Causal Analysis For Occurrence Report

OR NA—SS-SNL-2000-2015-0005, Unexpected Type of Failure of Thermal Battery

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Introduction

This causal analysis was conducted to address the issue identified in OR NA--SS-SNL-2000-2015-0005, Unexpected Type of Failure of Thermal Battery. The analysis was conducted using Timeline Analysis (Attachment 1), Cause and Effect Mapping (Attachment 2), a review of Human Performance Indicators (Attachment 3), and the DOE O232.2 Causal Analysis Tree (List 1), per CG100.6.6, Determine and Take Action.

Description of Event

(Ref: OR NA--SS-SNL-2000-2015-0005, Unexpected Type of Failure of Thermal Battery)

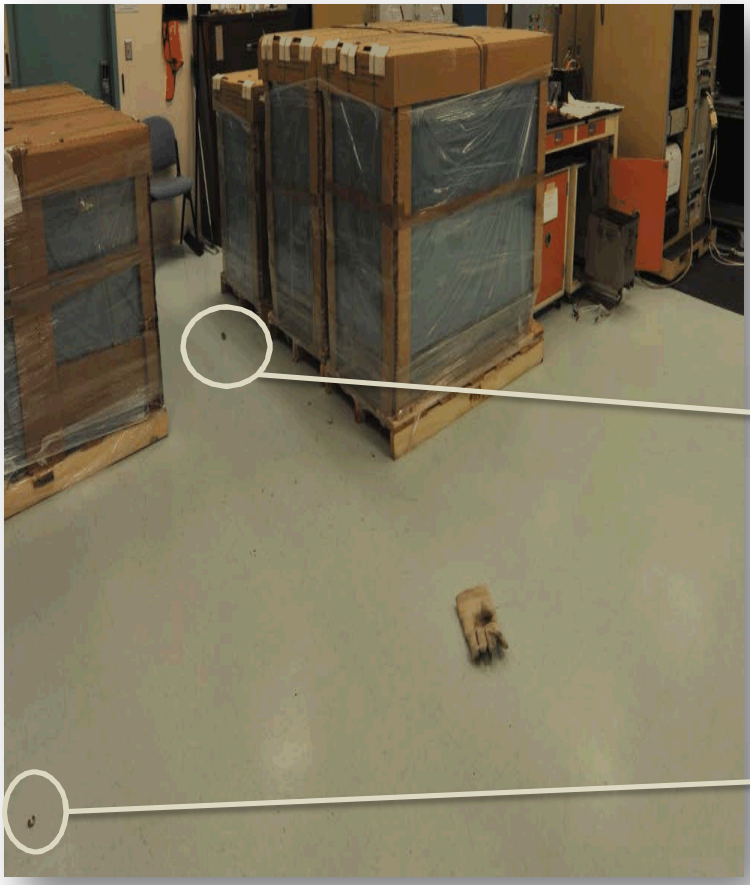
Summary:

On 6/26/2015 at approximately 1445 in 894/136, a pulse thermal battery (approximately the size of a commercial size C cell) experienced an unexpected failure following an electrical performance test that is routinely conducted on thermal batteries. A dedicated tester for this operation was used and it ran the test until the nominal 28-volt output of the battery had dropped to 5 volts, usually indicative of the battery being spent and safe enough to move. The failure occurred while a test operator was transferring the battery from the testing primary containment box to another primary containment box within the same room; initial indications are that the battery experienced an over-pressurization failure which led to the battery's base plate being expelled and the operator receiving a non-recordable injury (bruising to the palm of the hand) from the pressure of the expulsion. The operator was wearing the prescribed PPE (safety glasses and high temperature glove) and was handling the battery appropriately with an open, flat hand. Pictures of the scene are below.

OR NA--SS-SNL-2000-2015-0005, Unexpected Type of Failure of Thermal Battery Event Pictures

894/136 Thermal Battery Testing Lab

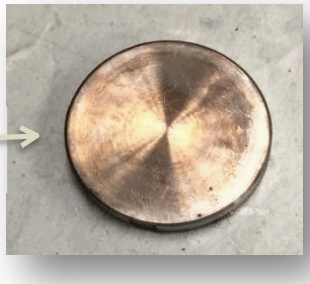
Battery Removed from Testing Box



Dispersion of Parts

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

Thermal Glove



Battery Base Plate

Details: During the morning of 6/26, two approved test operators started a non-abuse testing series for six development pulse thermal batteries in the 894/136 Thermal Battery Test Lab. This work was performed per the applicable Work Planning and Control Documentation, including an operating procedure (PSTG-OP-BTEVAL-6-F) and a Work Authorization Form (PSTG-WAF-0039-B). The two test operators were the alternate lab owner (Test Operator #1) and a technologist (Test Operator #2), both of whom are qualified and authorized to perform this type of testing activity. The test series entailed testing one battery at a time where the tester cable leads were soldered to the appropriate battery pins, the battery placed in a test fixture, and the fixture placed within a steel testing containment box that is within a secondary, ventilated cabinet. An electrical load profile is then applied to the battery to activate it to collect performance data; the test for this battery is approximately two minutes long, but the tester continues running the test until a predetermined output voltage is reached, indicative of the battery being spent and that a freeze out of the electrolyte is occurring. For this test, the battery test ran approximately one minute. After the test is complete, the data is read to ensure that the battery acted as intended and then the testing containment box is opened to perform a visual inspection of the battery to ensure there are no signs of off-normal conditions that would indicate an abnormal thermal event was in progress (discoloration of the stainless steel case, bulging of the case, glowing red coloration to the case, etc.). If there is any indication from data or visual observation of an abnormal thermal event, per the operating procedure, the operator leaves the battery in the containment box with ventilation for a minimum of 30 minutes. If it is determined there is no evidence of an off-normal condition, the test operator wearing appropriate PPE (safety glasses, high temperature glove) can remove the battery from the fixture and transfer it to another containment box for cooling, so another battery can be tested.

Four battery tests were successfully completed that morning and mid-afternoon. At approximately 2:40, 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 thermal event was occurring. Test Operator #2 then 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. It was observed that the solder used to connect the cable assembly to the battery was starting to melt. However, some batteries, even in their nominal conditions after a test, can reach temperatures high enough to melt any solder present on the battery pins. Test Operator #2, wearing safety glasses and a thermal glove on his left hand, removed the cable leads and unscrewed the fixture holder holding the battery in place. With his left, gloved hand, he 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. Test Operator 2 was taken to SNL Medical for evaluation, where it was determined that he received bruising to the hand, but it was not classified as a recordable injury. The other person also reported to medical as a precaution to have a noise evaluation performed due to the loud sound from the battery failure; the initial medical report shows no noise-related injury was incurred.

The Incident Command team secured the lab and performed initial air monitoring, which yielded no positive readings. At approximately 1645 hours on 6/26, the Incident Command Team and Industrial Hygiene cleared the room for reentry. Wearing the appropriate PPE (safety glasses, disposable booties), the lab owner shut down equipment in the lab and ensured that a thermal battery that was supposed to be tested was properly stored. Re-entry to the lab was minimized until a Work Authorization Form (WAF) was developed detailing the cleanup and evidence preservation methods. Industrial Hygiene

provided guidance on proper clean-up procedures. Additionally, the Center Director directed that all activities involving the testing of thermal batteries be paused until compensatory or permanent changes to operational procedures are defined. The Director will be the cognizant authority that will allow authorize activities to begin again. Critique/fact finding activities were performed on 6/29/2015.

See Attachment 1, 894 Battery Event Timeline, for additional information.

Table 1: Compensatory Actions

The following compensatory actions were taken after the event:

Action	Completed By	Date Completed
Center 2500 thermal battery testing operations were paused until compensatory or permanent changes to operational procedures are defined to prevent a recurrence of this event.	Center 2500 Director	6/29/15
Other battery testing operations in Center 2500 were paused until compensatory or permanent changes to operational procedures are defined to prevent a recurrence of this event.	Center 2500 Director	7/2/15
Interim supplemental Engineered Safety training was requested by the manager of the affected worker 7/1/15, offered to all Power Sources personnel, and held on 7/23/15.	Department 2547 Manager	7/1/15 and 7/23/15
An extent of condition review for Center 2500 and Division 2000 battery testing operations was initiated by the Division 2000 VP.	Division 2000 Vice President	7/14/15

Extent of Condition Review

There have been other events involving batteries in Division 2000 in recent years, see Table 2 below. A team has been formed (See Attachment 4) to perform the extent of condition review for these events and others aspects of Division 2000 battery work, so no further extent of condition review was performed as part of this causal analysis.

Table 2: Recent Division 2000 Battery Related Events

Report No. NA-SS-SNL-2000-	Title	Resp. Org.	Date
009-0001	Unexpected Activation of Thermal Battery in Bldg. 894	2540	1/12/09
2009-0006	Burn Injury from Heat Pellet Exothermic Reaction	2540	5/12/09
2010-0001	Laboratory Fire Involving Industrial-Type Lithium Batteries	2620	3/4/10

2011-0002	Rupture of Lithium-Thionyl Chloride Battery	2540	7/22/11
2012-0003	Ventilation Failure Leads to pH Excursion	2540	10/26/12
2014-0004	Legacy Thermal Battery Components Found During 6S Activity	2540	6/5/14
2015-0004	Management Concern Lithium Iron Phosphate Battery Pack Failure	2540	5/21/15
2015-0005	Unexpected Type of Failure of Thermal Battery	2540	6/26/15

Problem Statement

The issue addressed during this causal analysis was "Workers could have been seriously injured during thermal battery testing". With this as the focus of the investigation, determination of why the battery ruptured was not pursued. The hazards and consequences of battery rupture were clearly identified in the various work control documents. These are research and development batteries, therefore failure is an ongoing possible outcome.

Causal Discussion

An independent review team was chartered to investigate this incident and perform a broader review of Division 2000 battery operations (Attachment 4). The incident investigation was performed using interviews, document reviews, lab tours, and a formal team meeting on 7/15/15 to review the draft timeline and cause map. Completion of the timeline, cause map and report were done electronically by having the team review and comment on all documents. A team outbriefing was held 8/3/15. Changes to the cause map and corrective action plan were discussed and implemented in this report.

All participants were forthright, responsive to the team's inquiries, and clearly focused on improving worker safety and their related processes, not on blaming any individuals. Management support was visible and consistent throughout.

The vital few causes of this event were:

- the lack of engineered controls during post-test opening of the box and battery transport,
- inadequate administrative controls, including confusing/inadequate procedures that allowed open air transport of the battery if an abnormal thermal event condition went unrecognized, and
- gaps in implementation of engineered safety, as demonstrated by citing administrative controls such as reliance on visual indicators in the engineered controls section of the work control documents, possibly not viewing checking or moving the battery as part of the work to be reviewed for engineered controls, and an unrecognized failure mode.

This incident could have happened at any time to anyone involved in this process, given these latent weaknesses. See the cause map (Attachment 2) for the full causal analysis breakdown, List 1 for the occurrence reporting cause codes, and Attachment 3 for HPI error precursors.

The response to the event was exemplary, both in terms of immediate actions taken, and by the pausing of operations and chartering of an independent investigation for the event in question and extent of condition.

Organization 2540 has implemented Engineered Safety and, like any new effort, that implementation needs some fine tuning.

The battery organizations had recognized the need for better facilities and equipment and were working development of a new tester and testing facilities. The results of this causal analysis will be incorporated into those designs, as noted in the corrective action plan, Table 3.

Lessons Learned

Lessons learned will be developed as one of the corrective actions from this event.

Corrective Action Plan

Numerous causes were identified during this causal analysis. The corrective actions described in the following table are those most likely to prevent recurrence of this issue. No further action is planned for those causes which do not have a corrective action associated with them at this time.

Table 3: OR NA--SS-SNL-2000-2015-0005 Corrective Action Plan (CAP) (see List 1 after this CAP for full cause code descriptors)

Action	Issue from Cause Map Addressed	Owner	Due Date	Evidence of Completion
1. Develop a quantitative measurement method (such as thermal state, etc.) to be used on all thermal battery tests that is predictive of an abnormal thermal event in time to take appropriate actions.	Abnormal high temperature condition not recognized; Carrying battery, etc., is allowed by procedure if abnormal high temperature condition is unrecognized; Gaps in implementation of Engineered Safety. Cause codes: A3B2C05 A3B3C05 A3B3C06 A4B1C02 Couplet for A3 codes:	2540 Senior Manager	10/31/15	Documentation of adequacy of measurement method.

	A4B1C02			
2. For thermal battery testing, review engineered control options (such as having multiple new test boxes available that don't have to be opened, an additional casing on the battery, etc.), select design, set up project to implement, or document rationale for not adding engineered controls and risk acceptance by the 2500 Director.	No engineered controls or adequate PPE when checking or moving battery; Gaps in implementation of Engineered Safety. Cause codes: A4B1C02	2540 Senior Manager	11/30/15	Project plan to implement controls that includes: • Updating applicable work control documents • An effectiveness review six months after new engineered control(s) is/are installed and operating • Or Center 2500 Director approved documentation justifying not adding engineered controls.
3. Evaluate thermal battery testing operations (especially those controlled by rolled over/renewed PHSs/TWDs and any thermal battery testing operation where administrative controls were listed as engineered controls) prior to revising applicable control documents to ensure all hazardous work is controlled.	Procedures confusing; complex system and interfaces; Administrative controls inappropriately viewed as engineered controls; Rolled over/renewed PHSs/TWDs may receive less rigorous review than new ones; Checking or moving battery possibly not viewed as part of work controlled by the procedure; Unrecognized failure mode; Gaps in implementation of Engineered Safety. Cause codes:	2540 Senior Manager	10/31/15	List of: • Operations reviewed, • Issues found, and • New or updated work control documents, such as procedures, that resolved those issues.

	A3B2C05 A3B3C05 A3B3C06 A4B1C02 A5B2C05 Couplet for A3 codes: A4B1C02			
4. Revise as needed all thermal battery testing work control documents (WAF, OPs, etc.) to include the new quantitative measurement method, improve useability, define a clear document hierarchy, discuss abnormal event decision paths, ensure PPE and administrative controls are robust, with independent verification of critical decisions, and any other improvements identified as needed by the evaluation performed in corrective action 3 above. The procedure update process includes required reading and sign off.	Procedures confusing; complex system and interfaces; Battery carrying, etc., allowed by operating procedure if abnormal high temperature condition is unrecognized; Abnormal event decision path not well defined; Skill of the worker used to recognize abnormal events; No engineered controls or adequate PPE when checking or moving battery; Gaps in implementation of Engineered Safety. Cause codes: A3B2C05 A3B3C05 A3B3C06 A4B1C02 A5B2C05 A6B1C03 Couplet for A3 codes: A4B1C02	2540 Senior Manager	12/17/15	New or updated procedures.
5. As part of the Phase 2 review chartered by the Division 2000 VP, reevaluate the overall 2540 work planning/engineered safety system in light of the issues identified by this causal analysis and others that may be identified by the Phase 2 review.	All causes. Cause codes: A3B2C05 A3B3C05 A3B3C06 A4B1C02 A5B2C05 A6B1C03 Couplet for A3 codes: A4B1C02	4100 Director	12/31/15	Phase 2 2540 work planning and control assessment report.

6. Develop and publish lessons learned.	None, lessons learned are required for this OR. Cause codes: N/A	2540 Senior Manager and causal analysis team	9/30/15	Published lessons learned.
7. Develop training plan for PSTG personnel on key Engineered Safety concepts, including the controls hierarchy and failure modes analysis.	Gaps in implementation of Engineered Safety. Cause codes: A4B1C02	2540 Senior Manager	9/30/15	Plan that documents: • Training material • Sign in sheets • Procedure or similar document that requires the training, including training or retraining frequency • Completion dates for initial training.
8. Engage SMEs to aid the 2540 team in performing an effectiveness review six months after the deliverables from the final occurrence report are completed.	N/A, effectiveness reviews are required for ORs. Cause codes: N/A	2540 Senior Manager	6/30/16	Effectiveness review report.

List 1: Most Applicable Occurrence Reporting Cause Codes Selected from the DOE O232.2 Causal Analysis Tree from CG100.6.6 Determine and Take Action

(yellow indicates primary cause, others are contributing)

Human Performance

Causes:

- Abnormal high temperature condition not recognized
- Unrecognized failure mode
- Battery carrying, etc., allowed by operating procedure if abnormal high temperature condition is unrecognized

Cause codes:

- A3B2C05 Situation incorrectly identified or represented resulting in wrong rule used
- A3B3C05 Incorrect assumption that a correlation existed between two or more facts
- A3B3C06 Individuals underestimated the problem by using past events as basis

Required Couplet for Human Performance Cause Codes:

- A4B1C02 Job performance standards not adequately defined

Management

Causes:

- Gaps in implementation of Engineered Safety
- Administrative controls inappropriately viewed as engineered controls
- Rolled over/renewed PHSs/TWDs may receive less rigorous review than new ones
- No engineered controls or adequate PPE when checking or moving battery

Cause code:

- A4B1C02 Job performance standards not adequately defined

Procedures

Causes:

- Procedures confusing; complex system and interfaces
- Abnormal event decision path not well defined

Cause code:

- A5B2C05 Ambiguous instructions/requirements

Training

Cause:

- Skill of the worker used to recognize abnormal events

Cause code:

- A6B1C03 Work incorrectly considered “skill of the craft”

Approvals Page for the Causal Analysis Report for OR NA--SS-SNL-2000-2015-0005, Unexpected Type of Failure of Thermal Battery

Original signed by:		8-5-15
_____	_____	_____
Rudy Jungst, Senior Manager	Org. 2540	Date
Original signed by:		8-5-15
_____	_____	_____
Betsy Forbes, Senior Causal Analyst	Org. 41283	Date

Attachment 1: Building 894 Battery Incident Timeline

894 Battery Event
Time Line.xlsx

Attachment 2: Building 894 Battery Incident Cause and Effect Map

894 Battery Event
Cause Map.xlsx

Attachment 3: Building 894 Battery Incident Applicable Human Performance Improvement (HPI) Error Precursors

894 Battery Event
HPI.docx

Attachment 4: Building 894 Battery Incident Review Team Charter

Battery Incident
Review Team Charter