NASA SAFETY CENTER

SYSTEM FAILURE CASE STUDY

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Don't Mess With Excess

Texas Tech University Laboratory Explosion

January 7, 2010: A Texas Tech University (TTU) Chemistry graduate student was injured after an energetic compound he was working with detonated. The student lost three fingers, received burns to his hands and face, and suffered an eye injury. The lessons learned from the incident provide any institution conducting laboratory research, including NASA, with an important opportunity to compare its own policies and practices with those that existed at TTU leading up to the incident.

PROXIMATE CAUSE

- Violent energetic reaction
- Absence of proper personal protective equipment
- Unverified safety practice of dousing the compound with hexane to reduce volatility

UNDERLYING ISSUES

- Physical hazard management
- Lessons learned
- Safety oversight
- Research-specific safety training
- Granting agency responsibility

AFTERMATH

- Recognition of barriers to effective oversight and compliance
- Modification of organizational structure with emphasis on safety reporting
- Revision of granting agency's safety requirements for contracts
- Academia specific safety recommendations from CSB

Background

The ALERT Program

In October 2008, TTU entered into a subcontract agreement with Northeastern University (NEU) to participate in the Awareness and Localization of Explosive-Related Threats (ALERT) program. ALERT, funded by the U.S. Department of Homeland Security (DHS), seeks to effectively characterize, detect, mitigate, and respond to explosive related threats facing the United States and other nations. NEU and the University of Rhode Island led research by several other academic partners (including TTU) within the ALERT program.

TTU focused its research on how to detect energetic materials that could present a future security threat. This included synthesizing and characterizing new potentially energetic materials.

Nickel Hydrazine Perchlorate (NHP)

At the time of the incident, TTU students were testing nickel hydrazine perchlorate (NHP), an energetic compound of particular interest to the ALERT program because of its lethality and the ready availability of materials required to synthesize it. The danger of working with NHP lies in post-synthesis handling; the compound is extremely sensitive to friction and may detonate with the slightest disturbance.

Laboratory Preparations

Although TTU incorporated elements of the Occupational Safety and Health Administration (OSHA) Occupational Exposure to Chemicals in Laboratories Standard (29 CFR 1910.1450) in its laboratory operations, the TTU hygiene plan focused on toxic exposure hazards rather than physical hazards of chemical compounds handled in the laboratory.

Figure 1: TTU Department of Chemistry and Biochemistry. Source: TTU

The TTU laboratory practiced a 100-mg synthesis limit on energetic compounds; however, this limit was unwritten and only communicated by word of mouth from Principle Investigators (PIs) to students. In comparison, Navy guidelines caution that as little as 500 mg of energetic material can cause injury upon detonation.

TTU students intended to employ multiple analytical methods (e.g., differential scanning calorimetry, drop hammer tests, and thermal gravimetric analysis), to fully characterize the energetic properties of NHP. Realizing they would need to create several small batches of NHP to have enough compound to conduct their work, and amidst concerns of reproducibility between batches, the students opted to synthesize one large batch: approximately 10,000 mg/10 g—enough to complete all of the necessary tests.

The students did not consult the project PIs concerning the scale-up, as no written policies or procedures existed at the laboratory, departmental, or university levels which would have required the students to do so.

The graduate student injured in the incident, in his fifth year of graduate study, had been working on the ALERT project for about 1 year. Although the student independently researched energetic compounds in preparation for the ALERT program, he had not received any formal training or instruction in this field.

The Mishap

After synthesizing the large, 10-g sample of NHP, the graduate student involved in this incident observed clumping in the material. Believing that uniform particle size was vital in testing the NHP, the student transferred half of the NHP into a mortar and added hexane. Previously, students had observed that smaller amounts of the compound would not detonate under stress from impact or friction when wetted with water or hexane. Assuming that the volatility of the larger batch of NHP would be restricted in the same manner, the student began to gently break up the clumps of NHP with a pestle.

The student removed his goggles, and walked away from the mortar. The student then returned to the mortar to mix the portion of compound "one more time."

When the student resumed mixing, the NHP sample detonated. The student lost three fingers, received burns to his hands and face, and suffered injury to an eye. The blast was powerful enough to shatter part of the laboratory counter and damage adjacent equipment (Figure 2).

Proximate Causes

The NHP reacted violently because of the friction created when the compound was broken up between the mortar and pestle. Because no formal hazard assessment had been performed, the students worked with the material based purely on their limited observations of the compound's behavior in smaller quantities. While the NHP's volatility in finer powdered form was inhibited by water or hexane, the material was dry within the larger unbroken clumps and was in sufficient quantity to react violently with pressure and friction. The flammable hexane permeating the majority of the material and adding flammable vapor to the immediate area no doubt contributed to the reaction once ignition occurred.

Underlying Issues

Managing Physical Hazards

Although the OSHA Laboratory Safety Standard regulation is mandated in industry, it may see limited applicability in academia. As was noted by the Chemical Safety Board (CSB), the regulation's primary academic application is in controlling toxic exposure, which developed into a marginally authoritative, incomplete, and insufficiently communicated chemical hygiene plan at TTU.

Figure 2: Point of NHP detonation. Source: CSB

The TTU chemical hygiene plan stated that PIs were responsible for determining the hazards of chemicals generated within a laboratory, but neither TTU, nor its Chemistry Department, specifically trained researchers to identify hazards, describe an appropriate determination process, or verify that any evaluations had been completed prior to initiating experimental work.

None of the students under PI supervision in TTU's ALERT project were aware of a strict 100-mg limit, indicating to the CSB that they believed they should work with "very small amounts," on the order of 200 to 300 mg.

No formal hazard evaluation 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. Several individuals from the lab indicated that the decision to wear goggles was a personal choice which they based on personal perception of risk for each activity.

Lessons (Not) Learned

Two previous incidents had occurred within the same research groups approximately 3 years prior to the January 2010 explosion; however, some students within these groups indicated they were unaware of the incidents until after the 2010 event. Although no one was injured as a result, these incidents presented the PIs—and the entire TTU Chemistry Department—with an opportunity to close gaps in safety-critical knowledge and hazard awareness.

The first incident occurred in 2007 when a reaction from a student experiment began to emit nitrogen, causing loud bangs. Although the frightened student fled the laboratory, the key lesson informally passed on to other TTU students was the importance of staying with the experiment to provide direction to emergency responders instead of avoiding hazards. The event was not recognized as a lesson in hazard evaluation and risk assessment.

Later in 2007, a student unintentionally used the wrong units of measure and created an excess of 30 g of a known energetic material. After the student reported the synthesis at a group meeting, the PI immediately separated the 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 the research groups. Had the dangers of scale-up been formally communicated and reinforced as new students joined the research group, the likelihood of the occurrence of the 2010 incident may have been lessened.

While several academic institutions have attempted to compile lessons learned, there was no unifying standard from which the academic community could work cooperatively to share relevant lessons. In addition, there was no requirement or reporting system for tracking near-misses and incidents in the academic community. The two precursor events to the explosion show the value of robust close call, awareness, and lessons learned programs.

Figure 3: Workspace of a previous incident at TTU. Source: CSB

Lack of Oversight

Before the 2010 incident, the TTU Chemistry Department Safety Advisor and the laboratory safety inspector conducted safety audits and inspections of the 118 chemistry laboratories on campus. General laboratory safety violations were reported to the PI and the Department Chair. However, many university safety policies either did not exist or were not enforced. Remedial actions were often not taken. No single entity within the university was accountable for ensuring that the TTU Chemical Hygiene Plan was current, enforced, or pertinent to the laboratories or materials it was meant to control. As a result, PIs involved in energetic material research were generally aware of the Chemical Hygiene Plan, but not familiar with all of its content.

In academia, the PI generally has significant authority over personal research. If not effectively managed to maintain consistent behavior, this practice can create an environment where individual PIs perpetuate unique practices, often relying on informal communication in lieu of documented policies or procedures. This was the case at TTU prior to the 2010 incident. The PIs occasionally viewed laboratory safety inspections as infringing upon their academic freedom. Some PIs saw the notification of safety violations to the Chair as punitive, and felt that the safety inspections needlessly inhibited their research. Recommended safety changes were often considered outside the PI's control and any recommendations involving monitoring of laboratory activities were thought to be wasteful (the equivalent of "babysitting" of otherwise responsible students).

In addition, TTU's organizational structure did not facilitate opportunities for safety issues to be raised to authorities with the responsibility or means to ensure safety improvements were implemented. Before the 2010 incident, the organizational structure supported a "consultant" role for its Environmental Health and Safety organization, downplaying compliance findings to non-binding recommendations. No other group or person was empowered in an oversight role for compliance. Faculty members, including the PIs, reported to their Department Chair, Dean, and the Provost, who had direct authority over faculty. 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. However, there was no functional manager under the Vice President for Research who could facilitate compliance assessment. At the time of the 2010 incident, Environmental Health and Safety 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. No direct communication link existed within the organizational hierarchy to an authority who could enforce safety inspection results with the PIs. Environmental Health and Safety was not required, nor expected, to report its laboratory safety inspection reports or findings to either the Vice President for Research or the Provost.

No Research-Specific Safety Training

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's general laboratory safety training class offered online and in person by Environmental Health and Safety 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.

Granting Agency's Role

DHS is one of 19 federal agencies, including NASA, that collectively provide over $25.3 billion to academic institutions for scientific research (NSF, 2009). DHS lacked safety provisions specific to the energetic materials research being conducted by Texas Tech within its cooperative agreement with NEU.

The CSB identified the grant funding body's role in safety as a missed opportunity to influence positive safety management and behavior. The grant funding agency has the power to end a research contract and agreement and, thus, can play a strong role in raising safety awareness and preparedness by the researcher and university.

Aftermath

With respect to organizational structure, TTU recognized the barriers in place to effective oversight and compliance. The organization was modified so that the Environmental Health and Safety Director reports directly to the Vice President for Research, retaining independence from the Provost, Chemistry Department, and associated PIs. As a result, the Vice President of Research, who controls research funding, receives compliance reports and findings, and can direct spending within the Chemistry Department to resolve deficiencies. This organizational change also motivates the PI to optimize safety. While the PI remains focused on research, the organizational structure promotes response to safety deficiencies, prioritizes improvements, and installs accountability for adequate training and conduct of safe operations in the laboratories. In addition, specific guidelines and responsibilities were implemented to assure unique hazards are characterized by the PI prior to allowing students to perform independent laboratory procedures.

Recognizing the gaps in research direction that contributed to the 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 subcontracts:

- 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 controls are placed where applicable
- Independent review by subject matter experts of the safety protocols and practices is conducted

Figure 4: A NASA co-op student working with his supervisor. Source: NASA

As a result of its investigation, the CSB made six specific recommendations, many of which have been acted upon at TTU and in the academic community at large:

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 reports 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.

Since 2001, the CSB has researched 120 different university laboratory incidents. Each of these tragic incidents has in common a theme of highly educated and motivated individuals, often working independently with limited preparation for the task at hand. Many of the incidents involved preparation and support activities not considered to be the primary objective or most recognized hazardous threat. Though the CSB analysis focused primarily on chemical laboratory environments, most of the incidents involved physical hazards rather than toxic hazards.

Relevance to NASA

Comprehensive Chemical Hygiene Plans (prepared per NPR 8715.3 and 29CFR 1910.1450) are in effect at all NASA installations where chemical laboratories are active. Unlike at academic institutions, the OSHA regulations are completely applicable to our NASA workplaces, and our safety and research professionals are very familiar with effective chemical hygiene practices. In addition, it is common practice at NASA laboratories to closely couple the tenets of the hazard communication (29CFR 1910.1200) to comprehensively assure awareness of physical hazards beyond just potential toxic exposure to materials.

Figure 5: Yale senior, Michele Dufault participating in a micro-gravity experiment hosted by NASA's Johnson Space Center. Dufault died in April 2011, in a campus machine shop accident. Source: NASA

NASA's close call and lessons learned programs, and the NASA Safety Reporting Systems have been active for years, capturing the safety concerns and near misses from all facets of the NASA workforce. A recent estimate noted that as much 60% of hazard recurrence prevention is derived from the NASA close call program.

Application of NASA Comprehensive Hygiene Plans and close call and lessons learned programs protect students of NASA communities. Laboratory research by students is ongoing at NASA Centers and at college campuses supporting NASA research and education activities. At any given time, hundreds of students participate in NASA on-site activities through education outreach, intern, and cooperative education programs. Hundreds of other students and faculty members participate in NASA research grants across the country. Students are often exposed to many of the same potentially hazardous environments as regular full-time employees.

How NASA Grants Work

All NASA grants are subject to compliance "with all applicable federal, state, and local laws relating to safety" per 14CFR 1260.37. The NASA Technical Officer at each originating Center is responsible for reviewing and concurring with unique tasks and associated requirements. They work closely with Safety and Mission Assurance, Occupational Health, Environmental, Security, Information Technology, and Export Control representatives as necessary to assure NASA Research Announcements and associated grants identify unique technical, safety, and health provisions. In addition, strict requirements are in place to assure medical protocols are included on any research activities involving human subjects in accordance with 14CFR 1230. The recipients of NASA grants have specific responsibilities as well:

- The Recipient shall maintain a record of, and will notify NASA immediately of any accident involving death, disabling injury or substantial loss of property.

- The Recipient will advise NASA of hazards that come to its attention.
- Where the work involves flight hardware, the hazardous aspects, if any, of such hardware will be identified.

For the Students in NASA's Future

Even with the attention and scrutiny that goes with preparing grant provisions, it is the NASA and contractor veterans working directly with students, interns, cooperative education employees and faculty members that most influence their safety and health. Here are a few points to keep in mind while working with students and other academic representatives at NASA installations:

- Ensure that students and visiting professors get the same safety training your permanent employees receive. Sometimes there is self-imposed pressure to rush students through so they can get the most of the short time they are working with us. But remember, they are here to learn about their responsibilities to be safe employees as well. That first impression can last through an entire career wherever they end up working.
- Don't assume that students or visiting faculty understand unique hazards or precautions because of their education. This is true even for graduate students or doctoral candidates. While the principles of science and technology are the same everywhere, processes and conditions may be unique and potentially dangerous to those unaware of the local practices.
- Ask for feedback on training effectiveness and work to improve training relevance. Having new people on-board represents a valuable opportunity to collect fresh perspectives.
- Encourage students and visiting faculty to take safety and health information back to their respective campus (provided it is not sensitive). Even if it's familiar information, the media, methods, and tone of the information may represent a fresh way of conveying an important message that will resonate at home.
- Do not soften expectations or discipline for students or visiting faculty. While it is their home institution that has ultimate responsibility for performance and behavior, we can't overlook the responsibility we have to reinforce expectations for their safety.

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