CENTER 2500 LESSONS LEARNED

Title/Subject: Unexpected Type of Failure of Thermal Battery Resulting in a Near Miss to a Serious Injury

Lesson Learned Statement: Gaps in implementation of Engineered Safety resulted in a near miss to a serious injury.

Discussion of Activities:

Summary: On 6/26/2015 at 1445 in 894/136, a thermal battery (approximately the size of a commercial size C cell) experienced an unexpected failure following a routine test where the battery is activated. The failure occurred while a test operator was transferring the battery from the testing primary containment box to another containment box within the same room; initial indications are that the battery package ruptured after it went into thermal runaway which led to the operator receiving bruising to the palm of the hand from the pressure of the expulsion. The operator was wearing the prescribed PPE, which was safety glasses and a high temperature glove on the hand that was holding the battery

Details: During the morning of 6/26, two approved test operators started a test series for six development thermal batteries. This work was performed per the applicable Work Planning and Control Documentation, including an operating procedure (PSTG-OP-BTEVAL-6) and a Work Authorization Form.

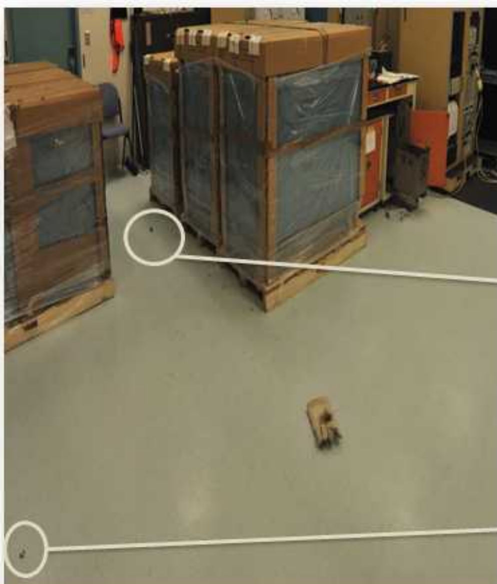
Four battery tests were successfully completed that morning and mid-afternoon. At approximately 1440, the test was started with the fifth battery. The test lasted approximately one minute. Per Test Operator #1, the data showed that the battery may have underperformed its electrical performance requirements but there was no immediate indication from the data that an abnormal test was occurring. Test Operator #2 opened the secondary cabinet, pulled out the containment box, and opened it to perform a visual inspection, which showed no obvious indication of an abnormal thermal event, such as the stainless steel container glowing red. Additionally, the dedicated tester for this operation ran the test until the nominal 28-volt output of the battery had dropped to 5 volts, which is another sign that is usually indicative of the battery being safe enough to move. Per the OP, if there is any indication from the test data or visual observation of an abnormal thermal event, the operator leaves the battery in the containment box with ventilation for a minimum of 30 minutes. If there is no indication of one of these off-normal conditions, the test operator can remove the battery from the test box wearing appropriate PPE (safety glasses, high temperature glove) and transfer it to another containment box for cooling, so another battery can be tested.

Test Operator #2, wearing safety glasses and a thermal glove on their left hand, removed the battery from the fixture and containment box and began walking to the other containment box to place the battery in it. After a couple of steps, Test Operator #2 observed a wisp of smoke from the glove near the base of the thumb and then a loud bang was heard and the battery was expelled from Test Operator #2's opened, gloved hand.

The two Test Operators and another person in the lab immediately vacated the lab to the building hallway. 911 was called for Incident Command response.

894/136 Thermal Battery Testing Lab

Battery Removed from Testing Box



Dispersion of Parts

Battery Canister
(Approximately the size of a commercial size C Battery)

Thermal Glove

Battery Base Plate

Analysis: Two separate analyses were performed to learn from this event. The first analysis was performed by an indendepent causal analysis team chartered with determining what weaknesses existed within the Work Planning and Control system that contributed to a condition where "workers could have been seriously injured during thermal battery testing". The second analysis was led by a battery engineering team to determine the technical basis of why the battery ruptured.

The independent causal analysis team performed a thorough review of the incident by reviewing the physical test set-up, interviewing the team members involved in the design and testing of the battery, and review of the operating envelope documentation (PHS, OP, WAF, and other TWDs). Overall, it was concluded that the causes of the event centered around gaps in implementation of Work Planning and Control "Engineered Safety" concepts:

- Methods were not properly defined to objectively identify that the battery was in an abnormal state and not safe to handle. For example, temperature monitoring (which was not required to always be performed) of the battery during the test would have indicated the battery was in an abnormal state. Instead, as documented in the OP, reliance on visual observation of test performance data and physical state of battery were insufficient to determine the state of the battery.
- It was thought that an abnormal thermal condition would be recognized before moving the battery; therefore, the step of "checking or moving the battery" was not analyzed for the implementation of engineering controls.
- Administrative controls were misinterpreted and less than adequate.
  - Administrative controls were misidentified as "engineered controls". For example, the WAF identified a tester alarm and temperature monitoring as engineering controls. While these are valuable methods of identifying if something is off-normal, they do not act as physical, engineered controls to protect the worker from a hazard.
  - The varying TWDs that applied to this operation (General Procedure, Operating Procedure, WAF, and PHS) had potentially confusing and conflicting guidance on how to evaluate and handle batteries post-test.

The battery's engineering team engaged with other Material and Metallurgy SMEs to evaluate the failure modes of the battery. It was determined during post-incident analysis that the closure weld failed during battery pressurization. The reason for this situation was that the effective weld penetration was less than 0.003 inch at some locations, significantly less than the 0.010 inch target. The origin for weld failure occurred at a location where the weld penetration was on the order of 0.002 inch. The characteristics that led to this situation are a low degree of pulse overlap (50% and less), poor seam tracking, and inadequate welding parameters due to insufficient communication from requester to technologist performing the operation.

Lessons Learned: Based on the analyses performed, the following are key lessons learned that can be used when conducting WP&C evaluations of test activities.

Work Planning and Control Activities:

- Remember that it may not be possible to engineer a perfectly safe process, so no system should be fully trusted, as there is always a potential for system failure. **Always expect the unexpected instead of assuming something is safe to proceed with until proven otherwise.**
- Evaluate if Work Planners and Work Planning Team Members understand the key concepts of Engineered Safety ("MN471021 *Work Planning and Control Criteria for Safe Design and Operations")*. While the technical staff and technologists may have in-depth education in their field, they may not have had the training necessary to identify and understand the differences between types of controls (engineered, administrative, and PPE) and how to perform a failure modes analysis. Increase understanding by taking WPC410 WP&C for

Managers, WPC420 WPC for Work Planners, watching concept specific WP&C videos, or the series "Redbook" hazard identification and analysis courses (RBK100 through RBK105).

- Engage SMEs to review the operation and all steps for hazards, including when a test activity is completed and an operator has to physically check an item's status or move it. Conditions may exist where workers may be exposed to hazards outside of those that occur during testing.
- Give renewed/rolled over documents (PHS, TWDs, etc.) the same scrutiny as new ones, especially if the document originated prior to implementation of Engineered Safety.
- Ensure the procedures have clear and consistent instructions so that the individuals performing the work have the objective quantitative measures to make safety decisions instead of having to rely on subjective qualitative indicators to evaluate under a "skill of the worker" condition. Procedures with contradictory information about controls and steps can leave a worker believing that a control/step is unnecessary.
- Operators should be more thoroughly trained on the recognition of the objective measurements and recognition of failures modes before conducting the work without Engineering Staff supervision.
- Remember that administrative controls for critical steps impacting worker safety should be robust and may require independent verification.

Engineering Methodology

- Material and design changes to components may introduce new failure modes and unintended consequences. With respect to this event, a material change was made to the battery package to accommodate a new welding technique and other experiments with the battery materials were being performed to optimize the thermal characteristics of the battery. These changes may have introduced unintended impacts to the package strength, weldability, and mechanical integrity.
- If you are depending on a weld or other hardware as an engineered safety barrier, its quality and integrity needs to be qualified or verified.

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