

## Texas Tech University Laboratory Explosion

No. 2010-05-I-TX

### ISSUES

- Laboratory safety management for physical hazards
- Hazard evaluation of experimental work in research laboratories
- Organizational accountability and oversight of safety



## 1.0 INTRODUCTION

On January 7, 2010, a graduate student within the Chemistry and Biochemistry Department at Texas Tech University (Texas Tech) lost three fingers, his hands and face were burned, and one of his eyes was injured after the chemical he was working with detonated. The Chemical Safety Board (CSB) investigated and found systemic deficiencies within Texas Tech that contributed to the incident: the physical hazard risks inherent in the research were not effectively assessed, planned for, or mitigated; the university lacked safety management accountability and oversight; and previous incidents with preventative lessons were not documented, tracked, and formally communicated. The lessons learned from the incident provide all academic institutions with an important opportunity to compare their own policies and practices to that which existed at Texas Tech leading up to the incident.

Looking beyond Texas Tech, the CSB identified a lack of good practice guidance recognized by the academic community; limitations in using the Occupational Safety and Health Administration's (OSHA) Occupational Exposure to Hazardous Chemicals in Laboratories Standard (29 CFR 1910.1450) as guidance for mitigating physical hazards in the laboratory; and a missed opportunity for a granting agency to influence safety practices. While a vast number of references, standards and guidelines have been developed to describe and promote different types of hazard evaluation methodologies in an industrial setting, similar resources that address the unique cultural and dynamic nature of an academic laboratory setting have not been generated. Good-practice guidelines would provide universities a metric to evaluate their current hazard evaluation procedures against, or for schools with none in place, would enable a more rapid process for their development. If universities choose to use OSHA's Laboratory Standard as guidance for developing a plan to mitigate chemical hazards, they need to understand that the standard was not created to address physical hazards of chemicals, but rather health hazards as a result of chemical exposures. Physical hazards though, as evidenced in the Texas Tech incident and the 2008 laboratory fire that resulted in the death of a staff research associate at University of California, Los Angeles (UCLA), are deserving of similar attention to that given to health hazards. Finally, the granting agency, which provides funding for the research and thus maintains a level of control and authority over the researchers, did not prescribe any safety provisions specific to the research work being conducted at Texas Tech until after the incident occurred.

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## 2.0 BACKGROUND

Texas Tech includes 11 colleges, a School of Law, and more than 160 Master's and doctoral degree programs. It has a student population of over 31,500 and maintains a Carnegie Foundation Classification as a doctoral research-extensive university.<sup>1</sup> Within the Department of Chemistry and Biochemistry (Chemistry Department), there are approximately 140 graduate and postdoctoral researchers, 225 undergraduate students, 26 faculty, and 19 staffers. At the time of the incident, the campus included 368 laboratories; 118 were part of the Chemistry Department.



## 3.0 PRE-INCIDENT EVENTS

In October 2008, Texas Tech entered into a subcontract agreement with Northeastern University (NEU) to participate in a program titled “Awareness and Localization of Explosive-Related Threats” (ALERT), which was (and continues to be) funded by the U.S. Department of Homeland Security (DHS).<sup>2</sup> Texas Tech’s research focus is the detection of energetic materials that could represent a future security threat and includes synthesizing and characterizing new potentially energetic materials.<sup>3</sup> NEU and University of Rhode Island lead the ALERT program, which includes Texas Tech and several other academic partners.<sup>4</sup>

The terms of the subcontract agreement between NEU and Texas Tech were intended to provide maximum scientific freedom to Texas Tech while remaining consistent with the overall objectives of the ALERT program and DHS regulations. Both the cooperative agreement between DHS and NEU and the subcontractor agreement between NEU and Texas Tech

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<sup>1</sup>Carnegie Foundation Classification, [http://classifications.carnegiefoundation.org/lookup\\_listings/institution.php](http://classifications.carnegiefoundation.org/lookup_listings/institution.php), accessed 8/4/11, and Texas Tech University Institutional Fact Summary, [http://www.ors.ttu.edu/News/newhome/Proposal\\_preparation/Boilerplate.pdf](http://www.ors.ttu.edu/News/newhome/Proposal_preparation/Boilerplate.pdf), accessed 8/4/11.

<sup>2</sup>ALERT’s stated mission is to “conduct transformational research, technology and educational development for effective characterization, detection, mitigation and response to the explosives-related threats facing the country and the world.” <http://www.northeastern.edu/alert/mission/>, accessed 8/4/11.

<sup>3</sup>As defined by *Rock Blasting and Explosives Engineering* (1994), “energetic material is mostly used to comprise all materials that can undergo exothermal chemical reaction releasing a considerable amount of thermal energy (emphasis in original).” An explosive energetic material is one that creates a high pressure shock wave when the products rapidly expand in volume.

<sup>4</sup><http://www.northeastern.edu/alert/>, accessed on 9/1/2011

stipulated a number of research practices that required pre-approval of research protocols by various committees before work could begin.<sup>5</sup> However, pre-approval of experimental protocols for the energetic work being conducted at Texas Tech was not required.

The injured Texas Tech student, in his fifth year of graduate study at the time of the incident, began working on the ALERT project about a year prior to the incident. None of the graduate student's previous work had been with energetics, thus when he began the project, he had to learn new techniques and methods. The graduate student did not receive any formal training for working with energetic compounds, but he stated to the CSB that he independently completed a literature review prior to beginning work to familiarize himself with similar energetic compounds. Safety restrictions, such as a 100 milligram limit on the amount of compound permitted to be synthesized, were verbally communicated by the two Principal Investigators (PIs)<sup>6</sup> of the research to some students. It was assumed senior graduate students would transmit the information to newer group members; however, no formal documentation system was in place to ensure that such information was effectively communicated to students and/or that students understood the information. Consequently, none of the students the CSB interviewed as part of its investigation, including those directly involved in the incident, stated they were aware of a strict 100 milligram limit. Instead, students indicated to the CSB they believed they should work with "very small amounts," on the order of 200 to 300 milligrams.

## 4.0 INCIDENT DESCRIPTION

Beginning about a month prior to the January 7 incident, the fifth-year graduate student and a first-year graduate student he was mentoring began synthesizing a nickel hydrazine perchlorate (NHP) derivative.<sup>7</sup> The amounts of NHP synthesized were on the order of 50-300 milligrams. Typical analytical techniques used in the laboratory to characterize the energetic properties of new compounds included differential scanning calorimetry (DSC),<sup>8</sup> drop hammer tests,<sup>9</sup> and thermal gravimetric analysis (TGA).<sup>10</sup> Due to the amounts of compound needed to run each analytical test,<sup>11</sup> the students synthesizing the NHP decided they would need to make several batches of the compound to fully characterize it; additionally, they had concerns of reproducibility between batches. They wanted to synthesize a single batch of NHP that would provide enough compound to complete all the necessary characterizations; thus, they decided to scale-up the synthesis of NHP to make approximately 10 grams.<sup>12</sup> The PIs of the research were not consulted on the decision to scale up. No written policies or procedures existed at the laboratory, departmental, or university levels which

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<sup>5</sup>The research practices requiring pre-approval of protocols included protection of human subjects, care and treatment of laboratory animals, and recombinant DNA and refer to the National Institute of Health's (NIH) Institutional Biosafety Committee (IBC). NIH states that as part of a PI's general responsibility, the PI (i.e. professor in charge of the research) should provide laboratory research staff with protocols describing potential biohazards and necessary precautions ([http://oba.od.nih.gov/rdna\\_ibc/ibc.html](http://oba.od.nih.gov/rdna_ibc/ibc.html), accessed on 8/4/2011)

<sup>6</sup>The PI is responsible for the conduct of scientific or educational research and the publication of its results. At a university, the PI is typically a professor in charge of the research, students, postdoctoral researchers, and technicians working in the laboratory.

<sup>7</sup>The events leading up to the January 7 incident were documented mainly with interviews conducted by the CSB because little written documentation was available. Laboratory notebooks were not dated and did not always indicate amounts of reactants used during synthesis.

<sup>8</sup>A technique that detects the absorption or release of heat of a sample as it is heated at a constant rate.

<sup>9</sup>Drop hammer tests can be used as a qualitative means to determine if a material can be safely handled with reasonable care by comparing relative impact sensitivities to those of known explosive materials.

<sup>10</sup>TGA is a technique detects the change in weight of a sample as a function of temperature or time.

<sup>11</sup>The laboratory protocols for DSC and TGA recommend 2 and 10 milligrams, respectively, although interviews indicated that closer to 20 milligrams were used for the TGA tests. The drop hammer tests require more sample, between 15 and 20 milligrams per drop, and several tests at various hammer heights to obtain meaningful data.

<sup>12</sup>The actual amount synthesized on the day of the incident is unknown since the product was never weighed.

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would have required the students to consult with the PIs before making this decision. Based on experience, the two students had discovered that smaller amounts of the compound would not ignite or explode on impact when wet with water or hexane, and they assumed the hazards of larger quantities of NHP would be controlled in a similar manner.

After the scale-up, the more senior student observed clumps in the product, and believed uniform particle size of the sample was important. As a result, he transferred about half of the synthesized NHP into a mortar, added hexane, and then used a pestle to gently break up the clumps. No formal hazard evaluation<sup>13</sup> was conducted to analyze the effectiveness of using either water or hexane to mitigate the potential explosive hazards associated with the quantity of NHP synthesized the day of the incident. At this point, the graduate student working on the clumps was wearing goggles, but removed them and walked away from the mortar after he finished breaking the clumps. Several individuals from the lab indicated that the decision to wear goggles was a personal choice which they based on how dangerous an activity was perceived to be.

The more senior student working with NHP returned to the mortar but did not replace his goggles while he stirred the NHP “one more time.” At this point, the compound detonated.

After the incident, all of the universities who were partners in the ALERT program implemented a voluntary stop-work order in the laboratories working with energetic materials. This stop-work was maintained until safety changes could be implemented and an independent review board made up of energetic materials experts could audit the laboratories’ written standard operating procedures and safety protocols. The stop-work order at Texas Tech lasted approximately 4 months and up to 10 months at the other universities.

## 5.0 INCIDENT ANALYSIS

With any serious event, it is all too common for attention to be focused on the actions and decisions of the individuals involved in the immediate activities preceding the event. Yet modern accident causation theory recognizes that incidents are not the result of a single malfunctioning piece of equipment or the erroneous actions of one person, but instead are the result of a number of failures and deficiencies at many levels within an organization and its technical community (CCPS, 2003, p.89-90). Focusing safety improvements at the immediate level of accident causation has limited reach and impact because doing so misses the underlying organizational factors that influence and contribute to an incident; examining higher-level system deficiencies within an organization and making safety changes at those levels have a much greater preventative impact.<sup>14</sup>

This theory of accident causation can be illustrated using James Reason’s aptly named “Swiss cheese model” within the context of an academic institution (Figure 1).<sup>15</sup> Reason uses his model to depict a series of safety layers (or system defenses) capable of preventing an incident. The holes represent gaps within each system where failure could occur. If a number of failures align, an incident results (Reason, 2000, p.769).

Thus, when the CSB investigates an incident, it not only examines the immediate events leading up to that incident, but it also looks beyond those events to the larger organization

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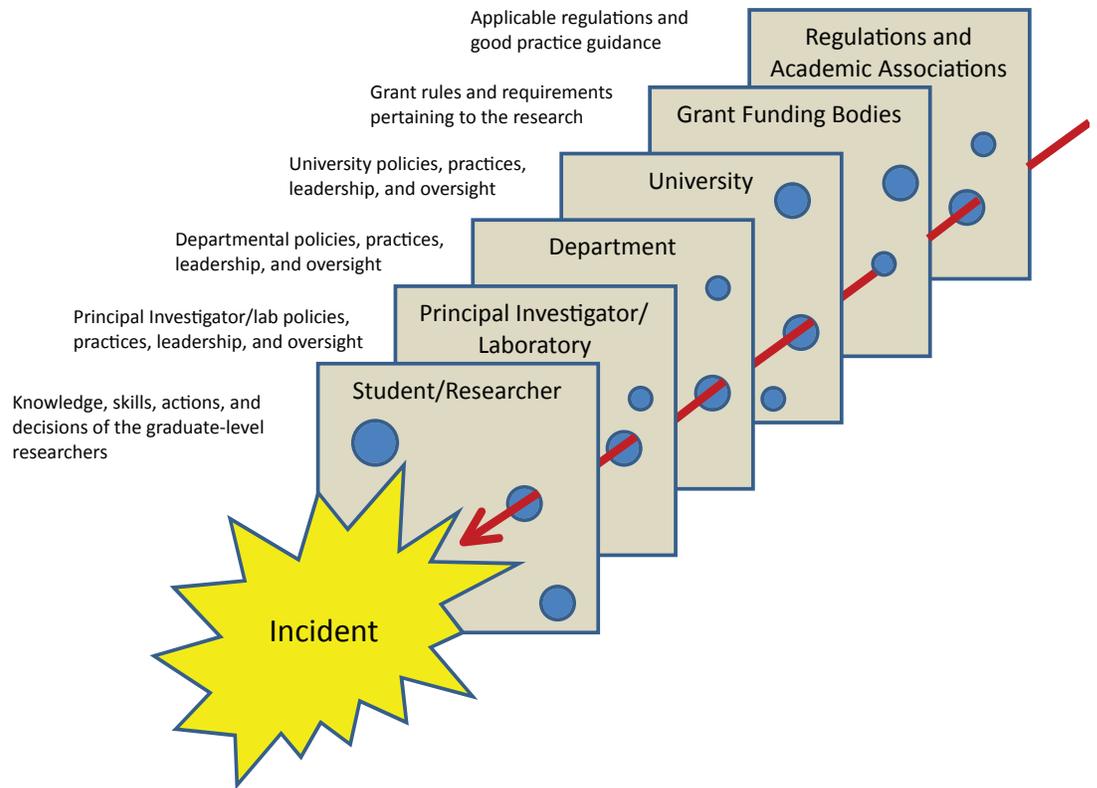
<sup>13</sup>A hazard evaluation is an organized effort to identify and analyze the significance of hazardous situations associated with a process or activity (CCPS, 2008, p. 15).

<sup>14</sup>The Center for Chemical Process Safety (CCPS) states that identifying the underlying or root causes of an incident has a greater preventative impact by addressing safety system deficiencies and averting the occurrence of numerous other similar incidents; conversely, addressing the immediate cause prevents only the identical incident from recurring (CCPS, 2003, p. 179).

<sup>15</sup>Reason’s “Swiss cheese model” illustrates the complexity and organizational layers that influence incident causation. Not addressed here are important issues that relate to the relative significance of the gaps or “holes” and the reliability or availability of the safety layers.

**FIGURE 1**

Examining a laboratory incident using James Reason's Swiss Cheese Model of Accident Causation as the framework for analysis



or company involved. It identifies the regulatory framework that existed at the time of the incident for the work being conducted, and the safety influence of technical associations and professional societies. Appendix A provides a more detailed visual representation of the CSB's investigative analysis; the agency used a modified technique of the AcciMap accident analysis tool, which aims to identify various decision-makers that have a potential for improving safety (Rasmussen, 2000, p. 20).

Through a review of evidentiary records, interviews, and post-incident observations, the CSB concluded that each layer of safety management within the institution had deficiencies that contributed to the January 2010 Texas Tech incident. Additionally, the CSB identified several gaps beyond the university itself where safety management and practices of the researchers could have been influenced to aid in prevention, including the grant funding agency, the existing laboratory safety regulations, and good practice guidance. Specifically, the CSB found:

- The physical hazards of the energetic materials research work were not effectively assessed and controlled at Texas Tech;
- Texas Tech's laboratory safety management program was modeled after OSHA's Occupational Exposure to Hazardous Chemicals in Laboratories Standard (29 CFR 1910.1450); yet, the Standard was created not to address physical hazards of chemicals, but rather health hazards as a result of chemical exposures;
- Comprehensive hazard evaluation guidance for research laboratories does not exist;
- Previous Texas Tech laboratory incidents with preventative lessons were not always documented, tracked, and formally communicated at the university;
- The research-granting agency, DHS, prescribed no safety provisions specific to the research work being conducted at Texas Tech at the time of the incident, missing an opportunity for safety influence; and
- Safety accountability and oversight by the principal investigators, the department, and university administration at Texas Tech were insufficient.

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## 6.0 PHYSICAL HAZARDS IN THE LABORATORY NOT MANAGED

### 6.1 TEXAS TECH LABORATORY MANAGEMENT POLICIES

In 1997 Texas Tech created a Chemical Hygiene Plan (CHP) intended to establish policies, procedures, and work practices to inform employees of hazards associated with chemicals in laboratories.<sup>16</sup> The CHP was developed in accordance with OSHA's Occupational Exposure to Hazardous Chemicals in Laboratories Standard (29 CFR 1910.1450). Developing the CHP was voluntary, as Texas is regulated by federal OSHA, and the State of Texas has not adopted state laws that would extend workplace safety regulations to public employees, including those of publicly funded universities, such as Texas Tech. The practice of a publicly funded university using the Laboratory Standard as guidance for creating its own Chemical Hygiene Plan is not uncommon. The CSB has observed other publicly funded universities in federal OSHA states also citing the Laboratory Standard as guidance.

As Texas Tech and various other academic institutions use OSHA's Laboratory Standard as guidance, exploring the impetus for and creation of the standard is useful. Before the standard was established, OSHA controlled exposure to hazardous chemicals through substance-specific standards or, if specific standards did not exist, through permissible exposure limits (PELs) listed in 29 CFR 1910, subpart Z. The substance-specific standards and PELs worked well for industrial settings where workers were exposed to large quantities of hazardous chemicals in standardized, continuous, or repetitive processes (51 FR 26663). OSHA acknowledged that in laboratories, however, workers typically use a larger variety of hazardous chemicals, but in smaller amounts than in an industrial workplace, and that chemicals and procedures can change frequently (Hanson, 1986, p.16-17; 51 FR 26684). In response, in 1990 OSHA created the performance-oriented Laboratory Standard that was intended to allow employers flexibility to create work practices and procedures specific to their laboratory operations (Hanson, 1986, p.16-17). According to the standard, the practices and procedures created by the workplace itself would be included in a written chemical hygiene plan.

Also included in the Laboratory Standard are two non-mandatory appendices intended to provide guidance to employers developing CHPs. Appendix A summarizes the first edition of the National Research Council's (NRC) *Prudent Practices for Handling Hazardous Chemicals in the Laboratories (Prudent Practices)* (1981). Since the standard was created, the NRC published three updated editions of *Prudent Practices*: one in 1983, one in 1995, and one in 2011. The motivation for the 1983 and 1985 versions was "to provide an authoritative reference on the handling and disposal of chemicals at the laboratory level" (NRC, 2011, p. vii-viii). The 1995 edition evolved to address laboratory culture as it related to safety, health, and environmental protection (NRC, 2011, p. vii-viii). The latest edition expands upon the "safety culture" concept with a much stronger emphasis on management practices needed to ensure that organizations do not neglect safety culture (NRC, 2011, p. vii-viii). However, Appendix A of the OSHA standard has not been revised to reference this newest edition of *Prudent Practices*.

The Laboratory Standard addresses hazardous chemicals, which are defined as chemicals that have been found through statistically significant evidence to cause possible acute or chronic health effects. The standard has a clear focus on health hazards resulting from carcinogens, toxins, irritants, corrosives, and other "exposure" type hazards. Chemicals with physical hazards, such as combustible liquids, compressed gases, explosives, or flammables, among others, are addressed by the standard only under the employer's training program

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<sup>16</sup>[www.depts.ttu.edu/ehs/Web/Docs/Chem\\_Hygiene\\_Plan.pdf](http://www.depts.ttu.edu/ehs/Web/Docs/Chem_Hygiene_Plan.pdf), accessed August 2011.

(1910.1450(f)(4)(i)(B)). The standard lacks a hazard evaluation requirement to identify or mitigate physical hazards.

OSHA’s initiative for a laboratory standard was to focus on hazardous chemicals. Ultimately, OSHA recognized that the CHP requirements of the standard did not address all laboratory hazards, but believed that the requirement to train employees on chemicals with physical hazards and other safety regulations would effectively provide protection (55 FR 3314).

Texas Tech’s CHP paralleled the OSHA Laboratory Standard, focusing on exposure hazards of hazardous chemicals. Table 1 lists many of the safety elements found in Texas Tech’s Chemical Hygiene Plan and identifies whether physical hazards were addressed within each. As indicated in the table, there is a requirement for written procedures, but the CHP explicitly states that the procedures are required for the use of carcinogens, mutagens,<sup>17</sup> or teratogens,<sup>18</sup> not physical hazards. Additionally, the CHP has requirements for hazard determinations, communication of hazards, and pre-approval of procedures, but again according to the CHP, these requirements do not extend to the physical hazards of chemicals.

In addition to the Chemical Hygiene Plan, Texas Tech also had several standard operating procedures (SOPs) that were applicable to laboratories on campus, including one titled “Handling and Storing Explosives.”<sup>19</sup> The stated purpose of this SOP was to “ensure the protection of all employees required to handle and store explosives while performing their duties and experiments.” As noted in Table 1, this SOP did address training on handling explosive materials, but it did not address any of the other safety elements listed in the CHP for chemical health hazards.

TABLE 1.

Safety elements addressed by Texas Tech’s CHP and its SOP, “Handling and Storing Explosives”

SAFETY ELEMENT	POLICY DOCUMENT	PHYSICAL HAZARDS OF CHEMICALS ADDRESSED
Perform hazard determination	CHP	
Reduce employee exposure	CHP	
Protective apparel	CHP	
Training on hazards of chemicals	CHP	✓
Training on handling of material through approved facility	University SOP	✓
Written procedures	CHP	
Standard operating procedures	CHP	
Communication of hazards	CHP	
Pre- approval of procedures	CHP	
Document material usage	University SOP	✓

The lack of policies in the laboratory, Chemistry Department, and university to help both manage work and set minimum expectations will be addressed throughout the case study.

<sup>17</sup>OSHA defines a mutagen as a substance or agent capable of altering the genetic material in a living cell (mutation), <http://www.osha.gov/dsg/hazcom/ghd053107.html>, accessed 9/22/2011.

<sup>18</sup>OSHA defines a teratogen as a substance that can cause malformations or alterations in the appearance or function of a developing embryo, <http://www.osha.gov/dsg/hazcom/ghd053107.html>, accessed 9/22/2011.

<sup>19</sup><http://www.depts.ttu.edu/opmanual/OP60.20.pdf>, accessed 9/22/2011.

## 6.2 HAZARD DETERMINATION

The university CHP stated that PIs were responsible for determining the hazards of chemicals generated within a laboratory, but neither Texas Tech nor its Chemistry Department trained researchers to determine hazards, described what an appropriate determination includes, or verified that any evaluations had been completed prior to experimental work commencing. *Prudent Practices* recognizes that “the ability to accurately identify and address hazards in the laboratory is not a skill that comes naturally, and it must be taught and encouraged through training and ongoing organizational support” (NRC, 2011, p.7). Although the CHP did not identify graduate students as responsible for determining hazards, it seems prudent that they too should receive similar training since they may be working in laboratories for extended periods without PI supervision.

While not all standards and practices used in the chemical process industry can be directly applied to an academic laboratory environment, drawing applicable parallels to harness the field’s experience and knowledge of hazardous activities involving chemicals can be useful. In the industrial sector, hazard determinations can be considered a three-part exercise that encompasses: (1) hazard evaluations and (2) risk assessments, both of which lead to (3) implementation of appropriate hazard mitigation strategies.

Hazard evaluations are “organized effort[s] to identify and analyze the significance of hazardous situations associated with a process or activity” and have been used in the chemical process industry for more than 30 years (CCPS, 2008, p. 15-16). The Center for Chemical Process Safety (CCPS) suggests that while hazard evaluations typically analyze equipment failure or human error, they can also identify deficiencies within an organization’s safety management system (p. 17). In his paper titled “Improving engineering research laboratory safety by addressing the human aspects of research management,” Zakzeski (2009) offers one model of how an academic laboratory borrowed concepts from the industrial and business worlds to promote safety, which included formal evaluations by the researchers working in the laboratory. These researchers learned to conduct Hazard and Operability (HAZOP) analyses, a common and well-accepted tool in the chemical industry to analyze the ways a process can fail and result in an accident (Crowl and Louvar, 1990). Additionally, the researchers self-audited and used external audits to enhance risk analyses in the laboratory. Because a university’s Environmental, Health and Safety (EH&S) staff will likely not have a complete and in-depth understanding of the unique research-specific hazards of every laboratory, audits by those involved in the research and others with similar backgrounds can potentially identify hazards that may otherwise go unnoticed and provide an opportunity for the PI to interact and mentor graduate students on hazard identification.

Risk assessment allows an organization to analyze the frequency and expected outcomes from potential incidents. It can be performed simultaneously with a hazard evaluation or separately once the evaluation is complete. Using a risk assessment, the organization can determine if it is appropriately emphasizing the most significant risks and/or how it might mitigate them.<sup>20</sup> Prior to the incident at Texas Tech, there was no ALERT-wide policy that limited the quantity of energetic compound that could be synthesized. Post-incident, the ALERT Safety Review Board, which was convened to review policies and procedures of all laboratories participating in the ALERT program, recommended a maximum limit of 500 milligrams. The Safety Review Board chose this limit because it follows guidelines set by the Navy, which determined that 500 milligrams can cause bodily injury, but that the injury will not be permanent. The Texas Tech PIs working with the ALERT program decided not to tolerate this level of risk, and so restricted the limit to just 50 milligrams in

<sup>20</sup>The NRC provides detailed lists of data resources concerning the properties of various physical and chemical hazards and outlines that summarize steps used to assess risks in handling toxic chemicals and physical hazards (NRC 2011, p. 48-79)

their laboratories. This decision was documented by Texas Tech’s Institutional Biosafety and Hazardous Material Committee (IBC).<sup>21</sup> Post-incident, the university began to include explosive materials in the scope of IBC reviewed research.<sup>22</sup>

Hazard mitigation is the process of eliminating or reducing the frequency of a risk, the potential consequences of a risk, or both. A common method to mitigate hazards is the use of personal protective equipment (PPE). In any workplace with hazards, an organization should examine the reliability of the controls used to mitigate or remove the hazards (ANSI/AIHA Z10-2005, p. 11). Some controls are more reliable; those controls that require an individual to act are less reliable, and thus, less desirable to mitigate hazards. PPE usage is on the lowest level of the hierarchy of control because it requires the individual to take action (i.e., determine appropriate PPE and then use that PPE each time) for the PPE to work as a control measure. This was evidenced in the Texas Tech lab where the incident happened – students were allowed to determine their PPE needs on an individual and situational basis. For example, several individuals reported that they used their ordinary prescription glasses for eye protection.<sup>23</sup> PIs in these laboratories made similar decisions concerning PPE, thus modeling the behavior.

Another type of control is a procedural or administrative one, which uses safe work practices and procedures to reduce risk, such as a documented procedure for how to safely use a piece of laboratory equipment. (CCPS, 2009, p.13). Post-incident, DHS, the granting agency, immediately initiated several administrative safety controls, including a requirement that all universities involved in the ALERT program generate written SOPs and protocols to be reviewed by an external board of experts. Additional post-incident administrative controls included a Safety Awareness Education Program to provide an “Explosive Safety Protocols and Procedures” course every six months<sup>24</sup> and a Safety Compliance Assurance Program.<sup>25</sup>

### 6.2.1 LACK OF HAZARD EVALUATION GUIDANCE IN RESEARCH LABORATORIES

The 2011 version of *Prudent Practices* includes a “Quick Guide” for physical, flammable, explosive, and reactive hazards (NRC, 2011, p. 66). The Quick Guide summarizes steps researchers might use when assessing hazards in their laboratories and includes questions that could lead researchers to consider potential hazards associated with their work. *Prudent Practices* does not include recommended hazard evaluation techniques labs might use to assure that all necessary risk information has been gathered, or any recommended practices for how a researcher might determine when an activity is particularly hazardous and may warrant input from someone with more experience.

In industry, companies use a variety of methodologies to assess hazards, and both guidelines and worked examples of the different techniques have been developed and published. For example, CCPS’s *Guidelines for Hazard Evaluation Procedures* is a 550-page book that presents 12 different hazard evaluation methodologies, provides worked examples to demonstrate what an effective evaluation encompasses, and identifies limitations of the various

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<sup>21</sup>Texas Tech’s IBC is made up of faculty, administration, and two community members that are not affiliated with TTU, in accordance with NIH guidelines. The TTU IBC provides guidance “regarding proper acquisition, handling, transfer, and disposal of potentially hazardous or regulated hazardous materials,” <http://www.depts.ttu.edu/ehs/Web/BiolSafety.aspx#CM>, accessed 9/15/2011.

<sup>22</sup>Texas Tech’s IBC defines “explosive” as “[a]ny substance or article, including a device, which is designed to function by explosion (i.e. an extremely rapid release of gas and heat) or which, by chemical reaction within itself, is able to function in a similar manner even if not designed to function by explosion. The term includes a pyrotechnic substance or article” (<http://www.depts.ttu.edu/ehs/Web/Docs/HazardousChemicalProtocolForm7.12.10.doc>, accessed 9/22/2011).

<sup>23</sup>According to *Prudent Practices*, “Ordinary prescription glasses do not provide adequate protection against injury because they lack side shields and are not resistant to impact” (NRC, 2011, p.109).

<sup>24</sup>Individuals in the ALERT program are required to attend the course within six months of joining the program and then at least every other year thereafter.

<sup>25</sup>The program includes yearly visits by the Safety Review Board to audit the safety program. Programs found to be deficient will have the opportunity to improve weaknesses. Failure to do so will result in a stop-work order.

techniques (CCPS, 2008, p.180). Figure 2, an abbreviated chart from *Guidelines for Hazard Evaluation Procedures*, identifies a number of work activities that may be performed in an industrial setting and indicates which of the 7 different methodologies listed would be most appropriate to assess the hazards of each.

FIGURE 2

Abbreviated chart from CCPS's *Guidelines for Hazard Evaluation Procedures* listing hazard evaluation methodologies and the appropriateness of each for a variety of industrial activities.

	SAFETY REVIEW	CHECKLIST	RELATIVE RANKING	PRELIMINARY HAZARD ANALYSIS	WHAT-IF	WHAT-IF/CHECKLIST	HAZOP
Research & Development	○	○	●	●	●	○	○
Pilot Plant Operation	○	●	○	●	●	●	●
Construction/Start-up	●	●	○	○	●	●	○
Routine Operation	●	●	○	○	●	●	●
Modification	●	●	●	●	●	●	●
Incident Investigation	○	○	○	○	●	○	●
Decommissioning	●	●	○	○	●	●	○

At academic institutions, the research of individual PIs can differ significantly;<sup>26</sup> consequently, the hazards of research can vary widely among different laboratories. Even within the same laboratory under a single PI, students commonly work on different projects that can pose diverse safety hazards. This indicates a need for guidance on various hazard evaluation methodologies and instruction on how and when each should be used within an academic laboratory research work environment. Detailed examples for multiple methodologies would help researchers determine the most effective way to evaluate the hazards of their work, whether they are due to routine procedures, modifications to current research, or entirely new endeavors.

When OSHA's Laboratory Standard was being created, OSHA identified the American Chemical Society (ACS) as being instrumental in establishing that practices in laboratories are different enough from those in industry to warrant different rules (Hanson, 1986, p.17). The ACS is a nonprofit organization, chartered by Congress, with more than 163,000 members, whose stated mission is "to advance the broader chemistry enterprise and its practitioners for the benefit of Earth and its people."<sup>27</sup> Just as laboratories warrant different rules, the CSB recognizes that industrial guidelines may not lend themselves to be directly applied to the dynamic environment of an academic laboratory without modification. An organization such as the ACS could create guidance appropriate for the academic laboratory setting. The ACS already has various committees (to which members are elected), divisions (groups of voluntary members), and task forces (formed by various committee and division members for a specific purpose or goal) that are focused on health and safety as it relates to chemistry. These include the *Committee on Chemical Safety*, the *Division of*

<sup>26</sup>The significance of this is amplified when contrasting the academic laboratory work environment to that of industrial chemical and refining facilities that often produce a limited number of products and function within well defined operating parameters.

<sup>27</sup>[http://portal.acs.org/portal/acs/corg/content?\\_nfpb=true&\\_pageLabel=PP\\_TRANSITIONMAIN&node\\_id=225&use\\_sec=false&sec\\_url\\_var=region1&\\_uuid=85cbc45b-0637-4f67-85f2-7068559c284c](http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_TRANSITIONMAIN&node_id=225&use_sec=false&sec_url_var=region1&_uuid=85cbc45b-0637-4f67-85f2-7068559c284c), accessed 9/2/2011

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*Chemical Health and Safety*, and the *Safety Culture Task Force*. The ACS is not a standard setting body, but it has published several examples of safety guidance that are widely accessed, including *Safety in the Academic Chemistry Laboratory* (2003).

### **6.2.2. NO TRAINING FOR RESEARCH-SPECIFIC SAFETY RISKS**

Beyond completing a literature review, the students synthesizing the NHP had no research-specific training, nor were the students' understanding of the risks formally assessed before they started the energetic materials research. At the time of the incident, most chemistry graduate students, including the one injured, had not taken the university-offered general laboratory safety training class, which was available both online and in person by EH&S staff. In fact, Chemistry Department students were not required to attend this general laboratory safety training, and the department had not documented attendance of the training since 2002. While general safety training would likely not have prevented the January 7 incident, the lack of training is an indication of deficiencies in the safety management program at the university. The only safety instruction most Chemistry Department graduate students received was the general safety training provided when they were teaching assistants (TAs), which consisted of watching a 1991 ACS safety video.<sup>28</sup> This video was intended for undergraduates and demonstrated basic lab safety principles. However, the safety training needs of undergraduates, who often perform "cookbook" laboratory work with well-understood and defined risks, differ greatly from those of students performing research (NRC, 2011, p.4). The ACS video does not address the need for hazard evaluations prior to commencing laboratory research.

### **6.2.3 LACK OF FORMAL DOCUMENTATION AND COMMUNICATION**

To increase the likelihood that all parties are knowledgeable and aware of the risks, safety-critical information should be provided in writing and additional steps should be taken to verify that the recipients understand the material. The laboratory where the January 7 incident occurred had no written protocols or SOPs for synthesizing NHP or other energetic materials, no written restrictions concerning the amount of compound to be synthesized, and no written mandatory safety requirements pertaining to the synthetic work. As such, at the time of the incident, there was no documented communication telling the students how to minimize the potential safety risks inherent in this research activity.

Formalizing policies and accepted work conduct does not necessarily prohibit a researcher from deviating from the laboratory standards, but the acceptable process for deviating should also be defined and the change documented. For example, the Department of Energy's *DOE Explosives Safety Manual*<sup>29</sup> describes how contractors and subcontractors are required to submit a written request for an exemption from a mandatory safety requirement (DOE, 2006, p. 5). The manual states that an experienced engineer reviews the request and that an approved request must include plans to mitigate any safety risks the change will introduce; in the chemical process industry, this is called management of change.

*Prudent Practices* acknowledges that "[t]he concept of change of management in the laboratory environment varies markedly from methods typically prescribed, for example in manufacturing operations. By its very nature, the business of conducting experiments is constantly changing. Therefore, it is part of everyday activities to evaluate modification and/or technological developments in experimental and scale-up processes" (NRC, 2011, p.13). Although *Prudent Practices* cites relevant resources of safety critical information, the CSB has found no guidelines or best practices on how laboratory environments might manage such changes, despite the inherent variable nature of the work that takes place within them.

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<sup>28</sup>The ACS video is no longer published but can be found here (<http://vimeo.com/6170550>), accessed 9/15/2011.

<sup>29</sup>[http://www.hss.doe.gov/enforce/docs/manuals/DOE\\_Manual\\_440\\_1\\_1A\\_Explosives\\_Safety\\_Manual.pdf](http://www.hss.doe.gov/enforce/docs/manuals/DOE_Manual_440_1_1A_Explosives_Safety_Manual.pdf), accessed August 2011

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Not managing these changes particularly places new graduate students at risk if their only training has been as undergraduates. Hill and Finster acknowledge that “[b]ecause new [undergraduate] students don’t have to design experiments, they also don’t have to think about designing good safety procedures into laboratory experiments because that has already been done by the author of the procedure. Unfortunately, in a sense, students get trained not to think as much about safety...” (2010, p. 6). Students in the energetic labs were not required to obtain permission or seek approval from their PIs prior to changing research experiment variables, including subjectively determined “small” increases of material synthesized and temperature variations. Supervisory involvement at Texas Tech with the daily laboratory research activities depended heavily on the students’ efforts to seek out the PI for advice or input. This system relied upon students correctly assessing when the PI, who possessed more experience and knowledge, should be sought out for consultation. There was no Texas Tech policy in place either at the laboratory, department, or university level that might provide guidance as to when it would be prudent to seek approval or input.

Two additional communication tools that could have been, but were not, used to their full potential at the Texas Tech lab to share daily laboratory activity information were group meetings and laboratory notebooks. Prior to the incident, weekly group meetings between students and PIs were held, but the focus was primarily on experimental results, not actual research activities and the safety implications of the work. Lab notebooks, often seen as a primary means of documenting research plans and activities, were not consistently reviewed by PIs and varied greatly among students; some students kept notes only on new discoveries while others also included daily work activities.

## 7.0 LESSONS NOT LEARNED FROM PREVIOUS INCIDENTS AND NEAR-MISSES

“Good organizations learn lessons from incidents and take actions to strengthen their safety processes and programs and foster a strong safety culture” (Hill and Finster, 2010, p. 31). Yet reporting and learning from incidents does not always occur. *Prudent Practices* states, “The ‘culture of chemistry’ is still at odds with that of safety. Some of us may have witnessed unsafe behavior or minor accidents, and yet, rather than viewing these incidents with concern and as opportunities to modify practices and behavior, we often have failed to act upon these ‘teachable moments.’” (NRC, 2011, p. viii)

Approximately three years prior to the January 2010 detonation, two previous incidents had occurred within the same research groups; however, some students within these groups indicated that they were unaware of the incidents until after the 2010 event. While no one was injured in the previous incidents, they presented the PIs, and the entire Chemistry Department, an opportunity to recognize gaps in safety-critical knowledge and hazard awareness.

The first incident occurred when a reaction was being completed by a student. The reaction began to emit nitrogen, causing loud bangs. After another student recommended removing the reaction from the ice bath it was in, the banging increased. This frightened the student and caused her to flee. The lesson learned, as reported to the CSB investigators, was that a student should not leave the scene because responders may need information to be able to mitigate the situation. While it is important that researchers are available to consult with emergency responders, the CSB concludes that other safety issues could also have been identified. Similarities between this incident and the 2010 detonation include:

- No formal hazard evaluation and risk assessment had been completed to characterize the potential danger of the research activity and to plan for the worst-case scenario;
- Student sought peer advice;

- No policy was in place at the laboratory, department, or university level to prompt a student to seek PI advice or evaluation of experimental activities.

Had remedial actions been taken after this 2007 incident, they could have played a preventative role in the 2010 event.

The second previous incident involved a scale-up situation within the same research groups; a student unintentionally used the wrong units of measure and created an excess of a known energetic material. While reporting the synthesis at a group meeting, the PI asked how much compound the student had made, at which point the student reported 30 grams; the PI immediately separated the 30 grams of explosive material into smaller, less hazardous quantities. The graduate student injured in the 2010 incident was a researcher in the laboratory at the time of this near-miss and witnessed the interaction between the PI and the student, but the near-miss was not reported to anyone outside of the research groups. Had the dangers of scale-up been formally communicated through written SOPs and reinforced as new students joined the research group, the likelihood of the occurrence of the 2010 incident may have been lessened.

Entities looking to improve safety should encourage the reporting of such incidents, even when injuries or damage do not result, as accidents and near-miss reports indicate critical areas where safety controls may be needed. The collection of reports from an entire department could be used as a safety metric to help determine how a department as a whole is doing and/or improving.

In addition, incident and near-miss reports could become a resource for future researchers as those individuals assess and mitigate the potential hazards of their work. Zakzeski (2008, p. 8) suggests storing near-miss reports in an online database accessible to researchers beginning work with new chemicals or processes.<sup>30</sup>

## 8.0 LACK OF ORGANIZATIONAL ACCOUNTABILITY AND OVERSIGHT FOR SAFETY

*Prudent Practices* acknowledges that “the ultimate responsibility for creating a safe environment and for encouraging a culture of safety rests with the head of the organization and its operating units....Even a well-conceived safety program will be treated casually by workers if it is neglected by top management.” (NRC, 2011, p.2) The CSB determined that research laboratory safety was not being adequately managed at Texas Tech.

Pre-incident, both the Texas Tech Chemistry Department Safety Advisor and the EH&S Laboratory Safety Inspector conducted safety audits and inspections of the 118 chemistry laboratories on campus; they frequently found general laboratory safety violations and reported their findings to the PI and the Department Chair. However, remedial actions were often not taken. Many university safety policies either did not exist or were not enforced (see Section 6.0 of this case study). No single person or entity within the university was accountable for ensuring that the CHP was up-to-date, enforced, and applicable to the laboratories it was meant to regulate. As such, the PIs involved in the energetic materials’ research were aware of the university CHP, but had not read the entire document. And the organizational structure inhibited opportunities for safety issues to be raised to those within the university with the necessary authority to ensure safety improvements were implemented.

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<sup>30</sup>For an example of an online near-miss database, view Department of Energy’s (DOE) Hydrogen Program website, which facilitates the sharing of lessons learned while working with hydrogen: <http://www.h2incidents.org/>.

## **8.1 DEFICIENT SAFETY MANAGEMENT ACCOUNTABILITY AND OVERSIGHT**

In order for safety to be properly managed, it should play a prominent role within the layers of the organizational hierarchy and with those that are involved in the work being conducted but may be outside the organization itself.

### **8.1.1 THE ROLE OF THE PRINCIPAL INVESTIGATOR**

In academia, the PI generally has significant authority over his/her research. At Texas Tech, the issue of academic “fiefdoms” was evident; in the fiefdom system, a department is broken into smaller units that have individuals in charge (in this context, “fiefs”), where these individuals “are nominally subordinate to a person or persons above them, but in practice do pretty much whatever they want so long as they do not stray too far into some other fief’s territory.” As such, “each fief has an intellectual or administrative territory over which he or she reigns.” (McCroskey, 1990, p. 474)

At academic research institutions, PIs may view laboratory inspections by an outside entity as infringing upon their academic freedom. This was the case at Texas Tech, where EH&S laboratory safety checks were not viewed as a means to understand how a PIs’ laboratory practiced safety in their absence. Instead, some PIs saw the notification of safety violations to the Chair as “building a case” against them, felt that the safety inspections inhibited their research, and considered recommended safety changes outside their control because they could not “babysit” their students.

To combat cultural issues (such as fiefdoms) and bring a focus to safety within any given organization, it is important to ensure that the reporting structure allows for communication of safety information to those within the organizational hierarchy that have the authority and resources to implement safety change. Often, the Department Chair is considered the responsible person for ensuring safety; however, in practice, the Chair holds this managerial role while at the same time maintaining his/her role as a principal investigator for research; thus, a potential conflict exists due to the duality of the position. Authority and oversight of safety at a level above the Chair is a critical component of safety management within an academic structure.

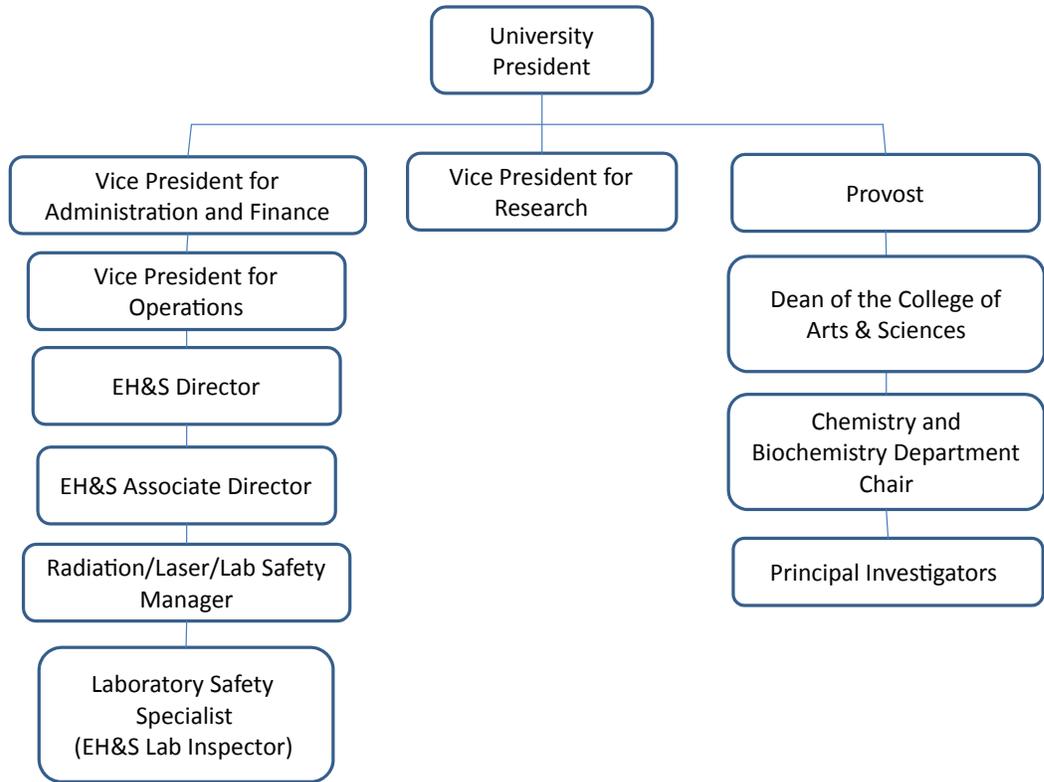
### **8.1.2 THE ROLE OF ENVIRONMENTAL HEALTH AND SAFETY**

Texas Tech’s CHP stipulated that the Chemical Hygiene Specialist function as the University Chemical Hygiene Officer (UCHO) and be responsible for overseeing all aspects of the CHP. The EH&S Inspector identified himself as the Chemical Hygiene Specialist, and EH&S was the group responsible for conducting laboratory safety inspections. Even so, EH&S had no authority to shut down a laboratory; rather, EH&S saw itself as a “consultant” advising the department about how to improve and maintain safety.

The organizational structure of Texas Tech supported this consultant role of EH&S, and no other group or person was appointed with an empowered oversight role. Faculty members, including the PIs, report to their Department Chair, Dean, and the Provost, who have direct authority over faculty and, as a result, can affect their behavior. The Vice President for Research has direct authority over research policies (including compliance policies) and internal research funds, both of which also allow for influence over faculty. At the time of the 2010 incident, EH&S was not under the authority of the Vice President for Research, but was part of the facilities office and reported to the Vice President for Administration and Finance (Figure 3). EH&S had no direct communication link within the organizational hierarchy to an authority who could enforce EH&S’s safety inspection recommendations with the PIs. EH&S was not required, nor expected, to report its laboratory safety inspection reports and findings to either the Vice President for Research or the Provost.

FIGURE 3.

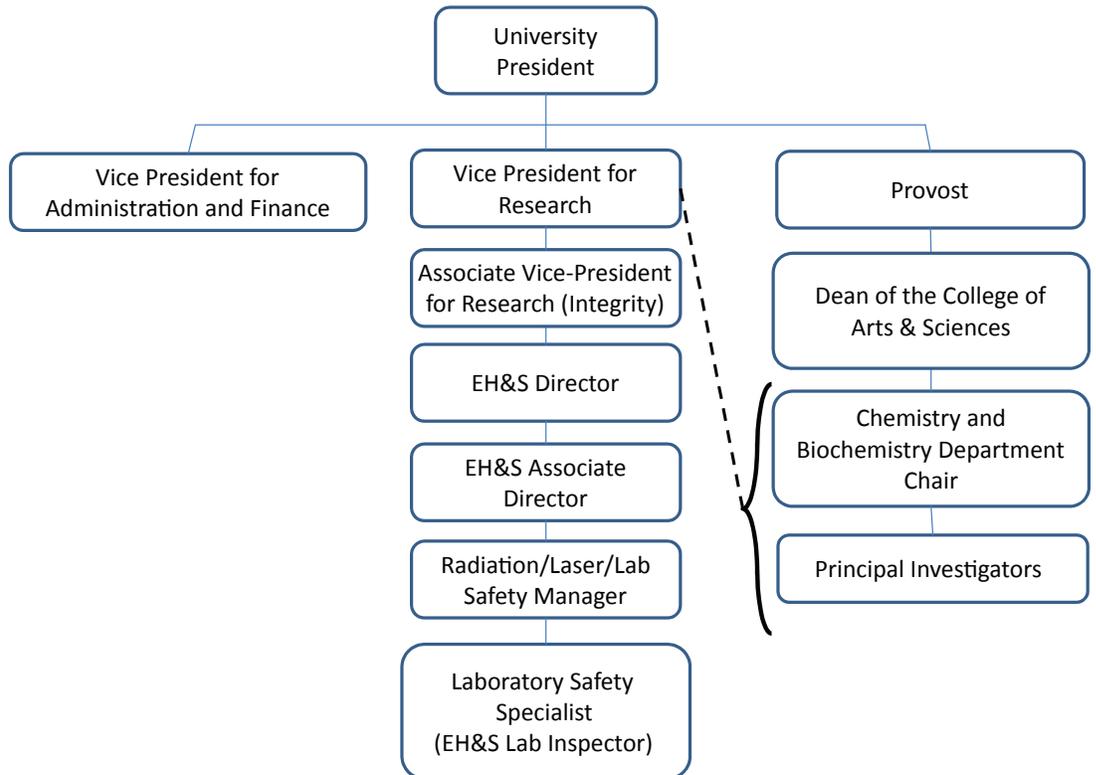
Simplified pre-incident organizational structure. Some positions are not included.



Post-incident, Texas Tech recognized these challenges and modified its organizational structure so that the EH&S Director reports directly to the Vice President for Research (Figure 4).

FIGURE 4.

Simplified post-incident organizational structure.. Some positions are not included. Note that EH&S reports to the Vice President who, through responsibilities of internal research funding and research policy enforcement, has influence over the faculty (indicated by dashed line).



## 8.2 THE GRANTING AGENCY'S ROLE IN LABORATORY SAFETY

DHS is one of 19 federal agencies that collectively provide over \$25.3 billion to academic institutions for scientific research (NSF, 2009), but not all of these agencies choose to include safety requirements or stipulations within their grant applications and cooperative agreements with researchers. DHS did not have safety provisions specific to the energetic materials research being conducted by Texas Tech within its cooperative agreement with NEU.

The Homeland Security Act of 2002 dictated that DHS would establish university-based center(s) to enhance homeland security. The Office of University Programs within DHS monitors the work in these Centers of Excellence, which support a variety of research, including but not limited to, microbial risk assessment, food system protection, and explosive-related threats. The Centers of Excellence are structured so that DHS has a direct cooperative agreement with the chair-university(ies) of the center, and the chairs subcontract work with core partners. The Centers receive a yearly grant, and DHS reviews the program plans of the chair-universities and core partners annually to assess accomplishments and goals for the following year.

The cooperative agreement with NEU included stock language concerning some research practices, such as those involving human and vertebrate subjects. However, it included no particular provisions for the safety of researchers working with energetic compounds, with the exception of a general condition making researcher safety the university's responsibility. The provisions for human and vertebrate subjects cite federal law mandating that researchers conduct their work under specified conditions.

The CSB identified the grant funding body's role in safety as a missed opportunity to influence positive safety management and behavior. *Prudent Practices* supports this finding in its latest edition: "When negligent or cavalier treatment of laboratory safety regulations jeopardizes everybody's ability to obtain funding, a powerful incentive is created to improve laboratory safety" (NRC, 2011, p. 6). Stated more bluntly: "Whoever is in control of the purse is in control of the institution" (McCroskey, 1990, p. 472). The grant funding agency has the power to end a research contract/agreement and, thus, can play an impactful role in raising safety awareness and preparedness by the researcher and university.

After the 2010 incident, the Office of University Programs in DHS added a new safety condition to the 2011 cooperative agreements with all universities funded by any of the DHS Centers of Excellence. This safety condition, the Research Safety Plan, has requirements that a contractor include these conditions in all sub-awards or subcontractors; specifically, that

- Possible research hazards associated with the types of research to be conducted under the award are identified;
- Research protocols or practices conform to generally accepted safety principles applicable to the nature of the research;
- Recipient's processes and procedures comply with the applicable protocols and standards;
- Recipient's processes and procedures prevent unauthorized activities conducted in association with this award;
- Faculty oversees student researchers;
- Research safety education and training to develop a culture of safety are provided;
- Security access control, where applicable; and
- Independent review by subject matter experts of the safety protocols and practices is conducted.



## 9.0 KEY LESSONS

1. An academic institution modeling its laboratory safety management plan after OSHA's Laboratory Standard (29 CFR 1910.1450) should ensure that all safety hazards, including physical hazards of chemicals, be addressed.
2. Academic institutions should ensure that practices and procedures are in place to verify that research-specific hazards are evaluated and mitigated.
3. Comprehensive guidance on managing the hazards unique to laboratory chemical research in the academic environment is lacking. Current standards on hazard evaluations, risk assessments, and hazard mitigation are geared toward industrial settings and are not fully transferable to the academic research laboratory environment.
4. Research-specific written protocols and training are necessary to manage laboratory research risk.
5. An academic institution's organizational structure should ensure that the safety inspector/auditor of research laboratories directly report to an identified individual/office with organizational authority to implement safety improvements.
6. Near-misses and previous incidents provide opportunities for education and improvement only if they are documented, tracked, and communicated to drive safety change.

## 10.0 RECOMMENDATIONS

### 10.1 OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION

#### 2010-5-I-TX-R1

Broadly and explicitly communicate to the target audience of research laboratories the findings and recommendations of the CSB Texas Tech report focusing on the message that while the intent of 29 CFR 1910.1450 (Occupational Exposure to Hazardous Chemicals in Laboratories Standard) is to comprehensively address health hazards of chemicals, organizations also need to effectively implement programs and procedures to control physical hazards of chemicals (as defined in 1910.1450(b)). At a minimum:

- a. Develop a Safety and Health Information Bulletin (SHIB) pertaining to the need to control physical hazards of chemicals; and
- b. Disseminate the SHIB (and any related products) on the OSHA Safety and Health Topics website pertaining to Laboratories (<http://www.osha.gov/SLTC/laboratories/index.html>)

## 10.2 AMERICAN CHEMICAL SOCIETY

### 2010-5-I-TX-R2

Develop good practice guidance that identifies and describes methodologies to assess and control hazards that can be used successfully in a research laboratory.

## 10.3 TEXAS TECH UNIVERSITY

### 2010-5-I-TX-R3

Revise and expand the university chemical hygiene plan (CHP) to ensure that physical safety hazards are addressed and controlled, and develop a verification program that ensures that the safety provisions of the CHP are communicated, followed, and enforced at all levels within the university.

### 2010-5-I-TX-R4

Develop and implement an incident and near-miss reporting system that can be used as an educational resource for researchers, a basis for continuous safety system improvement, and a metric for the university to assess its safety progress. Ensure that the reporting system has a single point of authority with the responsibility of ensuring that remedial actions are implemented in a timely manner.

### BEYOND TEXAS TECH

The CSB is greatly concerned about the frequency of academic laboratory incidents in the United States. Since 2001, the CSB has gathered preliminary information on 120 different university laboratory incidents including: a UCLA staff research associate who was fatally burned while working with t-butyl lithium in 2008, four injured at the University of Missouri in a June 2010 explosion involving hydrogen, and a June 2010 fire at Southern Illinois University that resulted in approximately \$1 million in damage. In previous years, other institutions<sup>31</sup> have attempted to collect data on laboratory incidents, but no nationwide reporting system for tracking near-misses and incidents exists; as a result, academia is missing a significant opportunity to communicate, educate, and improve laboratory safety. The role of grant-funding bodies in laboratory safety requires further examination; the changes DHS made after the Texas Tech incident suggest that grant-funding institutions may play a critical role in influencing immediate safety change.

While this case study focuses on only one laboratory event, the CSB is confident that a number of issues raised by this incident are relevant to academia as a whole. With over 110,000 graduate students and postdoctoral researchers estimated to be working in academic laboratories (NSF, 2010), these identified safety gaps and other issues deserve further examination and research in a larger, more comprehensive study on academic laboratory safety.

<sup>31</sup>For examples, see: The Laboratory Safety Institute Learning by Accident Volumes 1, 2, and 3; 2005, <http://labsafetyinstitute.org/index.html>, Chemical & Engineering News Safety Notes Index 1976-1989 published by the American Chemical Society in 1991, and Steere, N.V., Ed "Safety in the Chemical Laboratory," J. Chem. Education Vols. 1, 2, 3, 1967, 1970, 1974, and Renfrew, M. M., Ed. "Safety in the Chemical Laboratory," J. Chem. Education Vol 4, 1981.

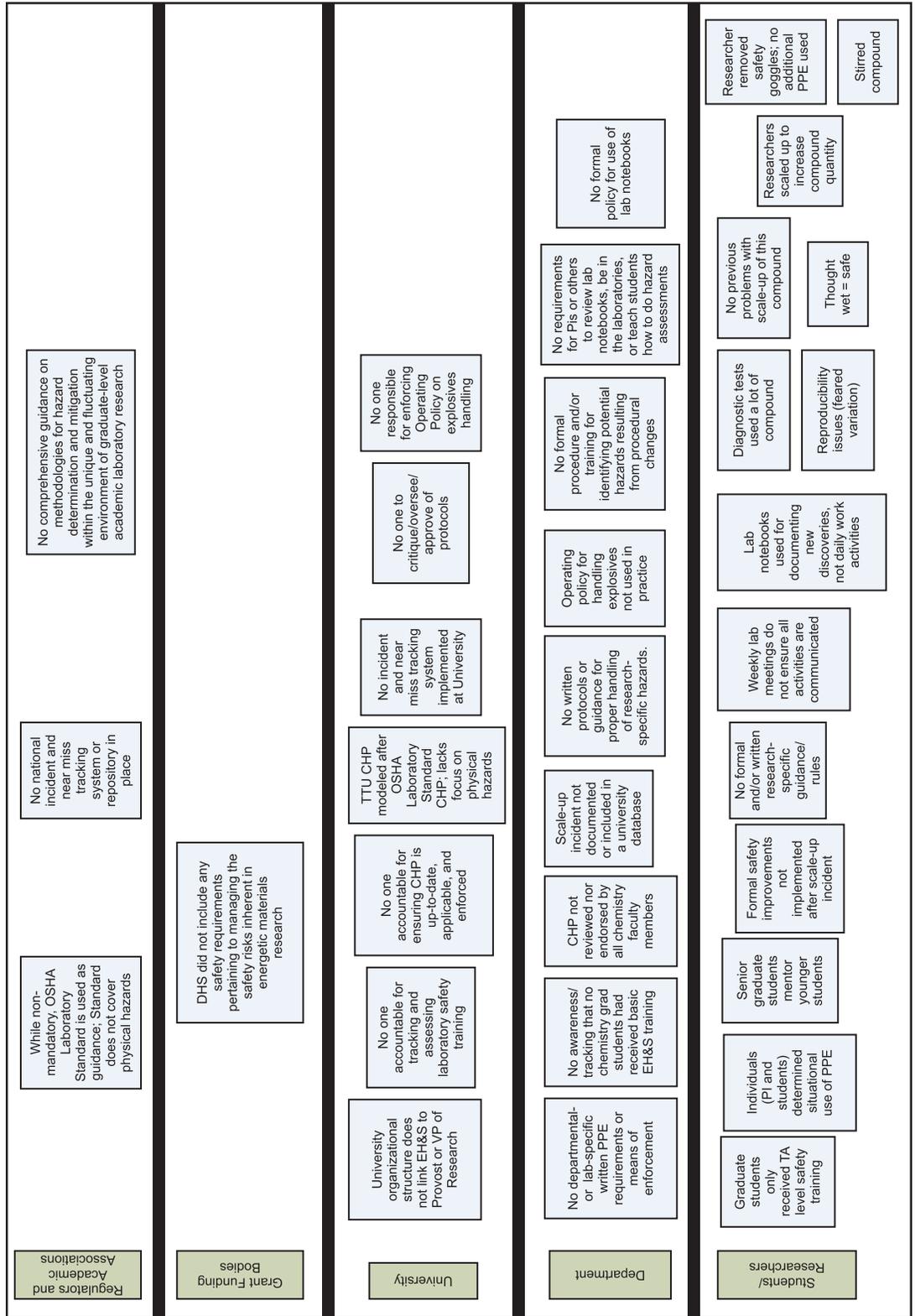
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## 11.0 REFERENCES

- Advisory Committee on the Safety of Nuclear Installations (ACSNI). *Study Group on Human Factors, Third Report: Organising for Safety*; London: HMSO, 1993.
- American Chemical Society (ACS), *Safety in the Academic Chemistry Laboratory, 7th ed.*, Washington DC:ACS 2003.
- American Institute of Chemical Engineers (AIChE). *Safety Culture: What is at Stake?* [http://www.aiche.org/uploadedFiles/CCPS/Resources/KnowledgeBase/Whats\\_at\\_stake\\_Rev1.pdf](http://www.aiche.org/uploadedFiles/CCPS/Resources/KnowledgeBase/Whats_at_stake_Rev1.pdf) (accessed June 6, 2011).
- American National Standard Institute (ANSI), *Occupational Health and Safety Management Systems*, ANSI/AIHA Z10-2005.
- Center for Chemical Process Safety (CCPS). *Guidelines for Hazardous Evaluation Procedures*; 3rd ed.; Center for Chemical Process Safety/AIChE, 2008.
- CCPS. *Guidelines for Investigating Chemical Process Incidents*; 2nd ed.; Center for Chemical Process Safety/AIChE, 2003.
- Crowl, D.A. and Louvar, J.F., Eds. *Chemical Process Safety: Fundamentals with Applications*; Englewood Cliffs: Prentice Hall, 1990.
- Department of Energy (DOE). *DOE Explosives Safety Manual*, DOE M 440.1-1A, <https://www.directives.doe.gov/directives/current-directives/440.1-DManual-1a/view?searchterm=None>, (accessed June 29, 2011).
- Hanson, D.J. OSHA's proposed exposure rule for labs offers much flexibility, *Chemical and Engineering News*. Aug. 24, 1986; pp 17-18.
- "Health and Safety Standards; Occupational Exposures to Toxic Substances in Laboratories; Proposed Rule," *51 Federal Register* 14, July 24, 1986; pp 26660 – 26684.
- Hill, R.H. & Finster, D.C. *Laboratory Safety for Chemistry Students*. New Jersey: John Wiley & Sons, 2010.
- McCroskey, J. C., & Richmond, V. P. Motivating faculty. In *Effective Communication for Academic Chairs*. Hickson, M., III & Stacks, D. W., Eds.; Albany, NY: State University of NY Press, 1992; pp 159-182.
- McCroskey, J. C. Fitting into the department. In *Teaching communication: Theory, Research, and Methods*, Daly, J. A., Friedrich, G. W. & Vangelisti, A. L., Eds.; Hillsdale, NJ: Erlbaum Associates, Inc., 1990; pp 471-479.
- National Research Council of the National Academies (NRC). *Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards*. Washington, DC: National Academies Press, 2011 (revised).
- National Science Foundation (NSF), Division of Science Resources Statistics. Survey of Earned Doctorates: 2010. <http://www.nsf.gov/statistics/nsf11306/> (accessed September 27, 2011).

- 
- National Science Foundation (NSF). Survey of Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions: FY 2007 (Updated September 2009). <http://www.nsf.gov/statistics/srvyfedsupport/> (accessed September 22, 2011).
- Occupational Exposures to Hazardous Chemicals in Laboratories: Final Rule. *55 Federal Register* 21; Jan. 31, 1990; pp 3300 – 3335.
- Persson, P., Holmberg, R., Lee, J., *Rock Blasting and Explosives Engineering*, Florida: CRC Press, 2010.
- Rasmussen, J. & Svedung, J. *Proactive Risk Management in a Dynamic Society*. Karlstad, Sweden: Swedish Rescue Services Agency, 2000.
- Reason, J. Human error: models and management. *British Medical Journal*, 320, 2000; pp 768-770.
- Zakzeski, J. Improving engineering research laboratory safety by addressing the human aspects of research management. *J. of Chem. Health and Safety*, 16(3), 2009; pp 5-20.

# APPENDIX A — MODIFIED ACCIMAP DEPICTING THE CSB'S ANALYSIS OF THE INCIDENT



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The U.S. Chemical Safety and Hazard Investigation Board (CSB) is an independent Federal agency whose mission is to ensure the safety of workers, the public, and the environment by investigating and preventing chemical incidents. The CSB is a scientific investigative organization; it is not an enforcement or regulatory body. Established by the Clean Air Act Amendments of 1990, the CSB is responsible for determining the root and contributing causes of accidents, issuing safety recommendations, studying chemical safety issues, and evaluating the effectiveness of other government agencies involved in chemical safety.

No part of the conclusions, findings, or recommendations of the CSB relating to any chemical accident may be admitted as evidence or used in any action or suit for damages. See 42 U.S.C. § 7412(r)(6)(G). The CSB makes public its actions and decisions through investigation reports, summary reports, safety bulletins, safety recommendations, case studies, incident digests, special technical publications, and statistical reviews. More information about the CSB is available at [www.csb.gov](http://www.csb.gov).

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U.S. Chemical Safety and Hazard Investigation Board  
Office of Congressional, Public, and Board Affairs  
2175 K Street NW, Suite 400  
Washington, DC 20037-1848  
(202) 261-7600