Operating Experience Summary

U.S. Department of Energy
Office of Health, Safety and Security
OE Summary 2014-02
April 25, 2014

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Laboratory Worker Safety: Work Planning, Hazard Analysis, and Supervision 1

The Office of Health, Safety and Security (HSS) analyzes external operating experience events and issues to inform Department of Energy (DOE) Line Programs and their workers about how to better ensure safe operations across the DOE Complex. In accordance with the requirements in DOE Order 210.2A, DOE Corporate Operating Experience Program, *HSS reviews operating experience from a variety of agencies and industries, including investigations and analyses from the Chemical Safety Board (CSB) and others.*

Although laboratory workers are primarily focused on their work, they cannot afford to become complacent with respect to personal safety and should be reminded that laboratories can be dangerous places where safety must be integrated into every aspect of their work. This article addresses the dangers that laboratory workers—specifically graduate students and resident or guest researchers—may face as a result of inadequate work planning, hazard analysis, and supervision. The events included here highlight the need for laboratory staff and supervisors to be mindful of safety when planning work and analyzing potential hazards, and they demonstrate the importance of adequate supervision.

A summary of events and lessons learned from several university laboratory accidents, high school laboratory accidents, and those that occurred at DOE laboratories is presented first, followed by recommendations for laboratory safety and accident prevention and resources for further information and application.

Severe Injuries Resulting from a Texas Tech University Laboratory Accident

The Chemical Safety Board (CSB) investigated a laboratory accident that occurred at Texas Tech University, in Lubbock, Texas, in January 2010. In this accident, a graduate student working with a mixture of nickel hydrazine perchlorate (NHP) lost three fingers, injured an eye, and received severe burns and cuts on his face and hands when the NHP exploded. Another student working with him was not injured. Investigators determined that the student had transferred 10 grams of synthesized NHP into a mortar, added hexane, and was using a pestle to break up clumps when the compound detonated. Figure 1-1 shows the laboratory table post-explosion. The details surrounding this accident and the investigation can be found in the CSB report at http://www.csb.gov/assets/1/19/CSB_Study_TTU_.pdf.

Figure 1-1. Post-explosion view of laboratory table at Texas Tech

CSB Findings

Incidents such as the Texas Tech accident 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's safety system and its technical community. In the case of the Texas Tech event, this included the laboratory, department, and university levels at Texas Tech, as well as Northeastern University, which contracted with Texas Tech to perform the NHP research, and the Department of Homeland Security (DHS), which funded the Awareness and Localization of Explosive-related Threats (ALERT) study. The CSB concluded that there were deficiencies within each layer of safety management in all three organizations that contributed to the incident.

Figure 1-2, taken from the CSB report, is based on James Reason's "Swiss Cheese" Model of Accident Causation. The holes in the figure represent gaps or weaknesses within safety system elements or "barriers" intended to prevent or impede a hazard from adversely impacting a worker's safety in a laboratory setting where failures could occur. If a number of failures align, an incident can result. In the case of the Texas Tech incident, the CSB found that numerous systemic deficiencies (i.e., gaps) 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 preventive lessons were not documented, tracked, or formally communicated.

Physical Hazards Not Assessed, Planned For, or Mitigated

The Texas Tech Chemical Hygiene Plan (CHP), which established policies, procedures, and work practices for those working with chemicals, was developed in accordance with Occupational Safety and Health Administration (OSHA) Standard 29 Code of Federal Regulations (CFR) 1910.1450, *Exposure to Hazardous Chemicals in Laboratories*. The OSHA Standard focuses on health hazards resulting from carcinogens, toxins, irritants, corrosives, and other "exposure" hazards; physical hazards for work with explosives are not addressed, other than their inclusion in employer training programs. Similarly, the CSB found that the Texas Tech CHP specifically addressed only the health hazards of chemical exposures, not physical hazards. For example, the CHP required written procedures and hazard determination for work with carcinogens or toxins, but there were no similar requirements for those working with explosive materials. The CSB learned that the laboratory where the incident occurred had no written protocols or procedures for synthesizing NHP or other energetic materials, no written restrictions concerning the amount of compound to be synthesized, no written mandatory safety requirements pertaining to the synthetic work, and no required training.

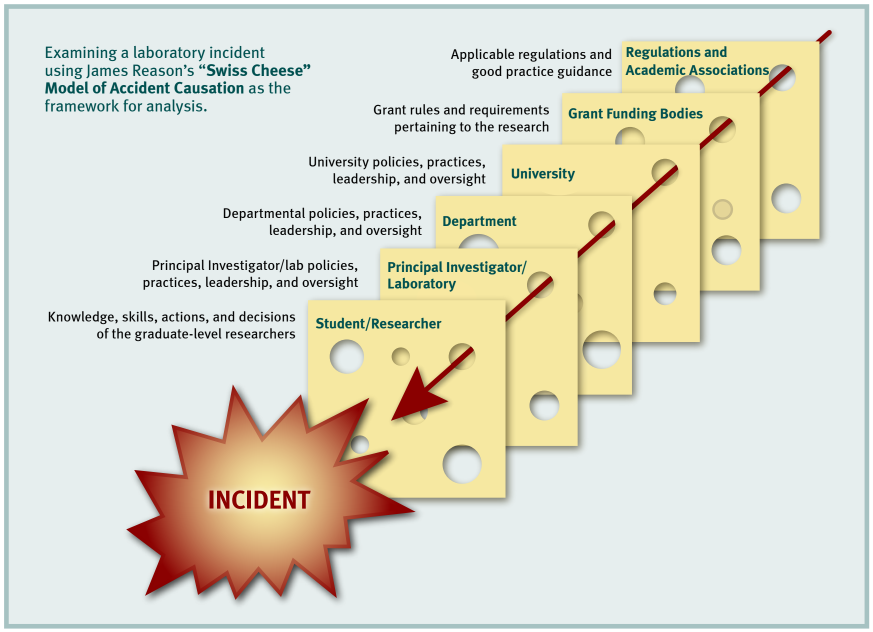

Figure 1-2. James Reason's "Swiss Cheese" Model of Accident Causation

In addition, the CSB noted that there was no comprehensive hazard evaluation guidance for any Texas Tech research laboratory.

All of these deficiencies contributed to the event, as shown in the following examples.

- The CSB found that the Principal Investigators (PI) communicated safety restrictions, such as a 100-milligram limit on the amount of compound permitted to be synthesized, to some students; however, there was no formal, written documentation to ensure that the information was effectively communicated and understood. When the CSB conducted interviews during the investigation, the students involved in the incident indicated that they were not aware of the strict 100-milligram limit for the NHP synthesis. They also said they did not think they needed to consult the PIs before scaling up to make 10 grams because there was no requirement to obtain permission or seek approval from their PIs before changing research experiment variables.
- The PIs were responsible for determining the hazards within a laboratory, but they were not trained to determine hazards, describe what an appropriate determination included, or verify that any evaluations had been completed before experimental work began. Researchers, such as the graduate student, also were not required to attend formal training on working safely in a laboratory setting. The graduate student performing the NHP work had only conducted a literature search about the properties of NHP. The students increased the amount of NHP they decided to synthesize based on their previous experience with smaller amounts of the compound and assumed that the NHP would not ignite or explode on impact when wet with water or hexane. They did not conduct a hazard evaluation or ask if one should be performed because it was not a requirement for their work.

> 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.
>
> *Prudent Practices* (NRC, 2011), taken from the CSB report

Lessons Learned Not Documented, Tracked, or Formally Communicated

The CSB determined that there was no requirement for tracking or reporting near misses in Texas Tech laboratories. Two similar incidents occurred in the same research group in 2007, but many of the students that the CSB interviewed did not know about them until the 2010 accident occurred. No one was injured in either of the 2007 incidents, but both incidents presented the PIs, and the Chemistry Department as a whole, with an opportunity to recognize that there were gaps in safety-critical knowledge and hazard awareness in the university's laboratories. The CSB identified the following issues from the first incidents that, if corrected, might have precluded the 2010 event.

- No formal hazard evaluation and risk assessment was completed after the first event to characterize the potential danger of the research activity and to plan for the worst-case scenario.
- No policy at the laboratory, department, or university level prompted students to seek PI advice or evaluation of experimental activities. The graduate student who was injured in the 2010 incident was in the laboratory in 2007 when a student inadvertently created an excess of 30 grams of an energetic material, which was witnessed by a PI who immediately separated the material into smaller, less hazardous quantities. However, the dangers of scaling-up the energetic material were never formally communicated or reinforced to students, and the near-miss was never reported to anyone outside the research group.

Had the dangers of scaling-up energetic material been communicated, the graduate student involved in the 2010 event might have realized the dangers involved in scaling up his experiment.

Lack of Safety Management Accountability and Oversight

For safety to be properly managed, it should play a prominent role within the layers of the organizational hierarchy and for those who are involved in the work being conducted. Safety accountability and oversight by the PIs, the department, and university administration at Texas Tech were insufficient to ensure safety.

The CSB determined that research laboratory safety was not adequately managed at Texas Tech, and many university safety policies were not enforced. The CSB also found that DHS did not have safety provisions specific to the energetic materials research being conducted by Texas Tech within its cooperative agreement with Northeastern University, and that the agreement between Texas Tech and Northeastern University included no provisions for the safety of researchers working with energetic compounds other than a condition making Texas Tech responsible for researcher safety. Among the CSB findings are the following.

- No single entity within the university was accountable for ensuring that the CHP was current, enforced, or applicable to the laboratories and materials it was meant to regulate, and many necessary safety policies either did not exist or were not enforced.
- The organizational structure of the university inhibited opportunities for safety issues to be raised to those with authority to ensure implementation of safety improvements.
- The Texas Tech Environmental Health and Safety (EH&S) inspector had no authority, and no other group or person was empowered with an oversight role; thus, safety recommendations could not be enforced. EH&S had no authority to shut down a laboratory and was neither required, nor expected, to report its laboratory safety inspection reports and findings to either the Vice President for Research or the Provost.
- PIs considered recommended safety changes outside their control because they could not "babysit" students.
- The DHS agreement with Northeastern University did not include safety provisions specific to either the energetic materials research conducted by Texas Tech or the safety of researchers working with the compounds. (The CSB identified this as a "missed opportunity" for DHS to influence positive safety management and behavior.) Prior to the incident at Texas Tech, there was no ALERT-wide policy that limited the quantity of energetic compound that could be synthesized.
- The Texas Tech subcontract with Northeastern University did not require pre-approval for experimental protocols for the energetic work.

Lessons Learned/CSB Recommendations

Based on the lessons learned at Texas Tech, the CSB recommended the following actions.

1. Ensure that all safety hazards, including physical hazards of chemicals, are addressed.
2. Ensure that practices and procedures are in place to verify that research-specific hazards are evaluated and mitigated.

3. Develop the specific written protocols and training needed to manage laboratory research risk.
4. Ensure that the safety inspector/auditor of research laboratories directly reports to an identified entity with organizational authority to implement safety improvements.
5. Document, track, and communicate near misses and previous incidents to drive safety change.

The CSB made the following recommendations for Texas Tech, OSHA, and the American Chemical Society.

Texas Tech

- Revise and expand the university 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.
- 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.

OSHA

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

ACS

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

Fatality Resulting from UCLA Laboratory Accident

The California State Division of Occupational Safety and Health (Cal/OSHA) investigated a 2008 laboratory accident at the University of California Los Angeles (UCLA) that resulted in the death of a Research Assistant (RA). Like the Texas Tech accident, the accident demonstrated the dangers in laboratories where students and staff, sometimes working without proper training or supervision, routinely handle toxic, flammable, and explosive compounds.

In December 2008, the RA was drawing tert-butyl lithium (t-BuLi) from a bottle into a syringe when the plunger came out of the syringe barrel, exposing the t-BuLi to the atmosphere. (Figure 1-3 shows a typical setup for syringing t-BuLi.) She was not wearing a lab coat, and the chemical, which ignites spontaneously in air, splashed onto her and ignited her sweater and gloves. Although an emergency shower was located nearby in the lab, she ran in the opposite direction,

Figure 1-3. Typical setup for syringing t-BuLi

toward the laboratory exit. Another researcher in the lab attempted to wrap his lab coat around the RA to extinguish the flames, but the lab coat also caught fire, so he poured water from a nearby sink on her, finally extinguishing the flames. The RA was burned on her hands, arms, and upper torso (43 percent of her body) and suffered additional inhalation injury from exposure to the t-BuLi. She died 18 days later.

Cal/OSHA Findings[1]

Cal/OSHA cited the UCLA chemistry and biochemistry department for lack of training, failure to document training, failure to correct previously identified unsafe laboratory conditions and work practices in the laboratory, and failure to ensure that employees wore appropriate personal protective equipment (PPE). Investigators specifically indicated that UCLA and the PI for the laboratory failed to properly train the RA to handle and transfer t-BuLi, failed to use appropriate Standard Operating Procedures (SOP) as required, and failed both to provide adequate PPE and to ensure that laboratory personnel used it. Following further investigation by Cal/OSHA special investigators, her supervisor (the PI) and the UCLA Board of Regents were charged with three counts each of willfully violating occupational health and safety standards.

Lack of Training

Cal/OSHA investigators learned that UCLA did not provide the RA with any general laboratory safety training during her employment. The investigators also determined that responsibility for worker safety was primarily the responsibility of PIs, but there was no requirement for PIs to attend safety training before conducting research in their assigned labs and no effort to evaluate whether the PIs were competent to comply with and enforce workplace and laboratory safety regulations before they supervised laboratory staff. Cal/OSHA findings included the following.

- The PI indicated that he "might have" provided the RA with general guidance on the procedures underlying the reaction, but he had no specific recollection of the guidance he offered or of providing formal training about the syringe transfer method.
- The organizational structure of the university inhibited opportunities for safety issues to be raised to those with authority to ensure implementation of safety improvements.

Failure to Use Appropriate SOPs in the Laboratory

Using t-BuLi requires special handling procedures that are outlined in two bulletins published by the manufacturer (Aldrich). The bulletins clearly state that "All users of these reagents must be fully qualified and experienced laboratory workers to handle pyrophoric reagents without problems. All users must be made aware of the very hazardous nature of these products." However, the cautionary information in the bulletins apparently was neither communicated nor put into use in the laboratory. The PI stated that he did not review the procedures outlined in the bulletins with the RA, did not ask her if she was aware of the procedures outlined in the bulletins, and did not discuss the risks associated with the use of t-BuLi with her. Cal/OSHA's review of actual laboratory practices revealed that many of the procedures that the PI used when working with the reagent were contrary to the procedures outlined in the manufacturer's bulletins. These decisions contributed to the accident, as indicated by the following missteps made by the RA.

- The RA attempted to make multiple transfers of t-BuLi using the same syringe. Although a common practice in the UCLA laboratory, multiple syringe use can result in plugged needles.

[1] The CAL/OSHA Findings discussion utilizes information as cited in the Cal/OSHA report located at http://s3.documentcloud.org/documents/286342/cal-osha-report.pdf. Additional details about this event can be found in this document.

- The RA used a 60-ml syringe to transfer approximately 53-ml of reagent, contrary to both the procedures outlined by the manufacturer and in scientific literature (i.e., the syringe must be at least twice the size of the intended transfer). The failure to follow the so-called "two times rule" can cause the plunger to become unstable and creates a greater likelihood that the plunger can inadvertently be pulled from the syringe barrel.
- Manual manipulation of the syringe plunger, confirmed as an accepted practice by the PI, is contrary to the manufacturer warnings that doing so can result in leaks, the accumulation of gas bubbles, air in the syringe, and difficulty in manipulation.

Failure to Ensure Use of PPE

The RA was not wearing a lab coat or other flame-resistant clothing on the day of the accident and was not using fire-resistant gloves or respiratory protection; however, the PI continued to maintain that a cotton lab coat was sufficient protection from the high degree of risk posed by the reagent. The PI told Cal/OSHA investigators that he "encouraged" the use of lab coats in the laboratory facilities, but researchers in his lab said that neither they nor the RA routinely wore them and that the PI did not enforce any rule requiring their use. Investigators also determined that UCLA's Environment, Health and Safety (EH&S) Department was well aware that research staff within virtually all laboratories at the University did not routinely wear lab coats or other PPE while working in the laboratories.

Cal/OSHA Conclusions

Investigators concluded that the laboratory safety policies and practices at UCLA were so defective that they rendered the University's required CHP and Injury and Illness Prevention Program essentially nonexistent. The lack of adequate lab safety training and documentation, lack of effective hazard communication practices, and repeated failure to correct persistent and repeated safety violations within University labs, led to a systemic breakdown of overall laboratory safety practices. Their findings and conclusions included the following deficiencies.

- As a critical component of the University's CHP, PIs are required to develop and implement SOPs relative to the use of hazardous chemicals, substances, processes, or operations that are carried out in the laboratory setting. In this case, the PI simply disregarded the open and obvious dangers and permitted the RA to work in a manner that knowingly caused her to be exposed to a serious and foreseeable risk of serious injury or death. If the PI had implemented an SOP as required, properly trained the RA, and ensured that she wore appropriate PPE, her death might have been prevented.
- The University EH&S Department conducted numerous inspections and was aware of continuous and pervasive safety violations within the laboratories, particularly with respect to the failure of personnel to use adequate PPE, but failed to correct recurring hazards. In fact, even after two incidents that resulted in significant burn injuries to employees who failed to wear required PPE, the EH&S Department took no action. Had they done so, this event may not have occurred.
- UCLA, through its failure to maintain an effective CHP and Injury and Illness Prevention Plan, through repeated inability of the EH&S Department to ensure enforcement of chemical safety requirements, and through the actions of the PI neglected its legal obligations to provide a safe working environment for lab personnel.

Corrective Actions

The University implemented a number of corrective actions as a result of this accident and the OSHA investigation. The UCLA Chancellor gave the EH&S Department the authority to shut down labs that do not comply with these actions and stipulated that a lab cannot reopen until the responsible PI appears before a university safety committee and provides an action plan to improve safety in the lab. The following corrective actions were implemented.

- EH&S now provides general safety training monthly, and researchers cannot receive keys to their labs until the training is completed.
- UCLA purchased flame-resistant lab coats for researchers using flammable reagents.
- Laboratory safety inspections have been standardized and expanded. Items identified as critical must be corrected within 48 hours; other deficiencies, within 30 days.
- University research personnel are required to quantify chemical, biological, and other hazards to assess risks, and must specify appropriate PPE and train all lab personnel in the use of the correct PPE for their experiments.

> "Researchers at UCLA do not always appreciate the tougher regime, sometimes seeing environmental inspectors as 'police', rather than partners in improving standards. Changing the culture is really going to be a long-term challenge," said [James] Gibson. "Some professors have even questioned the need for flame-resistant lab coats—a bitter irony given the circumstances of [the RA's] accident."
>
> *James Gibson is UCLA's Director of Environmental Health and Safety Department*
> (http://www.nature.com/news/2011/110418/full/472270a.html)

High School Laboratory Accidents

On January 2, 2014, in Manhattan, New York, two tenth-grade students received serious burns during a "rainbow experiment" in their chemistry class, which involved burning various metal flakes to create multicolored flames. As the students conducted the experiment, a blast shook the lab and a fireball hit the teens. A 16-year-old student received first-degree burns to her arm and hand and was treated and released; the other 16-year-old injured student was severely burned around his face and neck and was determined to be in critical condition at a local hospital.

On January 23, 2006, in Ohio, serious injuries occurred to a high school student involving the same rainbow experiment. In December 2013, the CSB published a video and safety message entitled "After the Rainbow," featuring the Ohio high school accident survivor from January 2006. The student describes how at age 15 she was burned over 40 percent of her body during a chemistry demonstration performed by her teacher at a boarding school. After the January 2, 2014, accident, the CSB stated that the accident was "all too similar to the one we highlighted in a recent video safety message that specifically focused on potential dangers in high school chemistry laboratories." Both the 2006 and 2014 high school accidents involved the same rainbow experiment, the teacher having too much accelerant near the experiment, lack of PPE (no safety goggles were worn), and observers (students) in very close proximity of the demonstration. The student in the Ohio accident advises other teens that "it's perfectly okay to speak up if you're not feeling safe, to always question, and if you're given a piece of information on safety, read it."[2]

[2] For more information, see: http://www.csb.gov/videos/after-the-rainbow/

Applicability to DOE

Although the CSB, OSHA, the ACS, and other organizations have recently focused attention on safety at university laboratories, many of their concerns and findings are applicable to government and industry laboratories as well. A search of the DOE Occurrence Reporting and Processing System (ORPS) database for occurrences in DOE laboratories for the years 2010 through 2013 identified 45 events involving guest researchers, post-doctoral students, and graduate students. These DOE laboratory incidents are similar to university incidents resulting from issues that included inadequate work planning and procedures, incomplete hazard analysis/communication, insufficient supervision, and improper or no use of PPE. Most of the incidents resulted in only minor injuries, but all had the potential for a more serious outcome.

Researcher Injury Resulting from Argonne National Laboratory-East Accident

An incident occurred on April 23, 2013, at Argonne National Laboratory-East, where an analytical chemistry laboratory researcher was sprayed with an Americium 241 standard dissolved in liquid in a 5-milliliter, sealed glass ampoule. The ampoule ruptured when the researcher scored the neck of it, spraying material out of the hood opening and onto his face and lab coat. Surveys found removable alpha contamination on his lab coat, as well as on the skin on his face (1,570 disintegrations per minute [dpm]/100 square centimeters [cm^2]) and chest (1,040 dpm/100 cm^2) and on his shirt (5,330 dpm/100 cm^2). (ORPS Report SC--ASO-ANLECSE-2013-0001)

Researcher Injury Resulting from Idaho National Laboratory Accident

In early February 2013, a researcher at Idaho National Laboratory was sprayed with a mixture of hot steam and molten salt while testing a sparger unit. The researcher suffered second- and third-degree burns, even though he was wearing appropriate PPE, including a face shield, thermal-rated lab coat, and thermal protective gloves. He was taken to a local hospital and released later that evening. (ORPS Report NE-ID--BEA-INLLABS-2013-0001)

An investigation of this event identified issues with hazard control, as well as with the researchers conducting work outside the boundaries of laboratory instructions, which resulted in defeating the barriers in place to mitigate hazards. In addition, no one was supervising the researchers during the experiment. Findings included the following.

- No walk-down was performed before starting work, although that was a requirement of the work management procedure, and the work package preparation was inadequate and did not accurately reflect the work that was to be completed.
- The researchers did not validate that the appropriate mitigation measures were in place, nor were they required to do so.
- The lack of oversight and performance monitoring by laboratory management impacted their ability to control and coordinate activities to ensure safe and reliable work performance.

Graduate Student Injury Resulting from Argonne National Laboratory-East Accident

Lack of supervision and training were also major contributors to an event that occurred on February 25, 2011, at Argonne National Laboratory. A guest graduate student had placed silica coated with trimethylgallium and palladium into separate round-bottomed flasks in a hood; while he was manipulating valves, he noticed that one flask had slipped from its original position and some of the palladium powder had been sucked up into a vacuum line. He closed the valves and removed the flask of trimethylgallium, which immediately reacted with oxygen and broke open. Investigators determined that the guest graduate student did not receive sufficient guidance and oversight from his mentor and that he had less than adequate skills for the work he was performing. (ORPS Report SC--ASO-ANLE-ANLECSE-2011-0002; final report issued May 9, 2011)

The corrective actions for this event provide guidance for all DOE laboratory supervisors with regard to supervision and mentoring of graduate student researchers and other guest researchers. The corrective actions included those listed below.

- Require supervisors of guest graduate students to sign a mentorship agreement that includes oversight requirements.
- Verify that all staff members responsible for students are current on the training course for supervising students.
- Provide guidance (including hazard analysis and controls) for when graduate students should have their own task and when they are to perform work under an existing overarching work control document.
- Ensure that all supervisors are aware of the requirements for supervising guest graduate students.

Preventing Events

Ensuring a safe environment in any laboratory setting is the combined responsibility of laboratory personnel; environmental, safety, and health personnel; and management. At DOE, the principles of both Human Performance Improvement (HPI) and Integrated Safety Management (ISM) can be applied to laboratory work to enhance safety.

Human Performance Improvement

The CSB investigation report on the Texas Tech accident referenced James Reason's "Swiss Cheese" Model of Accident Causation, which suggests that systemic failures, or accidents, occur from a series of events within the various barriers of a system. James Reason's model describes barriers as layers and within the different bariers there are holes that represent opportunities for failure. When holes in the barriers line up, a loss or accident can occur. The major deficiencies of a system are: (1) unsafe acts, (2) conditions (for unsafe acts), (3) unsafe supervision, and (4) influences of an organization (Figure 1-4). DOE-Handbook (HDBK)-1208-2012, *Accident and Operational Safety Analysis*, also applies HPI in DOE's accident investigation process.[3] In both the accidents in educational institutions and those at DOE labs, there were holes in the various barriers. However, the lack of supervision is the primary hole that led to many of the events. Figure 1-5 shows a number of deficiencies that can occur during supervision that were primary contributors to the UCLA event and to several of the DOE events discussed above, particularly the failure to provide adequate guidance, training, and oversight of student and guest researchers.

> Error management has two components: limiting the incidence of dangerous errors and—since this will never be wholly effective—creating systems that are better able to tolerate the occurrence of errors and contain their damaging effects.
>
> *James Reason*

Integrated Safety Management

The guiding principles and core functions of ISM impact safe operations by taking an overall systems approach to safety, and ISM implementation does not distinguish between students and other personnel working at DOE sites. DOE O 450.2, *Integrated Safety Management*, ensures that

[3] OE-HDBK-1208-2012, Accident and Operational Safety Analysis, is located at: http://energy.gov/hss/downloads/doe-hdbk-1208-2012.

DOE systematically integrates safety into management and work practices at all levels. In 1996, DOE published a policy statement (DOE P 450.4, *Safety Management System Policy*) on Safety Management Systems establishing the ISM system as its overarching framework for identifying and managing workplace hazards to ensure the protection of workers, the public, and environment. Since the establishment of ISM, injury and illness rates have declined across the Complex.

In addition, DOE G 450.4-1C, *Integrated Safety Management System Guide*, provides line and contractor management with information on effectively and efficiently implementing the ISM requirements described in DOE O 450.2. Students are afforded the same protections and assume the same duties and responsibilities as any DOE employee for safe work practices, and supervisors are to ensure that each student possesses a thorough understanding of safe work practices and that a hazard analysis has been completed before work begins. However in all of the DOE events, investigators determined that work planning and hazard analyses were deficient and that the researchers did not have all of the necessary training and skills needed to ensure safety.

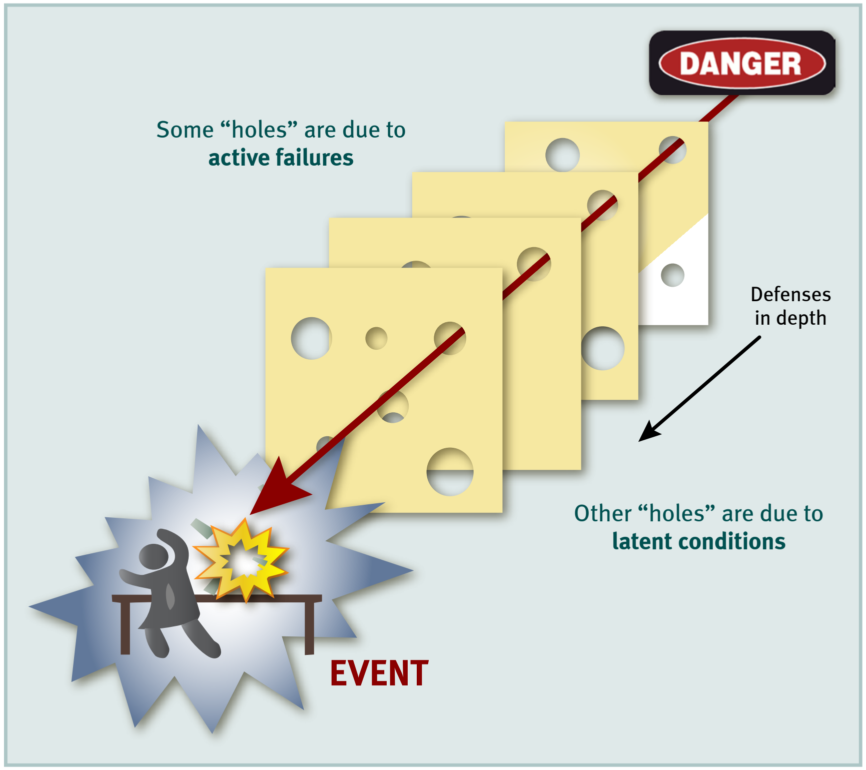

Figure 1-4. Reason's Accident Causal Chain

Supervised Inadequately

- Failed to provide guidance
- Failed to provide oversight
- Failed to provide training
- Failed to track qualifications
- Failed to track performance

Failed to Correct Problem

- Failed to correct document in error
- Failed to identify an at-risk worker
- Failed to initiate corrective action
- Failed to report unsafe conditions

Planned Inappropriate Operations

- Failed to provide correct information
- Failed to provide adequate time (for briefing)
- Improper staffing
- Task not in accordance with rules/regulations
- Failed to track adequate opportunity for rest

Violations of Supervisor

- Authorized unnecessary hazard
- Failed to enforce rules and regulations
- Authorized unqualified staff to work

U of CA, Riverside, Integrating Safety Into Operations, *J. Ducut, Ed.D.* (http://www.ehs.ucr.edu/safety/systems/presentation%20handout.pdf)

Figure 1-5. Supervisory deficiencies that can impact safety

Conclusion

It is essential that those working in laboratories take safety seriously and perform their work within the controls in place to identify hazards and protect workers from them. As the events at Texas Tech, UCLA, and high schools show, serious injury or death can result from not ensuring that work is properly planned and carried out and that all hazards are identified and the necessary precautions taken (e.g., wearing appropriate PPE). Supervisors should always thoroughly discuss work with researchers to describe the specific tasks they will be performing, address any potential hazards and error-likely situations, and generally prepare them for any possible consequences. This is particularly important in the laboratory setting, where an unfamiliar situation may be encountered or something unanticipated can occur. The textbox on the right includes a list of good practices to keep laboratory workers safe.

Help keep workers safe in the laboratory with the following good practices.

- Safety education of all personnel before entering the laboratory
- Appropriate use of protective equipment and clothing
- Safe handling of materials in laboratories
- Safe operation of equipment
- Safe disposal of materials
- Safety management and accountability
- Hazard assessment processes
- Safe transportation of materials between laboratories
- Safe design of facilities
- Appropriate emergency response
- Applicable government regulations

(http://www.nap.edu/openbook.php?record_id=12192&page=28)

Students and other guest researchers in the laboratory must also take responsibility for their own safety, and supervisors should stress that all researchers must take the following measures to protect themselves when performing experiments.

- Follow the work plan.
- Properly wear required PPE.
- Be aware of the identified hazards.
- Ask "what if?" in order to be prepared for unexpected or unidentified hazards.
- Stop work if conditions change.

Resources for Additional Information and Application

Chemical Safety Board, Texas Tech University Laboratory Explosion Case Study

DOE Policy 450.4A, *Integrated Safety Management Policy*

DOE Order 450.2, *Integrated Safety Management*

DOE G 450.4-1C, *Integrated Safety Management System Guide*

DOE-HDBK-1208-2012, *Accident and Operational Safety Analysis*

DOE Order (O) 225.1B, *Accident Investigations*

DOE Order 232.2, *Occurrence Reporting and Processing of Operations Information*

Reason, J., *Managing the Risks of Organizational Accidents*, Ashgate Publishing, 1997.

University of California Los Angeles Investigation Report 12-23/09

10 Code of Federal Regulations (CFR) 851, *Worker Safety and Health Program*

29 CFR 1910.1450, *Occupational Exposure to Hazardous Chemicals in Laboratories*

Accident Investigation into Mower Fatality at the Bryan Mound Site 2

On September 13, 2011, at the Department of Energy's (DOE) Strategic Petroleum Reserve (SPR) Bryan Mound Site (pictured in Figure 2-1), a recently-hired, untrained, subcontract Grass Cutter (G-1) was fatally injured when he struck three large, elevated pipes while operating a front-deck mower. On the day of the accident, the supervisor assigned four Grass Cutters to perform duties outlined in the Safe Work Permit (SWP): grass-cutting, weed-eating, and applying herbicide. G-1 had begun employment the day before the accident as a subcontractor to DM Petroleum Operations Company (DM), after working at the site for 23 years as a painter and mechanic. Although G-1 had occasionally performed grass-cutting in the past, he did not have experience with, or training on, the mower being used the day of the accident and had been assigned to weed-eating activities only until the supervisor could provide the required training. (ORPS Report FE--SPRO-SPR-BM-2011-0001; final ORPS Report not issued as of April 10, 2014)

The DM Site Maintenance Technician (SMT) supervising the Grass Cutters conducted a morning meeting and clearly communicated that G-1 would be working on weed-eating, not mowing, because he had not completed the requirements in "OJT for Large and Small Tractor Mowing." At about 0830 hours, the SMT again called all of the Grass Cutters together, reiterated that G-1 was to stay off the mowers and use the weed-eater; then left to participate in an Emergency Response Team (ERT) drill. The four Grass Cutters took their morning break, during which G-1 ate, drank, and interacted normally. Then G-3 and G-4 drove mowers to the Cavern 5 work site with G-1; G-2 went to mow at Cavern 5 area, which was some distance away from G-1. As lunchtime approached, G-3 and G-4 were preparing to leave the area—one to escort a visitor; one to get his lunch from the front gate. After expressing an interest in familiarizing himself with the mower and declining offers to accompany the others on their errands, G-1 sat on the mower seat and turned on the engine. The Grass Cutters warned G-1 not to drive the mower but did not make him get off the mower or insist that he accompany them to lunch. After warning him, they left him. Since G-1 was now alone, by default, G-2, who was mowing in the adjacent area, became the escort for G-1, but G-2 had not been informed that the others were leaving. As a result, G-2 could not stop G-1 from operating the mower.

Figure 2-1. Aerial photo of Bryan Mound Site

Mower-1 is placarded with a number of safety warning labels, including one on the front of the mower listing cautions, such as "Operator training required" and "Read operator's manual" (Figure 2-2). Sometime between 1120 hours and 1130 hours, with no coworkers present to stop him, G-1 operated the mower, cutting a path west, then southwest, then west, again, making a turn around an unmarked concrete obstruction—all of which indicated he was still in control. Between 1125 hours and 1130 hours, however, G-1 struck three large, elevated pipes with significant force (Figure 2-3). After the mower contacted and passed under the nearest and largest pipe, sufficient energy remained that when forward motion stopped, the front end of the mower lifted, leaving only a few inches of clearance between its seat and the pipe. From a distance, G-2 realized that G-1 had not moved and was leaning to the right side of the mower; G-2 arrived at the scene and notified the SMT by cell phone. Finding G-1 unresponsive and without a pulse, the SMT, who was a qualified ERT member, immediately requested ERT and ambulance assistance. The Galveston County Medical Examiner's Office declared death was caused by blunt force trauma resulting in severed spinal cord and internal bleeding.

Figure 2-2. Mower-1 warning label facing driver

The Investigation

After consulting with the Office of Fossil Energy, the Chief Health, Safety and Security Officer appointed an Accident Investigation Board to investigate the event to determine its causes and identify Judgments of Need (JON) to reduce the potential for similar accidents. Based on its investigation, the Board determined that the accident and fatality were preventable. The identified deficiencies were significant and warranted immediate management attention and corrective actions that could prevent recurrence. After reviewing corrective actions at SPR from 2000 to the present, the Board determined that long-standing issues associated with work planning and control and the safety culture still existed. Additionally, the Board noted that the DOE Independent Review Board that evaluated the July 2010 tank-cleaning fatality identified opportunities for improvement in understanding of, and adherence to, safety requirements, oversight programs, and other areas that were also pertinent to the mower accident.

Causes

After performing barrier, change, and error-precursor analyses, the Board identified the following causes.

Contributing causes collectively increase the likelihood of an accident but do not individually cause it. Collective causes for the mower fatality were (1) a less-than-adequate work control process; (2) G-1's lack of competency in operating the mower; (3) G-1's previous site experience, coupled with it being his first day on this job; (4) an unavailable supervisor; and (5) no escort for G-1.

Figure 2-3. Position of mower after accident

Root causes are factors that, if corrected, would prevent recurrence of the same or similar accident. The Board identified two root causes: G-1 failed to follow the supervisor's direction to stay off the mower; and the organizational Stop Work Authority policy and its implementation did not address less-than-imminent-danger situations.

Finally, a *direct cause* is the immediate event or condition that caused the accident: G-1 and the mower struck the elevated pipes.

Conclusions

The Board concluded that *work planning and control* was inadequate because the Job Hazard Analysis (JHA) process for large and small tractor mowing lacked inclusion of the applicable hazards from equipment manufacturers' operators' manuals and other identified applicable hazards and controls; periodic worker review; use of qualified operators; and a policy for conduct of pre-job briefings. The Board also concluded that the *on-the-job training* (OJT) program for Grass Cutters was not equipment-specific and lacked sufficient documentation with respect to content and that G-1 was not qualified to operate the mower because he had not completed either the required position training or the OJT to operate the mower.

The DM Stop Work Authority policy does not incorporate requirements of DOE Order 422.1, *Conduct of Operations*, to the extent necessary, resulting not only in a policy that lacks sufficient instruction and training, but one that was not used by the workers at the job site. The DM *equipment inspection and maintenance* program and pre-operational checklists do not include important information from the manufacturer's operator's manual, and the mower involved in the accident had several pre-existing equipment deficiencies, identified by an equipment expert after the accident. The *accident scene was not adequately preserved* immediately following the accident: DM management and staff were allowed access to the scene the afternoon of the accident before the Board's arrival onsite, and someone had engaged the brake pedal of the mower post-accident.

Numerous unidentified and unaddressed error precursors existed the day of the event. Had *Human Performance Improvement (HPI)* tools and techniques been used to communicate, manage, and defend against human error, the accident might have been prevented. *Lessons Learned were not effectively utilized* from corrective actions following the July 2010, SPR tank-cleaning fatality and, because organizations did not effectively review and use operating experience information to continuously learn and improve operations, long-standing problems existed related to failing to understand or comply with health and safety requirements. Grass Cutters did not follow the instructions given by Supervision on the day of the accident, and the site's escort policy was not implemented as required. Safety Organization Requirements in the Accident Prevention Manual were unclear and not consistently implemented.

Human Performance

Production and prevention always compete in workers' minds, and leaders have to constantly work to keep the facility and work environment safe. Leaders must ensure that prevention-centered attributes do not conflict with the production-centered attributes, that is, safety versus schedule. In normal human behavior, production behaviors take precedence over prevention **unless** there is a strong safety culture, nurtured by strong leadership. Within DOE, most serious events do not happen during high-hazard or complex operations because workers are paying attention, many people are involved, things move slowly, and everyone is mindful. Most serious events occur during so-called "routine" operations such as grass-cutting, operating heavy equipment, or performing electrical work. In this event, workers performing a routine operation did not exercise their stop work authority, follow JHA requirements, or follow the escort requirements. Because human beings may not know how to take the correct actions or may feel uncomfortable doing something different from their peers, their leaders must set, communicate, and model performance expectations and continually reinforce them.

The Board recommended more than 30 Judgments of Need (JON), including the ones described below.

- Ensure that hazards listed in equipment manufacturers' operators' manuals and other relevant references are included in the JHAs.
- Revise the Safe Work Permit (SWP) process to specifically include a review of JHAs for the work to be performed and to confirm that adequate controls are in place.
- Revise the SWP process to require the initiator to verify that assigned workers are trained and qualified to perform the work.
- Develop a pre-job briefing process that establishes a minimum set of requirements to be addressed commensurate with the hazards and complexities of the work.
- Ensure that there are adequate requirements and guidance to prevent disturbance of an accident scene and establish a more stringent control process at the scene of an event.
- Implement HPI principles and techniques to manage and defend against human error.

More information about the event, the JONs, and the Board's Recommendations is available in the Board's report, which can be accessed at http://energy.gov/hss/downloads/investigation-september-13-2011-fatality-strategic-petroleum-reserve-bryan-mound-site.

KEYWORDS: Training, OJT, mower, fatality, human performance, HPI, work planning, work control, accident investigation, AI

ISM CORE FUNCTIONS: Define the Scope of Work, Analyze the Hazards, Develop and Implement Hazard Controls, Perform Work within Controls, Provide Feedback and Improvement

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