U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy

Accident Investigation Report

Limited Scope Investigation into the NREL Science & Technology Facility Sulfuric Acid Spill on October 6, 2019

December 2019

Disclaimer

This report is an independent product of the Limited Scope Federal Investigation Board appointed by Derek G. Passarelli, Director, Golden Field Office, Office of Energy Efficiency and Renewable Energy. The Board was appointed to perform a Limited Scope Federal Investigation and to prepare an investigation report in accordance with the U.S. Department of Energy (DOE) Order 225.1B, *Accident Investigations.*

The discussion of the facts as determined by the Board and the views expressed in the report do not assume and are not intended to establish the existence of any duty at law on the part of the U.S. Government, its employees or agents, contractors, their employees or agents, or subcontractors at any tier, or any other party.

This report neither determines nor implies liability.

Release Authorization

On October 29, 2019, a Limited Scope Investigation Board was appointed to investigate the sulfuric acid spill in the Science and Technology Facility at the National Renewable Energy Laboratory in Golden, Colorado on October 6, 2019. The Board's responsibilities were completed on December 23, 2019, with respect to this investigation. The analysis and the identification of the Contributing Causes, Root Causes and the Judgments of Need resulting from this investigation were performed in accordance with DOE Order 225.1B, *Accident Investigations*.

The report of the Limited Scope Investigation Board has been accepted and the authorization to release this report for general distribution has been granted.

Derek G. Passarelli
Director, Golden Field Office
Office of Energy Efficiency and Renewable Energy

January 6, 2020
Date

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Acronyms

AWN	Automated Waste Neutralization
BMS	Building Management System
CAIS	Contractor Assurance Information System
CAS	Contractor Assurance System
CON	Conclusion
CRT	Chemical Response Team
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EOC	Emergency Operations Center
EPHA	Emergency Planning Hazards Assessments
ESP	Equipment Specific Procedure
ES&H	GFO Environmental, Safety and Health Staff
ESH&Q	Environment, Safety, Health and Quality
FTLB	Field Test Laboratory Building
GFO	Golden Field Office
HAZMAT	Hazardous Material
HPM	Hazardous Production Material
HVAC	Heating, Ventilation and Air Conditioning
IBRF	Integrated Biorefinery Research Facility
IH	Industrial Hygiene
ISM	Integrated Safety Management
JON	Judgment of Need
KOH	Potassium Hydroxide
LLP	Lab Level Procedure
LOTO	Lock Out/Tag Out
MCST	Materials and Chemistry Science and Technology
MOC	Management of Change
NREL	National Renewable Energy Laboratory
NREL-IT	NREL Investigation Team
OSEP	Office of Security and Emergency Preparedness
OSHA	Occupational Safety and Health Administration

PHA	Process Hazard Analysis
POC	Point of Contact
PPE	Personal Protective Equipment
RV	Readiness Verification
S&TF	Science and Technology Facility
SCBA	Self-Contained Breathing Apparatus
SERF	Solar Energy Research Facility
SOP	Safe Operating Procedure
SPM Flex	Honeywell Single Point Monitor Gas Detector
SWP	Safe Work Permit
QMP	Quality Management Program
WMFD	West Metro Fire Department

Acronyms of Personnel

ALD1	Associate Lab Director for Facilities and Operations
ALD2	Materials and Chemical Science and Technology (MCST) Associate Lab Director
ESH1	NREL ESH&Q Director
ESH2	S&TF ESH POC
ESH3	Issues Program Manager
ESH4	Safety & Health Program Manager
ESH5	Chemical Response Team Incident Commander (10/7-10/8)
ESH6	IH Program Leader
ESH7	IH Equipment Maintenance
ESH8	ESH POC Site Operations
ESH9	Fire Protection Authority Having Jurisdiction; also administered the first Process Hazard Analysis (PHA) on the project
ESH10	Pressure Safety Program Manager
ESH11	Laser Safety Officer & ESH Programs
ESH12	NREL Environmental Programs Manager
GFO1	Director, Golden Field Office
GFO2	Acting Deputy Director, Business Services Division (GFO)
GFO3	GFO Security and Emergency Preparedness Manager
GFO4	GFO Quality
GFO5	GFO Employee Concerns
GFO6	Environmental Oversight/NEPA
GFO7	Safety and Health Oversight
GFO8	Safety and Health Oversight
GFO9	GFO FEOSH/ Safety and Health Oversight
GFO10	Former GFO Environment, Safety and Health Office Director
OSEP1	Director of Office of Security and Emergency and Preparedness (OSEP)
OSEP2	OSEP Mission Support Group Manager
OSEP3	Emergency Preparedness Coordinator
RES1	Cleanroom coordinator; performed repairs and troubleshooting on the system
RES2	Research Principal Investigator (PI); performed repairs and troubleshooting on the system

RES3	Engineering and Informatics Group Manager; was Chemical Response Team (CRT) Incident Commander on Sunday night (10/6)
RES4	Research Operations Manager
RES5	Principal Investigator (PI)
ROD1	Research Operations Director
ROM1	Incident Commander, Research Operations Manager S&TF
ROM2	Research Operations Manager Solar Energy Research Facility, responded Sunday night
SO1	Site Operations / BMS technician
SO2	S&TF Chief Engineer
SO3	Facility Manager
SO4	PMEC for Cleanroom

Executive Summary

Introduction

On October 6, 2019, an employee for the Alliance for Sustainable Energy (the Alliance) discovered a sulfuric acid spill in the Science and Technology Facility (S&TF) at the National Renewable Energy Laboratory (NREL) in Golden Colorado. The Alliance manages and operates NREL on behalf of the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE). Approximately 20 gallons of concentrated sulfuric acid were released, resulting in damage to the first and second floors of the S&TF. The costs associated with this incident were estimated in the range of $1.5 - 2.1 million.

Although the estimated costs for the event were lower than the amount that would require a DOE Accident Investigation, the incident was significant enough that Derek Passarelli, Director of the EERE Golden Field Office (GFO), appointed a Limited Scope Department of Energy Investigation Board to investigate the spill and the emergency response. The Board completed its analysis and identified the Contributing Causes, Root Causes and the Judgments of Need (JONs) resulting from this investigation in accordance with DOE O 225.1B, *Accident Investigations*.

Accident Description

On the afternoon of Friday, October 4, 2019, work on the Automated Waste Neutralization (AWN) system ended for the day. An isolation valve was opened during work and was never closed. Later that evening, a float alarm in the AWN cabinet secondary containment was detected on the Building Management System (BMS), indicating that liquid was collecting inside the AWN cabinet, which served as the secondary containment. Staff checked the BMS, noted the alarm and conducted a visual inspection around the AWN cabinet, observing no fluid on the floor of the S&TF second floor corridor.

On October 6, at approximately 7:19 p.m., a Site Operations Technician reported liquid on the floor of the S&TF second floor service corridor, and an emergency response was subsequently initiated. At 7:49 p.m., liquid was found to be leaking onto the first floor from the second floor, which impacted the utilities housed beneath the second floor.

The Alliance's Chemical Response Team (CRT) was activated at 8:21 p.m., and the liquid was identified as sulfuric acid at 8:59 p.m. The CRT was able to enter the spill scene at 11:34 p.m., and the CRT continued operations over the next three days to contain the sulfuric acid and initiate cleanup activities. On October 9, incident responsibilities transitioned to Recovery Command, with a hazardous materials cleanup subcontractor taking on remediation work.

Acid leakage through the second floor caused significant damage to the electrical, HVAC, and fire suppression systems. An arc flash damaged an electrical bus, and a Protective Force Officer suffered minor respiratory irritation from airborne exposures. The acid spill extended to within eight feet of an open drain on the first floor, a near miss to an environmental release. The event necessitated a structural engineering review to confirm the integrity of the concrete in the second floor service corridor.

Major portions of the S&TF were closed for multiple weeks as a result of this incident. The second floor labs were available for re-occupancy on October 21, and the first floor spaces were re-opened on November 4, 2019.

Direct, Root, and Contributing Causes

Direct Cause – the immediate events or conditions that caused the accident.

The Board identified the **direct cause** of this accident to be the failure of the rotameter in the AWN system, which leaked sulfuric acid into the secondary containment. The secondary containment subsequently failed and released sulfuric acid from the cabinet into the corridor.

Root Cause – causal factors that, if corrected, would prevent recurrence of the same or similar accidents.

The Board identified three Root Causes of this accident:

- RC1: Thorough verification of chemical compatibility, component specifications and installation did not consistently occur. A rotameter was selected and installed and the secondary containment was repaired; both failed, leading to the accident.
- RC2: The float alarm, which was in place and functioning, did not shut down the acid pump or initiate a response action. Although the original Process Hazard Analysis (PHA) for the AWN included a leak sensor and alarm in containment, the installed float alarm did not perform as an engineering control as indicated in the PHA. In addition, there was no clear response protocol for the float alarm.
- RC3: Alliance did not recognize and act on the level of hazards and controls required for engineering and safe operation of the AWN system. There was inconsistent recognition of the impacts and significance of changes.

Contributing Causes – events or conditions that collectively with other causes increased the likelihood or severity of an accident but that individually did not cause the accident.

The Board identified 13 contributing causes to this accident:

- CC1: The Alliance accepted the AWN system in 2016 from Subcontractor 1 with indications of inadequate design, training, and preparedness to work on the system. Alliance accepted an AWN system without it being fully challenged with chemistry, and the warranty period expired before doing so.
- CC2: Numerous issues with the AWN system continued over a three year period, during which time the AWN System was rebuilt in-house. Alliance did not obtain or consistently engage qualified expertise in engineering, design, review and acceptance of the rebuilt system. Research and Research Operations were designing and operating the AWN system without necessary expertise.

- CC3: Ownership and operational roles, and responsibilities for the AWN system were not clearly defined.
- CC4: The Alliance selected commissioning to verify the adequacy, safety, and readiness of the redesigned AWN system. This approach is not consistent with the Alliance Hazard Identification and Control Program. The Alliance did not follow through with the commissioning process.
- CC5: Lock Out/Tag Out (LOTO) is not the correct work authorization process to follow for the work conducted. Work was performed that was not authorized.
- CC6: Workers did not coordinate activities when loading the sulfuric acid drum into the AWN cabinet. Adequate work planning and communication did not occur.
- CC7: Several key hazard identification and control elements were not fully implemented. For example, PHA corrective actions remained open at the time of the accident, neither a readiness verification nor a commissioning were not issued or were not completed, and multiple safe work permits pertinent to the work being performed were left to expire.
- CC8: On multiple occasions during the redesign of the AWN system hazard identification and control work processes were not used. There was a misunderstanding of work authorization processes and work was routinely performed and hazards were introduced when work was not authorized.
- CC9: Numerous AWN system function and design changes occurred without thorough review and impact analysis.
- CC10: Point-to-point testing did not identify that an incorrect address for the ammonia scrubber isolation valve was entered in the BMS. The isolation valve remained open when it should have been closed.
- CC11: Multiple opportunities to have identified and implemented applicable safety and emergency management standards and requirements that would have prevented the accident or minimized its consequences were missed.
- CC12: Interim measures and corrective actions from precursor events were not always implemented in a timely manner. Opportunities to learn from precursor events, employee concerns, and internal and external feedback were missed.
- CC13: The Board identified multiple instances in which worker behavior and decision-making led to work being performed outside of established procedures. These were not corrected, resulting in organizational drift.

Conclusions and Judgments of Need

Based upon the findings of this accident investigation, the Accident Investigation Board concluded that this accident was preventable.

Table ES-1 summarizes the Conclusions (CONs) and Judgments of Need (JONs) determined by the Board. The conclusions are those that the Board considered significant and are based on the facts and pertinent analytical results. Judgments of Need are managerial controls and safety measures believed by the Board to be necessary to prevent or minimize the probability or severity of a recurrence of this type of accident. Judgments of Need are derived from the conclusions and causal factors and are intended to assist managers in developing corrective actions and fostering continuous improvement.

In general, the Board's CONs can be binned into three major areas.

- First, while the Alliance has a well-structured set of ES&H policies and procedures, along with a knowledgeable and committed staff involved in their implementation, the Board identified some key gaps in the Alliance's Integrated Safety Management System. These include missing elements, lack of sufficient specificity, insufficient consideration of precursor events, and inadequate application of requirements.
- Second, the Board noted particular gaps in the Alliance's management of change and quality control practices. Ensuring reviews by qualified individuals for any and all modifications to processes, procedures, and systems will significantly increase the likelihood of identifying issues before they become incidents.
- Third, the Alliance has not always clearly defined roles and responsibilities to ensure programs and processes are well integrated. While program and project managers are effective in their roles, they do not always appear to understand how they interface with other programs, which can complicate implementation of applicable policies and procedures.

The Board also found opportunities for GFO to improve the effectiveness of its oversight activities. Clearly conducted and well-structured oversight will provide the Alliance with valuable perspective and feedback, and assist in identifying opportunities for improvement.

Table ES-1: Conclusions and Judgments of Need

Conclusions	Judgments of Need
CON1: The Board concluded that this accident was preventable.	**JON1:** The Alliance needs to implement the Board's Judgements of Need so that this and other similar accidents may be prevented.
CON2: The Alliance did not identify and implement engineering controls that were adequate to initiate an immediate and appropriate response.	**JON2:** The Alliance needs to ensure that engineering controls function to effectively contain the hazard.
CON3: The Alliance did not identify and implement administrative controls that were adequate to initiate an immediate and appropriate response and mitigate the consequences of the accident.	**JON3:** The Alliance needs to ensure administrative controls function to effectively contain the hazard and mitigate potential consequences.

Conclusions	Judgments of Need
CON4: The Alliance did not implement an effective management of change program that recognized the impact and significance of changes to systems and re-evaluated hazards and controls.	**JON4:** The Alliance needs to ensure that their lab-level work planning processes are fully integrated, functional, and capable of effectively identifying and recognizing changes to work processes that necessitate re-evaluation of hazards and controls with a level of rigor equivalent to the risk.
CON5: This event revealed multiple barriers that failed related to work planning and control processes.	**JON5:** The Alliance needs to conduct a thorough analysis of work planning and control processes and ensure that verifiable/defensible corrective actions are implemented for each related work planning and control causal factor.
CON6: The Alliance did not always communicate workplace hazards effectively through the Plan of the Week or Plan of the Day meetings.	**JON6:** The Alliance needs to ensure that employees are informed of workplace hazards.
CON7: There was a failure to verify chemical compatibility, component specifications, and installation.	**JON7:** The Alliance needs to ensure that an effective process is in place for designing, installing, and approving systems in-house. **JON8:** The Alliance needs to ensure that qualified personnel are responsible for and involved in the engineering of complex, hazardous systems.
CON8: The AWN system chemistry was not handled the same degree of rigor as other chemicals used to support cleanroom operations. Treating it as a hazardous production material (HPM) system would have greatly reduced the likelihood of system failure.	**JON9:** The Alliance needs to ensure that its chemical management programs include appropriate safeguards and controls.
CON9: Work was performed without effective engagement of relevant Alliance programs (e.g. pressure safety) to ensure appropriate standards and requirements were fully applied.	**JON10:** The Alliance needs to ensure sufficient resources are available for formal and rigorous design, testing, and readiness of laboratory activities.
CON10: ESH&Q programs and procedures are not uniformly flowed down and consistently implemented.	**JON11:** The Alliance needs to ensure ESH&Q programs and procedures are uniformly flowed down and implemented.

Conclusions	Judgments of Need
CON11: The Automated Waste Neutralization (AWN) system was accepted without validating it performed as designed and was compatible with broader research systems.	**JON12:** The Alliance should ensure an effective system is in place for verifying design and functionality of systems prior to acceptance from subcontractors.
CON12: A qualified chemical engineer was not engaged for the in-house redesign of the AWN system, which contributed to weaknesses in AWN system integrity (rotameter and containment failure).	**JON13:** The Alliance needs to ensure appropriate professional expertise is applied to design and engineering of Site Operations and research systems.
CON13: Confirmation and quality verification of the coding did not occur. Additionally, the system is not engineered to provide confirmation of the position of the valve to the operator resulting in operators being unaware of actual system configuration prior to verification of readiness for safe operation.	**JON14**: The Alliance needs to ensure integration of configuration control and quality processes that verify work is as intended for safe operations into work at all levels.
CON14: ESH&Q and engineering resources were not always sufficient to support the redesign of the AWN system. This contributed to delays in research and employees using work arounds.	**JON15:** The Alliance needs to ensure experts from ESH&Q, Site Operations and Research Operations are available to engage in work planning to ensure application of appropriate standards and requirements.
CON15: The Alliance missed opportunities to learn from precursor events, employee concerns, and internal and external feedback.	**JON16:** The Alliance needs to examine and strengthen its processes to learn from precursor events, employee concerns, and internal and external feedback throughout all of NREL.
CON16: Human performance and safety culture issues exist that led to system weaknesses and poor decision-making.	**JON17:** The Alliance needs to ensure sufficient focus is placed on continuing to mature its safety culture and strengthen its integrated safety management system.
CON17: The Alliance did not establish effective ownership, roles, and responsibilities for the AWN system.	**JON18**: The Alliance needs to ensure that roles and responsibilities are clearly defined in documents such as Boundary Agreements.

Conclusions	Judgments of Need
CON18: The Alliance did not define and implement effective roles and responsibilities for verifying the adequacy, safety, and readiness of the redesigned AWN system.	**JON19:** The Alliance needs to review processes to ensure formal and effective procedures for verifying the adequacy, safety, and readiness of laboratory systems are implemented.
CON19: The Alliance failed to recognize and seal cracks in load bearing concrete flooring, which led to penetration of concentrated sulfuric acid into and through the cracks in the flooring from the second to the first floor. Consequently, the sulfuric acid damaged equipment and building components and may have affected the structural integrity of load bearing concrete flooring.	**JON20:** The Alliance needs to review relevant standards such as NFPA-45, *Fire Protection in Laboratories*, in order to identify appropriate opportunities to improve chemical safety, protect workers and prevent or mitigate similar accidents. **JON21:** The Alliance needs to review NFPA 400, *Hazardous Materials Code*, and other relevant standards, in order to ensure the AWN and other hazardous systems are in compliance with chemical safety requirements. **JON22:** The Alliance needs to perform an engineering structural analysis of the S&TF load bearing concrete floor to verify structural integrity.
CON20: An exposure assessment, as required under 10 CFR Part 851, *Worker Safety and Health Program,* was not performed for the application of epoxy sealant in the AWN cabinets before work was conducted. Initial or baseline industrial hygiene assessments are required to be performed and documented.	**JON23:** Alliance needs to review its Industrial Hygiene program to assess compliance with 10 CFR Part 851 and implement required program elements.
CON21: The Alliance did not implement all the applicable requirements, such as an emergency management plan and a technical planning basis, as specified in DOE Order 151.1D, *Comprehensive Emergency Management System*. This may have exacerbated the consequences of the accident and jeopardized the safety of workers, the public, and the environment.	**JON24:** The Alliance needs to completely implement all applicable requirements of DOE Order 151.1D in order to have a fully integrated, functional, and capable emergency management program.

Conclusions	Judgments of Need
CON22: Neither Office of Security and Emergency Preparedness (OSEP) nor the Chemical Response Team (CRT) are effectively integrated into the chemical management process, and therefore, may not be aware of chemical hazards on site.	**JON24:** The Alliance needs to completely implement all applicable requirements of DOE Order 151.1D in order to have a fully integrated, functional, and capable emergency management program.
CON23: GFO has not developed a formal, risk-based approach to conducting ES&H oversight that appropriately targets Alliance programs and activities based on considerations of hazards and the maturity and performance of Alliance programs and management systems.	**JON25:** GFO needs to provide clear strategic direction, along with the necessary capabilities and systems support, to enable more effective oversight activities.
CON24: Trust and communication issues between GFO and the Alliance limit the effectiveness of GFO oversight activities.	**JON26:** GFO and the Alliance need to ensure that all staff are empowered to cooperatively work together to enable effective oversight. This should involve top-level management commitment along with follow through at all organizational levels.

1. Introduction

1.1. Appointment of the Board

On October 6, 2019, an employee for the Alliance for Sustainable Energy (the Alliance) discovered a sulfuric acid spill in the Science and Technology Facility (S&TF) at the National Renewable Energy Laboratory (NREL) in Golden Colorado. The Alliance manages and operates NREL on behalf of the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE). The spill resulted in damage to the first and second floors of the S&TF. On October 29, Derek Passarelli, Director of the EERE Golden Field Office (GFO) appointed a Limited Scope Investigation Board to investigate the spill. The Board completed analysis and the identification of the Contributing Causes, Root Causes and the Judgments of Need (JONs) resulting from this investigation in accordance with DOE O 225.1B, *Accident Investigations*.

1.2. Background

1.2.1. The DOE Office of Energy Efficiency and Renewable Energy

The mission of the DOE Office of Energy Efficiency and Renewable Energy (EERE) is to create and sustain American leadership in the transition to a global clean energy economy. Its vision is a strong and prosperous America powered by clean, affordable, and secure energy.

1.2.2. DOE EERE Golden Field Office

DOE EERE's Golden Field Office is dedicated to supporting the development of sustainable and environmentally clean energy. The GFO is responsible for oversight and implementation of EERE's financial assistance portfolio and oversight of NREL. NREL is the nation's preeminent laboratory solely dedicated to the research and development of renewable energy, energy efficient technologies, and the transfer of those technologies into the marketplace.

1.2.3. The National Renewable Energy Laboratory

In 2017, the National Renewable Energy Laboratory (NREL) celebrated 40 years of leading advanced energy research. Working with partners in industry and academia, NREL delivers the scientific foundation and new energy technologies that drive the country's economic growth. NREL's researchers and facilities, yield innovations that create new business opportunities and greatly reduce the risk of investment for energy companies and manufacturers.

Figure 1. National Renewable Energy Laboratory

Today's NREL, building on decades of work and ongoing advanced-energy research, tackles a range of energy challenges with an integrated approach. NREL seeks ways to strengthen the U.S. manufacturing sector research to advance the next generation of wind turbines and continues to enhance the solar technologies and other renewable generation technologies through innovation. NREL partners with utilities to help to secure the nation's energy grid and leads in developing cost-competitive, domestically sourced products like ammonia for fertilizer, ethylene for plastics, and acrylonitrile for carbon fiber. NREL is at the forefront of integrating biomass into the nation's petroleum infrastructure and conducts research and development to improve the efficiency of buildings, vehicles, and transportation systems.

1.2.4. Science and Technology Facility Description

Science and Technology Facility (S&TF) was designed specifically to reduce time delays associated with transferring technology to industry. The S&TF's 71,000 square feet is a multi-level facility of lab space, office space, and lobby connected by an elevated bridge to the Solar Energy Research Facility (SERF). The S&TF houses advanced material synthesis, characterization, and general support laboratories.

Figure 2. Science and Technology Facility

The S&TF provides numerous capabilities for a wide range of scientific investigations. Many of these capabilities are associated with specific cluster tools for modular deposition, processing, and characterization techniques. The cluster tools are configured around a system using a central robotic arm to transfer samples. Adjacent to the cluster tools is a 3,500-ft state-of-the-art cleanroom.

The capabilities of the Material and Chemical Science and Technology (MCST) directorate at NREL span from foundational scientific understanding to industry-relevant applied research and development for renewable energy and energy efficiency technologies. The MCST research includes materials discovery, development and characterization, as well as manufacturing and reliability science for renewable energy technologies including: photovoltaics, solar fuels, hydrogen production and storage, fuel cells, windows, batteries, thermoelectrics, and opto-electronics/lighting.

MCST provides expertise to the DOE EERE, the Office of Science, Advanced Research Projects Agency-Energy, as well as university and industry partners. The directorate is led by the Associate Laboratory Director and supported by the Leadership Team.

1.3. Scope, Purpose and Methodology of the Accident Investigation

The Limited Scope Accident Investigation Board began its activities on October 29, 2019, and completed its investigation on December 23, 2019. The scope of the Board's investigation was to identify relevant facts; analyze the facts to determine the Direct, Contributing, and Root Causes of the accident; develop Conclusions; and determine JONs for actions that, when implemented, prevent recurrence of the accident. The investigation was performed in accordance with the methodology described in DOE O 225.1B, *Accident Investigations*. The Board was tasked to:

- Perform independent determination of the causal factors of the accident, conclusions and judgments of need to prevent recurrence;
- Assess the NREL Contractor Assurance System (CAS), Safe Conduct of Work Program; and Site Maintenance Program, to include: internal self-assessments; oversight; hazard identification and control; boundary agreements; feedback and improvement; design engineering, and quality acceptance processes;
- Assess the adequacy of the emergency response/recovery to the accident to include: Comprehensive Emergency Management System; Chemical Response Team; and External Response Organizations; and industrial hygiene monitoring;
- Conduct an independent assessment and verification of the adequacy of the Contractor's investigation; and
- Assess GFO's oversight of the accident.

Figure 3 describes the accident investigation terminology used throughout this report.

Accident Investigation Terminology
A **causal factor** is an event or condition in the accident sequence that contributes to the unwanted result. There are three types of causal factors: direct causes, which is the immediate event(s) or condition(s) that caused the accident; root causes, and contributing causes. The **direct cause** of an accident is the immediate event(s) or condition(s) that caused the accident. **Root causes** are the causal factors that, if corrected, would prevent recurrence of the same or similar accidents. Root causes may be derived from or encompass several contributing causes. They are higher-order, fundamental causal factors that address classes of deficiencies, rather than single problems or faults. **Systemic root causes** involve a deficiency in a management system that, if corrected, would prevent the occurrence of a class of accidents. **Local root causes** involve a specific deficiency that, if corrected, would prevent recurrence of the same accident. **Contributing causes** are events or conditions that collectively with other causes increased the likelihood of an accident but that individually did not cause the accident. Contributing causes may be longstanding conditions or a series of prior events that, alone, were not sufficient to cause the accident, but were necessary for it to occur. Contributing causes are the events and conditions that "set the stage" for the event and, if allowed to persist or recur, increase the probability of future events or accidents. **Event and causal factors analysis** include charting, which depicts the logical sequence of events and conditions (causal factors that allowed the accident to occur), and the use of deductive reasoning to determine the events or conditions that contributed to the accident. **Barrier analysis** reviews the hazards, the targets (people or objects) of the hazards, and the controls or barriers that management systems put in place to separate the hazards from the targets. Barriers may be physical or administrative. **Change analysis** is a systematic approach that examines planned or unplanned changes in a system that caused the undesirable results related to the accident. **Error precursor analysis** identifies the specific error precursors that were in existence at the time of or prior to the accident. Error precursors are unfavorable factors or conditions embedded in the job environment that increase the chances of error during the performance of a specific task by a particular individual, or group of individuals. Error precursors create an error-likely situation that typically exists when the demands of the task exceed the capabilities of the individual or when work conditions aggravate the limitations of human nature.

Figure 3: Accident Investigation Terminology

2. The Accident

On October 6, 2019, a Site Operations Technician discovered a sulfuric acid spill on the second floor of the S&TF (Figure 4). The spill resulted in significant damage to the first and second floors' service corridors within the S&TF.

Figure 4. Sulfuric Acid Pooling on the Second Floor Service Corridor of the S&TF with Visible Cracks in the Floor

The incident resulted in the partial closure of the S&TF for four weeks. The Alliance originally estimated costs associated with this event to be $1.5 to $2.1 million, to include damage to equipment and infrastructure, cleanup and remediation expenses, lost work time, and third-party support services.

On October 29, the GFO Director appointed a Limited Scope Investigation Board to investigate the spill. The analyses, identification of the Contributing Causes, Root Causes, Direct Cause, Conclusions, and the Judgments of Need (JONs) resulting from this investigation were performed in accordance with DOE O 225.1B, *Accident Investigations*.

The Board began the investigation on October 30, 2019, and completed the investigation on December 23, 2019. The Board concluded that this accident was preventable.

2.1. Description of Work Activity

The S&TF is home to an ISO 5 (Class 100) cleanroom with airflow and humidity control to maintain superior particulates and process control. The 156-mm silicon wafer toolset includes the following two central features: a Singulus 13-bath, automated wet-bench processing tool, and a Tetreon four-stack diffusion furnace.

The Automated Waste Neutralization (AWN) System neutralizes industrial wastewater primarily generated from the Singulus Automated Wet Processing Station located in the cleanroom. This occurs through the use of a pH control system designed to meet discharge requirements.

The AWN system is supplied chemistry via a chemical delivery system that contains a base side and an acid side that neutralize cleanroom waste and exhaust. The AWN cabinet holds a 55 gallon drum of sodium hydroxide/potassium hydroxide blend and another 55 gallon drum of sulfuric acid.

2.2. Accident Description

On the afternoon of October 4, 2019, tuning of the chemistry delivery and work on the AWN system ended for the day. An isolation valve was opened during work and was never closed. Approximately three and one half hours later, a float alarm in the AWN cabinet secondary containment was detected on the BMS. On October 5, between 3:00 a.m. to 5:00 p.m. (Mountain Standard Time) the ammonia scrubber called for acid and the BMS called for fluid and opened the metering valve. The S&TF Chief Engineer (SO2)[1] checked the BMS, noted the alarm and subsequently conducted a visual inspection around the AWN cabinet. No fluid was observed on the floor of the S&TF second floor corridor.

On October 6, at approximately 7:19 p.m., a Site Operations Technician reported liquid on the floor of the S&TF second floor service corridor and an emergency response was subsequently initiated. At 7:49 p.m., liquid was found to be leaking onto the first floor, which impacted the utilities housed beneath the second floor.

Acid leakage through the second floor caused significant damage to the electrical, HVAC, and fire suppression systems. An arc flash damaged an electrical bus, and a Protective Force Officer suffered minor respiratory irritation from airborne exposures. The acid pool extended to within eight feet of an open drain on the first floor, a near miss to an environmental release. The event necessitated a structural engineering review to confirm the integrity of the concrete second floor.

[1] The purpose of the accident investigation is to understand and identify the causes that contributed to the accident so those deficiencies can be addressed and corrected. This, in turn, is intended to prevent recurrence and promote improved environmental protection and safety and health of DOE employees, contractors, and the public. Moreover, accident investigations are used to promote the values and concepts of a learning organization. Per DOE policy, this report does not identify individuals by name, instead assigns a code to all individuals interviewed or otherwise referenced. A table of acronyms used can be found on pages vi-vii.

CON1: The Board concluded that this accident was preventable.

JON1: The Alliance needs to implement the Board's Judgements of Need so that this and other similar accidents may be prevented.

2.3. Accident Response

On October 6, 2019, at 7:48 p.m., Alliance Protective Force Officers distributed a message stating, "A hazardous materials release from a sulfuric acid and sodium hydroxide cabinet has been reported at S&TF. The Research Operations Manager (RES4) and the Engineering and Informatics Group Manager (RES3) were en route." At 7:49 p.m., a Protective Force Officer entered the first floor service corridor and observed liquid dripping from the ceiling.

RES3 and RES4 arrived in less than 10 minutes to evaluate the spill. At 8:21 p.m., the CRT was activated due to the emergency situation. RES3 was identified as Incident Commander. At approximately 8:42 p.m., the CRT confirmed the liquid was sulfuric acid (pH was zero) and began to plan entry into the space. A text message sent at 9:12 p.m. stated the "CRT is preparing to enter the spill area to stop chemical spread and begin absorption process." At 9:31 p.m., a Protective Force Officer reported the first floor electricity would be turned off due to spill interacting with electrical conduits. At 9:50 p.m., an electrician arrived to turn off the power. At 11:34 p.m., Entry Team #1 entered the second floor service corridor. The initial CRT response activities concluded after 1:00 a.m., October 7, 2019.

Two employees reported complications as a result of the accident response. A Protective Force Officer reported to Occupational Health Services for evaluation of respiratory irritation from airborne exposures and was released without restriction. A CRT Entry Member who participated on two separate days received an injury after the Level B Suit they were wearing became bunched under their heels and caused pain. The injury was reported on November 8, 2019. Occupational Health Services made a diagnosis and the employee was returned to work with no restrictions.

2.4. Photographs of Acid Spill and Cleanup

Figure 5. The first floor service corridor of S&TF after absorbent materials were applied to the acid that dripped through cracks in the concrete floor of the second floor.

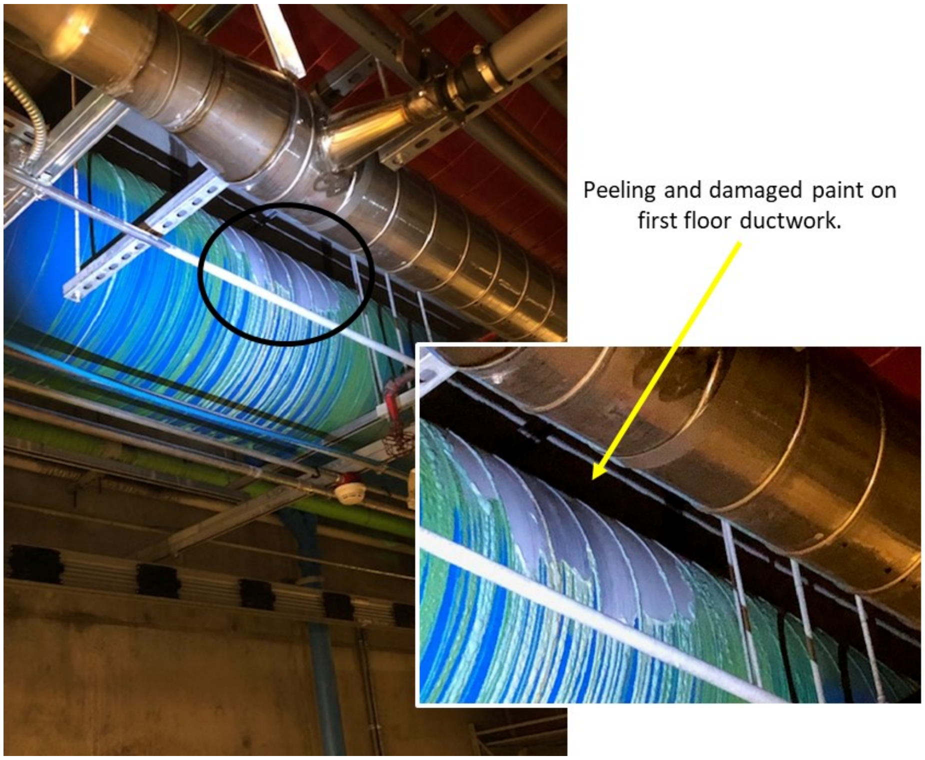

Figure 6: Damage to First Floor Ducts

Figure 7. Sulfuric Acid Coating the Sprinkler Head

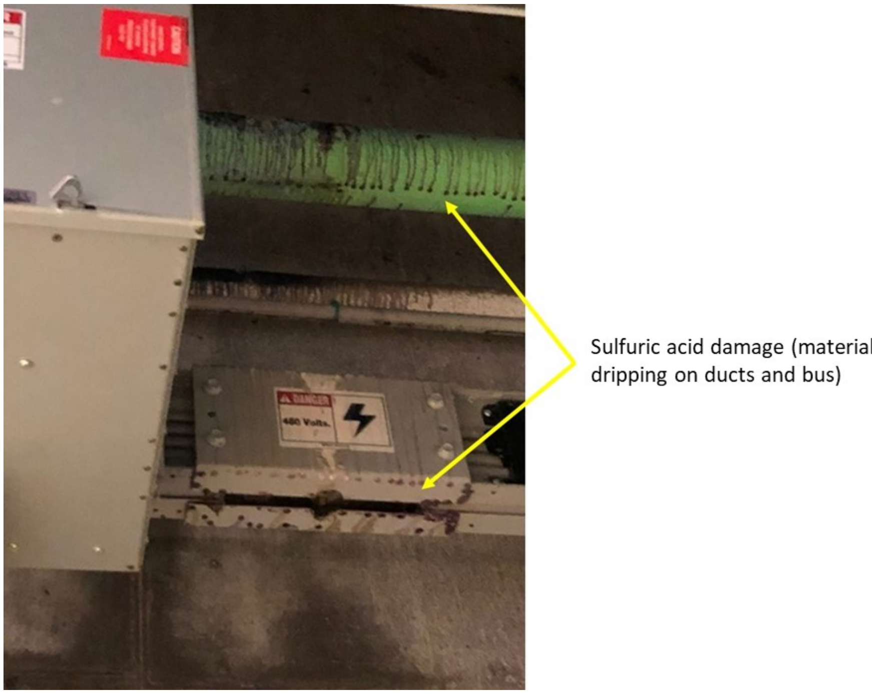

Figure 8. The 600 AMP Bus with Sulfuric Acid Damage

Figure 9. Sulfuric Acid Penetration through the Ceiling.

Figure 10. Sulfuric Acid on the Transformer

Figure 11. Sulfuric Acid on Various Items on the First Floor

Figure 12. Sulfuric Acid Pooling Around Items on the First Floor

2.6. Event Chronology

Table 1. Chronology of the Accident

Date	Time	Event
Precursor Events		
12/20/2012	Unknown	Enforcement Letter WEL-2012-05 Electrical Shock Near Miss - Outdoor Test Facility (OTF).
02/08/2013	3:13 a.m.	NREL Drum Rupture NTS--GO-ASE-NREL-2013-0008.
11/27/2013	Unknown	Enforcement Letter WEL-2013-04 Drum Rupture Event.
01/08/2015	Unknown	Memo issued Regulatory Assessment Review of 10/27-29/2014
04/25/2018	9:20 a.m.	Glovebox Rotameter failure due to chemical incompatibility at SERF E129.
06/11/2018	Unknown	Polysulfone rotameter was identified as failed part for SERF event.
10/04/2018	4:45 p.m.	FTLB Lab 232 Mercury Spill.
10/05/2018	5:00 p.m.	Solar Energy Research Facility Lab W125 Mercury Spill.
10/22/2018	Unknown	FTLB Lab 232 re-opens.
04/18/2019	3:10 p.m.	NREL Employee Concern Lab Level Procedure (LLP) Rollout.
04/26/2019	5:25 p.m.	NREL Employee Concern Flow down of Requirements.
07/24/2019	9:40 a.m.	S&TF 204 Flammable organometallic spill onto worker.
08/08/2019	5:15 p.m.	Integrated Biorefinery Research Facility (IBRF) and Field Test Laboratory Building (FTLB) Shock Event Work Pause
Historical Events		
2009	Unknown	Alliance purchases chemical cabinet later used in AWN system.
09/30/2016	Unknown	• AWN system accepted from Subcontractor 1. • System components demonstrated by Subcontractor 1 but complete system not challenged with chemistry.
01/2017 - 02/16/2017	Unknown	• AWN scrubber and chemical supply cabinet explained but not functional. • Unclear ownership of cabinet and contents.
02/22-04/21/2017	Unknown	• AWN system start up meetings held; • Parts ordered and AWN system documents developed; and • Cleanroom Commissioning report updated to include AWN system.

Date	Time	Event
05/2/ – 06/19/2017	Unknown	• Numerous issues with piping, secondary containment and pipe terminations; • Repairs continued throughout the month; and • Eventually determined the need to change to a different style of check valve.
07/06/ – 07/25/2017	Unknown	• AWN system PHA starts and ends for both acid and base side of cabinet; • Final PHA draft issued 07/28/2017; and • Final copy issued 08/04/2017.
08/2017	Unknown	• Safe Work Permit (SWP) developed for loading chemicals; SWP for Singulus tool start-up developed (neither SWP is issued); • 08/21/2017, contacted vendor regarding drum component checked compatibility; found to be compatible with sodium hydroxide and sulfuric acid; and • Shutdown sodium hydroxide supply to acid scrubber.
08/22/- 08/29/2017	Unknown	• Sodium hydroxide lost prime in pump line overnight; • Inadequate seals between drum insert and dip tube caused more priming issues; and • Issues continued.
Recent Events		
02/28/2018	Unknown	SWP issued to work on and start up AWN system.
04/25/2018	9:30 a.m.	Glovebox rotameter failure in the Solar Energy Research Facility (SERF) E129.
06/11/2018		Polysulfone rotameter was identified as failed part for SERF event.
09/12/2018	Unknown	PHA reviewed and updated to include treatment cabinets pump, piping, and chemistry changes specific to base supply. “System experiencing issues maintaining prime and crystallizing, as well as, delivering required chemistry to neutralize efficiently.”
2018	Unknown	Interview Notes from 10/16/2019; Starting doing dumps for Singulus and scrubber could not keep up. System on base side was way off, needed double the amount of chemical so this is why focus was on base side first.
11/07/2018	Unknown	Final draft PHA issued for base side. PHA identified the float alarm as an engineering control.
Events Leading up to the Accident		
03/18/2019	Unknown	SWP issued to drain and purge the AWN system, including supply tanks, scrubbers and AWN tanks.

Date	Time	Event
03/18/2019	Unknown	Lock out/Tag out (LOTO), Equipment Specific Procedure (ESP) drafted
04/04/2019	Unknown	LOTO ESP completed for future work
04/08 – 04/22/2019	Unknown	• System in LOTO for line blow out and began three times line purge; • Removed shelf from base side of cabinet and guts from acid side of cabinet; and • Found leak in containment of acid side of cabinets.
04/22-29/2019	Unknown	• "In cabinet control Panel" passed electrical inspection; • Start strip out of acid side of cabinet; and • Rework of plumbing in acid side of cabinet.
05/2-3/2019	Unknown	• Begin repairs to acid side of cabinet containment (plastic welding did not work). • Restart granted for testing and startup of AWN system via SWP.
05/07-13/2019	Unknown	• Sealant/Epoxy testing; • DevCon hp250 poor sulfuric acid adhesion and no documentation of resistance to concentrated sulfuric acid; and • Epoxy manufacturer recommended a sealant that is appropriate for both the base side blend and concentrated sulfuric acid.
05/13-14/2019	Unknown	• Confirmed both sides of the cabinet have containment leaks; and • SWP issued to re-epoxy secondary containment in both acid and base sides of cabinet and test with water.
05/15 – 06/03/2019	Unknown	Repair of cabinet containment and water testing occurs.
06/06/2019	Unknown	• Meeting to discuss AWN ownership, boundary agreement and path forward; • Determined a Readiness Verification (RV) would not be done, just a commissioning document; and • Agreed work could be performed according to the LOTO procedure.
06/18/2019	Unknown	Previously issued SWPs expired.
09/18 – 26/2019	Unknown	• AWN Acid cabinet work continues; • Drum(s) replaced and lines purged; • Acid Cabinet stripped out; • New Programmable Logic Controls (PLCs) installed; and • "In cabinet control Panel" passed electrical inspection.

Date	Time	Event
10/02-03/2019	Unknown	• AWN Acid cabinet upgrades and tuning occurs; • Upgrades complete; • No leaks from water test; • Sensors perform as expected; and • Building Management System (BMS) Technicians requested for tuning AWN valves.
10/04/2019	Unknown	• Sulfuric acid drum loaded, work started; • Several issues are experienced with pH and when tuning valves.
10/04/2019	Noon – 3:00 p.m.	• Ammonia scrubber isolation valve opened and never closed; and • Pump activated to deliver acid for fine tuning.
10/04/2019	3:30 – 6:36 p.m.	• Work on the AWN system ended for the day; and • Rotameter failed. Acid enters secondary containment. • Sulfuric acid leak alarm on the ammonia scrubber detected on BMS.
10/05/2019	3:00 a.m. – 5:00 p.m.	• Ammonia scrubber called for acid; • BMS called for fluid and opened metering valve; • Building Engineer checked BMS and noted alarm at 12:10 p.m.; and • Exterior of cabinet was visually checked at 5:00 p.m.; no liquid outside cabinet observed.
10/05 – 06/2019	10/05 - 5:00 p.m. to 10/06 - 7:00 p.m.	A hazardous materials release of sulfuric acid from the secondary containment of the AWN system.
10/06/2019	7:19 p.m.	A Site Operations Technician reported liquid in service corridor on second floor of S&TF.
Post-Accident Events		
10/06/2019	7:48 p.m.	*Text Message* – NREL: A hazardous materials release from a sulfuric acid and sodium hydroxide cabinet has been reported at S&TF. RES4 and RES3 en route.
10/06/2019	7:59 p.m.	*Text Message* – S&TF Chemical spill update: RES4 and RES3 are on scene, evaluating the spill.
10/06/2019	8:13 p.m.	*Text Message* – S&TF Chemical spill update: RES4 and RES3 waiting for ESH12 and ROM2 to respond as backup before entering spill location.
10/06/2019	8:21 p.m.	*Text Message* – NREL: The CRT has been activated due to the ongoing emergency situation at the S&TF.

Date	Time	Event
10/06/2019	8:26 p.m.	*Text Message* – CRT Update: ROM2 on scene. RES3 is Incident Commander. Pumps have been turned off to the chemical cabinet to stop the leak.
10/06/2019	8:30 p.m.	*Text Message* – CRT Update: CRT assembly location is S&TF Lab 127.
10/06/2019	8:42 p.m.	Initial responders enter the corridor to test the pH of the liquid.
10/06/2019	8:59 p.m.	*Text Message* – CRT Update: It is confirmed that the chemical is sulfuric acid the pH is 0 (zero). CRT is assembling.
10/06/2019	9:12 p.m.	*Text Message* – CRT Update: CRT team is preparing to enter spill area to stop chemical spread and begin absorption process.
10/06/2019	9:32 p.m.	A Protective Force Officer reported the first floor electricity would be turned off due to the spill interacting with electrical conduits.
10/06/2019	9:50 p.m.	An electrician arrived to turn off the electricity.
10/06/2019	10:09 p.m.	*Text Message* – CRT Update: CRT team planning entry into affected area.
10/06/2019	10:20 p.m.	*Text Message* – CRT Update: Medical clearance in progress for entry team members.
10/06/2019	11:21 p.m.	*Text Message* – CRT Update: Medical clearance still in progress.
10/06/2019	11:34 p.m.	*Text Message* – CRT Update: The entry team is preparing to enter the area for spill containment.
10/07/2019	12:31 a.m.	*Text Message* – CRT Update: Entry Team 1 is out and at Decon Station, more to follow.
10/07/2019	9:32 a.m.	*Text Message* – NREL: The CRT has been activated at the S&TF in response to a non-emergency situation. Respond to RSF 251 as you arrive.
10/07/2019	Unknown	• Alliance Remediation/decontamination contractor, Subcontractor 2 arrives and is then turned away from site. • Alliance works to get a new contractor, Subcontractor 3, on site for remediation/decontamination work.
10/07/2019	2:10 p.m.	Text Message – NREL: The CRT to make entry at S&TF to photograph and video impacted area, collection of gross contamination in impacted area.
10/07/2019	6:06 p.m.	Text Message – CRT Update: CRT operations in the S&TF have ceased for the rest of the day; they will resume tomorrow morning.
10/07/2019	Unknown	CRT Entry Member (entry participant on two separate days) receives an injury after the Level B Suit became bunched under his heels and caused pain.
10/08/2019	8:23 a.m.	Text Message – Request was made to get everyone on the CRT to meet in S&TF room 127 for a Briefing.
10/08/2019	11:20 a.m.	CRT makes entry to first floor in fully-encapsulated Level B with self-contained breathing apparatus (SCBA) to remove contaminated insulation from the copper pipes and cover them with Visqueen.

Date	Time	Event
10/08/2019	Unknown	CRT makes two additional entries on the second floor to decontaminate various items and take additional photos and video.
10/08/2019	1:30 p.m.	DOE/Golden Field Office (GFO) discusses criteria and options for an AIB.
10/08/2019	4:20 p.m.	Phone Memo was sent to GFO - Pleasant View Sanitation District contacted/notified regarding possible discharge of sulfuric acid into sanitation collection system (no release).
10/08-09/2019	Unknown	• CRT Response formally transitions to Recovery Command. • Recovery Objectives developed.
10/09/2019	Unknown	GFO notified of external investigators brought in to lead the Alliance Spill Investigation.
10/09/2019	Unknown	Subcontractor 3, retained as hazardous material (HAZMAT) cleanup contractor, arrives on-site.
10/09/2019	3:53 p.m.	Draft ORPS submitted – "Sulfuric Acid Release Results in Closure of Labs in the S&TF" (EE-GO--NREL-NREL-2019-TEMP).
10/07-11/2019	Varies	GFO Environment Safety and Health (ES&H) conducts oversight of response activities and documents observations.
10/16/2019	2:00 p.m.	• CRT holds debrief. • GFO ES&H observes CRT debrief and provides a follow up for GFO management.
10/18/2019	11:00 a.m.	NREL Investigation Team holds Preliminary Observations Outbrief.
10/18/2019	5:01 p.m.	S&TF second floor labs and corridor re-occupancy request approved by DOE/GFO with caveats.
10/29/2019	10:56 a.m.	DOE/GFO issues a Limited Scope AIB Appointment Letter; Letter updated 11/01/2019.
10/31/2019	2:00 p.m.	NREL Investigation Team holds Follow-up Observations Outbrief for the Federal Accident Investigation Board.
11/01/2019	12:20 p.m.	S&TF first floor re-occupancy request approved by DOE/GFO with questions and caveats.
11/07/2019	10:45 a.m.	ESH5 suspends Recovery Actions.

3. Assessments

3.1. Contractor Assurance System Internal Self-Assessment and Oversight

3.1.1. Contractor Assurance

DOE O 226.1B, *Implementation of Department of Energy Oversight Policy*, and DOE Policy (P) 226.2, *Policy for Federal Oversight and Contractor Assurance Systems*, require DOE contractors to implement a robust CAS that enables regular and transparent communications between the field office and the facility. Effective CAS implementation, includes sufficient transparency between the contractor and DOE Field Office and enables oversight in an environment of trust, accountability, integrity, and respect.

A key feature of the CAS is the Contractor Assurance Information System (CAIS). In 2017, the Alliance launched the revised CAIS Dashboard to provide greater transparency in operations, performance and metrics. The CAIS is structured for users to efficiently access programmatic and technical data. Prior to the CAIS launch, Alliance and GFO relied more heavily on face-to-face meetings and document requests to conduct oversight activities.

Implementation of CAIS has resulted in greater GFO access to lab operational data. Overall, the improvements in access to CAIS have improved communications between GFO and the Alliance. CAIS data access made discussions between them more productive, and enabled a more effective and informed approach to oversight.

GFO management is satisfied with CAIS access and functionality, and the Alliance expresses a willingness to address gaps in access when requested by GFO. However, GFO ES&H staff have noted a continued lack of visibility into certain areas of interest including: industrial hygiene, hazard identification and control, and the chemical response team. In addition, the Board found that ESH&Q information generated by the research divisions is less likely to be visible in the CAIS than information generated by the Facilities and Operations division.

3.1.2. Self-Assessment and Internal Oversight

PROC 200-7, *Corrective Action Management* (September 2019) supports many ESH&Q program elements and the Quality Management Program. PROC-200-7 provides guidance for both corrective actions and opportunities for improvement (OFIs) and includes "*steps to complete cause analysis, action plan development, implementation, verification, and closure*."

The Board discovered ESH&Q usage of the corrective action program did not incorporate issues, lessons learned and OFIs identified by the CRT. The Board could not determine whether CRT has a clearly defined process for tracking, ensuring closure of, and communicating lessons learned from its issues management process.

In addition, the Board found that some corrective actions from the AWN system Process Hazard Analysis (PHA) were not followed up on, and they are not included in the Alliance corrective action program. Corrective actions from PHAs should be captured in the Corrective Action Management Program, per PROC 200-7.

The Alliance does not maintain unified issues management tracking systems or Corrective Action Management systems. Separate systems are used by different divisions, which reduces opportunities for organizational learning, trending, and analysis.

The Alliance provides GFO with an annual assessment schedule and has procedures that define how internal self-assessment is conducted. GFO would benefit from greater ability to shadow and observe these assessment processes, but GFO staff report difficulty in coordinating these activities with the Alliance.

3.2. Safe Conduct of Work

The Board reviewed lab level programs and procedures including:

- Program 625-5, *Safe Conduct of Work* version effective January 2, 2019;
- Procedure 600-19, *Hazardous Production Materials Safety*, version effective January 29, 2017; and
- Procedure 600-2, *Hazard Identification and Control*, version effective date September 18, 2019.

These lab level documents describe a robust process that implements DOE Integrated Safety Management (ISM) requirements. The Board also reviewed several documents that demonstrate that employees are aware of and are implementing the Alliance's safety management system to an extent. However, the Board determined that there is a lack of rigor in some aspects of the implementation of the Alliance's ISM that contributed to the accident.

3.2.1. Hazard Identification and Control Program

The Board evaluated implementation of the Hazard Identification and Control program. The Board considered the PHA that was done for the AWN system, a Hazard Analysis Review (HAR) for the S&TF, the Safe Operating Procedure (SOP) for the Singulus tool, and Safe Work Permits (SWP) that were issued for work performed on the AWN system.

The July 2017, PHA for the AWN included a "Leak sensor and alarm in containment" as an engineering control for the scenario of drum leaking with resultant sulfuric acid spill, which upon alarm would have stopped the system in some way, such as turning off the pumps. However, the leak sensor (float alarm) was not installed as an engineering control and instead only logged an entry in the BMS. There was no response protocol connected with the float alarm, resulting in an inadequate response once the alarm was noticed.

CON2: The Board concluded that the Alliance did not identify and implement engineering controls that were adequate to initiate an immediate and appropriate response.

JON2: The Alliance needs to ensure that engineering controls function to effectively contain the hazard.

CON3: The Alliance did not identify and implement administrative controls that were adequate to initiate an immediate and appropriate response and mitigate the consequences of the accident.

JON 3: The Alliance needs to ensure administrative controls function to effectively contain the hazard and mitigate potential consequences.

The PHA was done for the initial configuration of the AWN system in July of 2017. The PHA was revised in September 2018. This was a demonstration of the use of management of change (MOC). In the PHA, the description of the change was, "Treatment Cabinets Pump, Piping, and Chemistry Changes specific to base supply," which indicates that the PHA modification was intended for the base supply alone. The PHA was not revisited for changes to the acid side.

The PHA identified the AWN cabinet as the required secondary containment, serving as the primary control for leaks within the AWN system (Figure 13). When the cabinet was found to be leaking in April 2019, the PHA was not reevaluated to ensure that the cabinet was still adequate as the primary control for a leak.

Figure 13. Automated Waste Neutralization System Chemical Delivery Cabinet

During a meeting on June 6, 2019, the Alliance decided that the AWN system would be commissioned rather than going through a Readiness Verification (RV). A PHA revision had been done for the rebuild of the AWN base side in September 2018, which demonstrates recognition that the rebuild was a major change that needed to be evaluated through the MOC process. According to Procedure 600-2, a change requiring a PHA revision should also require a formal readiness verification and work authorization, which are not addressed by the commissioning process. The Board notes that a commissioning process is not described in the Alliance hazard identification and control program. The Board found no evidence that a formal commissioning process was initiated for the acid side modifications to the AWN system.

While the PHA was revised for the base side, the PHA was not revised with the rebuild of the acid side of the cabinet in September and October 2019. A drawing for the base side redesign was re-used for the acid side because it was thought that there were minimal differences between the two sides. In its interviews, the Board found there was a misunderstanding on the part of Alliance employees involved as to whether the previous modification of the PHA included the changes to the acid side of the AWN cabinet.

CON4: The Board concluded that the Alliance did not implement an effective management of change program that recognized the impact and significance of changes to systems and re-evaluated hazards and controls.

JON4: The Alliance needs to ensure that their lab-level work planning processes are fully integrated, functional, and capable of effectively identifying and recognizing changes to work processes that necessitate re-evaluation of hazards and controls with a level of rigor equivalent to the risk.

CON5: The Board determined this event revealed multiple barriers that failed related to work planning and control processes.

JON5: The Alliance needs to conduct a thorough analysis of work planning and control processes and ensure that verifiable/defensible corrective actions are implemented for each related work planning and control causal factor.

Safe Work Permits that were written to conduct work on the AWN system expired on June 18, 2019. During this time, Alliance staff noted that ESH&Q was understaffed, with several vacancies occurring simultaneously. This required the remaining ESH&Q staff to take on additional work, reducing their availability to support the AWN system redesign.

Alliance research staff told the Board that in June they decided to conduct the ongoing AWN system work under a Lock Out/Tag Out (LOTO) procedure, so that they would not have to engage ESH&Q to renew or revise the SWP. The LOTO procedure is not a work authorizing document; the work should have continued under a renewal or revision of the SWP, which would have received further input from ESH&Q staff and explicit, signed approval from management.

CON14: The Board identified that ESH&Q and engineering resources were not always sufficient to support the redesign of the AWN system. This contributed to delays in research and employees using work arounds.

JON15: The Alliance needs to ensure experts from ESH&Q, Site Operations and Research Operations are available to engage in work planning to ensure application of appropriate standards and requirements.

On October 4, the acid drum was loaded into the AWN cabinet without adequate communication to line management, Site Operations, and ESH&Q. On October 5, a Site Operations employee noticed activation of the float alarm in the BMS and did a visual check of the second floor service corridor, which at the time showed no spill on the floor. The ongoing work and status of the AWN cabinet had not been communicated to SO2, and SO2 did not have a procedure that included response actions for the float alarm, as a result, he did not take any actions that might have mitigated the consequences of the system failures that were already underway.

CON3: The Board determined the Alliance did not identify and implement administrative controls that were adequate to initiate an immediate and appropriate response and mitigate the consequences of the accident.

JON 3: The Alliance needs to ensure administrative controls function to effectively contain the hazard and mitigate potential consequences.

CON5: The Board determined this event revealed multiple barriers that failed related to work planning and control processes.

JON5: The Alliance needs to conduct a thorough analysis of work planning and control processes and ensure that verifiable/defensible corrective actions are implemented for each related work planning and control causal factor.

CON6: The Alliance did not always communicate workplace hazards effectively through the Plan of the Week or Plan of the Day meetings.

JON6: The Alliance needs to ensure that employees are informed of workplace hazards.

The chemical cabinet used for the AWN system was approximately 10 years old at the time of the accident and was reported to have been moved to different areas of the facility. It was stated to have been partially used in one or more of these areas. During Subcontractor 1 work, a worker was observed standing on the plastic cabinet floor, rather than on a floor platform connected to the structural ribbing of the cabinet. Standing directly on the floor, without the braced platform, can cause cracks in the plastic. This may have been the source of the leaks in the cabinet that later required application of epoxy sealant (Figure 14 and 15). The Alliance staff did not recognize changes in operations that affected cabinet condition.

Figure 14. Cabinet with Epoxy added to Cracks in Cabinet

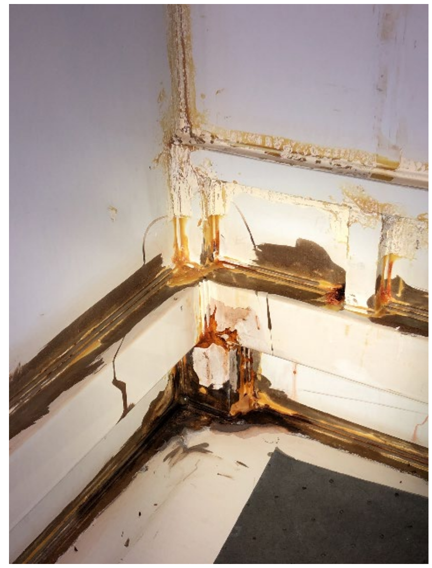

Figure 15. Damage to Cabinet Epoxy after Acid Spill

CON4: The Board concluded that the Alliance did not implement an effective management of change program that recognized the impact and significance of changes to systems and re-evaluated hazards and controls.

JON4: The Alliance needs to ensure that their lab-level work planning processes are fully integrated, functional, and capable of effectively identifying and recognizing changes to work processes that necessitate re-evaluation of hazards and controls with a level of rigor equivalent to the risk.

CON5: The Board determined this event revealed multiple barriers that failed related to work planning and control processes.

JON5: The Alliance needs to conduct a thorough analysis of work planning and control processes and ensure that verifiable/defensible corrective actions are implemented for each related work planning and control causal factor.

CON7: The Board concluded that there was a failure to verify chemical compatibility, component specifications, and installation.

JON 7: The Alliance needs to ensure that an effective process is in place for designing, installing, and approving systems in-house.

JON8: The Alliance needs to ensure that qualified personnel are responsible for and involved in the engineering of complex, hazardous systems.

The cleanroom chemistry is covered under the Hazardous Production Material (HPM) Safety procedure, which provides additional rigor in hazard identification and control. The AWN system, which exclusively supports cleanroom operations, was not treated as an HPM process, even though the AWN chemistry meets the criteria of NFPA rating 3 or 4 for health, flammability, and reactivity. The Alliance did place a Vertex monitoring point in the AWN cabinet exhaust duct, which is consistent practice with the HPM program, but otherwise did not treat the AWN system chemistry with the same level of rigor as an HPM process. Failure to consider the AWN system as part of the HPM program is inconsistent with its function.

CON8: The Board concluded that the AWN system chemistry was not handled the same degree of rigor as other chemicals used to support cleanroom operations. Treating it as a hazardous production material (HPM) system would have greatly reduced the likelihood of system failure.

JON9: The Alliance needs to ensure that its chemical management programs include appropriate safeguards and controls.

3.2.2. Pressure Safety Program

The *Pressure Safety Procedure*, 600-21, version effective August 22, 2019, applies to systems that operate above or below atmospheric pressure and should have applied to the AWN chemical delivery system. However, MCST Research and Research Operations personnel interviewed by the Board seemed unaware of the scope and function of this procedure, and the SWPs, which were written in coordination with ESH&Q staff, make no mention of pressure safety considerations.

Some of the safety issues addressed by the pressure safety procedure that might have mitigated or prevented this accident include:

- Using qualified designers and an independent review of pressure systems;
- Selecting pressure system components that meet operating demands and service;
- Selecting reliable engineered controls to maintain normal operating parameters;
- Pressure and/or leak testing new equipment;

- Sustaining Pressure System Documentation covering design and operation; and
- Sustaining structural integrity and compatibility of components throughout the pressure system and/or component life cycle.

CON9: The Board found that work was performed without effective engagement of relevant Alliance programs (e.g. pressure safety) to ensure appropriate standards and requirements were fully applied.

JON10: The Alliance needs to ensure sufficient resources are available for formal and rigorous design, testing, and readiness of laboratory activities.

CON10: ESH&Q programs and procedures are not uniformly flowed down throughout the organization and consistently implemented.

JON11: The Alliance needs to ensure ESH&Q programs and procedures are uniformly flowed down and implemented.

3.2.3. Quality Control Program

The Board reviewed PROG 225.2 *Quality Management Program* (QMP) (August 2019) which states, "*through implementation of the requirements outlined in this document, NREL maintains the technical, support, and managerial expertise, and supporting infrastructure required to deliver quality research, products, services, and work processes that 1) meet or exceed U.S. Department of Energy (DOE) and NREL requirements, 2) reflect applicable industry standards, and 3) meet or exceed internal and external customer expectations.*" The Board found evidence of inconsistent implementation of the QMP requirements.

In September 2016, the AWN system was accepted from Subcontractor 1 with indications of inadequate design. In June and October 2016, staff voiced concern regarding lack of training regarding the system start up, mechanical systems and controls. In January 2017, the AWN system including the chemical delivery cabinets were installed but were not functional.

At NREL, when purchased products are received they must be inspected to verify that they meet the specified requirements. The AWN system and subcontracted services associated with it were found to not perform as specified but were still accepted. It is unclear what established acceptance and performance criteria was used to inspect and test the AWN system in order to identify differences between expected and actual results in the operating environment.

CON11: The Board determined that the AWN system was accepted without validating it performed as designed and was compatible with broader research systems.

JON12: The Alliance should ensure an effective system is in place for verifying design and functionality of systems prior to acceptance from subcontractors.

MCST Research and Research Operations took on responsibility to redesign and operate the AWN chemical system. Between February and April 2017, start up meetings were held, parts were ordered and documents were developed for the AWN system. Additionally, the Cleanroom Commissioning Report was updated to include the AWN system. From May 2 to June 19, 2017, the AWN system experienced numerous issues with piping, secondary containment and pipe terminations.

MCST Research and Research Operations designed and operated the AWN system without necessary chemical engineering and design expertise. NREL management is responsible for verifying that work processes are planned and carried out by qualified and trained workers using approved and controlled procedures and processes. The requisite skills, hazards, technical requirements, and equipment required for the AWN were not clearly specified, understood, and documented. While MCST personnel have substantial expertise with cleanroom operations, they are not qualified chemical engineers.

CON12: The Board determined that a qualified chemical engineer was not engaged for the in-house redesign of the AWN system, which contributed to weaknesses in AWN system integrity (rotameter and containment failure).

JON13: The Alliance needs to ensure that the appropriate professional expertise is applied to the engineering of hazardous and complex systems.

Safe work permits were developed in August 2017 but were never finalized. The Alliance staff continued to attempt to correct issues with the AWN system including treatment cabinets' pump, piping, and chemistry changes specific to base supply. The Board found no record of the safe work permits being issued to perform work during this timeframe.

Repairs and adjustments for the AWN system continued throughout 2018. Work planning documents do not fully demonstrate application of appropriate standards and requirements to develop the AWN system and implement controls. Thorough verification of chemical compatibility, component specifications and installation did not consistently occur during this time; leaks occurred and new check valves, fittings and seals were needed on various occasions.

In May 2019, epoxy was applied to seams in the secondary containment; this epoxy was not tested for compatibility with 93 percent sulfuric acid, and the cabinet was only leak-tested with water. In September 2019, new Programmable Logic Controls (PLCs) were installed; an incorrect address for the isolation valve was subsequently entered in the BMS. This resulted in the ammonia scrubber isolation valve not closing.

On October 1, 2019, new rotameters were installed. Following connection of the sulfuric acid on October 4, at least one rotameter failed and subsequently the secondary containment failed, leading to the accident.

Figure 16. Failed Rotameter in the AWN Cabinet

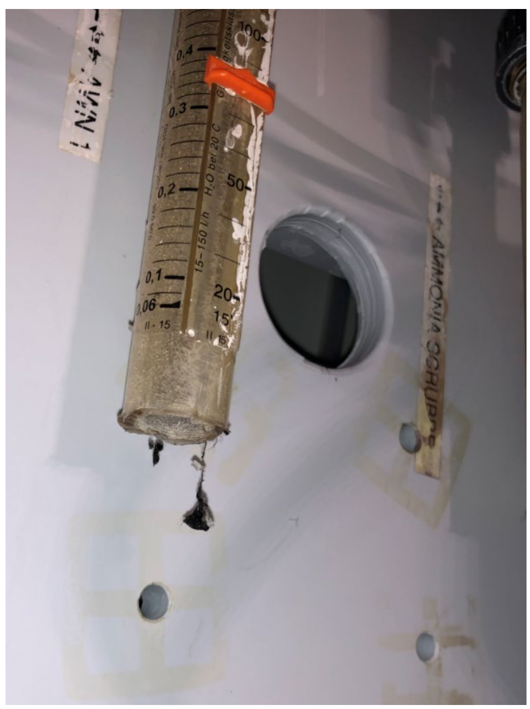

Figure 17. Failed Rotameter in the AWN Cabinet

Figure 18. Failed Rotameter Fitting

The AWN system had persistent issues that remained unsolved and delayed operation of the Singulus tool. Work continued to be planned and performed without full awareness and application of standards and requirements. Point-to-Point testing of the new coding did not demonstrate the system was designed with sound engineering/scientific principles that allowed validation of the coding. It is unclear what actions Management took to identify, resolve or eliminate the AWN system issues or prevent their recurrence.

CON7: The Board concluded that there was a failure to verify chemical compatibility, component specifications, and installation.

JON7: The Alliance needs to ensure that an effective process is in place for designing, installing, and approving systems in-house.

JON8: The Alliance needs to ensure that qualified personnel are responsible for and involved in the engineering of complex, hazardous systems.

CON13: The Board determined confirmation and quality verification of the coding did not occur. Additionally, the system is not engineered to provide confirmation of the position of the valve to the operator resulting in operators being unaware of actual system configuration prior to verification of readiness for safe operation.

JON14: The Alliance needs to ensure integration of configuration control and quality processes that verify work is as intended for safe operations into work at all levels.

CON14: The Board identified that ESH&Q and engineering resources were not always sufficient to support the redesign of the AWN system. This contributed to delays in research and employees using work arounds.

JON15: The Alliance needs to ensure experts from ESH&Q, Site Operations and Research Operations are available to engage in work planning to ensure application of appropriate standards and requirements.

The Board reviewed the ESH&Q Employee Concerns Program and ESH&Q Events to analyze employee feedback and corrective and preventive actions for potential precursors. The Board found missed opportunities to learn from recent precursor events, employee concerns, and internal and external feedback in the following cases:

- April 25, 2018, Glovebox Rotameter failure due to chemical incompatibility with a polysulfone rotameter, with similar materials of construction as the rotameter used in this event;
- October 4, 2018, Field Test Laboratory Building (FTLB) Lab 232 Mercury Spill which revealed weaknesses in Work Planning and Control (work performed but not authorized), industrial hygiene (IH) monitoring, and spill response;
- October 5, 2018, SERF Lab W125 Mercury Spill which indicated similar weaknesses in Hazard Identification and Control, work authorization, IH monitoring, and spill response;
- April 18, 2019, NREL Employee Concern regarding the Lab Level Procedure (LLP) Rollout. This employee concern specifically cited the Pressure Safety program which was not implemented for the AWN despite its applicability;
- April 26, 2019, NREL Employee Concern regarding the Flowdown of Requirements, where an employee noted inadequate communication of requirements; and
- August 8, 2019, Integrated Biorefinery Research Facility (IBRF) and FTLB Shock Events Work Pause, which identified weaknesses in PHA, Hazard Identification and Control processes;

Effective resolution of employee concerns and event corrective actions inform feedback and improvement which is a key element of QMPs.

At several points during the AWN system redesign process, the Alliance management relied on the talent of individuals rather than providing them the resources, skills and knowledge to perform work within the ISM system. On multiple occasions work was performed outside of established procedures, which was not recognized or corrected, leading to organizational drift.

CON15: The Board found the Alliance missed opportunities to learn from precursor events, employee concerns, and internal and external feedback.

JON16: The Alliance needs to examine and strengthen its processes to learn from precursor events, employee concerns, and internal and external feedback throughout all of NREL

CON16: The Board concluded that human performance and safety culture issues exist that led to system weaknesses and poor decision-making.

JON17: The Alliance needs to ensure sufficient focus is placed on continuing to mature its safety culture and strengthen its integrated safety management system.

3.3. Site Maintenance Program

3.3.1. Design, Engineering and Commissioning

The AWN system was designed and built by Subcontractor 1 as part of the cleanroom. The AWN system was accepted by the Alliance in September 2016, before it was adequately challenged. Because the research tools were not yet installed, the AWN system was tested with water, but not with acids or bases. There were also problems identified with the design and training provided by Subcontractor 1. Despite these problems, the Alliance accepted the AWN system. When the research tools were later installed and problems with the AWN system manifested, Subcontractor 1 was not helpful in resolving them, and the warranty expired soon thereafter. The delay in getting the AWN system operational resulted in delays in the research project it supported.

CON11: The AWN system was accepted without validating it performed as designed and was compatible with broader research systems.

JON12: The Alliance should ensure an effective system is in place for verifying design and functionality of systems prior to acceptance from subcontractors.

Once the Alliance accepted the AWN system from the vendor, and the warranty period expired, Site Operations was responsible for maintaining the system. Site Operations did not have the expertise to address the ongoing problems in AWN system performance, and MCST Research assumed the responsibility to resolve the problem of getting the AWN chemical delivery system functioning as needed. This eventually led to MCST staff rebuilding the AWN chemical delivery system. The Alliance staff told the Board that NREL has typically relied on third party engineering to provide chemical systems. The Alliance did not involve a qualified and experienced chemical engineer in the redesign, installation, or acceptance of the rebuilt AWN chemical delivery system.

CON12: The Board determined that a qualified chemical engineer was not engaged for the in-house redesign of the AWN system, which contributed to weaknesses in AWN system integrity (rotameter and containment failure).

JON13: The Alliance needs to ensure appropriate professional expertise is applied to design and engineering of Site Operations and research systems.

CON14: ESH&Q and engineering resources were not always sufficient to support the redesign of the AWN system. This contributed to delays in research and employees using work arounds.

JON15: The Alliance needs to ensure experts from ESH&Q, Site Operations and Research Operations are available to engage in work planning to ensure application of appropriate standards and requirements.

The rotameters were specified at the time the base side of the cabinet was being rebuilt, and were identified for use in both the base and the acid processes. The base side was the initial priority; the acid side was built later. The clear tube part of the rotameter was made of polysulfone, which is compatible up to 85 percent concentration of sulfuric acid. One of the rotameters, exposed to a concentration of 93 percent sulfuric acid, failed and caused sulfuric acid to leak into the cabinet, which served as the secondary containment. The secondary containment, which was repaired in-house, also failed and leaked the sulfuric acid onto the floor.

The Board concluded that both of these failures were linked to not using third-party expertise or acquiring in-house expertise for the redesign of the AWN chemical delivery system.

CON7: The Board concluded that there was a failure to verify chemical compatibility, component specifications, and installation.

JON7: The Alliance needs to ensure that an effective process is in place for designing, installing, and approving systems in-house.

JON8: The Alliance needs to ensure that qualified personnel are responsible for and involved in the engineering of complex, hazardous systems.

CON12: The Board determined that a qualified chemical engineer was not engaged for the in-house redesign of the AWN system, which contributed to weaknesses in AWN system integrity (rotameter and containment failure).

JON13: The Alliance needs to ensure appropriate professional expertise is applied to design and engineering of Site Operations and research systems.

3.3.2. Boundary Agreement

At NREL, Boundary Agreements are used to establish interfaces between facility and program systems in order to identify areas of management responsibility. Boundary Agreements are used to determine responsibilities such as maintenance, safety management, and resource allocation. The Board was provided the S&TF Boundary Agreement, Revision 0, November 20, 2014, which does not address the AWN system. Included in this document are other facility-provided services which typically describe program (Research) responsibilities as being the final connection to the tool.

The Board was also provided a separate spreadsheet, entitled "Cleanroom Boundary Agreement, Draft," last modified on August 16, 2016, which listed the program responsibilities for the Scrubbers and the AWN system as "Treatment Chemistry." The rest of the Scrubber and AWN system responsibilities was assigned to Site Operations.

On June 6, 2019, a meeting was held to discuss AWN system ownership, and an undocumented agreement was made to continue with Research owning the Treatment Chemistry.

The Board was not provided any documentation demonstrating that the boundary agreement for this project was finalized or had clearly defined responsibilities for maintenance, safety management, resource allocation, or management of the system. Staff interviews confirmed that the roles and responsibilities regarding the AWN chemical delivery system and its hazards and controls were not well defined between Site Operations and Research Operations. This lack of clarity resulted in incomplete implementation of hazard identification and control and work authorization processes for the AWN system modifications.

CON17: The Board determined that Alliance did not establish effective ownership, roles, and responsibilities for the AWN system.

JON18: The Alliance needs to ensure that roles and responsibilities are clearly defined in documents such as Boundary Agreements.

CON18: The Board determined that Alliance did not define and implement effective roles and responsibilities for verifying the adequacy, safety, and readiness of the redesigned AWN system.

JON19: The Alliance needs to review processes to ensure formal and effective procedures for verifying the adequacy, safety, and readiness of laboratory systems are implemented.

3.4. Worker Health and Safety Program

The Department has established the worker safety and health requirements that govern the conduct of contractor activities at DOE sites in 10 CFR Part 851, *Worker Safety and Health Program* (also known as the Rule). The Rule provides for a worker protection program to reduce or prevent occupational injuries, illnesses, and accidental losses by requiring DOE contractors subject to the Rule to provide their employees with safe and healthful workplaces. The Rule also establishes procedures for investigating whether a requirement of the Rule has been violated, for determining the nature and extent of any such violation, and for imposing an appropriate remedy. DOE sites implementing the Worker Safety and Health Program are required to utilize ISM, DOE's corporate approach for efficiently achieving its mission goals while maintaining the highest standard of safe operations.

The Board has determined that there were significant discrepancies found in implementing the requirements of 10 CFR Part 851 and DOE P 450.4, *Safety Management System Policy* associated with the accident. The Board also noted additional systemic program deficiencies.

The Alliance has many qualified and dedicated professionals. CRT responders are dedicated and motivated employees. However, the Board found weaknesses in IH, emergency preparedness, and emergency response practices. These gaps may not be apparent during routine operations, but they were clearly evident during the incident response. The Board found inadequate occupational exposure assessment, gaps in worker protection, and lack of communication and integration with other groups integral to the emergency response.

The following discrepancies were noted.

- The original contract document regarding the Cleanroom project included the AWN system. Blueprint and contract documents state NFPA-45, *Standard on Fire Protection for Laboratories Using Chemicals*, applied to the project since it was a renovation. The original code of record requirements change when there is a renovation to the most current fire code requirements. This is required under 10 CFR Part 851, Appendix A, "Pressure Safety." The scope of NFPA-45, per Section 1.1.1, applies to laboratory buildings, laboratory units, and laboratory work areas where chemicals have a NFPA rating of 2-4 for health, flammability or instability. Ninety-three percent sulfuric acid meets this criterion, as do many other chemicals used to support cleanroom operations.
- NFPA-45 Sections 5.1.5.1 and 5.1.5.2 state floor openings and penetrations should be sealed to prevent liquid leakage to lower floors, and that the sealing material should be compatible with chemicals being stored.

  Concrete flooring on the second floor, including both the AWN system and adjacent hazardous production material (HPM) chemical area, has cracks allowing liquids, if they escape their containment, to leak to the first floor. The floor surfaces both for the defined AWN and HPM areas should be sealed in order to comply with applicable requirements.

CON2: The Board concluded that the Alliance did not identify and implement engineering controls that were adequate to initiate an immediate and appropriate response.

JON2: The Alliance needs to ensure that engineering controls function to effectively contain the hazard.

CON9: The Board found that work was performed without effective engagement of relevant Alliance programs (e.g. pressure safety) to ensure appropriate standards and requirements were fully applied.

JON10: The Alliance needs to ensure sufficient resources are available for formal and rigorous design, testing, and readiness of laboratory activities.

CON19: The Board determined that the Alliance failed to recognize and seal cracks in load bearing concrete flooring, which led to penetration of concentrated sulfuric acid into and through the cracks in the flooring from the second to the first floor. Consequently, the sulfuric acid damaged equipment and building components and may have affected the structural integrity of load bearing concrete flooring.

JON20: The Alliance needs to review relevant standards such as NFPA-45, *Fire Protection in Laboratories*, in order to identify appropriate opportunities to improve chemical safety, protect workers and prevent or mitigate similar accidents.

JON21: The Alliance needs to review NFPA 400, *Hazardous Materials Code*, and other relevant standards, in order to ensure the AWN and other hazardous systems are in compliance with chemical safety requirements.

JON22: The Alliance needs to perform an engineering structural analysis of the S&TF load bearing concrete floor to verify structural integrity.

- During the spill response, Alliance used sulfuric acid detector tubes that were 10 months past their expiration. IH staff did not effectively track the expiration dates of the detector tubes stored in an IH refrigerator.
- Additionally, the SKC Inc.-supplied Draeger detector tubes for sulfuric acid are only for 1-5 mg/m^3 which is a high range and would not measure a lower level (ACGIH TLV 0.2 mg/m3); IH staff did not have a method for measuring at these lower levels.
- It was noted in the Galson Labs IH spill exposure monitoring report that samples were received from Alliance in sealed Parallel Particle Impactor cassettes instead of scintillation vials. The Alliance did not follow the correct method for handling the samples, specified in Occupational Safety and Health Administration (OSHA) ID-113. This may cause the reported sample results to be biased low.
- The IH staff did not own or certify the Honeywell Single Point Monitor Gas Detector, SPM Flex. Documentation for initial calibration and manufacturer's recommended calibration for the Flex could not be demonstrated. The Flex is owned and operated by Site Operations. Whether the initial calibration of the SPM Flex Gas Detector included an adjustment for an altitude of approximately 5,670 feet was not known. The IH program owner (ESH6) did not know which employees used the Flex during the HAZMAT response or during cleanup operations.
- The IH staff was not directly involved in use of either the Vertex hazardous gas multipoint monitoring system nor with the Honeywell Flex Single Point Gas Detector. Both systems are used for employee exposure monitoring, and IH staff should be directly involved as per OSHA, ACGIH and 10 CFR Part 851 requirements. Honeywell Flex and Vertex are sophisticated, highly versatile instruments capable of detecting releases at the parts per billion level. The Vertex system was not used to identify the presence of a leak of sulfuric acid, which may have helped with earlier identification of the leak and the determination of the chemistry involved.

CON9: The Board determined that work was performed without effective engagement of relevant Alliance programs (e.g. pressure safety) to ensure appropriate standards and requirements were fully applied.

JON10: The Alliance needs to ensure sufficient resources are available for formal and rigorous design, testing, and readiness of laboratory activities.

- No qualitative or quantitative exposure assessment, as required by 10 CFR Part 851 was documented to have been performed prior to application of epoxy sealant for the AWN cabinet.

CON20: An exposure assessment, as required under 10 CFR Part 851, *Worker Safety and Health Program,* was not performed for the application of epoxy sealant in the AWN cabinets before work was conducted. Initial or baseline industrial hygiene assessments are required to be performed and documented.

JON23: Alliance needs to review its Industrial Hygiene program to assess compliance with 10 CFR Part 851, and implement required program elements.

- It was reported that the implementation of safety and health program elements in different Alliance directorates are not consistently reviewed by the IH and other ESH&Q departments. It was stated that individual directorates function as semi-autonomous entities and that review outside the directorate does not always occur. This runs the risk of creating balkanized, non-integrated programs.
- The site-specific orientation training curriculum is not consistently applied, and some training records from the individual directorates were reported to not be available to EHS&Q. The lack of unified, coordinated training and hazard communication can limit the effectiveness of hazard identification and response.
- The Board found procedures are not uniformly flowed down, or enforced, and engagement of ESH&Q staff is inconsistent. This is further supported by two employee concerns from April 2019.

CON10: ESH&Q programs and procedures are not uniformly flowed down throughout the organization and consistently implemented.

JON11: The Alliance needs to ensure ESH&Q programs and procedures are uniformly flowed down and implemented.

- The Board noted previous gaps in handling toxic and hazardous chemicals with relevance to the S&TF spill. During the Board site visit, a Board member learned that staff in the S&TF failed to return a compressed gas cylinder of phosphine (a highly toxic and pyrophoric gas) to the manufacturer prior to its expiration date. Phosphine supports the Singulus tool. This expired cylinder, which was not properly tracked by the Alliance's chemical management program, developed a leak that continued for several months. A special contractor had to be brought from Texas with a unique cylinder container ("coffin") to remove and dispose of the cylinder safely.

- In 2016, methyl isobutyl ketone was inappropriately stored, formed peroxides, and had to be removed by the Bomb Squad.

CON15: The Board found the Alliance missed opportunities to learn from precursor events, employee concerns, and internal and external feedback.

JON16: The Alliance needs to examine and strengthen its processes to learn from precursor events, employee concerns, and internal and external feedback throughout all of NREL.

- As discussed in Section 3.2.2, the Board found that the implementation of NREL's pressure safety program, required by 10 CFR Part 851, Appendix A, Section 4, "Adequacy of the Emergency Management Program" was lacking. This suggests a vulnerability in the Alliance's worker safety and health program.

CON9: The Board determined that work was performed without effective engagement of relevant Alliance programs (e.g. pressure safety) to ensure appropriate standards and requirements were fully applied.

JON10: The Alliance needs to ensure sufficient resources are available for formal and rigorous design, testing, and readiness of laboratory activities.

- Alliance staff misinterpreted a LOTO equipment specific procedure to be sufficient to use in lieu of renewing and possibly revising an expired safe work permit. Staff stated they wished to use a LOTO or other procedure so that safety permits would not need to be renewed or revised. The willingness to use LOTO instead of pursuing formal work authorization documents suggests a vulnerability in the Alliance's worker safety and health program that may be worth pursuing.

CON5: The Board determined this event revealed multiple barriers that failed related to work planning and control processes.

JON5: The Alliance needs to conduct a thorough analysis of work planning and control processes and ensure that verifiable/defensible corrective actions are implemented for each related work planning and control causal factor.

4. Adequacy of the Emergency Management Program Implementation

4.1. Emergency Management Organization

The Alliance emergency management program falls under the Office of Security and Emergency Preparedness (OSEP). The Director of OSEP and two staff members briefed their program, gave a tour of their Emergency Operations Center (EOC), and were interviewed.

The OSEP personnel are experienced and devoted professionals who have procedures to protect employees, visitors, property, and the environment from injury, damage, or loss. This program has emergency response teams who can respond to and support minor incidents such as small chemical spills and detection alarms. According to the NREL Baseline Needs Assessment of Emergency Response Capabilities, "*the hazardous materials are controlled in a manner consistent with national fire codes and good industry practice.*" A Hazard Analysis Review is conducted for each of the major facilities. OSEP has developed and implemented an Occupant Emergency Plan for each major NREL facility. OSEP relies on contracted external fire, HAZMAT, and medical responders to provide care for emergency situations. The Alliance has a contract with the West Metro Fire Department (WMFD). The scope of work does provide chemical response expertise and support. The EOC is well organized and structured with adequate work stations, equipment, and procedures to handle emergency situations.

After the Director of OSEP and GFO Security & Emergency Preparedness Manager were notified of the sulfuric acid spill, neither performed in a direct role in the response and both determined not to stand up the EOC. However, they both remained informed during the event, primarily by protective force officers and the CRT.

4.2. Site Comprehensive Emergency Management Program Implementation

The provisions of DOE O 151.1D, *Comprehensive Emergency Management System*, apply to all Departmental elements. According to this order each DOE location must:

- Develop and participate in an integrated and comprehensive Emergency Management System;
- Establish and maintain a documented emergency management program that implements the requirements of applicable Federal, State, and local laws, regulations, and ordinances for fundamental worker safety programs; and
- Have the Headquarters Emergency Operations Center serve as the point of contact for all incidents, events, emergencies, emergency notifications and reports.

Additionally, each DOE site must establish and maintain an emergency management program that complies with the Emergency Management Core Program requirements.

Although the Alliance has some emergency management program elements, the Board has determined they have not achieved a fully integrated, effective set of program elements that would constitute compliance with DOE O 151.1D. These gaps, as noted below, could have negative impacts on the ability to respond effectively to emergency situations at NREL.

- OSEP has not developed and maintained an all-hazards emergency management plan. The structure of the current Alliance emergency operating system does not reflect a flow down from an emergency plan to documents (e.g., procedures and checklists) that provide the "how-to" instructions for all the emergency management program elements. They have instead an Occupant Emergency Program plan. If the Alliance had prepared a detailed emergency plan, that plan would describe the provisions for a response to events that requires comprehensive interactions with both internal operating organizations (e.g., CRT), GFO Environment, Safety and Health (ES&H), and external response agencies (e.g., WMFD).
- The Alliance has not completed the technical planning basis that forms the foundation of a comprehensive emergency planning program. This omission is a significant gap in complying with DOE O 151.1D. A non-existent or improperly conducted technical planning basis undermines the effectiveness of:
    - Hazards surveys;
    - Emergency planning hazards assessments (EPHAs), emergency actions levels (EALs),
    - Predetermined protective actions (PAs);
    - Protective action recommendations (PARs), and
    - The emergency planning zone.

Failure to properly formulate and implement PAs can place responders and Alliance personnel at increased risk of exposure to hazards.

CON21: The Board concluded that the Alliance did not implement all the applicable requirements, such as an emergency management plan and a technical planning basis, as specified in DOE Order 151.1D, Comprehensive Emergency Management System. This may have exacerbated the consequences of the accident and jeopardized the safety of workers, the public, and the environment.

JON24: The Alliance needs to completely implement all applicable requirements of DOE Order 151.1D in order to have a fully integrated, functional, and capable emergency management program.

4.3. Alliance Chemical Response Team

The CRT follows the Laboratory-level program PROG 625-13, *Chemical Response Team*. Alliance established the CRT to provide effective response to hazardous material events. The CRT provides both activation and response capabilities for NREL chemical operations and assists facilities using hazardous production materials in meeting occupancy emergency response requirements.

The CRT was established by the Alliance to provide response capabilities to hazardous materials events and to support H5 hazardous occupancies. The CRT is managed by the Alliance's ESH&Q Office and is comprised of volunteer members from various organizations within the Alliance and include research and operations staff; as such, a range of expertise and skills are represented. During a response, the CRT integrates with OSEP, but they are separate organizations. CRT response operations may range from an initial activation to assess and assist in minor events, to providing response capabilities for larger chemical spills.

The CRT is comprised of dedicated, committed and highly conscientious staff. Over 20 employees comprising both ESH&Q, Research and Site Operations Divisions responded to the accident in an exemplary manner, preventing the additional release of approximately 30 gallons of sulfuric acid from the second floor to the first floor. However, failure to follow procedures, confusion over the role of contracted HAZMAT response capabilities, and lack of preplanning were evident weaknesses.

The following discrepancies were noted:

- Some members of the CRT were not familiar with PROG 625-13, including its "no go" (when not to respond) criteria and its June 2019 revisions. The CRT should not have responded to a non-business hours HAZMAT spill according to PROG 625-13. WMFD, under contract with the Alliance, was the designated response contractor for a non-business hours HAZMAT response.

CON10: ESH&Q programs and procedures are not uniformly flowed down throughout the organization and consistently implemented.

JON11: The Alliance needs to ensure ESH&Q programs and procedures are uniformly flowed down and implemented.

- Two employees entered the spill scene to initially determine whether the fluid on the floor was sulfuric acid with only gloves, safety shoes, face shield and pH strips to test the material. (Figure 19) Acid resistant boots or other protective equipment including respiratory protection was not used, placing employees at potential risk. It is unknown if staff checked the Vertex fixed in place monitoring system, with an air sampling sensor in the exhaust of the acid cabinet, to determine whether detectable air born levels of sulfuric acid were present.
- During the spill response, pH paper wetted with deionized water was used as a measurement of airborne sulfuric acid levels. This action was endorsed by members of the CRT. pH paper should be used to detect the pH of liquids, but is not a reliable qualitative measurement of airborne exposure levels.
- Senior CRT members, including the program manager, stated they did not know the scope of work or qualifications of retained HAZMAT contractors. The Alliance environmental division prepares the scope of work for HAZMAT contractors and evaluates qualifications.

- Senior CRT members, including the program manager, stated they did not know the scope of work or qualifications of retained HAZMAT contractors. The Alliance environmental division prepares the scope of work for HAZMAT contractors and evaluates qualifications.
- Evaluation and selection of HAZMAT contractors should involve the IH staff and the CRT. The first contractor, Subcontractor 2, under contract with the Alliance, was activated for spill decontamination and cleanup. Subcontractor 2 arrived on site but was not used due to determination of inadequate qualifications. After considerable discussion during the incident, a new subcontractor, Subcontractor 3, was selected to perform the second stage of the spill response including decontamination. The selection process for Subcontractor 2 lacked rigor and awareness of the potential scope of HAZMAT response needs at NREL.

Figure 19. Testing of Liquids on the Floor with Incorrect Personal Protective Equipment. Note depth of Cracks in Concrete Floor

CON9: The Board determined that work was performed without effective engagement of relevant Alliance programs (e.g., pressure safety) to ensure appropriate standards and requirements were fully applied.

JON10: The Alliance needs to ensure sufficient resources are available for formal and rigorous design, testing, and readiness of laboratory activities.

- The Board found that procedures are not uniformly flowed down or enforced. There was reluctance to activate WMFD as noted in statements made by members of the CRT. “They take control of the building,” “The fire department is only for putting out fires,” “We can do a better job.” Working together with WMFD in a support role during the spill incident was not considered a viable choice. The CRT took approximately three hours to assemble before the first on-air entry.

CON16: The Board concluded that human performance and safety culture issues exist that led to system weaknesses and poor decision-making.

JON17: The Alliance needs to ensure sufficient focus is placed on continuing to mature its safety culture and strengthen its integrated safety management system.

- The Board noted several concerns with Vertere, the Alliance’s chemical inventory system. The system does not track all chemicals at NREL, contains insufficient information about chemical concentrations, and does not include or provide direct access to required hazard communication information. As a result, the database does not provide sufficient hazard identification information to support emergency operations, planning and response.

CON22: The Board concluded that neither Office of Security and Emergency Preparedness (OSEP) nor the Chemical Response Team (CRT) are effectively integrated into the chemical management process, and therefore, may not be aware of chemical hazards on site.

JON24: The Alliance needs to completely implement all applicable requirements of DOE Order 151.1D in order to have a fully integrated, functional, and capable emergency management program.

- During the spill, sulfuric acid was dripping through cracks from the second to the first floor service corridor. There was an arc flash involving an electrical bus. Additionally, water for the fire suppression system was not turned off immediately after it was noted sulfuric acid was dripping from the ceiling onto sprinkler heads (Figure 20). A professional, full time county HAZMAT team like WMFD might have recognized the need to shut off the electricity and water earlier on the first floor before the arc flash occurred. This action did not ensure adequate worker protection.

Figure 20. Sulfuric Acid Penetration through the Ceiling

CON16: The Board concluded that human performance and safety culture issues exist that led to system weaknesses and poor decision-making.

JON17: The Alliance needs to ensure sufficient focus is placed on continuing to mature its safety culture and strengthen its integrated safety management system.

5. Adequacy of the Contractor Investigation

The Board reviewed a final draft version of the NREL ESH&Q Event Investigation Report, received from the Alliance on November 22, 2019. The NREL Investigation Team (NREL-IT) was led by the Safety Engineering Manager from the Pacific Northwest National Laboratory, supported by a Chief Engineer and Division Director from the Oak Ridge National Laboratory and two Alliance ESH&Q staff. The draft report included a description of the event summarizing the results of the NREL-IT's analysis, and presenting the causal analysis results, JONs and recommendations.

The Board appreciates NREL-IT's openness and cooperation. The NREL-IT had been working on the event for over two weeks before the Board convened and immediately shared all documents and draft analysis with the Board. The NREL-IT also briefed the Board shortly after the Board convened to discuss their initial findings and observations. Having access to the NREL-IT files greatly reduced duplicative effort by the Board to gather documentary materials and evidence. The NREL-IT's willingness to share its initial assessment work, methodology, and thought processes enabled the Board to begin its analytical work more quickly and effectively. NREL-IT's cooperation, also clearly supported by the Alliance leadership, is commendable.

The Alliance's decision to convene the NREL-IT and support the development of this in-depth report, shows a very positive commitment to organizational learning. The decision to go beyond the minimum level of assessment required to comply with Departmental reporting requirements, and to empower NREL-IT to follow the facts where they lead, reflects well on the Alliance. The Alliance's behavior in this regard shows a commitment to addressing the expectations of DOE P 226.2, *Policy for Federal Oversight and Contractor Assurance Systems*, which calls for rigorous self-assessments, independent reviews, development of effective corrective actions, and sharing of lessons learned.

The Board finds the NREL-IT report does an excellent job of accurately describing the events leading up to and directly involved in the acid leak. The timeline is comprehensive, the process descriptions and assessments are clear and concise, and the overall document is technically sound. The report identifies a number of significant areas of concern along with procedural, programmatic, and implementation gaps that contributed to the event. The Board had already drafted CONs and JONs before it received the NREL-IT's Draft Report on November 22, 2019. The Board compared the NREL-IT's findings with its own, assessing the clarity, adequacy, and likely effectiveness of each set of conclusions. The Board finds that the NREL-IT's assessments, JONs, and Recommendations are largely consistent with much of the Board's analysis.

The NREL-IT report is factually well-grounded and touches on many important topics, but does not appear to have fully pursued some topics that would be beneficial for organizational learning, including the observations noted below. The Board offers the following observations and critiques of the NREL-IT report for the Alliance's consideration, and to improve future investigative efforts.

The Board placed observations and critiques into the following three major categories:

1. The NREL-IT report has insufficient development of recommendations and JONs.
    - The draft report does not present JONs or recommendations that speak directly to MOC, even though the NREL-IT investigation identified weaknesses in Alliance implementation of change management as a potential contributing cause.
    - The Alliance wording of JON #2 to ensure "adequate guidance to assist" is not actionable. The Board agrees that compromised safety controls should drive clear action, but is not clear what specific actions the Alliance should take to address this JON.
2. The NREL-IT report does not fully pursue whether the procedures and practices were sufficient as written, or why the Alliance's trained, knowledgeable staff operated outside of the defined parameters. As a result the NREL-IT report does not fully identify the underlying weaknesses that contributed to the event.
    - The NREL-IT's report mentions that the AWN system never functioned as desired, and that Research and Research Operations had to work on redesigning the system in the absence of the subcontractor. However, the investigation does not pursue this line of inquiry to determine why this happened and what can be done to avoid this situation in the future—for example, the NREL-IT did not ask why the Alliance accepted a system from a subcontractor without being able to validate its performance, or why there is no LLP or defined process for commissioning.
    - The NREL-IT's report discusses the fact that no work authorization documents were active at the time that the sulfuric acid drum was loaded into the cabinet prior to the event, but does not pursue this issue through a hazard communication and work planning and control perspective. Similarly, the NREL-IT does it fully evaluate why the staff who performed the work believed their work was authorized when it was not. NREL-IT successfully identified activities that were less than adequate, but did not take the next step to ask why the gaps existed and what underlying factors contributed to the system failure, which reduces the utility of this report for the Alliance and for DOE.
    - The Alliance's quality assurance program is not addressed in the NREL-IT report. The NREL-IT report identifies issues, such as errors in the BMS, inadequate testing of materials and activities to ensure compatibility and effectiveness, but does not ask whether the Alliance's quality assurance processes were sufficiently robust to identify and address similar circumstances.
    - The NREL-IT's barrier analysis identified that the PHA did not anticipate the potential failure of an engineering control, specifically the secondary containment. The NREL-IT did not pursue this observation in the report, which may have led to additional observations about the adequacy of the Alliance's hazard identification and control program.
3. The NREL-IT focus on shared system problems minimizes attention on key issues, including hazard identification and control, MOC, and work planning and control, that are not solely related to shared systems. The focus on shared system issues could cause the Alliance to

miss opportunities to address active and latent weaknesses in lab-wide systems that exist even when boundary issues are not significant.

This concern is most apparent in NREL-IT JON #7, which reads as follows: "*NREL needs to assure that the appropriate work planning and control process is implemented and followed to completion for work involving shared systems where there may be multiple paths available.*" This JON focuses only on shared systems, but the NREL-IT report finds weaknesses in work planning and control that are not inherently tied to unclear roles and responsibilities associated with shared systems. For example:

- All participants understood that Research was leading the AWN redesign and upgrade process, but there were multiple time periods where work was conducted without having a Safe Work Permit or other work authorization in place, including between April 2017 and February 2018.

- The Alliance had developed LLPs for its Chemical Response Team and for hazard identification. In its response to the incident, however, the CRT appeared to be improvising its response rather than relying on already-established procedures. This is not a shared system issue.
- The Board identified a precursor event, a two-week work pause in response to multiple electric shock events, where PHAs were not effectively followed up on. This precursor event also revealed weaknesses in hazard identification and control and work planning and control that also appear relevant to the S&TF incident and is not a shared system issue.

6. GFO Oversight

The Appointing Official tasked the Board with assessing GFO's oversight of the accident. The Board based its assessment on the requirements of DOE O 226.1B, *Implementation of Department of Energy Oversight Policy*, and DOE P 226.2, *Policy for Federal Oversight and Contractor Assurance Systems*, along with DOE O 151.1D, *Comprehensive Emergency Management System*.

6.1. GFO Oversight of the Accident Response

The Board found that GFO had a limited oversight role related to the accident. The Alliance provided timely notifications to GFO leadership when the incident was first discovered, and Alliance continued to provide GFO with updated information in real time. GFO ES&H staff were able to closely and thoroughly observe the Alliance CRT activities and document their observations. GFO staff were also able to observe the CRT debrief the following week, and provided a detailed and professional follow up to GFO management.

The Board found that GFO was not effectively integrated into the Alliance's emergency response activities. As the event was unfolding, neither the Alliance nor GFO were clear about GFO's roles, responsibilities, and authorities in a chemical emergency. While the Alliance provided regular communication to GFO, and GFO ES&H staff were able to observe Alliance response activities, the nature or extent of GFO involvement was not clearly defined.

Several factors contributed to the unclear GFO oversight role during the incident response. Emergency response plans and exercises on the Federal side had not fully prepared GFO to understand the proper protocol for its own actions during lab emergencies. Roles and responsibilities in emergency response were identified for GFO security, but not for ES&H functions. This gap became apparent in this incident, which involved a hazardous chemical spill. The lack of ES&H integration correlates with gaps in Alliance planning, assessment, and preparedness for chemical emergencies described in Section 4.

The Board has identified steps the Alliance should take to implement a more effective program that conforms to the requirements of DOE O 151.1D in Section 4. GFO needs to be effectively involved and in step with the Alliance during this process. GFO should properly review documentation and ensure that planning, policies and procedures are adequate, and that they appropriately interface with GFO roles and responsibilities, communications expectations, and authorities. Once the Alliance has put its emergency management program in place, it will be required to conduct self-assessments; GFO should be engaged in overseeing the self-assessment process as part of its oversight duties. GFO should also be involved in the emergency exercise plan, which would be reviewed by GFO and EERE, as the HQ Program Secretarial Office, and should include appropriate roles/authorities for GFO in the exercises.

CON23: The Board determined that GFO has not developed a formal, risk-based approach to conducting ES&H oversight that appropriately targets Alliance programs and activities based on considerations of hazards and the maturity and performance of Alliance programs and management systems.

JON25: GFO needs to provide clear strategic direction, along with the necessary capabilities and systems support, to enable more effective oversight activities.

CON24: The Board concluded the trust and communication issues between GFO and the Alliance limit the effectiveness of GFO oversight activities.

JON26: GFO and the Alliance need to ensure that all staff are empowered to cooperatively work together to enable effective oversight. This should involve top-level management commitment along with follow through at all organizational levels.

6.2. GFO Oversight of Precursor Events

The Board's report has already identified numerous contributing causes and precursor events that the Alliance could have addressed to prevent the accident and improve the response. GFO's ES&H oversight has not been sufficiently robust to help the Alliance identify and correct the latent deficiencies that contributed to the accident. GFO lacks a systematic approach to oversight, including a comprehensive issues management process, which results in issues being analyzed and tracked at the SME staff level. While GFO leadership is working to develop capabilities and systems to effectively analyze, track, and trend operational data to effectively target oversight objectives, these tools do not currently exist.

The lack of a formal, structured system has fueled the perception, reported by many Alliance staff, that GFO ES&H oversight of Alliance programs and activities is largely ad hoc and reactive. This negative perception of ES&H oversight by the Alliance correlates with GFO ES&H staff reporting an inability to access to relevant information through the CAIS and failure to be included in Alliance walk-throughs and assessments. These perceptions fuel a negative cycle that limits effective cooperation on the shared goal of successful mission accomplishment at NREL.

CON23: The Board determined that GFO has not developed a formal, risk-based approach to conducting ES&H oversight that appropriately targets Alliance programs and activities based on considerations of hazards and the maturity and performance of Alliance programs and management systems.

JON25: GFO needs to provide clear strategic direction, along with the necessary capabilities and systems support, to enable more effective oversight activities.

CON24: The Board concluded the trust and communication issues between GFO and the Alliance limit the effectiveness of GFO oversight activities.

JON26: GFO and the Alliance need to ensure that all staff are empowered to cooperatively work together to enable effective oversight. This should involve top-level management commitment along with follow through at all organizational levels.

7. Safety Culture

At DOE, poor safety performance, or even a single event, may marginalize a specific technology leaving it considered too hazardous to pursue. Well-informed leadership at all levels of the organization works to ensure that the vision, beliefs, and values (prevention-centered attributes) do not conflict with the mission, goals, and processes (production-centered attributes). Consistency and alignment promote both production and prevention behaviors - together generating the desired long-term results. It is critical that the visions, values, and principles established by leadership to support a strong safety culture are clearly communicated, and consistently reinforced.

In many cases, management believes that their visions, values, and principles have been established and communicated through the development of a policy or procedure, or the posting of signs. Staff behavior, however, may not fully embody these ideals. The challenge for leadership is to establish and reinforce the safety culture expectations continuously so workers are mindful and situationally aware during operations.

In recent years, the Alliance has initiated a variety of activities to measure and enhance the safety culture at NREL. As a result, the NREL Safety Culture Principles, which are rooted in the Battelle's *Safe Conduct of Research*, were introduced. Mission support and Research front-line leaders attend the Battelle Laboratory Operations Supervisor Academy to reinforce key safety culture principles and cultivate expected behaviors through mentoring, employee engagement and continuous development. Additionally, a Safety Culture Plan has been established with milestones that focus on safety culture surveys, communication, clarification, and integration using the Strategic Targets for Excellent Performance in Safety^{SM} model.

Alliance staff interviewed by the Board described positive efforts to improve the safety culture at NREL. Several different staff members described safety management at the Lab as making progress in moving from a reliance on individualized, expert-driven approaches towards more formal, documented processes and procedures for ensuring work is done safety and within proper controls. Management commitment and staff engagement are evident. Strategic plans are being developed to continuously mature the safety culture to address organizational weaknesses.

While the Alliance is to be commended for its safety culture efforts, the Board noted several instances in which worker behavior and management decision-making led to work being performed outside of established procedures and controls. These behaviors were not corrected, contributing to organizational drift away from the safe conduct of work. The Alliance should continue its safety culture efforts, and leverage the insights from this report to identify areas where continuous improvement will reinforce effective implementation of safe work processes.

CON16: The Board concluded that human performance and safety culture issues exist that led to system weaknesses and poor decision-making.

JON17: The Alliance needs to ensure sufficient focus is placed on continuing to mature its safety culture and strengthen its integrated safety management system.

7.1. Integrated Safety Management

Alliance is required to implement a Safety Management System in accordance with 48 CFR 970.5223-1, *Integration of Environment, Safety, and Health into Work Planning and Execution*. The requirement states that in performing work, the contractor shall perform work safely, in a manner that ensures adequate protection for employees, the public, and the environment, and shall be accountable for the safe performance of work. The contractor shall ensure that management of Environment, Safety and Health (ES&H) functions and activities becomes an integral but visible part of the contractor's work planning and execution processes. DOE's ISM approach relies on five core safety management functions and seven guiding principles. The core functions provide the necessary structure for any work activity, including emergency management, which could potentially affect the public, the workers, and the environment, while the guiding principles describe the environment or context for conducting work safely.

Five Core Functions of ISM

- Define the Scope of Work (CF1)
- Identify and Analyze the Hazards Associated with the Work (CF2)
- Develop and Implement Hazard Controls (CF3)
- Perform Work within Controls (CF4)
- Feedback and Improvement (CF5)

Seven Guiding Principles

- Line Management is Responsible for Safety (GP1)
- Clear Roles and Responsibilities (GP2)
- Competence Commensurate with Responsibilities (GP3)
- Balanced Priorities (GP4)
- Identification of Safety Standards and Requirements (GP5)
- Hazard controls tailored to work performed (GP6)
- Operations authorized (GP7)

The Board conducted a number of analyses based on the event facts, including a barrier analysis, change analysis and causal analysis. The barrier analysis is intended to identify management and physical barriers that contributed to the event. The change analysis examined unplanned or planned changes that caused undesired outcomes. The causal analysis required detailed review of the event to identify all potential factors to determine whether they are direct, root, or contributing causes of the accident. Through these analyses, the Board identified local causal factors, management system failures, and weaknesses in oversight processes.

Each identified factor was linked to ISM and human performance attributes where applicable. The Board identified 83 instances of active and latent error precursors related to Integrated Safety Management in this event (Table 2).

Table 2. Integrated Safety Management System Error Precursors

Guiding Principles		Core Functions	
4	Line Management Responsibility for Safety (GP1)	8	Define Scope of Work (CF1)
6	Clear Roles and Responsibilities (GP2)	6	Analyze Hazards (CF2)
4	Competence Commensurate with Responsibilities (GP3)	10	Develop/Implement Controls (CF3)
3	Balanced Priorities (GP4)	10	Perform Work (CF4)
10	Identification of Safety Standards and Requirements (GP5)	7	Feedback and Improvement (CF5)
7	Hazard Controls Tailored to Work Performed (GP6)		
8	Operations Authorization (GP7)		

7.2. Human Performance Improvement

The goal of Human Performance Improvement (HPI) is to facilitate the development of a facility structure that recognizes human attributes and develops defenses that proactively manage human error and optimize the performance of individuals, leaders, and the organization. The DOE-HDBK-1028-2009, *Human Performance Improvement Handbook*, Volumes 1 and 2, describe the HPI tools available for use at DOE sites.

A review of Human Performance examines an individual's abilities, tasks, and operating environment to determine if the organization supports them for success. The Board did not look at HPI from the perspective of program implementation, but did evaluate the role of Human Performance in this accident. The information provided in this section is based on the analysis of the events, conditions, processes, and barrier analysis information presented in this report.

A fundamental tenet of HPI is that human error is not a cause of failure alone, but rather an effect or symptom of deeper trouble in the safety system. In most cases, a significant event involves multiple breakdowns in defenses. While human error may trigger an event, it is the number and extent of flawed defenses that dictate the severity of the event. The site's safety culture and organizational effectiveness have a direct influence on human performance.

The existence of many flawed defenses is directly attributable to weaknesses in the organization or management control systems. The Anatomy of an Event Model (Figure 21) illustrates the elements that exist before an event occurs and is a very useful model to guide the analysis of an event from an HPI perspective. The elements analyzed are:

- the flawed defenses that allowed the event to occur or did not mitigate the consequences of the event;

- the error precursors that existed;
- the latent organizational conditions that allowed those to be in existence; and
- the vision, beliefs and values of management and workers.

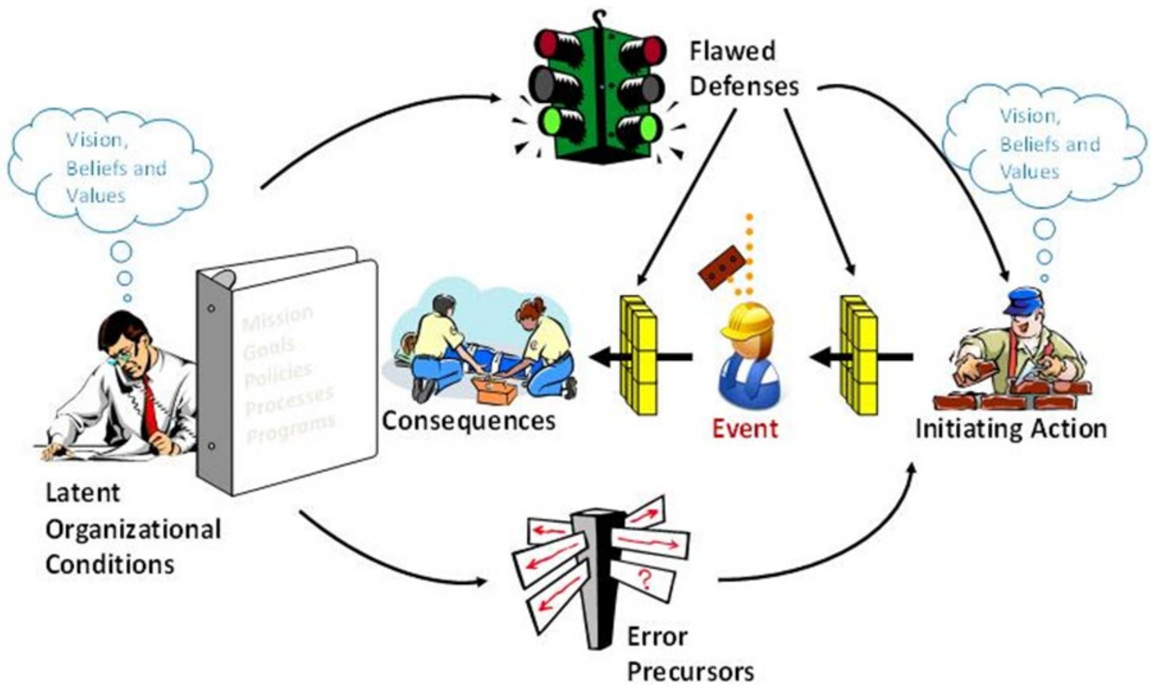

Figure 21. Anatomy of an Event Model

7.3. Error Precursors

Error precursors are unfavorable conditions that increase the probability for error during a specific action and create what are known as error-likely situations (Table 3). An error-likely situation typically exists when the demands of the task exceed the capabilities of the individual or when work conditions exceed the limitations of human nature. Error precursors exist in the work place before the error occurs, and thus are manageable. If precursors are identified before or during the performance of work, event consequences or severity can be reduced by identifying and eliminating organizational latent weaknesses that hamper the effectiveness of barriers.

Table 3. Human Performance Attributes

Task Demands. Specific mental, physical, and team requirements to perform an activity that may either exceed the capabilities or challenge the limitations of human nature of the individual assigned to the task; for example, excessive workload, hurrying, concurrent actions, unclear roles and responsibilities, or vague standards.
Individual Capabilities. Unique mental, physical, and emotional abilities of a particular person that fail to match the demands of the specific task; for example, unfamiliarity with the task, unsafe attitudes, level of education, lack of knowledge, unpracticed skills, personality, inexperience, health and fitness, poor communication practices, or low self-esteem.
Work Environment. General influences of the workplace, organizational, and cultural conditions that affect individual behavior; for example, distractions, awkward equipment layout, complex tagout procedures, at-risk norms and values, work group attitudes toward various hazards, or work control processes.
Human Nature. Generic traits, dispositions, and limitations of being human that may incline individuals to err under unfavorable conditions; for example, habit, short-term memory, fatigue, stress, complacency, or mental shortcuts.

According to DOE's EIP-120DE, *Accident Investigation Overview*, "…administrative barriers may weaken due to inadequate updates to rules, communication and training, and inadequate monitoring and enforcement." Additionally, the EIP-120DE states, "multiple layers may lead to complacency and diminish the ability to use and maintain the individual barrier layers". During review of PROG 625-5, *Safe Conduct of Work* the Board noted the Alliance uses a layered approach to promoting safe conduct of work which relies heavily on multiple administrative barriers. The assessment of human performance error precursors during the barrier analysis and causal analysis related to this accident, indicate a number of human performance weaknesses.

Use of work arounds occurred as Research and Research Operations designed and operated the AWN system without necessary expertise and work was conducted under LOTO rather than a SWP. Work was not adequately planned or performed according to established procedures contributing to organizational drift.

Staff over-estimated their capabilities in the design and build of AWN systems. Expert knowledge such as that of a qualified chemical engineer was missing during internal redesign, acceptance and installation of the AWN system.

The Alliance researchers and mission support staff are highly knowledgeable and skilled in a variety of areas. Biases regarding the staff capabilities impacted decision-making which led internal personnel to redesign the AWN system without the requisite education and experience. Biases regarding staff capabilities were also apparent during the CRT response.

Organizational complacency was indicated when opportunities to learn from precursor events, employee concerns, and internal and external feedback were missed.

Error precursors (conditions) associated with Human Performance attributes were analyzed by the Board to identify specific conditions that may have provoked error and led to the accident. The Board identified 57 instances of Human Performance Error Precursors (Table 4).

Table 4. Human Performance Error Precursors

	Task Demands (TD)		Individual Capabilities (IC)
2	Time Pressure (in a hurry) (TD1)	1	Unfamiliarity with task / First time (IC1)
	High workload (large memory) (TD2)	2	Lack of knowledge (faulty mental model) (IC2)
	Simultaneous, multiple actions (TD3)		New techniques not used before (IC3)
	Repetitive actions / Monotony (TD4)	4	Imprecise communication habits (IC4)
	Irreversible actions (TD5)	1	Lack of proficiency / Inexperience (IC5)
2	Interpretation requirements (TD6)		Indistinct problem-solving skills (IC6)
8	Unclear goals, roles, or responsibilities (TD7)		Unsafe attitudes (IC7)
6	Lack of or unclear standards (TD8)		Illness or fatigue; general poor health or injury (IC8)
	Work Environment (WE)		**Human Nature (HN)**
	Distractions / Interruptions (WE1)		Stress (HN1)
	Changes / Departure from routine (WE2)		Habit patterns (HN2)
	Confusing displays or controls (WE3)	1	Assumptions (HN3)
7	Work-arounds (WE4)	4	Complacency / Overconfidence (HN4)
	Hidden system / equipment response (WE5)		Mind-set (intentions) (HN5)
	Unexpected equipment conditions (WE6)	6	Inaccurate risk perception (HN6)
5	Lack of alternative indication (WE7)	8	Mental shortcuts or biases (HN7)
	Personality conflict (WE8)		Limited short-term memory (HN8)

8. Facts and Analysis

8.1. Barrier Analysis

After a basic chronology of events was developed, the Board performed a Barrier Analysis of the accident. To start the Barrier Analysis, the Board chose a target (the person or item to be protected) and the hazard (what the person or item is to be protected from). The Board chose as the target Workers, Property, and Environment and the hazard as sulfuric acid. There were 12 barriers identified and analyzed by the Board. The analysis indicated that all the barriers played a role in directly exposing the target to the hazard in this accident.

The result of the Barrier Analysis is presented in Appendix B.

8.2. Change Analysis

To further support the development of causal factors, the Board performed a Change Analysis of the accident. The Board examined the planned and unplanned changes that caused the undesired results or outcomes related to the event.

The Change Analysis is presented in Appendix C.

8.3. Event and Causal Factors Analysis

After performing the barrier, and change analyses, the Board assigned results from each analysis to events on the chronology of events. This involved assigning analysis results as conditions that were related to or caused the events on the chronology. Once conditions were assigned, the Board examined the events and causal factors to determine which events were significant (i.e., which events played a role in causing the accident).

The Board then assessed the significant events (and the conditions of each) to determine the causal factors of the accident.

The causal factors that resulted were:

Direct Cause (DC): The immediate events or conditions that caused the accident.

The Board identified the **direct cause** of this accident to be the failure of the rotameter in the AWN system, which leaked sulfuric acid into the secondary containment. The secondary containment subsequently failed and released sulfuric acid from the cabinet into the corridor.

Root Cause (RC): Causal factors that, if corrected, would prevent recurrence of the same or similar accidents. Root causes can be local (specific to the one accident), and/or systemic (common to a broad class of similar accidents).

The Board identified three root causes of this accident to be:

- RC1: Thorough verification of chemical compatibility, component specifications and installation did not consistently occur. A rotameter was selected and installed and the secondary containment was repaired; both failed, leading to the accident.
- RC2: The float alarm, which was in place and functioning, did not shut down the acid pump or initiate a response action. Although the original Process Hazard Analysis (PHA) for the AWN included a leak sensor and alarm in containment, the installed float alarm did not perform as an engineering control as indicated in the PHA. In addition, there was no clear response protocol for the float alarm.
- RC3: Alliance did not recognize and act on the level of hazards and controls required for engineering and safe operation of the AWN system. There was inconsistent recognition of the impacts and significance of changes.

The Root Cause Analysis table is presented in Appendix D.

Contributing Causes (CC): Events or conditions that collectively with other causes increased the likelihood or severity of an accident but that individually did not cause the accident. The Board identified 13 contributing causes to the sulfuric acid spill in the S&TF:

- CC1: The Alliance accepted the AWN system in 2016 from Subcontractor 1 with indications of inadequate design, training, and preparedness to work on the system. Alliance accepted an AWN system without it being fully challenged with chemistry, and the warranty period expired before doing so.
- CC2: Numerous issues with the AWN system continued over a three year period, during which time the AWN System was rebuilt in-house. Alliance did not consistently engage qualified expertise in engineering, design, review and acceptance of the rebuilt system.
- CC3: Ownership and operational roles, and responsibilities for the AWN system were not clearly defined.
- CC4: The Alliance selected commissioning to verify the adequacy, safety, and readiness of the redesigned AWN system. This approach is not consistent with the Alliance Hazard Identification and Control Program. The Alliance did not follow through with the commissioning process.
- CC5: LOTO is not the correct work authorization process to follow for the work conducted. Work was performed that was not authorized.
- CC6: Workers did not coordinate activities when loading the sulfuric acid drum into the AWN cabinet. Adequate work planning and communication did not occur.
- CC7: Several key hazard identification and control elements were not fully implemented. For example, PHA corrective actions remained open at the time of the accident, neither a readiness verification nor a commissioning were not issued or were not completed, and multiple safe work permits pertinent to the work being performed were left to expire.

- CC8: On multiple occasions during the redesign of the AWN system hazard identification and control work processes were not used. There was a misunderstanding of work authorization processes and work was routinely performed and hazards were introduced when work was not authorized.
- CC9: Numerous AWN system function and design changes occurred without thorough review and impact analysis.
- CC10: Point-to-point testing did not identify that an incorrect address for the ammonia scrubber isolation valve was entered in the BMS. The isolation valve remained open when it should have been closed.
- CC11: Multiple opportunities to have identified and implemented applicable safety and emergency management standards and requirements that would have prevented the accident or minimized its consequences were missed.
- CC12: Interim measures and corrective actions from precursor events were not always implemented in a timely manner. Opportunities to learn from precursor events, employee concerns, and internal and external feedback were missed.
- CC13: The Board identified multiple instances in which worker behavior and decision-making led to work being performed outside of established procedures, which was not corrected, resulting in organizational drift.

Event and causal factors (CF) analysis include charting, which depicts the logical sequence of events and conditions (causal factors that allowed the accident to occur), and the use of deductive reasoning to determine the events or conditions that contributed to the accident.

The Event and Causal Factor Analysis chart is presented in Appendix E.

9. Conclusions and Judgments of Need

Based upon the evidence obtained during this accident investigation, the Board concluded that this accident was preventable.

Table 5 summarizes the Conclusions (CONs) and Judgments of Need (JONs) determined by the Board. The conclusions are derived from the analytical results performed during this accident investigation for determining what happened and why it happened. Per DOE O 225.1B, *Accident Investigations*, the report must demonstrate that the Judgments of Need (JONs) are based on objective analysis and application of the core analytical techniques using the facts to develop the root and contributing causes. The report must also identify DOE and contractor management systems that, if corrected, could have prevented the accident so those systems can be addressed and corrected to prevent recurrence. The Events and Causal Factors chart (Table E-1) in Appendix E provides more detail, including the causal factors, specific conditions related to the causal factors, and associated CONs and JONs.

Table 5. Conclusions and Judgments of Need

Conclusions	Judgments of Need
CON1: The Board concluded that this accident was preventable.	**JON1:** The Alliance needs to implement the Board's Judgements of Need so that this and other similar accidents may be prevented.
CON2: The Alliance did not identify and implement engineering controls that were adequate to initiate an immediate and appropriate response.	**JON2:** The Alliance needs to ensure that engineering controls function to effectively contain the hazard.
CON3: The Alliance did not identify and implement administrative controls that were adequate to initiate an immediate and appropriate response and mitigate the consequences of the accident.	**JON3:** The Alliance needs to ensure administrative controls function to effectively contain the hazard and mitigate potential consequences.
CON4: The Alliance did not implement an effective management of change program that recognized the impact and significance of changes to systems and re-evaluated hazards and controls.	**JON4:** The Alliance needs to ensure that their lab-level work planning processes are fully integrated, functional, and capable of effectively identifying and recognizing changes to work processes that necessitate re-evaluation of hazards and controls with a level of rigor equivalent to the risk.

Conclusions	Judgments of Need
CON5: This event revealed multiple barriers that failed related to work planning and control processes.	**JON5:** The Alliance needs to conduct a thorough analysis of work planning and control processes and ensure that verifiable/defensible corrective actions are implemented for each related work planning and control causal factor.
CON6: The Alliance did not always communicate workplace hazards effectively through the Plan of the Week or Plan of the Day meetings.	**JON6:** The Alliance needs to ensure that employees are informed of workplace hazards.
CON7: There was a failure to verify chemical compatibility, component specifications and installation.	**JON7:** The Alliance needs to ensure that an effective process is in place for designing, installing, and approving systems in-house. **JON8:** The Alliance needs to ensure that qualified personnel are responsible for and involved in the engineering of complex, hazardous systems.
CON8: The AWN system chemistry was not handled the same degree of rigor as other chemicals used to support cleanroom operations. Treating it as a hazardous production material (HPM) system would have greatly reduced the likelihood of system failure.	**JON9:** The Alliance needs to ensure that its chemical management programs include appropriate safeguards and controls.
CON9: Work was performed without effective engagement of relevant Alliance programs (e.g. pressure safety) to ensure appropriate standards and requirements were fully applied.	**JON10:** The Alliance needs to ensure sufficient resources are available for formal and rigorous design, testing, and readiness of laboratory activities.
CON10: ESH&Q programs and procedures are not uniformly flowed down and consistently implemented.	**JON11:** The Alliance needs to ensure ESH&Q programs and procedures are uniformly flowed down and implemented.
CON11: The Automated Waste Neutralization (AWN) system was accepted without validating it performed as designed and was compatible with broader research systems.	**JON 12:** The Alliance should ensure an effective system is in place for verifying design and functionality of systems prior to acceptance from subcontractors.

Conclusions	Judgments of Need
CON12: A qualified chemical engineer was not engaged for the in-house redesign of the AWN system, which contributed to weaknesses in AWN system integrity (rotameter and containment failure).	**JON13:** The Alliance needs to ensure appropriate professional expertise is applied to design and engineering of Site Operations and research systems.
CON13: Confirmation and quality verification of the coding did not occur. Additionally, the system is not engineered to provide confirmation of the position of the valve to the operator resulting in operators being unaware of actual system configuration prior to verification of readiness for safe operation.	**JON14**: The Alliance needs to ensure integration of configuration control and quality processes that verify work is as intended for safe operations into work at all levels.
CON14: ESH&Q and engineering resources were not always sufficient to support the redesign of the AWN system. This contributed to delays in research and employees using work arounds.	**JON15:** The Alliance needs to ensure experts from ESH&Q, Site Operations and Research Operations are available to engage in work planning to ensure application of appropriate standards and requirements.
CON15: The Alliance missed opportunities to learn from precursor events, employee concerns, and internal and external feedback.	**JON16:** The Alliance needs to examine and strengthen its processes to learn from precursor events, employee concerns, and internal and external feedback throughout all of NREL.
CON16: Human performance and safety culture issues exist that led to system weaknesses and poor decision-making.	**JON17:** The Alliance needs to ensure sufficient focus is placed on continuing to mature its safety culture and strengthen its integrated safety management system.
CON17: The Alliance did not establish effective ownership, roles, and responsibilities for the AWN system.	**JON18**: The Alliance needs to ensure that roles and responsibilities are clearly defined in documents such as Boundary Agreements.
CON18: The Alliance did not define and implement effective roles and responsibilities for verifying the adequacy, safety, and readiness of the redesigned AWN system.	**JON19:** The Alliance needs to review processes to ensure formal and effective procedures for verifying the adequacy, safety, and readiness of laboratory systems are implemented.

Conclusions	Judgments of Need
CON19: The Alliance failed to recognize and seal cracks in load bearing concrete flooring, which led to penetration of concentrated sulfuric acid into and through the cracks in the flooring from the second to the first floor. Consequently, the sulfuric acid damaged equipment and building components and may have affected the structural integrity of load bearing concrete flooring.	**JON20:** The Alliance needs to review relevant standards such as NFPA-45, *Fire Protection in Laboratories*, in order to identify appropriate opportunities to improve chemical safety, protect workers and prevent or mitigate similar accidents. **JON21:** The Alliance needs to review NFPA 400, *Hazardous Materials Code*, and other relevant standards, in order to ensure the AWN and other hazardous systems are in compliance with chemical safety requirements. **JON22:** The Alliance needs to perform an engineering structural analysis of the S&TF load bearing concrete floor to verify structural integrity.
CON20: An exposure assessment, as required under 10 CFR Part 851, *Worker Safety and Health Program*, was not performed for the application of epoxy sealant in the AWN cabinets before work was conducted. Initial or baseline industrial hygiene assessments are required to be performed and documented.	**JON23:** Alliance needs to review its Industrial Hygiene program to assess compliance with 10 CFR Part 851, and implement required program elements.
CON21: The Alliance did not implement all the applicable requirements, such as an emergency management plan and a technical planning basis, as specified in DOE Order 151.1D, *Comprehensive Emergency Management System*. This may have exacerbated the consequences of the accident and jeopardized the safety of workers, the public, and the environment.	**JON24:** The Alliance needs to completely implement all applicable requirements of DOE Order 151.1D in order to have a fully integrated, functional, and capable emergency management program.
CON22: Neither OSEP nor the Chemical Response Team (CRT) are effectively integrated into the chemical management process, and therefore, may not be aware of chemical hazards on site.	**JON24:** The Alliance needs to completely implement all applicable requirements of DOE Order 151.1D in order to have a fully integrated, functional, and capable emergency management program.

Conclusions	Judgments of Need
CON23: GFO has not developed a formal, risk-based approach to conducting ES&H oversight that appropriately targets Alliance programs and activities based on considerations of hazards and the maturity and performance of Alliance programs and management systems.	**JON25:** GFO needs to provide clear strategic direction, along with the necessary capabilities and systems support, to enable more effective oversight activities**.**
CON24: Trust and communication issues between GFO and the Alliance limit the effectiveness of GFO oversight activities.	**JON26:** GFO and the Alliance need to ensure that all staff are empowered to cooperatively work together to enable effective oversight. This should involve top-level management commitment along with follow through at all organizational levels.

10. Board Signatures

Michael (Josh) Silverman
DOE Accident Investigation Board Chairman
U.S. Department of Energy
Director, Office of Environmental Protection and ES&H Reporting

Antonia Cruz
DOE Accident Investigator and Board Member
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Environment, Safety and Health Division

Rodger Dotson
DOE Accident Investigation Board Member
U.S. Department of Energy, Office of Fossil Energy

Elliot Stein
DOE Accident Investigator and Board Member
U.S. Department of Energy, Office of Science
Consolidated Service Center (CSC)

Edward Miller
DOE Accident Investigation Board Member
National Nuclear Security Administration
Office of Emergency Operations

David Freshwater
DOE Accident Investigation Board Member
National Nuclear Security Administration
Office of Emergency Operations

11. Board Members, Advisors and Consultants

Board Members

Michael (Josh) Silverman	Office of Environment, Health, Safety and Security Director, Office of Environment Protection and ES&H Reporting
Antonia Cruz	Office of Energy Efficiency and Renewable Energy, Golden Field Office DOE Trained Accident Investigator
Rodger Dotson	Office of Fossil Energy, National Energy Technology Laboratory
Elliot Stein	Office of Science, Consolidated Service Center Senior Industrial Hygienist DOE Trained Accident Investigator
David Freshwater	National Nuclear Security Administration Office of Emergency Management Emergency Management and Response Expert
Edward Miller	National Nuclear Security Administration Office of Emergency Management Emergency Management and Response Expert

Advisors

David K. Pegram	IFS LLC Safety Management Group Senior Advisor
Kristina Fehringer	Office of Energy Efficiency and Renewable Energy, Golden Field Office Subject Matter Expert
Nicole Serio	Office of Energy Efficiency and Renewable Energy, Golden Field Office Subject Matter Expert

Administrative Coordinator

Susan M. Keffer	Administrative Coordinator Project Enhancement, Inc. DOE Trained Accident Investigator
Meredith West	Administrative Coordinator Project Enhancement, Inc.

Appendix A. Appointment of an Accident Investigation Board

Department of Energy
Golden Field Office
15013 Denver West Parkway
Golden, Colorado 80401

October 29, 2019

MEMORANDUM FOR MICHAEL (JOSH) SILVERMAN
DIRECTOR
OFFICE OF ENVIRONMENTAL PROTECTION
AND ES&H REPORTING

FROM: DEREK G. PASSARELLI
DIRECTOR, GOLDEN FIELD OFFICE
OFFICE OF ENERGY EFFICIENCY &
RENEWABLE ENERGY
APPOINTING OFFICIAL

SUBJECT: Appointment of a Limited Scope Federal Investigation Board for the Sulfuric Acid Spill at the National Renewable Energy Laboratory (NREL) Science and Technology Facility (S&TF) on October 6, 2019

I am establishing a Limited Scope Department of Energy Accident Investigation Board (AIB) to investigate this accident. This accident is not expected to meet the criteria of DOE Order 225.1B, *Accident Investigations*. However, potential cleanup costs have been estimated to cost between $1.5 to $2.1 million dollars in property damage and decontamination.

I believe the seriousness of the incident warrants an investigation to understand how the underlying sources of operational vulnerability combined to result in failure and to understand where the Contractor's Safety Management System and processes can be improved to promote accident prevention, as well as GFO's role in overseeing contract performance.

You are appointed as the Investigation Board Chairperson. The Federal personnel on this limited scope AIB will include the following members:

- Antonia Cruz – Trained Accident Investigator - GFO
- Rodger Dotson – Safety Engineer - NETL
- Elliot Stein – Senior Industrial Hygienist – Office of Science/Chicago

The following personnel are identified as subject matter experts (SMEs) and will support the AIB as assigned:

- Sue Keffer – Project Enhancement Corporation
- Kristina Fehringer - GFO
- Nicole Serio - GFO

Additional SMEs may be requested for support as needed.

A representative of the GFO Office of Chief Counsel will support the team as an advisor.

The DOE Accident Investigation and Prevention (AIP) Program will support the AIB with advisors on a cost reimbursable basis as requested.

The Golden Field Office (GFO) will be responsible for assigning personnel to be part of the investigation team within three business days. All members of this investigation team are released from their normal regular duty assignments to serve on the investigation team, while the team is convened.

The Limited Scope of the investigation is to include:

- An independent analysis and determination of the causal factors of the accident, conclusions and judgments of need to prevent recurrence.
- An assessment of the NREL Contractor Assurance Program (CAP), Safe Conduct of Work Program, and Site Maintenance Program, to include; internal self-assessments, oversight, hazard identification and control, boundary agreements, feedback and improvement, design engineering and, quality acceptance processes, that may be involved in this accident;
- An assessment of the adequacy of the emergency response/recovery to the accident to include the Comprehensive Emergency Management System, Chemical Response Team and External Response Organizations and industrial hygiene monitoring;
- An independent assessment and verification of the adequacy of the Contractor's investigation; and
- An assessment of GFO oversight of the accident.

The Investigation Board's report shall address the core analytical techniques discussed in DOE O 225.1B, *Accident Investigations*, (i.e., events and casual factors, change analysis, and barrier analysis) and develop judgments of need that lead to corrective actions that will prevent recurrence. Lessons learned shall also be disseminated from the event, as required by the Order. The Board shall provide my office with periodic reports on the status of the investigation.

Submit draft copies of the factual portion of the investigation report to me, and to senior management for the Alliance for Sustainable Energy, the management & operating contractor for the National Renewable Energy Laboratory for factual accuracy review prior to finalization. The Chair should provide the draft report to the Office of the Associate Under Secretary for Environment, Health, Safety and Security (AU-1) for quality review prior to public release.

The final report should be provided to me, for my signature, within 45 days of convening the team. If additional time is needed, the Chair should notify me and request it. Discussion of the investigation and copies of the draft report will be controlled until I authorize release of the final report.

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The GFO Financial Oversight Office has allocated funds for expenses and costs associated with this Investigation from appropriation 8920/210321, Energy Efficiency and Renewable Energy Program Direction Funds, fund code 05464. Coordination for all funding needs, including allocations to travel and necessary purchase requisitions for support services such as court reporters shall be coordinated with Marlys Kinsey, Acting Deputy Director for Business Services, Golden Field Office, at (240) 562-1671, or email marlys.kinsey@ee.doe.gov, prior to expenses incurred.

If you have any further questions, please contact me at (240) 562-1742.

CC: Gary T. Staffo, AU-23

Department of Energy
Golden Field Office
15013 Denver West Parkway
Golden, Colorado 80401

November 1, 2019

MEMORANDUM FOR MICHAEL (JOSH) SILVERMAN
DIRECTOR
OFFICE OF ENVIRONMENTAL PROTECTION
AND ES&H REPORTING

FROM: DEREK G. PASSARELLI
DIRECTOR, GOLDEN FIELD OFFICE
OFFICE OF ENERGY EFFICIENCY &
RENEWABLE ENERGY
APPOINTING OFFICIAL

SUBJECT: Amended Appointment of a Limited Scope Federal Investigation Board for the Sulfuric Acid Spill at the National Renewable Energy Laboratory (NREL) Science and Technology Facility (S&TF) on October 6, 2019

I am amending the established Limited Scope Department of Energy Accident Investigation Board (AIB) to investigate this accident to include two additional members. This accident is not expected to meet the criteria of DOE Order 225.1B, *Accident Investigations*. However, potential cleanup costs have been estimated to cost between $1.5 to $2.1 million dollars in property damage and decontamination.

I believe the seriousness of the incident warrants an investigation to understand how the underlying sources of operational vulnerability combined to result in failure and to understand where the Contractor's Safety Management System and processes can be improved to promote accident prevention, as well as GFO's role in overseeing contract performance.

You are appointed as the Investigation Board Chairperson. The Federal personnel on this limited scope AIB will include the following members:

- Antonia Cruz – Trained Accident Investigator - GFO
- Rodger Dotson – Safety Engineer - NETL
- Elliot Stein – Senior Industrial Hygienist – Office of Science/Chicago
- David Freshwater – Emergency Management and Response Expert
- Edward Miller – Emergency Management and Response Expert

The following personnel are identified as subject matter experts (SMEs) and will support the AIB as assigned:

- Sue Keffer – Project Enhancement Corporation

- Kristina Fehringer - GFO
- Nicole Serio - GFO

Additional SMEs may be requested for support as needed.

A representative of the GFO Office of Chief Counsel will support the team as an advisor.

The DOE Accident Investigation and Prevention (AIP) Program will support the AIB with advisors on a cost reimbursable basis as requested.

The Golden Field Office (GFO) will be responsible for assigning personnel to be part of the investigation team within three business days. All members of this investigation team are released from their normal regular duty assignments to serve on the investigation team, while the team is convened.

The Limited Scope of the investigation is to include:

- An independent analysis and determination of the causal factors of the accident, conclusions and judgments of need to prevent recurrence.
- An assessment of the NREL Contractor Assurance Program (CAP), Safe Conduct of Work Program, and Site Maintenance Program, to include; internal self-assessments, oversight, hazard identification and control, boundary agreements, feedback and improvement, design engineering and, quality acceptance processes, that may be involved in this accident;
- An assessment of the adequacy of the emergency response/recovery to the accident to include the Comprehensive Emergency Management System, Chemical Response Team and External Response Organizations and industrial hygiene monitoring;
- An independent assessment and verification of the adequacy of the Contractor's investigation; and
- An assessment of GFO oversight of the accident.

The Investigation Board's report shall address the core analytical techniques discussed in DOE O 225.1B, *Accident Investigations*, (i.e., events and casual factors, change analysis, and barrier analysis) and develop judgments of need that lead to corrective actions that will prevent recurrence. Lessons learned shall also be disseminated from the event, as required by the Order. The Board shall provide my office with periodic reports on the status of the investigation.

Submit draft copies of the factual portion of the investigation report to me, and to senior management for the Alliance for Sustainable Energy, the management & operating contractor for the National Renewable Energy Laboratory for factual accuracy review prior to finalization. The Chair should provide the draft report to the Office of the Associate Under Secretary for Environment, Health, Safety and Security (AU-1) for quality review prior to public release.

The final report should be provided to me, for my signature, within 45 days of convening the team. If additional time is needed, the Chair should notify me and request it. Discussion of the

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investigation and copies of the draft report will be controlled until I authorize release of the final report.

The GFO Financial Oversight Office has allocated funds for expenses and costs associated with this Investigation from appropriation 8920/210321, Energy Efficiency and Renewable Energy Program Direction Funds, fund code 05464. Coordination for all funding needs, including allocations to travel and necessary purchase requisitions for support services such as court reporters shall be coordinated with Marlys Kinsey, Acting Deputy Director for Business Services, Golden Field Office, at (240) 562-1671, or email marlys.kinsey@ee.doe.gov, prior to expenses incurred.

If you have any further questions, please contact me at (240) 562-1742.

CC: Gary T. Staffo, AU-23

Appendix B. Barrier Analysis

Barrier analysis is based on the premise that hazards are associated with all tasks. A barrier is any means used to control, prevent, or impede a hazard from reaching a target, thereby reducing the severity of the resultant accident or adverse consequence. A hazard is the potential for an unwanted condition to result in an accident or other adverse consequence. A target is a person or object that a hazard may damage, injure, or fatally harm. Barrier analysis determines how a hazard overcomes the barriers, comes into contact with a target (e.g., from the barriers or controls not being in place, not being used properly, or failing), and leads to an accident or adverse consequence. The results of the barrier analysis are used to support the development of causal factors.

Table B-1: Barrier Analysis

Hazard: Sulfuric Acid			Target: Workers, Property, and Environment		
Barrier #	**What were the barriers?**	**How did each barrier perform?**	**Why did the barrier fail?**	**How did the barrier affect the accident?**	**ISM/HPI**
1.	Design/construction testing and acceptance process.	Barrier in place but failed.	AWN System was accepted before it was adequately challenged with chemistry because the Cleanroom tools were not installed. AWN system and controls were not included in the Vendor training.	Alliance accepted an AWN system without full challenging with chemistry; warranty period expired before fully challenging it with chemistry. AWN System was rebuilt in house, and not replaced.	ISM: GP5, GP7, CF2 HPI: TD8, WE7
2.	Qualifications and training; roles, responsibilities, accountabilities and authorities.	Barrier that if present or strengthened, could have prevented the event.	Qualifications for bulk chemistry system not formally identified. Ownership of equipment and contents were unclear.	Work was performed with inadequate engagement of relevant Alliance programs (e.g. pressure safety) to ensure appropriate standards and requirements were fully applied. Ownership and operational roles, and responsibilities for the AWN system were not clearly defined.	ISM: GP3, GP4, GP7, CF2, CF3, CF5 HPI: IC2, IC5, TD6, TD7

Hazard: Sulfuric Acid			Target: Workers, Property, and Environment		
Barrier #	**What were the barriers?**	**How did each barrier perform?**	**Why did the barrier fail?**	**How did the barrier affect the accident?**	**ISM/HPI**
3.	Application of standards and requirements to develop and implement controls. (ASME, ASTM, ACGIH, OSHA, NFPA, Alliance Pressure Safety Program)	Barrier that if present or strengthened, could have prevented the event or decreased its severity.	Expert knowledge did not inform decision-making. Work is planned and performed without full awareness and application of standards and requirements.	Multiple opportunities to have identified and implemented applicable safety standards and requirements were missed. This was observed during AWN system design/redesign and for CRT response.	ISM: GP3, GP4, GP7, CF2, CF3, CF5 HPI: IC2, IC5, TD6, TD7, TD8
4.	Hazard Identification and Control	Barrier that if present or strengthened, could have prevented the event or decreased its severity.	Alliance did not recognize the level of hazards and controls required for engineering and safe operation of the AWN system.	Several key hazard identification and assessment elements were not fully implemented. For example, Process Hazard Analysis (PHA) corrective actions remained open at the time of the accident, neither a readiness verification nor a commissioning were completed, and multiple safe work permits pertinent to the work being performed were left to expire.	ISM: GP5-7, CF(All) HPI: WE4, TD6, TD7, HN4, HN6
5.	Work Authorization	Barrier that if present or strengthened, could have prevented the event or decreased its severity.	Misunderstanding of work authorization processes and authorizing documents.	Work was performed and hazards were introduced (sulfuric acid) when work was not authorized.	ISM: GP1, GP2, GP7, CF4 HPI: TD8, TD7

Hazard: Sulfuric Acid			Target: Workers, Property, and Environment		
Barrier #	**What were the barriers?**	**How did each barrier perform?**	**Why did the barrier fail?**	**How did the barrier affect the accident?**	**ISM/HPI**
6.	Management of change and configuration control.	Barrier that if present or strengthened, could have prevented the event.	Inconsistent recognition of the impacts and significance of changes.	Numerous AWN system function and design changes occurred without thorough review and impact analysis.	ISM: GP5, GP6, CF1, CF2, CF5 HPI: WE4, HN6
7.	Effective resolution of employee concerns and event corrective actions inform feedback and improvement for the worker safety and health program.	Barrier that if present or strengthened, could have prevented the event.	Interim measures and corrective actions from precursor events were not always implemented in a timely manner.	Opportunities to learn from precursor events, employee concerns, and internal and external feedback were missed.	ISM: GP1, GP4, CF5 HPI: HN4, HN6
8.	Appropriate specification and installation of system components.	Barrier not fully implemented.	Thorough verification of chemical compatibility, component specifications and installation did not consistently occur.	A rotameter was selected and installed and the secondary containment was repaired; each item failed, leading to the accident.	ISM: GP3, GP5, CF2, CF3 HPI: HN4, HN6, TD8, WE4
9.	Engineering controls perform as intended.	Barrier that if present or strengthened, would have prevented the event.	The float alarm was in place but not designed as an engineering control.	Original PHA included a leak sensor and alarm in containment. However the installed float alarm did not perform as an engineering control as indicated.	ISM: GP5, GP6, CF3 HPI: WE7

Hazard: Sulfuric Acid			Target: Workers, Property, and Environment		
Barrier #	**What were the barriers?**	**How did each barrier perform?**	**Why did the barrier fail?**	**How did the barrier affect the accident?**	**ISM/HPI**
10.	CRT response follows established procedures, with adequate safety and health expertise to support response.	Barrier that if strengthened, would have improved the response.	The responders were unaware of changes to CRT procedures. The role of the external response organization was unclear and lack of preplanning for an event of this nature was evident.	The CRT responders relied on their expertise and understanding of CRT procedures rather than following the documented procedure. The CRT responded and did not engage an external response organization as required by the documented CRT procedure.	ISM: GP2, GP5, GP7, CF1, CF3, CF4 HPI: TD1, TD7, IC4, IC8, HN6
11.	Integrated and Comprehensive Emergency Management System.	Barrier that if strengthened, would have improved the response.	A lack of awareness of on-site hazards and inadequate preparation for responding to hazards.	A Comprehensive Emergency Management System is not fully implemented.	ISM: GP2, GP5, CF2 HPI: IC4, TD7
12.	An effective integrated safety management system that maintains a healthy respect for what can go wrong.	Barrier that if strengthened, could have prevented the event.	Reliance on the talent of the individual rather than the integrated safety management system.	Multiple instances in which worker behavior and decision-making led to work being performed outside of established procedures, which was not corrected, resulting in organizational drift.	ISM: GP (All), CF (All) HPI: HN4, HN6, TD7, WE4

Appendix C. Change Analysis

Change is anything that disturbs the "balance" of a system from operating as planned. Change is often the source of deviations in system operations. Change can be planned, anticipated, and desired, or it can be unintentional and unwanted. Change analysis examines the planned or unplanned disturbances or deviations that caused the undesired results or outcomes related to the accident. This process analyzes the difference between what is normal (or "ideal") and what actually occurred. The results of the change analysis are used to support the development of causal factors.

Table C-1: Change Analysis

#	Accident Situation	Accident-Free Situation	Difference	Evaluation
1.	AWN system accepted with indications of inadequate design, training, and preparedness to work on the AWN system. Numerous issues with the AWN system continued.	Alliance accepts an AWN system that is fully commissioned and effectively challenged (tested concurrently with research tools).	An adequate commissioning process that identified design deficiencies prior to acceptance.	System installation proceeded without resolution of concerns.
2.	Alliance continued to attempt to correct issues with the AWN system, to include treatment cabinets' pump, piping, and chemistry changes.	Alliance recognizes that the issues with the AWN system should be resolved by experts with the technical qualifications to address the issues.	Alliance did not consistently engage qualified expertise in engineering, design, review and acceptance of the rebuilt system.	The AWN system had issues that remained unresolved and delayed research operations.
3.	Leaks in the AWN cabinet secondary containment were identified. Repairs to secondary containment via plastic welding were not successful. A two-part epoxy product was used to repair secondary containment; the epoxy was not tested with chemical prior to use.	Alliance reassesses the effectiveness of the secondary containment as a primary control.	Alliance did not use reliable secondary containment.	Secondary containment failed.
4.	Research and Research Operations take on responsibility to redesign and operate the AWN system.	Site Operations would have taken ownership of the AWN system and would have obtained the necessary expertise to redesign and operate the AWN system.	Alliance did not obtain qualified personnel to redesign and operate the AWN system.	Research and Research Operations were designing and operating the AWN system without necessary expertise.

#	Accident Situation	Accident-Free Situation	Difference	Evaluation
5.	Confusion over AWN ownership and Boundary Agreement persisted. Attempts to clarify AWN ownership via Boundary Agreements were not successful.	Stakeholders would have a clear understanding of AWN system ownership and would have completed a detailed Boundary Agreement.	Ownership and operational roles and responsibilities of stakeholders for the AWN system were not clearly defined.	Alliance did not establish effective ownership and operational roles and responsibilities for the AWN system.
6.	Alliance did not complete the readiness process for the AWN system.	Alliance would have completed the Hazard Identification and Control process and developed all required documentation for readiness and operation of the AWN system.	Alliance selected commissioning as the process to use for determining the adequacy, safety, and readiness of the redesigned AWN system. This process is outside of established procedures.	The AWN system was not commissioned and the Hazard Identification and Control Process was not used. The AWN system was operated without readiness verification or commissioning.
7.	Work was performed under a LOTO ESP.	Work would have been performed according to the Alliance Hazard Identification and Control procedure.	LOTO is not the correct process to follow for the work conducted.	Work was performed that was not authorized.
8.	Sulfuric acid drum loaded into the AWN cabinet for tuning and other work on a Friday without authorization or notice to others.	Alliance would have discussed, planned, and authorized workers to load the sulfuric acid drum into the AWN cabinet.	Workers were under the impression that a LOTO ESP is a work authorizing document.	LOTO ESP is not a work authorizing document. Workers did not coordinate activities.
9.	Point-to-point testing did not identify that an incorrect address for the ammonia scrubber isolation valve was entered in the BMS.	Alliance's point-to-point testing of the coding would have validated that they were installed with correct coding.	Point-to-point testing that was performed did not identify the coding error.	The valve remained open when it should have been closed.

#	Accident Situation	Accident-Free Situation	Difference	Evaluation
10.	Float alarm in the secondary containment is sent to the BMS.	The float alarm in the secondary containment would have performed as an engineering control as defined in the PHA.	Alliance did not validate that a prescribed control was implemented.	The alarm did not shut down the acid pump and initiate a response action.
11.	Alliance staff responding to the alarm were aware that the AWN system was being worked on but were not informed of its configuration.	Research and Research Operations would have communicated the status of the AWN system and its hazards prior to leaving for the weekend.	Adequate work planning and communication did not occur.	Alliance Staff was not aware that hazardous material was released into secondary containment.
12.	Detailed protocol for responding to a float alarm for the AWN cabinet not in place.	Alliance would have a clear and detailed protocol for responding to float alarm for the AWN cabinet.	Existing response protocol not adequate.	Alliance Staff were unsure of how to respond to the alarm.
13.	Chemical Response Team (CRT) responds to an ongoing emergency situation that is after-hours and a no-go response, which is defined as such in their LLP.	The CRT would have identified that the event required activation of an external response organization.	CRT Incident Commander decided to manage the response internally.	An external response organization was not engaged and clean-up actions were delayed.
14.	Responding CRT members enter the scene to characterize the spill with gloves, face shields and safety boots.	CRT would have taken defensive actions and would not have entered the spill with inadequate personal protective equipment (PPE).	Responding CRT members accepted an inordinate level of personal risk by entering the scene with inadequate PPE.	CRT did not follow their LLP and placed employees at risk.

#	Accident Situation	Accident-Free Situation	Difference	Evaluation
15.	CRT personnel exposure monitoring and atmospheric sampling was accomplished with expired detector tubes and uncalibrated equipment.	Alliance would have used sampling and monitoring equipment that was appropriately sensitive to the contaminant and concentrations being monitored.	Alliance conducted work without obtaining valid baseline exposure data and relied on information that was not completely reliable.	Alliance used expired detector tubes not sensitive enough to detect contaminants. A Honeywell Single Point Monitor Gas Detector (SPM Flex) was used for exposure monitoring without verification of calibration data, training, and, recording of relative humidity.
16.	The Industrial Hygiene (IH) Staff did not verify and validate equipment used in exposure monitoring.	IH would have had ownership or co-ownership of equipment used in CRT exposure monitoring.	The IH Staff produced a report utilizing data from owners and users of the Flex without knowledge of the instrument calibration, maintenance, user training, etc.	Unreliable results could have contributed to inappropriate decision making.
17.	The Alliance's environmental contractor arrives and is turned away from site because their capabilities did not match the requirements for response and clean-up.	Alliance would have identified and selected a contractor with the necessary qualifications to respond and clean-up to a hazardous materials event.	Alliance was not fully aware of the skills and capabilities of their environmental remediation subcontractor.	Alliance was delayed in hiring a capable subcontractor.

Appendix D. Root Cause Analysis

Root causes are the causal factors that, if corrected, would prevent recurrence of the same or similar accidents. Root causes may be derived from or encompass several contributing causes. They are higher-order, fundamental causal factors that address classes of deficiencies, rather than single problems or faults.

Table D-1: Root Cause Analysis

Direct Cause	ISM/HPI
DC: The failure of the rotameter in the AWN system, which leaked sulfuric acid into the secondary containment. The secondary containment subsequently failed and released sulfuric acid from the cabinet into the corridor. **CON1:** The Board concluded that this accident was preventable. **JON1:** The Board determined that if the Alliance implements the Board's Judgements of Need that this, and other similar accidents, may be prevented.	GP (All), CF (All)

Root Cause(s)	ISM/HPI
RC1: Thorough verification of chemical compatibility, component specifications, and installation did not consistently occur. A rotameter was selected and installed and the secondary containment was repaired; both failed, leading to the accident. **CON7:** There was a failure to verify chemical compatibility, component specifications, and installation. **JON7:** The Alliance needs to ensure that an effective process is in place for designing, installing, and approving systems in-house. **JON8:** The Alliance needs to ensure that qualified personnel are responsible for and involved in the engineering of complex, hazardous systems.	GP3, GP5, CF2, CF3, HN4, HN6, TD8, WE4
RC2: The float alarm, which was in place and functioning, did not shut down the acid pump or initiate a response action. Although the original Process Hazard Analysis (PHA) for the AWN included a leak sensor and alarm in containment, the installed float alarm did not perform as an engineering control as indicated in the PHA. In addition, there was no clear response protocol for the float alarm. **CON2:** The Alliance did not identify and implement engineering controls that were adequate to initiate an immediate and appropriate response. **JON2:** The Alliance needs to ensure that engineering controls function to effectively contain the hazard.	GP5, GP6, CF3, HN4, TD8, WE7

Root Cause(s)	ISM/HPI
RC1: Thorough verification of chemical compatibility, component specifications, and installation did not consistently occur. A rotameter was selected and installed and the secondary containment was repaired; both failed, leading to the accident. **CON7:** There was a failure to verify chemical compatibility, component specifications, and installation. **JON7:** The Alliance needs to ensure that an effective process is in place for designing, installing, and approving systems in-house. **JON8:** The Alliance needs to ensure that qualified personnel are responsible for and involved in the engineering of complex, hazardous systems.	GP3, GP5, CF2, CF3, HN4, HN6, TD8, WE4
RC3: Alliance did not recognize and act on the level of hazards and controls required for engineering and safe operation of the AWN system. There was inconsistent recognition of the impacts and significance of changes. **CON4:** The Board concluded that the Alliance did not implement an effective management of change program that recognized the impact and significance of changes to systems and re-evaluated hazards and controls. **JON5**: The Alliance needs to ensure that their lab-level work planning processes are fully integrated, functional, and capable of effectively identifying and recognizing changes to work processes that necessitate re-evaluation of hazards and controls with a level of rigor equivalent to the risk.	GP5, GP6, CF2, CF3, CF4, HN6 WE4

Contributing Cause(s)	ISM/HPI
CC1: The Alliance accepted the AWN system in 2016 from Subcontractor 1 with indications of inadequate design, training, and preparedness to work on the system. The Alliance accepted an AWN system without it being fully challenged with chemistry, and the warranty period expired before doing so. **CON11:** The Automated Waste Neutralization (AWN) system was accepted without validating it performed as designed and was compatible with broader research systems. **JON12:** The Alliance should ensure an effective system is in place for verifying design and functionality of systems prior to acceptance from subcontractors.	GP5, GP7, CF2, TD8, WE7

Contributing Cause(s)	ISM/HPI
CC2: Numerous issues with the AWN system continued over a three year period, during which time the AWN System was rebuilt in-house. Alliance did not obtain or consistently engage qualified expertise in engineering, design, review and acceptance of the rebuilt system. Research and Research Operations were designing and operating the AWN system without necessary expertise. **CON12:** A qualified chemical engineer was not engaged for the in-house redesign of the AWN system, which contributed to weaknesses in AWN system integrity (rotameter and containment failure). **JON13:** The Alliance needs to ensure appropriate professional expertise is applied to design and engineering of Site Operations and research systems.	GP2, GP3, CF1, IC1, IC3, HN4, WE4
CC3: Ownership and operational roles, and responsibilities for the AWN system were not clearly defined. **CON17:** The Alliance did not establish effective ownership, roles, and responsibilities for the AWN system. **JON18**: The Alliance needs to ensure that roles and responsibilities are clearly defined in documents such as Boundary Agreements.	GP2, CF1, TD7
CC4: The Alliance selected commissioning to verify the adequacy, safety, and readiness of the redesigned AWN system. This approach is not consistent with the Alliance Hazard Identification and Control Program. The Alliance did not follow through with the commissioning process. **CON18:** The Alliance did not define and implement effective roles and responsibilities for verifying the adequacy, safety, and readiness of the redesigned AWN system. **JON19:** The Alliance needs to review processes to ensure formal and effective procedures for verifying the adequacy, safety, and readiness of laboratory systems are implemented.	GP7, CF1, TD7
CC5: LOTO is not the correct work authorization process to follow for the work conducted. Work was performed that was not authorized.	GP7, CF4, TD7
CC6: Workers did not coordinate activities when loading the sulfuric acid drum into the AWN cabinet. Adequate work planning and communication did not occur.	GP1, GP2, GP7, CF4
CC7: Several key hazard identification and assessment elements were not fully implemented. For example, PHA corrective actions remained open at the time of the accident, neither a readiness verification nor a commissioning were not issued or were not completed, and multiple safe work permits pertinent to the work being performed were left to expire.	GP5-7, CF(All), HN4, HN6, TD6, TD7, WE4
CC8: On multiple occasions during the redesign of the AWN system hazard identification and control work processes were not used. There was a misunderstanding of work authorization processes and work was routinely performed and hazards were introduced when work was not authorized.	GP1, GP2, GP7, CF4, TD7, TD8

Contributing Cause(s)	ISM/HPI
CC9: Numerous AWN system function and design changes occurred without thorough review and impact analysis. **CON5:** This event revealed multiple barriers that failed related to work planning and control processes. **JON5:** The Alliance needs to conduct a thorough analysis of work planning and control processes and ensure that verifiable/defensible corrective actions are implemented for each related work planning and control causal factor. **CON6:** The Alliance did not always communicate workplace hazards effectively through the Plan of the Week or Plan of the Day meetings. **JON6:** The Alliance needs to ensure that employees are informed of workplace hazards.	GP5, GP6, CF1, CF2, CF5, HN6, WE4
CC10: Point-to-point testing did not identify that an incorrect address for the ammonia scrubber isolation valve was entered in the BMS. The isolation valve remained open when it should have been closed. **CON13**: Confirmation and quality verification of the coding did not occur. Additionally, the system is not engineered to provide confirmation of the position of the valve to the operator resulting in operators being unaware of actual system configuration prior to verification of readiness for safe operation. **JON14:** The Alliance needs to ensure integration of configuration control and quality processes that verify work is as intended for safe operations into work at all levels.	CF3, IC4, TD1, WE4
CC11: Multiple opportunities to have identified and implemented applicable safety and emergency management standards and requirements that would have prevented the accident or minimized its consequences were missed. **CON9:** Work was performed without effective engagement of relevant Alliance programs (e.g. pressure safety) to ensure appropriate standards and requirements were fully applied. **JON10:** The Alliance needs to ensure sufficient resources are available for formal and rigorous design, testing, and readiness of laboratory activities.	GP3, GP4, GP7, CF2, CF3, CF5, IC2, IC5, TD6, TD7, TD8
CC12: Interim measures and corrective actions from precursor events were not always implemented in a timely manner. Opportunities to learn from precursor events, employee concerns, and internal and external feedback were missed. **CON15:** The Alliance missed opportunities to learn from precursor events, employee concerns, and internal and external feedback. **JON16:** The Alliance needs to examine and strengthen its processes to learn from precursor events, employee concerns, and internal and external feedback throughout all of NREL.	GP1, GP4, CF5, HN4, HN6

Contributing Cause(s)	ISM/HPI
CC13: The Board identified multiple instances in which worker behavior and decision-making led to work being performed outside of established procedures, which was not corrected, resulting in organizational drift. **CON16:** Human performance and safety culture issues exist that led to system weaknesses and poor decision-making. **JON17:** The Alliance needs to ensure sufficient focus is placed on continuing to mature its safety culture and strengthen its integrated safety management system.	GP (All), CF (All), HN4, HN6, TD7, WE4

Appendix E. Event and Causal Factor Analysis

An events and causal factors analysis was performed in accordance with the DOE Workbook, *Conducting Accident Investigations*. The events and causal factors analysis requires deductive reasoning to determine those events and/or conditions that contributed to the accident. Causal factors are the events or conditions that produced or contributed to the accident, and they consist of direct, contributing, and root causes. The direct cause is the immediate event(s) or condition(s) that caused the accident. The contributing causes are the events or conditions that, collectively with the other causes, increased the likelihood of the accident, but which did not solely cause the accident. Root causes are the events or conditions that, if corrected, would prevent recurrence of this and similar accidents.

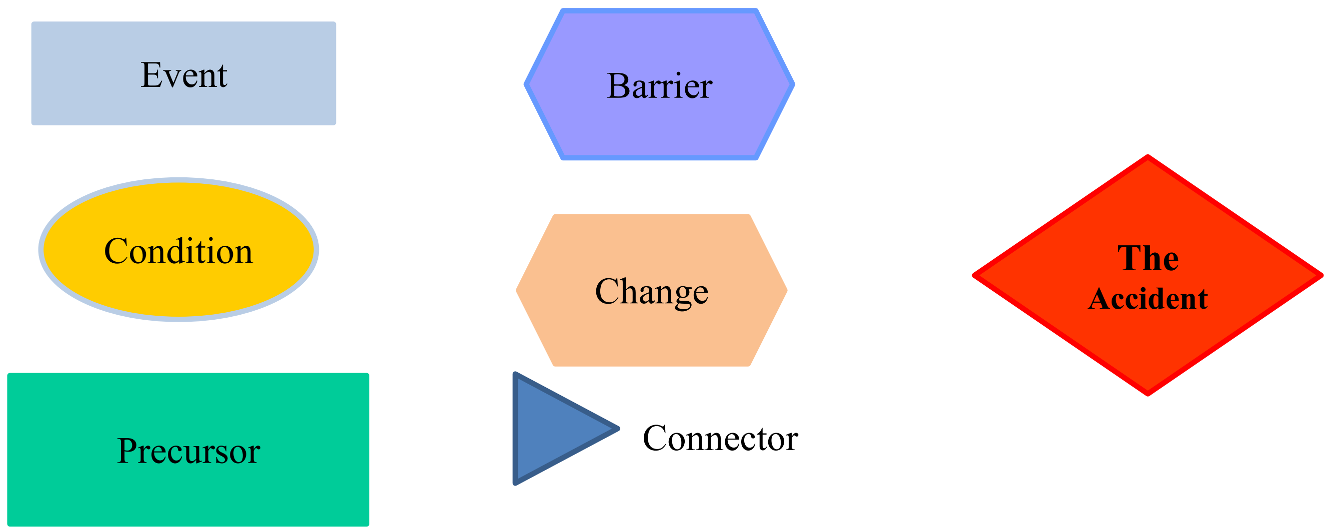
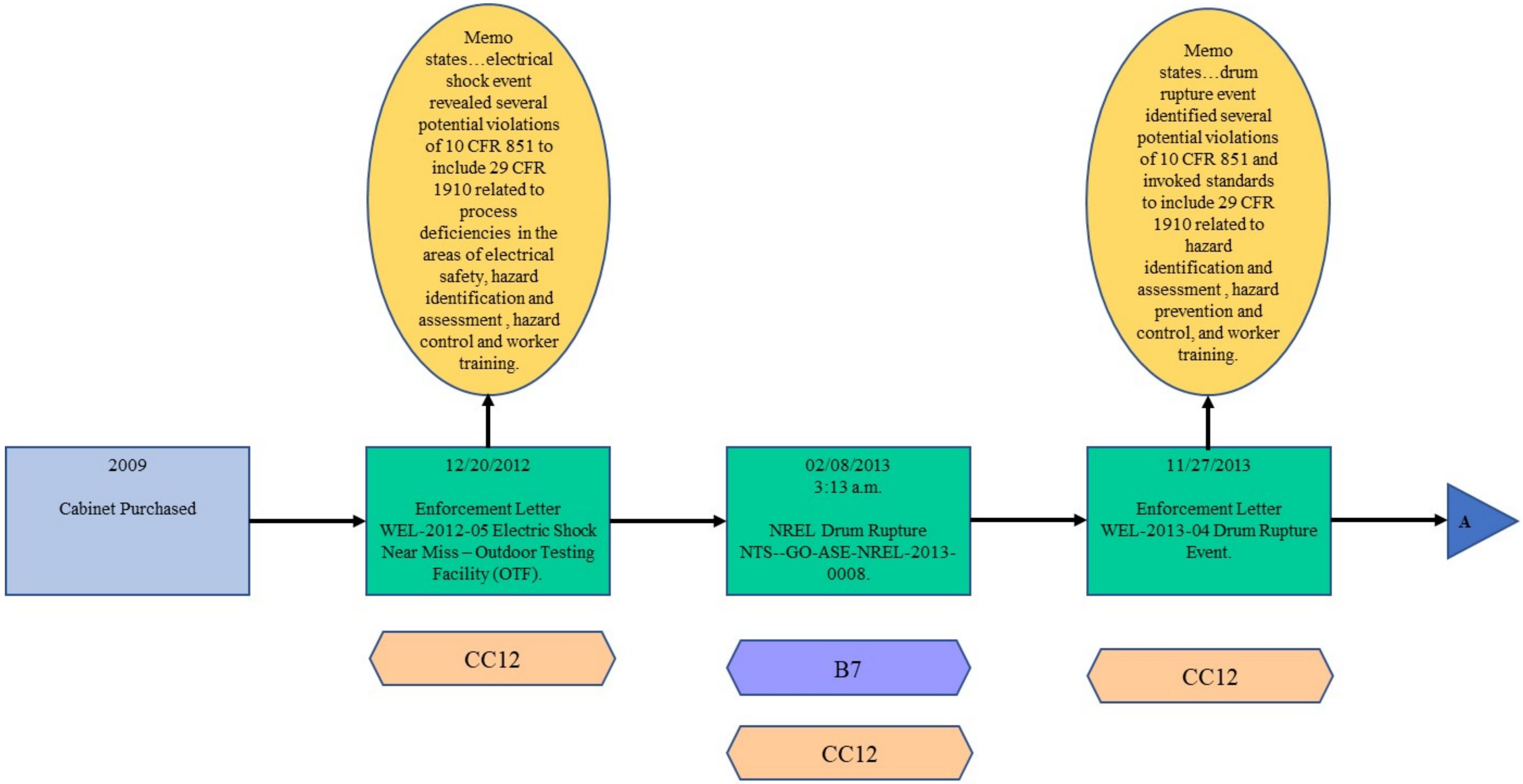
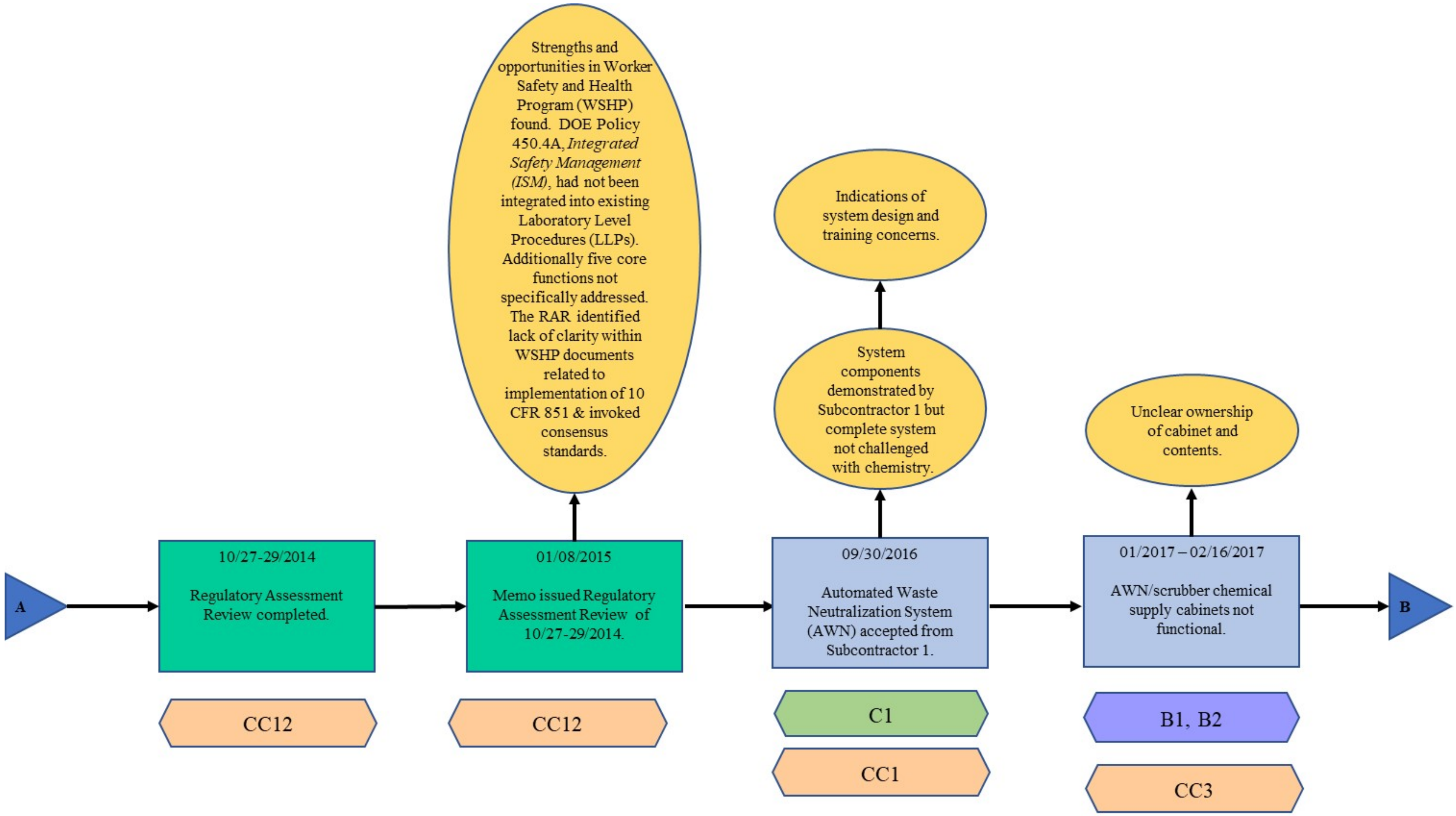
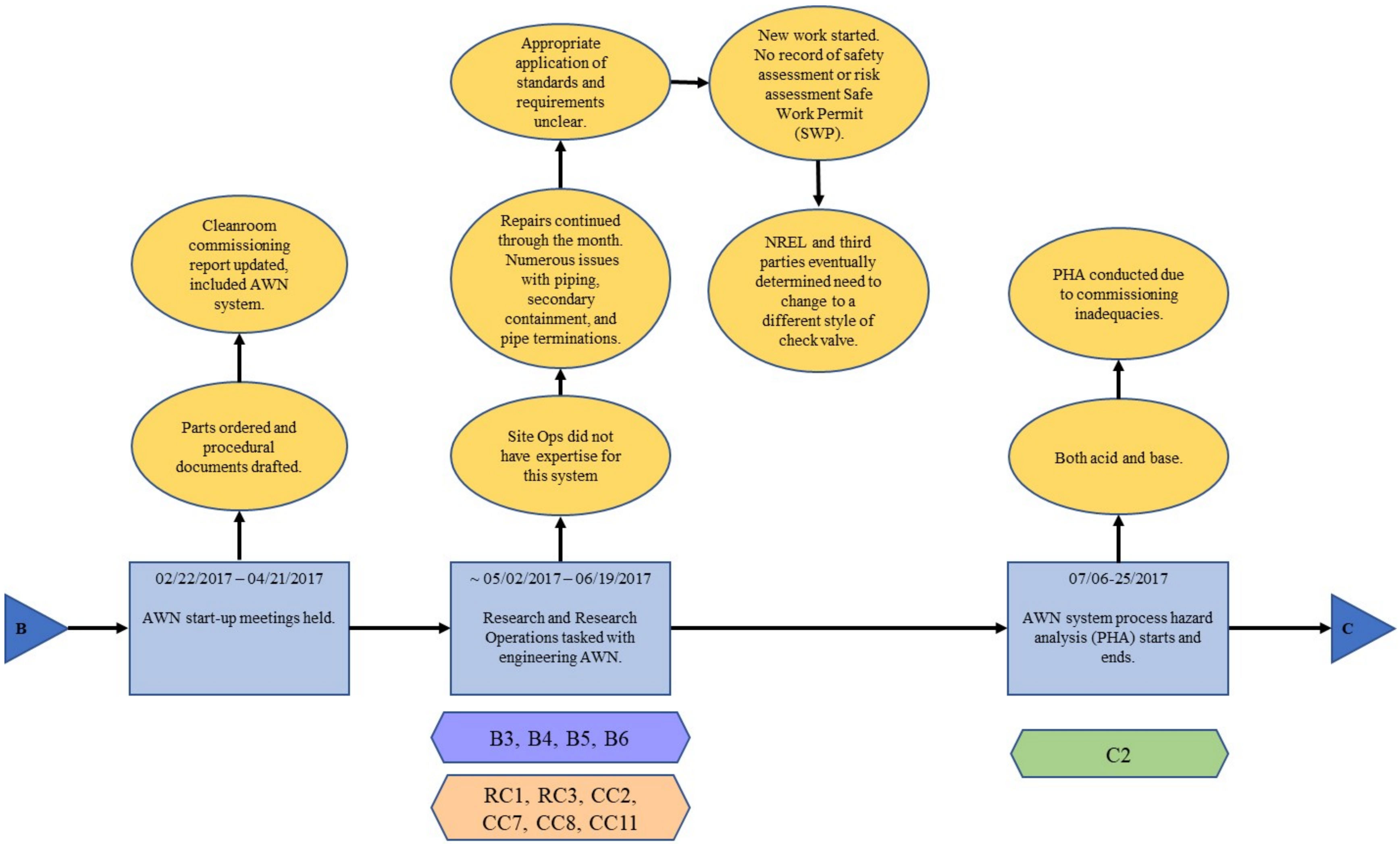
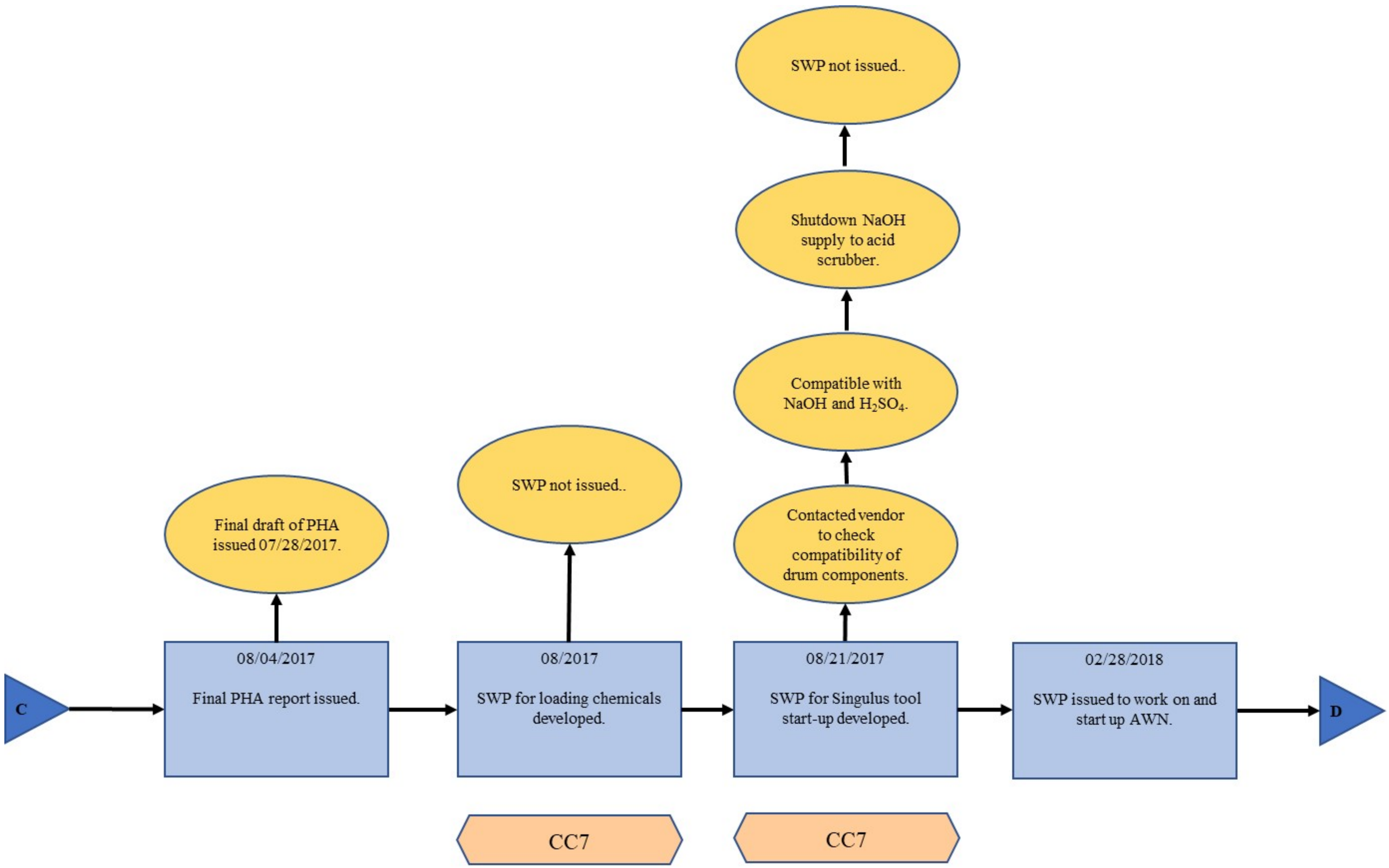


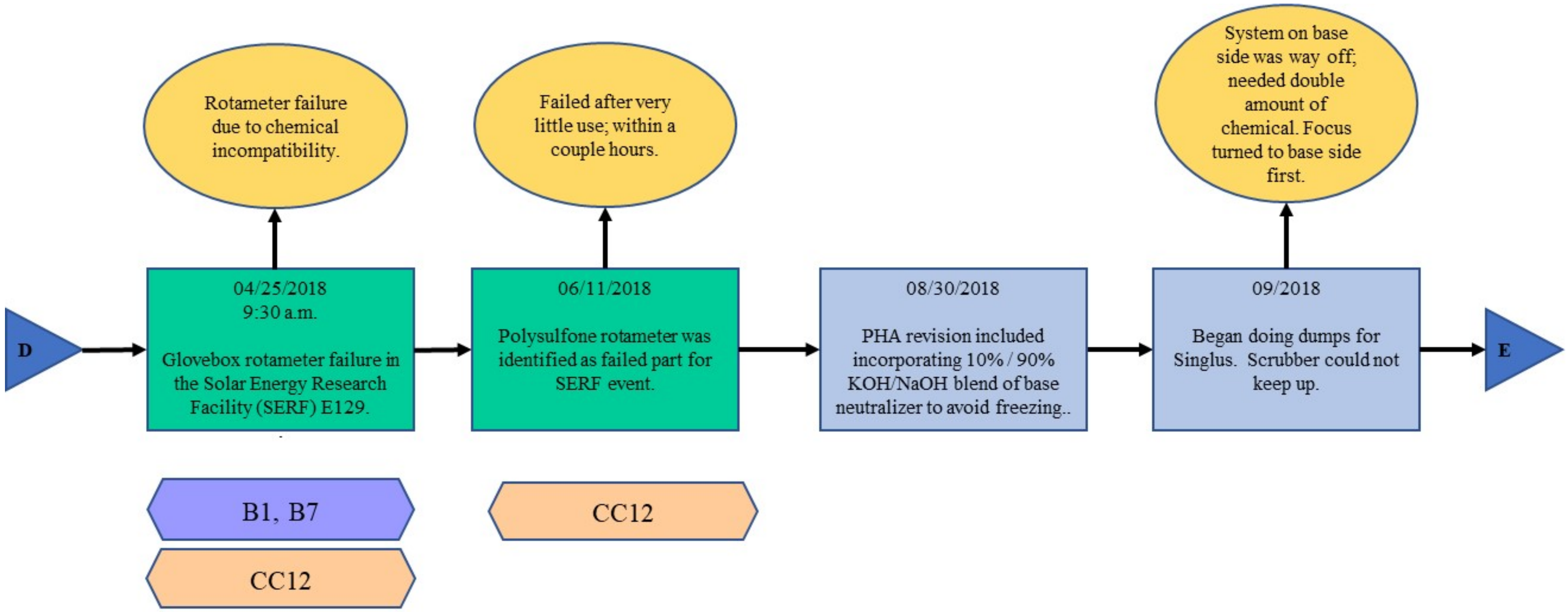
Table E-1: Event and Causal Factors Analysis

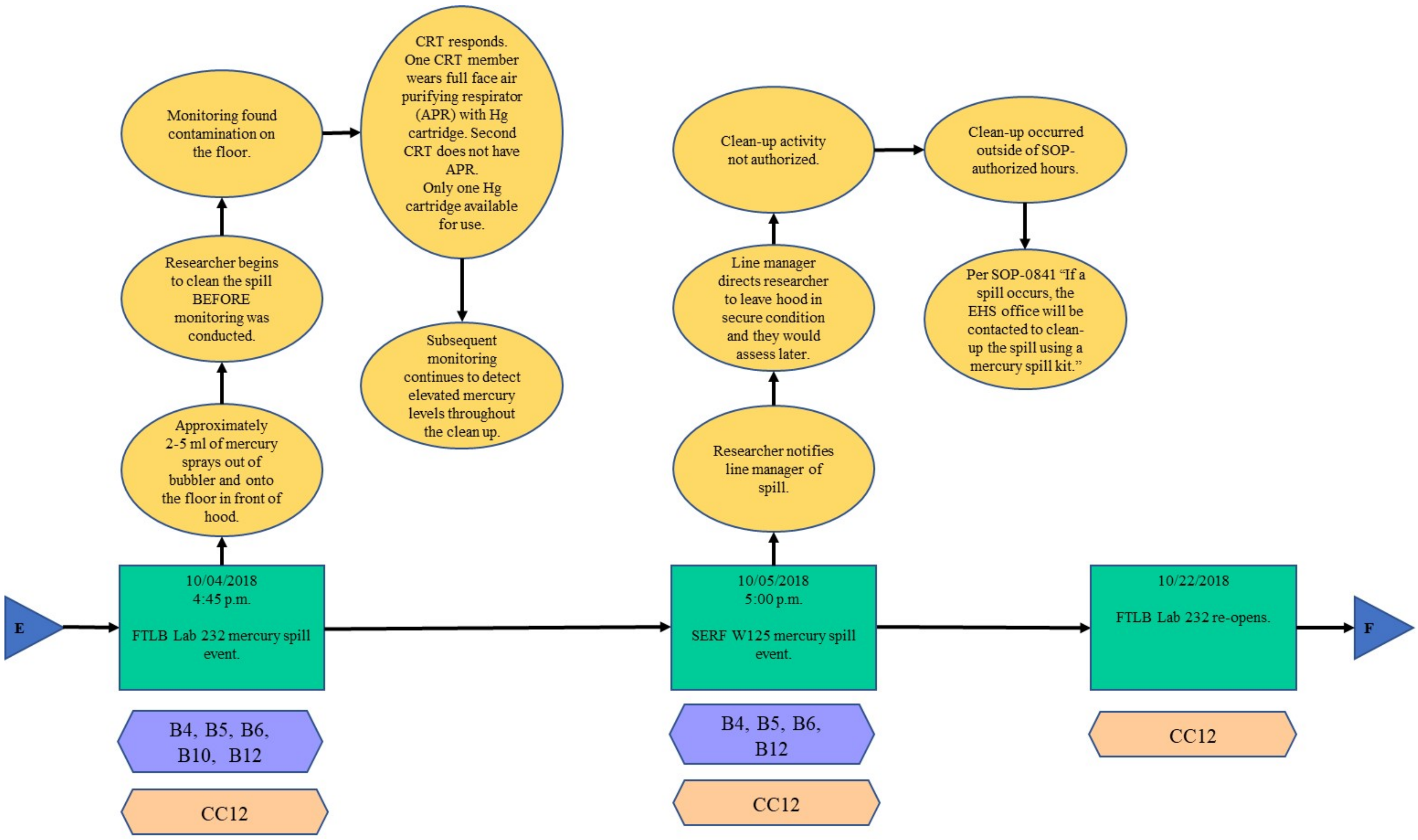


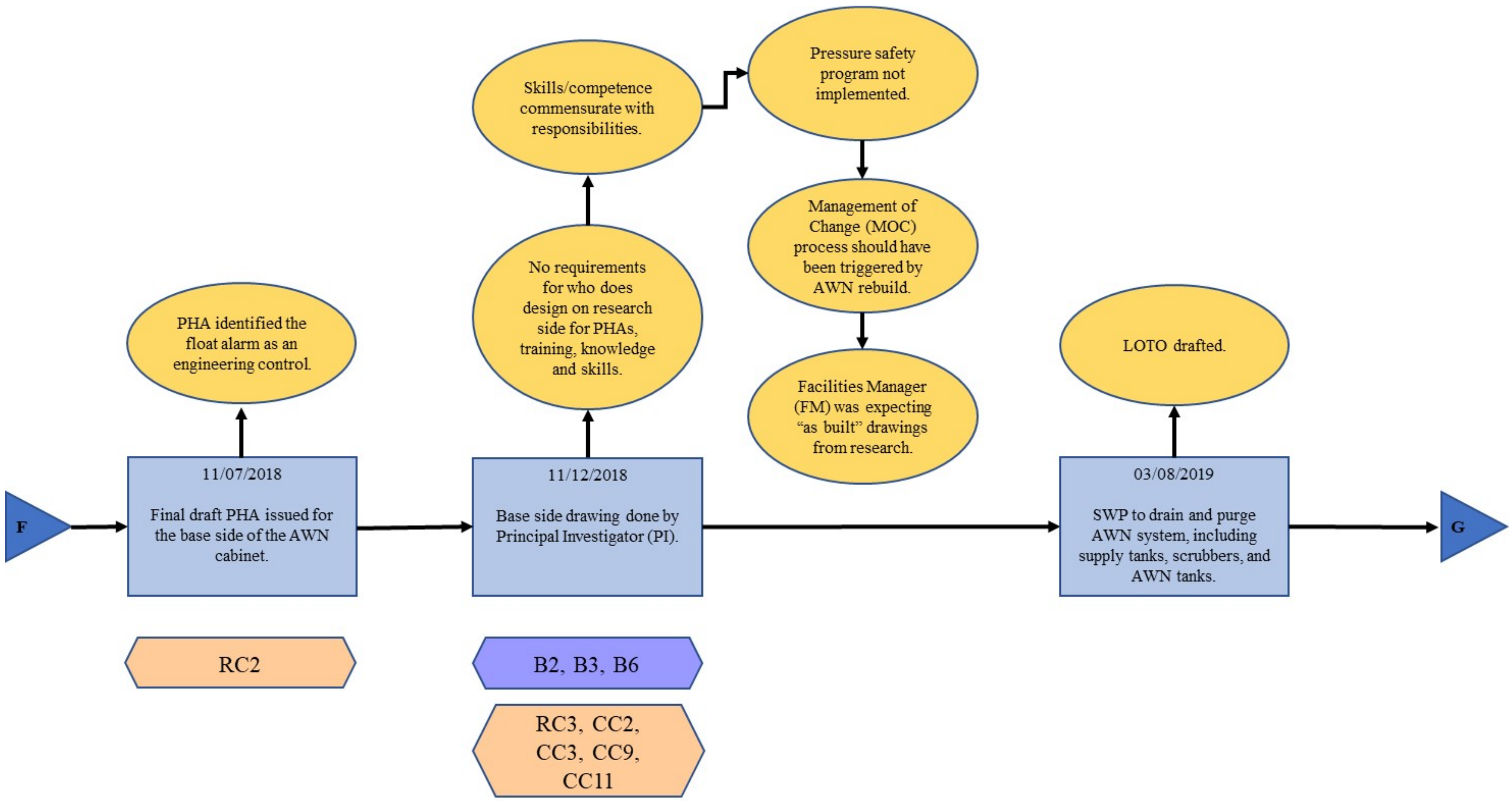

A
10/27-29/2014
Regulatory Assessment Review completed.
CC12
01/08/2015
Memo issued Regulatory Assessment Review of 10/27-29/2014.
Strengths and opportunities in Worker Safety and Health Program (WSHP) found. DOE Policy 450.4A, *Integrated Safety Management (ISM)*, had not been integrated into existing Laboratory Level Procedures (LLPs). Additionally five core functions not specifically addressed. The RAR identified lack of clarity within WSHP documents related to implementation of 10 CFR 851 & invoked consensus standards.
CC12
09/30/2016
Automated Waste Neutralization System (AWN) accepted from Subcontractor 1.
System components demonstrated by Subcontractor 1 but complete system not challenged with chemistry.
Indications of system design and training concerns.
C1
CC1
01/2017 – 02/16/2017
AWN/scrubber chemical supply cabinets not functional.
Unclear ownership of cabinet and contents.
B1, B2
CC3
B

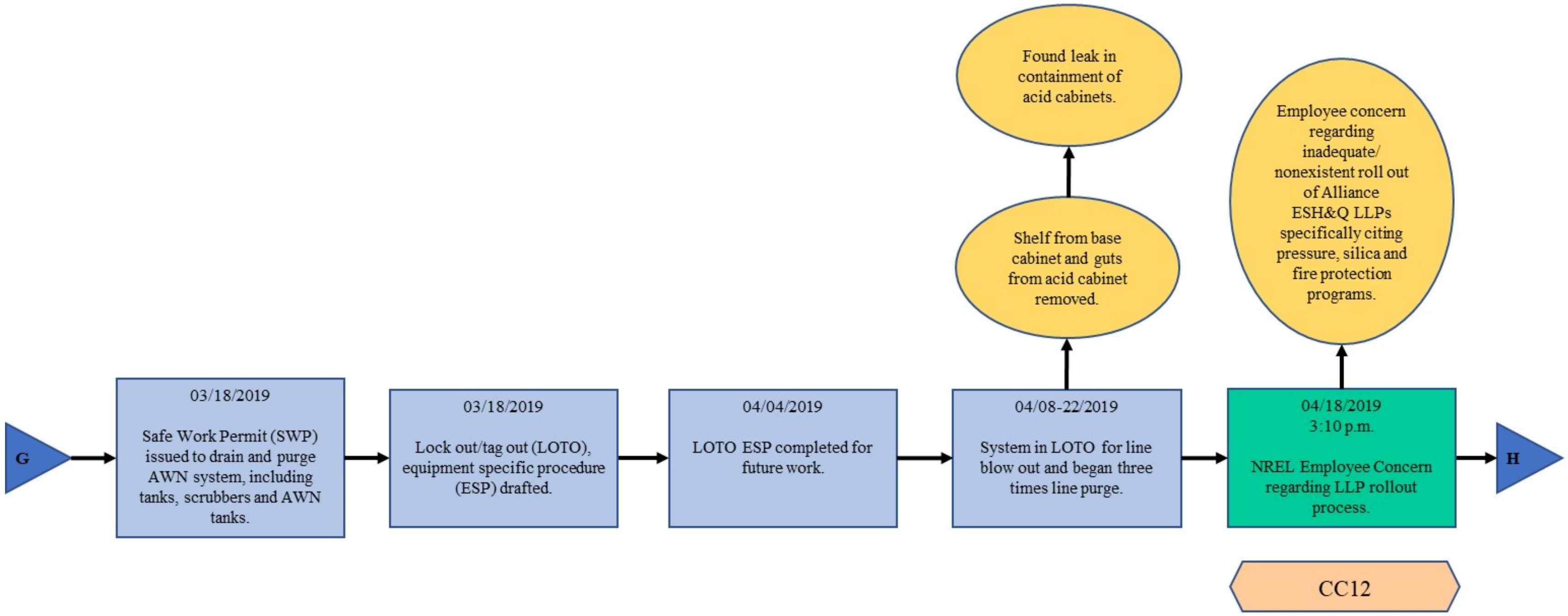

B
02/22/2017 – 04/21/2017
AWN start-up meetings held.
Parts ordered and procedural documents drafted.
Cleanroom commissioning report updated, included AWN system.
~ 05/02/2017 – 06/19/2017
Research and Research Operations tasked with engineering AWN.
Site Ops did not have expertise for this system
Repairs continued through the month. Numerous issues with piping, secondary containment, and pipe terminations.
Appropriate application of standards and requirements unclear.
New work started. No record of safety assessment or risk assessment Safe Work Permit (SWP).
NREL and third parties eventually determined need to change to a different style of check valve.
B3, B4, B5, B6
RC1, RC3, CC2, CC7, CC8, CC11
07/06-25/2017
AWN system process hazard analysis (PHA) starts and ends.
Both acid and base.
PHA conducted due to commissioning inadequacies.
C2
C

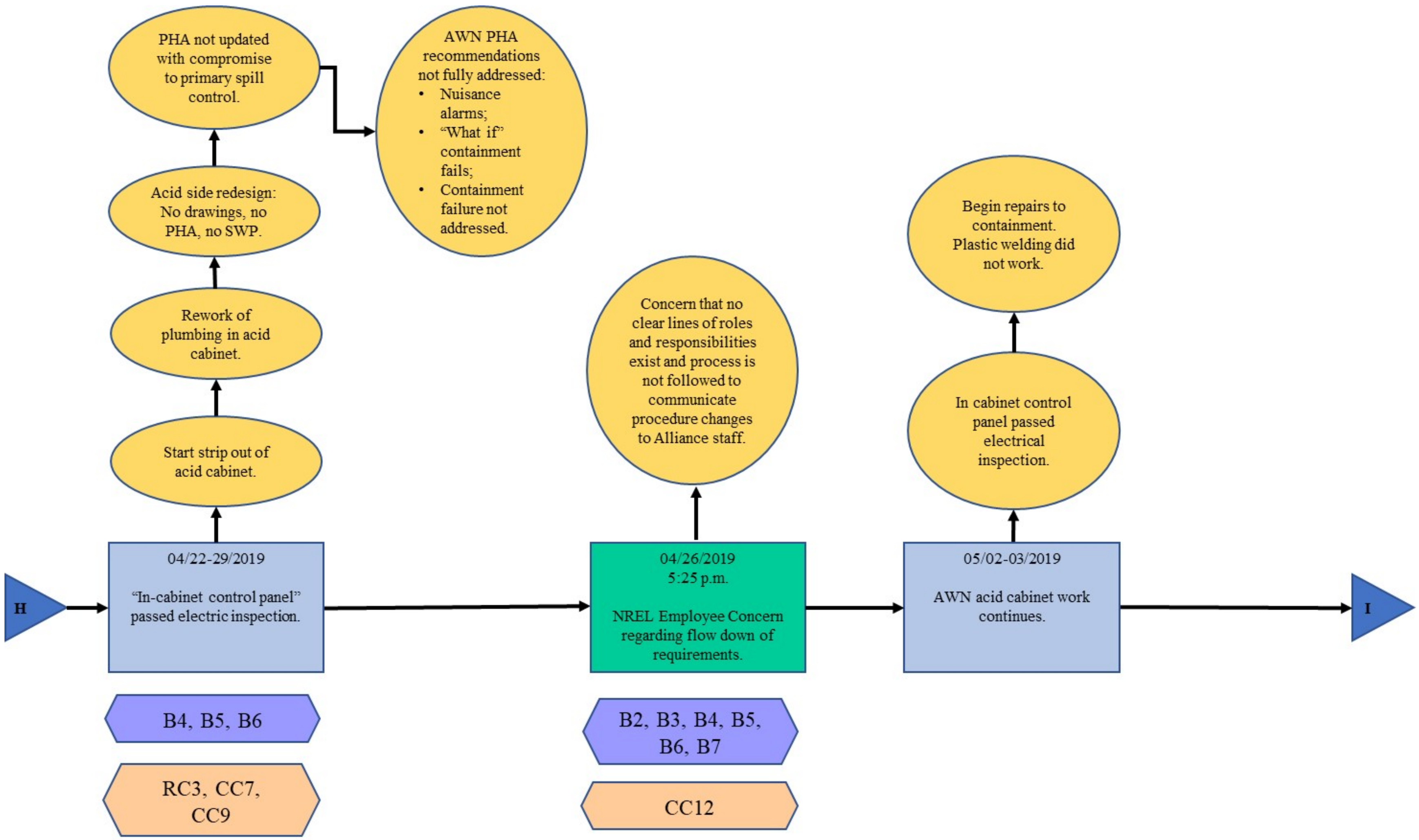

SWP not issued..
Shutdown NaOH supply to acid scrubber.
Compatible with NaOH and H_2SO_4.
SWP not issued..
Final draft of PHA issued 07/28/2017.
Contacted vendor to check compatibility of drum components.
C
08/04/2017
Final PHA report issued.
08/2017
SWP for loading chemicals developed.
08/21/2017
SWP for Singulus tool start-up developed.
02/28/2018
SWP issued to work on and start up AWN.
D
CC7
CC7

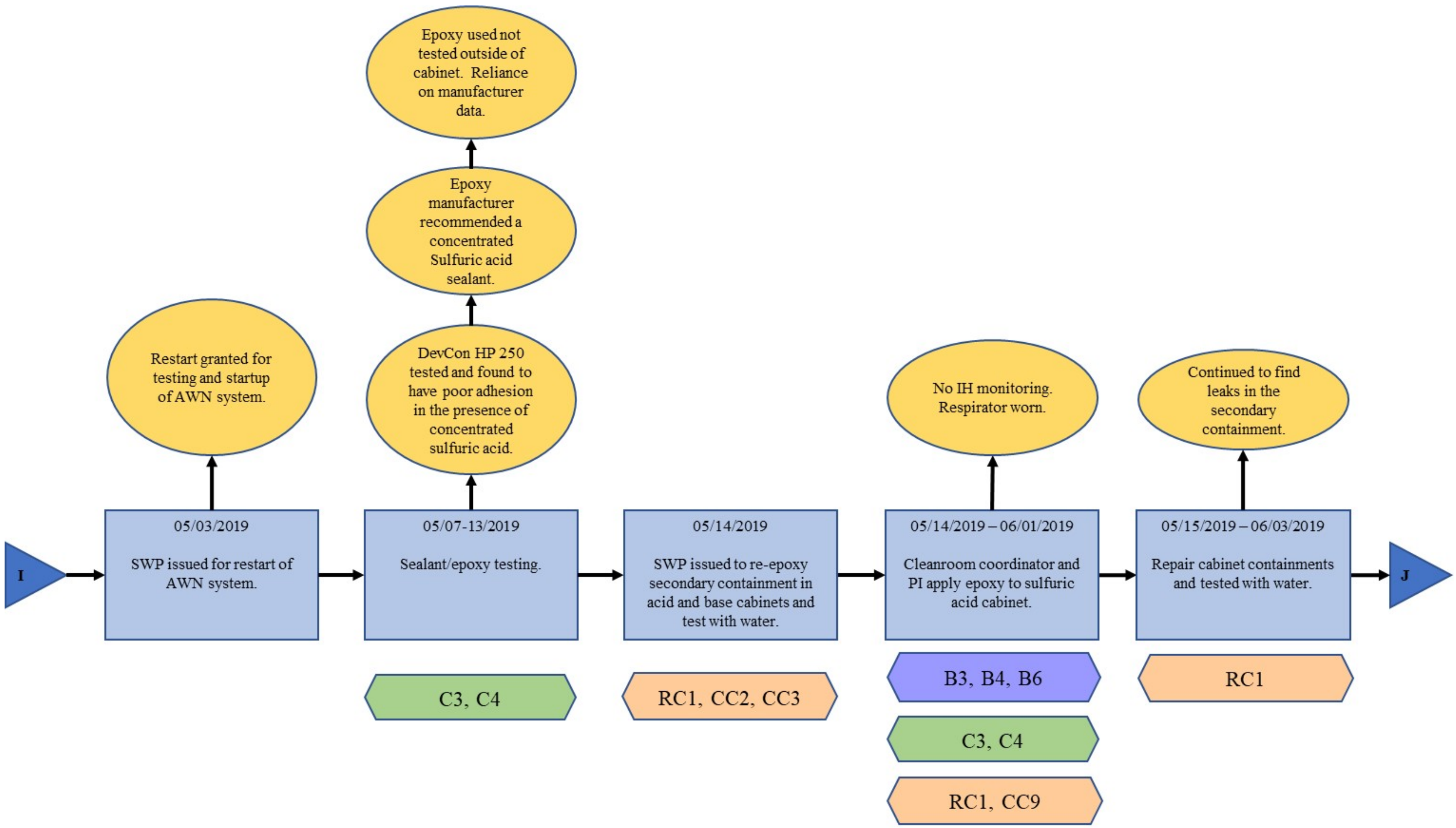

Rotameter failure due to chemical incompatibility.
Failed after very little use; within a couple hours.
System on base side was way off; needed double amount of chemical. Focus turned to base side first.
D
04/25/2018
9:30 a.m.
Glovebox rotameter failure in the Solar Energy Research Facility (SERF) E129.
06/11/2018
Polysulfone rotameter was identified as failed part for SERF event.
08/30/2018
PHA revision included incorporating 10% / 90% KOH/NaOH blend of base neutralizer to avoid freezing..
09/2018
Began doing dumps for Singlus. Scrubber could not keep up.
E
B1, B7
CC12
CC12

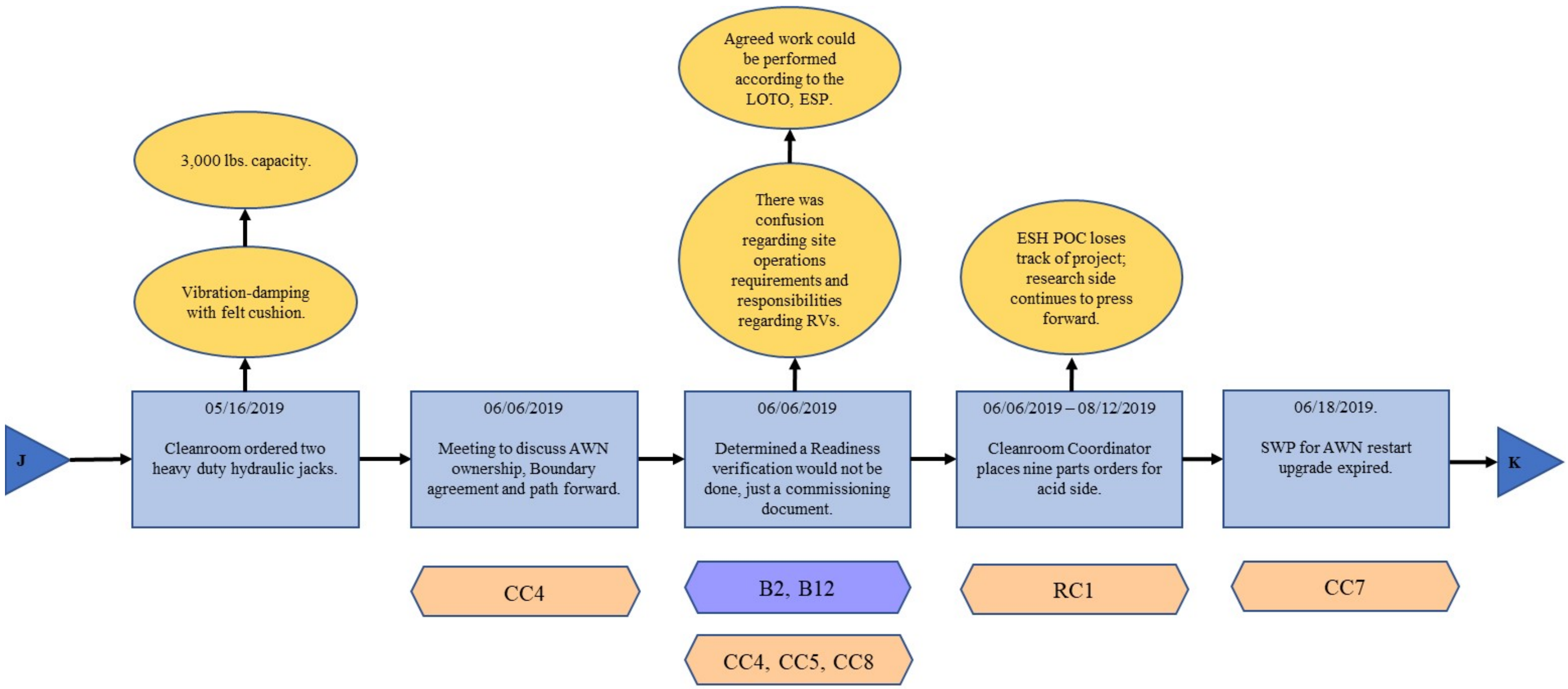

E
10/04/2018
4:45 p.m.
FTLB Lab 232 mercury spill event.
Approximately 2-5 ml of mercury sprays out of bubbler and onto the floor in front of hood.
Researcher begins to clean the spill BEFORE monitoring was conducted.
Monitoring found contamination on the floor.
CRT responds. One CRT member wears full face air purifying respirator (APR) with Hg cartridge. Second CRT does not have APR. Only one Hg cartridge available for use.
Subsequent monitoring continues to detect elevated mercury levels throughout the clean up.
B4, B5, B6, B10, B12
CC12
10/05/2018
5:00 p.m.
SERF W125 mercury spill event.
Researcher notifies line manager of spill.
Line manager directs researcher to leave hood in secure condition and they would assess later.
Clean-up activity not authorized.
Clean-up occurred outside of SOP-authorized hours.
Per SOP-0841 "If a spill occurs, the EHS office will be contacted to clean-up the spill using a mercury spill kit."
B4, B5, B6, B12
CC12
10/22/2018
FTLB Lab 232 re-opens.
CC12
F

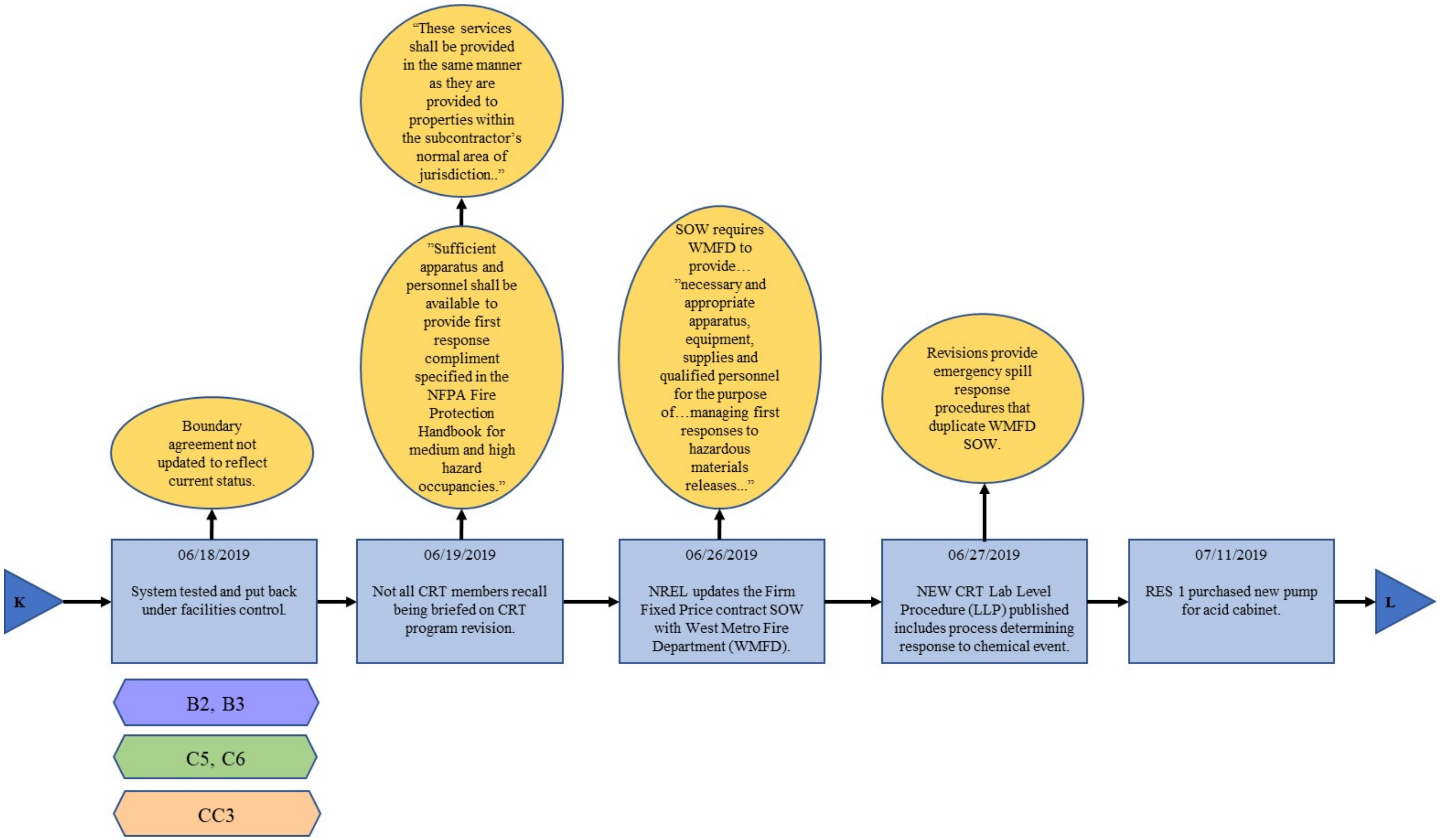

F
11/07/2018
Final draft PHA issued for the base side of the AWN cabinet.
PHA identified the float alarm as an engineering control.
RC2
11/12/2018
Base side drawing done by Principal Investigator (PI).
No requirements for who does design on research side for PHAs, training, knowledge and skills.
Skills/competence commensurate with responsibilities.
Pressure safety program not implemented.
Management of Change (MOC) process should have been triggered by AWN rebuild.
Facilities Manager (FM) was expecting "as built" drawings from research.
B2, B3, B6
RC3, CC2, CC3, CC9, CC11
03/08/2019
SWP to drain and purge AWN system, including supply tanks, scrubbers, and AWN tanks.
LOTO drafted.
G

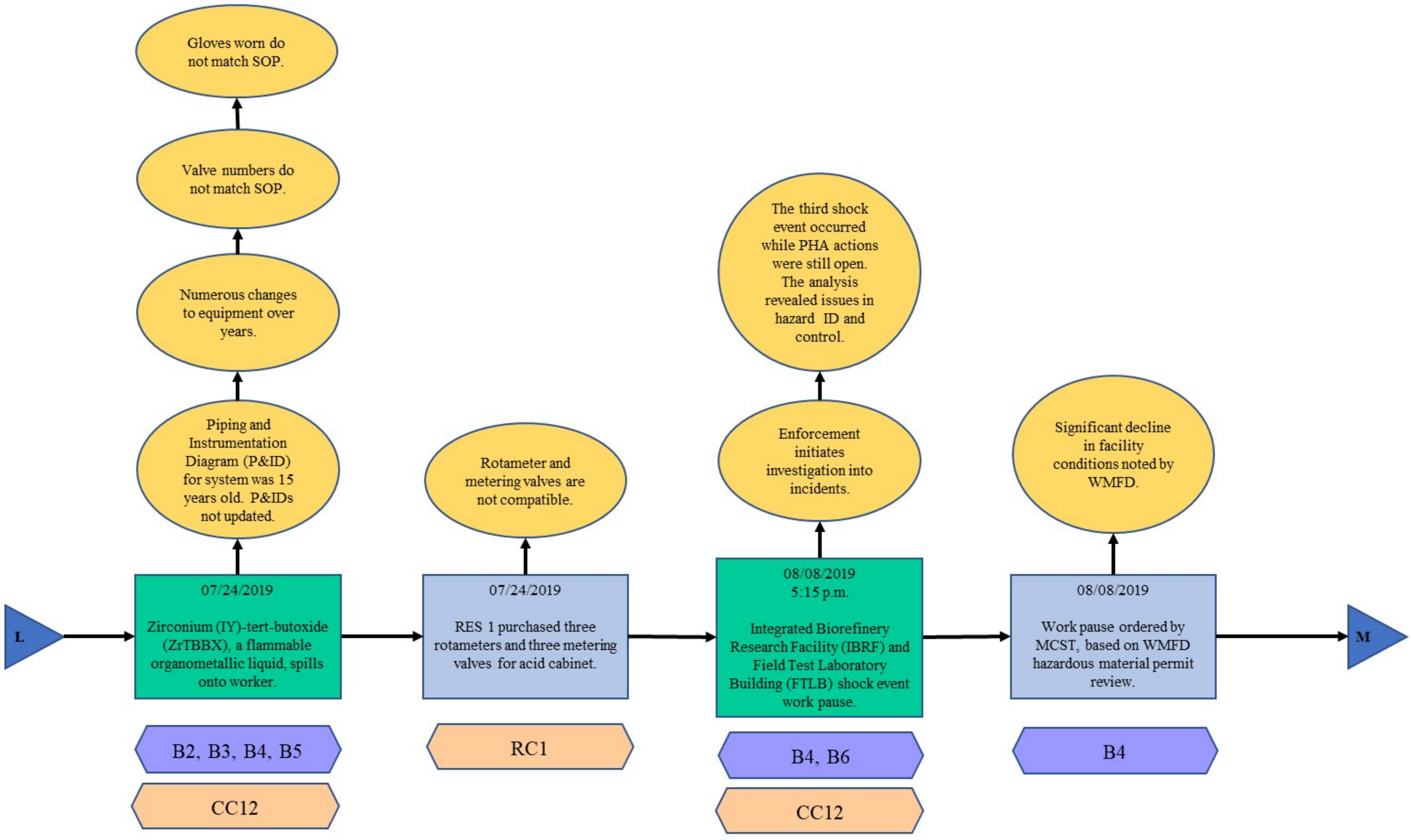

G
03/18/2019
Safe Work Permit (SWP) issued to drain and purge AWN system, including tanks, scrubbers and AWN tanks.
03/18/2019
Lock out/tag out (LOTO), equipment specific procedure (ESP) drafted.
04/04/2019
LOTO ESP completed for future work.
04/08-22/2019
System in LOTO for line blow out and began three times line purge.
Shelf from base cabinet and guts from acid cabinet removed.
Found leak in containment of acid cabinets.
04/18/2019
3:10 p.m.
NREL Employee Concern regarding LLP rollout process.
Employee concern regarding inadequate/ nonexistent roll out of Alliance ESH&Q LLPs specifically citing pressure, silica and fire protection programs.
CC12
H

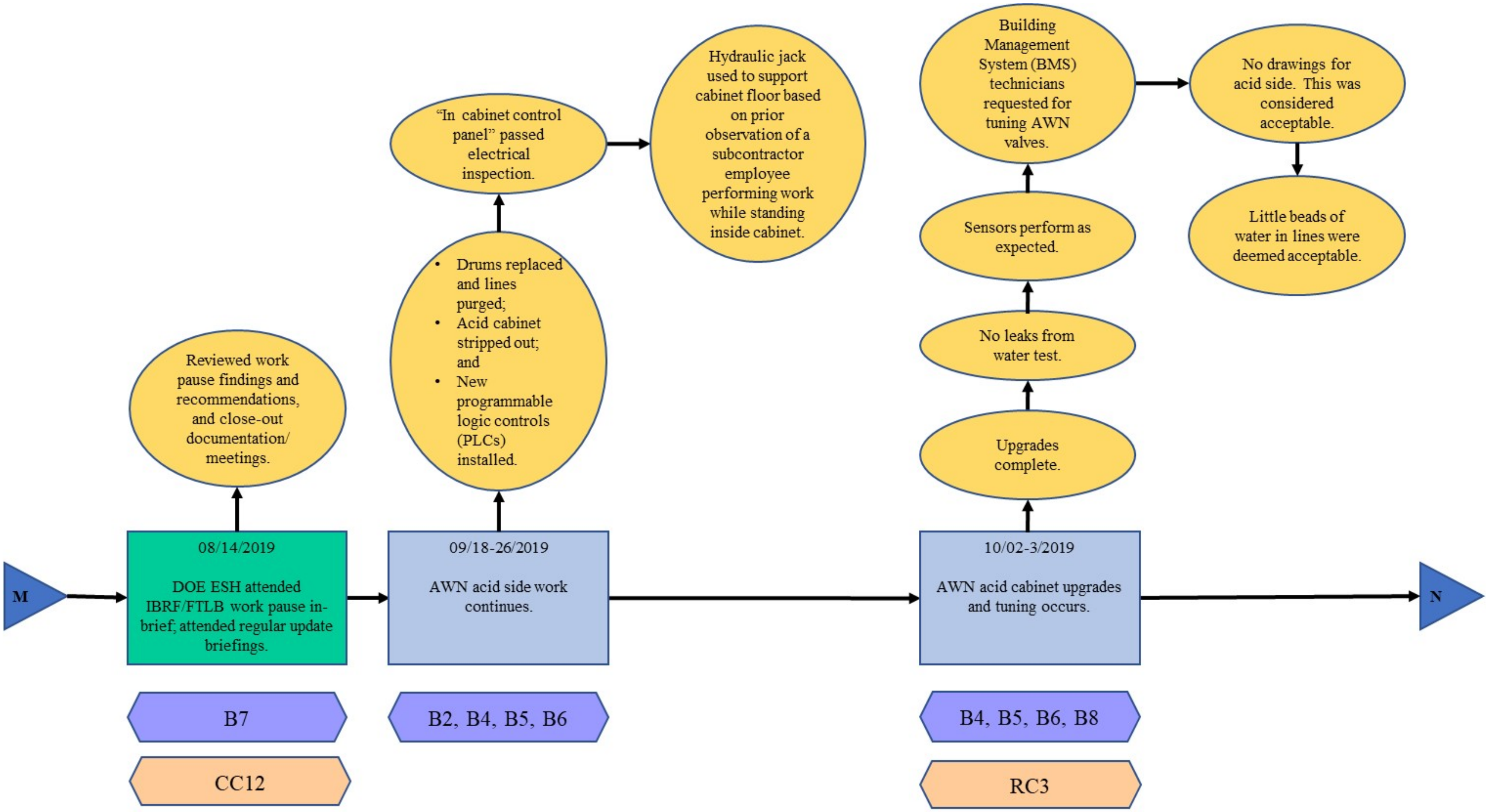

PHA not updated with compromise to primary spill control.
AWN PHA recommendations not fully addressed:
• Nuisance alarms;
• "What if" containment fails;
• Containment failure not addressed.
Acid side redesign: No drawings, no PHA, no SWP.
Rework of plumbing in acid cabinet.
Start strip out of acid cabinet.
H
04/22-29/2019
"In-cabinet control panel" passed electric inspection.
B4, B5, B6
RC3, CC7, CC9
Concern that no clear lines of roles and responsibilities exist and process is not followed to communicate procedure changes to Alliance staff.
04/26/2019
5:25 p.m.
NREL Employee Concern regarding flow down of requirements.
B2, B3, B4, B5, B6, B7
CC12
Begin repairs to containment. Plastic welding did not work.
In cabinet control panel passed electrical inspection.
05/02-03/2019
AWN acid cabinet work continues.
I

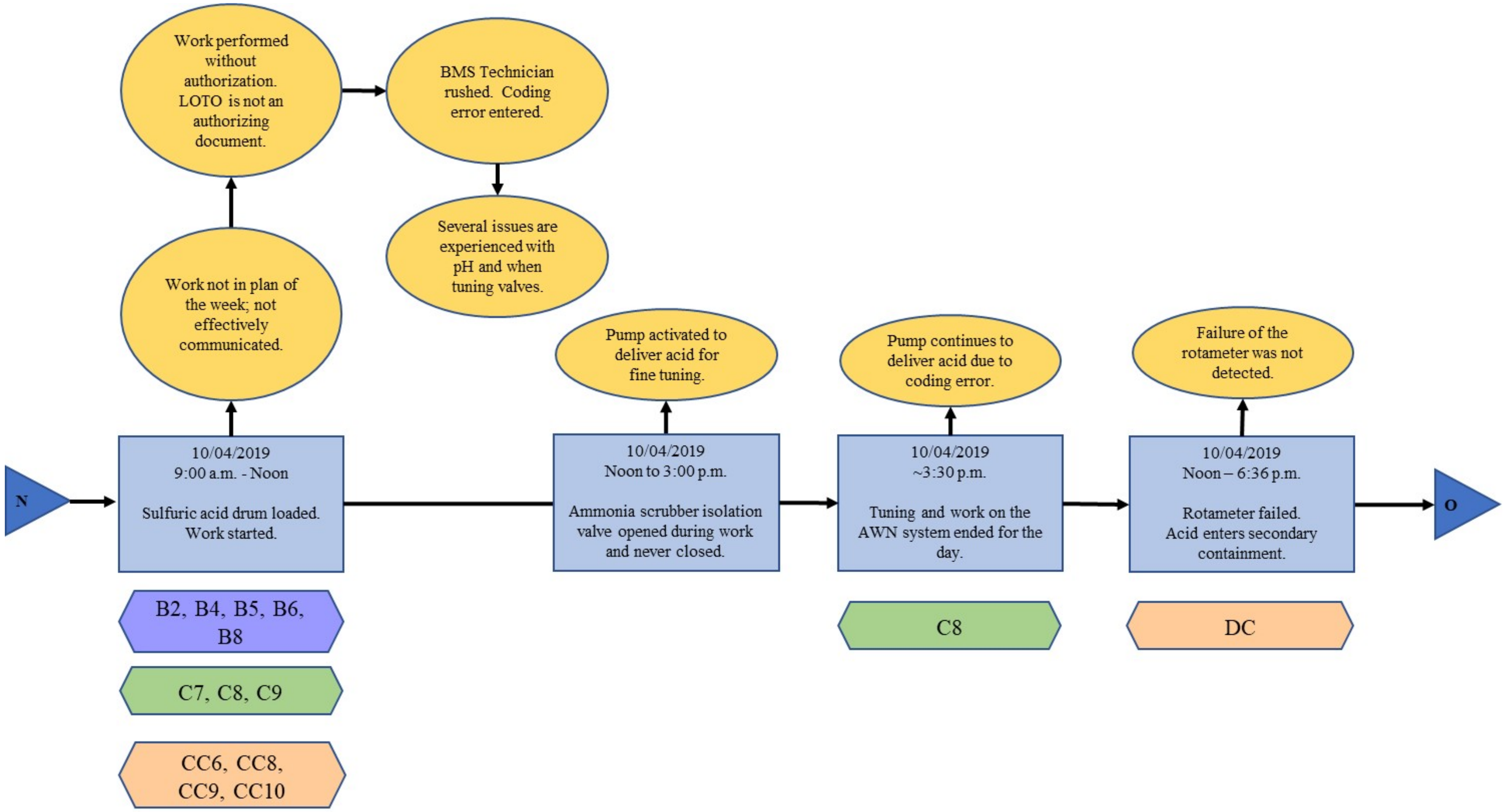

I
05/03/2019
SWP issued for restart of AWN system.
Restart granted for testing and startup of AWN system.
05/07-13/2019
Sealant/epoxy testing.
DevCon HP 250 tested and found to have poor adhesion in the presence of concentrated sulfuric acid.
Epoxy manufacturer recommended a concentrated Sulfuric acid sealant.
Epoxy used not tested outside of cabinet. Reliance on manufacturer data.
C3, C4
05/14/2019
SWP issued to re-epoxy secondary containment in acid and base cabinets and test with water.
RC1, CC2, CC3
05/14/2019 – 06/01/2019
Cleanroom coordinator and PI apply epoxy to sulfuric acid cabinet.
No IH monitoring. Respirator worn.
B3, B4, B6
C3, C4
RC1, CC9
05/15/2019 – 06/03/2019
Repair cabinet containments and tested with water.
Continued to find leaks in the secondary containment.
RC1
J

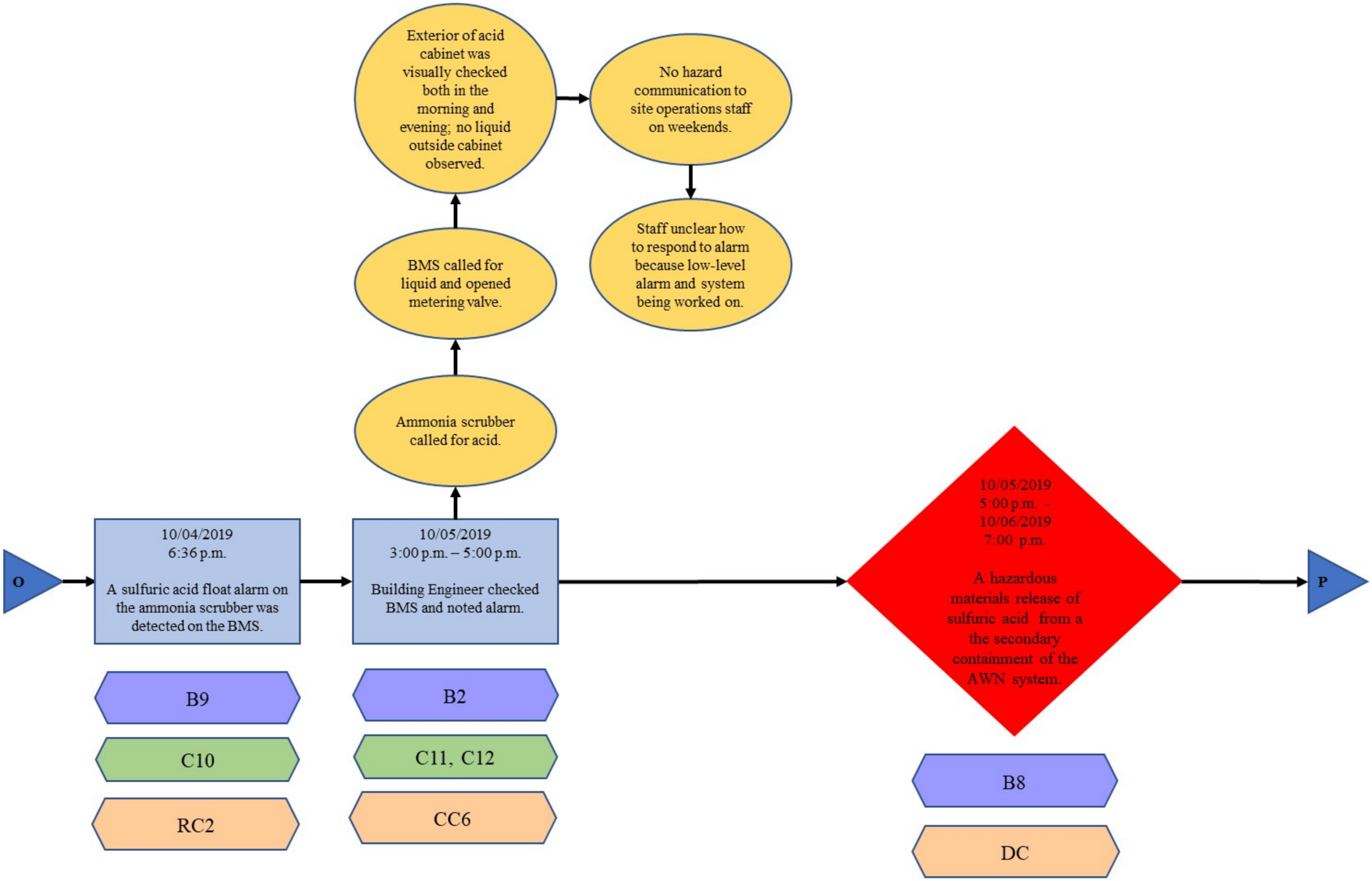

J
05/16/2019
Cleanroom ordered two heavy duty hydraulic jacks.
Vibration-damping with felt cushion.
3,000 lbs. capacity.
06/06/2019
Meeting to discuss AWN ownership, Boundary agreement and path forward.
CC4
06/06/2019
Determined a Readiness verification would not be done, just a commissioning document.
There was confusion regarding site operations requirements and responsibilities regarding RVs.
Agreed work could be performed according to the LOTO, ESP.
B2, B12
CC4, CC5, CC8
06/06/2019 – 08/12/2019
Cleanroom Coordinator places nine parts orders for acid side.
ESH POC loses track of project; research side continues to press forward.
RC1
06/18/2019.
SWP for AWN restart upgrade expired.
CC7
K

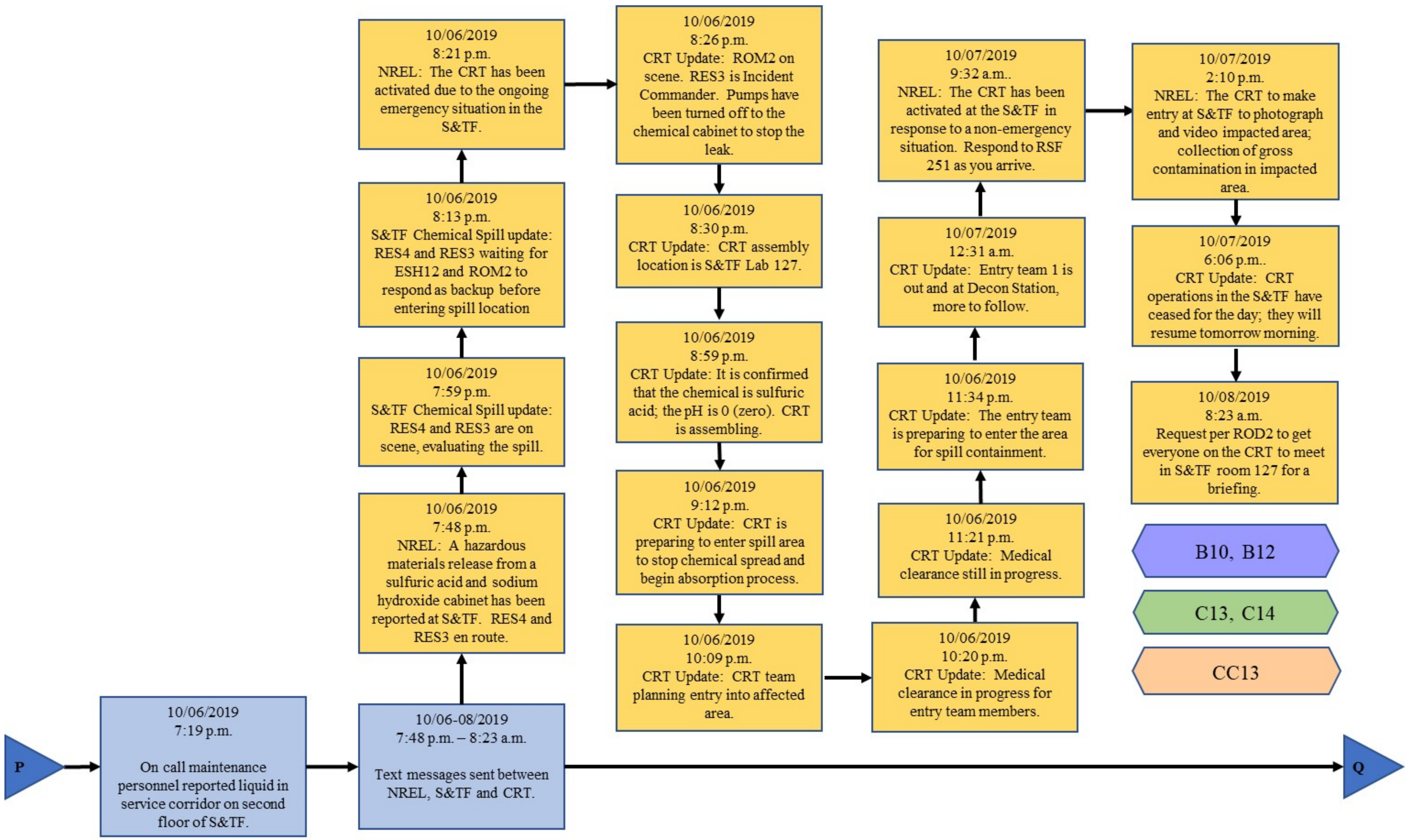

K
06/18/2019
System tested and put back under facilities control.
Boundary agreement not updated to reflect current status.
B2, B3
C5, C6
CC3
06/19/2019
Not all CRT members recall being briefed on CRT program revision.
"Sufficient apparatus and personnel shall be available to provide first response compliment specified in the NFPA Fire Protection Handbook for medium and high hazard occupancies."
"These services shall be provided in the same manner as they are provided to properties within the subcontractor's normal area of jurisdiction.."
06/26/2019
NREL updates the Firm Fixed Price contract SOW with West Metro Fire Department (WMFD).
SOW requires WMFD to provide… "necessary and appropriate apparatus, equipment, supplies and qualified personnel for the purpose of…managing first responses to hazardous materials releases..."
06/27/2019
NEW CRT Lab Level Procedure (LLP) published includes process determining response to chemical event.
Revisions provide emergency spill response procedures that duplicate WMFD SOW.
07/11/2019
RES 1 purchased new pump for acid cabinet.
L

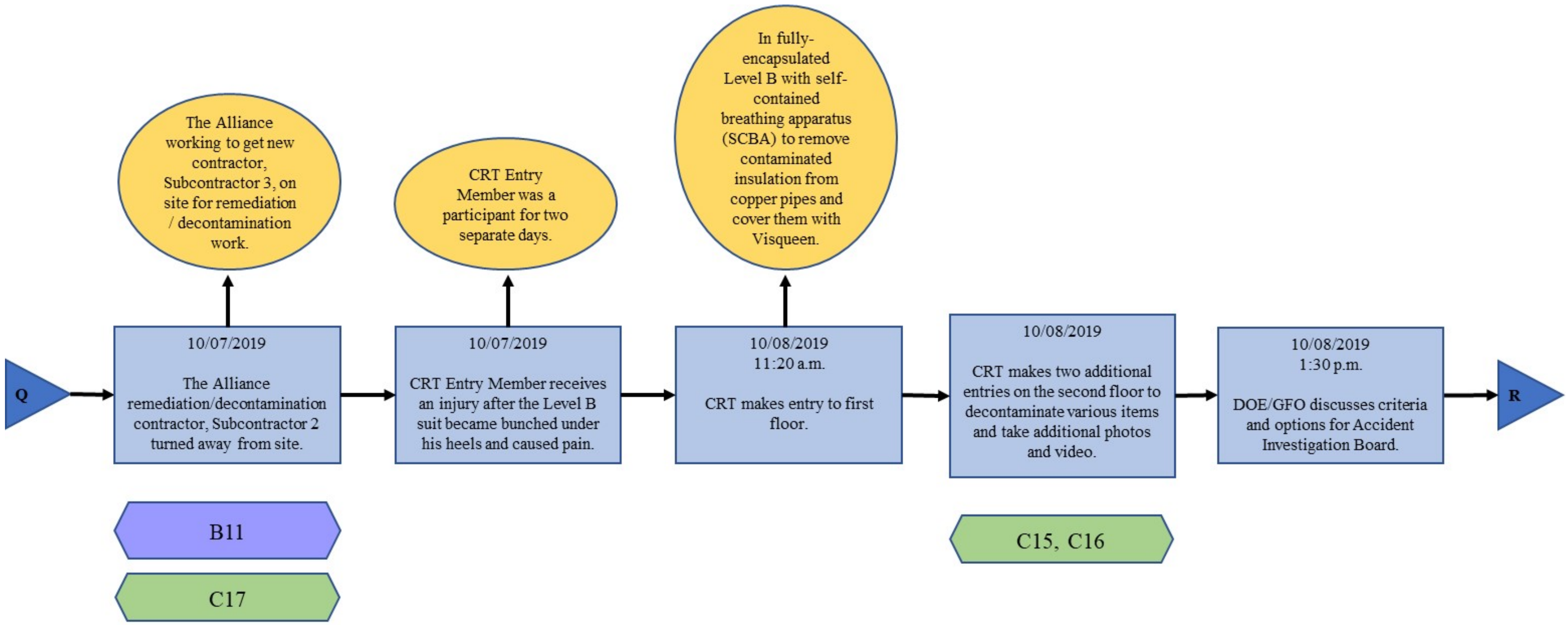

L
Gloves worn do not match SOP.
Valve numbers do not match SOP.
Numerous changes to equipment over years.
Piping and Instrumentation Diagram (P&ID) for system was 15 years old. P&IDs not updated.
07/24/2019
Zirconium (IY)-tert-butoxide (ZrTBBX), a flammable organometallic liquid, spills onto worker.
B2, B3, B4, B5
CC12
Rotameter and metering valves are not compatible.
07/24/2019
RES 1 purchased three rotameters and three metering valves for acid cabinet.
RC1
The third shock event occurred while PHA actions were still open. The analysis revealed issues in hazard ID and control.
Enforcement initiates investigation into incidents.
08/08/2019
5:15 p.m.
Integrated Biorefinery Research Facility (IBRF) and Field Test Laboratory Building (FTLB) shock event work pause.
B4, B6
CC12
Significant decline in facility conditions noted by WMFD.
08/08/2019
Work pause ordered by MCST, based on WMFD hazardous material permit review.
B4
M

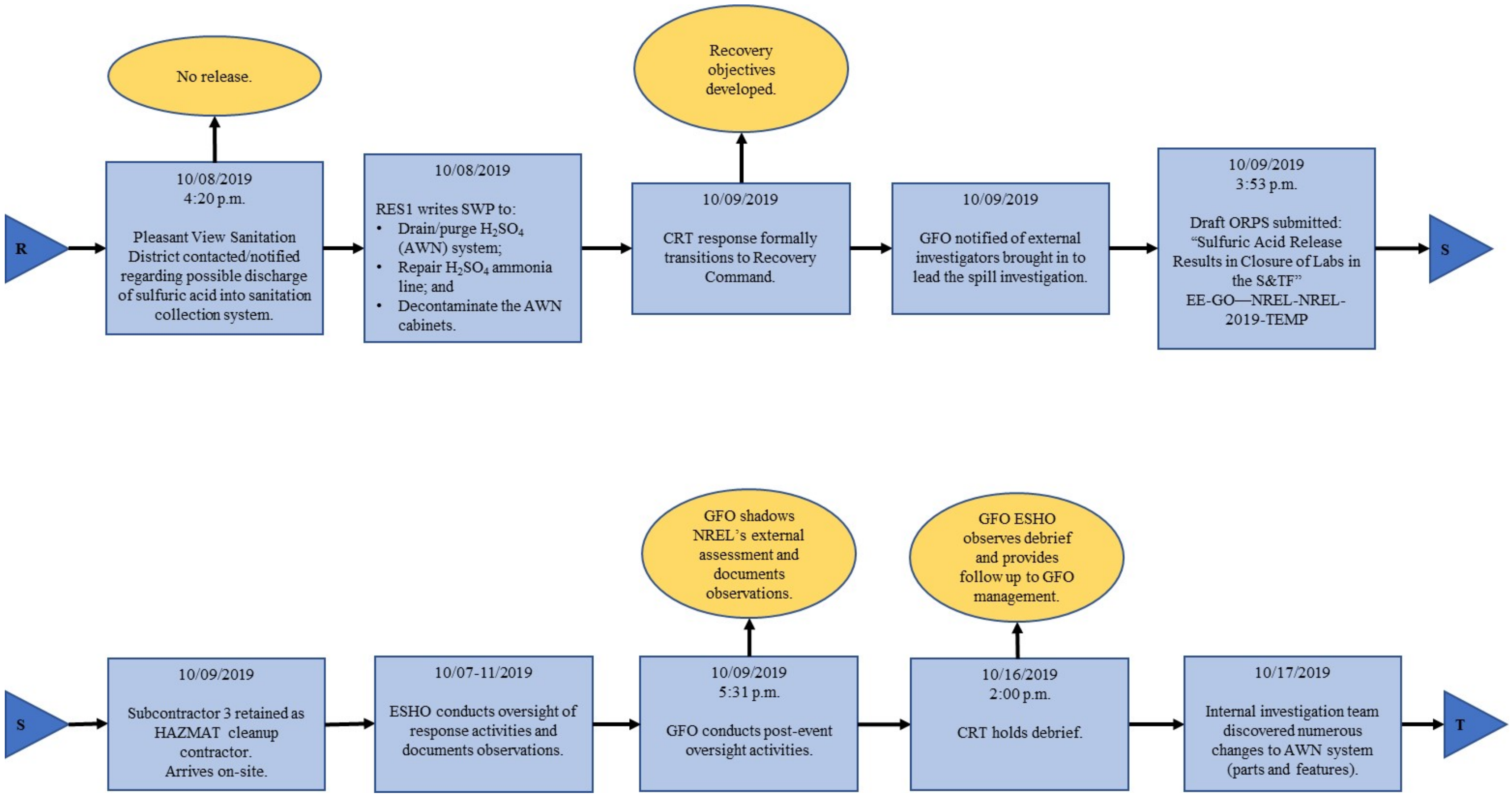

M
08/14/2019
DOE ESH attended IBRF/FTLB work pause in-brief; attended regular update briefings.
Reviewed work pause findings and recommendations, and close-out documentation/ meetings.
B7
CC12
09/18-26/2019
AWN acid side work continues.
• Drums replaced and lines purged;
• Acid cabinet stripped out; and
• New programmable logic controls (PLCs) installed.
"In cabinet control panel" passed electrical inspection.
Hydraulic jack used to support cabinet floor based on prior observation of a subcontractor employee performing work while standing inside cabinet.
B2, B4, B5, B6
10/02-3/2019
AWN acid cabinet upgrades and tuning occurs.
Upgrades complete.
No leaks from water test.
Sensors perform as expected.
Building Management System (BMS) technicians requested for tuning AWN valves.
No drawings for acid side. This was considered acceptable.
Little beads of water in lines were deemed acceptable.
B4, B5, B6, B8
RC3
N

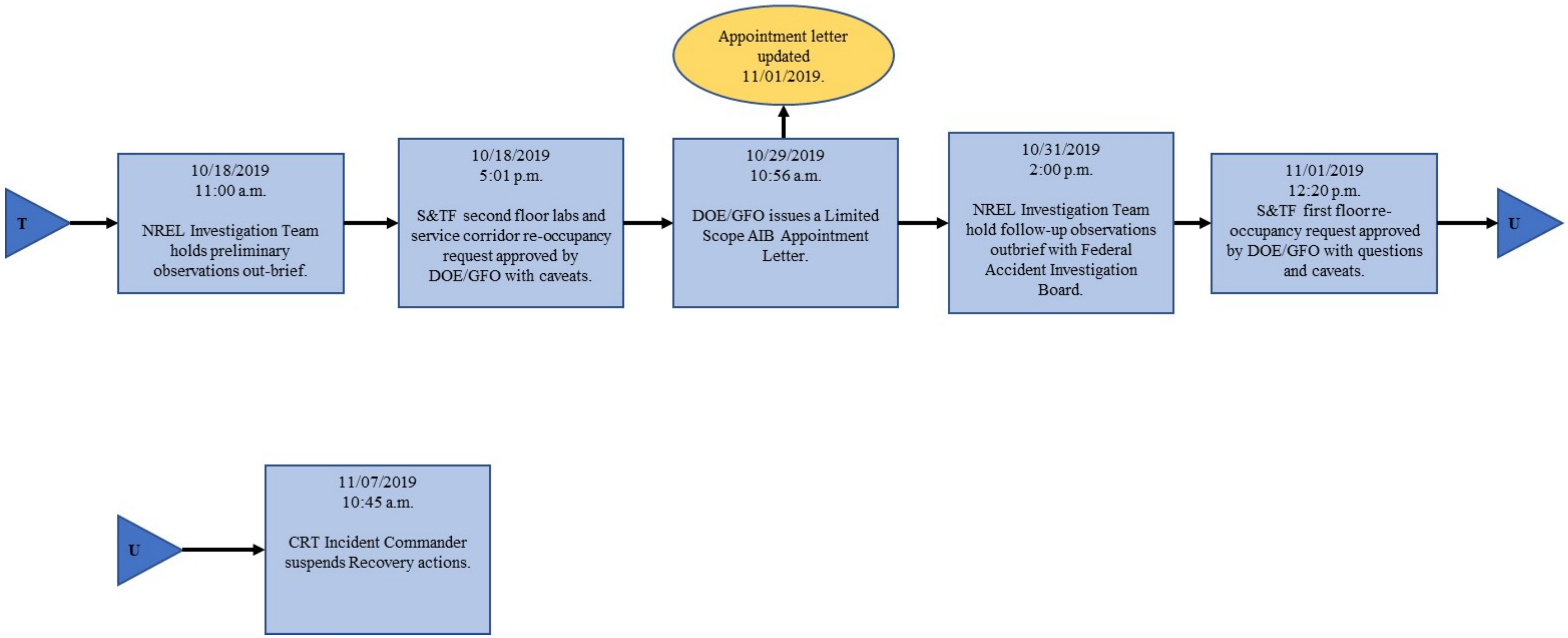

N
10/04/2019
9:00 a.m. - Noon
Sulfuric acid drum loaded. Work started.
Work not in plan of the week; not effectively communicated.
Work performed without authorization. LOTO is not an authorizing document.
BMS Technician rushed. Coding error entered.
Several issues are experienced with pH and when tuning valves.
B2, B4, B5, B6, B8
C7, C8, C9
CC6, CC8, CC9, CC10
10/04/2019
Noon to 3:00 p.m.
Ammonia scrubber isolation valve opened during work and never closed.
Pump activated to deliver acid for fine tuning.
10/04/2019
~3:30 p.m.
Tuning and work on the AWN system ended for the day.
Pump continues to deliver acid due to coding error.
C8
10/04/2019
Noon – 6:36 p.m.
Rotameter failed. Acid enters secondary containment.
Failure of the rotameter was not detected.
DC
O


O
10/04/2019
6:36 p.m.
A sulfuric acid float alarm on the ammonia scrubber was detected on the BMS.
B9
C10
RC2
10/05/2019
3:00 p.m. – 5:00 p.m.
Building Engineer checked BMS and noted alarm.
B2
C11, C12
CC6
Ammonia scrubber called for acid.
BMS called for liquid and opened metering valve.
Exterior of acid cabinet was visually checked both in the morning and evening; no liquid outside cabinet observed.
No hazard communication to site operations staff on weekends.
Staff unclear how to respond to alarm because low-level alarm and system being worked on.
10/05/2019
5:00 p.m. -
10/06/2019
7:00 p.m.
A hazardous materials release of sulfuric acid from a the secondary containment of the AWN system.
B8
DC
P


P
10/06/2019
7:19 p.m.
On call maintenance personnel reported liquid in service corridor on second floor of S&TF.
10/06-08/2019
7:48 p.m. – 8:23 a.m.
Text messages sent between NREL, S&TF and CRT.
10/06/2019
7:48 p.m.
NREL: A hazardous materials release from a sulfuric acid and sodium hydroxide cabinet has been reported at S&TF. RES4 and RES3 en route.
10/06/2019
7:59 p.m.
S&TF Chemical Spill update: RES4 and RES3 are on scene, evaluating the spill.
10/06/2019
8:13 p.m.
S&TF Chemical Spill update: RES4 and RES3 waiting for ESH12 and ROM2 to respond as backup before entering spill location
10/06/2019
8:21 p.m.
NREL: The CRT has been activated due to the ongoing emergency situation in the S&TF.
10/06/2019
8:26 p.m.
CRT Update: ROM2 on scene. RES3 is Incident Commander. Pumps have been turned off to the chemical cabinet to stop the leak.
10/06/2019
8:30 p.m.
CRT Update: CRT assembly location is S&TF Lab 127.
10/06/2019
8:59 p.m.
CRT Update: It is confirmed that the chemical is sulfuric acid; the pH is 0 (zero). CRT is assembling.
10/06/2019
9:12 p.m.
CRT Update: CRT is preparing to enter spill area to stop chemical spread and begin absorption process.
10/06/2019
10:09 p.m.
CRT Update: CRT team planning entry into affected area.
10/06/2019
10:20 p.m.
CRT Update: Medical clearance in progress for entry team members.
10/06/2019
11:21 p.m.
CRT Update: Medical clearance still in progress.
10/06/2019
11:34 p.m.
CRT Update: The entry team is preparing to enter the area for spill containment.
10/07/2019
12:31 a.m.
CRT Update: Entry team 1 is out and at Decon Station, more to follow.
10/07/2019
9:32 a.m..
NREL: The CRT has been activated at the S&TF in response to a non-emergency situation. Respond to RSF 251 as you arrive.
10/07/2019
2:10 p.m.
NREL: The CRT to make entry at S&TF to photograph and video impacted area; collection of gross contamination in impacted area.
10/07/2019
6:06 p.m..
CRT Update: CRT operations in the S&TF have ceased for the day; they will resume tomorrow morning.
10/08/2019
8:23 a.m.
Request per ROD2 to get everyone on the CRT to meet in S&TF room 127 for a briefing.
B10, B12
C13, C14
CC13
Q


Q
The Alliance working to get new contractor, Subcontractor 3, on site for remediation / decontamination work.
10/07/2019
The Alliance remediation/decontamination contractor, Subcontractor 2 turned away from site.
B11
C17
CRT Entry Member was a participant for two separate days.
10/07/2019
CRT Entry Member receives an injury after the Level B suit became bunched under his heels and caused pain.
In fully-encapsulated Level B with self-contained breathing apparatus (SCBA) to remove contaminated insulation from copper pipes and cover them with Visqueen.
10/08/2019
11:20 a.m.
CRT makes entry to first floor.
10/08/2019
CRT makes two additional entries on the second floor to decontaminate various items and take additional photos and video.
C15, C16
10/08/2019
1:30 p.m.
DOE/GFO discusses criteria and options for Accident Investigation Board.
R


R
No release.
10/08/2019
4:20 p.m.
Pleasant View Sanitation District contacted/notified regarding possible discharge of sulfuric acid into sanitation collection system.
10/08/2019
RES1 writes SWP to:
• Drain/purge H_2SO_4 (AWN) system;
• Repair H_2SO_4 ammonia line; and
• Decontaminate the AWN cabinets.
Recovery objectives developed.
10/09/2019
CRT response formally transitions to Recovery Command.
10/09/2019
GFO notified of external investigators brought in to lead the spill investigation.
10/09/2019
3:53 p.m.
Draft ORPS submitted: "Sulfuric Acid Release Results in Closure of Labs in the S&TF"
EE-GO—NREL-NREL-2019-TEMP
S
S
10/09/2019
Subcontractor 3 retained as HAZMAT cleanup contractor.
Arrives on-site.
10/07-11/2019
ESHO conducts oversight of response activities and documents observations.
GFO shadows NREL's external assessment and documents observations.
10/09/2019
5:31 p.m.
GFO conducts post-event oversight activities.
GFO ESHO observes debrief and provides follow up to GFO management.
10/16/2019
2:00 p.m.
CRT holds debrief.
10/17/2019
Internal investigation team discovered numerous changes to AWN system (parts and features).
T


Appointment letter updated 11/01/2019.
T
10/18/2019 11:00 a.m. NREL Investigation Team holds preliminary observations out-brief.
10/18/2019 5:01 p.m. S&TF second floor labs and service corridor re-occupancy request approved by DOE/GFO with caveats.
10/29/2019 10:56 a.m. DOE/GFO issues a Limited Scope AIB Appointment Letter.
10/31/2019 2:00 p.m. NREL Investigation Team hold follow-up observations outbrief with Federal Accident Investigation Board.
11/01/2019 12:20 p.m. S&TF first floor re-occupancy request approved by DOE/GFO with questions and caveats.
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11/07/2019 10:45 a.m. CRT Incident Commander suspends Recovery actions.