Operating Experience Summary

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Fatality While Driving Gradall Material Handler on a Remote Forest Service Road 1

On October 1, 2013, a Tice Electric Company (Tice) employee was fatally injured while driving a Gradall, Model 534D9-45, Material Handler (Gradall) on a Montana Forest Service Road, when the Gradall left the roadway, rolled down an embankment, and rolled over him. The driver was enroute from a remote mountaintop Bonneville Power Administration (BPA) radio station to an established pickup point for the Gradall; the accident was witnessed by others who were following closely behind on the narrow road. The BPA Chief Safety Officer appointed an Accident Investigation Board (Board) to investigate the accident, analyze the causes, and make recommendations to prevent recurrence.

Background

BPA is one of four regional Federal power administrations within the Department of Energy (DOE). It markets power from all Federally-owned hydroelectric projects in the Northwest and manages facilities necessary to transmit that power. Tice provides contract electrical services and electrical construction, including services for electrical power substations and has completed emergency generator (EG) replacement, fiber-optics installation, battery replacement, and facility construction projects for BPA.

The Electrical Construction Company (EC), which offers contract electrical services and labor for electrical construction, provides safety watchers for work on BPA facilities.

Work Location and Activity

BPA's Patrick's Knob Radio Station (Figures 1-1 and 1-2) was being upgraded with an EG replacement under a single project plan. The replacement was a high priority due to generator-set damage earlier in the year and station accessibility issues during the upcoming winter.

BPA contracted with Tice to replace the EG under a Master Contract that included project-specific instructions and technical specifications. BPA approved Tice's Site-Specific Safety Plan (SSSP) and provided the Notice to Proceed (NTP) on September 9, 2013. Tice started onsite work the week of September 23, 2013, to replace the existing EG, renovate the building, make minor structural modifications, and replace other electrical equipment and fixtures. The assigned work

Figure 1-1. BPA's Patrick Knob Radio Station

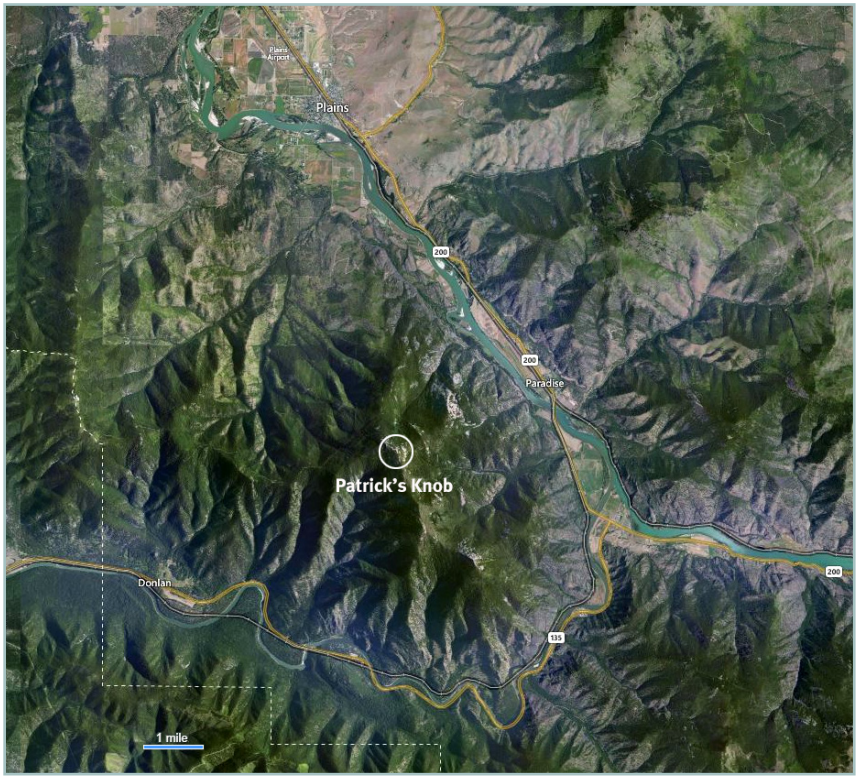

Figure 1-2. Remote location of Patrick's Knob

crew consisted of a Tice Lead Electrician (TLE), Tice Lineman (TL), Tice Material Handler Employee (TMHE), and the Electrical Construction Company Safety Watch (ECSW).

To facilitate removal of the old EG and placement of a new one, Tice rented the Gradall, which was equipped with a Roll Over Protection System (ROPS)* that included an operator seatbelt as part of the system. The Gradall (Figure 1-3) was delivered to an access point on Forest Service Road 508, referred to as the "second cattle guard," and the TLE drove it the 11.5 miles up to the radio station site. The SSSP noted that the last 4 miles of the road had reduced space where vehicles could not

* ROPS is also an acronym for Roll Over Protection Structure

Figure 1-3. Gradall Model 534D9-45 Material Handler with ROPS

pass without one moving off the road and that for safe travel vehicle speeds had to be less than 5 miles per hour.

During the day, Tice workers completed various jobs: painting the building interior; disconnecting the old EG; setting the new EG on rollers in the EG room; and loading the old EG onto a flatbed truck for return to BPA. The TMHE operated the Gradall several times during the day, and there were no abnormal mechanical conditions or problems. In the afternoon, the TLE decided to return the Gradall to the "second cattle guard" delivery site so the rental agency could pick it up. The TMHE was to load additional materials onto the flatbed, then follow TLE down the road. All workers agreed that at some point the TMHE would catch up and need to pass the TLE in the slower-moving Gradall. The TMHE was to signal the TLE by honking the horn, and the TLE would move over to allow him to pass.

The TL stayed at the worksite after the TLE and TMHE were on the road and loaded rigging slings and other materials into a pickup truck before leaving. He caught up to the Gradall after the TMHE's flatbed truck had already passed the TLE. The TL stayed 3–5 truck lengths behind the Gradall as they went down Road 508; the TL's vehicle was in four-wheel-drive low and first gear.

After securing the radio station worksite, the ECSW started down Road 508, where he caught up to the TL, who was still following TLE in the Gradall. He also stayed 3–5 truck lengths behind. Their speed averaged 4 miles per hour.

The Event

About 4 miles from the worksite, the TL saw the Gradall leave the road and the TLE attempting to steer it back onto the road. However, the Gradall left the road and paused at the edge, leaning to the downside of the hill. Then the TL saw the TLE attempt to exit the Gradall from the uphill side as it rolled off the road edge and out of sight. Although a seatbelt was installed on the Gradall, there was no evidence available to the Board to determine whether the TLE was wearing the seatbelt while driving or not. However, the Board determined that the TLE was not belted in when the Gradall rolled over.

Emergency Response

Immediately following the accident, the TL went to the embankment where the accident took place. The ECSW called 911, then grabbed a first-aid kit and followed the TL to the accident scene. They could not find the TLE's pulse, but they attempted cardiopulmonary resuscitation (the TLE's blocked airway prevented rescue breaths.) Emergency responders from the Rural Fire Department (Rescue 1) arrived 38 minutes after the 911 call and determined that the TLE could not be resuscitated. The Rescue 1 Incident Commander called the county coroner and Search and Rescue to assist in retrieving the TLE's body.

The Investigation and Causes

The Board determined the facts of the accident and analyzed them to determine what happened, why it happened, and the actions necessary to prevent recurrence.

- The *direct cause* is the immediate event or condition that causes an accident. In this event, the Board concluded that the direct cause of the accident was the operator's "exposure to fatal blunt force trauma during rollover of the Gradall."
- *Root causes* are factors that, if corrected, would prevent recurrence of the same or similar accident. In this event, the Board concluded that there were two root causes: the Gradall leaving the roadway and the TLE attempting to exit the machine as it rolled over.
- *Contributing causes* are events or conditions that increase the likelihood of the accident but do not cause the accident. The Board determined that the single contributing cause was the narrow roadway with brushy overgrowth and steep embankments.

Because the Gradall had traveled 4 miles in 56 minutes, (an average speed of about 4 miles per hour, which complied with the SSSP 5-mile-per-hour limit), the Board concluded that speed was not a factor in the accident. The Forest Service Road was 12 feet wide; dry, hard gravel; generally straight and in good condition; with less than a 2 percent grade at the accident location. The Board could not determine, based on available evidence, why the Gradall left the roadway. Figure 1-4 shows the road at the accident site.

The Gradall was equipped with a ROPS that included an operator seatbelt as part of the system. After the accident, BPA inspected the ROPS and found it was undamaged (Figure 1-5). The seatbelt was also inspected and it appeared to be in good condition. The Board determined that if the TLE had used the seatbelt and stayed within the ROPS framework,

Figure 1-4. Personnel are standing at point of rollover (white arrow indicates the direction of Gradall's travel and orange marks indicate Gradall's tire tracks leaving roadway)

Figure 1-5. Gradall on flatbed after recovery from accident scene shows ROPS intact

his fatal injuries may not have occurred. The text box below, *Roll Over Protection System Saves Lives*, and the table on the followingpage provide information on operator protection.

The Board encountered difficulties collecting evidence and conducting witness interviews due to conflicting views between the onsite Contractor's management and BPA regarding authority to conduct an accident investigation, limits of the investigation scope, and legal implications of releasing information. Before leaving the scene of the accident, the Board had obtained a verbal agreement with a Tice Safety Manager to share witness statements from Tice to facilitate the BPA investigation. However, upon the advice of Tice legal counsel, Tice did not provide the witness statements it had collected. In addition, the Board had determined that follow-up interviews would be necessary, but the Board was not

Roll Over Protection System Saves Lives

A ROPS is a protective frame mounted on the machine; it extends above the operator's seat and may consist of one, two, or four posts.

ROPS is designed to bear the weight of the machine during a rollover event and minimize the likelihood that the machine will overturn completely, thereby reducing the possibility that the operator will be crushed.

ROPS must be used in combination with a seatbelt because ROPS only provides protection if the operator remains in the seat. Operators who do not use seatbelts may be ejected from the machine and then crushed between the machine and the ground, or strike the ROPS as they are thrown from the equipment. OSHA investigations of rollover events for the years 2000–2006 found that the combination of ROPS plus seatbelt usage saved lives. For example, in 19 events where there was a ROPS but operators did not wear their seatbelts, 14 of the 19 operators were killed. Some of the operators had removed their seatbelts and jumped, negating the protection offered by the ROPS. **In the five events where seatbelts were used and vehicles were equipped with ROPS, all operators survived.**

Source: *OSHA Safety and Health Bulletin*, SHIB 09-29-2008

From 2000 to 2006, the Occupational Safety and Health Administration (OSHA) investigated more than 50 rollover accidents that involved a variety of makes and models of rollers/compactors. Its investigation demonstrates how important it is for equipment operators to use the combination of ROPS plus seatbelt in a rollover accident.

OSHA Investigations of Fatalities in Rollover Accidents

# of Events OSHA Investigated	Was ROPS in Place?	Were Seatbelts Used?	Fatalities
5	Yes	Yes	0
19	Yes	No	14
1	No	No	1
6	No	Unknown	6

granted access to the witnesses to do so. The Board requested, but did not receive, information regarding toxicology analysis performed following the accident. As a result, the Board was unable to use these results to affirm the TLE's fitness for duty.

Work Processes and Controls

Site-Specific Safety Plan

The Board reviewed the SSSP and determined that it was complete and adequate for the work being performed on the day of the event. In addition, the BPA Safety Office had reviewed and approved the SSSP prior to issuing the NTP. The NTP specified that the SSSP must be onsite so workers could review it. That expectation was conveyed to Tice, as well as the stated expectation that the Contractor was to ensure that all workers were familiar with the SSSP's contents. However, through interviews, the Board found that not all workers were aware that the SSSP was at the worksite. The Board determined that this fragmentation of expectation was a weakness in executing the management controls for safety.

Blood-borne Pathogen Protocol

In its review of the emergency response to the accident, the Board found an area of concern: execution of a blood-borne pathogen protocol. The Board found that at least one worker may have been exposed to the TLE's blood during the attempt to perform rescue breaths at the accident site because there was a significant amount of blood. This could have resulted in an exposure, even though the worker used a barrier. There was delayed response to conducting an exposure assessment and no follow-up on possible exposure to blood at the accident site. OSHA requires immediate activation of the protocol upon exposure, and Tice captures this OSHA requirement in its Safety Manual as a "within 24 hours" requirement. However, based on Tice's blood-borne pathogen incident report, a medical referral was not implemented, and an exposure assessment did not occur until 3 days after the accident, not within 24 hours as required.

Job Hazard Analysis and Daily Job Briefings

The SSSP provided the job description and identified the associated hazards. A Job Hazard Analysis (JHA) is a comprehensive evaluation of a work site that is intended to be more comprehensive than what would be covered by routine job briefings, tool box meetings, and similar methods. The Board determined that Tice performed, and documented, a JHA for this contract work and that the general hazards associated with it had been identified.

The Board reviewed the contract, the SSSP, and Tice's Safety Manual to determine how the job briefings related to the work performed. The Board found the instructions in the SSSP for daily documented safety meetings and job briefings confusing, which represented a weakness in Tice's management barriers for accident prevention. The confusing language also represented a potential gap in ensuring adequate and effective worksite safety processes and controls.

The SSSP required daily and weekly toolbox safety briefings to be held both before each work shift and when the work presented new hazards. The Board requested physical copies of

the briefings to document that the safety briefings had taken place, but they were not provided. However, the Board concluded that the briefings were adequate for the work being performed.

Training and Certification

The Board reviewed the Tice-provided training and certification records for the TLE. The records documented that TLE was trained and demonstrated proficiency and that he was certified to operate the Gradall material handler in accordance with company requirements.

Findings and Recommendations

After analyzing the facts to determine what happened and what needs to be done to prevent recurrence, the Board arrived at nine Findings and made a corresponding Recommendation for five of them, as summarized in the table to the right and on the following page. More information about the event and the Board's Findings and Recommendations is available in the Board's report, which can be accessed at http://energy.gov/ehss/downloads/accident-investigation-october-1-2013-tice-electric-company-employee-fatality-near.

KEYWORDS: Bonneville Power Administration, BPA, rollover, Roll Over Protection System, ROPS, Gradall, Material Handler, TLE, lead electrician, Patrick's Knob, radio station, Tice Electric Company, Site Specific Safety Plan, SSSP, Electrical Construction Company, fatality

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

Board's Findings	Board's Recommendations
F1: The Gradall left the road creating an equipment rollover situation.	No recommendation.
F2: TLE attempted to exit Gradall prior to roll over, which would have defeated the safety restraint (seatbelt) component of the rollover protection system that includes safety restraints in addition to the Roll Over Protection Structure (ROPS).	**R1:** The Board recommended that, if applicable, equipment operators' training include detailed explanation of the ROPS and safety restraints and what to do during a rollover event.
F3: Use of a seatbelt while operating the Gradall Material Handler is undetermined.	No recommendation. There was no factual evidence available to determine if seat belt was or was not utilized.
F4: The crew's rescue effort was performed in a safe and timely manner. Professional emergency medical services response was timely.	No recommendation.
F5: Conflicting views between contractor management and BPA regarding authority to conduct an accident investigation, scope limits, and legal implications created difficulties collecting evidence, conducting follow-up witness interviews, and obtaining the required information.	**R2:** The Board recommended that BPA evaluate the need to include additional information about contractor accident reporting and investigating in contract packages, including BPA accident investigation protocol. Information should convey a clear demarcation for when an accident would be investigated by BPA.

Board's Findings	Board's Recommendations
F6: The Board requested but was not provided medical information on which to base conclusions about the TLE's medical state, fitness for duty, or official cause of death.	**R3:** The Board recommended that BPA's Medical Officer assess the medical information if it is received. **R4:** The Board recommended that BPA's Contracting Office insert language in all master contracts and contract releases that explicitly states that if requested, BPA's Medical Officer will be provided all relevant medical information as soon as it becomes available in the event of a BPA Contractor injury or fatality.
F7: The Board was provided sufficient evidence to determine that TLE had been trained to operate material handlers.	No recommendation.
F8: A Site Specific Safety Plan (SSSP) was developed for the job but was not conveyed to all workers at the worksite. **F9:** The fragmentation of expectations for communicating the SSSP to workers is a weakness in executing management controls for safety.	**R5:** The Board recommended that contract language, Notice to Proceed, and SSSP contain expectations for conveying site safety elements of the plan to all contractor workers including subcontractors, and that those expectations be included on the SSSP cover page. The site foreman or manager should brief each worker on the contents before starting any work on site.

Board's Findings	Board's Recommendations
F10: There was a delay in activating a blood-borne pathogen protocol.	**R6:** The Board recommended that Tice should evaluate performance on executing a blood-borne pathogen protocol for this accident.
F11: The SSSP was not clear on expectations for conducting both weekly safety meetings and daily job briefings (toolbox safety meetings).	**R7:** The Board recommended that the SSSP be revised to clarify expectations and documentation requirements for the two types of briefings. **R8:** The Board recommended that the BPA contracting and safety office evaluate and determine if documenting daily job briefings should be a requirement, if the requirement should be included in contract language, and if the briefing documentation could be verified by inspection on request.

The Occupational Safety and Health Administration (OSHA) requires that material handling machinery manufactured on or after September 1, 1972, shall be equipped with ROPS which meet the minimum performance standards prescribed in §1926.1001 and 1926.1002, and equipment manufactured prior to that date must be retrofitted (§1926.1000). ROPS must:

- absorb the applied energy which will support, based on the ultimate strength of the metal, at least two times the weight of the prime mover applied at the point of contact;
- minimize the likelihood of a complete overturn and therefore minimize the possibility of the operator being crushed; and
- provide a vertical clearance of at least 52 inches from the work deck to the ROPS at the point of ingress or egress.

Source: OSHA.gov

Lithium Fire at the Sandia National Laboratories' Plasma Material Test Facility Highlights Opportunities for Improvement in Work Planning and Hazards Analysis

2

On August 26, 2011, an explosion and a lithium fire occurred at Sandia National Laboratories' (SNL) Plasma Materials Test Facility (PMTF) Electron Beam (EB) vacuum test chamber. (Figure 2-1 shows an aerial view of SNL; Figure 2-2 shows the PMTF Electron Beam 1200-kW System.) The accident significantly damaged the EB-1200 kilowatt (kW) equipment and resulted in damage to the facility. Two workers in the test chamber's immediate vicinity were not injured; fortunately, the worker closest to the chamber had moved away just prior to the event, but was knocked to the floor. Three of the five workers who were in the general vicinity of the explosion had ringing in their ears, but were returned to work without restrictions. (ORPS Report NA--SS-SNL-1000-2011-0007; final report issued September 21, 2012)

Accident Summary

The experiment being conducted at the time of the accident integrated several systems: a vacuum test chamber; two electron beam lines for heating elements within the chamber; coolant loops for the chamber and the electron beam guns; a high pressure helium loop for heating and cooling; and a self-contained liquid lithium system. This latter system, Liquid Metal Integrated Test System or LIMITS, was being used to circulate molten lithium from a heated reservoir into the vacuum test chamber and then return it to the furnace.

During set-up for the experiment, liquid lithium flowed inadvertently into the lithium preheater while the preheater was at ~200°C (before it had been preheated to ~400°C as specified in the Test Plan). This resulted in rapid failure in the face of the lithium preheater panel. When the preheater failed, molten lithium sprayed from thin cracks in the preheater across the chamber into the beam line of the electron beam gun, where it struck and fractured an alumina ceramic liner. The ceramic liner separated coolant (which was used to cool this region of the chamber during operation of the high-power electron beam gun) from the vacuum environment in the chamber. The fracturing of the liner allowed the coolant (water and polypropylene glycol) to contact molten lithium, which resulted in an explosion and fire.

Figure 2-1. Aerial photo of Sandia National Laboratories

Causal Analysis Results

A causal analysis was performed to evaluate human performance improvement, management systems, and other accident information and identify causes and provide the basis for formulating corrective actions.

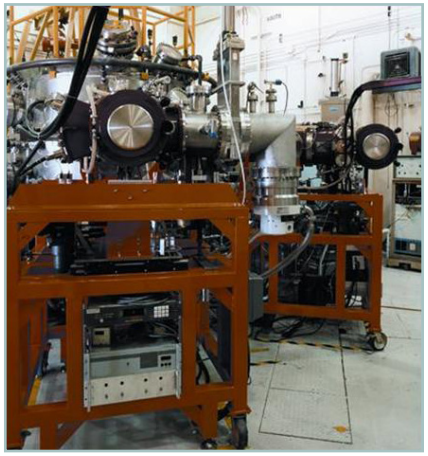

Figure 2-2. PMTF Electron Beam-1200-kW System[1]

The *direct cause* was determined to be material failures in the lithium preheater and ceramic cooling annulus that allowed a reaction between molten lithium and the water. A metallographic analysis requested by Sandia's Investigation Team determined that thermal shock-induced liquid metal embrittlement, which can occur when parts are under stress, caused the failure of the lithium preheater.

Two *root causes* were identified: (1) the inadequate design selection process for the lithium preheater, and (2) an incomplete hazard analysis to identify controls necessary to prevent lithium and water coming into contact with one another. The final Investigation Team report noted that the work-acceptance decision was performed before all hazards may have been known.

The final Investigation Team report identified additional causes for the event, including the areas summarized below.

- Invalid assumptions led to inappropriate risk acceptance. The work approval and authorization identified only handling the lithium between the furnace and the cask; it did not address pumping lithium into a target in the EB1200 vacuum chamber, which was the work planned to be performed. As a result, the task was categorized as low rigor. Escape of lithium from the closed loop into the vacuum vessel was not identified as a significant hazard.
- There was less-than-adequate work planning and control (WP&C). The work was improperly classified as low hazard in the Primary Hazards Screening process and low rigor in the WP&C process. In the workplace, logbook entries were informal and lacked requirements; work control for set-up work prior to the test lacked adequate rigor and formality; and the team's mental model did not match the actual experimental system configuration.
- Risks were not adequately reviewed. No SNL readiness activity had been performed before the experiment started, even though there were "firsts" in the integration of the two systems. The Fire Protection Assessment performed for PMTF mistakenly identified lithium batteries instead of lithium metal (a missed opportunity to call attention to the hazard). In addition, National Fire Protection Association codes and standards were not fully applied in the complex.
- Training and documentation were inadequate.
- Workers may have perceived schedule pressure. A prior decision had been made to suspend the project the next working day. This decision may have had the unintended consequence of placing perceived schedule pressure on the workers and activities.

Work Planning and Control

Work Planning and Control (WP&C) for this new work at the PMTF was less than adequate. Workers did not fully understand the controls in place or how the system operated, perhaps as a result of inadequate training. There had been a missed opportunity to improve WP&C when corrective actions from prior assessments of PMTF were not completed. It was unclear who had responsibility to track deficiencies and corrective actions to closure, and management was not aware that assigned actions were not being addressed.

[1] The EB-1200 system consists of two, 600-kW electron guns attached to a 1.25-meter-high by 2-meter-diameter semi-cylindrical vacuum test chamber (D Chamber).

Extent-of-Condition Review

- After the formal accident investigation was completed, an extent-of-condition review was performed to find other SNL activities that had used similar quantities of pure lithium metal in their operations. Although it was determined that there were no other equivalent activities, SNL Managers across all Divisions met more than a dozen times to discuss extent-of-condition commonalities and to share recommendations. Their focus was more generic and emphasized such factors as human performance, task demands, program characteristics, and work environment.

The final Investigation Team report noted that:

> Some identified accident precursors were common to the 2008 Sandia rocket sled accident and other PMTF accidents, indicating that Sandia-wide assessment and analysis are needed.

For further information on the 2008 Sandia rocket sled accident, refer to the textbox on the right.

The subsequent SNL-wide extent-of-condition review of activity-level work was performed to identify areas/operations with the following characteristics.

- Organizations with isolated operations. Isolation could be the result of geographic separation or the result of the work not being viewed as a central element of the performing organization's mission.
- Organizations that are experiencing funding challenges or other issues that increase the complexity of the manager's role and create conflicting priorities.
- Work that has been incorrectly classified as *low rigor*. Work that is sufficiently behind schedule so as to encourage shortcuts.

The 2008 Sandia Rocket Sled Accident

The rocket sled event referenced above occurred at the SNL Technical Area III Sled Track in October 2008. A contractor worker was preparing a test package when a rocket motor ignited prematurely and began moving down the track, knocking him to the ground. He sustained first- and second-degree burns to his hands, arms, and face; a 10-inch gash on his right leg; and a broken femur on that same leg. A Type B Accident Investigation (AI) was conducted. (ORPS report NA--SS-SNL-1000-2008-0014)

The AI final report is available at http://energy.gov/ehss/downloads/type-b-accident-investigation-october-9-2008-employee-injured-when-rocket-motor.

After its investigation, the Board concluded that Laboratory management did not fulfill its responsibilities to meet 10 CFR Part 851, *Worker Safety and Health Program*, and DOE Manual 440.1-1A, *DOE Explosives Safety Manual*, requirements to control explosive hazards; did not adequately train employees in hazards and precautions required for explosives operations; and workers did not understand explosives safety requirements or Conduct of Operations principles.

The Board also found that the Sandia Integrated Management System was not adequately implemented for these tests, and pointed out that two previous ORPS reports had been made for similar events (1993 and 2003). It was unknown if lessons learned from these events had been disseminated and whether they could have prevented later events.

Corrective Actions

SNL personnel committed to more than 30 corrective actions (CA); several of the CAs most pertinent to this article are listed below.

- Develop and offer a Lithium Safety Awareness briefing.
- Develop an Engineering and Operations Management Plan describing the minimum requirements for engineering and safety review processes involved in design of hardware systems, experiments, or operations. This includes the embracing of WP&C processes incorporating engineered

safety principles that include a more thorough analysis of hazards and failure modes and mitigation though engineering controls and/or administrative controls.

- Perform an awareness activity at all-hands meetings about recognizing and taking action when an unexpected condition is encountered.
- Coach the Management Team on WP&C processes annually and cascade the briefing to workers.
- Clearly define roles and responsibilities of the Line Manager, Laboratory Manager, and Principal Investigators to clearly communicate expectations regarding engineering and WP&C processes, formality of operations, and training.
- Perform a gap analysis to ensure compliance with applicable NFPA requirements for lithium storage and use.
- Communicate lessons learned from this accident to the Line Implementation Working Group and other Sandia organizations to raise awareness across SNL.

Note: Five corrective actions were canceled because current programmatic funding for operations at the PMTF was terminated. If funding is secured at a later time, the corrective actions will be reinstated, implemented, and verified as part of a readiness review.

Lessons Learned

SNL personnel identified the following primary lesson learned from this accident.

> Identifying and evaluating every serious potential hazard is a critical step when conducting a test that involves integration of multiple systems being used in new ways. Simply combining systems with the expectation that each component will work as expected is not adequate to protect members of the workforce.

Each of the systems involved in the August 26, 2011, accident had previously been used separately to conduct experiments, and, based on this experience, personnel did not adequately consider integrated failure modes. The failure of the heat transfer test component was a possibility; however, (a) the preheater's failure, and (b) the reaction of liquid lithium with materials (viewed as not accessible due to their location) were not sufficiently considered or evaluated.

The EB-1200 system had not been used previously for work with molten lithium. However, molten lithium experiments had been conducted successfully in a different PMTF (EB-60) system.

Recommended actions from this primary lesson learned include performing a complete hazard analysis, including incorporating safety engineering principles, and failure mode analysis for any work or test with the potential to result in serious injury or consequences.

Conclusion

Before conducting an experiment that involves integration of multiple systems used in new ways, it is crucial to identify and evaluate every potential hazard and failure mode. Work planning that simply combines systems, expecting that each component will work as it has in the past and not present new hazards, is not adequate to protect workers.

At the PMTF, experiments with molten lithium had previously been conducted using the LIMITS and the EB-60 system. Because each system had been used previously to conduct lithium experiments, personnel placed too much confidence in that past performance and did not fully consider new failure modes that might exist when the LIMITS system was integrated into experiments using the EB-1200 system.

The preheater failure, combined with the possibility that lithium could contact other materials inside the vacuum test chamber, was not sufficiently considered or evaluated. The pre-work process of asking *What if?* should be part of every work planning effort. Only by considering all the possibilities—including worst-case or low-probability failure scenarios—can facilities and work planners ensure that their operations can be conducted safely.

KEYWORDS: Lithium, hazards analysis, work planning, vacuum test chamber, WP&C, PMTF, EB-1200, EB-60, rocket sled, Type B Accident Investigation

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