Texas Tech incident report and UCLA laboratory fatality. *Journal of Chemical Health and Safety*, 20(2), pp.6–13.

Olewski, T. et al., 2015. Building process safety culture in a research laboratory: A case study on experimental research at Texas A & M University at Qatar. In *Hazards Asia Pacific symposium*. pp. 1–9.

Shallcross, D.C., 2014. Safety shares in the chemical engineering class room. *Education for Chemical Engineers*, 9(4), pp.e94–e105.

Toy, V. & Dotson, K., 2013. ANSI/AIHA/ASSE Z10. A Standard for Every Organization. *Professional Safety*, 58(7), pp.26–27.

Véchot, L.N., Casson, V. & Olewski, T., 2014. Training future engineers to be committed to safety. *QScience Proceedings*, pp.1–8.