U.S. DEPARTMENT OF ENERGY | Office of Science

Accident Investigation Report

Electrical Shock Accident Resulting in Employee Injury at SLAC on December 27, 2022

DISCLAIMER

This report is an independent product of the Accident Investigation Board appointed by Juston K. Fontaine, Deputy Director for Field Operations. The Board was appointed to perform an accident investigation and to prepare an investigation report in accordance with the Department of Energy 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 December 29, 2022, an Accident Investigation Board was appointed to investigate the electrical shock accident at the SLAC National Accelerator Laboratory (SLAC) that resulted in serious injuries to an employee. The Board's responsibilities have been completed with respect to this investigation. The analysis and the identification of the direct cause, contributing causes, root cause, and the Judgments of Need resulting from this investigation were performed in accordance with Department of Energy Order 225.1B, *Accident Investigations*, dated 3/4/2011.

I accept the findings of the Board and authorize the release of this report for general distribution.

Juston Fontaine

____ 4/24/2023

Juston K. Fontaine, Deputy Director for Field Operations
Office of Science, Department of Energy

EXECUTIVE SUMMARY

On 12/27/2022, in preparation for scheduled preventive maintenance work activities on several electrical substations and downstream loads, a SLAC National Accelerator Laboratory (SLAC) High Voltage Electrician made hand contact with a bare energized (live) circuit part inside a 12.47 kV three-phase electrical switchgear cubicle, resulting in severe injuries to the hands and face.

On 12/29/2022, the U.S. Department of Energy, Office of Science, Deputy Director for Field Operations appointed a DOE Accident Investigation Board (Board) to investigate the event to determine the facts and circumstances related to the event and identify possible weaknesses in institutional Lockout/Tagout (LOTO) and Work Planning and Control programs at SLAC. The objective was to analyze the event and determine direct, root, and contributing causes, and from these provide Judgments of Need.

The Board's analysis identified fundamental issues in SLAC's management of physical assets, procedure-based work execution, as well as program assessments and corrective action management.

First, at the institutional level, SLAC infrastructure priorities and configuration of systems failed to ensure a stable physical configuration of the electrical distribution system for safe conduct of work activities. SLAC developed a compliance-based preventive maintenance and testing program with the intent to improve the reliability and safety of the electrical distribution system; however, insufficient resources for replacement of feeder cables after maintenance test failures led to frequent configuration changes, increased complexity, and unmaintained drawings and hazard labels. This subsequently impacted SLAC's ability to develop quality outage plans for safe execution by workers.

Second, SLAC failed to effectively evaluate worker comprehension and implementation of its policies and procedures and to provide sufficient supervisory and management presence in the field to assess implementation. While institutional Electrical Safety and Control of Hazardous Energy (CoHE)/LOTO programs appear adequate on paper, they are no longer being effectively implemented in the field due to the lack of field oversight. Multiple undetected procedural deviations and CoHE program violations the day of the outage resulted in a number of employees in different work crews being exposed to uncontrolled hazardous energy, each instance of which could have led to serious injury.

Finally, some of the long-standing conditions present at the time of the accident had been recognized by SLAC from prior assessment activities, including the absence of up-to-date electrical distribution system drawings. Significant corrective action commitments, including updating of single line drawings, remained open and unresolved. The extent of this problem has been exacerbated by a lack of periodic, objective assessment of the CoHE/LOTO program implementation.

This environment resulted in unintended consequences to work planning and execution. The work planning process, from development to approval, lacked the rigor required to produce a work package that could be executed safely, and did not actively solicit or consider input from the workforce. Skill-based performance mode had been occurring undetected long enough for procedural non-compliance to become the norm and cause systematic erosion in the implementation of controls reflected in the institutional policies and procedures.

SLAC's management overly relied on a few highly experienced workers wearing overrated arc flash personal protective equipment (PPE). This effectively bypassed the need for proper electrical risk assessments with full identification of all hazards and controls, which would have identified all instances where PPE was required. This was coupled with inadequate work plan reviews, abbreviated job walkdowns, and the absence of pre-job briefings. Inadequate field assessments over several years allowed this culture to self-reinforce and take root; additionally, the configuration management issues related to drawings and labels that had been identified for years have yet to be corrected.

When the outage plan introduced a different approach that included a partially energized switchgear as an intermediate step, the associated hazards were not identified on the work plan and was not recognized by the work team. The injured worker had a different mental model of the outage plan, and multiple procedural deviations went undetected by anyone on the high voltage team. They fully believed that the cabinet they entered was already deenergized and did not realize they had strayed outside of the safe area established by the energy isolation boundary. This led them to not wear PPE or perform absence of voltage verification before coming into contact with exposed live circuit parts.

In consideration of these and other causes detailed in this Accident Investigation report, the Board determined that the **root cause** for the accident was:

Management failed to ensure effective continuous evaluation and oversight of mission support infrastructure and programs to identify and manage risks in work execution:

- **Infrastructure priorities and configuration of systems failed to ensure a stable physical configuration for safe conduct of work activities.**
- **Field oversight failed to detect issues related to the effectiveness of SLAC procedures and their implementation during work activities.**
- **The institutional issues management process failed to ensure that identified program issues were corrected, evaluated for effectiveness, documented, and closed in a timely manner.**

The Board identified 16 Judgments of Needs representing improvements, that if fully considered beyond the short term, will provide the necessary foundation for SLAC to build upon, in order to reduce the potential for recurrence of similar events. The CONs and JONs are documented in Section 5 of this report.

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ACRONYMS

A	Amperes
AC	Alternating Current
AED	Automatic External Defibrillator
ASTM	American Society for the Testing of Materials
ATPV	Arc Threshold Performance Value
ATS	Automatic Transfer Switch
BRK	Breaker
Board	Accident Investigation Board
CC	Contributing Cause
CCR	California Code of Regulations
CEE	Chief Electrical Engineer
CoHE	Control of Hazardous Energy
CPT	Control Power Transformer
DC	Direct Current
DDFO	Deputy Director for Field Operations
DOE	U.S. Department of Energy
E_{BT}	Energy Breakthrough
ECF	Event and Causal Factors
EH	Electric Hazard
EIP	Energy Isolation Plan
EFCOG	Energy Facilities Contractors' Group
EMS	Emergency Medical Services
EMT	Emergency Medical Technician
EP	Error Precursor
EPD	Electrical Power Department
EPR	Ethylene Propylene Rubber
EPRP	Enterprise Risk Management Program
ESC	Electrical Safety Committee
ESH	Environmental, Safety, and Health
ESO	Electrical Safety Officer
EWP	Electrical Work Plan
F&O	Facilities and Operations Division
FACET-II	Facility for Advanced Accelerator Experimental Tests
FEH	Far Experimental Hall
FOC	Facilities Operations Center
FY	Fiscal Year

ACRONYMS (CONT.)

HP	Human Performance
HPI	Human Performance Improvement
HV	High Voltage
HVE	High Voltage Electrician
HVP	High Voltage Planner
IIPP	Injury and Illness Prevention Plan
IR	Interaction Region
JON	Judgment of Need
kA	kiloamp
kV	kilovolt
LAEW	Lead Authorized Electrical Worker
LB	Lockbox
LM	Line Manager
LCLS	Linac Coherent Light Source
LOTO	Lockout/Tagout
LSST	Large Synoptic Survey Telescope
LV	Low Voltage
LVE	Low Voltage Electrician
M	Million
MCC	Motor Control Center
MPFDE	Menlo Park Fire District Engine
MSS	Master Substation
NEH	Near Experimental Hall
NETA	InterNational Electrical Testing Association
NFPA	National Fire Protection Agency
ORPS	Occurrence Reporting and Processing System
PEP	Positron-Electron Project
PIC	Person In Charge
PM	Preventive Maintenance
PO	Purchase Order
POC	Point of Contact
PPE	Personal Protective Equipment
PSPS	Public Safety Power Shutoff
RC	Root Cause
S522	Substation 522
SC	Office of Science
SCADA	Supervisory Control and Data Acquisition

ACRONYMS (CONT.)

SLAC	SLAC National Accelerator Laboratory
SMCS	San Mateo County Sheriff
SSO	DOE SLAC Site Office
SSRL	Stanford Synchrotron Radiation Lightsource
SSSP	Site-Specific Safety Plan
SOW	Scope of Work
SWO	Switching Order
U.S.	United States
V	Volt
WFDA	Woodside Fire District Ambulance
WIP	Work Integration Plan
WPC	Work Planning and Control
ZVV	Zero Voltage Verification

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1.0 INTRODUCTION

1.1 Background

At approximately 0910 hours on 12/27/2022, a SLAC National Accelerator Laboratory (SLAC) High Voltage Electrician suffered burns to the face and hands while preparing an electrical substation for scheduled preventive maintenance work during a holiday shutdown.

On 12/29/2022, the United States (U.S.) Department of Energy (DOE) Office of Science (SC) Deputy Director for Field Operations (DDFO) directed an incident investigation to determine the facts and circumstances related to the event and identify possible weaknesses in the institutional Lockout/Tagout (LOTO) and Work Planning and Control (WPC) programs at SLAC. At the time, the event did not meet the determination criteria provided in DOE Order 225.1B Appendix A, item 2.a.(2). "any single accident that results in the hospitalization for more than five calendar days, commencing within seven calendar days of the accident, of one or more DOE, contractor, or subcontractor employees or members of the public due to a serious personal injury or acute chemical or biological exposure."

On 1/9/2023, the DDFO appointed a DOE Accident Investigation Board (Board) to investigate the event in accordance with DOE Order 225.lB, *Accident Investigations*. The action and charge as communicated in the 12/29/2022 memorandum remained the same for the appointed Board, which added additional expertise to the appointed Board's composition. The appointment memoranda are included in Appendix A to this report.

1.2 Site Description

SLAC is a multi-program national laboratory operated by Stanford University under the management and operating contract with the DOE. The laboratory is located in Menlo Park, California adjacent to the Stanford University Campus. The site occupies 426 acres of land owned by Stanford University. The property was originally leased by Stanford University in 1962 to the U.S. Atomic Energy Commission, the predecessor to the DOE, and renewed in 2010, extending the lease agreement through 2043.

The SLAC mission is to explore how the universe works at the biggest, smallest, and fastest scales and develop tools used by scientists around the globe. SLAC supports the DOE mission, which is to ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions.

SLAC continues to build on its history of particle physics and accelerator research to advance a wide range of scientific program area. This includes operation of a 2-mile-long particle accelerator producing high intensity X-rays used for advanced imaging and experimentation.

SLAC houses three DOE SC sponsored user facilities:

- Stanford Synchrotron Radiation Lightsource (SSRL), which produces bright X-ray light for probing matter at the atomic and molecular level, enabling advances in energy production, environmental cleanup, nanotechnology, new materials and medicine;
- Linac Coherent Light Source (LCLS), whose brilliant X-ray laser pulses allow researchers to make stop-action movies of chemistry in action, explore proteins for new generations of pharmaceuticals and recreate extreme conditions; and
- Facility for Advanced Accelerator Experimental Tests (FACET-II), providing high-energy electron beams for researching particle accelerator technologies.

As cited in the SLAC Fiscal Year (FY) 2022 Annual Laboratory Plan, Human Capital breakdown includes:

- 1,685 Full Time Equivalent Employees
- 20 Joint Faculty
- 235 Postdoctoral Researchers
- 276 Graduate Student
- 37 Undergraduate Students
- 2,062 Facility Users
- 12 Visiting Scientists

SLAC's total real property inventory consists of 364 assets, including 172 buildings (2.35 Million [M] gross square feet), 166 other structures and facilities, and 26 trailers. The most common land use of these properties is mixed-use, composed of offices, laboratories, research facilities, and support structures. Approximately one-fourth of the square footage is dedicated to underground tunnels and unique experimental facilities – the largest being the 2-mile-long Klystron Gallery and corresponding accelerator housing. FY 2021 total costs were $497M, with the majority of funding coming from Basic Energy Sciences at $349M. Other sources of funding included High Energy Physics, Energy Efficiency and Renewable Energy, Fusion Energy Sciences, Biological and Environmental Research, Advanced Scientific Computing Research, Nuclear Physics, and others.

1.3 SLAC Electrical System Configuration

SLAC receives power from the Pacific Gas & Electric local utility at 230 kV over a single transmission line terminating at the Master Substation (MSS). From there, it is split into two (2) 230 kV / 12.47 kV transformers to feed MSS Buses 1 and 2. Buses 1 and 2 in turn feed MSS Buses 3, 4, 5 and 6, which are used to distribute power across the site through a network of 12.47 kV underground vaults, duct banks, and manholes to the science and utilities loads. SLAC has an alternate feed from the local utility over a 60 kV transmission line, with limited capacity. It also connects to MSS Buses 1 and 2 through a 60 kV / 12.47 kV transformer. *Note: Figure 1-3, provided by SLAC, shows 69 kV but the Board confirmed with SLAC that it is 60 kV.*

The accident occurred in Building 626, which houses the substation for Interaction Region 2 (IR-2). This area is geographically located at the East end of the SLAC campus. The area is known as the Positron-Electron Project (PEP) Ring area and was the site for the PEP and PEP-II science projects. PEP operated from 1980 to 1994 and PEP-II from 1999 to 2008. The different Interaction Regions are named IR-12, IR--2, IR-4, etc., based on their relative 'clock' positions around the ring, such that IR-12 is North, at the 12 o'clock position, IR-2 is at the 2 o'clock position, and so on. See Figures 1-1 and 1-2.

The 12.47 kV electrical distribution and its substations in the PEP area take their names and designations from the PEP infrastructure. Newer substations in the area that postdate the PEP, such as S522, no longer follow this nomenclature. The entire PEP 12.47 kV distribution area is fed from MSS Breaker (BRK) 75 on Bus 5 and BRK69 on Bus 3, with the exception of Substation IR-8, which has a dedicated feeder from MSS BRK31 on Bus 4. See Figure 1-3. For a complete single line drawing of the entire SLAC 12.47kV distribution system, see Appendix B.

Figure 1-1: Aerial overview of SLAC looking Northeast.

Figure 1-2: Closer aerial overview of SLAC looking Northeast showing the outage area.

Figure 1-3: View of IR-2 Area looking Southwest.

Figure 1-4: View of IR-2 Substation Area with rendering of IR2 Switchgear and location of accident inside Building 626.

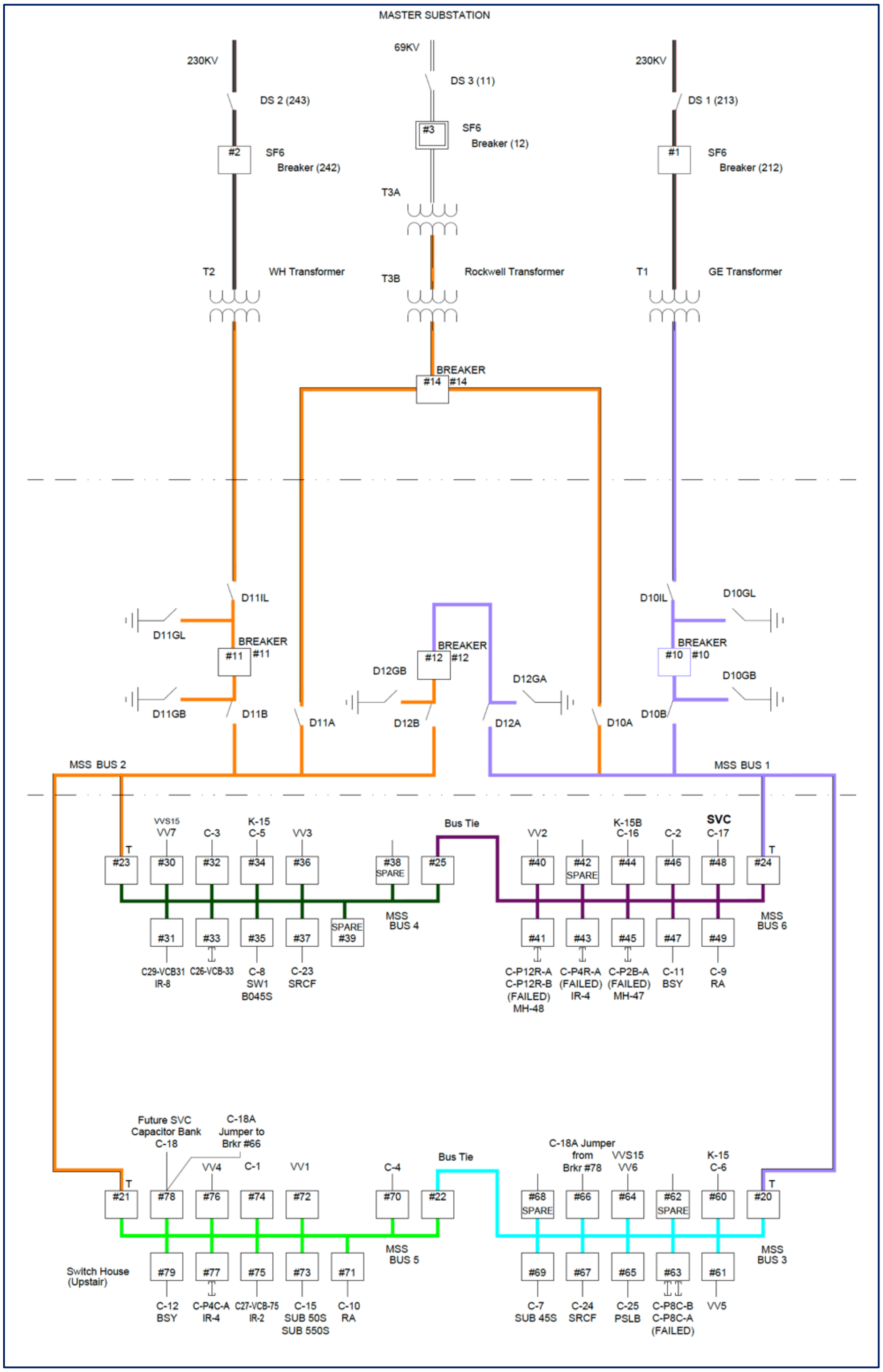

Figure 1-5: Configuration of Master Substation (from S4010 ES7 0018 Rev 00 dated 11/16/2021). BRK75 directly feeds IR-2 Substation, while BRK69 provides a back feed. Alternate feed should read 60 kV instead of 69 kV.

1.4 Accident Investigation Scope, Conduct, and Methodology

The initial Occurrence Reporting and Processing System (ORPS) report described the event as an arc flash injury. In order to determine the facts and circumstances related to the arc flash incident, as well as possible weaknesses in the institutional LOTO and WPC programs at SLAC, the Appointing Official directed the Board to conduct an investigation to identify causal factors, including a review of any relevant policies, procedures, work practices, or actions related to the incident, and, as appropriate, an extent of condition. The review included the following:

1. Determination of the facts leading to the incident.
2. Review of the adequacy of the Laboratory's immediate response, interim actions, and extent of condition evaluation in response to this incident.
3. Assessment of the application of the WPC process used to determine the scope of work (SOW), identification of hazards and the work controls prior to the worker initiating the work.
4. Assessment of the procedures for and actions taken to conduct, document, and perform the maintenance work within the controls.
5. A causal analysis to determine the root and contributing causes of the arc flash incident.
6. Review and assessment of the status and adequacy of corrective actions from previous LOTO and work control incidents to prevent similar issues.
7. Assessment of the adequacy of the Laboratory's LOTO policies and implementation.
8. Determination of whether broader systemic weaknesses are present in the Laboratory's WPC and LOTO programs.

The Board consisted of five DOE representatives, and one representative each from the Thomas Jefferson National Accelerator Facility and the Lawrence Berkeley National Laboratory. The Board Members included personnel with significant leadership and subject-matter expertise in high-rigor operations, human factors, causal analysis, high-voltage electrical safety, as well as safety culture and work process and control. The Board Chairperson appointed a Trained Accident Investigator from a list provided by the Office of Environment, Health, Safety & Security. The two contractor Board Members were selected for their exceptional level of electrical expertise and operational backgrounds and were vital to ensuring a rigorous investigation of the accident. The memoranda from the Appointing Official stated the Board Members, in consultation with their respective management, were relieved of all other duties while participating in the Board.

Board Members reviewed and analyzed the circumstances surrounding the accident to determine its cause(s) and understand lessons learned to reduce the potential for recurrence of similar accidents. This analysis included an assessment of potential deficiencies in safety management systems. Board Members followed the structure for conducting accident investigations as identified in DOE-HDBK-1208-2012, *Accident and Operational Safety Analysis*. The terminology used in DOE accident investigations is defined in Figure 1-6.

The Board Members conducted their investigation using the following methodology:

- Facts relevant to the accident were gathered and identified through interviews, documents and evidence reviews, and examination of physical evidence, allowing the Board Members to develop the chronology.

- Events and Causal Factors (ECF) charting, barrier analysis, change analysis, and human error precursor analysis techniques were used to analyze the facts, identify the cause(s) of the accident, and draw conclusions.
- Based upon the conclusions drawn, Judgments of Need (JONs) were identified to prevent recurrence.

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 cause** is the immediate event(s) or condition(s) that caused the accident.
>
> **Contributing causes** are events or conditions that collectively with other causes increased the likelihood or severity 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 event and conditions that 'set the stage" for the event and, if allowed to persist or recur, increase the probability of future events or accidents.
>
> **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 that single problems or faults.

Event and causal factors analysis includes 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 or error during the performance of a specific task by a particular individual or group of individuals.

Judgments of Need are managerial controls and safety measures necessary to prevent or minimize the probability or severity of accident recurrence.

Figure 1-6: Accident Investigation Terminology

The Board Members were onsite at SLAC from 1/16-25/2023, to meet with associated staff, gather physical evidence, conduct interviews, review SLAC procedures and processes, and begin developing the ECF Chart.

The Board's charge included direction to address immediately any specific critical items of an urgent nature that the Board identified during the course of the review. On 1/20/2023, the Board consulted with and obtained concurrence from the Appointing Official to communicate to SLAC Management four critical items that the Board discovered during fact finding. The Board observed notable gaps that, even with interim measures in place, represented substantial risk for injury in the SLAC High Voltage Electrical work practices. These items (provided in Appendix C) were communicated verbally to SLAC and Stanford University senior leadership on the afternoon of 1/20/2023.

From 1/30/2023 through 3/22/2023, the Board had daily virtual meetings to analyze information, evaluate causes, and develop JONs. The Board continued to meet periodically through 4/14/2023 to address feedback and finalize the report. The Board Chairperson provided periodic updates on the status of the report to the Appointing Official.

2.0 THE ACCIDENT

2.1 Description

Scope Overview

During the holiday shutdown, several electrical preventive maintenance (PM) activities were scheduled to be performed between 12/27/2022 and 12/30/2022 in the IR-2 substation (Building 626), substation 522 (S522), and their downstream loads. The PM included all standby-power panels that are dual fed from both normal power and backup generators. IR-2 substation consists of 12.47 kV switchgear inside Building 626. S522 substation consists of 12.47 kV switchgear inside Building 522. Both IR-2 and S522 substations are fed from a single feeder from BRK75 at the Master Substation (MSS) (Figure 2-1). IR-2 is also fed from IR-12. The work was to be performed by electricians from the Facilities and Operations (F&O) Electrical Power Department (EPD), including the SLAC High Voltage (HV) and Low Voltage (LV) groups, and an electrical subcontractor.

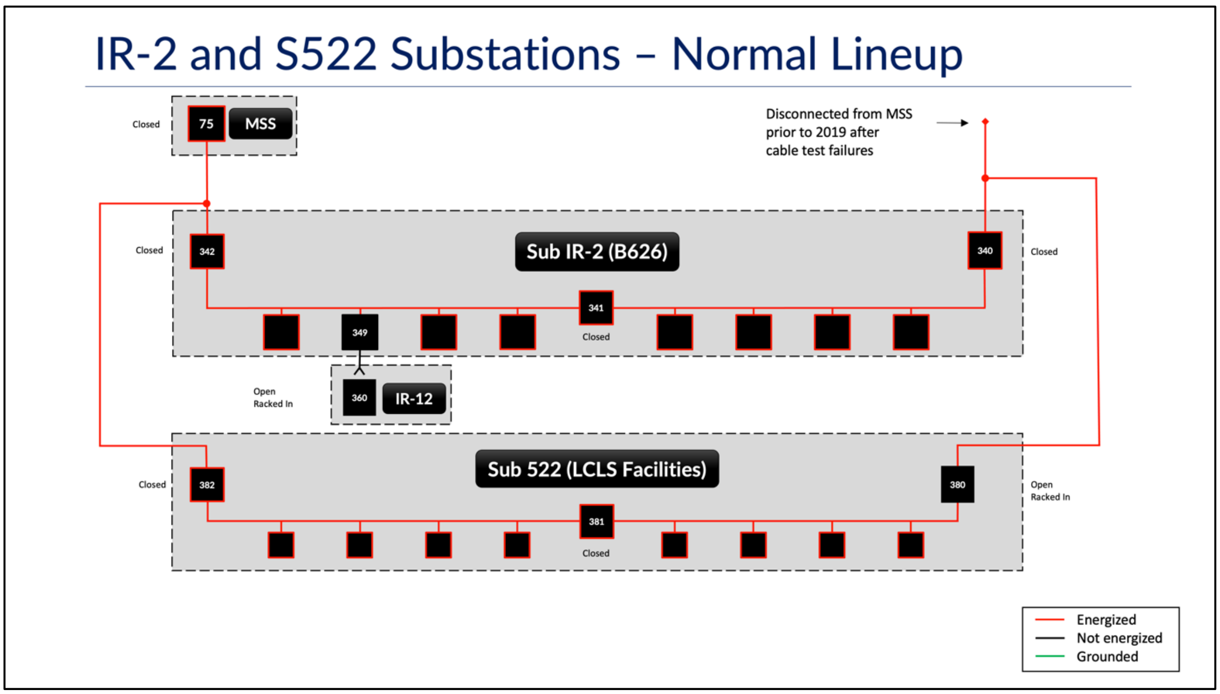

Figure 2-1: Normal lineup for Substations IR-2 and S522.

This work was sequenced in electrical work plan (EWP), *F&O Electrical Power Department, Sub B522--B626 Preventative Maintenance, December 2022* (provided in Appendix D). This EWP had several components, including switching orders, energy isolation plans, and complex LOTO permits. The isolation plan for the work to be performed was to occur in two phases.

The location of the accident and actual conditions at the time are shown in Figure 2-2.

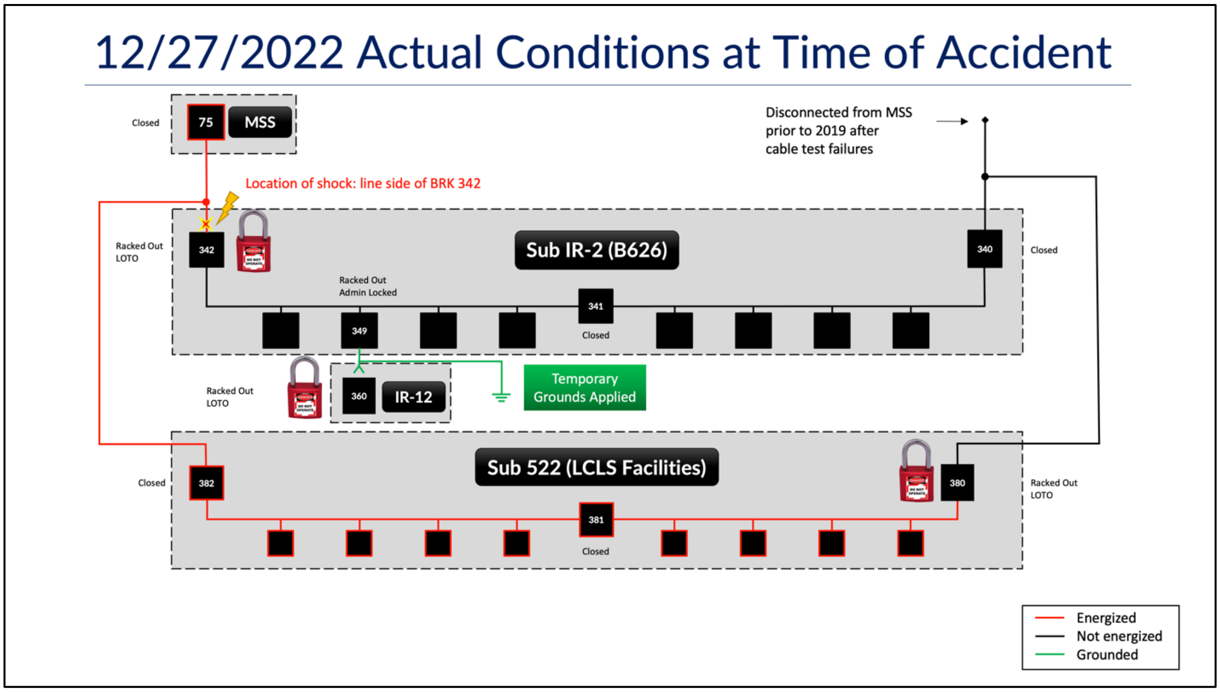

Figure 2-2: Location of and conditions at the time of the accident.

Phase 1 (Figure 2-3) was scheduled to isolate power to IR-2 (but not S522) to allow maintenance of the panels in the IR-2 area before the connection of temporary generators. The EWP utilized switching order #1 (SWO1) and energy isolation plan #1 (EIP1) to isolate hazardous energy for those tasks. Neither SWO1 nor EIP1 completely removed power from IR-2. The line side of main BRK342 would remain energized. No PM tasks were to be performed in Building 626 or the IR-2 substation under the first phase of the isolation.

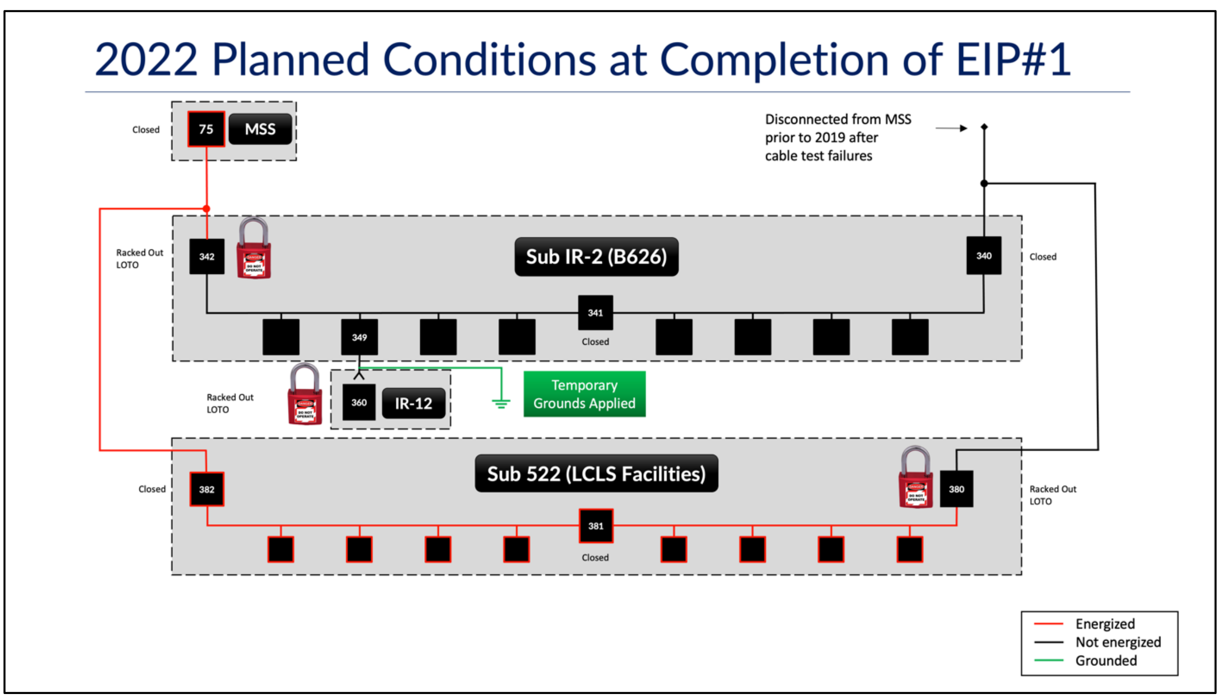

Figure 2-3: Planned lineup for Substations IR-2 and S522 for Phase 1

Phase 2 (Figure 2-4) consisted of full isolation of both IR-2 and S522 substations and was covered by SWO2 and EIP2. Phase 2 consisted of performing all remaining maintenance. Subcontractors were scheduled to perform maintenance on certain panels at S522 before connecting a separate set of temporary generators. Once IR-2 and S522 were fully isolated, the scope included performing PM on the 12.47 kV breakers in Substations IR-2 and S522, and downstream equipment. An electrical testing subcontractor would perform all of the InterNational Electrical Testing Association (NETA) tests required for the maintenance.

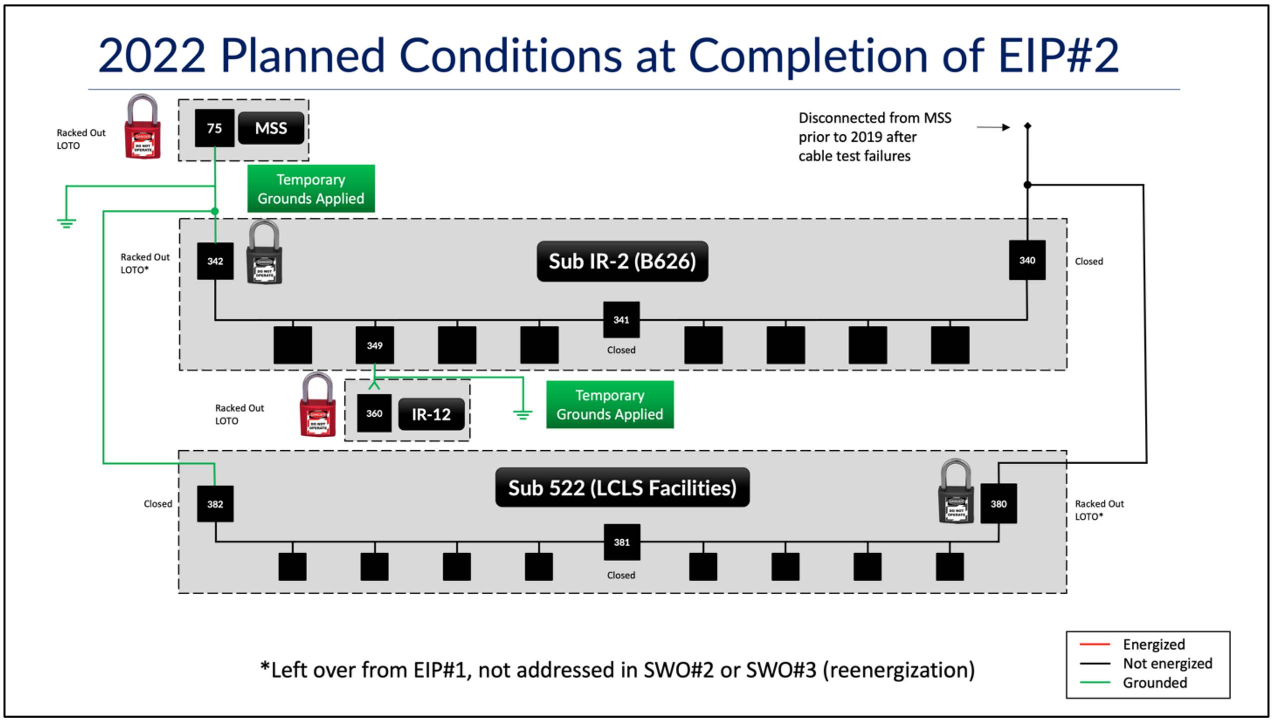

Figure 2-4: Planned lineup for Substations IR-2 and S522 for Phase 2.

<u>Pre-Planning</u>

High Voltage Planner #2 (HVP2) performed a walkdown with the subcontractor as part of the bidding process. The contract was signed on 12/12/2022. Work planning was completed on 12/15/2022 when the EWP was authorized and released. Both High Voltage Electrician #1 (HVE1 – injured worker) and HVE2 were assigned as a Person in Change (Lead Authorized Electrical Worker [LAEW]) for the performance of the EWP and reviewed the EWP on 12/15/2022 as part of the EWP approval process.

HVE1 and HVE2, along with HVP2, performed an informal walkdown of the work to be performed in accordance with the EWP on 12/22/2022. This consisted of visiting Building 626 and discussing the work at a high level. Neither the EWP nor any drawings were used during this walkdown.

<u>Day of work</u>

At 0600 on 12/27/2022, the HV group met to discuss the day's work assignments. The HV Supervisor assigned HVE3 and HVE4 as floaters to assist HVE1 and HVE2 with the IR-2 PM EWP.

A Facility Operations Center (FOC) coordination meeting was held at 0630. This meeting was attended by several groups within F&O including HV; LV; heating, ventilation, and air conditioning; fire protection;

instrument technicians; and utilities mechanics. The meeting covered the day's outage and overall sequence for the outage, as well as how each group was going to coordinate their responsibilities. A representative from the electrical subcontractor also attended this meeting.

Upon adjourning from the FOC coordination meeting, HVE1 took charge of executing the EWP. HVE1 performed the EWP up to the procedural step that directs performance of SWO1. The first switching action on SWO1 was to occur in Building 726 and directed verifying BRK360 was open, racking out the breaker, and applying a lock to BRK360. In Building 726, HVE1 found BRK360 physically removed from its cubicle due to unrelated work. This was not identified on SWO1. At 0730, HVE1 applied Group LOTO lock #112 to the rack out mechanism of BRK360 and established lockbox #8 (LB8) by applying their lock to LB8 and placing key #112 inside. HVE1 signed on to LB8 and applied their personal LOTO lock to the lockbox closing latch. HVE2 and HVE3 applied grounds to the back of BRK360 (Figure 2-5). Applying grounds at this location was not directed by SWO1 but was identified on EIP1.

Figure 2-5: Building 726 with BRK360 racked out and grounds installed.

The next switching action on the SWO1 was to verify open, rack out, and lock out BRK380 located inside of S522 (Figure 2-6). HVE1, HVE2 and HVE3 arrive at S522, and HVE4 arrived shortly thereafter. HVE1 and HVE2 verified BRK380 was open and racked it out. At approximately 0735, HVE1 applied Group LOTO lock #101 to BRK380 rack out mechanism and placed key #101 in LB8.

Figure 2-6: Building S522 (Substation 522).

<u>Building 626 Before Break</u>

HVE1 and HVE2 arrived at Building 626, IR-2 substation around 0742 (Figure 2-7). They proceeded to open BRK342, which deenergized the bus and all downstream loads. HVE1 and HVE2 observed the lights in Building 626 go out as expected, and HVE1 concluded at this point that IR-2 switchgear was deenergized.

Figure 2-7: Northwest view of Building 626.

At the same time, HVE3 and HVE4 in Building 522 observed the lights go out initially, then after a few seconds an Automatic Transfer Switch (ATS) actuated, and the lights came back on. This was not an expected response for either HVE3 or HVE4. HVE4 contacted HVE1 over the radio to inquire about the unexpected response and was told that the switchover was normal. HVE4 asked HVE1 to come to S522 to explain the configuration of the ATS.

Prior to departing for S522, HVE1 and HVE2 proceeded to use a remote racking device to rack out BRK342, standing approximately 15 feet away. They applied Group LOTO lock #73 to the racking mechanism and placed the key into LB8.

At this point HVE2 noticed the BRK342 arc flash label listed two separate sources (Figure 2-8). SLAC's standard practice for all arc flash labels is to include source (fed from) information. HVE2 was concerned that the label indicated that BRK75 at the MSS was one of the sources and shared their concern with HVE1. However, HVE1 did not acknowledge or respond to the verbal communication.

Figure 2-8: Arc flash label on BRK342 (B626/IR-2) showing BRK75 as a source.

HVE1 then performed what they considered to be a Zero Voltage Verification (ZVV) on a 120V service receptacle on the wall inside Building 626, and confirmed the receptacle was dead. HVE1 and HVE2 then concluded that IR-2 switchgear was now fully isolated and deenergized, with no other source of power. HVE1 recalled that HVP1 was present and confirmed that IR-2 was deenergized. HVP1 disputed this recollection.

HVE1 proceeded to open the disconnect for the substation battery, which now isolated all control power to the switchgear and disabled all meters, relays, and indicating lights on the front of the switchgear. This was done to prevent battery discharge, so that the electrical subcontractors who would perform switchgear and breaker maintenance later in the outage would have sufficient battery charge for their tasks. The substation battery disconnect step was not included in the EWP.

HVE1 and HVE2 then initiated a second lockbox, LB6. While not included in the EWP, the stated purpose of the second lockbox was to establish a LOTO for the Low Voltage Electricians (LVEs) to connect the generator at Building 620. The timely connection of this generator was a priority and of high importance in order to eliminate excessive downtime of the IR-2 storm sump pumps. These sump pumps were vital to prevent flooding of Building 620, which houses an ISO14644-1 Class 6 rated clean room and the Large Synoptic Survey Telescope (LSST) Project.

HVE1 stated that their preference was for HVE2 to establish a separate lockbox (LB6) to avoid having the key for the generator isolation lock in LB8. This would allow convenient release of the generator without having other workers remove their locks from LB8.

HVE2 then applied their personal LOTO lock to LB6 closing latch, applied a different Group LOTO Lock #111 to BRK342, and placed its key into LB6. HVE2 initiated the Complex LOTO Permit for EIP1 with LB6 at 0800. Six LVEs applied their personal LOTO locks to LB6 between 0801 and 0807 and set out to work on connecting the temporary generator and perform other activities inside electrical panels in Building 620. LB6 only contained one key, for Lock #111, and no other locks were applied for energy isolation. LB6 did not have a SLAC orange Group Lockout Master Lock tag for identifying it as completed.

HVE1 contacted FOC and informed them that switching at Building 626 was completed at 0801. After leaving Building 626, HVE1 went to S522 to discuss the ATS transfer with HVE3 and HVE4 (Figure 2-9). HVE4 expressed concern that BRK75 was still closed, energizing S522. Although HVE1 acknowledged the concern, they did not recognize that BRK75 was still feeding the line side of BRK342, and that IR-2 switchgear was therefore still partially energized.

Figure 2-9: S522 Substation, BRK380 at left, ATS at right.

Upon exiting Building 626, HVE2 performed a ZVV on a 480V junction box between Motor Control Center (MCC) #1 and MCC #2, which is identified in SWO1.

<u>Break</u>

At around 0815, HVE1, HVE2, HVE3 and HVE4 left the IR-2 area and proceeded to Building 35 for their morning break.

<u>Building 626 After Break</u>

HVE1, HVE2, and HVE3 returned to Building 626 after break, arriving sometime around 0845. HVE4 was tasked to drive a forklift to assist the subcontractors with setting up test equipment by the IR-2 pump pad outside of Building 626.

Note: HVE1 stated in post-incident interviews that they do not recall any events after the break. All of the following is reconstructed from interviews with other personnel and the Board's analysis of evidence.

Upon returning to Building 626, HVE2 engaged with subcontractors to discuss various aspects of the breaker preventive maintenance activities at the MCCs, including tips on adjusting settings and equipment staging. HVE2 had been a subcontractor at SLAC in the past and had relevant experience in the SOW at hand.

Between 0847 and 0907, six of the subcontractors applied their personal LOTO locks to LB6, which was inside Building 626, and signed onto the Complex LOTO Permit for EIP1.

Meanwhile, HVE3 assisted HVE1 in performing a ZVV at the secondary terminals of Transformer 350, which is adjacent to Building 626 and directly feeds MCC #1.

Inside Building 626

HVE1 asked HVE3 for assistance inside Building 626. HVE1 followed HVE3 as they entered the building through the northwest entrance door (streetside) (Figure 2-10), walked behind the switchgear, and proceeded to the rear cubicle of BRK342.

Figure 2-10: View of IR-2 Switchgear from NW entrance door of Building 626.

HVE3 observed that the door to the cubicle was already unlatched and cracked open but thought that the switchgear was deenergized. HVE3 had not applied a personal LOTO lock to any of the lockboxes or isolation points. HVE1 and HVE3 were wearing only their arc-rated daily wear and rain gear.

HVE3 was in the process of hanging a grounding hook on the wall behind the switchgear, on a disconnect box, when HVE1 moved between HVE3 and the cubicle and swung open the door. HVE1 then reached into the open rear compartment (line side) of the BRK342 cubicle with their left hand and lifted an insulation boot off the top of phase A surge arrestor at the bottom of the cubicle. This exposed a bolted connection energized at 7.2 kVAC phase to ground (each phase of a 12.47 kV 3-phase system is 7.2 kV to ground). While reaching in, HVE1 was also holding on to the grounded cubicle enclosure with their right hand.

HVE3, who was standing directly behind HVE1, noticed over their shoulder HVE1 reaching in and lifting the insulating boot, then immediately going into a tight contraction. HVE1 grunted, squatted down but did not release. HVE3 recognized that HVE1 was being shocked and could not let go. HVE3 saw that HVE1's raincoat tail was sticking out, grabbed HVE1 by the coat tail, and forcefully yanked HVE1 out of the energized cubicle. This interrupted the shock current. HVE1 fell face first to the floor where they remained initially unresponsive.

Immediately prior to the electrical shock event, HVE2 observed that HVE1 and HVE3 entered Building 626 and followed them in shortly thereafter. Upon entry HVE2 observed a subcontractor in front of the switchgear trying to place a personal LOTO Lock on LB6, but all of the holes were already taken, and no hasp had been applied. As HVE2 explained to the subcontractor that a lock would need to be removed in order to apply a hasp, they described seeing a flash and hearing a zapping sound and yelling. HVE2 found HVE1 on the ground and HVE3 kneeling next to him. Emergency response and follow on actions are described in Section 2.3.

2.2 Event Chronology

Table 2-1 **s**ummarizes the events and actions associated with the accident described in Section 2.1, *Description*. This table is designed to assist with the context around events on the day of the accident. A detailed description of the timeline associated with this accident is provided in the Event and Causal Factors Chart.

Table 2-1: Event Chronology

Sequence	Date and Time (PST)	Event
1	**12/15/2022 (1309)**	EWP *F&O Electrical Power Department, Sub B522-B266 Preventative Maintenance, Decem*ber *2022* authorized and released
2	**12/22/2022**	HVP2 walks down EWP at a high level with HVE1 and HVE2
3	**12/27/2022 (0600)**	SLAC HV Group Tailgate Meeting held in Building 35.
4	**12/27/2022 (0630)**	SLAC FOC Coordination Meeting held in Building 35.
5	**12/27/2022**	HVE1, HVE2, and HVE3 depart Building 35 for Building 726.
6	**12/27/2022 (0700)**	HVE1, HVE2, and HVE3 arrive Building 726 to perform LOTO on BRK360, perform ZVV check, and install grounds in back of BRK360
7	**12/27/2022 (0730)**	HVE1 established Group LB8 with lock #112
8	**12/27/2022**	HVE1, HVE2, and HVE3 depart Building 726 for Building S522.
9	**12/27/2022**	HVE1, HVE2, and HVE3 arrive Building S522, followed by HVE4
10	**12/27/2022 (0735)**	HVE1 and HVE2 rack out BRK380 at Building S522 and LOTO with lock #101
11	**12/27/2022**	HVE1 and HVE2 leave Building S522 for Building 626. HVE3 and HVE4 remain at Building S522
12	**12/27/2022 (0742)**	HVE1 and HVE2 arrive Building 626 and open BRK342 using remote switching.
13	**12/27/2022**	HVE1 and HVE2 rack out BRK342 using remote racking, apply Group LOTO lock #73, and put key into LB8
14	**12/27/2022**	HVE2 recognized arc flash label on BRK342 showing two separate power sources: 1) BRK75 located at MSS Building 16 2) BRK360 located in Building 726 HVE2 informs HVE1
15	**12/27/2022**	HVE1 tests a 120V receptacle inside of Building 626 for absence of voltage to Building 626.
16	**12/27/2022**	HVE1 isolates battery bank located inside Building 626 to prevent draining of batteries during maintenance work to be conducted inside of Building 626 by SLAC subcontractor.

Sequence	Date and Time (PST)	Event
17	**12/27/2022 (0800)**	HVE2 applies additional group LOTO lock #111 to BRK342 and initiated LB6 for LVEs to perform installation/connection of generator
18	**12/27/2022 (0801)**	HVE1 notifies FOC that switching of BRK342 is completed.
19	**12/27/2022 (0801-0807)**	Six SLAC LVEs sign on to LB6
20	**12/27/2022**	SLAC LVEs begin work to connect temporary generator
21	**12/27/2022**	HVE4 told HVE1 that BRK75 was still closed and energizing S522
22	**12/27/2022**	HVE2 completed first ZVV for MCC #2 at Junction Box located at IR-2
23	**12/27/2022 (~0815)**	HVE1, HVE2, HVE3, and HVE4 depart IR-2 for break at Building 35.
24	**12/27/2022 (~0820)**	HVE1, HVE2, HVE3, and HVE4 arrive Building 35.
25	**12/27/2022**	HVP1 directs HVE4 to operate forklift in assisting SLAC subcontractor in moving of test gear. HVE4 departs Building 35 for Building 626.
26	**12/27/2022**	HVE1, HVE2, and HVE3 depart Building 35 for Building 626.
27	**12/27/2022 (~0845)**	HVE1, HVE2, and HVE3 arrive Building 626.
28	**12/27/2022**	HVE2 talks to SLAC subcontractor personnel about breaker setting adjustment.
29	**12/27/2022**	HVE1 and HVE3 perform ZVV at transformer 350 for MCC #1.
30	**12/27/2022 (0850-0907)**	Six SLAC subcontractor personnel sign the LOTO of LB6 at Building 626.
31	**12/27/2022**	SLAC subcontractor entered Building 626 to apply lock on LB6 as directed by another SLAC subcontractor.
32	**12/27/2022**	HVE1 and HVE3 go to back of BRK342 panel.
33	**12/27/2022**	SLAC subcontractor finds all lock spots on LB6 taken (full). Discusses with HVE2.
34	**12/27/2022**	HVE3 turns their back to BRK342 to stage a ground stick.
35	**12/27/2022**	HVE1 reaches into BR342 cubicle and lifts Phase A Surge Arrestor Insulating Boot.
36	**12/27/2022**	HVE1 makes hand contact with a bare energized (live) circuit part inside a 12.7kV, three-phase, electrical utility distribution switchgear cubicle.
37	**12/27/2022 (~0910-0912)**	**HVE1 receives high-voltage shock**
38	**12/27/2022**	HVE3 pulls HVE1 off circuit by grabbing HVE1's raincoat.
39	**12/27/2022**	HVE3 yells for help.
40	**12/27/2022 (0910-0912)**	HVE2 calls 911 via cell phone.
41	**12/27/2022**	SLAC subcontractor attempts to contact SLAC extension 5555 on cell phone but does not connect (area code and three-digit prefix not used).

Sequence	Date and Time (PST)	Event
42	**12/27/2022 (~0917-0918)**	HVP1 contacts SLAC Security via radio channel 4 to request dispatch of SLAC Emergency Medical Technicians (EMTs) to Building 626.
43	**12/27/2022 (~0917-0918)**	SLAC EMTs request nature of event. HVP1 stated "electrocution."
44	**12/27/2022**	HVP1 closes BRK342 cubicle panel.
45	**12/27/2022 (0920)**	Two SLAC EMTs arrive at Building 626 scene of event with Automatic External Defibrillator (AED).
46	**12/27/2022**	AED positioned on HVE1, but no shock advised.
47	**12/27/2022 (0924)**	Menlo Park Fire District Engine (MPFDE) and Woodside Fire District Ambulance (WFDA) arrive SLAC Main Gate.
48	**12/27/2022 (0925)**	MPFDE and WFDA arrive scene of event at Building 626.
49	**12/27/2022 (0929)**	SLAC Environmental Safety and Health Division Director notified of event.
50	**12/27/2022 (0942)**	DOE SLAC Site Office notified of event.
51	**12/27/2022 (0948)**	WFDA transported HVE1 to Stanford Hospital.
52	**12/27/2022 (0948)**	San Mateo County Sheriff arrives scene of event at Building 626.
53	**12/27/2022**	MPFDE departs event scene.
54	**12/27/2022**	San Mateo County Sheriff departs event scene.
55	**12/27/2022 (1230)**	SLAC Security locked and barricaded Building 626.

2.3 Emergency Response

Facts

After HVE3 pulled HVE1 away from the cubicle, they immediately yelled for help. HVE2 was nearby and saw HVE1 lying on the ground and unconscious. At ~0910, HVE2 called 911 from their cell phone and contacted the San Mateo County Emergency Management Services (EMS) System. Dialing 911 from a cell phone puts the caller in direct contact with the San Mateo County dispatch center (EMS). However, it does not automatically activate SLAC Security, which always has two Emergency Medical Technicians (EMTs) equipped with a vehicle and an Automatic External Defibrillator (AED).

SLAC EMS system can be activated via radio channel 4, or by dialing extension 5555 from any SLAC landline. These two options are the preferred method as it immediately establishes the required coordination efforts between SLAC Security and San Mateo County EMS, facilitating a timelier response of emergency vehicles and broader exchange of information between the event scene and both SLAC EMS personnel and other management team members. One can also use a cell phone, but the caller must dial (650) 926-5555. Interviews suggest that a SLAC subcontractor attempted to contact SLAC EMS via extension 5555 on a cell phone but did not connect as the area code and three-digit prefix were not used.

At ~0917, HVP1 was concerned whether emergency services were activated, and contacted SLAC Security via radio channel 4 to notify and request dispatch of the SLAC EMTs to Building 626. During this time, HVP1 also shut the rear door panel of the BRK342 cubicle. Two roving SLAC EMTs were dispatched from different locations on the site, with both arriving at Building 626 at ~0920.

SLAC EMTs were directed to enter Building 626 from the street side door. Each had their 'jump bag' when they entered the building, which includes first aid and other medical equipment. SLAC EMTs proceeded to cut off HVE1's clothing and utilized an AED to analyze HVE1's heart rhythm by placing the AED pads on the torso of HVE1. The AED diagnosis indicated that no shock was advised. During interviews, SLAC EMTs identified burns on HVE1's face, hands, and fingers. As HVE1 began to regain consciousness, SLAC EMTs were unable to gather any additional vital signs (i.e., pulse, blood pressure, respiration, temperature) on HVE1 prior to MPFDE and WFDA arrival.

MPFDE and WFDA arrived the SLAC Main Gate at 0924, with both vehicles reaching the scene at ~0925. The WFDA paramedic was directed to enter through the northeast side entry door (Figure 2-11) where they directed the SLAC EMTs to continue removing the remainder of HVE1's clothing to look for additional evidence of burns.

Figure 2-11: Building 626 northeast entrance door.

The MPFDE personnel also entered and provided a backboard for the SLAC EMTs and WFDA to use inside of Building 626 to initially roll HVE1 onto, and transport HVE1 outside of the building and onto the WFDA gurney. SLAC EMTs indicated the manual ground and test device (similar in size to a breaker) was in close proximity to the northeast side entry door and needed to be slightly moved in order to expedite transport of HVE1 out of Building 626.

At approximately 0948, WFDA departed the scene with lights and sirens, and transported HVE1 to Stanford Hospital. San Mateo County Sheriff (SMCS) arrived at the Building 626 event scene at ~0948. The SMCS interviewed HVE3, then proceeded to Stanford Hospital to interview HVE1.

Analysis

Emergency Response

By grabbing HVE1 by the coat tail, HVE3 successfully removed HVE1 from the cubicle and interrupted the shock. However, they also put themselves at significant risk of becoming a second victim. During the interview, HVE3 immediately recognized that they put themselves in danger by the manner in which contact release was performed. The Board observed in walkarounds of other substation buildings at least two insulated rescue hooks stored on wall hooks next to grounding clusters (Figure 2-12). No rescue hook was staged in Building 626.

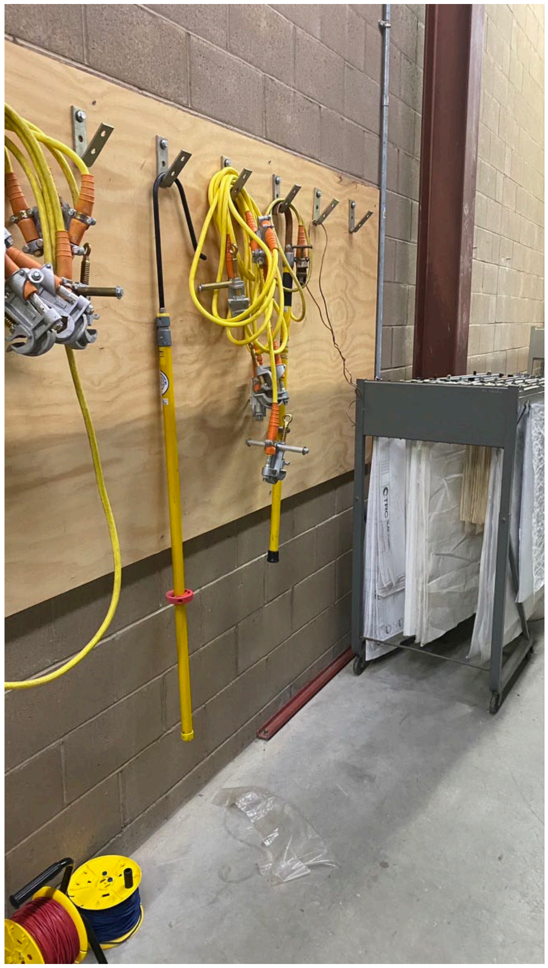

Figure 2-12: Example of insulated rescue hook stored in the Master Substation.

A secondary means of interrupting the shock would have been to open the energy isolation source. After HVP1 arrived on-scene and closed the door, there was an opportunity to call for BRK75 to be opened to make the scene safe, as the door was not latched. This option was not acted upon. The door to the energized cubicle remained unlatched and unbolted until SLAC made their initial Building 626 entry on 1/3/2023 to validate the safety and status of the equipment.

The time between the accident and the arrival of the AED is estimated at 8 to 10 minutes. The two other HVE's present at the scene were Cardiopulmonary Resuscitation/AED trained. The American Heart Association states that "Effective AED programs are designed to deliver a shock to a victim within three to five minutes after the person collapses." A shock event creates a significant risk of heart fibrillation. It could happen immediately or anytime within the following 24 hours, and the risk is significantly more pronounced for high voltage shocks. The SLAC stance on AEDs is that electrical workers do not need to know the location of the nearest AED since they should just call roving SLAC EMT's. However, response time was delayed by not immediately calling extension 5555 on a landline. The Board noted that a landline was present on the IR-2 Pump Pad directly outside of Building 626 (Figure 2-13) but could not determine whether it had been used to report the event. The phone did not have any labels to indicate how to activate extension 5555. From its physical appearance alone it seemed non-functional, but it was still operational.

Figure 2-13: Functional landline phone located at IR-2 Pump Pad.

Had the EWP been classified as Red work, a Non-Construction Tailgate Briefing Form containing the following information would have been triggered:

> "If life-threatening, call 911. Also call SLAC Site Security (ext. 5555) to report the incident. If non-life-threatening, contact the supervisor and PM and SLAC Site Security (ext. 5555) to report the incident. Seek first-aid treatment from the SLAC Occupational Health Center (Building 028). (See Emergency Management: Emergency Notification, Response, and Reporting Procedures.)"

There is no indication that calling extension 5555 from a cell phone will fail to reach SLAC Security. The Emergency Management procedure includes an image of SLAC Incident Notification cards (Figure 2-14) that does not show the appropriate full number. There is no mention in the document that activating SLAC EMTs with an AED requires calling extension 5555, or that it could also be activated using the SLAC radio system.

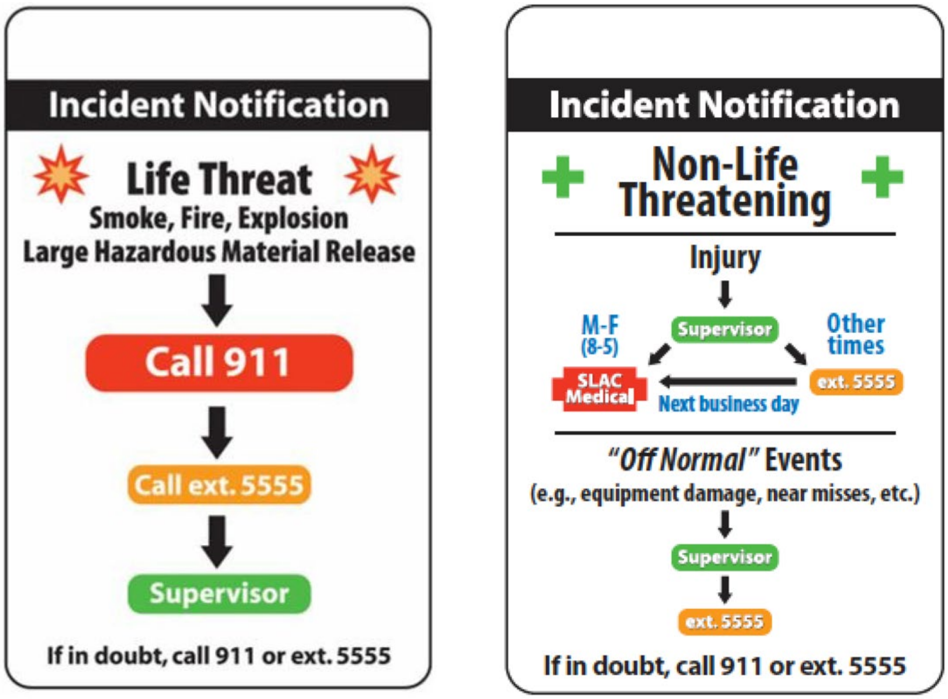

Figure 2-14: Incident Notification Card as illustrated in Emergency Management: Emergency Notification, Response, and Reporting Procedures.

In this accident, once the AED was applied, no shock was advised. However, the potential exists for impacts in other circumstances. Although the EMT response was adequate, the emergency readiness could have been improved and included in a Tailgate Briefing. A JON (JON 16) addressing emergency readiness for accident response is cited in Section 3.1.4 *Perform Work Within Controls* analysis.

Analysis of the Shock Event

The Board reviewed Supervisory Control and Data Acquisition (SCADA) related records and looked for any recordings of the fault. However, the current was too low for pickup by the upstream overcurrent protective device, which did not trip and did not register an event. There was no recorded voltage sag. The average load current that day at BRK75 was 35-40 A, recorded at 15-minute intervals.

The Board performed a visual inspection of the rear cubicle of BRK342 to look for damage or other indications. There was no readily apparent damage inside the cubicle. See Appendix E for detailed inspection of IR-2 switchgear information.

The point of contact for the right hand is clearly visible halfway up the edge of the open enclosure. There is a blackened and heat-damaged area, with some of the paint missing in the middle (Figure 2-15). The pattern was verified to be consistent in size and shape with the right-hand glove inside web between the thumb and index finger.

Figure 2-15: Back of BRK342 Cubicle.

The damage on the top connector of the surge arrestor was not immediately apparent until close inspection with a camera. On the front there is a small, slight metal discoloration. On the back of the threaded connector there are some charred deposits, either organic or from the work glove. The insulating boot has a small area of black deposits along the lower edge. There is no other damage or marking inside the switchgear enclosure. In addition, the enclosure appeared clean, without debris or dust. There was no visible evidence of insulator degradation or contamination, and no evidence of tracking. See Figures 2-16 to 2-19.

Figure 2-16: BRK342 rear cubicle after it was placed in an electrically safe work condition for the Board. The protective grounds were added for the Board and were not in place at the time of the accident.

Figure 2-17: Front view of the phase A surge arrestor bolted connection showing minor thermal discoloration.

Figure 2-18: Rear view of the phase A surge arrestor bolted connection showing deposits and slight thermal discoloration.

Figure 2-19: Rear view of the phase A surge arrestor insulating boot showing some soot deposits.

The Board determined that the principal mechanism of injury was a high voltage electrical shock.

Inspection of the switchgear after the event showed that there was none of the widespread soot deposit throughout the cabinet surfaces that would be characteristic of an arc flash event, and the upstream protective relay did not detect a fault current. Inspection of the PPE showed no soot deposits or charring characteristic of an arc flash event. An arc flash happens with thousands of amps of fault current. In this case there was less than 2 A of arcing current. There is clear evidence of electrical arcing at the points of contact, which is consistent with a high voltage shock. The Board determined that the reported burns to the face were likely caused by the UV radiation of the arcing. The hand injuries were caused by direct arcing damage.

The Board did not have any additional information pertaining to the nature of injuries beyond what was reported by the SLAC EMTs and the SMCS's case report. The reported burns to the face were most likely caused by radiation energy (UV, like a welding burn) of the arc at the points of contact. However, the principal mechanism of injury was shock. There was no electrical fault causing an arc flash event, in the sense that there was no direct arcing from phase to ground or phase to phase.

It is noteworthy that the insulated bus and circuit parts in the back of BRK342 prevented arcing at the point of contact and release from escalating into a full 3-phase to ground arcing fault and arc flash event. Supplemental bus insulation on air-insulated switchgear is not required by either code or equipment safety standards but represents an option that may be specified at the time of purchase. This was an engineering control that performed as intended, and mitigated the severity of injuries that may have otherwise been sustained by HVE1 and HVE3 from a 3-phase to ground arc fault condition.

Based on information from interviews, the Board estimated that the duration of the high voltage shock was more than 2 seconds and less than 10 seconds. The standard minimum human reaction time used for electrical safety calculations is 2 seconds. The shock current and arcing at the hands caused immediate traumatic injuries to the hands.

The SLAC Electrical Safety Officer (ESO) calculated an electrical severity score of 62,000 per the Electrical Severity Measurement Tool (Rev. 4) developed by the Electrical Facilities Contractors Group

(EFCOG) Electrical Safety Community of Practice. Assumptions included a wet environment. Although the switchgear was in a dry building, it was raining significantly that day, the worker was wearing a raincoat, and some of the clothing items may have been wet. The Board concurred with the calculation. An electrical severity score greater than or equal to 3,301 corresponds to the extreme category of significance.

2.4 Post-Event Accident Scene Preservation and Management Response

Facts

Accident Scene Preservation

By 1030 on 12/27/2022, the doors to Building 626 were closed, locked with the existing door locks, and barricaded. At 1230, the SLAC Security Manager applied supplemental security locks to the Building 626 doors, keyed such that no one could access without Security Manager and COO authorization. There was no further entry until 1/03/2023.

On 1/3/2023, with concurrence by the DOE SLAC Site Office (SSO), SLAC personnel entered Building 626 via the northeast entry door to validate the safety and status of the equipment in the area; that was the first entry into Building 626 since it was secured on 12/27/2022 by the SLAC Security Manager. Video of the entry, in addition to still photos, were taken to capture and document those conditions present. Building 626 was re-secured by the SLAC Security Officer after the entry on 1/3/2023 was completed. No further entry was made into Building 626 until 1/18/2023.

On the morning of 1/18/2023, at approximately 1100, three members of the Board performed a walkthrough of Building 626 to identify conditions prior to any collection of physical evidence in support of the Board investigation. Access was made through the northwest entry door (street side), continued past the front of the switchgear, and followed around the back of the switchgear with members returning to the northwest entrance door. The two other entrances to Building 626 were secured (northeast door and north roller door) and never accessed that day.

Once the initial walkthrough was conducted, physical evidence was tagged with blue 'painters' tape' and a written numeric designator was given to identify each article (e.g., Item-1, Item-2, Item-3, etc.). Identification and tagging of physical evidence began at the front of the switchgear, working back around the northeast side, and continuing on to the back of the switchgear (south end).

Not all articles inventoried, photographed, and collected that day were removed from Building 626 due to their physical size, weight, or nature. Installed systems/sub-systems within Building 626 were not inventoried. Remaining items were inventoried, collectively bagged, and transported by Board Members via government vehicle to Building 52, and securely stored in the Truckee River Conference Room 206.

On 1/18/2023, the Board Chairperson received custody of a red EMT bag, brought to Building 52 by SLAC Security personnel. This red bag contained two articles of clothing removed from HVE1 by the responding EMTs on the day of event. The red bag included a leather Dickies® brand belt and Carhartt work pants. These items were added to the Board evidence.

On 1/25/2023, at around 1000, a member of the Board was notified by the HV Group Supervisor that six additional pieces of potential physical evidence were available for review. Around 1015, the Board Member went to Building 35 to inventory, photograph, and collect those six items which included:

Item	Item Description	Item Designator
1	White MSA Hard Hat	HH-1
2	Personal Handkerchief	HKR-1

Item	Item Description	Item Designator
3	SLAC Duty Electrician Pager	PG-1
4	Retractable Key Chain with 19 keys	PK-1
5	Retractable Key Chain with 16 keys	PK-2
6	Flashlight Key Chain with 4 keys	PK-3

Once inventoried, the articles were bagged and transported from Building 35 to Building 52, via government rented vehicle, and stored in the Truckee River Conference Room 206 with the rest of the Building 626 evidence.

On 1/25/2023, the Board re-verified, inspected, and packaged all the inventoried physical evidence located inside of the Building 52 Truckee River Conference Room to facilitate the transfer of custody of the collected evidence to the SSO Manager. Packaging and transfer of the physical evidence was completed around 1500 that day; the transfer of custody was officially accepted by the DOE SSO Manager at Building 52. Upon acceptance, two of the Board Members assisted the SSO Manager in transferring the physical evidence from Building 52 to Building 53, where they were met by a SLAC Security Officer.

All physical evidence was taken to the Building 53 Tahoe Conference Room 1036, re-photographed by the SLAC Security Officer, and placed inside a lockable cabinet with the assistance of the SSO Manager. All articles were stored inside the cabinet, with the exception of the grounding stick, which was too long to fit inside the cabinet.

Upon completing the storage of the physical evidence, the Evidence Transfer Log was signed and dated with time stamp, by both the SSO Manager (1/25/2023 Time 1603) and SLAC Security Officer (1/25/2023 Time 1604).

Upon departure from SLAC, the Board released the scene back to SSO on 1/25/2023.

Management Response

The following is the timeline of management response events:

12/27/2022 SLAC ES&H Director was notified of the event at 0929.

12/27/2022 SSO was notified of the event at 0942.

12/27/2022 SLAC categorized the event as meeting the following Occurrence Reporting and Processing System (ORPS) reporting criteria:

- Group 2 - Personnel Safety and Health, Subgroup A - Occupational Injuries and Exposures, (3) RL-High, “Any single occurrence, injury, or exposure resulting in an occupational injury that requires in-patient hospitalization for five or more days, commencing within seven days from the date of injury” and,
- Group 2, Subgroup D – Hazardous Energy, (1) RL-High, “Any unexpected or unintended personal contact (e.g., burn, shock, injury, etc.) with a hazardous energy source (e.g., live electrical power circuit, mechanical hazards, steam, pressurized gas, etc.).”

12/27/2022 DOE SC DDFO requested additional details from SLAC concerning the 12/27/2022 event, what actions were executed correctly, what deficiencies were immediately apparent as well as what actions are being taken by the Laboratory to assure that work can proceed safely.

12/27/2022 SLAC stopped all yellow/red and high voltage work including control of hazardous energy (CoHE).

12/28/2022	SLAC developed a compensatory verification process for urgent CoHE work.
12/29/2022	DOE SC DDFO issued memo to direct an accident investigation at SLAC related to the 12/27/2022 event.
12/30/2022	Initial ORPS report, SC--SSO-SU-SLAC-2022-0019, IR2 Electrical Arc Flash Injury Incident, submitted.
12/30/2022	SLAC responded to the DOE SC DDFO's 12/27/2022 memo.
1/2/2023	SLAC commissioned an IR-2 Arc Flash Incident – Fact Finding Initiation and Continuation activity.
1/3/2023	SLAC received approval by SSO to record a video of controlled entry into Building 626 to validate the safety of the equipment and area.
1/9/2023	DOE SC DDFO amended 12/29/2022 memo to officially commence a DOE Accident Investigation Board per DOE O 225.1B, Accident Investigations; SC DDFO Appointing Official and appointed Deputy Site Manager at ORNL Site Office as Board Chair.
1/9/2023	SLAC held an all-employee virtual town hall to establish a stand down, discuss recent incidents and discuss plans for enhanced work planning and control activities for the Control of Hazardous Energy work.
1/12/2023	SLAC held an all-employee virtual town hall to summarize stand down activities, progress to date.
1/13/2023	SLAC IR-2 Arc Flash Incident Fact Finding Report completed.
1/16/2023	DOE Board arrives on site.
1/17/2023	SLAC prepares Building 626 for DOE Board entry. Board completed inspection and collection of evidence and notified the SSO Manager for their release.

Analysis

Accident Scene Preservation

Building 626 was locked by SLAC Security Director at approximately 1230 on 12/27/2022. Prior to being locked, both LB6 and LB8 were removed from Building 626 and placed in Building 625. Those two lockboxes were associated with the work performed that day. Additionally, it was noted that three pieces of HVE1's clothing were likely moved from their original location, as left during initial response, and consolidated into a single pile in front of the switchgear. The three pieces of clothing included the following:

1. T-Shirt
2. Outer garment/Work Shirt
3. Raincoat

Regardless of intent, movement of any physical evidence at or from the event scene should always be cautiously considered during initial scene preservation to reduce the risk of, or limit altering, losing, or destroying any potential information that would otherwise be gained by the investigation team. At that point, no further entries were made into Building 626 until 1/3/2023.

On 1/3/2023, SLAC personnel accessed Building 626 to conduct a video-recorded entry to validate the safety and status of the equipment and area, including opening the cubicle door panel at the rear of breaker 342 and examining the interior of the cubicle.

The 1/3/2023 entry video provided by SLAC revealed several items of interest to the Board Members. The back panel door for BRK342 is designed to be secured (closed) either through the use of bolts, a lock and hasp, or a combination of both. One detail noted in the video was a hex head bolt, laying on the ground, near the outer corner of the BRK342 cubicle. The bolt holes on the back of BRK342 door panel are not threaded and require a fixed fastener clip in which a bolt could be threaded into. The video shows one installed fixed fastener clip about halfway up the panel door. Though not confirmed, the clip appears to be capable of accepting a hex head bolt similar in size to the one laying on the floor, as seen in Figure 2-20.

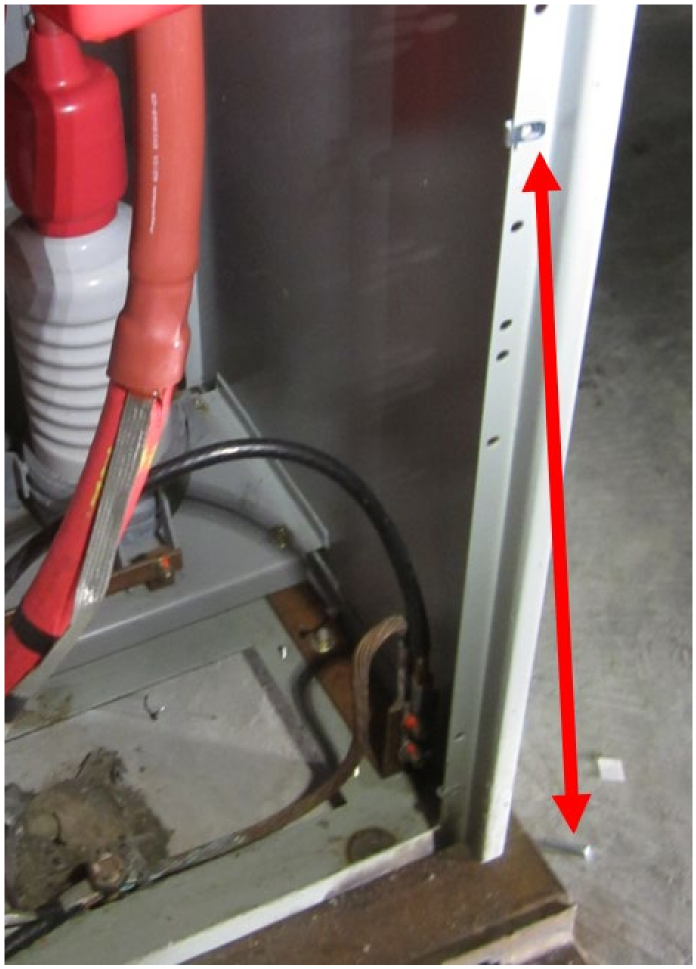

Figure 2-20: Rear of BRK342 Cubicle (Panel door opened).

Entry into Building 626 by the Board Members on 1/18/2023 did not identify or find this bolt on the ground or surrounding area. This might have been due to the door panel not being fully secured (bolted) on 12/27/2022. It was noted, since BRK75 did not trip during the event, the rear of BRK342 cubicle remained energized from 12/27/2022 to 1/3/2023, and that no action was considered necessary by SLAC personnel to open BRK75 during that time frame. However, to facilitate a re-entry into Building 626 and post-event inspection of BRK342, opening of BRK75 was required. Details in the execution of this re-entry is discussed in Management Response below. Upon completion of the SLAC team inspection, SLAC determined that BRK342 was safe to be reenergized, and the bolt on the floor was likely used to secure the door panel on 1/3/2023. BRK75 was re-closed, and BRK342 remained locked out. With the exception of the line side of BRK342, Building 626 IR-2 switchgear remained deenergized.

The Board noted the two post-event actions initiated on BRK75 (opening and closing of the breaker on 1/3/2023), were not consistent with standard scene preservation. However, it is recognized by the Board that the action to isolate power and inspect BRK342 cubicle was consistent with standard safe practices to ensure equipment involved with an adverse event remained capable of operating safely as designed.

SLAC personnel did inform Board Members that several, additional conditions had changed from the time SLAC Security locked Building 626 on 12/27/2022 and the video recorded entry on 1/3/2023.

This includes the following:

1. LB6 and LB8 were removed from the inside of Building 625 and placed inside Building 626 prior to SLAC Inspection Team leaving Building 626 on 1/03/2023.
2. Additionally, the HV Group Lockbox (also identified with duct tape as 'IR-12') used for the 01/03/2023 entry was placed inside of Building 626 prior to SLAC Inspection Team leaving Building 626 on 1/03/2023.
3. HVE1's workpants and belt that had been cut-off during initial response on 12/27/2023, had been bagged by SLAC EMTs, removed from the scene, and transferred to the SLAC Security Officer on the day of the accident. These items were subsequently delivered to the Building 52 Truckee River Conference Room 206 and received into Board custody by the Board chairperson on 1/18/2023 at 1440.

Appendix F provides details of the Board's inspection of the PPE in evidence.

Additionally, there were eight personal items retrieved from HVE1 by SLAC Security on the day of event. These items were photographed and delivered to the HV Group Supervisor at Building 35 on 12/28/2022 (Figure 2-21) and included the following:

1. White MSA Hard Hat
2. Ray Ban Sunglass Case
3. Personal Handkerchief
4. SLAC Duty Electrician Pager
5. Retractable Key Chain with 19 keys
6. Retractable Key Chain with 16 keys
7. Flashlight Key Chain with 4 keys
8. Personal Car Key Chain (Honda key and approximately 3 other keys on a key ring)

Figure 2-21: Items delivered to SLAC HV Group Supervisor on 12/28/2022.

Of the eight items delivered to the HV Group Supervisor, two of them were returned to HVE1's family prior to arrival of the Board, and though accounted for, were not taken into inventory. They include:

1. Ray Ban Sunglass Case
2. Personal Car Key Chain (Honda key and approximately 3 other keys on a key ring)

On 1/25/2023, a Board Member was informed by the HV Group Supervisor that these remaining six items were available for the Board. At around 1015, the Board Member left for Building 35 to take custody of all six items. The items were inventoried and photographed at Building 35 (Figure 2-22) and then transferred to the Truckee River Conference Room 206 at Building 52 to be stored with the physical evidence obtained from Building 626 on 1/18/2023.

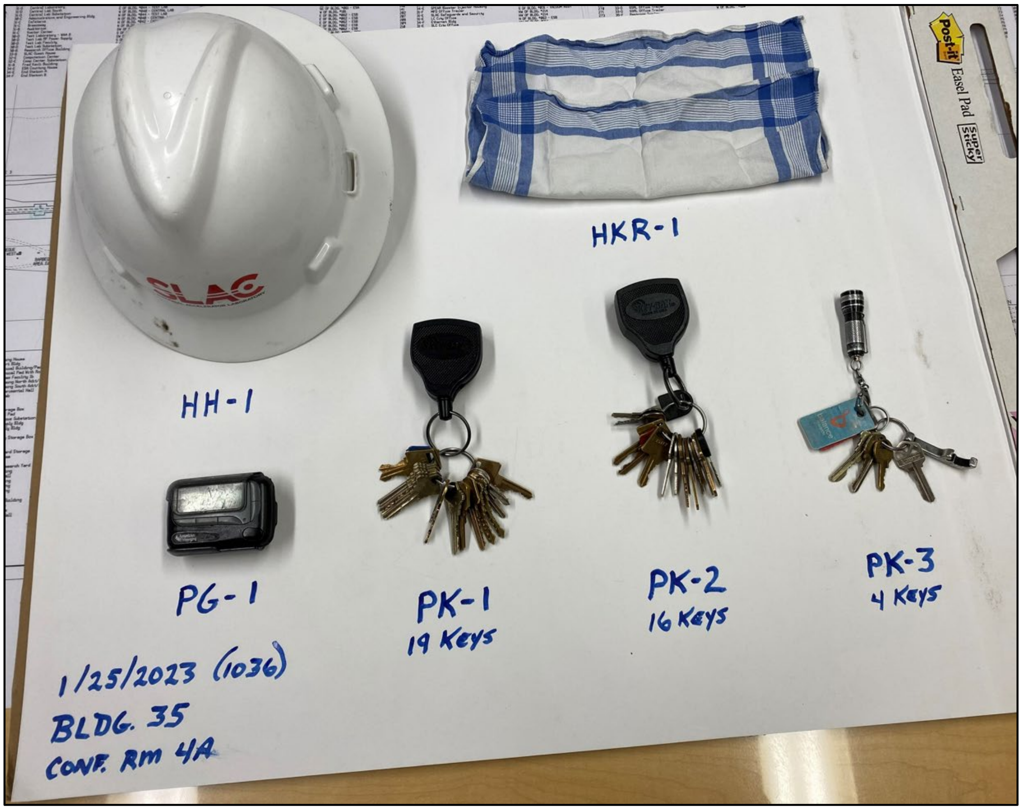

Figure 2-22: HVE1 items received by Board on 1/25/2023.

Of those six items, the White MSA Hard Hat was placed into Board custody and entered into physical evidence to be controlled. Given the nature of the remaining five items (PG-1, HKR-1, PK-1, PK-2, and PK-3), as well as the length of time and custody chain prior to Board receipt, the Board determined the items were releasable back to the DOE SLAC Site Office for disposition as required/desired.

The presence of these conductive articles inside the restricted approach boundary during the performance of high voltage switching and testing activities is indicative of a lack of rigor in applying safe electrical work practices.

<u>Management Response</u>

There was proper notification to SLAC Management and SSO to determine ORPS reporting criteria on 12/27/2023. Upon being notified that DOE was chartering an independent Board, SLAC paused any further event analysis activities.

SLAC had to address the impact of major electrical system outage for an extended duration due to the accident investigation. To address this necessity, on 12/30/2022, SLAC developed a revised work planning process for urgent CoHE work. This included:

- All activities involving CoHE required a compensatory verification process. The only exception was personnel safety – where emergency action must be taken to protect people, property, plant, equipment, or the environment.
- For initial authorization and release of urgent CoHE work, a "Compensatory Verification of Urgent CoHE Checklist" was developed, and the subsequent verification performed by the Deputy Director for Operations and Deputy Director for Projects & Infrastructure and submitted for concurrence to SSO before work was released.

- The purpose of the checklist was to confirm that steps of work planning, authorization and release are completed and responsible individuals for each step were identified. This included:
    - Scope of the task was clearly defined and documented including verification of documentation to existing configuration, field walkdown has been performed, Personal Protective Equipment (PPE) was clearly specified by task, independent review has been performed, lookalike equipment was delineated from equipment being worked on.
    - Potential hazards identified, reviewed, and mitigating measures were communicated and implemented.
    - New CoHE pre-job briefing process was implemented and readiness (training) of staff to carry out the task.

Between 12/28/2022 and 1/16/2023, SSO reviewed seven work plans developed by SLAC following the new process, and all seven work plans were rejected due to various issues identified.

Even with the interim measures SLAC Management put in place since the day of the event, the Board observed notable gaps that represented substantial risk for injury in the SLAC High Voltage Electrical work practices. (See Appendix C.)

3.0 FACTS AND ANALYSIS

3.1 ISM/Work Planning and Controls

3.1.1 Define the Scope of Work

Facts

The overarching SLAC work planning control procedure is Environmental, Safety, and Health (ESH) Manual Chapter 2, *Work Planning and Control*. Additionally, ESH Manual Chapter 8, *Electrical Safety*, provides work planning requirements for electrical work and ESH Manual Chapter 51, *Control of Hazardous Energy*, provides requirements for LOTO and ZVV.

The SOW for the outage was to perform 5-year electrical PM at the IR-2 and S522 substations and their respective loads. The scope included preventive maintenance and electrical system testing to be performed by a subcontractor. Since IR-2 and S522 substations are fed from a common set of feeders from the MSS, both need to be shut down at the same time.

Outage planning began approximately six to eight weeks before the scheduled outage. F&O EPD management began, for the first time, using a new process to ensure work planning products were completed prior to commencement of work. This consisted of three checks. The first check consisted of a review with management to verify the work was planned, scheduled, and scoped. The second check was an intermediate check to evaluate the status of work planning products. The third check was the deadline by which all work planning products were to be complete.

The second check occurred approximately two weeks before the third check. The third check was scheduled and performed on 12/15/2022. Work was scheduled to be performed 12/27-30/2022. The customary number of work planners were not available for developing the outage EWP, and two of the four planners were also assigned to work on PG&E Public Safety Power Shutoff (PSPS) preparations. Although priority was given to the outage planning, both had to be completed by the end of the year.

During the work planning process, the EWP was not classified as Red work in accordance with ESH Manual Chapter 2, *Work Planning and Control*.

Due to holiday leave constraints, the number of workers available to complete the work scope during the outage was significantly reduced (provided estimates varied widely from 60-300) to thirty. Instead of shutting down IR-2 and S522 substations at the same time (as had been done in 2018), an outage plan was developed that staggered the shutdown into two phases, as enough resources were not available to perform all the required actions in parallel. Phase one consisted of isolating power to the IR-2 downstream loads (but not S522) to allow maintenance of the panels in the IR-2 area before the connection of temporary generators. Phase two would fully isolate IR-2 and S522 and would allow performing maintenance on panels at S522, connecting temporary generators, and then performing maintenance on all of the remaining equipment for both substations IR-2 and S522 areas.

During the planning process, HVE1 and HVE2 were both assigned as Person in Charge (LAEW) for the EWP.

The EWP prepared by HVP1 was submitted for review at 1051 on 12/15/2022. On 12/15/2022, HVE1 signed the EWP at 1219 and HVE2 signed the EWP at 1153.

A total of nine signatures were recorded on the EWP, and all were electronically time stamped on 12/15/2022:

- HVP1 (also the Assistant Substation Manager), as the EWP Preparer;
- HVE1 and HVE2, designated as Person in Charge (Lead Authorized Electrical Worker);

- The HV Supervisor, and two other F&O planners, for Authorization and Release of the EWP;
- Three Area/Building Managers, responsible for Buildings B950 and B999, Buildings B620, B621, and B624, and the Assistant Substation Manager, respectively.

HVE1 and HVE2 were not provided an opportunity to review the EWP prior to HVP1 submitting it for review signatures.

Three authorization signatures were on the EWP. The signature statement for authorization reads:

> "I have reviewed the steps, hazards, and controls described in this JSA. Workers are qualified (e.g., licensed or certified, as appropriate, and in full compliance with SLAC training requirements) to perform this activity." The authorization signatures were recorded at 1156, 1236, and 1309 on 12/15/2022.

Two release signatures were on the EWP. The signature statement for release reads:

> "[ ] Red work? (if yes, document release via WIP and tailgate meeting) otherwise [ ] I have communicated unique hazards, boundary conditions, and so on with the authorizer or listed worker(s) and have coordinated this job with affected occupants. Listed workers are released to perform described SOW. List boundary conditions, notes, etc. List boundary conditions, notes, etc.: Work in manholes at the vehicular traffic areas. Work near energized electrical equipment"

No box was checked for any release signature to indicate they had performed the actions required for their signature. Work was not planned to occur in manholes. The EWP release signatures were recorded at 1048, 1051, and 1114 on 12/15/2022.

Analysis

Implementing a new work planning process based on the three checks, in addition to utilizing some of the normal HVP resources for another project, created a sense of time pressure for the remaining HVPs. Their view was that there were not enough resources within the planning group to adequately plan the outage. In addition, record rainfall leading up to the outage resulted in flooding and erosion concerns in IR-2 area, increased environmental pressures the day of the outage and further raised schedule urgency and resource load.

HVP1 and HVP2 did not perform an adequate field verification during planning. Specifically, they did not identify BRK360 as removed and required it to be racked out on SWO1. A structured, thorough field verification of the EWP would have identified several other inaccuracies and discrepancies, triggering an additional review or revision prior to approval.

To address the drastic reduction in available resources, the planners developed a modified outage plan that released some of the work while the switchgear at IR-2 was still partially energized. While this condition was communicated to the workers participating in the outage, its impact was not fully recognized.

CC-4: The outage planning process assigned insufficient resources and time for the increased maintenance scope and, instead, staggered the outage plan that introduced partially energized switchgear.

Assigning two LAEWs introduced confusion about who had overall responsibility for the EWP as well as the individual switching orders and energy isolation plans.

The EWP was not classified as Red work per ESH Manual Chapter 2. SLAC defines Red work as work that requires detailed planning and coordination because of the number of interdependent controls and/or different work groups required to complete the SOW. Red work thresholds are defined as:

- work requiring three or more work permits, or
- construction work, or
- work where three or more work groups must coordinate their activities.

The work planned that day met the threshold of Red work. This was not identified by anyone who signed the EWP. By not classifying the work as Red, this resulted in a failure to plan with the required rigor for complex, high hazard work. Red work requires additional administrative controls, to include additional reviews by more organizations, such as ESH, and additional, documented briefs prior to releasing work. By contrast, the 2018 maintenance outage for IR-2 and S522 substations was classified as Red work by the HVPs.

Authorizers/approvers did not perform all tasks as stipulated in the authorizing attestation statements. Additionally, the persons releasing the work did not indicate by checking an appropriate box nor perform all tasks as stipulated in the release statements.

The rigor of the reviews performed during approval of the EWP were inadequate, in that numerous errors, omissions, and inconsistencies with the EWP were not identified during the review, authorization, or release processes. Examples include:

- EIP1 includes placing grounds at BRK360. Grounds at BRK360 were only to be placed as part of SWO2 and EIP2.
- SWO1 directs to rack out BRK360, but it was already removed from its cubicle for preexisting work.
- Single lines were incomplete. They did not show any of the isolations for EIP1. ZVV locations for LV work under EIP1 were shown mixed in with isolations for EIP2. No ZVV location was shown for the 12.47 kV switchgear. Additionally, not all isolations, ZVV points or grounds were identified, and those that were did not differentiate between various phases of the EWP.
- SWO1 step numbers were out of order and included multiple duplicates of step numbers in nonsequential order.
- SWO2 directs the HV electricians to place grounds before all isolations are in place.
- Neither SWO2 nor SWO3 addressed the restoration of BRK342 and BRK380, which were racked out and locked out in SWO1.
- The first Stop step (Step 2.04) in the EWP was written for re-energizing breakers, which wouldn't occur until much later in the work evolution.
- EIP1 incorrectly placed ZVV at BRK342:
  - This ZVV was not required for this phase of work.
  - This directed HVE1 to perform a ZVV at an energized location.

CC-5: The planning process failed to produce a work package that could be executed safely.

JON 8: SLAC Management needs to clarify and reinforce requirements for preparation, review, and approval of work plans.

3.1.2 Analyze Hazards

Facts

The EWP does not document an arc flash risk assessment for tasks involving an arc flash hazard. Specifically, it does not identify arc flash boundaries or PPE on a task basis. Each step or task on the EWP has a column for listing associated hazards, which reads "Hazard (include shock and arc flash hazard information from the hazard label affixed to the equipment or from the electrical analysis engineer)." Multiple steps in the EWP identify these hazards as 'Electric shock, arc flash' or 'Electric shock.'

The EWP does not document a shock risk assessment for tasks involving a shock hazard. Specifically, it does not identify limited approach boundaries, or restricted approach boundaries, or PPE on a task basis.

The SOW for the LVEs in phase one included connecting a temporary generator to the normal power supply of an ATS. The ATS feeds the IR-2 Sump Pumps and was considered a critical load that merited both normal and backup power during the maintenance outage. This would result in two (2) mobile generators connected to a single ATS: one mobile generator is permanently connected to the emergency side of the ATS, and a second mobile generator would be temporarily connected to the normal side of the ATS (Figure 3-1). This connection to the normal side of the ATS was to be made inside a junction box that also contained the load side feeder from the ATS to the loads.

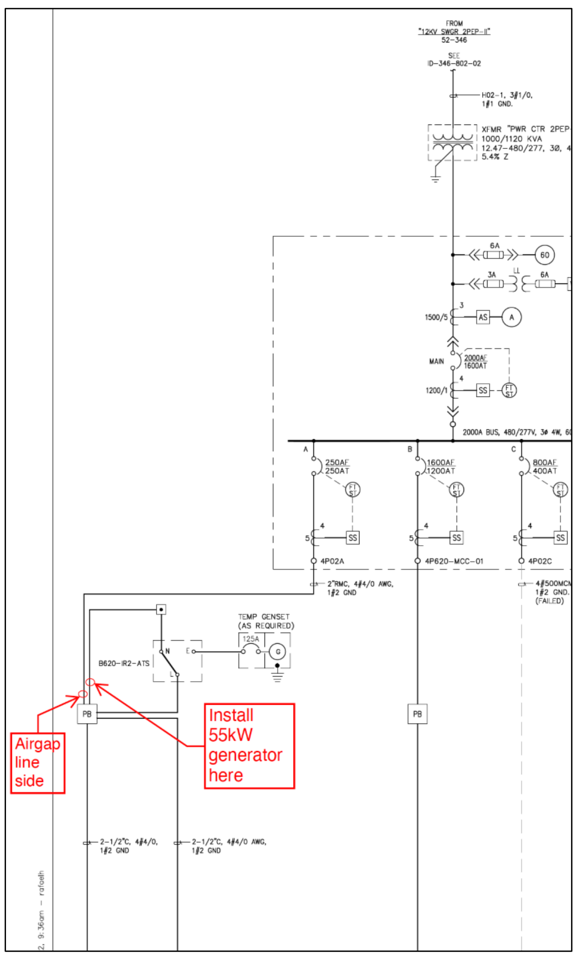

Figure 3-1: Temporary Generator Installation Location.

The EWP directs air gapping in a 480V junction box on the normal power supply to the ATS, without isolating and locking out power from the mobile generator on the emergency power supply of the ATS.

The EIP1, EIP2, SWO2 require installation of grounds before the isolation is complete.

Analysis

The EWP did not identify all hazards. The EWP did not incorporate all elements of a job safety plan as required by National Fire Protection Agency (NFPA) 70E (2021) 110.5(I)(1), nor provide the required information identified on the EWP form. The review and approval process allowed the general statement in lieu of the requirements:

- Identification of the hazards associated with each task.
- A shock assessment for each task involving a shock hazard.
- An arc flash risk assessment for each task involving an arc flash hazard.

The EWP directed LVEs to place the control switch for the standby mobile generator to the off position. No accompanying step directed the installation of a LOTO at the control switch. This was an uncontrolled source of hazardous energy for the electricians performing the generator installation tasks. The LVEs did not recognize this as a hazard.

The HVP1 and HVP2 did not recognize the hazard of installing grounds in a circuit before the complete isolation is in place. The work planning review and approval process failed to identify developed, hazardous work steps specified in the EWP. HVE1, HVE2, HVE3, and HVE4 did not recognize this as a hazard.

JON 9: SLAC Management needs to ensure that processes align known hazards with controls throughout the work planning and execution.

3.1.3 Develop/Implement Hazard Controls

Facts

The EWP identified several hazard controls for individual tasks conducting electrical work that included the following:

- Wear proper PPE required for Arc flash Category.
- Wear PPE required for Substations. Use Chicken switch and remote racking devices as needed.
- Wear proper PPE.
- Wear PPE required for Substations.

During the work planning process, the EWP was not classified as Red work in accordance with ESH Manual Chapter 2, *Work Planning and Control*.

A walkdown with HVP2, HVE1, and HVE2 was performed on 12/22/2022.

Analysis

The EWP did not fully identify hazard controls, such as alerting techniques for look-alike equipment. The identified controls in the EWP do not align with the ESH manual.

The EWP did not identify specific controls for the arc flash hazard for individual tasks. Specifically:

- The arc flash boundary was not identified.

- PPE required to enter the arc flash boundary was not identified.

The EWP did not identify specific controls for the shock hazard for individual tasks. Specifically:

- The limited approach boundary was not identified.
- The restricted approach boundary was not identified.
- PPE required to enter the restricted approach boundary was not identified.

By not classifying the EWP as Red work, additional planning reviews were not performed. Red work requires the planner to also prepare a work integration plan (WIP) to document planning efforts. The WIP requires an ESH review, and this review did not happen. This was a missed opportunity to develop the appropriate hazard controls. Additionally, to release Red work, a tailgate briefing is required for each worker. For Red work that has a lab-wide impact, an Associate Lab Director must concur on the WIP. This level of management engagement was missing from planning this outage.

The walkdown performed on 12/22/2022 was informal. The EWP was not present during the walkdown, and no single line drawings were referenced. The only location visited during the walkdown was Building 626, where a high-level discussion of the tasks associated with the outage occurred. The absence of a structured walkdown contributed to HVE1 and HVE2 not being adequately prepared for the complexity of the work. They did not understand the overall two-phase sequence of the outage, nor that by keeping S522 energized, IR-2 would remain partially energized (see Figure 3-2). Additionally, roles and responsibilities assigned to two LAEWs were not clarified, leading to confusion on the day of the outage.

Walkdowns are not clearly defined in ESH Manual Chapter 2, *Work Planning and Control* in that it states, "Note walking the specific area and surrounding areas where the work is to be performed may be required to understand fully the hazards and necessary controls." ESH Chapter 51 provides for (but does not mandate) an optional walkdown of energy isolation point to verify proper lockout. While SLAC indicated that it conducted four walkdowns prior to starting work, there is no clearly documented requirement or expectation to conduct walkdowns to verify the accuracy of the EWP or prepare workers to safely execute the EWP.

CC-6: Unclear expectations for walkdowns resulted in miscommunication of the scope, hazards, and controls from the planning group to the workers executing the work, and a lost opportunity to identify issues with the work package.

JON 10: SLAC Management needs to define requirements and expectations for walkdowns during work planning processes and prior to work performance.

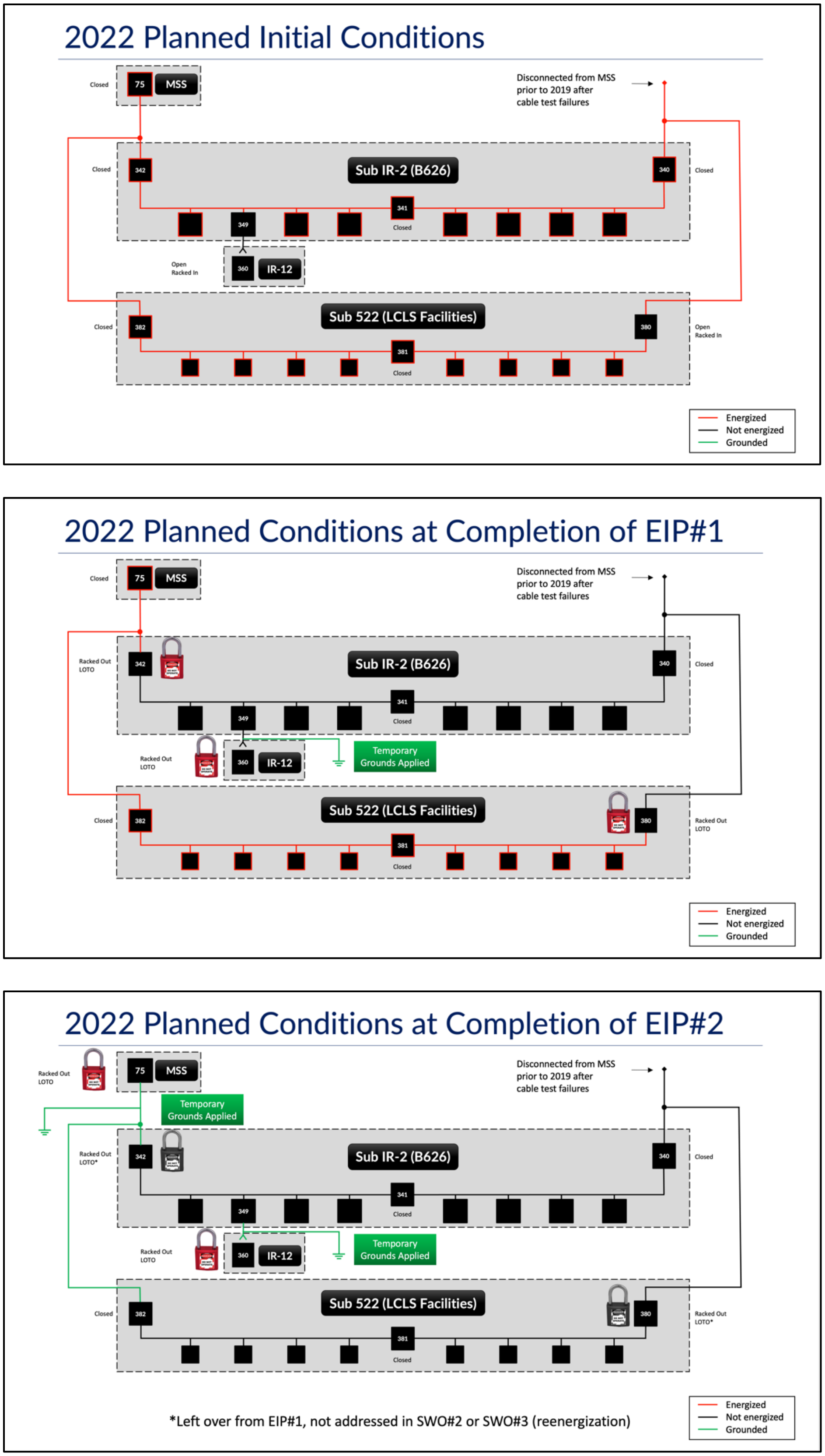

Figure 3-2: Planned Initial and Completion Conditions.

3.1.4 Perform Work Within Controls

Facts

On the day of the outage, work release was completed in two steps: the HV Tailgate Meeting at 0600 and the FOC Coordination Meeting with all participating crafts at 0630. After release, the HV Electrical team consisted of four HV Electricians: HVE1, HVE2, HVE3 and HVE4. HVE1 and HVE2 had been formally assigned to the EWP.

- HVE1 and HVE2 were both assigned as Person In Charge (PIC)/(LAEW) on the EWP, and each of them signed the Worker Acknowledgment signature page of the EWP.
- HVE2 was assigned as the lead for SWO1 and EIP1, which covered just the installation of temporary generators at Building 626.
- HVE1 was assigned as the lead for SWO2 and EIP2, which would cover the balance of work after both IR-2 and S522 were fully isolated.
- HVE3 and HVE4 were assigned as 'floaters,' which restricted them to only assist HVE1 and HVE2 in the execution of the EWP. During interviews it was consistently clarified that floaters were not authorized or released to perform any of the steps of the EWP or SWOs or be placed in any situation that would expose them to hazards related to the EWP. They were only to perform minor tasks such as getting missing tools, extra batteries, or would be assigned to emergent tasks related to the outage to prevent distracting HVE1 and HVE2 from their EWP duties.

HVE1, HVE2 and HVE3 first went to Substation IR-12 at Building 726. HVE1 took charge as the PIC/LAEW for SWO1 and EIP1. HVE1 initiated EIP1 by signing the Complex LOTO Permit and applying their personal LOTO lock to the latching mechanism of LB8.

Although SWO1 directed verifying open and racking out BRK360 at IR-12 substation, the team found that BRK360 was already removed from the cubicle. BRK360 had been removed as part of a separate work evolution involving HVE1. HVE1 was the assigned lead for that job, and already had personal LOTO locks at IR-12 / BRK360 and IR-2 / BRK349, in effect isolating both ends of the feeder connecting IR-2 and IR-12 substations.

Finding that BRK360 was already removed, HVE1 applied a group LOTO lock #112 to BRK360, put the key in LB8, and directed HVE2 and HVE3 to perform ZVV and install grounds in the rear cubicle of BRK360. Although SWO1 did not mention application of grounds, it was included as a step in EIP1.

HVE1, HVE2 and HVE3 then proceeded to Substation S522 at Building 522, where they met up with HVE4. There they verified BRK380 already opened, then racked out BRK380 using a remote racking device, wearing arc-rated daily wear, and standing approximately 15-20 feet away. HVE1 applied Group LOTO lock #101 and put the key in LB8.

HVE1 and HVE2 then proceeded to Substation IR-2 at Building 626, while HVE3 and HVE4 remained at S522. HVE1 and HVE2 opened BRK342 using remote switching. The lights in Building 626 went out, which was the expected response for HVE1 and HVE2. At the same time, the lights went out in Building 522, and after a few seconds' delay, came back on when an ATS actuated. HVE3 and HVE4 were surprised that the lights went out and came back on and contacted HVE1. HVE1 was aware of this issue from past outages and reassured HVE4 that this was in fact expected.

HVE1 and HVE2 then racked out BRK342 using a remote racking device, wearing arc-rated daily wear, and standing approximately 15-20 feet away. HVE1 applied Group LOTO lock #72 and put the key in LB8.

At this point HVE2 noticed that the BRK342 arc flash label displayed two separate sources. SLAC standard practice for all arc flash labels is to include source ('fed from') information. HVE2 was concerned that the label indicated that BRK75 at the MSS was one of the sources and shared their concern with HVE1. However, HVE1 did not acknowledge or respond to the verbal communication.

HVE1 then checked for absence of voltage on a 120V service receptacle on the wall inside Building 626, and confirmed the receptacle was dead. During interview, HVE1 stated that this was a ZVV and that it was done to prove that the IR-2 substation was completely dead. HVE1 and HVE2 then concluded that IR-2 switchgear was fully isolated and deenergized, with no other source of power. HVE1 stated in an interview that HVP1 was also present for switching and racking BRK342. HVE1 recalls asking HVP1 if IR-2 was deenergized and HVP1 replying in the affirmative. HVP1 disputes this recollection.

HVE1 then proceeded to open the disconnect for the substation battery, which isolated all control power to the switchgear and disabled all meters, relays and indicating lights on the front of the switchgear. This was done to prevent battery discharge, so that the subcontractors who would perform switchgear and breaker maintenance later would have sufficient battery charge for the task.

After leaving Building 626, HVE1 went to S522 to discuss the ATS transfer with HVE3 and HVE4. HVE4 expressed concern that BRK75 was still closed, energizing S522. HVE1 acknowledged the concern.

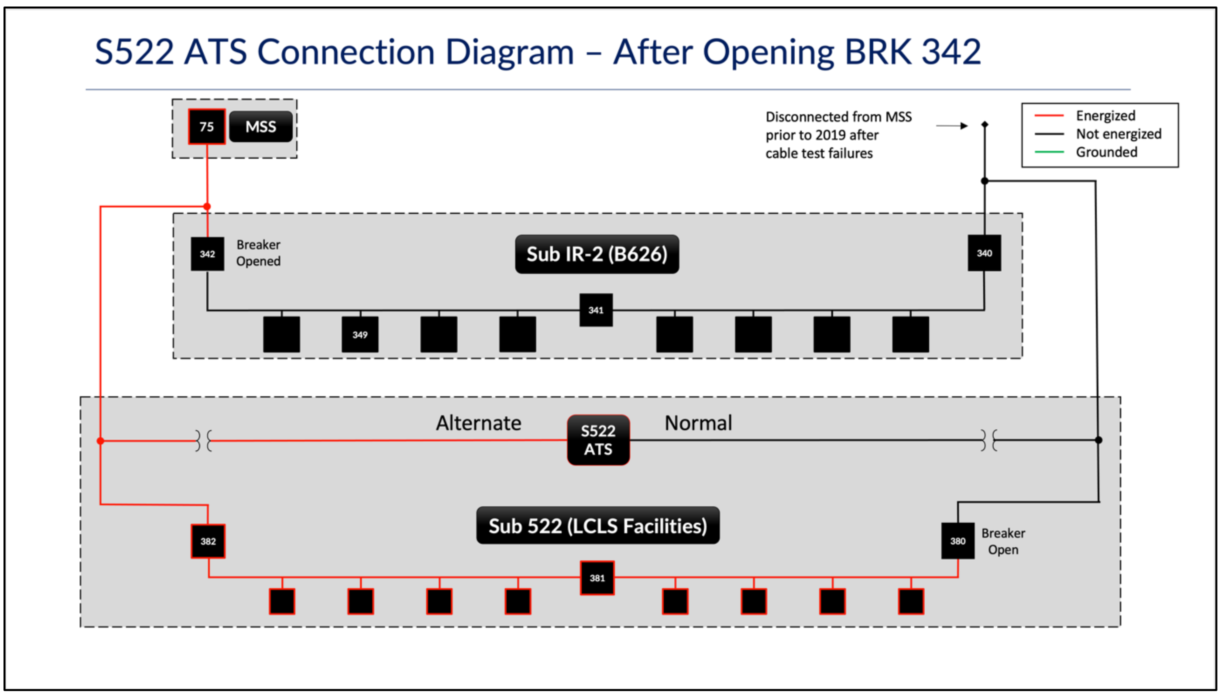

Figure 3-3: Substation 522 ATS Connection Diagram after opening BRK342.

Upon exiting Building 626, HVE2 performed a ZVV on a 480V junction box between MCC #1 and MCC #2 so that subcontractors could get to work. After break, HVE3 assisted HVE1 in performing a second ZVV for the subcontractors at the secondary terminals of Transformer 350, which directly fed MCC #1. At some point after break but before the event, multiple feeder breakers in IR-2 substation were opened and left racked in: BRKs 344, 346, 348, and 350.

HVE1 then asked HVE3 for assistance inside Building 626. HVE1 followed HVE3 as they entered the building, walked behind the switchgear, and proceeded to the rear cubicle of BRK342. HVE3 observed that the door to the cubicle was already unlatched and cracked open but thought that the switchgear was deenergized. HVE3 had not applied a personal LOTO lock to any of the lockboxes or isolation points. HVE1 and HVE3 were wearing only their arc-rated daily wear and rain gear.

HVE3 was in the process of hanging their grounding hook on the wall behind the switchgear on a disconnect box, when HVE1 moved between HVE3 and the cubicle and swung open the door. HVE1 then reached into the open cubicle with the left hand and lifted an insulation boot off the top of phase A surge arrestor at the bottom right-hand side of the cubicle. This exposed a bolted connection energized at 7.2 kV phase to ground (each phase of a 3-phase 12.47 kV system is 7.2 kV to ground). While reaching in, HVE1 was also holding on to the grounded cubicle enclosure with their right hand. This initiated the high voltage shock event.

<u>*Analysis*</u>

Roles and responsibilities were shifted at the very start when HVE1 immediately took control of SWO1 and EIP1 as PIC/LAEW. In the EWP, these had been assigned to HVE2. However, HVE2 is a relatively junior worker and deferred to HVE1's experience, knowledge, and direction, and did not question the change. When asked in interview about HVE2's and HVE3's roles, HVE1 stated that they were just there for assistance in the execution of the switching. HVE1 did not recognize HVE2 as the LAEW for the first phase of the outage and did not recognize that HVE3 was only assigned as a floater with restricted duties.

Although a Tailgate Meeting happened at 0600 with the HV crew, it did not meet the required intent or content of the Tailgate Briefing defined in ESH Manual Chapter 2, *Work Planning and Control*. At the Tailgate Meeting, workers were given their work assignments and asked whether they had any concerns about the EWPs they were handed.

A Tailgate Briefing is required for Red work and is defined in Chapter 2 as a "Review by workers and their supervisor of an activity immediately before release to ensure worker understanding of the interdependent hazards and controls, hold points, unique area hazards, and agreement on how to execute the work. Work planning meetings where multiple work groups' or departments' work activities are coordinated and released."

The EWP was not identified as Red work. Some of these elements were met, but the overview was superficial and did not dive into anything specific for the SWOs or EIPs. As noted in Section 2.3, the Non-Construction Tailgate Form is used to document final release of Red work by SLAC. Key sections of this form allow for the supervisor to capture and initiate critical discussion points with the work crew, including but not limited to, 'Discussion of Hazards,' 'Required PPE,' and 'Important Highlights.' It also provides direction for executing Emergency Procedures and initiating Emergency Management Services (Figure 3-4). However, there is no distinguishing guidance provided with regards to the use of a cell phone vice SLAC landline. This presents a potential risk for delaying EMS. Should an individual dial extension 5555 from their cell phone, they will not reach (connect) with SLAC Site Security personnel who are the primary source for dispatching on-site roving SLAC EMTs who can provide initial response sooner than San Mateo County EMS dispatch. Though dialing 911 from a cell phone is always a viable option, it is vital that all personnel are continually aware of, and ready to execute emergency procedures.

> **Emergency Procedures**
>
> If life-threatening, call 911. Also call SLAC Site Security (ext. 5555) to report the incident. If non-life-threatening, contact the supervisor and PM and SLAC Site Security (ext. 5555) to report the incident. Seek first-aid treatment from the SLAC Occupational Health Center (Building 028). (See <u>Emergency Management: Emergency Notification, Response, and Reporting Procedures</u>.)

Figure 3-4: Emergency Procedures section of SLAC Non-construction Tailgate / Release Form.

Additional emergency response analysis is covered in Section 2.3.

JON 16: SLAC needs to reassess their level of readiness to respond to accident situations.

The Tailgate Meeting also did not cover the required content of an electrical Job Briefing as specified in ESH Manual Chapter 8, *Electrical Safety*. An electrical Job Briefing in Chapter 8 states that:

> "Before starting each job, the supervisor or designee must conduct a job briefing with the employees involved. The briefing must cover subjects such as hazards associated with the job, work procedures involved, special precautions, energy source controls, and PPE requirements. (Refer to NFPA 70E and 8 CCR 2940 for more details)."

This appears to be based on the 2015 edition of NFPA 70E. SLAC is contractually obligated to follow the latest edition of NFPA 70E, and adopted NFPA 70E-2021, which requires the Job Briefing to cover the documented Job Safety Plan, which in turn must include specific task-level shock and arc flash risk assessments. While the EWP, together with its associated SWOs or EIPs, meet most of the requirements, the task-level shock and arc flash risk assessments were not conducted.

The very first line of SWO1 has the instructions "Pre-job briefing (required)." The line is not initialed, or time stamped. The first initials (HVE1 and HVE2) begin on the next line for Step 1, "Notify FOC of Intent to switch."

As a result of not conducting an effective tailgate briefing or job briefing, the HV work team missed a significant opportunity for clarifying roles and responsibilities and for reviewing the scope, hazards, and controls.

CC-7: A comprehensive Tailgate Briefing was not performed to fully communicate the roles and responsibilities as well as task-level scope, hazards, and controls, to all of the assigned workers.

JON 11: SLAC Management needs to strengthen requirements and expectations for tailgate briefings.

In an interview, HVE1 indicated they were planning to establish just one EIP, with a pause after BRK342 to allow generator connection and get the subcontractors to work. Further, HVE1 stated they were intending to fully isolate IR-2 and S522 with a total of four isolations (BRK360, BRK380, BRK342 and BRK75) and two sets of temporary protective grounds (at BRK360 and BRK75) so that the HV subcontractors would be working between two sets of grounds. HVE1 did not recognize that the two steps of the outage plan were in fact captured in two SWOs and two EIPs. EIP1 partially isolated IR-2 substation at BRK360, BRK380, and BRK342, and EIP2 fully isolated IR-2 substation and S522 at BRK360 and BRK75.

In reviewing the EWP, SWOs and EIPs, the number of errors, omissions and inconsistencies made it difficult for the Board to determine the real intent of the EWP without discussing it with the HVPs. The isolation and ground points were not included for EIP1, and one single line drawing used to identify low-voltage ZVV points for EIP1 had the isolations for EIP2 instead. EIP1 mistakenly included grounds for BRK360, and the final switching order to restore power after the outage left out closing BRK342. This is discussed in detail in Sections 3.1.1 through 3.1.3 of this report. The consequence during work execution is that there may have been enough inconsistency and confusion in the EWP to cause confirmation bias, allowing HVE1 to make different conclusions and attempt to implement their own mental picture of the overall outage plan. However, at no point in the execution of the EWP did the HV team stop to inquire about inconsistencies in the work package.

The HV work team also deviated from safe electrical work practices established in ESH Manual Chapter 8, *Electrical Safety* and Chapter 51, *Control of Hazardous Energy-Zero Voltage Verification Procedure*. Most notably, the performance of ZVV on the 12.47 kV switchgear was not consistent with the required practice to “test all circuit elements and electrical parts to which workers may be exposed.” Specifically, HVE1 stated in interview that they used a ZVV on a 120V receptacle in Building 626 to prove that the 12kV switchgear was fully deenergized. It remains somewhat unclear to the Board specifically what task was intended to be performed in the back of BRK342. HVE3 stated that they were preparing to perform ZVV, and this is consistent with the fact that this step had not yet been initialed in the copy of the EWP in use. However, at this point, no ZVV equipment had yet been staged in Building 626. The HV Supervisor stated that the equipment and PPE required for ZVV, namely 100 cal/cm^2 arc flash suits, Class 2 (17 kVAC) voltage rated gloves, proximity meters, contact meters and live-line insulating sticks for both HVE1 and HVE3 were found in their work vehicles after the event. HVE3 was holding a grounding hook and was in the process of hanging it on the wall behind the switchgear, on a disconnect box (Figure 3-5).

Figure 3-5: Grounding Hook (Stick) hanging on the wall disconnect directly behind the rear cubicle of BRK342. BRK342 is the last vertical cubicle on the left.

The Board observed the process for performing ZVV and placing grounds in the back of BRK75 on 1/18/2023 during the site visit (Figure 3-6). The sequence observed was:

1. Don 100 cal/cm^2 arc flash suits and Class 2 (17 kVAC) voltage rated gloves.

2. Open the cubicle door.
3. Perform a live/dead/live test with a proximity, capacitive tester attached to an insulated stick on the unshielded cables in the cubicle.
4. Perform a live/dead/live test with a contact, capacitive tester attached to an insulated stick after lifting the insulators with the stick (the Board was not able to see which insulators were lifted).
5. Discharge the cable stored energy with a grounding hook and cable attached to an insulated stick.
6. Apply temporary protective grounds manually.
7. Doff the PPE.

Both the proximity tester (Amprobe TIC 300 Pro) and the contact tester (Bierer VDA040P) used at SLAC are of capacitive type. This means that they only detect AC voltage, and will not detect stored energy in a cable, which is a DC charge.

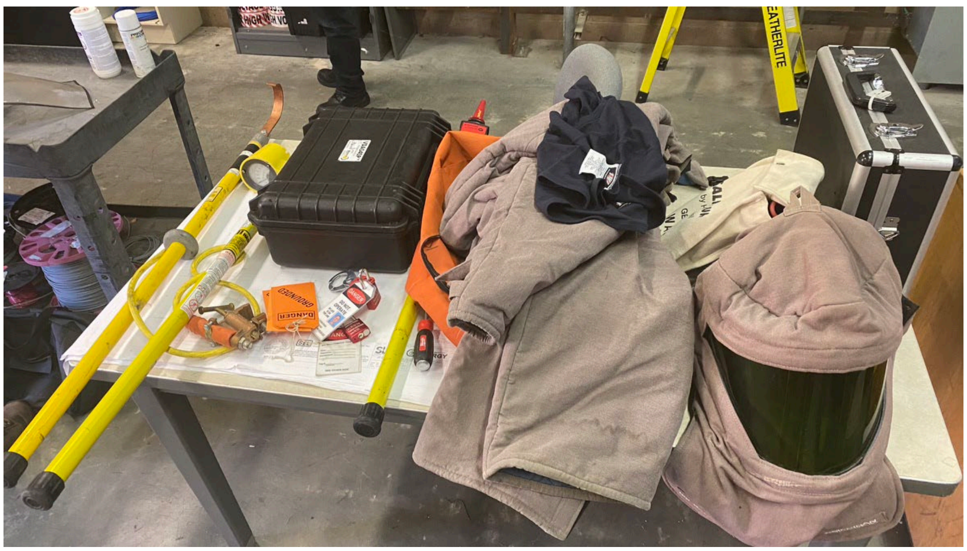

Figure 3-6: Example of PPE staged in preparation for ZVV and grounding at MSS BRK75 on 1/18/2023.

Note that different sites, both within and outside of DOE, employ various methods for establishing an electrically safe work condition on medium voltage switchgear. Some locations use only a proximity tester (always capacitive), some use only a contact tester (resistive or capacitive), and some combine both. Some locations will either use a resistive contact tester, which can both detect and discharge stored energy, and some just apply the temporary grounds with a live line insulating stick, where the initial contact dissipates any stored energy.

The Board inquired about the need for lifting the insulating boots by hand. Statements from all HVEs interviewed were consistent in that there are two favored test spots for ZVV on switchgear, both in the cable section behind the gear. The first is by lifting the insulating cover off of the feeder cable connection bus. If this is not feasible because the insulator is tight, then the second is by lifting the insulating boot off of the surge arrestor. Both are normally done by using the tip of the contact tester and a live-line tool to reach in and lift the insulation. The Board was able to see this demonstrated on equipment that had already been placed in an electrically safe work condition. However, some of the HVEs stated that the surge arrestor boot can also be too tight, so they sometimes have to reach in with voltage rated gloves and lift the boot manually. In BRK342 cubicle, the HV Supervisor demonstrated lifting the boot with the contact tester; the boot was loose and easy to lift (Figure 3-7).

Figure 3-7: HV Supervisor demonstrating how the contact tester is used to lift the insulating boot to barely expose the top of the surge arrestor on Phase A of BRK342 cubicle (already in an electrically safe work condition).

HVE1, HVE2 and HVE3 repeatedly stated that they believed that the IR-2 switchgear was fully deenergized. HVE2 and HVE3 repeated this belief to the San Mateo County Sheriff right after the event. HVE1 stated multiple times in interview that they did not know of any other sources to IR-2 substation, and that after performing ZVV at the 120V receptacle, concluded that IR-2 was fully deenergized. HVE1 further stated that the EWP contained no warning about an additional source still providing power to IR-2 substation.

In addition, work under LB6 was released to the six LVEs and later to the six subcontractors performing maintenance on the emergency panels. This indicates that HVE1 and HVE2 both felt that the EIP1 had been sufficiently established to release work under the lockbox, including all ZVVs being performed satisfactorily.

Based on the evidence, it is the Board's conclusion that HVE1 was not intending to perform ZVV, but rather to discharge the stored energy from the cables. By doing this, the HV team took an action expected to be part of establishing an electrically safe work condition and attempted to perform the step without having other controls in place. Even assuming that ZVV had previously been correctly performed, additional required steps to safely discharge the cable were not performed. Specifically:

- A 'test before touch' was not performed. ESH Manual Chapter 8 encourages liberal 'test before touch' with a proximity tester and requires it when the jobsite has been left unattended. This would have detected the presence of energized components in BRK342 rear cubicle.
- All workers should have applied personal locks to LB8. HVE3 recognized that the door to the rear cubicle of BRK342 was already opened but entered the arc flash boundary of the cubicle

without applying their personal LOTO lock. This could have been a chance to fully understand the SOW and the energy isolation boundary.

The exact reason for HVE1 selecting the rear cubicle of BRK342 was unclear. All of the members of the HV crew and HVPs agreed that standard practice at SLAC was to perform ZVV on 12.47 kV switchgear in the rear cubicle of a selected breaker. Although a grounding and testing cart (which can be inserted into a breaker racking mechanism to connect to the bus) was located in Building 626, these are not used at SLAC for performing ZVV or grounding in the front of the switchgear.

The Board analyzed multiple possible scenarios for HVE1's selection of BRK342:

- HVE1 possibly intended to enter the back of BRK340 instead BRK342. The final lineup of the breakers in IR-2 substation was such that all breakers were open with the exception of the tie breaker (BRK341) and the other mains (BRK340). A ZVV at the rear of BRK340 would have been logical, and ostensibly should have been the selected location in the EIP.
- HVE1 possibly chose to enter the back of BRK342 because the feeder from BRK75 to IR-2 previously came to BRK340 in the original configuration (see Section 3.3.1 for additional information). If HVE1 did not remember the configuration change, then BRK342 would have been a logical location for ZVV based on the prior IR-2 configuration.
- HVE1 possibly chose to enter the back BRK342 because EIP1 specifically identifies BRK342 as the location for ZVV. Although the Board also concluded that HVE1 was not in fact performing ZVV, selecting BRK342 because of EIP1 could have been a logical reason. If HVE1 had been following the EWP, SWO1 and EIP1, this would be consistent. However, HVE1 made a number of deviations from the documents and stated they were establishing a complete LOTO of IR-2 and S522 substations with four isolations and two set of grounds. This indicates they were not in fact following the EIP, but rather their own mental model of how IR-2 was connected.

Ultimately, HVE1's statements guided the Board to conclude that BRK342 was selected because they believed IR-2 was fully deenergized, and so the location did not matter.

Also of concern is the neglect of the shock and arc flash boundaries. Since no formal risk assessment was performed, neither shock protection boundaries nor the arc flash boundary were established before the door to the rear cubicle of BRK342 was opened. Although shock and arc flash boundaries are distinct, in practice workers will don both shock and arc flash PPE at the same time, since it is the voltage-rated gloves that provide arc flash protection to the hands.

Further, the arc flash boundary on the label for BRK342 was incorrect (64 inches instead of 59 feet) (Figure 3-8). The low value is an order of magnitude less than what should have been expected for the incident energy. During multiple interviews with planners and staff, there was no awareness of the necessity to use, establish or control the arc flash boundary in either planning or execution of work. The stated purpose of the arc flash label is primarily to specify the PPE rating. However, F&O EPD has a policy to require 100 cal/cm^2 arc flash suits for all high voltage work regardless of the labeled incident energy. As a result, all interviewed agreed that they just wear their 100 cal/cm^2 arc flash suits and therefore do not need to consult the arc flash label. This in turn results in a lack of field-checking of the labels, such that the incorrect arc flash boundary on the BRK342 label could not be identified during execution of the SWO.

Figure 3-8: BRK342 Arc flash label shows two (2) sources, including MSS BRK75. It also indicates an arc flash boundary of only 64," whereas it should be 59 feet.

As a direct consequence of this recurring practice of not establishing the arc flash boundary, workers were exposed to the arc flash hazard in multiple instances the day of the event:

- When using the remote racking device at BRK380, the incident energy was 20.57 cal/cm^2 at 36 inches working distance, and the arc flash boundary was 55 feet, one inch. By remote racking within 15-20 feet, the workers were inside the arc flash boundary.
- When using the remote racking device at BRK342, the incident energy was labeled at 16.8 cal/cm^2 at 36 inches working distance, and the arc flash boundary was 64 inches. After the Board inquired about this with F&O Engineering, it was corrected to 21.77 cal/cm^2 and 59 feet, 0 inches. By remote racking within 15-20 feet, the workers were inside the arc flash boundary and were not wearing the appropriate arc flash PPE.
- When the door to the rear of cubicle BRK342 was opened, HVE1 and HVE3 were inside the arc flash boundary without appropriate PPE. The shock event could have been an arc flash event, for instance if the grounding stick had been applied to lift the insulator instead of lifting it by hand, in which case these two workers would have been exposed to injury from the blast. Other persons, including HVE2 and the subcontractor attempting to place their lock on LB6, were also inside the arc flash boundary without appropriate PPE.

CC-9: Workers and Planners did not understand how to apply and control the shock and arc flash boundaries, resulting in worker exposure without appropriate PPE.

The Board observed during multiple interviews of F&O personnel a widespread and noticeable emphasis on PPE and skill of the craft. Some of those interviewed described HVE1 as someone who would never willingly violate PPE requirements for ZVV. Others were in disbelief at the accident and simply asked, "why didn't [HVE1] just wear PPE?" The Chief Electrical Engineer (CEE) expressed that SLAC provides a number of engineering controls and PPE that go above and beyond the requirements, including remote racking, remote switching and 100 cal/cm^2 arc flash suits. The CEE stated that all HVE1 had to do was wear the PPE. All of those interviewed shared their belief that HVE1 was highly qualified and experienced, and trusted their judgment in the execution of any HV Switching Order. HVE2 recalled that, after the Tailgate Meeting, HVE1 stated this was an “easy” job.

HVE1 was notified on two separate occasions with concerns about BRK75 and did not recognize the importance of the communication or stop to better understand the questions being asked. As a result, critical information on the BRK342 arc flash label about BRK75 being a source, and the indications that S522 was still energized from BRK75 were ignored and its associated hazards were not identified. Although HVE2 and HVE4 attempted to share their concerns, this was overridden by their own belief that HVE1 was in charge and knew what they were doing. HVE1 either did not respond, or responded but did not act on the concerns by HVE2 and HVE4. In turn, HVE2 and HVE4 did not press further. Although the F&O SWO procedure requires 100% Agreement by all those participating in the switching, less than adequate communications and deference to HVE1’s skill preempted further discussion. Workers were not able to self-identify that they were not in agreement, which would have triggered involvement of the HVPs, HV Supervisor, or ESO. The HV team missed an opportunity to fully understand the system configuration and identify a major deviation in the execution of the SWO.

CC-10: Ineffective communications during the execution of the Switching Order resulted in critical information on equipment status indicators being ignored and hazards not being recognized.

The Board reviewed two copies of field-completed EWPs for 12/27/2022. The first was in large (11”x17”) format and was used by HVE1 but signed by both HVE1 and HVE2. The second was in small (8.5”x11”) format and was used by HVE2 for establishing LB6.

The two LAEWs signed the EWP Worker Acknowledgment that states the following:

> “I understand and will adhere to the steps, hazards, and controls in this EWP. I understand that performing steps out of sequence may pose hazards that have not been evaluated nor authorized. I will contact the person who authorized my work continuing, if the scopes of work changes or new hazards are introduced, I understand my stop work authority and responsibility.”

HVE1 made two exclamation point (!) annotations on the first EWP, both during preparatory steps preceding execution of SWO1:

- Step 1.04: “LEAW Verify building manager for B620 is aware of the 4-hour outage to perform Preventive Maintenance before the generator is connected.” Note: ‘LEAW’ is an administrative error in the EWP and was intended to read ‘LAEW.’ (See Figure 3-9.)
- Step 2.03: “SLAC HV Electricians to place B620 E-generator controls in Off position.”

The purpose of the exclamation point notations is unclear but may indicate that HVE1 was aware of the urgency to get the generators connected as part of phase 1.

Hazard Analysis

1 - Notifications and Verifications				
Step or Task	**Step or Task Description**	**Hazard** (include shock and arc flash hazard information from the hazard label affixed to the equipment or from the electrical analysis engineer)	**Control** (include electrical safety PPE based on the electrical hazard information)	**Timestamp and Initials of Electricians performing step**
1.01	Using the COVID 19 best practices	Continued transmission of COVID 19 virus	Follow the latest procedures laid out by ESH for COVID 19 using the current COVID 19 JSA.	[redacted]
1.02	Verify WPC documentation is approved	Proceeding with unapproved work	Verify all needed signatures are in place.	
1.03	SLAC HV Electricians verify Remote Operation (Chicken Switch & Racking) devices are readily available in B726 & B626 Substations and in properly working condition	Entrance to Substation: Electric shock, arc flash injury	Wear PPE, Observe arc flash labeling	
! 1.04	LEAW Verify building manager for B620 is aware of the 4-hour outage to perform Preventive Maintenance before the generator is connected	Proceeding with "unreleased" work	Obtain verbal or written release from building or area manager	

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Figure 3-9: EWP showing the blue exclamation point to the left of step 1.04.

HVE1 made a number of yellow highlights on the EWP that seemed to focus on equipment ID and locations. In the column marked "Timestamp and Initials of Electricians performing step," one person marked four initials in the first row (for HVE1, HVE2, HVE3 and HVE4) with no time stamp, and then drew a line all the way down to the first stop point, 2.04.

On SWO1, one person marked 2 initials in the first row (for HVE1 and HVE2), with no time stamp, and then drew a line all the way down to the first completing the isolation at BRK342. Lock numbers L-112 and L-101 are written for BRK360 and BRK380, but no lock is written for BRK342. Subsequent ZVV steps performed on the 12.47 kV switchgear and the 480V panels were not marked off as complete.

On EIP1, one person marked 4 initials in the first row (for HVE1, HVE2, HVE3 and HVE4) with no time stamp. No line is drawn for subsequent steps. Lock numbers L-112, L-101 and L-73 are written for BRK360, BRK380, and BRK342. In interviews, the Board learned that these are typically assigned and written before execution by the LAEW.

The HV team repeatedly deviated from the documented work plan and its established controls. Specifically:

- Grounds were placed at BRK360 that were not in SWO1.
- ZVVs were performed out of order, starting with ZVVs at the MCCs instead of at the 12.47 kV switchgear.
- Two ZVV's were performed in a location different than indicated on SWO1 and EIP1:
  - MCC #2 ZVV was performed at the junction box.
  - IR-2 switchgear ZVV was performed at a 120 V receptacle.
- The battery disconnect was opened, although this was not in the SWO or EWP. This action disabled front panel indicating lights, meters, and relays.
- Multiple 12.47 kV breakers were opened in IR-2 that were not listed in SWO1. The Board could not determine who opened these or why they were opened.
- HVE3, a floater assigned to only assist HVE1 and HVE2, participated in a number of tasks that exposed them to hazardous energy.

Given the extensive nature of deviations observed, the Board concludes that the work team was not following the documented EWP, SWOs or EIPs in a step-by-step manner, and only used them for occasional checks. Instead, they were following a mental plan based on HVE1's system knowledge and a flawed perception of the high-level overview given by the HVP during the walkdown on 12/22/2022. The Board also concludes that there was an over-reliance on skill-based performance along with standardized and prescribed PPE. This obviated the need for task-level shock and arc flash risk assessments, resulting in a number of hazards and associated controls being missed during execution of the work.

Finally, by not performing absence of voltage verification (whether ZVV or 'test before touch') in the cubicle that was opened, the workers relied only on their personal belief that the cubicle was deenergized, and failed to identify that they had in fact strayed outside of the energy isolation boundary and into an energized cubicle.

CC-8: The work team deviated multiple times from the approved work plan without stopping either to question why they were doing it or analyze the hazards, which led to reliance on skill-based rather than rule-based execution.

JON 14: SLAC Supervisors need to conduct ongoing field verification of compliance with approved work plans, including mandatory step-by-step sequencing where required.

3.1.5 Feedback and Improvement

Facts

The most recent CoHE program self-assessment was performed in September of 2021. The self-assessment report has not been approved by the ESH division director. As such, issues identified in the report have not been recorded for corrective action assignment and tracking. This assessment largely identified administrative and execution deficiencies with a focus on construction project group lockouts. Some identified discrepancies include:

- Did not identify LOTO ID on Complex LOTO Permit.
- LAEW did not sign Complex LOTO Permit.
- An inadequate isolation was identified by an electrical sub-contractor performing 'test before touch.'
- The EIP for the job was not completed.
- The name of the LAEW was not present, and energy isolation steps and ZVV steps were not signed off.
- The single line drawing included with the EWP was not an issued drawing.
- The included drawing had been superseded and the most current version of the drawing was not used during EWP preparation.

The SLAC Electrical Safety Committee was discontinued in 2010.

Analysis

Field oversight by F&O line supervision and scheduled CoHE program self-assessments were not effective in identifying unsafe work practices. Reviews were largely focused on administrative requirements without determining how the LOTO program is actually implemented in practice. The annual authorized worker certification procedure is not an effective tool to assess work practices in the field. The procedure does not comply with the NFPA 70E (2021) requirements to perform field audits of work in progress annually. (See Section 3.3.4)

Field audits are a valuable tool to determine if workers are executing program requirements at the job site and it is missing from their program. The ESO is currently in a fully remote work status, which excludes them from conducting field audits of electrical safety and CoHE practices in the field. SLAC has not identified any other electrical safety SME available for field audits on site. SLAC management was not effective in identifying significant discrepancies in the performance of safe electrical work practices and CoHE program implementation, including ESH oversight.

JON 15:	**SLAC Management needs to ensure CoHE Program assessment and required annual periodic inspections are conducted.**

When the SLAC Electrical Safety Committee (ESC) stopped meeting, an important mechanism for providing input to ESH and SLAC management concerning electrical safety practices and implementation was removed. An ESC is a valuable resource for evaluating policies and procedures. Additionally, an ESC provides feedback on work practices and the members can contribute to program assessments. It was noteworthy that the last recorded ESC meeting minutes in 2010 included an agenda item covering the newly implemented designation of Lead Authorized Worker [sic] that was instituted to clearly identify a singular person responsible for managing and coordinating the Group LOTO activities. The EWP associated with this accident identified two LEAWs, nullifying the original intent. Within SLAC's ESH Manual Chapter 2, Section 2.2, the following statement is made:

> "The ESC may be convened from time to time as the need arises to review major electrical safety program changes or to provide advice on unique, unusual or particularly complex electrical safety concerns."

The ESC is a management resource that is not utilized. Despite several significant electrical safety events within SLAC and the DOE complex over the past 12 years, none have compelled SLAC to reconvene an ESC.

Workers are not providing feedback on work procedures after performance. The same or similar errors and omissions were identified by the Board upon reviewing EWPs performed prior to the accident. This indicates a breakdown in the post-work feedback processes. If feedback was provided to HVPs, it was not incorporated in the EWPs. If the HVPs solicited feedback, none was provided by the HV Group. Retaining and reviewing completed work packages can be an important component of an annual program audit, as is applied with Confined Space permits. Additionally, no formal process was used to capture EWP field changes, to record those changes for incorporation into future work plans.

Whether it was in response to the TA-53 accident at LANL in 2015 or some other reason, SLAC's EPD group recognized the value in creating "Danger Energized Keep Out" magnetic signs to help workers distinguish switching equipment that remained energized where adjacent equipment had been deenergized. However, the use of these signs was never mandated through an ESH Manual chapter or F&O policy. Over a relatively short period of time the use of these signs in the field was abandoned, and work plans had not specified their use. One of these signs was available within Building 626 in plain sight of anyone entering the building from the street-side as illustrated in Section 3.3.1. SLAC was ineffective in translating a lessons learned/safety initiative into sustained day-to-day operations.

The SLAC HPI training course, ESH 431, references the 2015 LANL TA-53 arc flash event and specifically highlights some of the associated human performance errors and necessity to clearly mark/distinguish between energized and deenergized equipment where look-alike equipment is present. Students taking the HPI training are given a quick reference tool to help them recognize error likely conditions and general techniques to help mitigate the associated risk. It's unclear if expectations are communicated to managers and line supervisors who complete the HPI training on applying the training principles to their work planning process and procedures.

The content in SLAC's Hazardous Energy Control training, ESH 157, includes photographs and descriptions of several events and conditions, including lessons learned from the fatality at the National High Magnetic Field Laboratory at Florida State University. Another example included a recent event at SLAC where two workers were in a scissor lift inspecting structural components on a crane with only one of the two workers having applied their CoHE lock and tag to the crane power disconnect.

Utilization of real events in worker training programs, including local incidents, are an exemplary means to convey lessons learned information to students. Real events impart relevance and significance on hazardous energy control program adherence and responsibilities. However, the impact will be less pronounced if not accompanied by incorporation of the lessons learned into safety policies and work planning.

3.2 Human Performance Error Precursor Analysis

The Board examined applicable error precursors as identified in the DOE-HDBK-1028-2009, *Human Performance Improvement Handbook, Volume 1: Concepts and Principles*, *Attachment B, Common Error-Precursor Descriptions*, to identify if and where error precursors were in existence in relation to the accident.

Human Performance (HP) Error Precursors (EP) are unfavorable conditions embedded at the job site that increase the probability for error during a specific action. In general, they are capable of creating mismatches between a task and the individual. Error precursors interfere with successful performance of a task and increase the probability for error. Simply stated, they are behavior or performance shaping factors.

EPs are identified by categories as represented by the TWIN acronym. Each category contains associated conditions as indicated by a corresponding alpha-numeric value as noted in Table 3-1.

Table 3-1: Common Error Precursors

Task Demands	**Individual Capabilities**
T1. Time Pressure (in a hurry)	I1. Unfamiliarity with task / First time
T2. High workload (large memory)	I2. Lack of knowledge (faulty mental model)
T3. Simultaneous, multiple actions	I3. New techniques not used before
T4. Repetitive actions / Monotony	I4. Imprecise communication habits
T5. Lack of proficiency / Inexperience	I5. Lack of proficiency / Inexperience
T6. Interpretation requirements	I6. Indistinct problem-solving skills
T7. Unclear goals, roles, or responsibilities	I7. Unsafe attitudes
T8. Lack of or unclear standards	I8. Illness or fatigue; general poor health or injury
Work Environment	**Human Nature**
W1. Distractions / Interruptions	N1. Stress
W2. Changes / Departure from routine	N2. Habit patterns
W3. Confusing displays or controls	N3. Assumptions
W4. Work-arounds	N4. Complacency / Overconfidence
W5. Hidden system / equipment response	N5. Mind-set (intentions)
W6. Unexpected equipment conditions	N6. Inaccurate risk perception
W7. Lack of alternative indication	N7. Mental shortcuts or biases
W8. Personality conflict	N8. Limited short-term memory

Out of the four error precursor categories, the analysis identified ten distinct conditions on the day of the accident. Table 3-2 summarizes the identified error precursor conditions and the number of times each one occurred during the day of the accident.

Table 3-2: Identified Error Precursor Conditions

Category	Condition	Specific Description of Condition	Error Precursor Code	Number of Occurrences
Task Demands	Time Pressure	Record rainfall leading up to the outage, resulting in flooding and erosion concerns in IR-2 area, increased environmental pressures the day of the outage and further raised schedule urgency and resource load.	T1	2
Task Demands	Interpretation requirements	Situations requiring "in-field" diagnosis, potentially leading to misunderstanding or application of wrong rule or procedure	T6	4
	Lack of or unclear standards	Ambiguity or misunderstanding about acceptable behaviors or results; if unspecified, standards default to those of the front-line worker (good or bad)	T8	2
Work Environment	Changes / Departure from routine	Departure from well-established routine	W2	3
	Hidden system / Equipment response	Lack of information conveyed to individual that previous action had any influence on the equipment or system	W5	1
	Unexpected equipment conditions	System or equipment status not normally encountered creating an unfamiliar situation for the individual	W6	1
	Lack of Alternative indication	Inability to compare or confirm information about system or equipment state because of the absence of instrumentation	W7	1
Individual Capabilities	Imprecise communication habits	Communication habits or means that do not enhance accurate understanding by all members involved in an exchange of information	I4	2
Nature (Human)	Mindset (intentions)	Tendency to "see" only what the mind is tuned to see (intention); preconceived idea	N5	4
	Inaccurate risk perception.	• Personal appraisal of hazards and uncertainty based on either incomplete information or assumptions. • Unrecognized or inaccurate understanding of a potential consequence or danger.	N6	5

It is important to note that error precursors are, by definition, prerequisite conditions for error and, therefore, exist before an error occurs. If discovered and removed, job-site conditions can be changed to minimize the chance for error. The Board identified several error precursors present at the time of the accident on 12/27/2022. Appendix G provides a summary and evaluation of those key events leading up to the accident.

3.3 SLAC Institutional Management Processes

3.3.1 Configuration Management

Facts

The accident occurred at Building 626, which houses the substation for IR-2. The area is known as the PEP ring area and was the site for the PEP and PEP-II science projects. PEP-II operated from 1999 up until it was ended in 2008. Since then, the area's facilities have since been partially repurposed for various other science projects. The LCLS Near Experimental Hall (NEH) and the Far Experimental Hall (FEH), as well as the LSST, are examples of big science projects in the IR-2 area.

Most of the PEP Ring 12.47 kV substations (5 of 7) are of a standard 'main-tie-main' construction and were originally dual-fed from the MSS. This means that each substation had two 12.47 kV feeders, one to each main breaker, originating from two separate breakers at the MSS. The exceptions are the IR-6 substation, which has a single main feed from the IR-4 substation, and the IR-10 substation, which has only one breaker fed from the IR-12. Most of the 12.47 kV feeder cables from the MSS to the PEP area date from the start of PEP-II (circa 1999), are of standard Ethylene Propylene Rubber (EPR) construction and are run through a common set of underground duct banks, vaults, and manholes. EPR cables have a typical life expectancy of 20-30 years, which can vary depending on installation damage, moisture intrusion and other factors.

S522, a newer substation installed before 2011 as part of the LCLS project, did not have the funding to install dedicated feeders from the MSS, and instead was tapped off the feeders to the nearby IR-2 substation. S522 feeds the LCLS NEH and FEH Central Utilities Plant and is also of standard 'main-tie-main' construction. In this original 2011 lineup, MSS BRK75 fed both IR-2 Bus 1 (BKR340) and S522 Bus 1 (BRK380). MSS BRK45 fed both IR-2 Bus 2 (BKR342) and S522 Bus 2 (BRK382). (See Figure 3-10.)

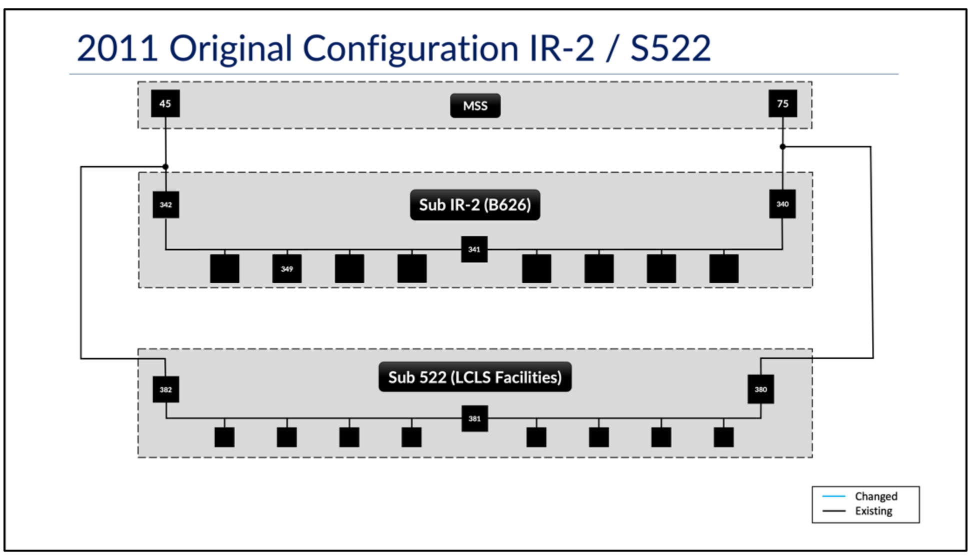

Figure 3-10: Feeder configuration when S522 was originally installed, tapped off of the two feeders to IR-2 substation, fed from BRK45 and BRK75.

Starting in 2015, F&O EPD implemented an Electrical Maintenance Program consistent with the requirements of NFPA 70E-2015, which now included safety-related maintenance requirements. As part of the program, F&O EPD began non-destructive testing ("tan-delta very low frequency" tests) of the 12.47 kV feeder cables across the site. Cables that failed the test were placed out of service pending replacement.

As a result of the age of the cables, at least 9 out of 11 cables tested in the PEP area failed, but not all at once. Without the PEP funding to replace all failed cables, F&O sustained power to the area by singling up substation feeders, establishing cross-connects, and using separable cable connectors to splice various sections of cable together in the common manholes.

By 2019, both feeder cables to IR-2 / S522 had failed and been removed from service and a new feeder was installed from BRK33 (Figure 3-11).

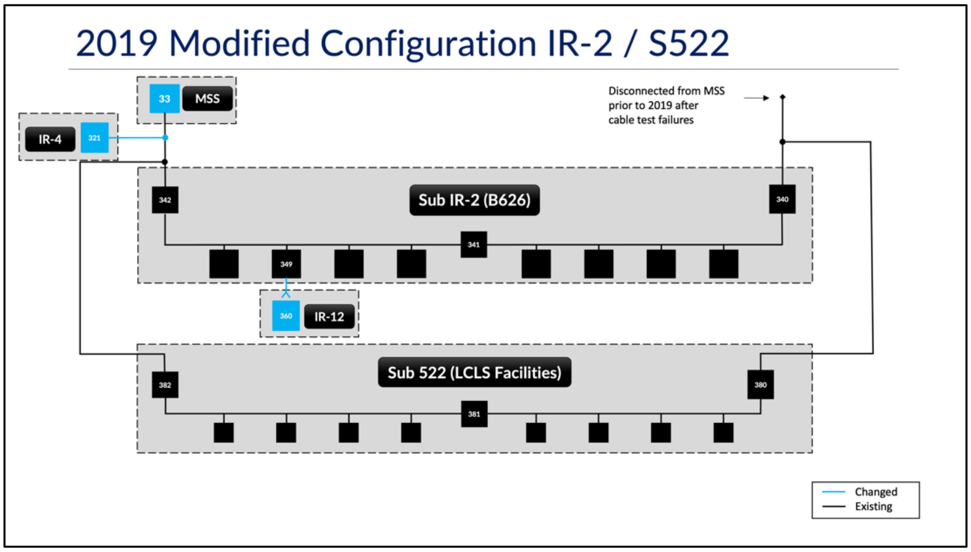

Figure 3-11: Feeder configuration as of 12/19/2019. The feeder from MSS BRK75 on the right has been eliminated, and the feeder on the left is now fed from MSS BKR33. IR-4 and IR-12 both lost their feeders from MSS and are connected to IR-2.

In 2021 another configuration change was performed to establish a single feeder from BKR75 to IR-2 and S522. BRK75 was now configured to feed Bus 2 instead of Bus 1 as was originally installed in the 2011 configuration. IR-4 was re-fed from IR-12's main breaker instead of BRK33. This configuration was in place at the time of the accident on 12/27/2022 (Figure 3-12).

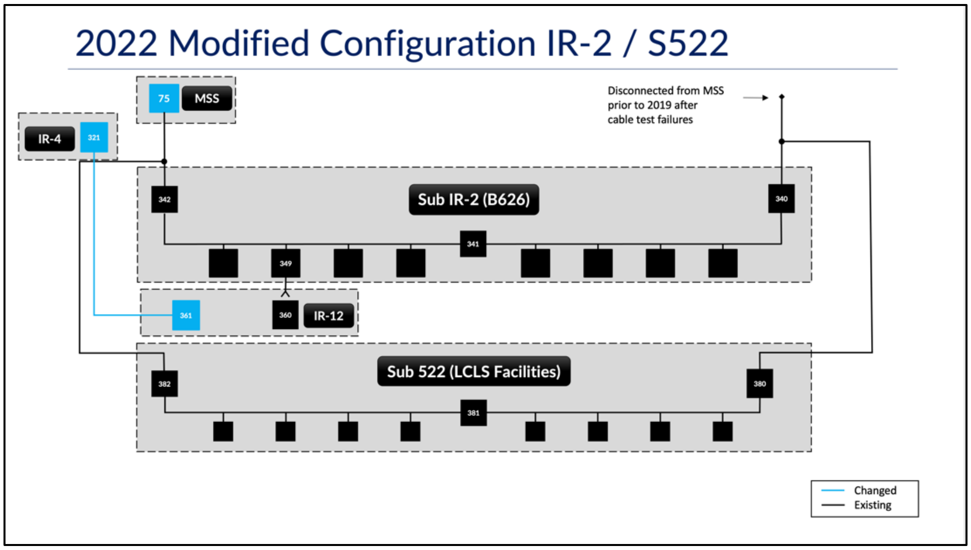

Figure 3-12: Feeder configuration as of 12/27/2022. The feeder from MSS on the left is now fed from BKR75. IR-4 is also now fed from the other main breaker at IR-12.

The CEE stated that EPD intends to replace one of the failed feeders in the duct bank and bring it directly to IR-2 substation BRK342 and leave the existing feeder from BRK75 dedicated to S522. However, there is no funding for the project. There is also an intent to replace both feeders to the IR-4 substation.

Drawings are posted in IR-2, S522 and IR-12, but are not up to date.

- In IR-2, the posted drawings are manufacturer drawings and do not show any connection to MSS.
- In S522, the posted drawings show the original configuration from 2011, where BRK75 feeds both IR-2/BRK340 and S522/BRK380.
- In IR-12, the posted schematic shows that BRK361 is fed from the MSS BRK41, instead of now feeding IR-4 substation. The arc flash label on BRK363 still shows MSS BRK 41 as a source, whereas it is now temporarily fed from Sub 45S.

Analysis

Physical Configuration of Feeder Distribution

By connecting S522 to the IR-2 feeders instead of installing dedicated feeders, the result was that IR-2 and S522 substations could no longer be deenergized independently from each other. This built in a permanent engineering compromise, such that all of the 5-year PM for both substations would have to be performed concurrently in a single outage. However, by 2022, the full scope of the outage exceeded the resource capabilities of F&O.

In addition, IR-2 and S522 substations incurred a number of feeder reconfigurations over the last 10 years. As the cables in the PEP area aged and failed testing, they were deenergized, disconnected, grounded, and abandoned in place.

The Board reviewed the EWP for the 5-year maintenance outage that occurred in 2018 for IR-2 and S522. In that outage, all of the substations were shut down. When it was time to plan the 2022 winter 5-year maintenance outage for IR-2 and S522, planners were faced with a number of additional constraints: there were not enough personnel to execute all of the maintenance on panels that would be connected to temporary generators for both IR-2 area and S522 area at the same time, and each substation area had critical equipment that could not be left offline more than a few hours. This led planners to innovate and develop an outage plan that staggered the shutdown of IR-2 and S522. This directly led to leaving IR-2 partially energized at BRK342 at the completion of EIP1. In effect, planners had to make compromises in order to develop an executable plan.

F&O EPD provided an annotated single line drawing dated 2019 showing numerous cable failures to the PEP area (Figure 3-13):

- IR-2 shows (2) failed cables from BRK45 and BRK75, and single feeder from BRK33.
- IR-4 shows (2) failed cables, and a temporary feed from the IR-2 feeder.
- IR-8 shows (3) failed cables, and a single feeder from MSS.
- IR-10 shows a single questionable cable.
- IR-12 shows a failed cable and a cross-feed from IR-2 with a questionable cable, and a cross-feed from Subs 45S.

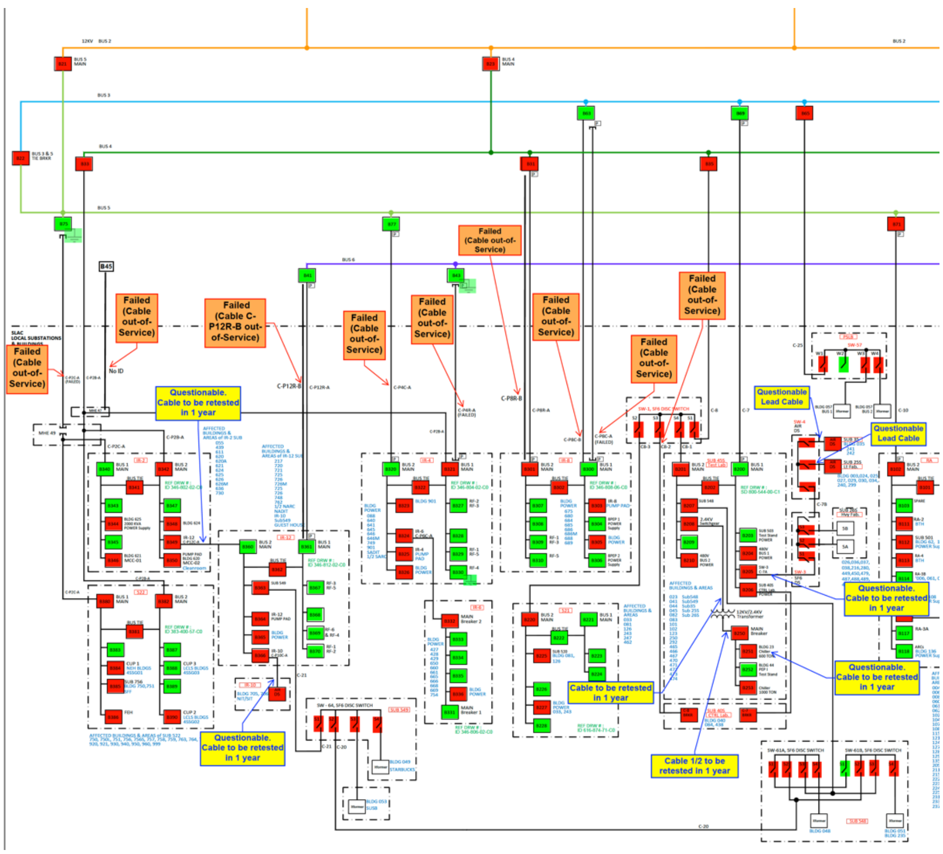

Figure 3-13: Annotated single line drawing from 2019 showing numerous failed cables to the PEP distribution area and multiple cross-feeds. Annotations by SLAC.

At present, a 2021 single line drawing shows there are still seven failed cables that are disconnected, grounded, and left in place. The cable feeding IR-10 from IR-12 has failed test but has been left in service, ostensibly because there was no option to refeed IR-10.

F&O EPD also provided a spreadsheet “Cable Testing Report Card” dated 9/1/2022 used for tracking and reporting on cable testing and results. It covers 211 individual feeder cables or cable sections, spanning 32 miles in total length. Of these, ~5 miles of cables have failed test and are out of service. 121 cables or cable sections (13.1 miles) are marked as overdue for test based on a 5-year test periodicity.

While the cross-feeds have created some additional power resilience in the form of multiple feed pathways, this also became an exceedingly complex and non-standard configuration. Further, this engineering practice became normalized across the PEP 12.47 kV distribution area. As cables failed and F&O funding was lacking for replacement, increasingly complex configuration solutions were developed to maintain power to the substations. Over time, what might have been temporary fixes turned into long term solutions and became an acceptable model for electrical distribution configuration control. This resulted in a reduced perception of risk during both the planning and execution phases.

EPD successfully initiated an Electrical Maintenance Program to reduce the safety risk to workers from aging cables. However, without the funding for timely replacement of the cables to maintain the original design, the safety risk was actually transferred instead of mitigated, and even increased as the necessary outages to keep performing maintenance became more and more complex.

CC-2: Compliance to maintenance requirements without sufficient resources resulted in reactive changes to the physical configuration of the 12.47 kV distribution system, with unintended consequences that increased complexity for work performed.

JON 3: Given the number of temporary modifications that have become permanent, SLAC EPD needs to develop and implement a risk-informed plan that aligns the electrical system configuration to safely support operations and maintenance activities.

JON 4: SLAC management needs to evaluate the operational risk associated with the EPD maintenance program test failures in advance of work authorization.

Configuration Management for Drawings and Labels

Several electricians were surprised when the control power ATS for S522 switched over when BKR342 at IR-2 was opened. The Board requested drawings to help explain the condition. The drawing provided out of SEDA, the SLAC drawings database, still reflected the 2011 lineup and matched the drawings posted on the wall inside S522 (Figure 3-14).

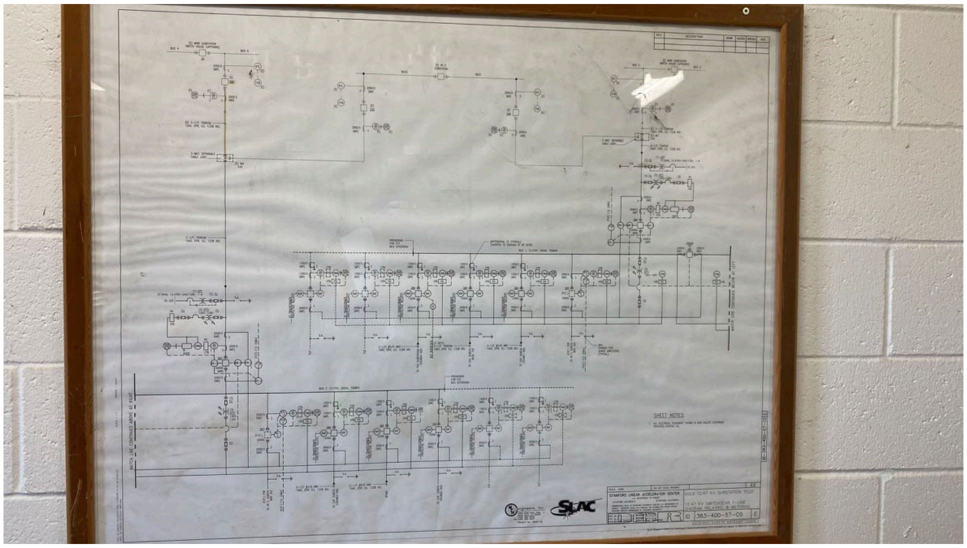

Figure 3-14: Posted single line drawing at S522 still showing the 2011 configuration, including connection to IR-2.

The ATS normal power source was selected to the line side of BRK380, which used to be fed from BRK75. After the reconfiguration that eliminated the direct feeder to IR-2 and S522 Bus 1 (sometime before 2019), the line side of S522 / BRK380 was now only fed from IR-2 through BRK342 (Bus 2 main), the BRK341 (tie) and BRK340 (Bus 1 main) (Figure 3-15). So, when BKR342 at IR-2 was opened, the normal supply to the ATS was interrupted and it transferred to the line side of BRK382, which was fed directly from BRK75 (Figure 3-16). This ATS configuration was unnecessarily complex. Control power interruptions from unrelated switching at IR-2 could have been eliminated if the ATS was reconfigured such that the normal side was the line side of BRK382. More importantly, the lack of updated drawings either in the field or in the EWP prevented ready diagnosis and forced the electricians to rely on expert knowledge alone.

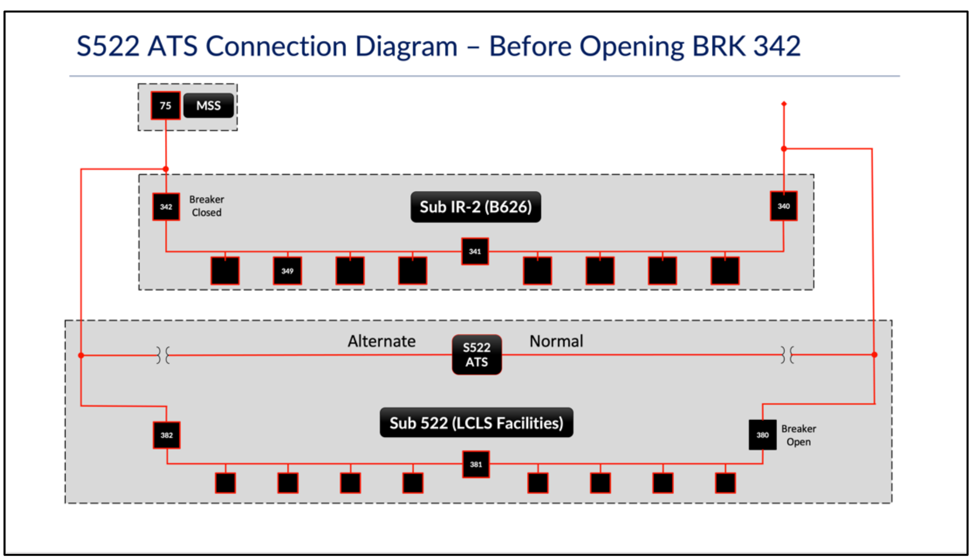

Figure 3-15: S522 ATS status on 12/27/2022 right before opening BRK342. The ATS is powered from both sides but is connected to the Normal Source on the right.

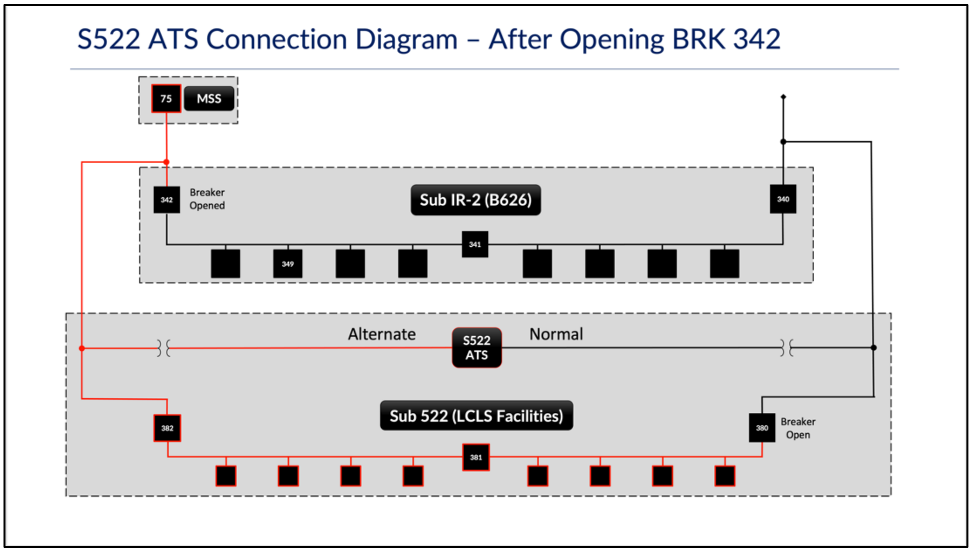

Figure 3-16: S522 ATS status on 12/27/2022 right after opening BRK342. The ATS is powered from the Alternate Source on the left. After a few seconds, the ATS transferred to the Alternate Source.

The condition of arc flash labels was less than adequate. Although SLAC has a practice of including the source (fed from) information directly on the label, some of these are out of date. The EWPs do not list arc flash information and just state "wear proper PPE," with the expectation that qualified persons can use the labels to determine the appropriate controls. However, the condition of arc flash labels does not permit reliable field usage.

Examples include (Figure 3-17 through Figure 3-20):

- Newer labels were placed on the main breakers at IR-2 and S522 to reflect the configuration change in 2021. However, all of the old labels remain in place on the other breakers. Even older labels (dated 2008) are on the rear doors of S522.
- IR-12, BRK361 is labeled as "Fed from IR-4," whereas it is IR-12 that feeds IR-4. The three arc flash labels on BRK361 have different values and do not match.
- IR-12, BRK363 had an arc flash label dated 2015 on BRK363 that showed MSS BRK41 as a source, even though there is a temporary sign above saying it is fed from Sub 45S.
- S522, BRK380 has an arc flash label on the rear cubicle that incorrectly states that it is fed from MSS BRK75.
- Arc flash labels throughout the site have started to fade, some to the point of becoming completely illegible.

Figure 3-17: BRK342 Arc flash label indicates an arc flash boundary of only 64", whereas it should be 59 feet.

Figure 3-18: BRK361 in IR-12 is labeled as "Fed from IR-4," whereas it is IR-12 that feeds IR-4. The three arc flash labels have different values and do not match.

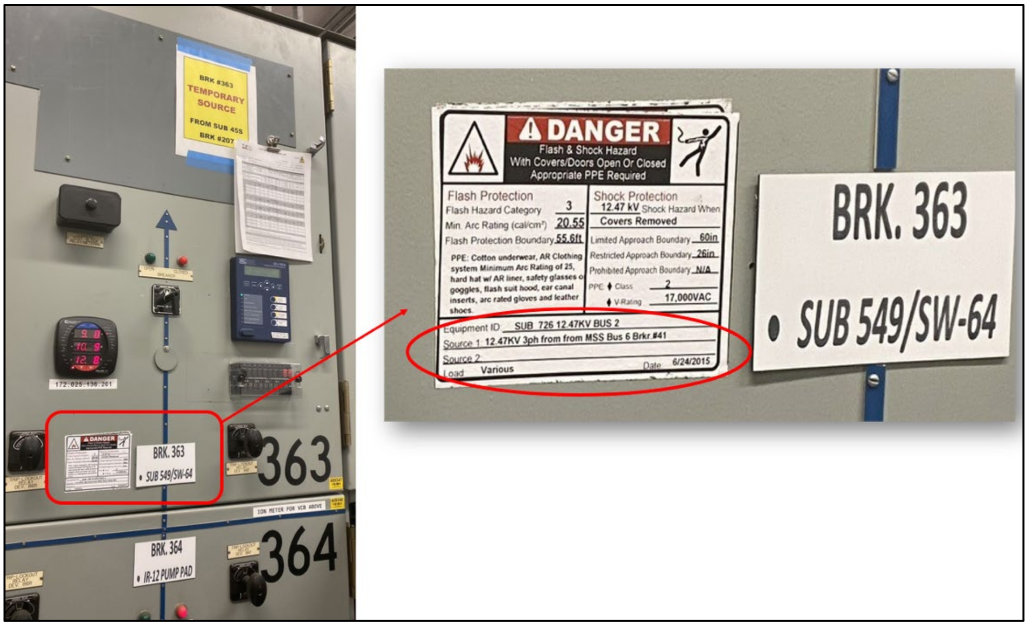

Figure 3-19: Example of 'temporary source' to IR-12 from Sub 45S that has been in place since before 2019 as a result of cable failures. The arc flash label still shows a single source from BRK41, and the arc flash values do not reflect updated conditions.

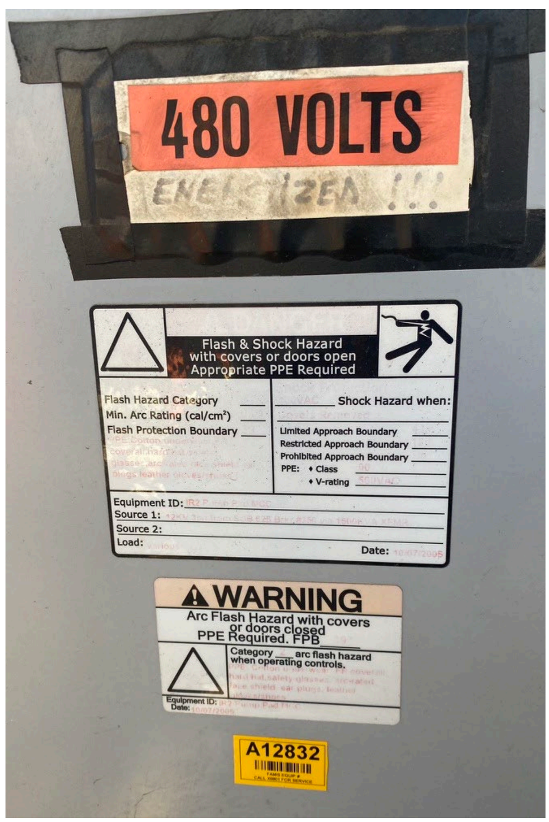

Figure 3-20: Illegible Arc flash label on MCC #1 at IR-2 Pump Pad where a ZVV was performed on 12/27/2022.

Less than adequate configuration management of the PEP 12.47 kV electrical power distribution led to challenging work planning, out of date labels and drawings, partially energized gear, and reduced perception of risk. As a result of insufficient configuration management, HVEs were not all equally aware of the multiple changes and had different mental models of the system configuration. Drawings and labels were known to be either not available or inaccurate, to the point that they were not consulted. Although HVEs knew that the outage de-energization plan was staggered, they did not understand that IR-2 would remain partially energized from MSS BRK75.

CC-3: Multiple configuration changes to the electrical distribution system feeding IR-2 and S522 during the previous years did not include the updating of applicable drawings, equipment identifications tags, and arc flash labels to reflect actual field conditions.

JON 2: SLAC Management needs to ensure that configuration of systems is accurately documented consistent with field conditions and available for use.

JON 5: SLAC Management needs to validate and maintain accurate equipment identification and hazard labels.

3.3.2 Supervision and Oversight of Work

Facts

The CEE has been at SLAC since 2006 and in the position for approximately one year at the time of the accident. The CEE was not at the job site when the accident occurred.

The HV group supervisor has been at SLAC for 19 years, with 10 years' experience in the HV group, and became the HV group supervisor approximately one year prior to the accident. The HV group supervisor was not at the job site when the accident occurred.

HVP1 and HVP2 were at the job site and have previous experience as HVEs. HVP1 was the previous HV group supervisor.

The ESH Coordinator assigned to F&O reports to the ESH Division Director. The ESH Coordinator for F&O is further supported by two staff members specifically assigned to provide oversight and inspections of construction projects.

Analysis

There are many work planning models. One example model balances three elements with respect to work planning and execution. Those elements are procedures, trained workers, and supervision. If fewer resources are invested in training, this likely must be compensated for in either the procedure or supervision (or both). Similarly, if a procedure cannot be very detailed because there are too many different paths to take and decisions that need to be made in a timely manner, this must be compensated for by increasing the training of the workers and/or through increased supervision. This model of work can be used as a problem prevention tool to think through an organization's strengths and weaknesses in each element and make adjustments as necessary. A conscious effort can then be made to adjust the size/detail of procedures, training, and supervision based on the complexity of the task, level of training/experience, precision needed for the job, and impact on safety. Weaknesses in EWP development and execution were not identified by

SLAC supervisors or managers. As a result, no evaluation occurred to determine if the training or supervision was adequate for the planned outage.

The HV group supervisor is extremely knowledgeable and conscientious and has a clear idea of how they expect the HV group electricians to do work. However, their expectations did not match work as performed. For example, 'floaters' are not expected by the supervisor to perform tasks in the EWP, just provide ancillary support. On the day of the accident however, HVE3 and HVE4 were performing tasks contained in the EWP. This indicates a certain level of detachment with respect to supervising the day-to-day work of the electricians in the HV group.

Lack of supervisory or EHS oversight allowed CoHE and electrical work practices to deteriorate to an unsafe level over time. The Board interprets the actions surrounding the creation of LB6 as a failure of supervision and oversight, in that this specific circumstance was allowed to occur. The HV and LV group electricians, as well as HVP2 in their capacity as subcontractor representative, accepted LB6 as adequate and did not question it, contrary to SLAC's own procedures and training.

While present at the job site, HVP1 and HVP2 did not exercise effective supervisory oversight to identify and correct unsafe electrical work practices, even though both have relevant experience with HV group electrical work practices and CoHE. Additionally, HVP1 missed the opportunity to intervene on a procedural change at the job site without evaluating the potential for introducing new hazards. In this case, HVP1 was present when the battery bank disconnect was opened, which removed all front panel indicators that would have provided visual indication the switch gear in Building 626 remained partially energized.

Safe work practices are reinforced through a healthy safety culture, including supervisor oversight and peer interactions.

Line management or supervisors did not ensure persons assigned to the work understood the specific hazards and controls.

The ESH Division Manager and Deputy Manager described their office as being responsible for developing and maintaining ESH programs and policies and providing support to the Directorates. The ESH Coordinators are embedded/co-located in the line organizations to facilitate their support in a timely and efficient manner. Regular meetings are held among the Safety Coordinators and ESH Division management to communicate the status of ESH programs and share information.

SLAC Manual Chapter 42, *Subcontractor Safety*, section 2.3 covers the responsibilities of the Project Manager for Non-Green Work, stating:

> "An SM (Service Manager) will be assigned to all non-green service subcontracts. At the discretion of line management, the SM will also fulfill the responsibilities of the PM (Project Manager)."

Section 2.3 also includes responsibilities assigned to the Project Manager/Service Manager including requesting and approving subcontractor's Site-Specific Safety Plan, completion of the Non-Green Work Procedure, and ensuring subcontractor compliance with SLAC requirements. Subcontractor oversight and approval responsibilities are likewise assigned to the ESH Coordinator in Section 2.7 of Chapter 42.

The ESH Coordinator for F&O was not able to furnish examples or records supporting the completion of prior field oversight activities on service subcontractor work, nor an example where feedback had been provided on service subcontractor performance of hazardous energy control activities. Upon inquiry, ESH Division Management has not set any expectations on the frequency, manner, or documentation of field oversight activities to be performed by ESH Coordinators, instead deferring to the ESH Coordinator's discretion on how support is provided to the line organization.

Based on the evidence and interviews collected by the Board, service subcontractors are not being managed by SLAC to verify written program compliance with SLAC requirements, including vetting of subcontractor training and qualifications relevant to their SOW. More broadly, and at multiple organizational levels, oversight responsibilities are not being fulfilled to objectively evaluate and monitor the performance of work in the field, as specified in SLAC policies and procedures.

3.3.3 Safety Management Systems

Facts

The overarching SLAC Injury Illness and Prevention Program, including all of its Safety Management Programs, processes, and procedures, are captured in its ESH Manual. The most relevant chapters for the incident include:

- Chapter 2, *Work Planning and Control,* released 5/10/2021.
- Chapter 8, *Electrical Safety*, released 7/5/2022.
- Chapter 42, *Subcontractor Safety*, released 5/21/2021.
- Chapter 51, *Control of Hazardous Energy*, released 7/5/2022.

The SLAC ESO is the program owner for both Chapters 8 and 51. Chapter 51, *CoHE* captures the institutional LOTO Program and includes the requirements for ZVV. All other electrical safety requirements are in Chapter 8, *Electrical Safety*.

By contract, SLAC is required to comply with the latest version consensus standards and develop a schedule to implement the latest version consensus standards for approval by SSO. The SLAC Electrical Safety Program states that SLAC follows the latest NFPA 70E at the start of the year after publication. As such, SLAC was subject to the requirements of NFPA 70E-2021 at the time of the incident.

Analysis

The Board did not perform an assessment of the ESH Manual or its individual programs and did not assess either the Electrical Safety Program or the CoHE Program. However, it made a number of observations during the course of its investigation.

Chapter 2, *Work Planning and Control*

Overall, the ESH Manual Chapter 2 WPC Program is well-defined. The Board noted various gaps in the implementation of Chapter 2 that are of consequence to the accident. These gaps are identified and analyzed in Section 3.1 of this report.

Chapter 8, *Electrical Safety*

Overall, the Electrical Safety Program is well-defined. The Board noted a few gaps that are of consequence to the accident:

- The requirement for a Job Briefing in Section 10.1 conforms to the 2015 edition of 70E and has not been updated to the 2021 edition. The newer edition requires the Job Briefing to cover the documented Job Safety Plan. Also, the Job Briefing is embedded in a section called "General Safety Rules" and is not integrated into other WPC functions, such as the Tailgate Briefing in Chapter 2. A proper Job Briefing or Tailgate Briefing could have better communicated the overall hazards and controls for the outage.
- The requirement for a written Job Safety Plan for every job, that includes task-specific shock and arc flash risk assessments, is not contained in Chapter 8. The EWP required by Section 10.3.3 substantially meets the requirements of a documented Job Safety Plan, but its required components could be updated to match 70E-2021.

- The two-person rule of Section 10.3.7 closely matches the language of OSHA 1910.269(l)(2). It has been modified somewhat to match NFPA 70E boundary language. Like OSHA, it does not specify the role of the second person. OSHA has issued a letter of interpretation that the second qualified person referenced in 1910.269 "should be able to point out poor work practices to their fellow employees." The safety watch roles and responsibilities are well defined in Section 2.6, and if used would fully meet OSHA intent. However, there are no prescriptive conditions that trigger the use of a safety watch, as it must only be used "when deemed appropriate by the supervisor." A Safety Watch Person was not called out in the EWP for this outage, nor was it found in prior EWPs reviewed by the Board. The Board believes that a dedicated Safety Watch Person as described in Chapter 8 could have prevented the incident, while the Two-Person Rule as written, could not.
- Chapter 8 does not contain any mention of alerting techniques, nor does it prescribe the use of alerting techniques for lookalike equipment that remains energized after the equipment to be worked upon has been placed in an electrically safe work condition. SLAC has made previous use of magnetic signs to identify energized gear, and these are available throughout the site. One of these was found, unused, on the side of IR-2 substation near the entrance (Figure 3-21). However, there is no reference in Chapter 8 to when these should or must be used.
- Chapter 8 does not explicitly incorporate elements of HP into its electrical risk assessment procedure as required by NFPA 70E-2021, Article 110.5(H)(1). This was unexpected given that SLAC has demonstrated that it has a substantive (optional) HPI training course (ESH-431) that was developed and taught by the SLAC ESO and contains a number of relevant electrical safety applications. Some of the examples in the training specifically address the hazards of lookalike equipment and partially energized switchgear, including lessons learned from the 2015 arc flash accident at LANL. However, these are not integrated into either electrical safety work practices or WPC for electrical work. ESH-431 is currently not required training, but 98 personnel from F&O have completed the training, including 39 from EPD.
- Chapter 8 does not prohibit the wearing of jewelry or conductive articles within the restricted approach boundary as required by NFPA 70E-2021, Article 130.8(D). Conductive articles were worn by HVE1 into the restricted approach boundary, including two bundles of keys on retractable lanyards attached to their belt. The presence of these conductive articles during the performance of high voltage switching and testing activities, even if covered by outerwear, is indicative of a lack of rigor in applying safe electrical work practices.

Figure 3-21: Temporary yellow magnetic Danger sign applied to IR-2 switchgear. The photo on the left shows the sign as found by the Board on the side of the gear. The photo on the right shows the sign applied to the rear door of BRK342 cubicle after the event for demonstration purposes by the HV Supervisor.

- Chapter 8 does not include an emergency response section that would include safe contact release and actions needed to activate EMS, rapidly obtain an AED, and make the scene safe. While insulated rescue hooks were noted in multiple substations (Figure 3-22), none were present in Building 626, and these are not used or staged as part of emergency preparedness. Emergency call numbers posted inside substations are several years out of date.

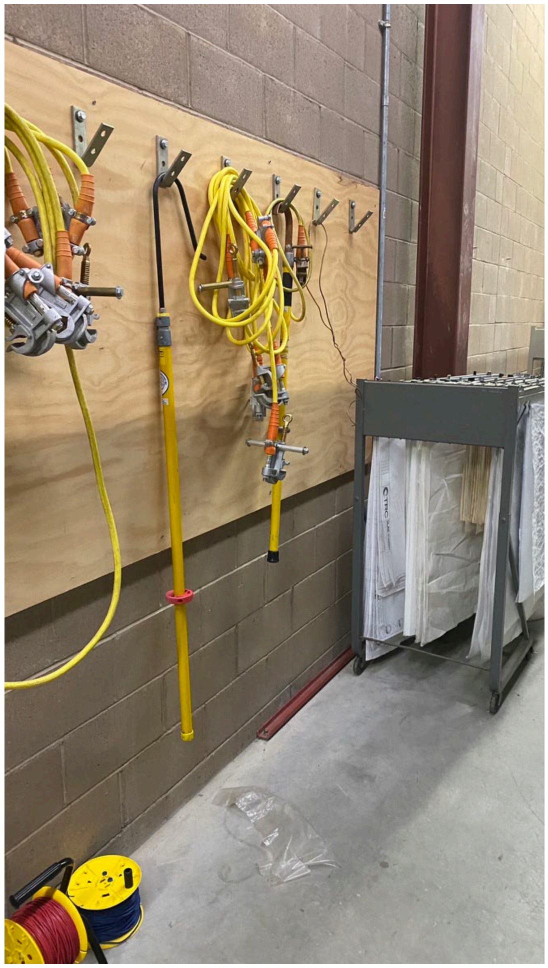

Figure 3-22: Insulated rescue hook stored in the Master Substation.

Field observations during Board onsite activities:

- Job briefings were not performed in accordance with SLAC requirements.
- Arc flash boundaries are not used, established, or controlled. As a result, bystanders are allowed too close to switching activities, and HV workers in daily arc-rated wear are inside the arc flash boundary when performing remote switching and racking. The remote switching panel in Building 522 appears to be within the 55-foot arc flash boundary of the switchgear.
- Exterior labeling of electrical equipment and buildings is in extremely poor shape (Figure 3-23).
- Workers mentioned using 'breaking the plane' as the boundary for applying personal LOTO, whereas this should be the Limited Approach Boundary once the equipment has been placed in an electrically safe work condition.
- Two sets of voltage-rated gloves (both Class 0 / 1000VAC and Class 2 / 17 kVAC) found in HVE1's work vehicle were last tested on 5/10/2022 (Figure 3-24). These are required to be retested every 6 months, and so were past due after 11/9/2022.

Figure 3-23: The main door to Building 626 / IR-2 Substation features dilapidated safety signs. The Danger sign on top has come off, and the label indicating minimum PPE for entry is peeled off and illegible.

Figure 3-24: Class 0 (left) and Class 2 (right) sets of voltage gloves found in HVE1's work vehicle.

- Multiple instances of uncontrolled, exposed live parts were noted inside substation buildings:
    - 120 VDC battery banks are left exposed to unintentional contact. The CEE directed that the battery bank inside IR-2 substation was to be covered with temporary insulating blankets before allowing the Board to enter. Other substations, such as IR-12 and S522, had the same recognized condition that was not mitigated. (See Figure 3-25 through Figure 3-27.)

Figure 3-25: Battery bank at IR-2 Substation with insulating blankets over exposed energized terminals.

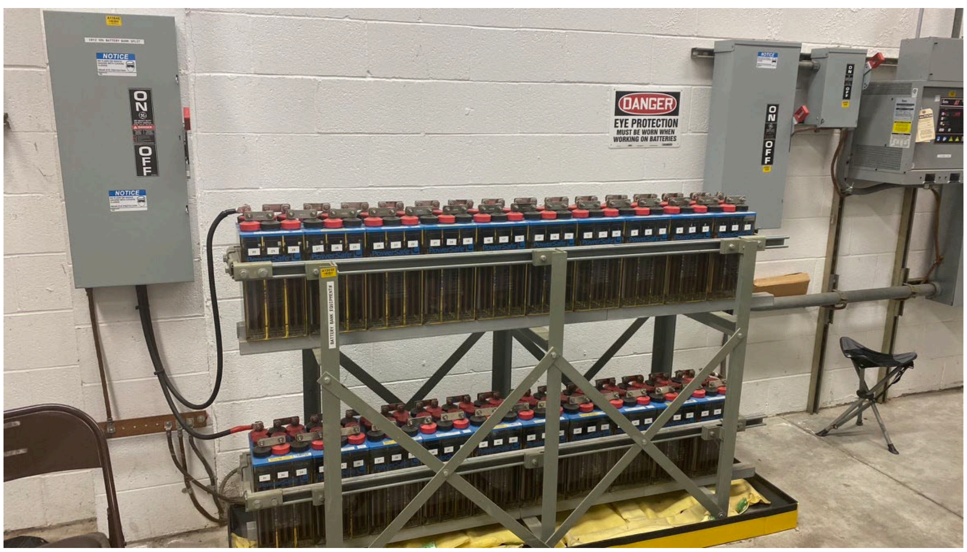

Figure 3-26: Battery bank at IR-12 Substation with exposed energized terminals.

Figure 3-27: Battery bank at S522 Substation with exposed energized terminals.

- In Building 16 Master Substation, the rear cabinets of the main SCADA control and display panels are left uncovered, with exposed live 120 V AC and DC components inside (Figure 3-28). While the CEE stated these were finger safe, they did not appear to be rated at IP2X, and the multiple signs state that these are considered exposed.
- Although these buildings are normally only accessible to qualified persons with keys to the entrance doors, the exposures are unnecessary and demonstrate an insensitivity to the hazards.

Figure 3-28: Back of MSS SCADA racks, labeled "Caution 120V AC/DC Exposed Energized Parts" all around.

<u>Chapter 42, Subcontractor Safety</u>

The SLAC ESH Manual Chapter 42 describes how to qualify prime subcontractors and identify and manage all ESH aspects of subcontracted work. It also includes expectations for communicating responsibilities for subcontractor safety to affected SLAC and subcontractor personnel and communicating ESH expectations and hazard mitigation requirements, as documented in the hazard-specific chapters of SLAC ESH Manual, to affected SLAC and subcontractor personnel. Overall, the Chapter 42 is well defined at addressing the flow down of requirements and setting expectations for subcontractors working on site at SLAC.

Specific to the event, the Board made the following observations:

The SOW during the Holiday Shutdown included PM and electrical system testing to be performed by a subcontractor. The subcontractor's specific SOW and contract requirements were contained in a firm fixed-price contact within SLAC Purchase Order (PO) 22526, "Sub 522 & 626 Electrical Testing and Maintenance." The PO was signed by the SLAC Contract Administrator and SLAC Point of Contact (POC) on 12/9/2022, and subsequently signed by the subcontractor's owner/president on 12/12/2022. The SLAC POC identified in the contract was also a principal planner of the EWP for the holiday outage and associated PM work.

The following statements were included within the PO for the service subcontractor that was responsible for performing electrical system PM and testing:

- "Supplier shall contact POC for on-site safety requirements, job briefing and schedule prior to beginning work."
- "The subcontractor shall be NETA/NICET [National Institute for Certification in Engineering Technologies] accredited or approved equivalent and provide a minimum of one accredited/equivalent level technician for each non-accredited/equivalent technician."
- Subcontractor shall participate in all LOTO activities, in accordance with the SLAC Control of Hazardous Energy (COHE) procedures."

SLAC ESH Manual Chapter 42, *Subcontractor Safety*, includes the following requirements:

- Section 3 requires all subcontractors at SLAC to either submit an injury and illness prevention plan (IIPP) that complies with the DOE Worker Safety and Health Program (10 CFR 851) or adopts SLAC's 851-compliant IIPP.
- Section 2.7 requires subcontractor submittal of a Site-Specific Safety Plan (SSSP) for ESH Coordinator review and approval.

In conjunction with the work to be performed under the PO, the information submitted by the subcontractor to the SLAC POC was limited to the following worker training and qualification records:

- NETA certifications
- First Aid/CPR certifications
- OSHA hazardous energy control training completion certificates (1910.147)

Contrary to SLAC ESH Manual Chapter 42 requirements, SLAC did not require the subcontractor to submit an IIPP or SSSP for approval. SLAC also did not require the subcontractor to submit their company's hazardous energy control program for review and acceptance. Training completion certificates for OSHA 1910.147 alone would not cover how a company implements its written hazardous energy control program in accordance with the Standard. When coupled with the fact that subcontractors were not required to complete SLAC CoHE training (ESH 157R), there was no contractual means in place to affirm subcontractor workers were briefed on or understood the Group LOTO requirements contained in SLAC ESH Manual Chapter 51. The SLAC POC for the PO/subcontractor affirmed there was no formal process in place to assess or record if individual service subcontractors understood the relevant requirements of SLAC's hazardous energy control program.

Chapter 51, Control of Hazardous Energy

The CoHE Program in Chapter 51 is well-defined, structured, and complete. The Board noted a few gaps that are of consequence to the accident:

- Testing requirements of NFPA 70E-2021 Article 120.4(B)(6) are not incorporated into the ZVV process:
  - There is no requirement to "define the boundary of the electrically safe work condition." In the event, workers unknowingly crossed into the hazardous areas of the energy isolation boundary. It was not identified on the single line drawings attached to the EWP, and none of the documents included a warning that IR-2 remained partially energized.
  - There is no requirement to establish "planning considerations that include methods of verification where there is no accessible exposed point to take voltage measurements." HV workers have expressed that they need to routinely lift insulating covers off of circuits parts in order to perform contact ZVV. Sometimes, the insulators are on too tight to remove with a live line tool and must be lifted by hand. This exact scenario played out during the incident. For example, ball and socket grounding equipment have insulating covers designed to be removed with an insulating stick and could be a safer means to test and place grounds.

- The EIP required in association with a Group LOTO is required to be performed step by step. Similarly, the SWO and the EWP are also required to be performed step by step. Some workers defer to the SWO only, and use the EIP as a final state checkoff, while others state that they place both side by side to execute in parallel. Meanwhile, isolations not covered under the SWO are left out and sometimes put in the EWP, sometimes not. This leads to confusion as to which document is a procedure, which one is to be followed, and inconsistency in practice.

JON 13: SLAC Management needs to ensure the alignment between the EWP, SWO, and EIP, including better defined roles and responsibilities and interdependence between the documents.

- The Chapter 51 ZVV process includes a step that could be misconstrued and applied unsafely. After opening the energy isolations, determining that equipment will not operate, and applying locks and tags, Step 4 states that the electrical worker "discharges and grounds all energy storage components." Step 5 is to perform ZVV. The hazard is that someone could attempt to discharge a high-energy circuit that is still fully energized without performing ZVV first. The same step in NFPA 70E-2021 reads differently, only stating: "Release stored electrical energy." Performing this step before ZVV is about allowing the required self-discharge time to elapse or performing a controlled discharge with a tool rated for the full available energy. Grounding should not happen until after ZVV. While the Board does not believe this sequence played a factor in the accident, the Board did conclude that the HV team was about to apply a ground stick to a live high voltage component without performing ZVV. Even had HVE1 not made contact while lifting the insulating boot, this next step would have had disastrous consequences for both workers involved, who were not wearing the appropriate PPE.

Many of the following findings related to implementation of CoHE the day of the accident are considered severe and are of serious concern to the Board:

- SWO2 directed placement of temporary protective grounds before all isolations were implemented. The Board reviewed a number of SWOs dating back to 2018. Past SWOs orders clearly established all isolations first, then performed all ZVVs, then required workers to apply personal LOTO locks, then directed application of grounds. However, this fell out of practice over the last few years, such that it has now become routine to isolate, ZVV and apply grounds at each location before moving to the next. This practice places workers at risk, especially when/if workers execute steps out of sequence.

- Contrary to Chapter 51, Group LOTO locks were consistently applied without the Group LOTO tags (Figure 3-29) to identify them as associated with a Group Lockbox. Lockboxes were not identifiable such that they could be associated with the correct EIP, once the document was removed from the protective sleeve. The Board had considerable difficulty in determining which locks belonged to which procedure. When asked, the Board was told that the lock number is written on the EIP and SWO for tracking purposes. However, if the EWP is unknown or cannot be found, it remains very difficult to determine the purpose of the lock. The Board found key #111 in LB6, but since there was no EIP attached, it took several days and multiple site walks to finally locate the lock on BRK342, as this was not an expected location.

Figure 3-29: Group LOTO locks applied to BRK342 without Group LOTO tags and without any identifying information other than the number on the lock.

- LV Electricians were directed by the EWP to perform a simple LOTO at 2PEP-I, Breaker A to perform air-gapping of normal power to the ATS at Building 620 (Figure 3-30). However, the work was to be performed inside a junction box that also contained the load side feeder wires from the ATS. This should have also required LOTO isolation of the emergency generator, and therefore a Complex LOTO.

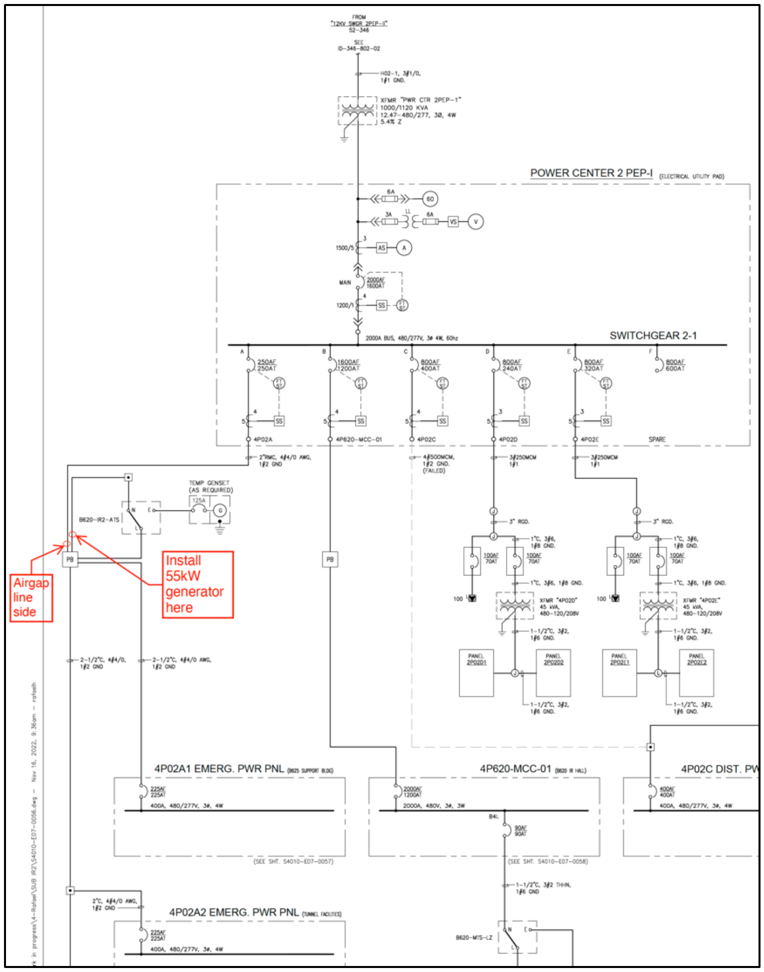

Figure 3-30: Cropped capture of single line drawing attached to EWP showing where to air gap the normal power to the ATS. The load side feeder runs through the same enclosure. Breaker A in Power Center 2 PEP-I is directly upstream and is fed from BRK346 in IR-2 substation.

- Isolating at 2PEP-I, Breaker A when the upstream power was already secured by EIP1 presents a different challenge. Since there was no power on the line side of 2PEP-I Breaker A, a ZVV downstream would not prove that the isolation was correctly implemented. A better solution would have been to develop a separate lockbox, with an EIP that added one group LOTO lock to LB8 and another to the generator.
- It appears that HVE1 recognized the overall intent. They did not want to have a generator group LOTO lock key added inside LB8. This would require every worker locked on to the box to pause work and remove their locks in order to retrieve the generator lock key. However, they misinterpreted the EWP structure and believed that HVE2 was to set that up while they (HVE1) proceeded with the full isolation of IR-2 and S522.
- HV and LV electricians then developed a new lockbox (LB6) that contained a group LOTO lock for BRK342. No EIP was used since it was a considered a "Simple LOTO." No LOTO lock was applied to the Building 620 E-generator since the EWP only directed to place the generator controls in "off" position. As a result, the single lock (#111) applied to BRK342 did not isolate all sources of power to the downstream equipment. An additional three isolations would have been required for safe work (BRK360, BRK380, and the emergency generator).

- Contrary to Chapter 51, no orange Master Group LOTO Lock tag was attached to the LAEW's personal lock on LB6. This orange tag is to signify that the lockbox is completed and ready for use. Despite this, HVE2 released LB6 for the LVEs to apply personal locks. The six LVEs did not question the completeness of the lockbox. In interviews, one stated that when they saw they lights go out, they knew the substation was deenergized and they could go apply their LOTO locks.
- Workers signed onto LB6 by signing the Complex LOTO Permit associated with EIP1 and attached to a copy of the EWP used by HVE2, but different than the one being used by HVE1. In HVE2's copy, EIP1 was not completed, and the page was left blank, with no lock numbers or check off initials.
- One LVE interviewed stated that after locking on to LB6 they performed ZVV with a non-contact voltage detector.
- Later, after break, six subcontractors also joined LB6. Again, this lockbox did not provide protection from upstream circuits as only BRK342 was controlled. It was not clear whether this was at HVE2's direction, or if this happened without HVE2's knowledge.
- Finally, a 7th subcontractor arrived at around 0900. This subcontractor was scheduled to arrive later to participate in EIP2 and perform maintenance on the 12.47 kV breakers. Although EIP2 had not even been started, they were directed by another subcontractor to go apply their personal LOTO lock to LB6. By then, the LAEW (HVE2), the six LVEs, and the six subcontractors had already filled up all (13) available attachment points on the lockbox. The 7th subcontractor could not apply their lock and proceeded to inquire with HVE2 who had just entered Building 626. HVE2 just directed the seventh subcontractor to get someone to remove their lock and use a hasp and did not question why subcontractors had locked on to the box.

Field Observations during Board onsite activities:

- Contrary to Chapter 51, Group LOTO locks were consistently applied without the Group LOTO tags to identify them as associated with a Group Lockbox.
- Contrary to Chapter 51, administrative locks are used with red and black Danger tags that are identical to the red, white, and black danger tags used for control of hazardous energy (Figure 3-31). This was observed throughout all visited spaces. When questioned, the Board was told this was an acceptable practice.

Figure 3-31: Examples of administrative locks applied with LOTO tags.

- EPD provided tags to the Board for use as personal LOTO tags that did not comply with Chapter 51 requirements (one was an administrative tag, and another was a group LOTO tag) and required repeated prompting by the Board to correct.
- The High Voltage Lockbox used on 1/3/2023 (to fully isolate IR-2 and S522 substations for inspection of BRK342 rear cubicle) was found next to LB6 and LB8 in Building 626:
    - The lockbox was identified with green duct tape as "IR-12 Lockbox", whereas it was used for IR-2.
    - An orange Group Lockout Master tag (Figure 3-32) was still attached to the lockbox with the HV Supervisor's personal LOTO lock. No LOTO ID was written on the tag, and it had HVE1's name on it. (HVE1 had not been onsite since 12/27/2022.)
    - Only one key was in the box, for the lock applied to BRK360 at IR-12. The associated EIP also had BRK75 isolated and grounds applied. However, the key for BRK75 had already been removed to close BRK75 and reenergize S522 at the end of the 1/03/2023 outage. The condition of the lockbox, with the orange tag, would indicate that the full LOTO was still established.

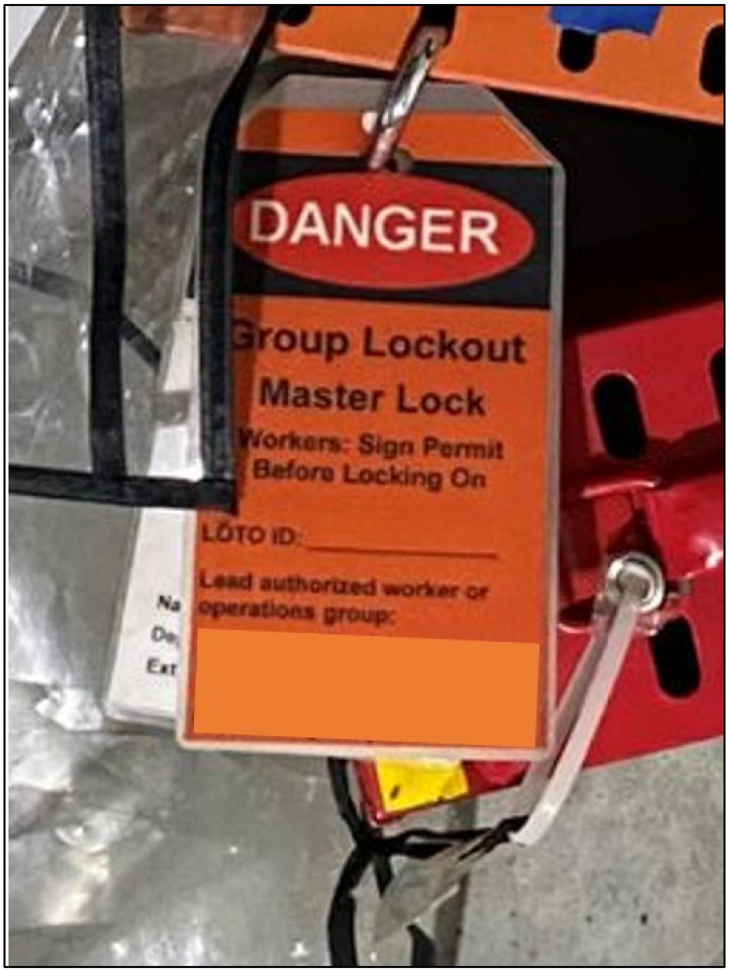

Figure 3-32: Group Lockout Master Lock Tag.

- The switching order executed on 1/18/2023 was performed out of order. The switching crew opened, racked out and locked out BRK75 before going to IR-12 to verify and lock out BRK360. As a result, grounds were applied at BRK75 before all isolations were controlled. The Board inquired about the out of sequence actions, and the CEE replied that it was not out of order since BRK360 was already removed from its cubicle.

Based on the observations above, the Board concludes there was a complete loss of administrative and physical control of the CoHE process during the outage. The LAEWs did not understand the scope of their EIPs, did not execute them to plan or in conformance with the Chapter 51 Group Lockout Procedure, and did not control who applied locks or for what scope. There was no site supervision or electrical safety oversight to detect the deviations as they occurred, and the entire outage team demonstrated wide-spread non-compliance to Chapter 51 requirements. This resulted in multiple serious violations and exposures to uncontrolled hazardous energy, each of which could also have led to serious injury. Amidst multiple, concurrent near-miss events, the HVEs inadvertently strayed outside of the energy isolation boundary and did not perform absence of voltage verification in the cubicle (neither ZVV nor 'test before touch'), resulting in the shock accident. Even after the accident, with mitigating actions in place, the Board observed numerous administrative violations of the CoHE program, and SLAC was never aware of the extent of uncontrolled hazard exposure that was present.

CC-1: The lack of field oversight, ineffective self-assessments, and lack of reinforcement of the need to follow established CoHE and safe electrical work practices resulted in a complete loss of administrative and physical control of the CoHE/LOTO Program.

3.3.4 Training and Qualifications

Facts

The training and qualification requirements germane to the outage and work to be performed by F&O electricians are referenced in SLAC ESH Manual Chapter 8, *Electrical Safety*, and Chapter 51, *Control of Hazardous Energy*. The applicable training courses and refresher frequencies are listed below:

- AED/CPR, ESH 205/205R (24 months)
- Environmental Safety and Health Orientation, ESH 219 (24 months)
- Electrical Low/High Voltage, ESH 274 (36 months)
- Control of Hazardous Energy, ESH 157/157R (36 months)
- Control of Hazardous Energy Practical Demonstration, ESH 157PRA (12 months)

SLAC uses a commercial vendor for training course ESH 274, while the other training cited above is developed and administered in-house. The training courses reviewed were interactive requiring the student to correctly respond to content questions to proceed to the next module, and a minimum passing score is required at the end to receive credit for the course.

Analysis

The slides used for training courses ESH 219, ESH 274, and ESH 157R were reviewed and found to be largely aligned with regulatory requirements and corresponding ESH Manual content. The ESH orientation training identifies the 2-Person Rule is for the additional person to remain in the area to render immediate assistance in the event of an emergency. As similarly noted in Section 3.3.3, SLAC's 2-Person Rule referenced in the ESH orientation training excludes the OSHA expectation that the second person should be able to point out poor work practices to their fellow employees.

The hazardous energy control section of the ESH orientation training includes the statement:

> "Subcontractors must ensure that their LOTO program conforms to SLAC requirements."

This training content does not align with or reflect the responsibilities for SLAC personnel to review and approve subcontractor submittals, including training qualifications and subcontractor field compliance, in accordance with ESH Manual Chapters 42 and 51.

The training and qualifications records for SLAC high and low voltage electricians that signed onto the Group LOTO form on 12/27/2022 were cross referenced against the training above. With limited exceptions, F&O personnel in this cohort were found to be up to date with these training requirements.

SLAC's safety program is structured similar to other Laboratories in that subcontractors are not authorized to perform switching activities on electrical distribution systems. As such, subcontractors performing work on equipment or electrical distribution systems downstream of an electrical isolation point must apply their personal lock onto isolations established by SLAC's F&O electricians. As noted in Section 3.3.3 of this report, service subcontractors participating in this outage were not required to complete SLAC's CoHE training or the corresponding practical. Subcontractors are required to complete the SLAC ESH orientation training for badging and site access. All subcontractors signed-onto the 12/27/2022 Group LOTO form were confirmed to be up to date on completion of ESH orientation training. The slides used in that training cover important work planning and safety content, including but not limited to an overview of SLAC's Red, Yellow, and Green work classification system, ISM principles, Stop Work authority, reporting emergencies, and the 2-Person Rule. However, no details were included in the safety orientation training on SLAC's group lockout that would allow subcontractors to understand and safely participate in those joint activities.

The *Control of Hazardous Energy Practical Demonstration* (ESH 157PRA) is required annually for individuals to remain qualified to participate in maintenance lockout activities specified in ESH Manual Chapter 51. To receive credit for this training, the worker must demonstrate competency in performing a lockout procedure to the satisfaction of a LOTO Inspector, and the worker attest they watched a brief refresher video. The LOTO Inspector can be any other individual qualified to participate in CoHE work and need not be from another group or Division. Demonstration of competency may be acquired by performing an actual lockout procedure for the LOTO Inspector to witness. Alternative means of demonstrating proficiency are allowed if the student routinely participates in lockout activities, including performing a lockout on similar equipment, or verbal and simulated actions that demonstrate understanding and competence.

Based on the release of Group LB6 allowing SLAC LVEs and service subcontractors to start work without recognition by multiple participants to confirm the presence of the orange Group LOTO Master Lock tag and failure to witness or confirm the presence of all necessary energy isolations, the Board concludes SLAC's LOTO Inspector process and corresponding Authorized Worker Certification Procedure were not effective in affirming worker competency to implement lockout procedures.

JON 7: SLAC Management needs to ensure that continuing training effectively confirms worker competency to perform CoHE activities through practical demonstration.

3.4 Contractor Assurance

3.4.1 Assessing Management Response to Recent SLAC Operational Incidents/Occurrences

Facts

Between October of 2021 and 12/27/2022, SLAC classified 21 events or conditions that met the reporting criteria in DOE Order 232.2A, *Occurrence Reporting and Processing of Operations Information.* Of those 21 events, the Board considered 13 to be related to the control of hazardous energy, including three electrical shock events classified as ORPS significance "High." Also of note, seven events over the prior 14 months had a nexus to the configuration and integrity of accelerator and experimental safety systems.

As of January 2023, SLAC completed their investigation on 10 of 13 hazardous energy control related events during the prior 14 months, with all three investigation reports from electrical shock events either pending release or in-progress.

In late January 2023, the SLAC Office of Contractor and Quality Assurance (CQ&A) released a report on common cause analysis for the events between October 2021 and December 2022. This report summarizes that SLAC management should initiate corrective actions to address recurrent issues with work planning and control and hazardous energy control.

Analysis

The Board noted a wide range of rigor and completeness in SLAC's investigation reports and corrective action commitments stemming from the recent events, which can be anticipated due to the variability in between events in complexity, significance, and consequence.

3.4.2 Assessments and Issues Management

Facts

A review of SLAC's integrated assessment schedule records between FY 2013 and FY 2022 identified 808 scheduled assessments across a wide range of Laboratory operations, projects, and program areas:

- SLAC self-assessments* = 388
- SLAC Site Office = 227
- Stanford University = 151
- State/County/City = 32
- Other = 10

* - some listed self-assessments may include outside participation.

Between FY 2013 and FY 2022, there were six (6) assessments that covered some aspect of electrical safety and/or CoHE programs. One of those was an independently led assessment, and another included outside/peer participation.

The SIIMS information provided also reflected that some Directorates did not have corrective action data entered into the system, including the 5/2/2022 event involving failure to apply LOTO control of hazardous energy at the SLAC LCLS-II Cryoplant.

Table 3-3: SLAC Schedule of Electrical Safety / COHE Assessments – FY 2013 to FY 2022

FY	Self-Assessment Title (ID#)	Description	Report Status
2020	Electrical Safety and CoHE-LOTO Programs (1697)	From NFPA 70E-2018 Article 110.1 (K) Auditing: The electrical safety program shall be audited to verify that the principles and procedures of the electrical safety program are in compliance with this standard. This scope of this assessment includes of the Control of Hazardous Energy (Lockout/Tagout) Program.	In-progress
2016	Control of Hazardous Energy (CoHE)/ Electrical Safety (830)	Status of electrical maintenance, training, audits of "in process" field lock outs in accordance with ESH Manual CH. 8. To be consistent with the dates shows on our ES&H Business Plan.	Completed w/ Issues
2016	Electrical Maintenance program effectiveness (543)	Review the effectiveness of the O&M put in place by Facilities as follow-up to VVS-13 fire report and CAP. This shall include review of maintenance plan and execution, recordkeeping including results of post-maintenance testing, inspection reports, qualifications of staff, drawings, KPIs. Availability, reliability, and functionality of key electrical components (sampling thereof) shall be reviewed as part of this assessment. SMEs from other DOE labs or FFRDCs (e.g., JPL, NASA, Ames) will be part of this assessment.	Completed w/ Issues
2015	Construction Safety electrical Energization Review	A field review led by a SME from Sandia will focus on electrical energization at our active construction sites.	Completed w/ Issues
2014	Electrical & Mechanical Critical equipment assessment (366)	Inform a plan to increase the life expectancy of critical mission readiness systems and assess recovery strategy post failure to minimize unscheduled downtimes.	Completed w/o Issues
2013	Control of Hazardous Energy (CoHE)/ Electrical Safety/LOTO (108)	Permits/EWPs, Safety plans, LOTO documentation. Compliance with drivers and SLAC requirements. Review written program or plan, review training records, observe work and interviews workers.	Completed w/ Issues

Analysis

The report from the most recent Electrical Safety and CoHE-LOTO Program self-assessment completed in 2021 has not yet been issued as final. The FY 2016 Electrical Safety and CoHE-LOTO Program self-assessment report is listed as complete; however, the corrective actions stemming from that assessment are listed in the SLAC issues management system (SIIMS) as 'Draft.' Additionally, planned assessments on the "Flow-down of WPC Requirements to Subcontractors" were scheduled to be conducted in FY 2015, FY 2018, and FY 2020, but all were cancelled.

The excerpt below is from a closed corrective action from the 2013 VVS-1B Arc Flash Investigation and CoHE/Electrical Safety/LOTO assessment, with the intention of serving as an interim action until the accuracy of single-line drawings is addressed:

> The burden is on management to ensure that appropriate resources are available to workers for their use in planning lockouts. NFPA 70E states that "[when] up-to-date drawings are not available, the employer shall be responsible for ensuring that an equally effective means of locating all sources of energy is employed." <u>Workers indicated they are aware of the need to take extra steps when up-to-date drawings are not available.</u> System walkdowns and tracing of circuits to identify sources of hazardous energy were mentioned in worker interviews. <u>Line management should confirm that the compensatory measures being taken are adequate to ensure the proper identification of all hazardous energy sources when planning lockouts</u>. This confirmation should apply not just to electrical single-line diagrams, but also to other high-level documents if they are determined to be similarly deficient.

It is of particular note that the corrective action within the same 2013 assessment to address inaccurate single line drawings remained open up to and beyond the date of the December 2022 accident. Subsequent program assessments in 2016 and 2019 similarly recognized inadequate electrical system drawings, and the corrective actions associated with those assessments likewise remain open. Identifying that workers need to undertake additional steps to overcome inaccurate electrical system drawings is not a sustainable solution, even if coupled with line management compensatory measures. When interviewed by the Board, the acting Director of F&O stated the need to improve as-built electrical distribution drawings was among their highest priorities along with critical equipment maintenance.

Electrical distribution system failures have prompted SLAC to develop and implement a 5-year electrical system PM and testing program as a means to improve reliability of the electrical utility and mitigate the risk to the science mission. A distribution transformer fire/failure occurred during the Board's on-site investigation, highlighting the continued relevance of this vulnerability. The F&O portion of the Institutional Risk Heat Map recognizes the potential impact of electrical distribution system failures (see Enterprise Risk Section below). When tests on electrical distribution conductors have not passed performance specification, the near-term solution has been to redistribute the site power using other existing conductors. This default option has been implemented because of the associated cost to remove and replace conductors, and it requires advanced coordination and scheduling to minimize the impact to the science programs. The Department's funding for science projects doesn't customarily include costs to maintain aging infrastructure systems, making it more difficult for Laboratory's to budget and get in front of such system degradations.

The stop-gap practice of redistributing the electrical power across the SLAC site has made the challenge of maintaining the electrical system drawings even more difficult, which is a concurrent issue recognized for at least the past 10 years. By automatically abandoning failed conductors and reconfiguring the electrical distribution system, the unintended consequence on the management of electrical system drawings and safe work planning had not been fully recognized by SLAC management.

Several of the observations and specific programmatic weakness concluded by the Board from this accident investigation have been previously recognized by SLAC as a result of assessment activities or incident investigations. While it's unrealistic to expect corrective actions to remain effective indefinitely, SLAC is not adequately managing the assessments, reports, and issues it has already identified. This is further exacerbated by the less than full participation by all Directorates in the CQ&A action tracking system.

JON 6:	**SLAC Management needs to ensure issues and corrective actions are consistently documented, prioritized, and objectively tracked to closure.**

3.4.3 Enterprise Risk Management

<u>Facts</u>

SLAC implements an Enterprise Risk Management Program (ERMP) that establishes the requirements applicable to all levels at the Laboratory and provides a standardized approach to attempt to identify, analysis, mitigate, monitor, and communicate risks.

The ERMP derives its overall context and basic operating framework from the following sources:

- The SLAC Management Plan, which describes how the laboratory is managed,
- The Laboratory Strategic Plan, which establishes strategic vision,
- The Annual Laboratory Plan, which sets the strategy and mission objectives,
- The Performance Evaluation and Measurement Plan, which sets DOE's expectations for SLAC's performance,
- The SLAC Prime Contract, which sets the parameters for managing and operating the Laboratory; and
- Feedback from the bi-annual Board of Overseers review of Laboratory operations.

SLAC uses a Risk Matrix to evaluate the overall characterization of an identified risk, by determining each risk's probability and severity, which develops an overall Risk Level. The risk level then serves as the basis for prioritization and mitigation decisions.

<u>Analysis</u>

The Board received the SLAC Institutional Risk Heat Map from October 2022. SLAC leadership identified 16 risks, to be tracked at the institutional level based on the outcome of the Risk Scores. The risk entitled 'Utilities and Infrastructure' was one of the highest rated institutional risks on the Heat Map, with a Current Severity of 'Very High' and a Current Likelihood of 'High.' This risk states that "*IF facilities, utilities, and infrastructure are not available, invested in, effectively maintained and managed and updated in line with current industry standards and Laboratory mission objectives, THEN capabilities will erode and SLAC will not be able to execute its mission and deliver projects that meet full mission and science needs.*"

Although the 'Utilities and Infrastructure' risk encompasses the electrical distribution system, by

- not acting on previously identified issues over the last decade-plus,
- automatically abandoning failed conductors,
- performing near-term electrical system configuration compensatory measures and turning them into long-term solutions, and
- iteratively reconfiguring the electrical distribution system without updating drawings,

the Board concluded the full magnitude of electrical distribution system risks and its unintended impacts on safe work execution do not appear to be either fully recognized and/or properly managed by the various levels of SLAC leadership.

JON 1: Stanford University needs to assure infrastructure risks are evaluated, documented, and managed.

3.5 Site Office Oversight

Facts

The DOE SLAC Site Office (SSO) is one of ten SC site offices managing DOE performance-based management and operating contracts for national laboratory operation. The mission of SSO is to enable innovative, effective, and safe operations to allow SLAC to consistently deliver world class science.

Within SC, the site office is a SC line management organization that reports to the DDFO. Within SC, the Headquarters (HQ) organization establishes policy and direction while Field organizations implement that policy and direction. The SSO is responsible and accountable for the stewardship and management of the SLAC contract and oversight of the operational and management performance of the contractor. The SSO discharges its responsibilities for contract management, mission integration, federal stewardship, and internal operations through a standard SC Site Office structure of three divisions, including Mission Integration & Project, Business, and Operations.

Site office responsibilities include conducting oversight of the contractor programs and management systems, including assurance and oversight systems, to determine if they are performing effectively and complying with contract requirements, as well as providing timely feedback to the contractor on performance. The SSO has manuals, program descriptions, and standard operating procedures that define the expectations and processes to perform their assigned mission and functions.

In 2019, the SLAC and Berkeley Site Offices were merged into the Bay Area Site Office to manage the SLAC and Lawrence Berkeley National Laboratory contracts. The SSO was re-established as an individual Site Office in 2021, with the Site Office Manager continuing to serve in a dual role for both the SLAC and Berkeley Site Offices until the appointment of the SSO Manager in July 2022. SSO staff execute their oversight responsibilities as an integrated team in partnership with Stanford University and SLAC to implement the DOE's mission. Primary ESH expertise is performed by SSO personnel, supplemented by additional technical support from the SC Office of Safety and Security as necessary.

In the past, the SSO had 15-16 federal staff, with a peak staffing of 18. As contractor performance improved, the previous SSO Manager gradually reduced staffing to 11. SSO is in the process of recruiting three safety professionals in addition to the one currently on board. The newly promoted Operations Division Director, previously a SSO Safety Engineer, continues to perform dual duties in the interim.

The SSO has an established assessment program designed to manage and oversee the contract, ensure that mission and mission support activities at SLAC are conducted in a safe, secure, effective, and efficient manner, and provide SSO with written procedures for implementing an effective assessment program. The program includes formal assessments, walkthroughs and surveillances, and self-assessment as well as corrective actions, effectiveness reviews, and feedback and improvement. These activities are designed to provide the SSO Manager with sufficient knowledge and awareness of site and contractor activities to make informed decisions about hazards, risks, priorities, and resource allocation, and provide direction and timely feedback on contractor performance.

At SSO, Operational Awareness is defined as the sum of all interactions between SSO and Stanford University, in their role as management and operating contractor for SLAC, that support the management of the SLAC site, facilities, operations, and programs. The primary emphasis of the SSO Operational Awareness Program is to ensure that SLAC develops and implements an effective and efficient Contractor Assurance System that meets the contractual requirements and ensures that mission objectives are achieved. Operational Awareness includes a variety of formal and informal interactions between the Site Office and SLAC, including attendance at contractor meetings; conduct of walkthroughs, inspections, surveillances, and follow-up actions; participation in functional reviews, audits and other SSO assessment activities, and ongoing monitoring of work processes, systems, and facility operations.

SSO staff remain cognizant of ESH aspects in their assigned facilities and programs through ongoing operational awareness and surveillance activities. Staff members also have responsibility for federal oversight of various site wide ESH programs implemented by SLAC.

To facilitate SSO's oversight responsibilities in monitoring performance, periodic assessments are conducted on SLAC programs. SSO assessments are integrated with the SLAC assessment system. On an annual basis, SSO reviews SLAC operational performance and focuses their assessment resources on the higher risk areas. Due to resourcing challenges, SSO relies on day-to-day oversight in observing areas of higher risk.

In the FY 2021, SSO had six scheduled independent assessments. Four of the assessments were cancelled and the remaining two completed without issues. In the FY 2022, SSO had two scheduled independent assessments. Both of those were noted in the report as not started. None of the scheduled assessment were of electrical safety. SSO personnel performed and documented 41 walkthroughs of SLAC activities in CY 2021 and 61 in CY 2022.

As part of its laboratory appraisal process, SC conducts an annual evaluation of the scientific, technological, managerial, and operational performance of the contractors who manage and operate its ten national laboratories. The SC laboratory appraisal process uses a common structure and scoring system across all ten of its Laboratories. Structured around eight performance goals, it emphasizes the importance of delivering the science and technology necessary to meet the missions of DOE; of operating the Laboratories in a safe, secure, responsible, and cost-effective way; and of recognizing the leadership, stewardship and value-added provided by contractor managing the Laboratory. Each Site Office evaluates the Laboratory's performance against the management and operating objectives (Goals 5-8). Site Offices and Science Programs provide input regarding the contractor's performance with respect to Goal 4 *Provide Sound and Competent Leadership and Stewardship of the Laboratory* to the SC leadership who subsequently determine the Laboratory's score in this area. The formal annual appraisal is a critical element of SSOs oversight and performance feedback responsibilities.

Annual DOE evaluations of SLAC for FY 2021 and FY 2022 cited safety and operational issues at SLAC. In the FY 2021 Goal 4 evaluation, DOE cited SLAC and noted that operational performance was inconsistent through most of FY 2021 and that there were a significant number of incidents that represented departures from known and established operating protocols. Additionally, the evaluation noted that "both Stanford and SLAC's Contractor Assurance System were slow to detect and then act on developing negative performance trends in FY 2021" including areas of safety and operational performance.

In the FY 2022 Goal 4 evaluation, DOE noted that:

> "During FY 2022, SLAC experienced significant leadership challenges, which resulted in a high number of safety and operational incidents, a continuing negative trend in safety incidents rates, and delays to projects impacting schedule and costs. Environment, Safety and Health (ES&H) leadership did not adequately review or analyze leading and lagging indicators for safety incidents and trends. As a result, SLAC was not able to anticipate the impact of safety incidents to respond appropriately which required the SLAC Site Office to emphasize to SLAC leadership the necessary actions (safety pauses, stand downs, setting expectations) to ensure safety and improve project performance."

For the FY 2022 Objective 4.1 evaluation, the SSO explicitly noted:

> "SLAC was slow to fill critical leadership positions over the past year which resulted in lack of knowledge and experience necessary to prevent performance degradation when responding to the numerous safety incidents and delays of key projects, e.g., LCLS-II and Cooling Tower (CT) 1701 Upgrades. Consequently, SLAC reacted to situations and did not take proactive actions to prevent the unsafe trend. The lack of urgency and senior leadership resulted in the laboratory inappropriately

accepting risks, insufficient resource planning, and unauthorized operation of facilities as highlighted below"

SSO also provided Goal 5 feedback that cited significant incidents and noted that:

"In FY 2022, there were numerous and troubling performance failures in implementing SLAC's ES&H programs which resulted in SLAC operating outside its established safety envelope."

In addition to the annual evaluation, Site Offices provide feedback throughout the year to the laboratory contractor. This feedback can be provided through routine meetings, e-mails, or formal letters, including letters of direction. SSO has provided clear and consistent performance feedback to SLAC through both e-mails and formal letters including:

- Letter on 8/12/2020, in response to a material trend in both accidents and near misses at Lawrence Berkeley National Laboratory and SLAC, the SSO Manager transmitted a letter setting forth requirements regarding management presence, support infrastructure, employee readiness, communication, tracking and trending, and safety pauses.
- E-mail on 4/11/2022 from the SSO Manager to the SLAC Laboratory Director encouraging a safety pause/stand down in light of disturbing safety trends.
- E-mail on 5/9/2022 from the SSO Manager to the SLAC Laboratory Director withdrawing SSO approval of Accelerator Safety Envelope for two SLAC accelerators due to operations without proper configuration control.
- E-mail on 5/23/2022 from the SSO Deputy Manager to the SLAC Laboratory Director expressing concern about the continued incidents still occurring on site.
- Letter of Direction on 6/22/2022 from the SSO Manager to the Stanford University Vice President for SLAC directing a plan for LCLS-II Project Leadership Transition and Contingency that included concerns about recent increasing trends of safety incidents resulting in two safety standdowns.
- E-mail on 8/12/2022 from the SSO Manager to the SLAC Laboratory Director expressing concern with the recent events that have occurred regarding work being conducted without the necessary authorization.
- E-mail on 8/27/2022 from the SSO Manager to the Stanford University Vice President for SLAC expressing concerns about continued instances of expired authorization or staff overriding authorizations to change safety systems configuration.
- E-mail on 9/2/2022 from the SSO Manager to the SLAC Laboratory Director expressing a concern regarding an event involving a vacuum chamber over-pressurization resulting in a ruptured burst disk.

On 1/21/2023, the SSO Manager issued a Letter of Suspension to Stanford University for all work and activities that involve 277 V systems and above until further notice. The letter required SLAC to submit a plan and corrective actions within two weeks of the letters issuance and SSO approval for any mission critical activities involving the suspended systems.

Analysis

After being notified of the accident, the SSO Manager visited the accident scene that day and has been engaged in the Laboratory's associated actions since that time. The SSO interacted with SLAC Leadership on activities in stopping work and required SSO review and concurrence of any LOTO or CoHE work before work could proceed. Based on interviews with both SSO and SLAC personal, it was clear that the SSO Manager, along with their management team, has established an engaged and open relationship with the contractor.

As noted above, the SSO was reestablished as an independent Site Office in 2021 during the pandemic when most federal personnel were teleworking. SSO is experiencing Federal staffing challenges due to staffing shortages and difficulty in recruiting to the local area, as well as the Department-wide return to work in March 2022 while encouraging programs to strategically leverage workplace flexibilities such as telework, remote work, and alternative/flexible work schedules as tools to help attract, recruit, and retain the best possible workforce.

The SSO Operations Division is expected to be onsite 50 percent or more of their time with the remainder able to telework 50 percent or greater of their duty time. The SSO Manager recently has increased the expectation for SSO staff to conduct field observations in response to the operational challenges at SLAC. The SSO Manager recognized the staffing challenges and requested and received approval for additional staffing. The SSO Manager indicated that the three additional safety personnel currently being recruited will allow them to bring oversight back up to previous levels of engagement.

SSO conducts its oversight in accordance with an annual assessment plan. The assessment plan includes SSO independent activities as well as assessments that are integrated with SLAC activities. SSO reviews contractor risk registries and meets annually with each risk registry manager to identify risks in SLAC management and operations. Under ideal circumstances, SSO would have been engaged in more formal independent assessments during the past three years; however, given current resource constraints and SLAC operational performance, Federal oversight of safety management has been heavily focused on field engagement rather than formal assessment. In response to an increased number of incidents, particularly in WPC and CoHE, the SSO increased expectation for federal staff to augment onsite oversight activities. Examination of documented SSO observations and issues revealed that current SSO field surveillance is above pre-pandemic levels.

SSO has consistently provided extensive informal and formal written feedback on contractor performance. SSO communicates concerns with incidents and performance in real time to SLAC management. As noted in Section 3.4.1, between October of 2021 and 12/27/2022, SLAC classified 21 events or conditions that met the DOE Order 232.2A reporting criteria. SSO responded immediately to events with questions, expectations, and even technical direction to bring attention and action to bear. In the months leading up to the accident, SSO repeatedly expressed concerns about the increasing trends of safety incidents.

Coupled with the day-to-day engagement on operational performance, SSO provided explicit evaluations of SLAC performance in both the FY 2021 and FY 2022 Performance Evaluation Reports. In FY 2021, the site office called out a series of safety concerns, including a failure to perform a required zero-energy check. In FY 2022, SSO again cited ongoing concerns with safety performance and SLAC's failure to take proactive actions to prevent the unsafe trend. SLAC's ratings for FY 2022 were significantly lower than FY 2021 Goal 5, *ES&H and Environmental Management*.

Identifying and communicating these issues is a clear indication that SSO is focused on continually monitoring SLAC performance and providing relevant feedback for SLAC consideration and action. Consistent with the requirements of DOE O 226.1B, SSO has evaluated SLAC performance and communicated oversight results and other issues in a timely manner to both line management and contractor management.

Even with SSO's focus on continuous monitoring and feedback as well as recognition of and action on staffing challenges which was consistent with established expectations, SSO oversight was not effective in ensuring that SLAC's programs were sufficiently robust to prevent the increasing trend of safety incidents since 2020, and ultimately this accident. Explicit and extensive informal and formal feedback (PER feedback) by SSO over a period of two years failed to result in a performance turnaround by the M&O Contractor. However, the Board determined that DOE oversight was not a causal factor in the accident.

4.0 CAUSAL ANALYSIS AND RESULTS

4.1 Events and Causal Factor Analysis

The Board used several analytical techniques to determine the causal factors of the accident, including Barrier Analysis, Change Analysis, Event & Causal Factors Analysis, and Human Error Precursor Analysis. Causal factors are events or conditions necessary to produce or contribute to the accident.

The Board assessed each of the causal factors, categorizing them as either direct, contributing, or root causes. The direct cause is the immediate event or condition that caused the accident. Contributing causes are the events or conditions that collectively increased the likelihood or severity of the accident but did not individually cause the accident. Root causes are the most basic events or conditions that if eliminated or modified would prevent recurrence of the same or similar accident. The direct, contributing, and root causes, as defined in Figure 1-1, Accident Investigation Terminology, are included at the end of this section.

Based on the causal factors, the Board identified Conclusions (CONs) from which it developed Judgments of Needs (JONs). The CONs and JONs are documented in Section 5 of this report.

4.1.1 Barrier Analysis

The purpose of Barrier Analysis is to identify hazards associated with a target in an accident and the barriers that should have been in place to prevent the accident from occurring. For an accident/event to occur, there must be an exposure of the hazard to the target (worker). A hazard is the potential for unwanted energy flow that results in an adverse consequence. A target is a person or object that a hazard may damage, injure, or fatally harm. A barrier is any means used to control, prevent, or impede the hazard from reaching the target, thereby reducing the severity of the resultant accident or adverse consequence. Barriers are a part of a system or work process to protect personnel and equipment from hazards.

When an accident occurs, a hazard comes in contact with a target because barriers either did not exist, were not used, or were not effective in mitigating the hazard.

The Board identified multiple barriers that were in place or designed to have kept this accident and its subsequent results from occurring. The analysis identified several causal factors related to existing barriers that were in place but were either bypassed or unused. The Board noted that many of the barriers in place and available at SLAC, if collectively utilized, would have provided a level of defense-in-depth capable of defending the worker from the hazard should one or more of them have failed. Though not exhaustive, the following key barriers included:

- <u>Configuration Management</u>: Multiple configuration changes to the electrical distribution system exceeded the capabilities of SLACs Configuration Management System to administratively support those changes necessary to reflect actual field conditions and communicate associated hazards.
- <u>Work Planning & Control</u>: The erosion of the disciplined approach to the WPC process resulted in the complacent development, review, and approval of the EWP.
- <u>Walkdowns</u>: The EWP review walkdown lacked the formality and intent of established SLAC directives designed to prepare the HVEs for the corresponding complexity of work to be executed.
- <u>Tailgate Briefings</u>: Tailgate briefings became informal and lacked the rigor and discipline needed for HVEs to understand existing hazards and the controls put in place to mitigate those hazards, and to allow for questions and/or concerns to be fully communicated.
- <u>Performing work within established controls</u>: The lack of consistent management expectations to perform work within existing controls allowed HVEs to execute work in the skill-based performance mode and add, modify, ignore, or execute steps outside of established work controls.

- CoHE/LOTO: Programmatic efforts to control hazardous energy had diminished to a point where both the management and workforce teams lost complete physical and administrative control of the CoHE/LOTO program.
- PPE: Hazards were not identified or analyzed for all tasks in the EWP. Approach boundaries were not used for donning PPE. In some cases, the labels included erroneous information.

Appendix H is the Board's Barrier Analysis Worksheet containing a detailed description of identified barriers the Board determined to be ineffective.

4.1.2 Change Analysis

Change analysis examines planned or unplanned changes that cause undesired results or outcomes. Change is anything that disturbs the balance of a system operating as planned. Change can be planned, anticipated, and desired, or it can be unintentional and unwanted. The Change Analysis process compares the difference between what is normal (or ideal) and what occurred.

The Board analyzed multiple changes identified during the investigation, which are detailed on the Change Analysis Worksheet in Appendix I. The summary of this analysis identified several causal factors relating to change, including:

- Limited resources to support the outage resulted in a staggered shutdown, which introduced the hazard of partially energized equipment as well as an elevated sense of urgency to complete the job.
- Numerous errors, omissions, and inconsistencies among the Building 626 Outage EWP, SWO, and EIP.
- Building 626 Outage work was not formally classified as Red, thus failing to trigger a WIP and additional reviews.
- Not all the HVEs who worked the Building 626 Outage participated in the walkdown.
- A pre-job briefing was not performed.
- Field conditions did not match expected/briefed conditions (BKR360 racked-out).
- Building 626 Outage work executed outside of scope activities.
- The switching order did not specify the exact location of ZVV for the 12.47 kV switchgear.

4.1.3 Event & Causal Factors Analysis

An ECF analysis was performed in accordance with DOE-HDBK-1208-2012, "*Accident and Operational Safety Analysis, Volume 1: Accident Analysis Techniques.*" The ECF analysis begins with analyzing the facts and identifying the events or conditions that were in place at the time of the accident. The event and causal factors identified are then included on the ECF Chart, provided in Appendix J.

4.2 Anatomy of the Event

Section 3 details a number of systemic weaknesses that have developed over a period of time and preceded the accident. The Board concludes that the precipitating factor was the change to the outage strategy for IR-2 / S522. By staggering the outage into two phases, due to limited resources, the IR-2 substation was left partially energized at the conclusion of the first phase. This is not to say that this change alone was the root cause for the event, far from it. A rigorous work plan combined with disciplined work execution could have handled the change with relative ease to safely perform the work. However, this change introduced a new, unrecognized hazard at an unexpected time and location. This answers the question, "why now?" but is not sufficient alone to cause the accident.

It is helpful to use the 'Anatomy of an Event' model in the following figure, taken from DOE's Human Performance Improvement (HPI) Handbook (Figure 4-1). By identifying the various elements of the figure one can better appreciate how the event on 12/27/2022 was able to occur.

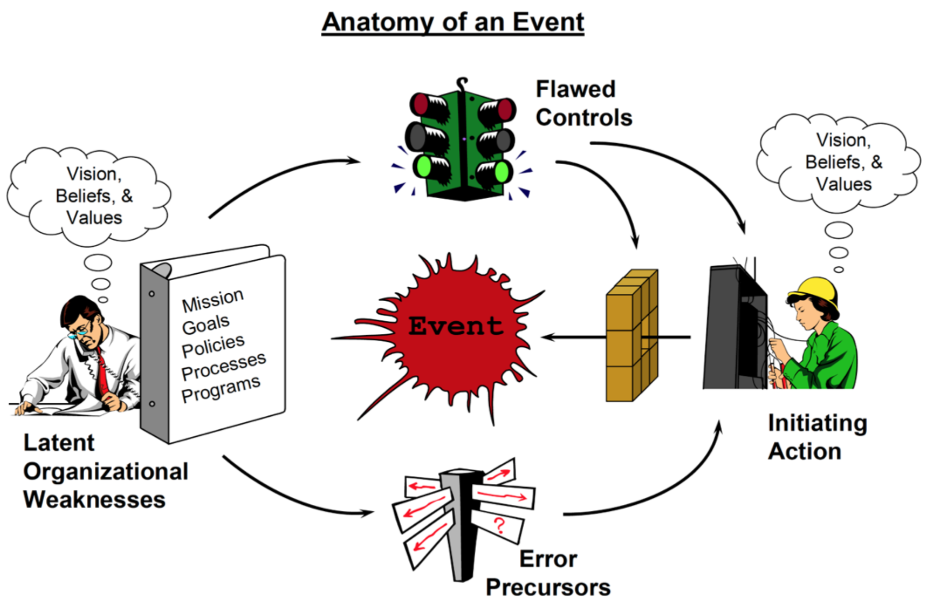

Figure 4-1: Anatomy of an event, from DOE HPI Handbook.

<u>Latent Organizational Weaknesses</u>

First, when S522 substation was installed for the LCLS project, funds were not made available for dedicated feeders from the Master Substation. From the beginning, by tapping its feeders from the nearby IR-2 substation, it removed an engineering control for performing maintenance. Then when SLAC adopted a policy to perform electrical maintenance in compliance with NFPA 70E-2015, it did not recognize the full resource commitment that would be required to bring aging infrastructure up to date. Instead of developing a graded maintenance approach matching the resources that would be available, and requesting additional resources as needed, SLAC instead appears to have adopted a compliance-first approach, where maintenance was no longer optional. For the aged 12.47 kV cables across the site, this led to a practice of test-and-fail maintenance followed by forced de-energization without resources available to properly replace, decommission, or otherwise safely dispense with the equipment. To incur such a high number of cable failures and keep operations running was quite the engineering feat. However, it resulted in a reactive and repeated reconfiguration of Lab's 12.47 kV distribution, with accentuated impact in the PEP distribution area. The ever-increasing complexity of the distribution was matched with the inability to maintain drawings and labels up to date for safe work planning and execution. In turn, the required maintenance outages also became more complex in both planning and execution. And while SLAC correctly identified the weaknesses in system drawings, it neither recognized the cause nor corrected the deficiency. Instead, the persistent and widely known failure to update system drawings resulted in a culture where drawings were neither consulted nor trusted. Configuration changes directly affected IR-2 / S522 substations multiple times leading up to the event, and not all of their drawings and labels were up to date.

Second, a near-total lack of qualified field observations has led to a significant normalization of deviation in electrical safe work practices. Some of these deviations are in WPC but the most alarming are the extensive deviations observed in the implementation of the CoHE program, which includes the practice of ZVV. It is not known when the deviation began. However, the Board notes that there has not a been a single Electrical Safety Subject Matter Expert onsite to provide field assurance since the beginning of the COVID-19 pandemic. A Deputy Lab ESO position was approved and posted in 2020 but has never been filled. EPD does not have anyone in a safety support role that is trained in electrical safe work practices. Further, several of the key leadership positions in EPD are newly filled due to staff departures, resulting in a relatively inexperienced leadership team. Two of the HV workers involved were hired during the pandemic and may not have ever seen what the work practices were supposed to be. As a result, qualified persons have been performing work without any level of safety oversight for at least one year, and possibly up to three.

Third, all of the Electrical Safety and CoHE program assessments since 2015 have been self-assessments, with limited field observations and no outside expertise to provide independent feedback. Even with the gaps noted by the Board in the written ESH programs, for the most part these should have been fully adequate to provide effective hazard recognition and development of controls, **had they been followed** by those performing WPC and work execution. Effective independent assessments would have readily discovered the gaps in work execution and helped strengthen the Lab's self-assessment processes and electrical safety culture.

Flawed Controls

Sections 3.1.1 through 3.1.3 detail the extent of errors, omissions and inconsistencies present in the approved work package. These can be traced back to the latent organization weaknesses, either from lack of resources to fully develop and review a quality plan, or from specific hazards and controls not being recognized such as identified energy isolation boundaries.

The planning process for this outage had an additional resource stressor, in that two of the four planners were diverted to work on Public Safety Power Shutoff plans with the local utility company. This outage produced a particularly flawed work plan. Limited planning resources could not devote enough time to perform quality checks and reviews, and instead relied on the skill and experience of the workers who would execute the plan.

Of particular notice was that many of the issues with the work plan were readily apparent to anyone attempting to read and follow through the sequence of actions or interpret the drawings provided. The Board had significant difficulty making sense of some of the steps because they didn't line up, added duplicates, or misplaced certain actions. That these readily apparent issues made it all the way past the workers' reviews signals that the workers 1) did not feel the need to review the plan in detail and 2) did not really intend to rely that much on the documented work plan for execution. They would instead rely on their own skills and knowledge.

Error Precursors

The Board observed that F&O EPD demonstrates a persistent culture of skill-based performance mode in both work planning and execution. The phenomenon of skill-based performance mode is well documented in DOE's HPI Handbook, which formed the basis for NFPA 70E Informative Annex Q, "Human Performance and Workplace Electrical Safety," introduced in NFPA 70E-2018. Skill-based performance mode is addressed in NFPA 70E, Q.4.3:

> "A person is in skill-based mode when executing a task that involves practiced actions in a very familiar and common situation. Human performance is governed by mental instructions developed by either practice or experience and is less dependent on external conditions. The time devoted to processing the information is in the order of milliseconds. Writing one's signature is an example of skill-based performance mode. A familiar workplace procedure is typically performed in skill-based performance mode, such as the operation of a low-voltage molded case circuit breaker.

The relatively low demand on attentional resources required when an individual is in skill-based human performance mode can create the following errors:

(1) Inattention: Skill-based performance mode errors are primarily execution errors involving omissions triggered by human variability, or not recognizing changes in task requirements or work conditions related to the task.

(2) Perceived reduction in risk: As familiarity with a task increases, the individual's perception of the associated risk is less likely to match actual risk. A perceived reduction in risk can create "inattentional blindness" and "insensitivity to the presence of hazards."

In performing the HP EP Analysis (Section 3.2), the most prevalent error precursor was 'inaccurate risk perception,' appearing five times, followed by 'interpretation requirements' occurring four times. This is consistent with skill-based mode errors. This behavior was not limited to the workers executing the plan but was also evidenced in the work planning team as well as the electrical line managers. After the accident, at no time did anyone (other than the ESO) ever refer back to the documented institutional processes to answer questions, explain documented expectations, or otherwise guide the Board in understanding factors related to the incident.

JON 12: SLAC Management needs to ensure that the known human performance improvement error precursors are considered in work planning processes and during work execution.

Vision, Beliefs and Values

The Board observed that all of the SLAC workers and managers interviewed demonstrated a desire to perform work safely. However, they were also very much unaware of the extent of deviations that had become normalized in the course of everyday work. Most were very surprised that HVE1 had been injured. They attributed the direct cause to not wearing PPE and did not understand how such an experienced worker who was highly regarded for their expertise could have just decided not to wear it that day. SLAC is very keen to point out that their PPE is rated much higher than is required, and that the 100 cal/cm^2 arc flash suits are mandatory for high voltage work regardless of the indicated arc flash incident energy. Unfortunately, this essentially has transmuted to a belief that a skilled person with overrated PPE can overcome any work planning deficiency and has contributed to a near-complete erosion of other electrical safety controls.

Surprisingly, the subcontractor who had attempted to place their lock on the filled lockbox was the only person interviewed who asked why a 'test before touch' had not been performed. Test before touch is a cornerstone of electrical safety principles. Every electrical safety program must continuously reinforce this belief to such an extent that it becomes second nature, as 'test before touch' is always under the singular control of the qualified person placing their hands in the equipment. PPE will always eventually come off before work, and without a proper 'test before touch' this will leave the worker exposed to undetected hazardous energy.

Initiating Action

The Board recognizes that it does not fully understand the initiating action, specifically why HVE1 manually lifted the insulating boot off the surge arrestor. The Board has determined based on the preponderance of the evidence that the final intended task was not to perform ZVV in the switchgear. Instead, it was to perform a discharge of stored energy on equipment that was fully believed to be isolated from the normal power sources. This practice is inconsistent with the institutional processes, as stored energy discharge is part of establishing an electrically safe work condition.

Knowing that the available resources to execute the outage were limited, the work planners introduced an intermediate step with partially energized gear. Additional controls that might have been triggered were omitted, such as marking of lookalike equipment or warnings in the work package. After the walkdown, HVE1 knew that there was a change but failed to grasp its significance and did not review the work package in detail. Instead, they relied on their own system knowledge and developed a faulty mental model of how the outage was supposed to be structured. The work plan contained so many issues that workers had to rely on skill-based performance mode but had no guiding documentation in the field that could have helped them sort it out on their own. Instead of recognizing this as a concern, work proceeded without stopping. Workers made additional choices to deviate from the overall sequence to expedite connection of generators by both SLAC LV workers and subcontractors. By the time of the event, the work had already been released and started, and the 12.47 kV ZVV was likely deemed unnecessary, with the exception of discharging the bus.

Although no work was expected in the gear for the first phase, the work plan unnecessarily directed ZVV for the 12.47 kV lineup. No specific location was given, and the ZVV was of lower priority compared to the 480 V ZVVs that were needed to get contractors to work.

Ultimately, the initiating action resulted in straying outside of the energy isolation boundary and not adequately performing absence of voltage verification (either ZVV or 'test before touch'), leading to the shock.

Summary

It is important to appreciate that several of these elements were self-reinforcing or self-defeating. Strict compliance to the maintenance requirements of NFPA 70E led to greatly increased configuration risks and a greater drain on scarce resources. Inaccurate drawings and labels resulting from ineffective configuration management led to distrust, disuse, and finally breaking the feedback loop from the field that is necessary to find and correct errors. Documenting configuration management as a recurring deficiency only reinforced the perception that the drawings could not be relied upon.

In many cases the Board had difficulty determining whether a failed barrier was a causal factor because it was defective or because it was not used. Examples include:

1. A tailgate or job briefing was not performed. Had it been performed according to Chapter 2 and Chapter 8, the listed requirements did not cover all required task-level elements.
2. The arc flash boundary on the front of BRK342 was not used to establish PPE requirements for remote switching and racking of the breaker. Had it been used, it was incorrect by an order of magnitude and would have led to an exposure.
3. HV electricians did not consult the posted drawings in S522 building to understand why the ATS transferred. Had they consulted it, the drawing would have shown incorrect information.
4. HVE1 did not use their voltage rated gloves. Had HVE 1 used voltage rated gloves, they were past due for testing.
5. HV electricians did not consult the EIP to perform ZVV on the switchgear. Had they attempted to follow the EIP which identified the ZVV location to be the only portion of the substation that was still energized.

Tools that are not used are not sharpened and lose their ability to serve their purpose. Tools that cannot reliably fulfill their purpose will not be readily used.

The Board concludes that skill-based performance mode had been occurring undetected long enough for procedural non-compliance to become the norm and cause systematic erosion of those controls that were supposedly implemented by the institutional policies and procedures. All of the elements in the HPI Anatomy of an Event had been present in a sustained manner for several years prior to the event. The accumulated complexity of the electrical distribution system overwhelmed the ability to develop a safe and executable work plan, introducing a new hazard (partially energized gear) without being identified or controlled. A culture of over-reliance on experienced workers with PPE short-circuited the need for detailed work plan reviews and walkdowns and fell victim to errors of inattention and reduced perception of risk. Inadequate field assessments over several years allowed this culture to self-reinforce and take root, and the issues related to configuration management that had been identified for years were never corrected.

4.3 Results

4.3.1 Direct Cause

The Board concluded that the direct cause of the accident was:

- HVE1 made hand contact with a bare energized (live) circuit part inside a 12.47 kV three-phase electrical utility distribution switchgear cubicle.

4.3.2 Contributing Causes

The Board identified ten contributing causes for the incident and its consequences. The contributing causes were:

Contributing Cause 1: The lack of field oversight, ineffective self-assessments, and lack of reinforcement of the need to follow established CoHE and safe electrical work practices resulted in a complete loss of administrative and physical control of the CoHE/LOTO Program.

SLAC did not follow the requirements of its CoHE Program, nor ensure that deficiencies in implementation were identified. On the day of the outage alone, repeated violations resulted in multiple personnel being exposed to uncontrolled hazardous energy. Although the institutional Electrical Safety and CoHE/LOTO Programs appear adequate on paper, they are no longer being effectively implemented in the field due to the lack of field oversight. The end result was that the worker strayed outside of the energy isolation boundary and did not safely perform absence of voltage verification (whether ZVV or 'test before touch').

Contributing Cause 2: Compliance to maintenance requirements without sufficient resources resulted in reactive changes to the physical configuration of the 12.47 kV distribution system, with unintended consequences that increased complexity for work performed.

Limited resources available for sustaining the PEP distribution area, coupled with actions intended to comply with NFPA 70E maintenance requirements, led to feeder cables being placed out of commission and to a gradual erosion of safety by design at the switchgear level. The standard dedicated main-tie-main feeder configuration was replaced with temporary single mains, back feeds, and tap feeds to reduce operational costs for the limited repurposing of the PEP distribution area to meet smaller science projects. The continued lack of funding prioritization resulted in temporary fixes turning into permanent solutions. As a result, less than adequate configuration management and physical system configuration control led to unnecessarily complicated work planning and work execution.

Contributing Cause 3: Multiple configuration changes to the electrical distribution system feeding IR-2 and S522 during the previous years did not include the updating of applicable drawings, equipment identifications tags, and arc flash labels to reflect actual field conditions.

SLAC did not effectively maintain the configuration of the electrical distribution system. Inaccurate drawings and labels resulting from ineffective configuration management led to their distrust and disuse, and caused the feedback loop from the field that is necessary to find and correct errors to breakdown. This led to the perception that the drawings could not be relied upon. As a result, HVEs were not all equally aware of the multiple system configuration changes throughout the years and had different mental models of the system configuration.

Contributing Cause 4: The outage planning process assigned insufficient resources and time for the increased maintenance scope and, instead, staggered the outage plan that introduced partially energized switchgear.

SLAC did not effectively manage the planning of the outage. Several factors during the planning of this complex work evolution led to the development of a modified outage plan that allowed work with the system partially energized. Planned resources were significantly reduced from the original estimate, the SOW was increased, and the work was to be accomplished in a fixed number of days in between holiday weekends. Environmental conditions, coupled with a strong desire to complete tasking while minimizing potential project/asset impact, elevated the sense of urgency in accomplishing the work. These constraints on resources, schedule, and work scope did not allow workers sufficient time to fully understand sequencing of tasking and adapt to field conditions.

Contributing Cause 5: The planning process failed to produce a work package that could be executed safely.

SLAC did not follow the requirements of their documented WPC process. For this work, they did not capture the complexity of the scope, identify all hazards, or specify sufficient controls. They did not adequately differentiate roles and responsibilities nor validate/verify work steps during planning. Finally, both reviews and approval of the work plan were less than adequate.

Contributing Cause 6: Unclear expectations for walkdowns resulted in miscommunication of the scope, hazards, and controls from the planning group to the workers executing the work, and a lost opportunity to identify issues with the work package.

SLAC does not clearly define the minimum elements of a structured walkdown and the associated responsibilities, such that the walkdowns performed prior to the work execution lacked the rigor to identify fundamental errors and omissions in the plan.

Contributing Cause 7: A comprehensive Tailgate Briefing was not performed to fully communicate the roles and responsibilities as well as task-level scope, hazards, and controls, to all of the assigned workers.

SLAC's current requirements for Tailgate Briefings do not adequately capture the elements from the SLAC ESH Manual Chapter 8 Job Briefing for electrical work and do not reflect all of the requirements of the latest version of NFPA 70E. As a result, all persons assigned to the work did not understand the specific hazards and controls.

Contributing Cause 8: The work team deviated multiple times from the approved work plan without stopping either to question why they were doing it or analyze the hazards, which led to reliance on skill-based rather than rule-based execution.

Contributing Cause 9: Workers and Planners did not understand how to apply and control the shock and arc flash boundaries, resulting in worker exposure without appropriate PPE.

Both shock and arc flash hazards were present in the back of the cubicle once the door was open. By disregarding the hazards before opening the door, the workers were exposed to both without mitigation.

Contributing Cause 10: Ineffective communications during the execution of the Switching Order resulted in critical information on equipment status indicators being ignored and hazards not being recognized.

Information being shared between members of the work crew were not resolved before proceeding with work activities, including the switchgear having dual sources of power and unexpected system responses upon opening a breaker in a different substation. The informal disposition of concerns and conditions was not commensurate with the degree of affirmative communications needed for energy isolation activities.

4.3.3 Root Cause

The Board determined that the root cause for the accident was:

Management failed to ensure effective continuous evaluation and oversight of mission support infrastructure and programs to identify and manage risks in work execution:

- Infrastructure priorities and configuration of systems failed to ensure a stable physical configuration for safe conduct of work activities.
- Field oversight failed to detect issues related to the effectiveness of SLAC procedures and their implementation during work activities.
- The institutional issues management process failed to ensure that identified program issues were corrected, evaluated for effectiveness, documented, and closed in a timely manner.

This root cause is reflective of the many elements represented in the contributing causes.

5.0 CONCLUSIONS AND JUDGMENTS OF NEED

The Board concluded that SLAC has failed to continuously evaluate and oversee mission support infrastructure and programs to identify and manage risks in work execution. The conclusion is based on the analysis and identification of a number of contributing causes addressing both programmatic and discrete failures that, considered together, created the environment in which an accident of this severity could occur.

At the institutional level, infrastructure priorities and configuration of systems failed to ensure a stable physical configuration for safe conduct of work activities. In order to achieve scientific mission objectives, national laboratories must establish and maintain diverse assets. SLAC's failure to effectively manage these assets created an environment that fails to consistently support safe and effective operations to achieve their scientific mission.

Integrated safety management requires not only defining work, analyzing and controlling hazards, and performing work within controls, but also feedback and improvement. The Board determined that SLAC's processes failed to effectively identify and correct issues to continually improve work processes. This can be seen in both their assessment and issues management program implementation.

Finally, SLAC failed to provide adequate and effective field oversight, missing the opportunity to detect issues related to the effectiveness of SLAC procedures and their implementation during work activities.

Below is a list of conclusions as determined throughout the report analysis:

CON-1: Work Planning and Control failed to properly identify the hazards and controls associated with the work.
CON-2: SLAC Management failed to provide oversight of critical work planning elements.
CON-3: SLAC Management failed to establish defined roles and responsibilities for the work.
CON-4: Lack of management oversight and supervision led to normalization of deviations in work practices.
CON-5: There was a complete loss of administrative and physical control of the CoHE/LOTO process.
CON-6: Less than adequate configuration management led to inaccurate representation of the electrical distribution system.
CON-7: Inaccurate mental model led to wrong actions taken.
CON-8: Skill-based performance mode led to erosion of procedural compliance.

Table 5-1 provides the reader with a high-level understanding of the collective results from the Board's analysis and is not an exhaustive representation of the complex associations of factors. The crosswalk links the causal factors and contributing causes based on the ECF chart and under very specific conditions. From this, CONs and JONs were assigned by the Board.

Table 5-1: Results Crosswalk

CF No.	Causal Factor	Contrib. Cause(s)	CON No.	JON No.
CF-1	Additional complexity required leaving IR-2 partially energized for about 4 hours	CC-2 CC-4	6	1, 2, 3, 4
CF-2	Numerous errors, omissions, and inconsistencies among the EWP, SWO, and EIP	CC-5	1, 2	6, 8, 9, 10, 11, 12, 13, 14
CF-3	Work not formally classified as Red; it failed to trigger a WIP	CC-5	1, 2	3, 8, 9, 12

CF No.	Causal Factor	Contrib. Cause(s)	CON No.	JON No.
CF-4	No work package or single line drawing used during walkdown	CC-6	2	6, 9, 10, 11
CF-5	Not all HVEs who worked the B626 EWP on 12/27 participated on this walkdown	CC-6	2, 3	10, 11
CF-6	HVE3 and HVE4 assigned as floaters to HVE1 and HVE2 at B626 without pre-job briefing	CC-7	2, 3	10, 11, 16
CF-7	Not all required reviews for the B626 Outage were performed	CC-5	1, 2	8, 9, 10, 11, 12 ,13, 14
CF-8	B626 EWP, SWO, and EIP discrepancy not identified	CC-5	1, 2, 3, 6	8, 9, 10, 11, 12, 13, 14
CF-9	First meeting after extended holiday weekend	CC-4	1	12
CF-10	Walkdown done 4-5 days prior to execution. Potential change in field conditions/loss of familiarity	CC-4	2	9, 10, 11, 12
CF-11	Workers late due to heavy rain; catching up after holiday weekend (Distraction)	CC-4	1	12
CF-12	Discrete Job Briefing, as per Chapter 8 and NFPA 70E, did not occur	CC-7	2, 3	10, 11, 16
CF-13	HVE3 and HVE4 not fully briefed to scope/hazards/controls	CC-7	2, 3	10, 11, 16
CF-14	Work executed outside of scope activities	CC-1 CC-4 CC-8	1, 4, 5	12, 14
CF-15	Field conditions did not match expected / briefed conditions (BRK360 racked-out)	CC-1 CC-8	1, 2, 4, 6, 8	8, 10, 14
CF-16	Work step added to approved EWP without additional HA/Approval	CC-1 CC-8	4, 5, 7, 8	7, 8, 12, 13, 14
CF-17/19	EWP did not include an arc flash risk assessment for remote racking	CC-1 CC-9	1, 4	8, 9
CF-18	EWP did not include an arc flash risk assessment for remote switching	CC-1 CC-9	1, 4	8, 9
CF-20	HVE2 verbalized arc flash concern to HVE1. No recognition of further communication by HVE1	CC-10	5, 7	7
CF-21	Posted drawings for IR-2 were not up to date, did not reflect current conditions	CC-2 CC-3	1, 6	2, 5, 6, 10
CF-22	Lights out, 0V at receptacle. HVEs believed IR-2 was deenergized. Improper ZVV and understanding of energy isolation boundary	CC-3 CC-8	6, 7, 8	2, 5, 7, 14, 15
CF-23	All front panel indicators, meters, and status lights were disabled	CC-3 CC-8	4, 7, 8	12
CF-24	Two LAEW's with unclear roles and responsibilities	CC-1	3, 4, 5	7, 9

CF No.	Causal Factor	Contrib. Cause(s)	CON No.	JON No.
CF-25	HVE1 acknowledged but did not understand relevance to IR-2 being partially energized	CC-10	5, 7	2, 3, 7
CF-26	Posted drawings for S522 were not up to date, did not reflect current conditions	CC-2 CC-3	1, 6	1, 2, 6
CF-27	SWO1 required performing ZVV at the 12kV B626 switchgear prior to conducting MCC #2 ZVV	CC-1 CC-8	4, 5, 7, 8	7, 13
CF-28	SWO1 required performing ZVV at the 12.47 kV B626 switchgear prior to conducting MCC #1 ZVV	CC-1 CC-8	4, 5, 7, 8	7, 13
CF-29	HVE1 believed IR-2 was already fully deenergized and selected BRK342	CC-1 CC-3 CC-8	2, 4, 6, 7, 8	2, 5, 7, 12, 14, 15
CF-30	HVE1 and HVE3 did not wear appropriate arc flash PPE within the arc flash boundary	CC-1 CC-9	4, 7, 8	2, 5, 7, 14
CF-31	No ZVV performed	CC-1 CC-8	5	7, 12, 14
CF-32	HVE1 did not wear appropriate shock protection PPE for entering the Restricted Approach Boundary of 26”	CC-1 CC-9	4, 7, 8	2, 5, 7, 14
CF-33	HVE3 did not think that the back of BRK342 was energized	CC-7	3, 5, 7	7, 9, 12, 14
CF-34	HVE3 not included in B626 walkdown or briefing	CC-7	2, 3, 5, 7	10, 11, 16
CF-35	Test Before Touch with proximity tester not performed after worksite left unattended	CC-1	5, 7, 8	7, 14

Based on the facts, analysis, causal factors, identified causes, and subsequent conclusions, the Board identified 16 Judgments of Need:

JON 1: Stanford University needs to assure infrastructure risks are evaluated, documented, and managed.

JON 2: SLAC Management needs to ensure that configuration of systems is accurately documented consistent with field conditions and available for use.

JON 3: Given the number of temporary modifications that have become permanent, SLAC EPD needs to develop and implement a risk-informed plan that aligns the electrical system configuration to safely support operations and maintenance activities.

JON 4: SLAC management needs to evaluate the operational risk associated with the EPD maintenance program test failures in advance of work authorization.

JON 5: SLAC Management needs to validate and maintain accurate equipment identification and hazard labels.

JON 6: SLAC Management needs to ensure issues and corrective actions are consistently documented, prioritized, and objectively tracked to closure.

JON 7: SLAC Management needs to ensure that continuing training effectively confirms worker competency to perform CoHE activities through practical demonstration.

JON 8: SLAC Management needs to clarify and reinforce requirements for preparation, review, and approval of work plans.

JON 9: SLAC Management needs to ensure processes align known hazards with controls throughout the work planning and execution.

JON 10: SLAC Management needs to define requirements and expectations for walkdowns during work planning processes and prior to work performance.

JON 11: SLAC Management needs to strengthen requirements and expectations for tailgate briefings.

JON 12: SLAC Management needs to ensure that the known human performance improvement error precursors are considered in work planning processes and during work execution.

JON 13: SLAC Management needs to ensure the alignment between the EWP, SWO, and EIP, including better defined roles and responsibilities and interdependence between the documents.

JON 14: SLAC Supervisors need to conduct ongoing field verification of compliance with approved work plans, including mandatory step-by-step sequencing where required.

JON 15: SLAC Management needs to ensure CoHE Program assessment and required annual periodic inspections are conducted.

JON 16: SLAC needs to reassess their level of readiness to respond to accident situations.

6.0 ACCIDENT INVESTIGATION BOARD MEMBER SIGNATURES

Approved by:

M. G. Branton 4/16/2023

Michele G. Branton, Chair — Date
Deputy Manager, Oak Ridge National Laboratory Site Office
Office of Science, Department of Energy

Juan Adrover 4/17/2023

Juan (Rick) Adrover — Date
Electrical Safety Program Manager
Thomas Jefferson National Accelerator Facility

Samuel Bigger 4/17/2023

Samuel B. Bigger — Date
Manager, Ames Site Office
Office of Science, Department of Energy

Jason Brustad 4/16/2023

Jason Brustad — Date
Accident Prevention and Investigation Program Manager
Office of ES&H Reporting and Analysis (EHSS-23), Department of Energy

J. R. Castañeda-Hernández 04/17/2023

J. Raúl Castañeda-Hernández, Trained Accident Investigator — Date
Office of Associate Deputy Manager for Operations, Pantex
National Nuclear Security Administration, Department of Energy

Steven J. Neilson 4/17/2023

Steven Neilson — Date
Office of Safety and Security
Office of Science (SC-41.1), Department of Energy

4/16/2023

Mark A. Scott — Date
Electrical Projects Department Head
Projects Infrastructure and Modernization Division, Lawrence Berkeley National Laboratory

APPENDIX A

Accident Investigation Board Appointment Memoranda

Department of Energy
Office of Science
Washington, DC 20585

December 29, 2022

MEMORANDUM FOR MICHELE G. BRANTON
ORNL SITE OFFICE DEPUTY MANAGER
OFFICE OF SCIENCE

FROM: JUSTON K. FONTAINE
DEPUTY DIRECTOR FOR FIELD OPERATIONS
OFFICE OF SCIENCE

SUBJECT: Incident Investigation at SLAC National Accelerator Laboratory

BACKGROUND: On December 27, 2022, an arc flash incident occurred in Building 626 at the SLAC National Accelerator Laboratory (SLAC). During an activity to perform zero-voltage checks on a de-energized 12 KV conductor to verify lockout/tagout (LOTO), an arc flash occurred when an electrician was removing the cover of the conductor. The individual suffered burns to the face and hands. SLAC is currently conducting an internal fact-finding analysis.

In addition to this most recent event, over the past year, there have been several incidents at the Laboratory where LOTO policies or protocols were not appropriately implemented to mitigate hazardous energy sources before initiating work. Additionally, deficiencies in work planning and control (WPC) practices have contributed to a number of incidents over the same period.

ACTION: In order to determine the facts and circumstances related to the arc flash incident as well as possible weaknesses in the institutional LOTO and WPC programs at SLAC, I am directing that an investigation be conducted to identify causal factors, including a review of any relevant policies, procedures, work practices, or actions related to the incident. The review should also explore, as appropriate, an extent of condition. This review should include, but is not limited to the following:

1. Determine the facts leading up to the incident.
2. Review the adequacy of the Laboratory's immediate response, interim actions, and extent of condition evaluation in response to this incident.
3. Assess the application of the WPC process used to determine the scope of work, identification of hazards and the work controls prior to the worker initiating the work.
4. Assess the procedures for and actions taken to conduct, document, and perform the maintenance work within the controls.
5. Conduct a causal analysis, using recognized methodologies, as needed, to determine the root and contributing causes of the arc flash incident.
6. Review and assess the status and adequacy of corrective actions from previous LOTO and work control incidents to prevent similar issues.
7. Assess the adequacy of the Laboratory's LOTO policies and implementation.

8. Determine whether broader systemic weaknesses are present in the Laboratory's WPC and LOTO programs.

CHARGE: I am appointing you as the Team Lead for this effort. In this capacity, you are to establish a DOE investigation team, with laboratory support as appropriate, to investigate the incident. Please provide a draft report no later than March 1, 2023, which includes findings and recommendations aimed at identifying and correcting deficiencies that contributed to the arc flash incident as well as any broader programmatic weaknesses or lessons learned that would improve future activities. If, during the course of the review, specific critical items of an urgent nature are identified, please address these issues immediately and provide a summary of findings.

cc:
Jessica Halse, Associate Deputy Director for Field Operations
Hanley Lee, SLAC Site Office Manager

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Department of Energy
Office of Science
Washington, DC 20585

January 9, 2023

MEMORANDUM FOR MICHELE G. BRANTON
OAK RIDGE SITE OFFICE DEPUTY MANAGER
OFFICE OF SCIENCE

FROM: JUSTON K. FONTAINE
DEPUTY DIRECTOR FOR FIELD OPERATIONS
OFFICE OF SCIENCE

SUBJECT: Amended Charge for Accident Investigation at SLAC National Accelerator Laboratory

On December 29, 2022, the attached memorandum was issued to establish a DOE investigation team to investigate an arc flash incident that occurred in Building 626 at the SLAC National Accelerator Laboratory (SLAC) on December 27, 2022.

At that time, the incident did not meet the determination criteria provided in DOE O 225.1B Appendix A. Subsequent to the issuance of the initial charge memorandum, the incident meets the criteria of DOE O 225.1B, Appendix A, item 2.a.(2) (any single accident that results in the hospitalization for more than five calendar days, commencing within seven calendar days of the accident, of one or more DOE, contractor, or subcontractor employees or members of the public due to a serious personal injury or acute chemical or biological exposure). Therefore, I am amending my previous direction to formally appoint an Accident Investigation Board (AIB).

You are appointed as the Board Chairperson and are to conduct this investigation in accordance with DOE O 225.1B. The AIB will be composed of the following members:

- Samuel B. Bigger, Manager, Ames Site Office
- Jason Brustad, Office of ES&H Reporting and Analysis
- J. Raúl Castañeda-Hernández, Office of Associate Deputy Manager for Pantex Plant Operations – Trained Accident Investigator
- Steve Neilson, Office of Safety and Security
- Rick Adrover, Thomas Jefferson National Accelerator Facility
- Mark A. Scott, Lawrence Berkeley National Laboratory
- Rizwan Shah (ad hoc), Office of Environmental Protection and ES&H Reporting

The Trained Accident Investigator is appointed from the list provided by the Office of Environment, Health, Safety & Security. The appointment of contractor electrical expertise from other DOE Laboratories is necessary to ensure appropriate investigation of this incident.

All members of the AIB, by this letter and in consultation with their respective management, are released from their regular duty assignments to serve on the AIB, during the period the AIB is convened.

The action and charge as communicated in the attached memorandum issued on December 29, 2022, remain the same for this appointed AIB.

Attachment

cc:
Jessica Halse, Associate Deputy Director for Field Operations
Todd Lapointe, Director, Environment, Health, Safety & Security
Samuel Bigger, Ames Site Office Manager
Jason Brustad, Office of ES&H Reporting and Analysis
J. Raúl Castañeda-Hernández, Office of Associate Deputy Manager for Pantex Plant Operations
Steve Neilson, Office of Safety and Security
Mark Scott, Lawrence Berkeley National Laboratory
Rick Adrover, Thomas Jefferson National Accelerator Facility

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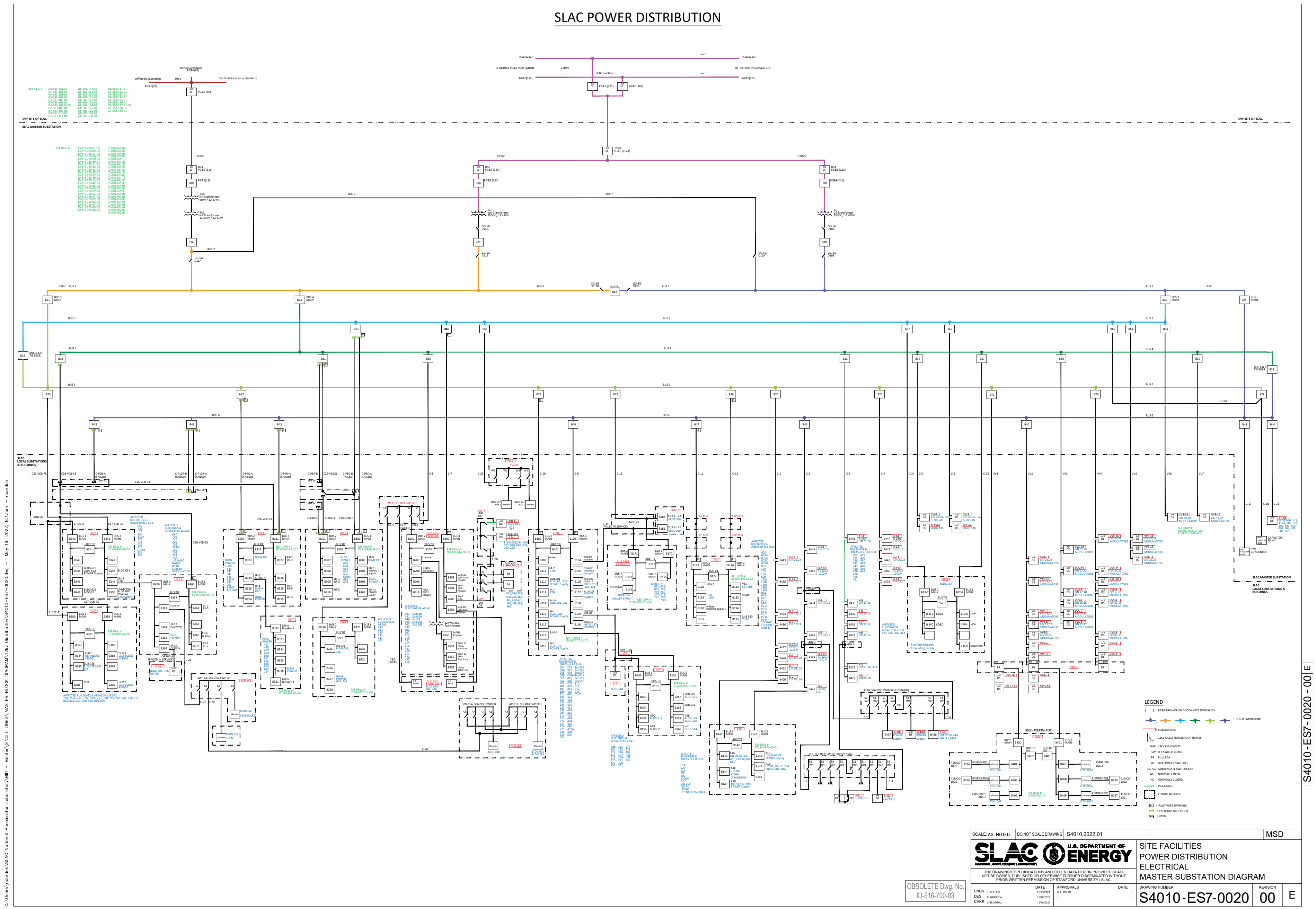
APPENDIX B

SLAC Power Distribution Electrical Master Substation Diagram



SLAC POWER DISTRIBUTION
SCALE: AS NOTED
DO NOT SCALE DRAWING
S4010.2022.01
MSD
THE DRAWINGS, SPECIFICATIONS AND OTHER DATA HEREIN PROVIDED SHALL NOT BE COPIED, PUBLISHED OR OTHERWISE FURTHER DISSEMINATED WITHOUT PRIOR WRITTEN PERMISSION OF STANFORD UNIVERSITY / SLAC.
SITE FACILITIES
POWER DISTRIBUTION
ELECTRICAL
MASTER SUBSTATION DIAGRAM
OBSOLETE Dwg. No.
ID-616-700-03
DRAWING NUMBER
S4010-ES7-0020
REVISION
00
E
S4010-ES7-0020 - 00 E
C:\Users\ricardon\SLAC National Accelerator Laboratory\BIO -- Master\SINGLE LINES\MASTER BLOCK DIAGRAM\12kv Distribution\S4010-ES7-0020.dwg -- May 19, 2022, 8:15am -- ricardon

APPENDIX C

Board Communication To SLAC Senior Leadership On January 20, 2023

The Board is here to understand and identify the causes that contributed to the accident so those deficiencies can be addressed and corrected.

The Board intended to provide an end of week briefing on the status of the Board's efforts thus far, which we will get into in a moment. However, the Board's charge requires that we address immediately any specific critical items of an urgent nature that the Board identifies during the course of the review. The Board has notified our Appointing Official this morning and will be sharing those specific critical items with you now.

Before we get into those items, the Board would like to acknowledge some positive items we have observed:

- The workers in the field (High Voltage work) want to do the right thing, and believe they are.
- We have observed a number of behaviors that indicate that the workers are conscientious and want to do a good job.
- We especially note that the high voltage Supervisor is thorough, thoughtful, safety-minded and accountable.
- We have also observed that the HV team planning efforts are extensive and inclusive.

The Board recognizes that you have put additional interim control measures in place since the event. We have also observed that notable gaps remain. Even with interim measures in place, the Board believes there is substantial risk for injury in the HV Electrical work practices.

Specifically, the Board observed:

- Multiple required elements of Chapter 51, *Control of Hazardous Energy* are not being followed. This results in elevated risk to employees and subcontractors performing work under these hazardous energy controls. Troubling examples include 1) work is being authorized before LOTO procedures are fully completed, and 2) procedures are being performed out of sequence or split up between personnel to be done in parallel.
- The management in F&O electrical maintenance planning are not actively engaged in supervising work at the job site, do not appear to fully recognize work practice deficiencies, or consistently address deficiencies when identified.
- Conduct of electrical job briefings in support of Switching Orders and LOTO procedures are not effectively identifying hazards and implementing controls per the plan. For example, the board has observed instances where electrical job briefings are not being done immediately before the job, hazards and controls are not discussed, and there is no discussion of what could go wrong or emergency response actions.
- Planning and execution of field work is overly dependent on expert-based capabilities rather than supervised procedural compliance.

APPENDIX D

Electrical Work Plan for 12/27/2022 Outage

This is the field copy of the EWP and associated documents used by HVE1 and turned over to the Board after the accident.

- Pages C-2 through C-12 is the EWP
- Pages C-13 and C-14 are SWO1. The accident occurred at the third step 5 on page C-13.
- Page C-15 is EIP1. The accident occurred at step 7 on page C-15.
- Page C-16 is Complex LOTO #1
- Page C-17 is the single line drawing associated with SWO1 and EIP1
- Pages C-18 and C-19 are SWO2 (not executed)
- Page C-20 is EIP2 (not executed)
- Page C-21 is Complex LOTO #2 (not executed)
- Pages C-22 through C-24 are single line drawings associated with SWO2 and EIP2
- Page C-25 is SWO3 for system restoration (not executed)

F&O Electrical Power Department
Sub B522-B626 Preventive Maintenance
December 2022

[redacted]

SLAC NATIONAL ACCELERATOR LABORATORY

ENVIRONMENT, SAFETY & HEALTH DIVISION

Chapter 8: Electrical Safety

Electrical Work Plan

Product ID: nnn | Revision ID: nnnn | Date Published: Date | Date Effective: Date
URL: http://www-group.slac.stanford.edu/esh/forms/ewp.pdf | .doc

1) Job / Activity: **Perform Preventive Maintenance on B522 & B626 Substations and downstream subs B950s, B999s, B756 and the downstream loads.**		Start Date: **12/27/2022**	Valid Through: **12/26/23**
Prepared by: [redacted]	Person in Charge (LAEW): [redacted]	Other Reviewer/s: [redacted]	

Scope of Work Summary:

Section 1.- Notification and verifications

i. **Verify Authorization and Release has been obtained.**
ii. **Verify affected end use equipment is secured.**
iii. **All other pre-work verifications have been completed.**

Section 2.- Electrical Isolation and ZVV of MCC's and panels fed from Sub 626, PM MCC's, Generator installation (Isolation by SLAC Electricians witnessed by Subcontractor)

i. **SLAC Electricians perform Electrical Isolation and LOTO of 12.47kV breakers at Subs 522, 726 & 626.**
ii. **Subcontractor perform PM's on MCC's targeted for temp power, SLAC Electricians PM E-power panels and ATS.**
iii. **SLAC Electricians install generators at Pump Pad MCC & at primary of ATS for E-power**

Section 3 – Complete global LOTO, PM Boiler MCC's, Install generator for Boiler

i. **LAEW completes Sub 522/626 LOTO**
ii. **SLAC Electricians perform PM's on B950 MCC01 & MCC02**
iii. **SLAC Electricians install generator for Boiler**
iv. **SLAC Electricians perform ZVV Sub 522, 626, 756 & 999**

Section 4.- Subcontractor performs substation testing & maintenance per contract / SLAC Support for B950 PCW Skid Project / SLAC Cable Testing

i. **SLAC LowVolt Electricians perform ZVV and QC for subcontractor at B950 4MCC03-950 per *B950 PCW Skid Project***

Section 5- SLAC QC's completed subcontractor work, Power restoration

i. **SLAC Electricians complete their assigned PM's**

ii. **SLAC Electricians QC subcontractor work**

iii. **LAEW verify all work complete, and all worker locks are removed from group lockbox.**

iv. **LAEW and SLAC Electricians begin power restoration process**

NOTE:

In case of discovered unexpected conditions:

LAEW shall stop electrical work, contact Electrical Engineer.

EPD Electrical Engineer shall discuss unexpected conditions with ALL personnel participating in test run.

EPD Electrical Engineer, LAEW, and shall review redlined design documentation and perform all needed investigation.

EPD Electrical Engineer and LAEW shall modify the Electrical Work Plan and inform personnel participating in test run about changes in approved document.

Hazard Analysis

1 - Notifications and Verifications				
Step or Task	**Step or Task Description**	**Hazard** (include shock and arc flash hazard information from the hazard label affixed to the equipment or from the electrical analysis engineer)	**Control** (include electrical safety PPE based on the electrical hazard information)	**Timestamp and Initials of Electricians performing step**
1.01	Using the COVID 19 best practices	Continued transmission of COVID 19 virus	Follow the latest procedures laid out by ESH for COVID 19 using the current COVID 19 JSA.	[redacted]
1.02	Verify WPC documentation is approved	Proceeding with unapproved work	Verify all needed signatures are in place.	
1.03	SLAC HV Electricians verify Remote Operation (Chicken Switch & Racking) devices are readily available in B726 & B626 Substations and in properly working condition	Entrance to Substation: Electric shock, arc flash injury	Wear PPE, Observe arc flash labeling	
1.04	LEAW Verify building manager for B620 is aware of the 4-hour outage to perform Preventive Maintenance before the generator is connected	Proceeding with "unreleased" work	Obtain verbal or written release from building or area manager	

1.05	LEAW Verify building managers for IR-2, B950, B999, B960, B940, B921, B750 are aware of the outage and has been notified	Proceeding with "unreleased" work	Obtain verbal or written release from building or area manager	
1.06	LAEW request FOC to Verify Fire Techs, Inst Techs, HVAC and Mechs that their systems have been secured	Not verifying potentially could cause safety hazard, false alarms and disruption of equipment operation	Obtain verbal confirmation from FOC or the trades	
1.07	LAEW Verify that the generator is in place and cabling is laid out and ready for connection at B950s MCC 4MCC01-950	Not verifying potentially could cause delays in connecting temp power and building services	Verify in place	
1.08	LAEW Verify that the generator is in place and cabling is laid out and ready for connection at B756 ATS for B750	Not verifying potentially could cause delays in connecting temp power and building services	Verify in place	
1.09	LAEW Verify that the generator is in place and cabling is laid out and ready for connection at B626M Pump Pad	Not verifying potentially could cause delays in connecting temp power and building services	Verify in place	
1.10	LAEW Verify that the generator is in place and cabling is laid out and ready for connection at B625 Junction Box to the ATS.	Not verifying potentially could cause delays in connecting temp power and building services	Verify in place	
1.11	LAEW Verify that the cabling is laid out and ready for connection Between MCC-02 and 251-P1-MCC (B624)	Not verifying potentially could cause delays in connecting temp power and building services	Verify in place	

2. Perform Switching to Isolate B626 Substation, Subcontractor MCC PM's, Install generators				
Step or Task	**Step or Task Description**	**Hazard** (include shock and arc flash hazard information from the hazard label affixed to the equipment or from the electrical analysis engineer)	**Control** (include electrical safety PPE based on the electrical hazard information)	**Timestamp and Initials of Electricians performing step**
2.01	SLAC LAEW verify all HVAC, Fire, Instrument Tech and Utility Mechanics are ready for the outage	Not verifying potentially could cause safety hazard, false alarms and disruption of equipment operation	Obtain verbal confirmation from FOC or the trades	
2.02	SLAC HV Electricians to notify FOC the intent to perform switching for B626 Substation's Preventive Maintenance	Not verifying potentially could cause safety hazard, false alarms and disruption of equipment operation	Receive conformation via FOC, direct contact	
2.03	SLAC HV Electricians to place B620 E-generator controls in Off position.	Electric shock, arc flash	Wear proper PPE required for Arc flash Category	
2.04	STOP LAEW and SLAC Electricians pause prior to closing any breakers or energizing any equipment and ensures that all pre-energization requirements and steps above are complete Unexpected condition(s) during energization: Work must be paused, and the condition evaluated to determine the appropriate path forward. The cause of the condition must be understood before moving forward. Pause criteria must include: • If worksite conditions require a change in or departure from the work plan • If unexpected conditions or equipment responses are encountered • Work planning must be revisited and revised accordingly • Work must be re-authorized by the functional supervisor prior to proceeding Work must be re-released by the building/area manager prior to proceeding			
2.05	SLAC HV Electricians perform switching order "B626 PM Gen Install" to shut down power and begin E-power and MCC Maintenance	Electric Shock, Arc Flash	Wear PPE required for Substations. Use Chicken switch and remote racking devices as needed	
2.06	SLAC HV Electricians at B626 Perform ZVV in the 12kV switchgear and 480V Switchgear, Subcontractor to witness	Electric shock, arc flash	Wear proper PPE required for Arc flash Category	
2.07	SLAC HV Electricians at B620 Perform ZVV in the 480V MCC #1 And MCC 02 Subcontractor to witness	Electric shock, arc flash	Wear proper PPE required for Arc flash Category	
2.08	SLAC HV Electricians perform Zero Voltage Verification at MCC 251-P1-MCC in B624, subcontractor to witness.	Electric Shock, Arc Flash	Wear proper PPE	

2.09	SLAC HV Electricians at B625 Perform ZVV in the 480V ATS Junction Box.	Electric shock, arc flash	Wear proper PPE required for Arc flash Category	
2.10	SLAC Electricians apply personal LOTO to group lockbox "B626 PM Gen Install" and sign on	None		
2.11	Perform walkthrough with Contractor of the Lockout and have them sign on LOTO releasing the contractor	Electric shock,	Wear PPE required for Substations	
2.12	SLAC Low Volt Electricians apply LOTO on Breaker A in 2PEP-1 and perform preventive maintenance on E-power circuit and make portable generator connection at utility power junction box.	Electric Shock, Arc Flash	Wear proper PPE	
2.13	Contractor to perform the Preventive Maintenance in B620, B624 & B626M Pump Pad.	Electric shock,	Wear PPE required for Substations	
2.14	Perform QC inspection of B625 Generator connection, Preventive Maintenance and Air Gap *Note: Everyone needs to stand Down when Generator is started and building load is added*	Electric shock,	Wear proper PPE	
2.15	Perform QC inspection of B620 & B624 Preventive Maintenance and Connect Generator via B626M Pump Pad Junction Box fed from MCC#1 *Note: Everyone needs to stand Down when Generator is started and building load is added*	Electric shock,	Wear proper PPE	
2.16	SLAC Low Volt Electricians remove LOTO on Breaker A in 2PEP-1 and once the rental Generator is running and loaded return B620 E-generator controls to the "On" position.	Electric Shock, Arc Flash	Wear proper PPE	
2.17	SLAC Electricians and Contractor to remove LOTO from Lock Box "B626 PM Gen Install"	None		
2.18	SLAC HV Electricians to verify open and apply group LOTO to the Main breakers in MCC #1 on the pump Pad and MCC 251-P1-MCC and place in group lock box "B522-B626 PM"	Electric shock,	Wear proper PPE	

3.-Perform Switching to Isolate Substation 522, MCC PM's, complete global LOTO				
Step or Task	**Step or Task Description**	**Hazard** (include shock and arc flash hazard information from the hazard label affixed to the equipment or from the electrical analysis engineer)	**Control** (include electrical safety PPE based on the electrical hazard information)	**Timestamp and Initials of Electricians performing step**
3.01	Perform the B756/ B750 ATS generator connection	Electric shock,	Wear proper PPE	
3.02	SLAC HV Electricians to notify FOC the intent to perform switching for B522 Substation's Preventive Maintenance	Not verifying potentially could cause safety hazard, false alarms and disruption of equipment operation	Receive conformation via FOC, direct contact	
3.03	 LAEW and SLAC Electricians pause prior to closing any breakers or energizing any equipment and ensures that all pre-energization requirements and steps above are complete Unexpected condition(s) during energization: Work must be paused, and the condition evaluated to determine the appropriate path forward. The cause of the condition must be understood before moving forward. Pause criteria must include: • If worksite conditions require a change in or departure from the work plan • If unexpected conditions or equipment responses are encountered • Work planning must be revisited and revised accordingly • Work must be re-authorized by the functional supervisor prior to proceeding • Work must be re-released by the building/area manager prior to proceeding			
3.04	SLAC HV Electricians to complete Switching Order "B522-B626 PM"	Electric shock, arc flash	Wear PPE required for Substations. Use Chicken switch and remote racking devices as needed	
3.05	SLAC HV Electricians at B522 Perform ZVV in the 12kV switchgear and B950s 480V MCC 4MCC01-950, Subcontractor to witness	Electric shock, arc flash	Wear proper PPE required for Arc flash Category	
3.06	SLAC HV Electricians at B626 Perform ZVV in the 12kV switchgear and 480V switchgear, Subcontractor to witness	Electric shock, arc flash	Wear proper PPE required for Arc flash Category	
3.07	SLAC HV Electricians at B756 Perform ZVV in the 12kV switchgear and 480V switchgear, Subcontractor to witness	Electric shock, arc flash	Wear proper PPE required for Arc flash Category	
3.08	SLAC HV Electricians at B999 Perform ZVV in the 12kV switchgear and 480V switchgear, Subcontractor to witness	Electric shock, arc flash	Wear proper PPE required for Arc flash Category	
3.09	Perform walkthrough with Contractor of the Lockout and have them sign on LOTO releasing the contractor	Electric shock,	Wear PPE required for Substations	

4 – Subcontractor Testing & Maintenance / B950 PCW Skid Support / SLAC Cable Testing				
Step or Task	**Step or Task Description**	**Hazard** (include shock and arc flash hazard information from the hazard label affixed to the equipment or from the electrical analysis engineer)	**Control** (include electrical safety PPE based on the electrical hazard information)	**Timestamp and Initials of Electricians performing step**
4.01	Contractor to perform the Preventive Maintenance in B626, B522, B756 & B999 and Downstream loads	Electric shock,	Wear PPE, apply personal LOTO	
4.02 (12/28/22)	SLAC LowVolt Electricians perform ZVV at B950 4MCC03-950, subcontractor to witness	Electric shock, arc flash	Wear proper PPE required for Arc flash Category	
4.03 (12/28/22)	Subcontractor apply personal LOTO at group lockbox, sign permit and perform their work per contract. Remove LOTO & sign off permit when complete. SLAC LowVolt Electricians to QC	Electric shock,	Wear PPE, apply personal LOTO	
4.04	HV Electricians to perform Testing on the 12kV cables feeding B626 & B522, coordinate with the subcontractor for access	Electric shock,	Wear PPE required for Substations Ensure coordination with the subcontractor via verbal communication and walk down. Follow Testing procedures including barricades..	

5 - Perform QC. Perform Switching to Energize 522 & 626 Substations				
Step or Task	**Step or Task Description**	**Hazard** (include shock and arc flash hazard information from the hazard label affixed to the equipment or from the electrical analysis engineer)	**Control** (include electrical safety PPE based on the electrical hazard information)	**Timestamp and Initials of Electricians performing step**
5.01	Perform QC inspection of B626, B522, B756 & B999 and downstream loads Preventive Maintenance	Electric shock,	Wear PPE required for Substations	
5.02	Turn Off the Generator and disconnect temp generator cables feeding B626M Pump Pad Junction Box fed from MCC#1. Remove LOTO and close the main breakers in B626M Pump Pad MCC#1 and B624 MCC 251-P1-MCC	Electric shock,	Wear PPE required for Substations	

5.03	In B620 MCC-02 open breaker #C3 feeding the Cleanroom Panel B620-4DP-101	Trips and falls due to low area lighting	Have a battery power flashlight available	
5.04	SLAC HV Electricians to set configurations in B522, B626, B756, B950s & B999	Electric shock,	Wear PPE required for Substations	
5.05	LEAW Verify building managers for B999, B626, B756, B950 & B522 are aware of the outage and has been notified	Not verifying potentially could cause safety hazard, false alarms and disruption of equipment operation	Obtain verbal or written release from building or area manager	
5.06	LAEW request FOC to Verify Fire Techs, Inst techs, HVAC and Mechs that their systems have been secured or reconfigured	Not verifying potentially could cause safety hazard, false alarms and disruption of equipment operation	Obtain verbal confirmation from FOC or the trades	
5.07	SLAC HV Electricians to notify FOC the intent to perform switching for B522 Substation's Power restore	Not verifying potentially could cause safety hazard, false alarms and disruption of equipment operation	Receive conformation via FOC, direct contact	
5.08	 LAEW and SLAC Electricians pause prior to closing any breakers or energizing any equipment and ensures that all pre-energization requirements and steps above are complete Unexpected condition(s) during energization: Work must be paused, and the condition evaluated to determine the appropriate path forward. The cause of the condition must be understood before moving forward. Pause criteria must include: • If worksite conditions require a change in or departure from the work plan • If unexpected conditions or equipment responses are encountered • Work planning must be revisited and revised accordingly • Work must be re-authorized by the functional supervisor prior to proceeding • Work must be re-released by the building/area manager prior to proceeding			
5.09	SLAC HV Electricians to perform switching order "B522-B626 Restore"	Trips and falls due to low area lighting Electric shock, arc flash	Have a battery power flashlight available Observe and use minimum PPE per arc flash labeling Use Remote Control Panel &Use remote Racking Device	
5.10	SLAC HV Electricians to verify and Let FOC know all B522, B626, B666 & B901 are re-energized.	Not verifying potentially could cause safety hazard, false alarms and disruption of equipment operation	Obtain verbal confirmation from FOC	
5.11	Perform the B625 ATS generator disconnection and transfer to normal Power	Electric shock,	Wear PPE required for Substations	
5.12	Perform the B756/B750 generator disconnection and transfer to normal Power	Electric shock,	Wear PPE required for Substations	

5.13	Verify the HVAC systems are back on line in B620 and close in B620 MCC-02 breaker #C3 feeding the Cleanroom Panel B620-4DP-101			
5.14	Perform the B950s generator disconnection and transfer to normal Power	Electric shock,	Wear PPE required for Substations	

AUTORIZATION AND RELEASE

Authorization

Authorizer (administrative or functional supervisor, foreman, POC) I have reviewed the steps, hazards and controls described in this JSA. Workers are qualified (that is, licensed or certified, as appropriate, and in full compliance with SLAC training requirements) to perform this activity.

[redacted]

Name (print) Signature Date

Authorization

Authorizer (administrative or functional supervisor, foreman, POC) I have reviewed the steps, hazards and controls described in this JSA. Workers are qualified (that is, licensed or certified, as appropriate, and in full compliance with SLAC training requirements) to perform this activity.

[redacted]

Name (print) Signature Date

Authorization / Release

Authorizer (administrative or functional supervisor, foreman, POC, FCM) I have reviewed the steps, hazards and controls described in this JSA. Workers are qualified (that is, licensed or certified, as appropriate, and in full compliance with SLAC training requirements) to perform this activity.

[redacted]

Name (print) Signature Date

Release

Area or Building Manager ☐ Red work? (if yes, document release via WIP and tailgate meeting) otherwise ☐ I have communicated unique area hazards, boundary conditions, and so on with the authorizer or listed worker(s) and have coordinated this job with affected occupants. Listed workers are released to perform described scope of work. List boundary conditions, notes, etc.

List boundary conditions, notes, etc: Work in Manholes at the vehicular traffic areas. Work near energized electrical equipment

[redacted]

Name (print)	Signature	Date

[redacted]

Name (print)	Signature	Date

Asst. Substation Manager ☐ Red work? (if yes, document release via WIP and tailgate meeting) otherwise ☐ I have communicated unique area hazards, boundary conditions, and so on with the authorizer or listed worker(s) and have coordinated this job with affected occupants. Listed workers are released to perform described scope of work. List boundary conditions, notes, etc.

List boundary conditions, notes, etc: Work in Manholes at the vehicular traffic areas. Work near energized electrical equipment

[redacted]

Name (print)	Signature	Date

Worker Acknowledgment

Worker: I understand and will adhere to the steps, hazards, and controls in this EWP. I understand that performing steps out of sequence may pose hazards that have not been evaluated nor authorized. I will contact the person who authorized my work prior to continuing, if the scopes of work changes or new hazards are introduced. I understand my stop work authority and responsibility.

Print	Sign	Date
[redacted]	[redacted]	12/22/22
[redacted]	[redacted]	12/27/22
[redacted]	[redacted]	

SLAC HV SWITCHING ORDER

480V Switchgear Breakers and 12 kV, 60 kV, 230 kV Breakers, Switches, and Disconnects

SECTION 1 -- DESCRIPTION

Switching Log ID: B626 PM Gen Install PURPOSE: De-energize B626 and down stream loads to perform pre-generator PM DATE: 12/27/2022

SECTION 2 -- APPROVAL

[redacted] Date:
Date:
[redacted] Date:
Date:

SECTION 3 -- SWITCHING ORDER

ALL VVS 12kV AIR DISCONNECT SWITCHES ARE PROHIBITED FROM ENERGIZED OPERATION

WARNING: ALL OTHER 12kV AIR DISCONNECT SWITCHES MUST BE VERIFIED IF ENERGIZED OPERATION IS PERMITTED

Step Number	Substation or Location	Operation (Notify, Verify, Open, Close, Install, Remove, etc)	Equipment or System Voltage	Equipment or bus ID, and breaker or switch ID, and breaker or switch description	Instructions or Comments	Performed By (initials), Date and Time
					Pre-job briefing (required)	
1		Notify		FOC	Intent to switch	[redacted]
2	B726	Verify Open	12kV	Breaker #360	Use Chicken Switch	
3	B726	Rack Out	12kV	Breaker #360	Use Remote Racking Device	
4	B726	Apply B626 PM Gen Install Group LOTO	12kV	Breaker #360 L-112	Use Proper PPE	
5	B522	Verify Open	12kV	Breaker #380	Use Chicken Switch	
6	B522	Rack Out	12kV	Breaker #380	Use Remote Racking Device	
7	B522	Apply B626 PM Gen Install Group LOTO	12kV	Breaker #380 L-101	Use Proper PPE	
5	B626	Open	12kV	Breaker #342	Use Chicken Switch	
6	B626	Rack Out	12kV	Breaker #342	Use Remote Racking Device	
7	B626	Apply B626 PM Gen Install Group LOTO	12kV	Breaker #342	Use Proper PPE	
5	B626	Perform ZVV	12kv	Switchgear	Use Proper PPE	
7	B626M	Perform ZVV	480V	MCC #1	Use Proper PPE	
7	B620	Perform ZVV	480V	MCC-02	Use Proper PPE	

B626 PM Gen Install_VL.xlsx

1 of 2

Step Number	Substation or Location	Operation (Notify, Verify, Open, Close, Install, Remove, etc)	Equipment or System Voltage	Equipment or bus ID, and breaker or switch ID, and breaker or switch description	Instructions or Comments	Performed By (Initials), Date and Time
7	B624	Perform ZVV	480V	MCC 251-P1-MCC	Use Proper PPE	
12	B626	LAEW apply master group LOTO in group lockbox: B626 PM Gen Install and signs on				
13	B626	SLAC Electricians & Subcontractor Apply individual Locks to Group Lockbox: B626 PM Gen Install and Signs on				
14		Notify		FOC	Switching is complete	

B626 PM Gen Install_VL.xlsx

2 of 2

SLAC GROUP LOCKOUT - ENERGY ISOLATION PLAN

PAGE _1___ of 1

SECTION 1 – LOTO IDENTIFICATION

LOTO ID: B626 PM Gen Install LOTO PURPOSE: B626 and down stream loads to perform PM & gen install DATE: 12/27/2022

LOCATION/EQUIPMENT: B726, B626 & B522

LEAD AUTHORIZED WORKER or OPERATIONS GROUP: F&O EPD HiVolt SUBCONTRACTOR(S) Specialized Engineering Services

SECTION 2 – LOCK and TAG PLACEMENT, ZERO ENERGY VERIFICATION, VERIFICATION OF NON-OPERATION, GROUNDING (AS APPLICABLE)

ENERGY ISOLATION POINT NO. (STEP NO.)	ENERGY ISOLATION DEVICE/EQUIPMENT IDs ZERO VOLTAGE VERIFICATION or VERIFICATION OF NON-OPERATION test points LOCATION OF GROUNDS MASTER LOCK ON GROUP LOCKBOX (always the last step in the Energy Isolation Plan)	LOTO STATE OR POSITION	PERFORMED or WITNESSED BY
1	B726 12kV Breaker #360 L-112	Open, Racked Out LOTO'd	[redacted]
2	B726 12kV Breaker #360 Perform Zero Voltage Verification	Zero Voltage	
3	B726 Install grounds on Breaker #360 load Cables		
4	B522 12kV Breaker #380 L-101	Open, Racked Out LOTO'd	
5	B522 12kV Breaker #380 Perform Zero Voltage Verification	Zero Voltage	
6	B626 12kV Breaker #342 L-73	Open, Racked Out LOTO'd	
7	B626 12kV Breaker #342 Perform Zero Voltage Verification	Zero Voltage	
8	LAEW apply master group LOTO in group lockbox: B626 PM Gen Install and signs on		
9	SLAC Electricians and subcontractor Apply individual Locks to Group Lockbox: B626 PM Gen Install and Signs on		

SECTION 3 – ENERGY ISOLATION PLAN APPROVAL

Prepared By: [redacted] Date: Reviewed By: [redacted] Date:

1 August 2011 SLAC-I-730-0A10J-005-R001 coheTemplateEIP.xlsx

COMPLEX LOCKOUT PERMIT FOR ELPs AND GROUP LOCKOUT/TAGOUT

PAGE _1_ of _1_

SECTION 1 -- REFERENCE INFORMATION

LOTO ID Procedure ID: B626 PM Gen Install   B626 and down stream loads to perform PM & gen Install

SECTION 2 -- LEAD AUTHORIZED WORKER AND CONTRACTOR SUPERVISOR(S) - SIGN WHEN ENERGY ISOLATION IS COMPLETE, AND LOTO IS READY FOR AUTHORIZED WORKER SIGN ON

[redacted]

print   sign   date / time

SLAC Authorized Workers shall not sign on until authorized by the SLAC LEAD AUTHORIZED WORKER or OPERATIONS GROUP

CONTRACTOR SUPV: [redacted]

print name, sign, and company name

Contractor Authorized Workers shall not sign on until authorized by the SLAC LEAD AUTHORIZED WORKER or OPERATIONS GROUP and CONTRACTOR SUPV.

SECTION 3 -- SLAC AUTHORIZED WORKER SIGN-ON AND SIGN OFF

AUTHORIZED WORKER SIGN ON	DATE / TIME	AUTHORIZED WORKER SIGN OFF	DATE / TIME
[redacted]		print sign	
print sign		print sign	
print sign		print sign	
print sign		print sign	
print sign		print sign	
print sign		print sign	
print sign		print sign	
print sign		print sign	
print sign		print sign	

SECTION 4 - CONTRACTOR AUTHORIZED WORKER SIGN-ON AND SIGN OFF

AUTHORIZED WORKER SIGN ON	DATE / TIME	AUTHORIZED WORKER SIGN OFF	DATE / TIME
print print		print print	
print print		print print	
print print		print print	
print print		print print	
print print		print print	
print print		print print	
print print		print print	
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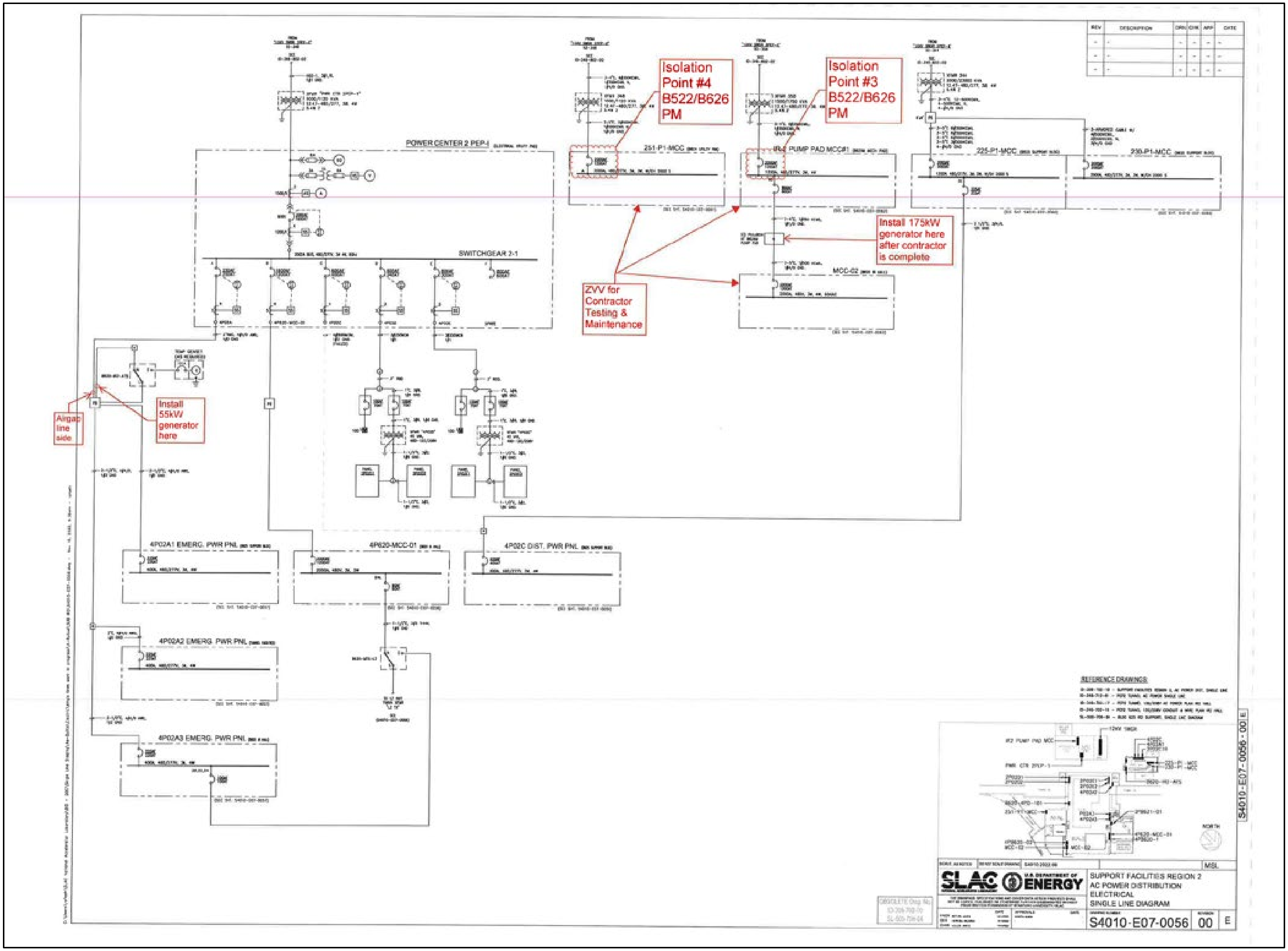
print print		print print	

1 August 2011   SLAC-I-730-0A10J-006-R001   cdsTemplateComplexPermit.xlsx



Isolation Point #4 B522/B626 PM
Isolation Point #3 B522/B626 PM
POWER CENTER 2 PEP-I
SWITCHGEAR 2-1
251-P1-MCC
IR-2 PUMP PAD MCC#1
225-P1-MCC
230-P1-MCC
Install 175kW generator here after contractor is complete
ZVV for Contractor Testing & Maintenance
MCC-02
Airgap line side
Install 55kW generator here
4P02A1 EMERG. PWR PNL
4P620-MCC-01
4P02C DIST. PWR PNL
4P02A2 EMERG. PWR PNL
4P02A3 EMERG. PWR PNL
REFERENCE DRAWINGS
SLAC
U.S. DEPARTMENT OF ENERGY
SUPPORT FACILITIES REGION 2
AC POWER DISTRIBUTION
ELECTRICAL
SINGLE LINE DIAGRAM
S4010-E07-0056
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E

SLAC HV SWITCHING ORDER

480V Switchgear Breakers and 12 kV, 60 kV, 230 kV Breakers, Switches, and Disconnects

SECTION 1 -- DESCRIPTION

Switching Log ID: B522-B626 PM PURPOSE: De-energize B522 and down stream loads to perform PM DATE: 12/27/2022

SECTION 2 -- APPROVAL

[redacted] Date:
Date:

[redacted] Date:
Date:

SECTION 3 -- SWITCHING ORDER

ALL VVS 12kV AIR DISCONNECT SWITCHES ARE PROHIBITED FROM ENERGIZED OPERATION

WARNING: ALL OTHER 12kV AIR DISCONNECT SWITCHES MUST BE VERIFIED IF ENERGIZED OPERATION IS PERMITTED

Step Number	Substation or Location	Operation (Notify, Verify, Open, Close, Install, Remove, etc)	Equipment or System Voltage	Equipment or bus ID, and breaker or switch ID, and breaker or switch description	Instructions or Comments	Performed By (initials), Date and Time
					Pre-job briefing (required)	
1		Notify		FOC	Intent to switch	
2	B726	Verify Open & Racked Out	12kV	Breaker #360	Use Chicken Switch	
3	B726	Verify B522-626 Group LOTO	12kV	Breaker #360	Use Proper PPE	
3	B726	Perform ZVV	12kV	Breaker #360 Load Cables	Use Proper PPE	
3	B726	Install Grounds & Tags	12kV	Breaker #360 Load Cables	Use Proper PPE	
4	B016/MSS	Open	12kV	Breaker #75	Use Time Delay on Relay	
6	B016/MSS	Rack Out	12kV	Breaker #75	Use Remote Racking Device	
7	B016/MSS	Apply B522-626 Group LOTO	12kV	Breaker #75	Use Proper PPE	
8	B016/MSS	Perform ZVV	12kV	Breaker #75 Load Cables	Use Proper PPE	
9	B016/MSS	Install Grounds & Tags	12kV	Breaker #75 Load Cables	Use Proper PPE	
10	B522	Perform ZVV	12kV	12kV Switchgear	Use Proper PPE	
11	B626	Perform ZVV	12kV	12kV Switchgear	Use Proper PPE	

Step Number	Substation or Location	Operation (Notify, Verify, Open, Close, Install, Remove, etc)	Equipment or System Voltage	Equipment or bus ID, and breaker or switch ID, and breaker or switch description	Instructions or Comments	Performed By (initials), Date and Time
12	B522	LAEW apply master group LOTO in group lockbox: B522-626 PM and signs on				
13	B523	SLAC Electricians & Subcontractor Apply individual Locks to Group Lockbox: B522-626 PM and Signs on				
14		Notify		FOC	Switching is complete	

B522-B626 PM

2 of 2

SLAC GROUP LOCKOUT - ENERGY ISOLATION PLAN

PAGE _1___ of 1

SECTION 1 -- LOTO IDENTIFICATION

LOTO ID: B522-B626 PM
LOTO PURPOSE: De-energize B522 & B626 and down stream loads to perform PM
DATE: 12/27/2022
LOCATION/EQUIPMENT: B726, B626, B522 & B016
LEAD AUTHORIZED WORKER or OPERATIONS GROUP: F&O EPD HIVolt
SUBCONTRACTOR(S) [redacted]

SECTION 2 -- LOCK and TAG PLACEMENT, ZERO ENERGY VERIFICATION, VERIFICATION OF NON-OPERATION, GROUNDING (AS APPLICABLE)

ENERGY ISOLATION STEP NO.	ENERGY ISOLATION DEVICE/EQUIPMENT IDs ZERO VOLTAGE VERIFICATION or VERIFICATION OF NON-OPERATION test points LOCATION OF GROUNDS MASTER LOCK ON GROUP LOCKBOX (always the last step in the Energy Isolation Plan)	LOTO STATE OR POSITION	PERFORMED or WITNESSED BY
1	B726 12kV Breaker #360 (Isolation Point #1)	Open, Racked Out LOTO'd	
2	B726 12kV Breaker #360 Perform Zero Voltage Verification	Zero Voltage	
3	B726 Install grounds on Breaker #360 load Cables		
4	B626M Pump Pad MCC#1 Main Breaker (Isolation Point #3)	Open, LOTO'd	
5	B624 MCC 251-P1-MCC Main Breaker (Isolation Point #4)	Open, LOTO'd	
6	B950s MCC 4MCC01-950 Main Breaker (Isolation Point #5)	Open, LOTO'd	
7	B016 12kV Breaker # 75 (Isolation Point #2)	Open, Racked Out LOTO'd	
8	B016 12kV Breaker # 75 Perform Zero Voltage Verification	Zero Voltage	
9	B016 Install grounds on Breaker #75 load Cables		
10	LAEW apply master group LOTO in group lockbox: B522-B626 PM and signs on		
11	SLAC Electricians and subcontractor Apply individual Locks to Group Lockbox: B522-B626 PM PM and Signs on		

SECTION 3 -- ENERGY ISOLATION PLAN APPROVAL

[redacted] Date:
[redacted] Date:

COMPLEX LOCKOUT PERMIT FOR ELPs AND GROUP LOCKOUT/TAGOUT

PAGE __1__ of __1__

SECTION 1 -- REFERENCE INFORMATION

LOTO ID or Equipment-Specific Lockout/Tagout Procedure ID: B522-B626 PM   De-energize B522 & B626 and down stream loads to perform PM

SECTION 2 -- LEAD AUTHORIZED WORKER AND CONTRACTOR SUPERVISOR(S) - SIGN WHEN ENERGY ISOLATION IS COMPLETE, AND LOTO IS READY FOR AUTHORIZED WORKER SIGN ON

[redacted] ______ sign ______ date / time

SLAC Authorized Workers shall not sign on until authorized by the SLAC LEAD AUTHORIZED WORKER or OPERATIONS GROUP

CONTRACTOR SUPV: ______ [redacted]

print name, sign, and company name

Contractor Authorized Workers shall not sign on until authorized by the SLAC LEAD AUTHORIZED WORKER or OPERATIONS GROUP and CONTRACTOR SUPV.

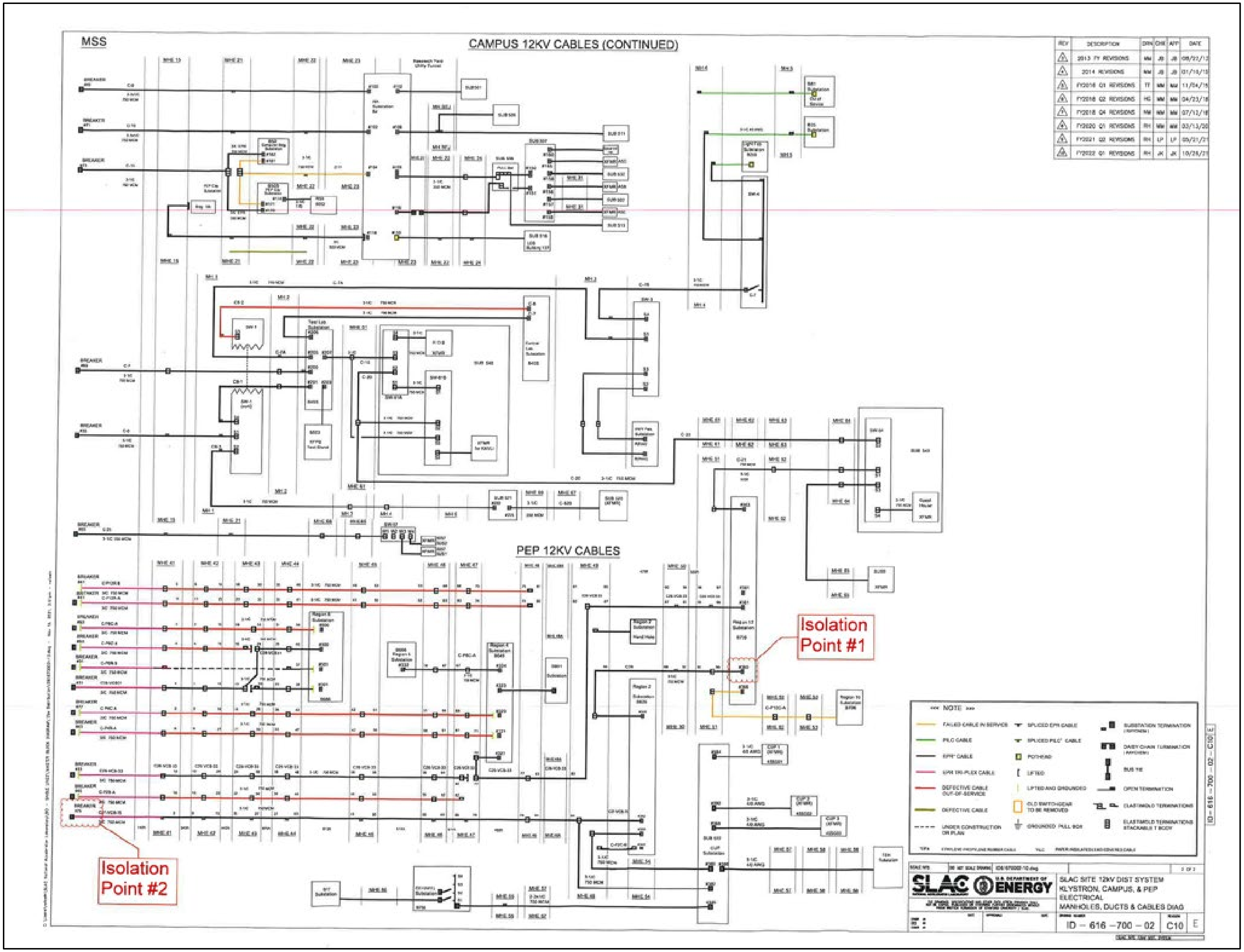
SECTION 3 -- SLAC AUTHORIZED WORKER SIGN-ON AND SIGN OFF

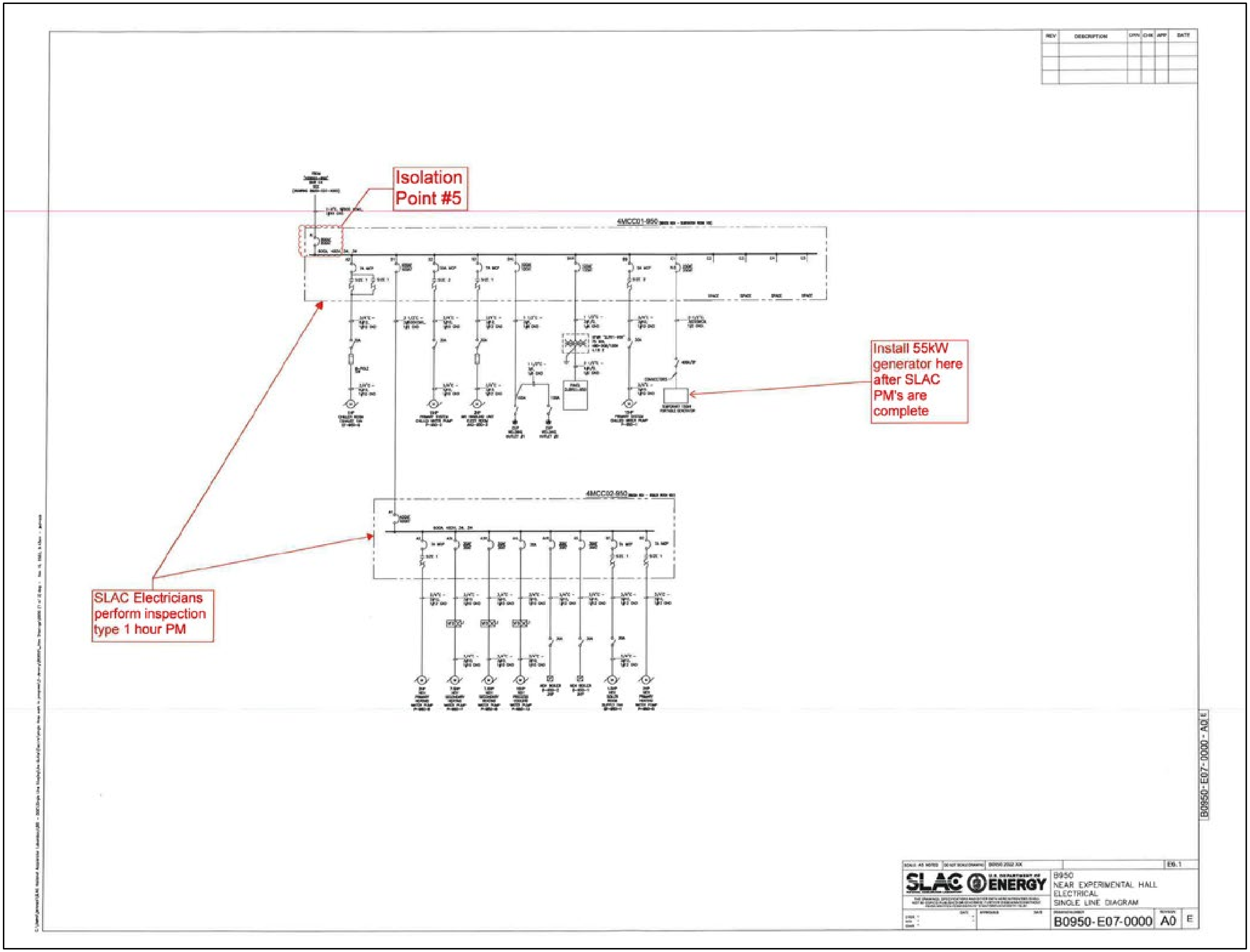
AUTHORIZED WORKER SIGN ON	DATE / TIME	AUTHORIZED WORKER SIGN OFF	DATE / TIME
print sign		print sign	
print sign		print sign	
print sign		print sign	
print sign		print sign	
print sign		print sign	
print sign		print sign	
print sign		print sign	
print sign		print sign	

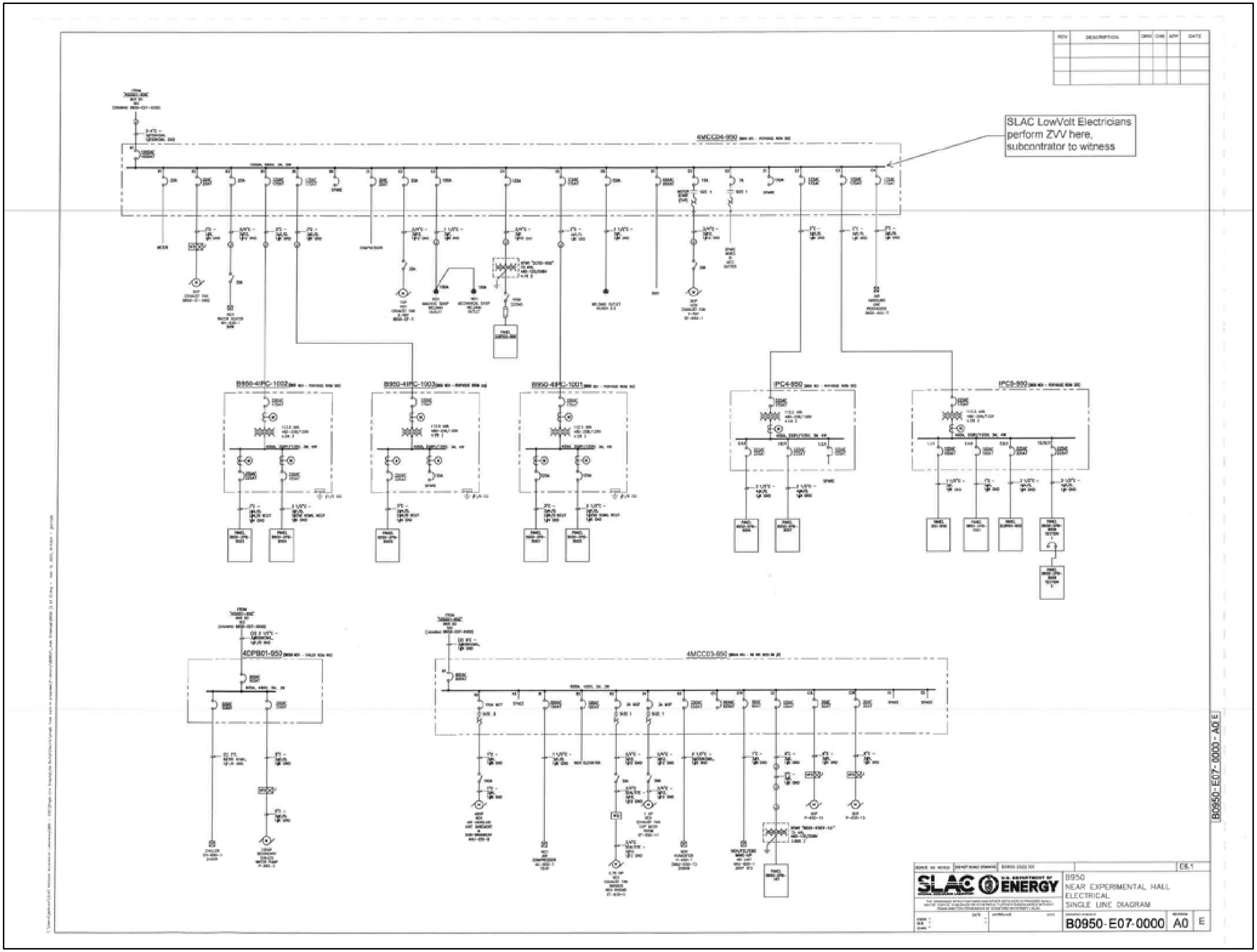
SECTION 4 - CONTRACTOR AUTHORIZED WORKER SIGN-ON AND SIGN OFF

AUTHORIZED WORKER SIGN ON	DATE / TIME	AUTHORIZED WORKER SIGN OFF	DATE / TIME
print print		print print	
print print		print print	
print print		print print	
print print		print print	
print print		print print	
print print		print print	
print print		print print	
print print		print print	

1 August 2011   SLAC-I-730-0A10J-006-R001


MSS
CAMPUS 12KV CABLES (CONTINUED)
PEP 12KV CABLES
Isolation Point #1
Isolation Point #2
SLAC SITE 12kV DIST SYSTEM
KLYSTRON, CAMPUS, & PEP
ELECTRICAL
MANHOLES, DUCTS & CABLES DIAG
ID – 616 –700 – 02
C10


Isolation
Point #5
4MCC01-950
Install 55kW
generator here
after SLAC
PM's are
complete
4MCC02-950
SLAC Electricians
perform inspection
type 1 hour PM
B950
NEAR EXPERIMENTAL HALL
ELECTRICAL
SINGLE LINE DIAGRAM
B0950-E07-0000
A0
E
B0950-E07-0000 - A0, E


SLAC LowVolt Electricians
perform ZVV here,
subcontrator to witness
4MCC04-950
B950-4IPC-1002
B950-4IPC-1003
B950-4IPC-1001
IPC4-950
IPC5-950
4DPB01-950
4MCC03-950
SLAC
ENERGY
B950
NEAR EXPERIMENTAL HALL
ELECTRICAL
SINGLE LINE DIAGRAM
B0950-E07-0000
A0
E
E6.1
B0950-E07-0000-A0 E

SLAC HV SWITCHING ORDER

480V Switchgear Breakers and 12 kV, 60 kV, 230 kV Breakers, Switches, and Disconnects

SECTION 1 -- DESCRIPTION

Switching Log ID: B522-B626 Restore PURPOSE: Energize B522 & B626 including down stream loads DATE: 12/30/2022

SECTION 2 -- APPROVAL

[redacted]	Date:	[redacted]	Date:
	Date:		Date:

SECTION 3 -- SWITCHING ORDER

ALL VVS 12kV AIR DISCONNECT SWITCHES ARE PROHIBITED FROM ENERGIZED OPERATION

WARNING: ALL OTHER 12kV AIR DISCONNECT SWITCHES MUST BE VERIFIED IF ENERGIZED OPERATION IS PERMITTED

Step Number	Substation or Location	Operation (Notify, Verify, Open, Close, Install, Remove, etc)	Equipment or System Voltage	Equipment or bus ID, and breaker or switch ID, and breaker or switch description	Instructions or Comments	Performed By (initials), Date and Time
					Pre-job briefing (required)	
1		Notify		FOC	Intent to switch	
2	B726	Remove Grounds & Tags	12kV	Breaker #360 Load Cables	Use Proper PPE	
3	B016/MSS	Remove Grounds & Tags	12kV	Breaker #75 Load Cables	Use Proper PPE	
4	B522	SLAC Electricians & Subcontractor remove individual Locks to Group Lockbox: B522-626 PM and Signs off				
5	B522	LAEW removes master group LOTO in group lockbox: B522-626 PM and signs off				
6	B016/MSS	Remove B522-626 Group LOTO	12kV	Breaker #75	Use Proper PPE	
7	B016/MSS	Rack In	12kV	Breaker #75	Use Remote Racking Device	
8	B016/MSS	Close	12kV	Breaker #75	Use Time Delay on Relay	
9	B522	Verify	12kV/480V	Energized including down stream load	Pre-job briefing (required)	
10	B626	Verify	12kV/480V	Energized including down stream load	Pre-job briefing (required)	
11	B726	Remove B522-626 Group LOTO	12kV	Breaker #360	Use Proper PPE	
12		Notify		FOC	Switching is complete	

B522-B626 Restore 1 of 1

APPENDIX E

Board Visual Inspection of IR-2 Switchgear

The Board performed a visual examination of the IR-2 Switchgear on 1/19/2023.

Visual examination of the IR-2 switchgear supports the Board's conclusion that HVE1 sustained a high voltage shock from hand to hand and was not injured by an arc flash. Further, condition of maintenance or quality of installation was not a factor in the event.

Figure E-1: Building 626, housing IR-2 Substation, front door view.

Figure E-2: IR-2 Switchgear, viewed from front door entrance. BRK340 is the closest and BRK342 is the farthest.

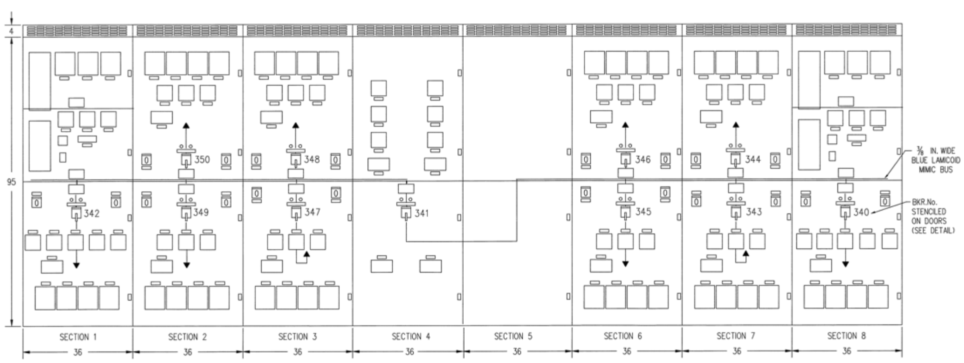


Figure E-3: Front sketch of IR-2 Switchgear. BRK342 cubicle is on the left.

IR-2 switchgear is of standard Medium Voltage Metal Clad Switchgear construction with eleven rackable vacuum circuit breakers. IR-2 substation is built with two main breakers (Breakers BRK340 and BRK342), two buses (bus 1 and bus 2), a single tie breaker (Breaker BRK341), and eight feeder breakers (Breakers BRK343 through BRK350).

Labels on the front indicate that the switchgear was manufactured in 1997 by CGI Systems Paramount, CA. It is rated for 15 kV, 2000 A supply and 1200 A section, with an AIC of 28 kA. Test stickers indicate that it was last maintained in 2018.

The following IR-2 switchgear breaker configuration was observed on 1/19/2023 and, except as indicated, represents the configuration at the time of the incident:

- BRK340: racked in and closed, springs charged.
- BRK341: racked in and closed, springs charged.
- BRK342: racked out and open, springs charged, with 3 locks and tags applied:
    - Red Lock #72, with a Danger LOTO Tag and no other markings
    - Red Lock #111, with a Danger LOTO Tag and no other markings
    - Gold Lock "HV Operations," with a Danger LOTO Tag and HVS's name and dated 1/18/2023. *Note: this was added after the incident.*
- BRK343: racked out and open, springs charged, with (1) gold lock and a Danger LOTO tag.
- BRK344: racked in and open, springs charged, no locks applied.
- BRK345: racked out and open, springs charged, with (1) gold lock applied without a tag.
- BRK346: racked in and open, springs charged.
- BRK347: racked out and open, springs charged, with (1) gold lock applied with a Notice tag and an Orange Danger - Grounded tag.
- BRK348: racked in and open, springs charged.
- BRK349: racked in and open, springs charged, with HV1's personal Danger LOTO lock and tag applied on the mechanical interlock device. An Orange Danger - Grounded tag is affixed to the open/close handle outside the cubicle door.
- BRK350: racked in and open, springs charged.

The IR-2 substation 120 VDC substation battery disconnect was found open, isolating control power to the switchgear. Unlike Sub 522, IR-2 substation is not equipped with Control Power Transformers (CPTs) and does not have an ATS for control power and building lighting. As a result, all of the front panel status lights, meters and relays are deenergized and dark, and the building lighting and emergency lights are also off. The only light in the building is either daylight through open doors or temporary portable lighting.

Insulating sheeting was applied over the exposed 120 VDC substation battery bus on 1/19/2023 to prevent inadvertent contact by the Board Members. This was done at the direction of the SLAC ESO and CEE, with consent by the Board.

Figure E-4: IR-2 Substation 120 VDC Battery Bank was covered in insulating sheeting on 1/19/2023. Battery disconnect immediately adjacent to the right was opened by HVE1 on 12/27/2022.

<u>Substation Drawings</u>

Substation drawings were posted on the side of the switchgear nearest the front entrance. The drawings were prints of the original manufacturer's drawings and did not show specific connections to the MSS, IR-12 or S522.

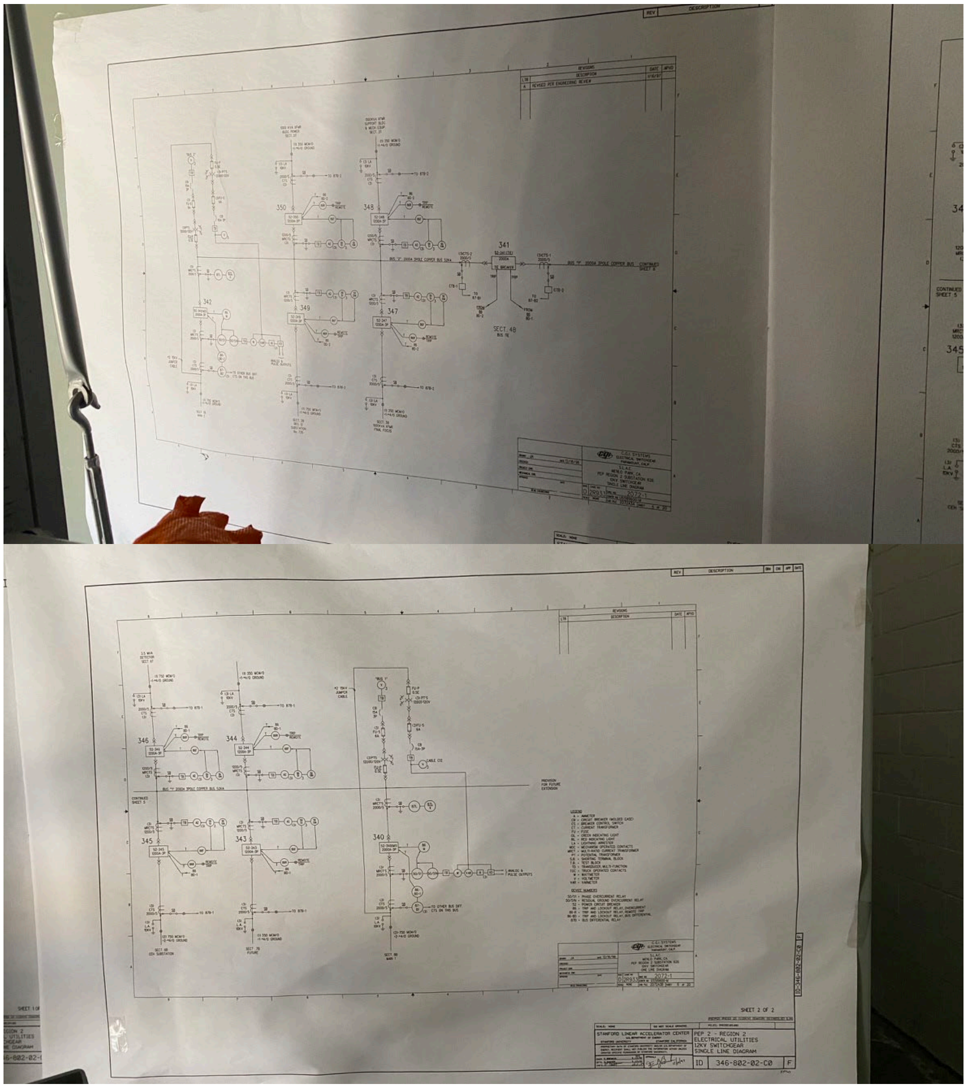


Figure E-5: Drawings posted on the side of IR-2 do not show connections to MSS, S522 or IR-12.

Arc Flash Labels

The arc flash labels on BRK340 and BRK342 are dated 12/17/2021 and indicate an arc flash incident energy of 16.8 cal/cm^2 at a 36” working distance, with an arc flash boundary of only 64”. The arc flash boundary is too low for that incident energy and working distance. The Board inquired with EPD, and corrected values were provided: 21.88 cal/cm^2 at a 36” working distance, with an arc flash boundary of 59 feet. The arc flash label dates of 12/17/2021 align with the last feeder cable configuration change performed in 11/2021.

All of the other breakers have arc flash labels dated from 6/24/2015. The tie breaker, BRK341, has the 2015 label, showing an arc flash incident energy of 17.94 cal/cm^2 at a 36” working distance, with an arc flash boundary of 48.4 feet.

Figure E-6: **BRK342 Arc flash label indicates an arc flash boundary of only 64", whereas it should be 59 feet.**

Figure E-7: **BRK340 Arc flash label indicates an arc flash boundary of only 64", whereas it should be 59 feet.**

Figure E-8: BRK341 Arc flash label is still from 2015 and shows arc flash boundary of 48.4 feet.

<u>BRK342 Front Cubicle</u>

The front cubicle of BRK342 was in satisfactory condition. There was no indication of damage. The breaker was locked out in the racked-out position.

Figure E-9: Front view of BRK342.

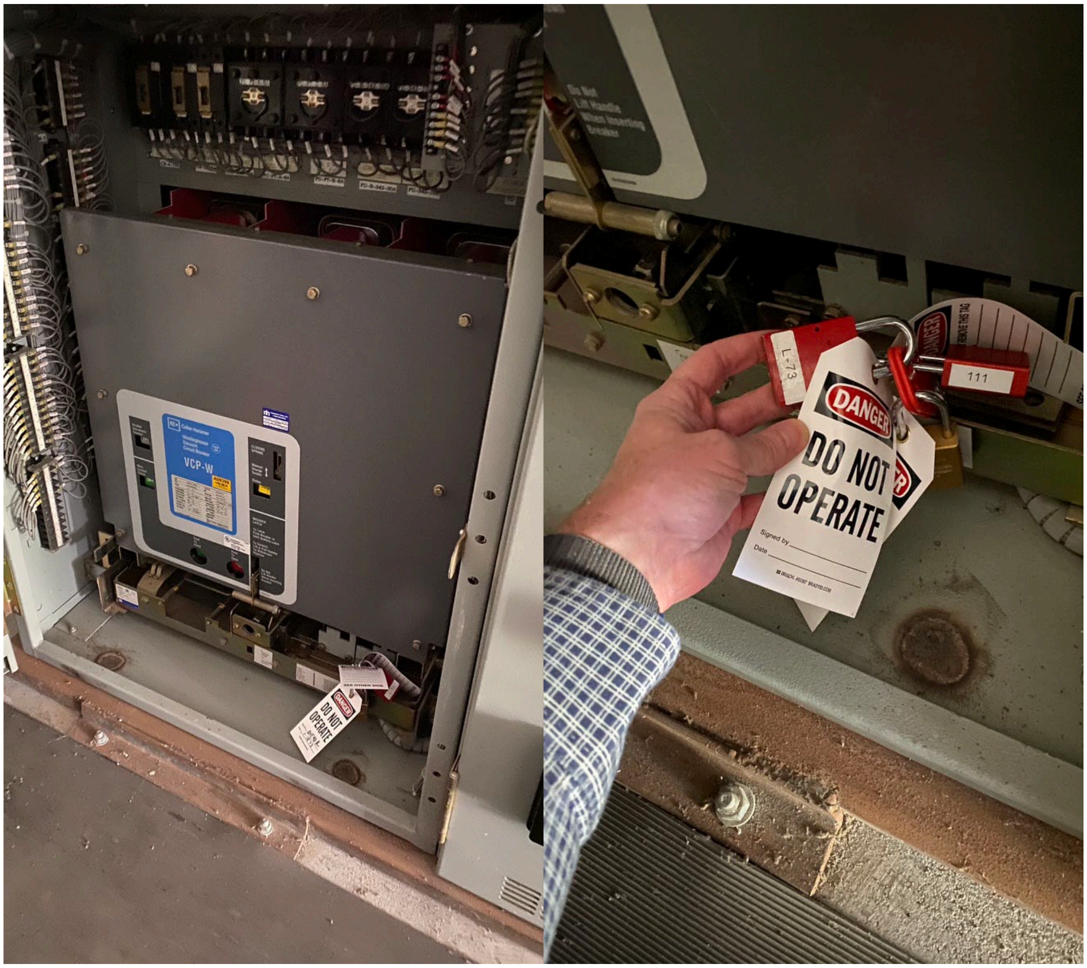


Figure E-10: Front view of BRK342, locked out in the racked-out position. The key for Lock #73 was found in LB8, and the key for Lock #111 was found in LB6.

<u>BRK342 Rear Cubicle</u>

The access and working clearance around the rear of BRK342 cubicle were clear of obstructions. The distance between the cubicle door and the building wall was measured at 56”, 16” less than the minimum 72” required for 12.47 kV, condition 2 in the NEC Table 110.34(A).

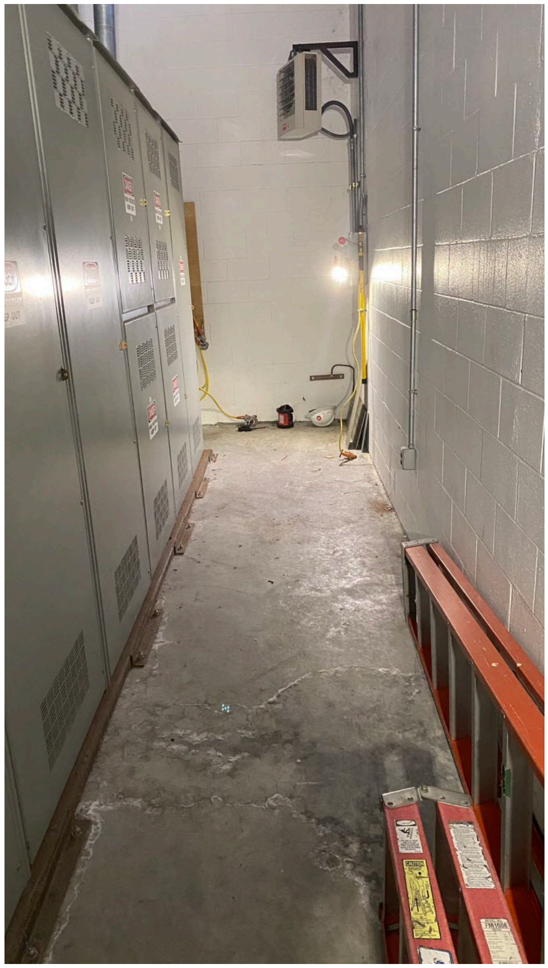


Figure E-11: View of clear access at the rear of IR-2 switchgear. BRK342 rear cubicle is farthest.

Figure E-12: Working clearance behind BRK342 was measured at 56”. The ground clamp is for the discharge stick found hanging on the wall disconnect and staged for work by HVE3.

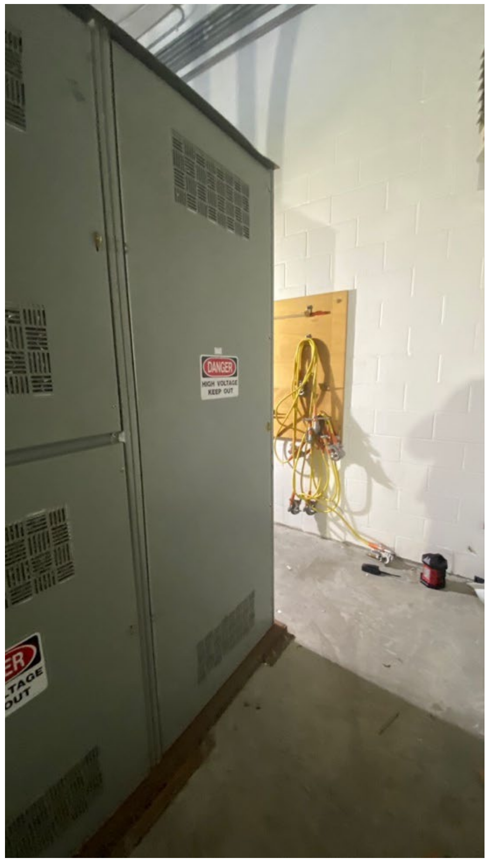


Figure E-13: Rear door of BRK342 cubicle.

There is minimal damage. The point of contact for the right hand is clearly visible about 40” up the edge of the open enclosure. There is a blackened and heat-damaged area, with some of the paint missing in the middle. The pattern was verified to be consistent in size and shape with the right-hand glove inside web between the thumb and index finger.

Figure E-14: Location of shock contact area for right hand.

Figure E-15: Close-up of shock contact area for right hand.

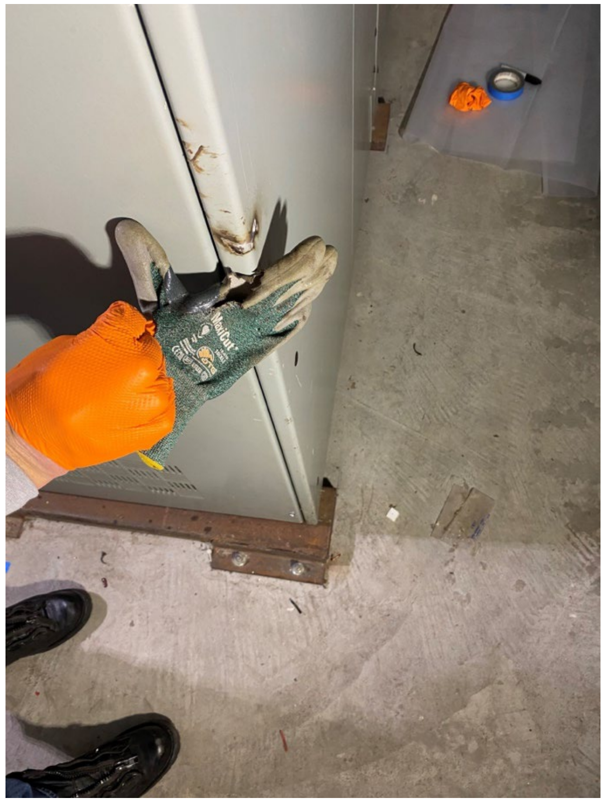


Figure E-16: Comparison of glove damage to the shock contact area for right hand.

Figure E-17: View of BRK342 rear cubicle without protective grounds applied (1/3/2023).

Figure E-18: View of BRK342 rear cubicle with protective grounds applied, as observed by the Board. Protective grounds were applied at the request of the Board (1/19/2023).

Figure E-19: Top of Phase A Surge Arrestor with insulation boot lifted, where HVE1 left hand made contact (location of shock).

Figure E-20: All three Surge Arrestors with insulation boots lifted.

Figure E-21: Top of Phase A Surge Arrestor showing minimal heat discoloration on the front.

Figure E-22: Top of Phase A Surge Arrestor showing deposits on the rear. Also visible is soot and thermal damage to the insulating boot.

The damage on the top connector of the surge arrestor was not immediately apparent until close inspection with a camera. On the front there is a small, slight metal discoloration. On the back of the threaded connector there are some charred deposits, either organic or from the work glove. The insulating boot has a small area of black deposits along the lower edge.

There is no other damage or marking inside the switchgear enclosure. In addition, the enclosure appeared clean, without debris or dust. There was no visible evidence of insulator degradation or contamination, and no evidence of tracking.

APPENDIX F

Board Visual Inspection of PPE and Clothing

The Board performed a visual examination of the PPE and other clothing worn by HVE1. These included:

- Right hand work glove
- Arc-rated shirt
- Arc-rated pants
- Arc-rated high visibility raincoat
- Work boots
- Hard hat

Note: no safety glasses were recovered.

Visual examination of the PPE items supports the Board's conclusion that HVE1 sustained a high voltage shock from hand to hand and was not injured by an arc flash.

<u>Work Glove</u>

The Board performed a visual examination of HVE1's right-hand work glove. Per the EMT report, the left-hand work glove was left on for removal at the hospital. The right-hand glove shows multiple punctures and tears with scorched and heat-damaged edges along the inside web between the thumb and index finger. These are consistent with arcing at points of contact. The glove has a thicker rubber pad directly on the center of the web and was not punctured. Damage occurs on the edges of the thick rubber pad and up along the middle of the index finger. This overall damage pattern is consistent with a sustained high voltage shock current exiting at multiple points along the area of tightest grip and maximum contact with the cubicle enclosure.

Figure F-1: Work glove was found turned inside out in Building 626, showing tears in the web of the thumb and index finger.

Figure F-2: Work glove turned out showing tear across index finger.

Figure F-3: Work glove was a cut-resistant glove.

Figure F-4: Close up of internal damage to the glove, showing multiple small holes and charring consistent with shock current and arcing along inside of thumb and index finger.

<u>Arc-Rated Shirt</u>

Emergency response personnel had to cut the jacket, shirt and pants off of HVE1 resulting in multiple jagged cuts all over the clothing, including holes from several attempts where the material was too thick to cut.

The shirt was verified to be arc-rated to 9.5 cal/cm^2 ATPV. There was no noticeable scorching or burn mark on the arc-rated shirt. Whatever slight scorching may be present is indistinguishable from dust and dirt normally present on worker clothing. Additionally, the front of the shirt was covered in dirt and is assumed to have happened when HVE1 was prone on the floor (face-down) immediately after contact release and before regaining consciousness. Other than the cuts performed by the EMT and buttons missing from the shirt (presumably when first attempting to apply AED electrode pads) there was no damage to the shirt. There is either dirt or soot on the cuffs, but the Board was not able to determine which. No residue came off with rubbing. There are slight water marks on the cuffs, indicating that they were wet and dirty at some point, but it is not known whether these were wet the day of the accident.

Figure F-5: Front of arc-rated shirt showing some dirt but no sign of arc flash burning.

Figure F-6: Left and Right sleeve cuffs on the arc-rated shirt showing either dirt or possible soot and slight water marks but was inconclusive.

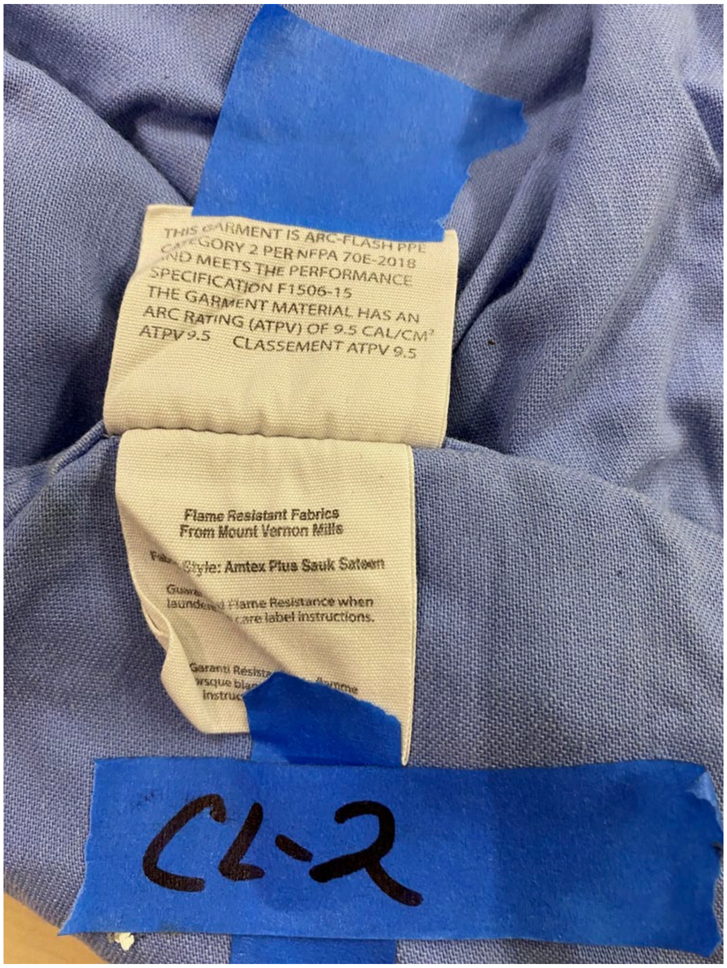


Figure F-7: Arc-rated shirt rated at 9.5 cal/cm^2 (ATPV).

<u>Arc-Rated Pants</u>

The pants were verified to be arc-rated to 12.2 cal/cm^2. There was no noticeable scorching or burn mark on the arc-rated pants. Some wear patterns are considered consistent with normal wear and tear for work clothing. Other than the cuts performed by the EMT there was no damage to the pants.

Figure F-8: Front of arc-rated pants showing some dirt but no sign of arc flash burning.

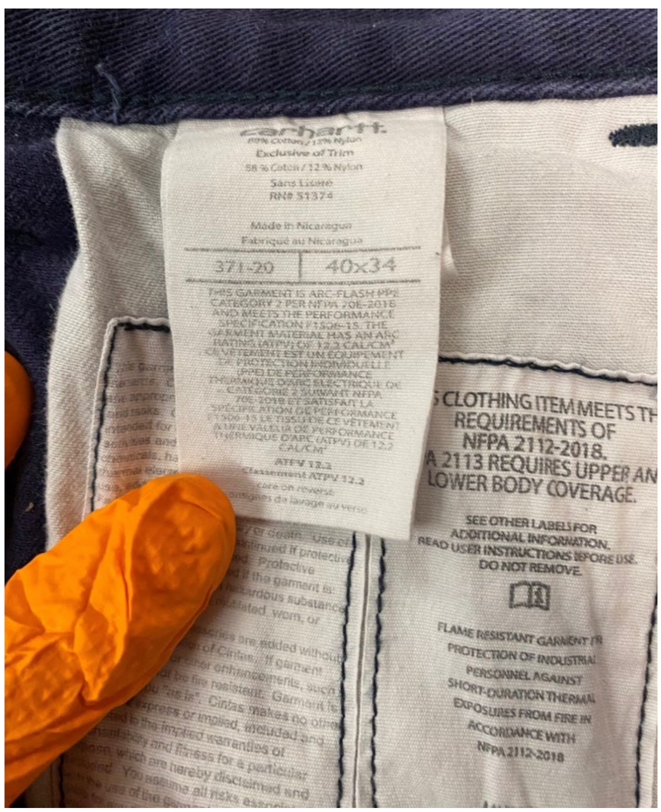


Figure F-9: Arc-rated pants are rated at 12.2 cal/cm^2 (ATPV).

Arc-Rated Rain Jacket

Emergency response personnel had to cut the jacket, shirt and pants off of HVE1 resulting in multiple jagged cuts all over the clothing, including holes from several attempts where the material was too thick to cut. The rain jacket was verified to be arc-rated at 24 cal/cm^2 ATPV. There was no noticeable scorching or burn mark on the arc-rated jacket.

The left sleeve of the rain jacket features a small (<1”) jagged hole of irregular shape close to the wrist. It features slight heat deformation (wrinkling) on the orange exterior surface around it and some blackening on the white interior surface material. This may have been caused by a shock entry point but remains inconclusive.

Figure F-10: Front of arc-rated high-visibility rain jacket with no sign of arc flash damage.

Figure F-11: Inside of left sleeve cuff there is a small open hole with either dirt or minor soot deposits. Possible arcing point.

Figure F-12: **Outside of left sleeve cuff there is a small open hole with minor heat shrinkage and wrinkling. Possible arcing point.**

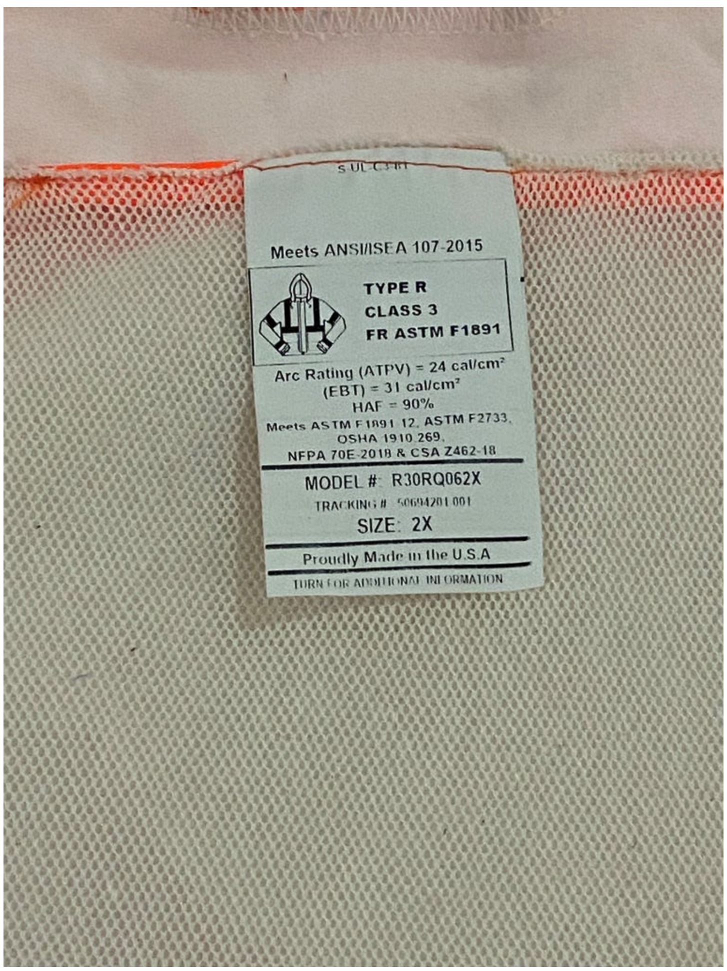


Figure F-13: Arc-rated raincoat is rated at 24 cal/cm^2 (ATPV) and 31 cal/cm^2 (E_{BT})*

*Note about ATPV vs E_{BT}:

ATPV and E_{BT} are defined in ASTM F1959/F1959M, "Standard Test Method for Determining the Arc Rating of Materials for Clothing":

- ATPV is "the incident energy (cal/cm^2) on a material or a multilayer system of materials that results in a 50 percent probability that sufficient heat transfer through the tested specimen is predicted to cause the onset of a second-degree skin burn injury based on the Stoll curve."
- E_{BT} is "the incident energy (cal/cm^2) on a material or a material system that results in a 50 percent probability of breakopen. Breakopen is a material response evidenced by the formation of one or more holes of a defined size [an area of 1.6 cm^2 (0.5 in.^{2}) or an opening of 2.5 cm (1.0 in.) in any dimension] in the innermost layer of arc-rated material that would allow thermal energy to pass through the material."

ATPV is the most common rating found on arc-rated clothes. In layman's terms, ATPV is loosely related to "let-through." The best analogy is if you hold up a garment to sunlight, you can still see some light filtering through. E_{BT} is often used for more fragile garments that tend to tear apart under the energy of an arc flash. Garments are tested for both ATPV and E_{BT}, and the lower value is applied. Raincoats and balaclavas used to be rather fragile compared to the treated 80% cotton/20% nylon arc-rated fabrics, and so they would have an EBT rating. In this case, the raincoat EBT value is higher than the ATPV, indicating a strong arc-rated fabric.

Work Boots

The Board performed a visual examination of HVE1's work boots and one white sock that remained at the scene. There was no visible evidence of a shock exit point from the feet. The work boots appear relatively new, are in good condition, and are Electrical Hazard (EH)-rated per ASTM F2413. EH rating means that the boots are constructed and manufactured so that the footwear outsole provides a supplemental form of protection to the wearer from hazardous step potential (the difference in electrical potential between the feet) while standing on the ground. They are capable of withstanding the application of 18,000 VAC at 60 Hz for 1 min with no current flow or leakage current in excess of 1.0 mA under dry conditions when tested as per lab conditions. Unlike dielectric overshoes, these are not credited as shock protection PPE since they are not regularly tested and can be easily compromised with nails and tacks commonly found in industrial and construction settings. However, should a shock occur, they can provide a limiting resistance to lower shock current through the soles of the feet.

Figure F-14: Work boots.

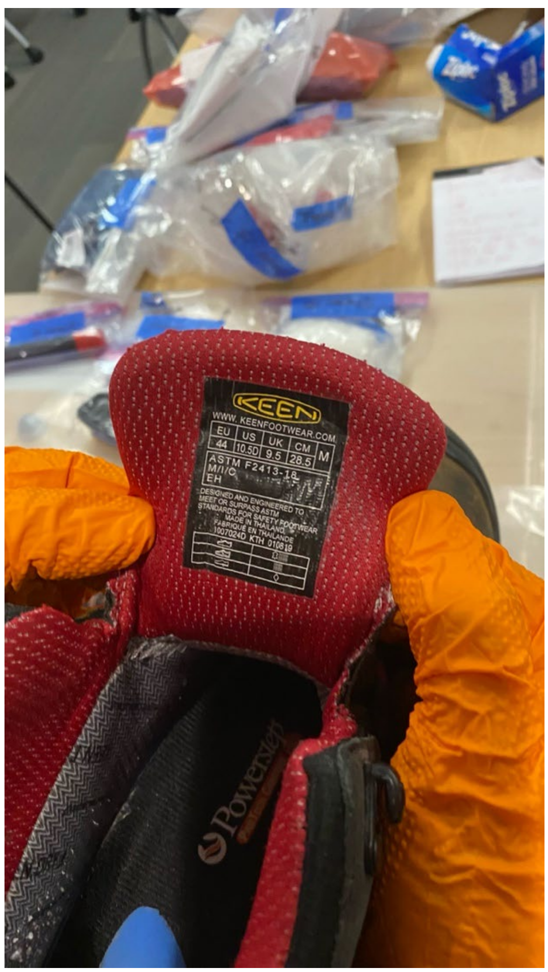


Figure F-15: Work boots are EH-rated.

Hard Hat

The hard hat was Type 1 Class E (Electric) and was manufactured in 2019. Type E means that it is rated for 20,000 V, but it is not credited as shock protection PPE as these are not periodically tested. Class E will likely protect the head from inadvertent contact with energized parts and to some degree from ejected parts. A dark soot-like mark is readily apparent on the brim. It is not known if this occurred during the accident. Rubbing produced no residue and it appears the plastic is permanently marked. It is unlikely that an ejected hot spark could have caused this and remains inconclusive.

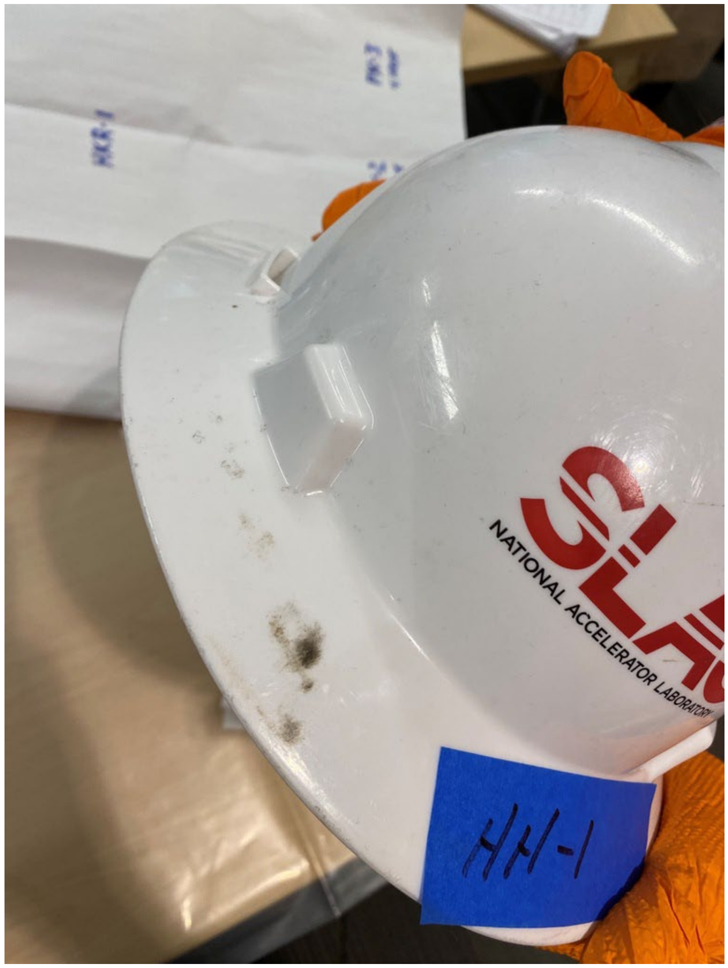


Figure F-16: Hard hat shows a possible soot deposit or heat damage mark. No residue will come off with rubbing.

Figure F-17: Hard hat was of Class 1 Type E and was manufactured in 2019.

APPENDIX G

EPs for Key Events Leading Up To The Accident

#	Event	EP Description	Evaluation
1	0600 HV tailgate meeting after extended Holiday period.	• Departure from well-established routine (W2).	• The 0600 HV Tailgate meeting held on 12/27/2023 was the first meeting held for the HV group after coming back from an extended Holiday weekend and/or vacation period (W2).
2	Electricians arrive Building 726 to LOTO, perform ZVV and install grounds in back of BRK360.	• Unfamiliar or unforeseen task or job site conditions that potentially disturb an individual's understanding of a task or equipment status (W2). • System or equipment status not normally encountered creating an unfamiliar situation for the individual (W6). • Unrecognized or inaccurate understanding of a potential consequence or danger (H6). • Situations requiring "in-field" diagnosis, potentially leading to misunderstanding or application of wrong rule or procedure (T6).	• Upon arrival to B726, HVEs find BRK360 already racked out and removed. This was an unexpected field condition; however, no further discussions or notifications to the supervisor were initiated (W2, W6). • HVEs were not aware of the hazards of placing grounds on BRK360 prior to all isolations being controlled by LOTO (H6). • HVEs deviated from the approved work plan, relying on skill-based rather than rule-based performance of work without stopping to question why they were doing it and what potential hazards were being introduced without analyzing those hazards (T6).
3	HVE1 and HVE2 perform remote switching and racking inside of an arc flash boundary without the appropriate level of PPE.	• Unrecognized or inaccurate understanding of a potential consequence or danger (H6). • Situations requiring "in-field" diagnosis, potentially leading to misunderstanding or application of wrong rule or procedure (T6). • Ambiguity or misunderstanding about acceptable behaviors or results; if unspecified, standards default to those of the front-line worker (good or bad) (T8).	• The EWP did not include an arc flash risk assessment for remote switching and racking nor did the HVEs question the absence of this information (T8). • HVEs did not understand how to apply and control the arc flash boundary, resulting in worker exposure (T6). • HVEs went inside the arc flash boundary without arc flash PPE, and remote switching and racking was performed inside the arc flash boundary without arc flash PPE (H6). • No discussions involving arc flash boundaries were covered at the 0600 HV Tailgate (T8).
4	HVE2 recognized arc flash label on BKR342 shows two separate	• Tendency to "see" only what the mind is tuned to see (intention); preconceived idea (H5).	HVE2 verbalized their concerns regarding the arc flash label to HVE1, however, no recognition or further communication efforts were developed (H5, H6, and I4).

#	Event	EP Description	Evaluation
	power sources. No recognition or further communication on the part of HVE1.	• Personal appraisal of hazards and uncertainty based on either incomplete information or assumptions (H6). • Unrecognized or inaccurate understanding of a potential consequence or danger (H6). • Communication habits or means that do not enhance accurate understanding by all members involved in an exchange of information (I4).	
5	HVE1 tested a 120 V receptacle in Building 626 for absence of voltage in lieu of conducting a ZVV	• Departure from a well-established routine (W2). • Tendency to "see" only what the mind is tuned to see (intention); preconceived idea (H5). • Lack of information conveyed to individual that previous action had any influence on the equipment or system (W5).	• After the lights went out in B626, HVE1 tested for absence of voltage at a wall receptacle as a substitute for conducting a ZVV (W2). • Based upon the results of the receptacle test (no voltage), coupled with an improper understanding of the energy isolation boundary, HVE1 believed B626 was fully deenergized (H5). • This resulted in HVE1 holding an incorrect assumption of the system configuration, believing that if the receptacle was dead, then the entire switchgear was also dead / fully deenergized (W5).
6	A Field change to the EWP was added to disconnect Building 626 battery bank without evaluating the potential for any existing or new hazards to materialize.	• Personal appraisal of hazards and uncertainty based on either incomplete information or assumptions. (H6). • Unrecognized or inaccurate understanding of a potential consequence or danger (H6). • Inability to compare or confirm information about system or equipment state because of the absence of instrumentation (W7). • May miss information that is not expected or may see something that is not really there (H5).	• This action was added to prevent draining the batteries during the execution of the PM activities. However, by doing so, this eliminated system indicator lights that would allow personnel to visually identify the system was still being energized from another power source (H6). • Without the indicator lights being operational, there was no way for the operator to visually be aware that power was still being supplied to BRK342, reinforcing the mindset that BRK342 was completely de-energized (W7, H5).
7	HVE4 told HVE1 that BRK75 was still closed and energizing S522.	• Tendency to "see" only what the mind is tuned to see (intention); preconceived idea (H5).	• HVE1 acknowledged information but did not understand relevance to IR-2 (Building 626) being partially energized (H5, H6, I4).

#	Event	EP Description	Evaluation
		• Personal appraisal of hazards and uncertainty based on either incomplete information or assumptions (H6). • Unrecognized or inaccurate understanding of a potential consequence or danger (H6). • Communication habits or means that do not enhance accurate understanding by all members involved in an exchange of information (I4).	
8	HVE2 completed first ZVV for MCC #2 at Junction Box.	• Situations requiring "in-field" diagnosis, potentially leading to misunderstanding or application of wrong rule or procedure (T6).	• SWO1 required performing ZVV at the 12kV Building 626 switchgear prior to conducting a ZVV at MCC #2. The HVEs deviated from the approved work plan without stopping either to question why they were doing it, analyze the hazards, and relied on skill-based rather than rule-based execution (T6).
9	HVE1 and HVE3 perform ZVV at XFMR 350 for MCC-1	• Situations requiring "in-field" diagnosis, potentially leading to misunderstanding or application of wrong rule or procedure (T6).	• SWO1 required performing ZVV at the 12kV Building 626 switchgear prior to conducting MCC #1 ZVV. The HVEs deviated from the approved work plan without stopping either to question why they were doing it, analyze the hazards, and relied on skill-based rather than rule-based execution (T6).

APPENDIX H

Barrier Analysis Worksheet

Barrier	How did the Barrier perform?			Why did the Barrier fail?	How did the Barrier affect the accident?	ISM	HPI
	In Place?	In Use?	Effective?				
Configuration Management (System components, Drawings, and Postings/Labeling)	Yes	Partial	Partial	Multiple configuration changes to the electrical distribution system exceeded the capabilities of SLACs Configuration Management System to administratively support those changes necessary to reflect actual field conditions and communicate associated hazards.	The challenging configuration changes to the electrical power distribution led to complicated work planning, partially energized gear, and reduced perception of risk.	GP1 GP4 GP5 GP6 CF1 CF2 CF3	T6 T7 T8 W2 W3 W4 I2 I4 N2 N4 N6
Electrical Work Plan (Work Planning & Control)	Yes	Partial	Partial	The erosion of the disciplined approach to the WPC process resulted in development, review, and approval of the EWP that lacked critical elements to ensure safety and contained numerous errors and/or discrepancies.	Failure to properly implement a disciplined approach to the WPC process created multiple and significant vulnerabilities in the work execution that directly led to the accident.	All GPs CF1 CF2 CF3	T5 T8 I4 W2 W3 W4 N3 N4 N6 N8
Walkdown	Partial	Partial	No	The EWP review walkdown lacked the formality and intent of established	The lack of a formally structured walkdown contributed to HVEs not	GP1 GP2	T1 T6

Barrier	How did the Barrier perform?			Why did the Barrier fail?	How did the Barrier affect the accident?	ISM	HPI
	In Place?	In Use?	Effective?				
				SLAC directives designed to prepare the HVEs for the corresponding complexity of work to be executed.	being adequately prepared for the complexity of the work.	GP5 GP6 CF1 CF2	W1 W4 N4 N5
Tailgate Briefing	Partial	No	NE	Tailgate Briefings became informal and lacked the rigor and discipline needed for HVEs to understand existing hazards and the controls put in place to mitigate those hazards, and to allow for questions and/or concerns to be fully communicated.	Informal tailgate meetings did not provide HVEs with the necessary information for them to be aware of existing or missing controls to safely execute the work.	ALL GP CF1 CF2 CF3	T7 W2 N3 N4 N5 I7
Perform work within controls	Yes	Partial	Partial	The lack of consistent management expectations to perform work within existing controls allowed HVEs to execute work in the skill-based mode and add, modify, ignore, or execute steps outside of established work controls.	Reliance on the workers' skill and willingness to deviate from written procedures, coupled with the loss of the mental model of the configuration of the system due to not having adequate procedures/drawings/plans in place, created a high probability of failure during the work evolution.	ALL GP All CF	W1 W4 N3 N4 N5 N6
CoHE/LOTO	Partial	Partial	No	Programmatic efforts to control hazardous energy had diminished to a point where both the management and workers lost complete, physical, and administrative control of the CoHE/LOTO program.	The workers found themselves on the hazardous side of the energy isolation boundary for the stage of work being performed.	ALL GP CF1 CF2 CF3 CF4	W1 W4 N3 N4 N5 N6 N7
Stop Work	Yes	No	NE	Workers accepted variations in field and operational conditions and did not execute Stop or Pause Work Authority.	There were numerous opportunities in the field to question discrepant information/conditions. Stopping	GP2 GP3 GP4	T7 I1 I4

Barrier	How did the Barrier perform?			Why did the Barrier fail?	How did the Barrier affect the accident?	ISM	HPI
	In Place?	In Use?	Effective?				
					work would have given the opportunity to pause, discuss and clarify the work, implement the 100% Agreement Rule on the path forward, and potentially prevent this accident.	GP5 GP6 CF1 CF2 CF3 CF4	I5 I7 W1 W2 N3 N4 N5
Indicators	Yes	No	NE	Visual indicators (i.e., lights) used to provide system status of switchgear to personnel inside of Building 626 were disabled during an unplanned, undocumented field change to the EWP.	When indicators were disabled, this removed the last visual indicator that there was power feeding the building, specifically no longer visually indicating there was a source still feeding BRK342.	GP6 GP7 CF1 CF2 CF3 CF4	W2 W3 W7
Temporary Signage	Partial	No	NE	Previous SLAC practices for temporary signage, such as alerting techniques or flagging and blocking, to help workers identify energized equipment were not required or consistently applied.	Workers failed to recognize the backside of BKR342 was on the hazardous side of the energy isolation boundary.	GP5 GP6 ALL CF	W7 N4
Equipment Enclosures	Yes	No	NE	The back panel of BRK342 in Building 626 was unlatched without taking required precautions.	Workers were exposed to hazardous energy.	CF2 CF4	W1 W2 W4 W6 N3 N4 N5 N6

Barrier	How did the Barrier perform?			Why did the Barrier fail?	How did the Barrier affect the accident?	ISM	HPI
	In Place?	In Use?	Effective?				
Zero Voltage Verification (ZVV)	Yes	Partial	No	ZVV activities were not accurately reflected in work documentation, were performed out of order, and were performed at locations different than indicated by the EWP.	By not performing the ZVV in the back of BRK342, workers failed to identify the circuit was energized prior to entering the HV switchgear cubicle, believing it to be deenergized.	GP2 GP6 CF2 CF4	T5 I7 W4 W6 N3 N4 N5 N6 N7
Proximity Test (Test Before Touch)	Yes	No	NE	Management expectations of all conditions under which proximity testing is to be conducted, were not fully communicated and understood by workers.	By not performing Test Before Touch, workers did not identify the circuit was energized before reaching in.	GP2 GP4	T6 I7 W4 N3 N4 N5 N6 N7
Two-person rule	Partial	Partial	Partial	Differences between the Two-person rule and the Safety Watch, their respective roles and responsibilities, and when they are to be applied, are not fully understood and implemented.	The presence of other qualified persons in Building 626 did not prevent an unsafe act. However, the second person (HVE3) was able to perform contact release and forcefully remove HVE1 from the cubicle.	CF2 CF3 CF6 GP1 GP2 GP4	T7 I2 W4 N3 N6
Personal Protective Equipment (PPE)	Yes	No	NE	Workers did not wear appropriate PPE for the tasks, either through poor communication or lack of appreciation for the hazards involved.	Workers were not protected from the exposure or direct contact with energized circuits commensurate with the hazard.	GP2 GP3 GP4	T6 I7 W1 W4 N3

Barrier	How did the Barrier perform?			Why did the Barrier fail?	How did the Barrier affect the accident?	ISM	HPI
	In Place?	In Use?	Effective?				
							N4 N5 N6 N7
Insulated Bus Switchgear	Yes	Yes	Yes	The insulated bus and circuit parts in the back of BRK342 prevented arcing at the point of contact from escalating into a full 3-phase to ground arcing fault and arc flash event. Supplemental bus insulation on air-insulated switchgear is not required by either code or equipment safety standards but represents an option for owner specifications. This was an engineering control that performed as intended.	The insulated switchgear mitigated the severity of injuries sustained by HVE1 and HVE3 by preventing a 3-phase to ground arc fault from occurring.	GP6 CF3	
Arc Rated Daily Wear	Yes	Partial	Yes	Both HVE1 and HVE3 were partially dressed in arc-rated daily wear (long-sleeve shirt and pants rated at least 8 cal/cm^2) and HVE1 was wearing a raincoat rated at least 24 cal/cm^2.	Arc rated daily wear could not have fully prevented arc flash injuries, but it would have limited the severity of the injuries in the event of an arc flash event.	GP6 CF3	

Items noted as 'NE' represent barriers that were required to be in place but were not used. The Board did not evaluate these barriers for effectiveness.

APPENDIX I

Change Analysis Worksheet

Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
Reduced resources to support outage, coupled with environmental and project/asset concerns, resulting in staggering activities and making compromises to enable execution	• Assigned resources commensurate with PM complexity; 'traditional' 5-year PM evolution for the planned work (2018 PM outage). • Clearly communicated and understood by all parties involved; outage schedule time sufficient to safely execute all SOW. • Full SOW deenergized prior to authorization of PM work.	• Initially resources planned to conduct PM were significantly reduced; management decision to have 30 employees on site. • Scope of maintenance increased to include all emergency panels, shutting down time-limited critical systems such as boiler and floodwater pumps. • Scheduled in between holiday weekends with fixed number of days to perform all work and limited workforce availability. • Record rainfall leading up to the outage, resulting in flooding and erosion concerns in IR-2 area, increased environmental pressures the day of the outage and further raised schedule urgency and resource load.	• Constraints on resources, schedule, and work scope didn't allow workers sufficient time to fully understand sequencing of tasking and adapt to field conditions. • These constraints led the planners to develop a modified outage plan that released some of the work while the switchgear at IR-2 was still partially energized. While this condition was communicated to the workers participating in the outage, its impact was not fully recognized. • Pressure, self-imposed or not, coupled with a strong desire to complete tasking while minimizing potential project/asset impact, elevated a sense of urgency.

Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
Numerous errors, omissions, and inconsistencies existed among the EWP, SWO, and EIP	• ‘Work as planned’ should equal ‘work as done.’ • EWP, SWO, EIP, and JSA should be consistent, with minimal errors or inconsistencies. • Appropriate time is allotted to prepare adequate work plans.	• EIP1 incorrectly placed ZVV at BRK342 • EIP1 included placing grounds at BRK360, but not SWO1. • SWO1 directed to rack out BRK360, but it was already racked out. • Single lines were incomplete and did not show all isolations, ZVV points or grounds, and did not differentiate between various phases of the EWP. • SWO step numbers were out of order and included duplicates. • SWO2 directed the HVEs to place grounds before all isolations were in place. • EWP directed air gapping in 480V disconnect box without isolating power from standby generator (uses control power switch instead). • The first Stop step in the EWP was written for re-energizing breakers, which wouldn’t occur until much later in the work evolution.	The WPC review and approval process failed to identify the numerous errors, omissions, and inconsistencies, resulting in a work package that could not be safely executed.

Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
Work was not formally classified as Red, failing to trigger a work integration plan (WIP)	Work characterized as Red triggered the initiation of a work integration plan	The work to conduct the PMs was never formally characterized as Red work.	Absent of characterization, the process didn't allow for the initiation and implementation of a Work Integration Plan (WIP) which is used to document planning, coordination, and release of complex/Red work including additional safety analysis reviews as well as incorporating the SLAC Site Specific Safety Plan and Hazard Evaluation and Planning eTool summary.
No work package or single line drawing was used during the 12/22/2022 walkdown	Workers should have used single line drawings	The workers would have been referencing the single line drawings in the field during the walkdown.	Workers did not have the opportunity during the walkdown to identify that the single line drawing for IR-2 was missing, that single line drawings were unclear and not differentiated between EIPs, and other items that were missing.
Not all HVEs who worked the Building 626 EWP on 12/27/2022 participated on the 12/22/2022 walkdown	All workers involved in the job should have completed a pre-job walkdown	HVE3 and HVE4 were assigned to the job without understanding the scope of the work.	Because HVE3 was not prepared, they did not understand the configuration of IR-2 at the time of the event and was not able to intervene with knowledge that BRK75 was energized and that the back of BRK342 was therefore energized. This prevented a clear understanding of specific work activities that may have helped HVE3 to prevent HEV1 from entering cubicle.
HVE3 and HVE4 assigned as floaters to HVE1 and HVE2 at Building 626 without pre-job briefing	Workers supporting their new assignment are given job-specific briefings to familiarize themselves with the EWP, configuration of isolation points, sequence of work activities, non-electrical hazard mitigation controls, emergency readiness protocol, and	Floaters were not assigned clear responsibilities and were not familiar with the scope, hazards, and controls specific to potential assignments.	HVE3 ended up as a second person to HVE1 without any knowledge of the system configuration, SOW, hazards, or controls. With the door halfway open, HVE3 was not in position to intervene or stop work.

Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
	fulfillment of their new roles and responsibilities.		
Not all required reviews for the Building 626 Outage were performed.	All required reviews performed prior to the outage.	All required reviews were not performed.	This work was not formally identified as Red work, which triggers additional reviews by other functional area SMEs. However, based on interviews, most employees recognized this as Red work.
Building 626 EWP, SWO, and EIP discrepancy not identified.	Reviews of EWP, SWO, and EIP would identify discrepancies. All required reviews were performed.	Thorough reviews were not performed.	The rigor of the reviews that were performed failed to identify obvious discrepancies. Work planning did not begin early enough, or was not resourced adequately, to allow for thorough reviews prior to planning deadlines.
First meeting after extended holiday weekend.	Work planning factors in adequate site familiarization and work assignments when extended pauses in work occur.	Time not allowed to transition back to work before a high-risk evolution	Employees executed a complex outage immediately following a major holiday, introducing HPI error precursors.
Discrete Job Briefing as per ESH Manual, Chapter 8, and NFPA 70E did not occur	A job briefing per NFPA 70E and Chapter 8 would have been held before the start of work	The job briefing did not occur. A Job briefing would have covered all elements of the job safety plan, providing the employees with knowledge of the hazards, controls, system status, and to give them the opportunity to ask questions/raise concerns.	A number of barriers included in standard electrical safe work practices were missed: arc flash and shock protection boundaries, arc flash PPE for remote switching and racking at Building 522 and Building 626 (or being outside the buildings), alerting for lookalike equipment that remains energized.
Work executed outside of scope activities	Only work within the scope of authorized activities is performed	Unauthorized work was performed	A disciplined approach to recognizing procedural deviations on step 1 of the SWO could have led to further alertness to issues with the work package.

Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
Field conditions do not match expected/briefed conditions (BRK360 racked out)	Field conditions would have been properly identified during the preparation of the SWO and reflected in the SWO.	A proper walkdown was not performed that would have identified the unexpected condition	Unexpected field conditions forced the work team to either stop work on step 1 of the SWO or proceed with understanding that they knew better than the work planner.
Work step added to approved EWP without additional HA/Approval	Only work within the scope of authorized activities is performed.	Unauthorized was performed.	If an additional work step was needed, then stop work and get clarification and approval from all of the signers of the SWO before proceeding.
Work plan did not include an arc flash risk assessment for remote racking and/or switching	EWP includes an arc flash risk assessment for remote racking and/or switching	EWP did not include an arc flash risk assessment	The absence of this assessment did not provide the workers with a clear understanding of the hazards and appropriate controls required for the task. The workers did not question the absence of this information
HVE2 verbalized the concern (arc flash label) to HVE1. No recognition or further communication	Team members effectively communicate conditions and hazards until a satisfactory resolution and mutual acceptance of conditions is reached	One team member recognized BRK342 being dual fed, but there was no follow up discussion on the condition and associated consequences to the work task.	The ineffective communication allows work to proceed allowing potentially relevant hazard information to go unrecognized. Missed opportunity to exercise the '100% Agreement Rule.' Without 100% agreement, higher management involvement (HV Supervisor, HV Engineer or ESO) required for resolution.
Lights went out in Building 626 and there was no voltage at the wall receptacle; HVEs believed IR-2 was fully deenergized based on an improper ZVV and an improper understanding of the energy isolation boundary.	A proper ZVV was performed to verify the isolation of the downstream work. They would have understood the energy isolation boundary and that voltage was still present on the line side of BRK342.	The HVEs assumed that IR-2 was fully deenergized even though a proper ZVV of the 12.47 kV switchgear had not been performed.	When the HVEs opened the door to the back of BRK342, they believed that IR-2 completely deenergized. They were not prepared to test for absence of voltage, either with meters or PPE for the potential hazard.
All front panel indicators, meters, and status lights were disabled	Front panel indicators, meters and status lights would still be on.	Front panel indicators not available to determine equipment configuration	Had the indicators been energized, the digital voltmeters above BRK342 front panel would have shown ~7200 VAC. Additionally, having lights on the switchgear could have prevented

Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
			the natural human impression of a building cold and dark, with no hazardous energy at the back of BRK342.
Drawings for S522 were not up to date, did not reflect current condition	A program exists to actively update electrical drawings on the power distribution configurations as changes are made, and periodically validated through field surveillances. Outdated drawings are clearly distinguished from official records and legacy drawings purged from the field.	S522 drawings still showed that BRK75 fed IR-2 BRK340 and S522 BRK380, and therefore did not address the configuration change that was executed in 2021.	Workers at S522 were not able to quickly diagnose the reason for the ATS switching over. Diagnosing the unexpected response would have led to discussion on the configuration change for BRK75, and the fact that the rear of BRK342 was still energized.
SWO1 required performing ZVV at the 12kV Building 626 switchgear prior to conducting MCC-1 and MCC-2 ZVVs	ZVVs performed in the order required by SWO1	Procedure was not performed in order	Workers utilized skill-based mode to execute procedures
SWO1 did not specify exact location for ZVV	SWO1 would have specified the exact location for ZVV	SWO1 did not specify exact location for ZVV	Workers were not clear on where to perform ZVVs. Lack of specificity in the EWP forced the workers to make in field determinations.
EIP1 specified ZVV at BRK342 but did not specify load vs line/bus/front or back	EIP1 would have specified the exact location for ZVV, such as rear cubicle of BRK340	EIP1 lacked sufficient location detail for performing the ZVV.	Absent having a specific location for the ZVV, the worker defaulted to standard practice
EWP single line drawings did not differentiate or capture all isolation points or ZVV locations between the two SWOs and two EIPs	EWP single line drawings clearly identify ZVV locations for all SWOs and EIPs	Different single line drawings were not used to highlight the change in conditions, isolations, and ZVV points between the 2 phases of the outage.	The inaccurate drawings added to confusion on system configuration and hazardous energy controls. Workers could not tell what the expected end condition at the conclusion of SWO1 and EIP1 was, nor identify potential issues with the planning package.
ZVV at 12kV switchgear was not necessary for the SOW covered by EIP1	Associated SWO1 would have specified only necessary ZVV activities to complete the work.	SWO1 added a ZVV step at IR-2 where it was not required.	Since the scope did not call for a ZVV at IR-2, this made it impossible to determine the right location for ZVV, forcing the worker to rely

Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
			solely on the procedure. The EIP called for ZVV at BRK342.
Temporary signage, such as alerting techniques or flagging & blocking, was not used to identify that the back of BRK342 was still energized	Temporary signage would have been used to mark the rear of BRK342 as energized	There was no identification at the rear of BRK342 indicating it was energized.	Workers entered BRK342 with a belief that it was already deenergized, whereas it was in fact still energized from BRK75. If the signage had been applied, workers would have been aware of energized condition on the backside of BRK342.
HVE1 and HVE3 did not wear appropriate arc flash PPE within the arc flash boundary	Workers would identify arc flash boundary and wear PPE when inside	HVE1 and HVE3 were not fully protected from arc flash.	HVE1 and HVE3 were not fully protected from arc flash during the event.
No ZVV performed	Prior to hands on work, all electrical equipment is verified as de-energized conducting a ZVV test. (Test Before Touch)	A ZVV was not conducted prior to entry and hands-on work conducted inside of BRK342.	A ZVV is the last line of defense to avoid unexpectedly working on energized electrical equipment. Absent this last defense, there were no other controls in place to allow anyone to recognize the cubicle was still energized prior to hands on.
HVE1 did not wear appropriate shock protection PPE for entering the Restricted Approach Boundary of 26”	Worker would wear appropriate shock PPE before entering the restricted approach boundary	HEV1 did not wear shock PPE when required.	HVE1 did not recognize the restricted approach boundary applied to this task and, in not doing so, entered into the boundary without wearing the appropriate level of PPE.
HVE3 did not think that the back of BRK342 was energized	Worker understands the equipment configuration and status.	HVE3 did not understand the equipment configuration and status	By not understanding the equipment configuration or status, HVE3 was not able to provide any useful backup to HVE1.
HVE3 not included in Building 626 walkdown or briefing	A pre-job brief is performed.	A pre-job brief was not performed.	A pre-job brief would have provided the information HVE3 needed to safely perform the task prior to performing the task. If that had been provided, HVE3 may have been able to provide useful backup to HVE1.
Test Before Touch with a proximity tester not performed after worksite left unattended	After returning from break, and assuming ZVV had already been done before	A Test Before Touch was not performed after break.	Electricians routinely stage and use proximity testers to confirm the absence of voltage, especially when the worksite is left unattended.

Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
	break, a qualified person would have used a proximity tester to double check absence of voltage.		This practice is reinforced through a healthy safety culture, including supervisor oversight and peer interactions.
HVE1 reached into BRK342 cubicle	Worker would use a live-line tool to lift the surge arrestor.	HVE1 did not use live-line tools for operations inside the restricted approach boundary for systems over 600V.	Not using live line tools exposed HVE1 to the hazard.
EVENT: HVE1 made hand contact with bare energized (live) circuit part inside a 12.7kV three-phase electrical utility distribution switchgear cubicle.	Energized circuit identified prior to workers making contact.	The hazard (energized wire) would have been identified and mitigated.	There was no way for anyone to visually identify if power was being supplied to the back of BRK342 or not. With no other means used to verify the status of the switchgear prior to making hand contact (i.e., proximity, voltmeter, etc.), nobody stopping or warning HVE1 from touching the gear, and an incorrect mental model of system status, HVE1 made contact with an energized wire.

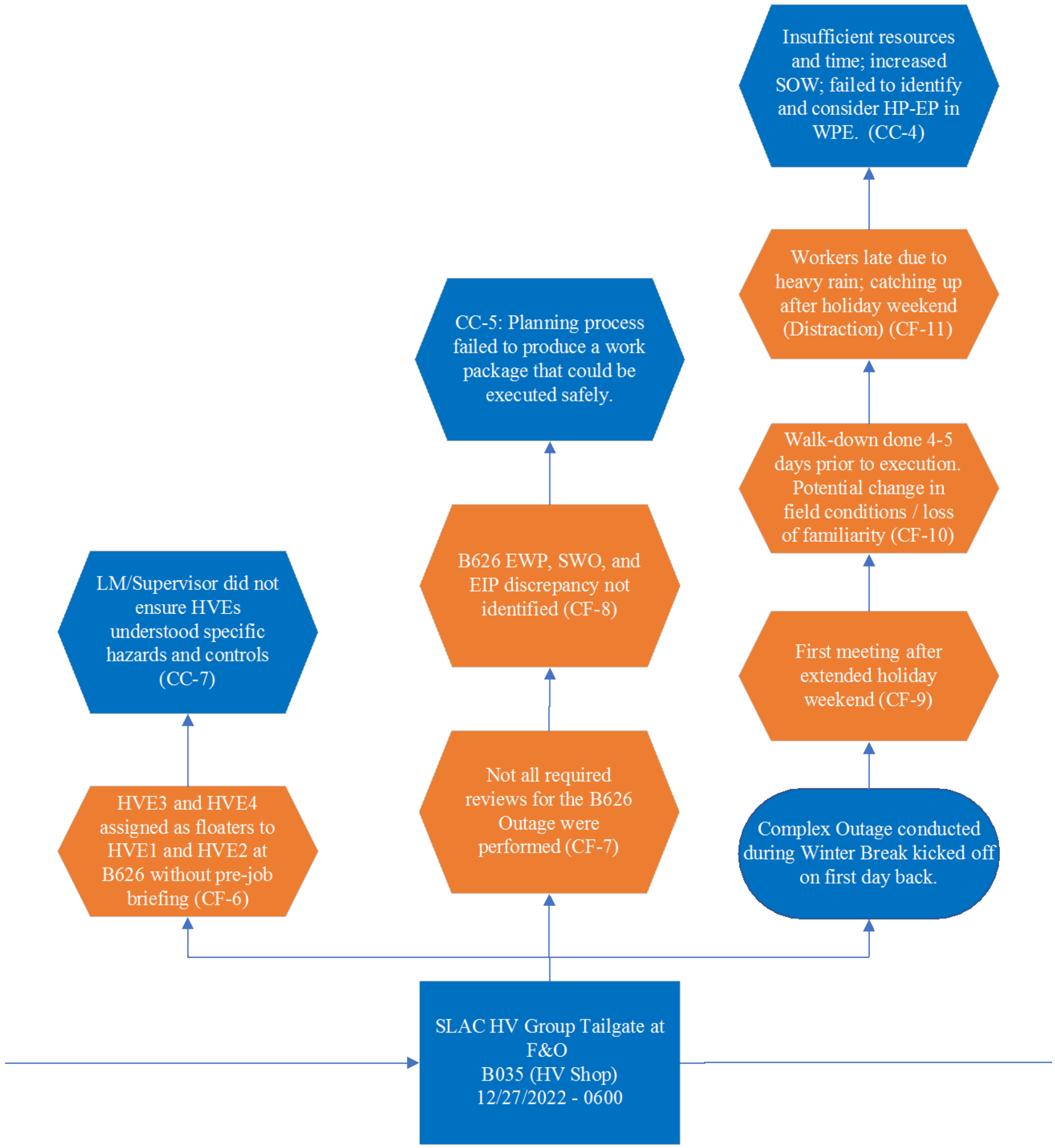
APPENDIX J

Events and Causal Factors Chart

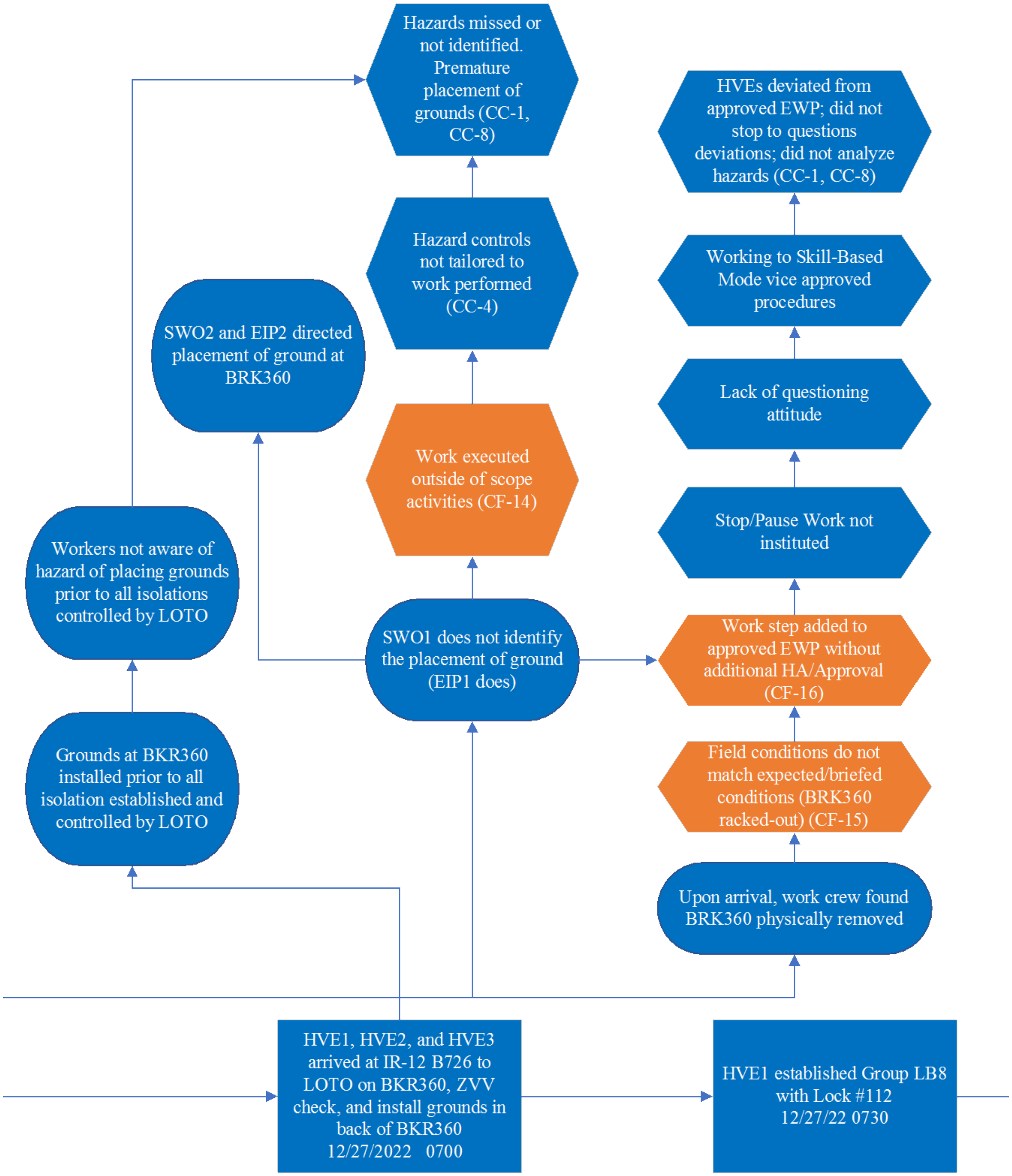
Notes:

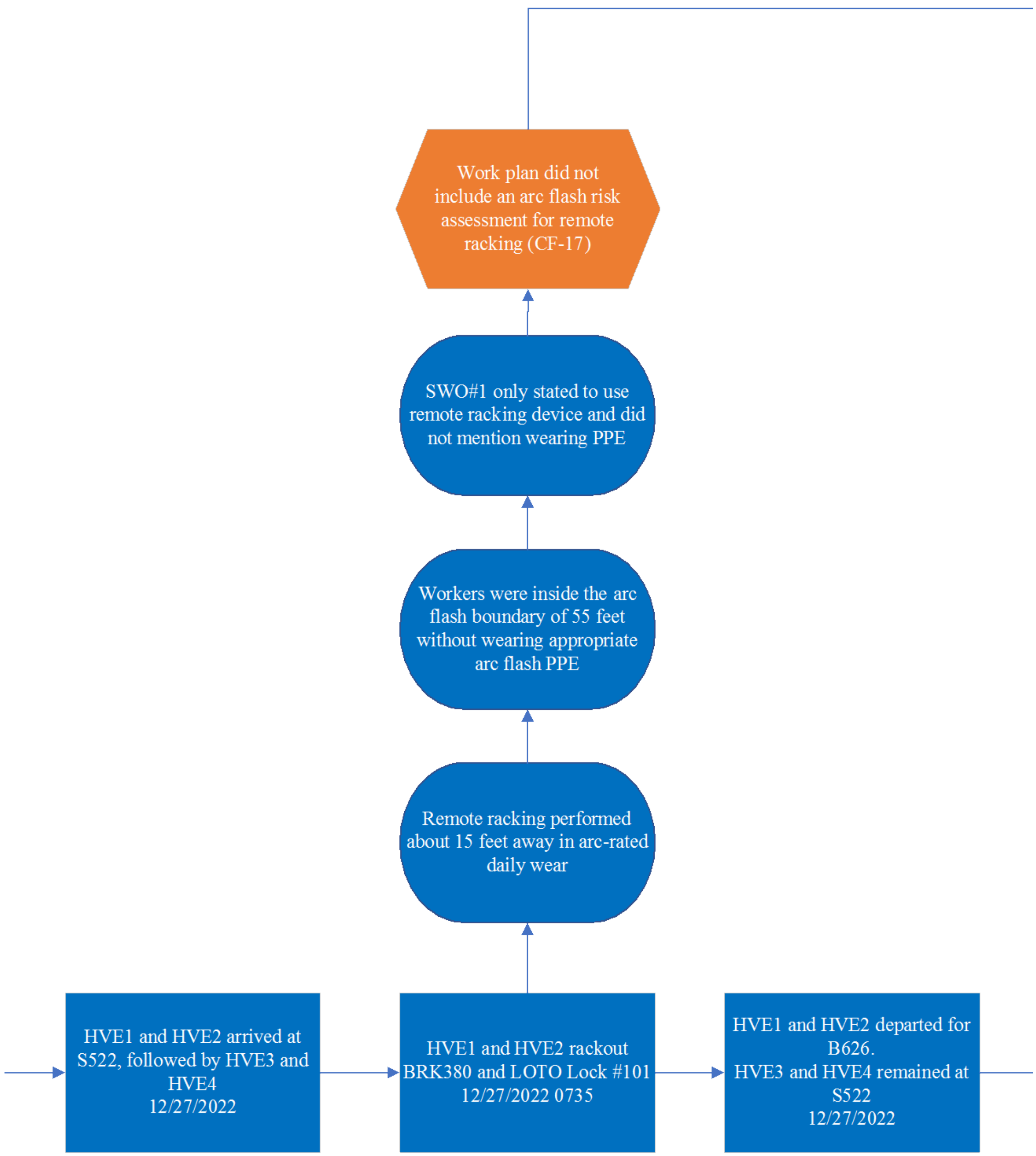
- Causal factors are noted with a CF-# in parentheses within the causal factor shape.
- Contributing causes (CC) are noted in two ways.
    - If a CC is cited verbatim in the chart, it is noted as CC-#: with narrative.
    - If a CC is related to a causal factor or another CC, the CC is denoted with a CC-# in parentheses at the end of the narrative.

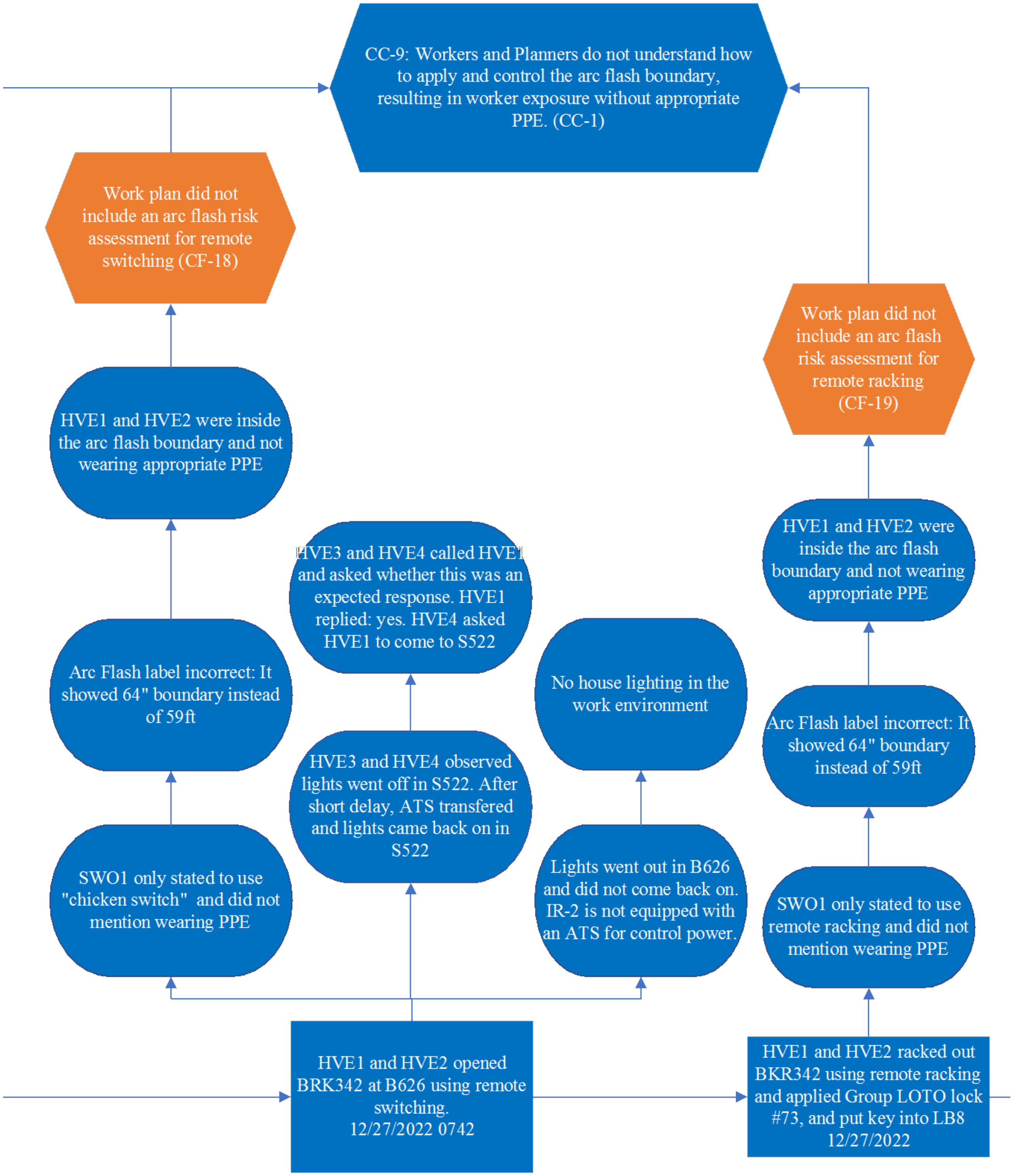
Insufficient resources and time; increased SOW; failed to identify and consider HP-EP in WPE. (CC-2, CC-4)
Existing maintenance resources could not support maintenance activities on IR-2 and S522 emergency power panels simultaneously
IR-2 and S522 share a feeder from BKR 75, cannot fully deenergize IR-2 without shutting down S522.
Additional complexity required leaving IR-2 partially energized for about 4 hours (CF-1)
Outage plan introduced a sequence to shut off IR-2 first, install generators and then shut off S522 as well
CM and Outage Planning
CC-5: Planning process failed to produce a work package that could be executed safely.
Work not formally classified as RED; it failed to trigger a WIP (CF-3)
Numerous errors, omissions, and inconsistencies among the EWP, SWO, and EIP (CF-2)
Time pressure to meet final check prior to B626 Outage and prior to holiday stand down
Of the 4 planners, 2 senior planners were supporting other projects
B626 EWP authorized and released
12/15/2022 - 1309
Walk-down requirements not defined. Unclear expectations and inconsistent execution (CC-6)
Errors in the work plan not recognized during the walkdown
Walkdown was done only at IR-2 and did not include IR-12 or S522
Not all HVEs who worked the B626 EWP on 12/27 participated on this walk-down (CF-5)
No work package or one-line used during walk-down (CF-4)
Last walk-down prior to performing B626 Outage
HVP1 walked-down EWP at a "high level" with HVE1 and HVE2
12/22/2022

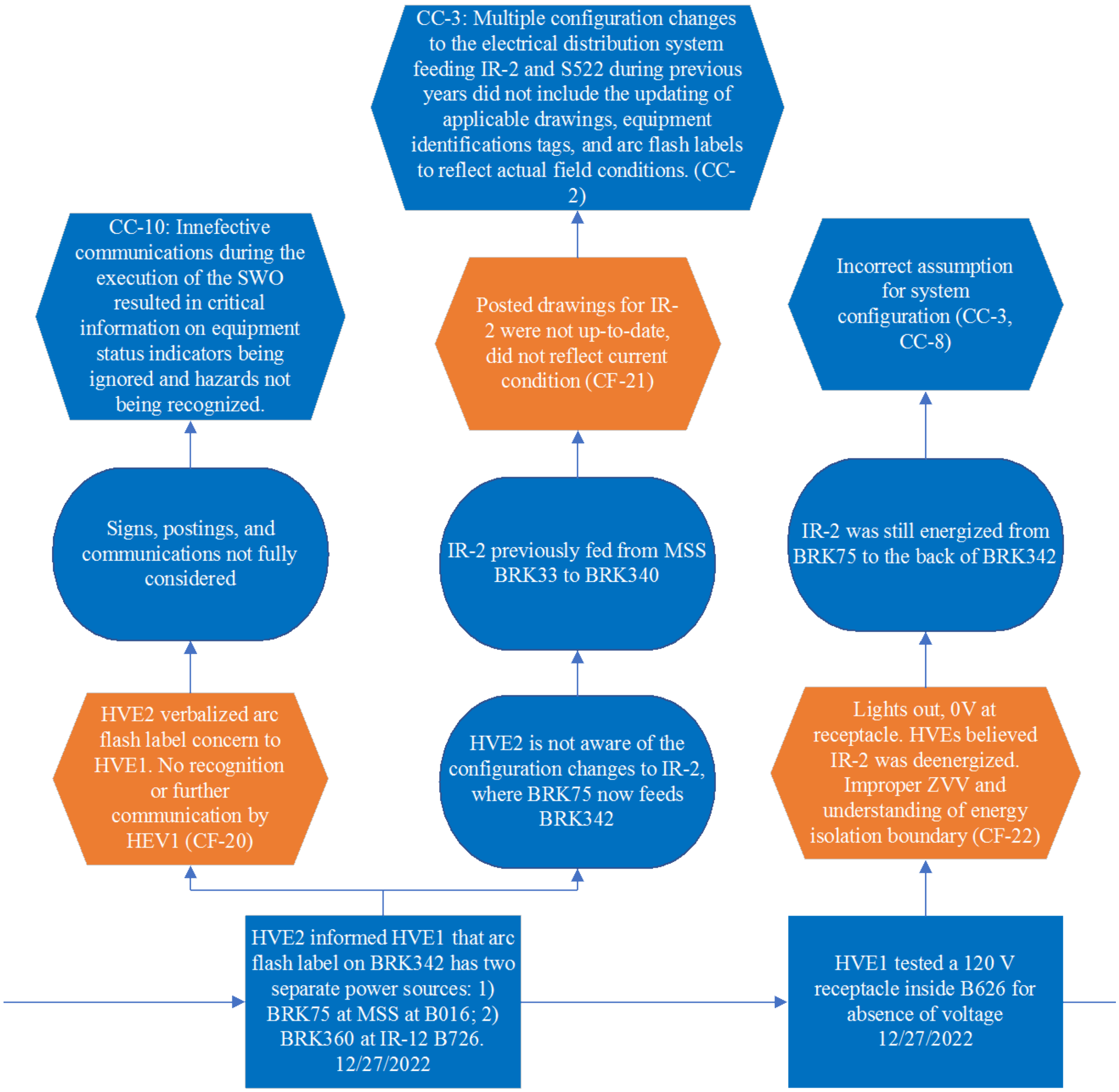

Insufficient resources and time; increased SOW; failed to identify and consider HP-EP in WPE. (CC-4)
Workers late due to heavy rain; catching up after holiday weekend (Distraction) (CF-11)
CC-5: Planning process failed to produce a work package that could be executed safely.
Walk-down done 4-5 days prior to execution. Potential change in field conditions / loss of familiarity (CF-10)
LM/Supervisor did not ensure HVEs understood specific hazards and controls (CC-7)
B626 EWP, SWO, and EIP discrepancy not identified (CF-8)
First meeting after extended holiday weekend (CF-9)
Not all required reviews for the B626 Outage were performed (CF-7)
HVE3 and HVE4 assigned as floaters to HVE1 and HVE2 at B626 without pre-job briefing (CF-6)
Complex Outage conducted during Winter Break kicked off on first day back.
SLAC HV Group Tailgate at F&O B035 (HV Shop) 12/27/2022 - 0600

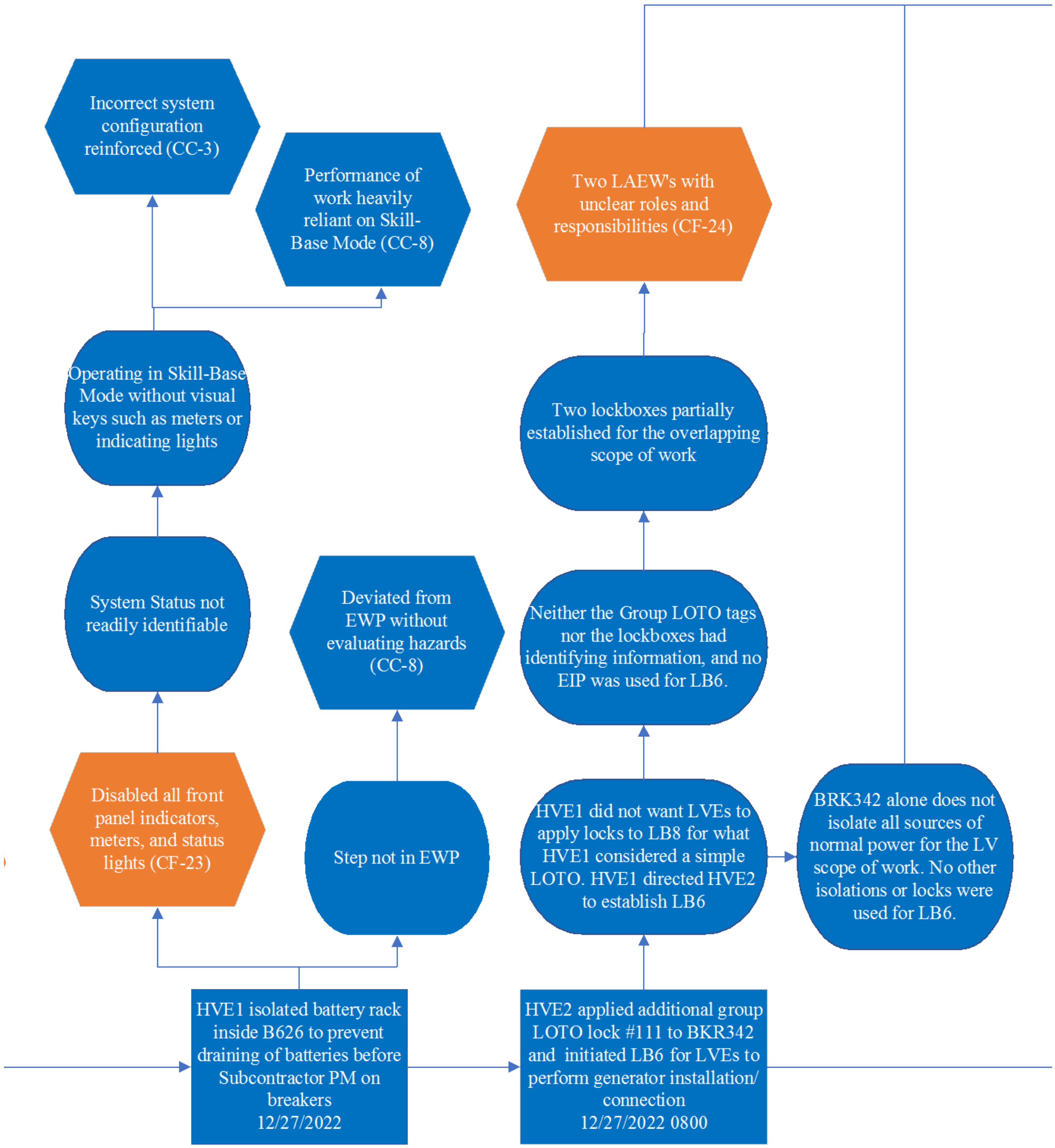

Failed to identity and consider HP-EP (CC-4)
Area prone to flooding. Diesel pumps required to assist electric pumps in lead/lag configuration to keep up with heavy rainfall
Work could not start until HV Group completed SWO#1 and EIP1
Urgency to complete the PM on the emergency panels for the clean room area pumps
Would lose ISO certification of Clean Room
Concern about flooding the LSST Clean Room
Flooding in the room for 251-P1-MCC: ~1-2" of water
Significant rain prior to and day of event on 12/27/22
One Subcontractor employee attended
SLAC FOC Coordination Meeting at F&O B035 (HV Shop) 12/27/2022 - 0630
HVE1, HVE2, and HVE3 departed F&O B035 for B726 12/27/2022
Emergency equipment required at the job site not identified. (CC-7)
Posted emergency signs throughout the site (entrance doors, etc.) lack specific detail on activating EMS. (CC-7)
Discussions with personnel regarding the initiation of Emergency Response Personnel not fully considered
HVEs not adequately briefed to specific hazards/ controls associated with work assigned (CC-7)
Clear roles and responsibilities for critical aspects of the job not defined (CC-7)
HVE3 and HVE4 not fully briefed to scope, hazards, or controls (CF-13)
No job specific hazards discussed, including shock protection or arc flash boundaries
Discrete Job Briefing, as per Chapter 8 and NFPA70E, did not occur (CF-12)

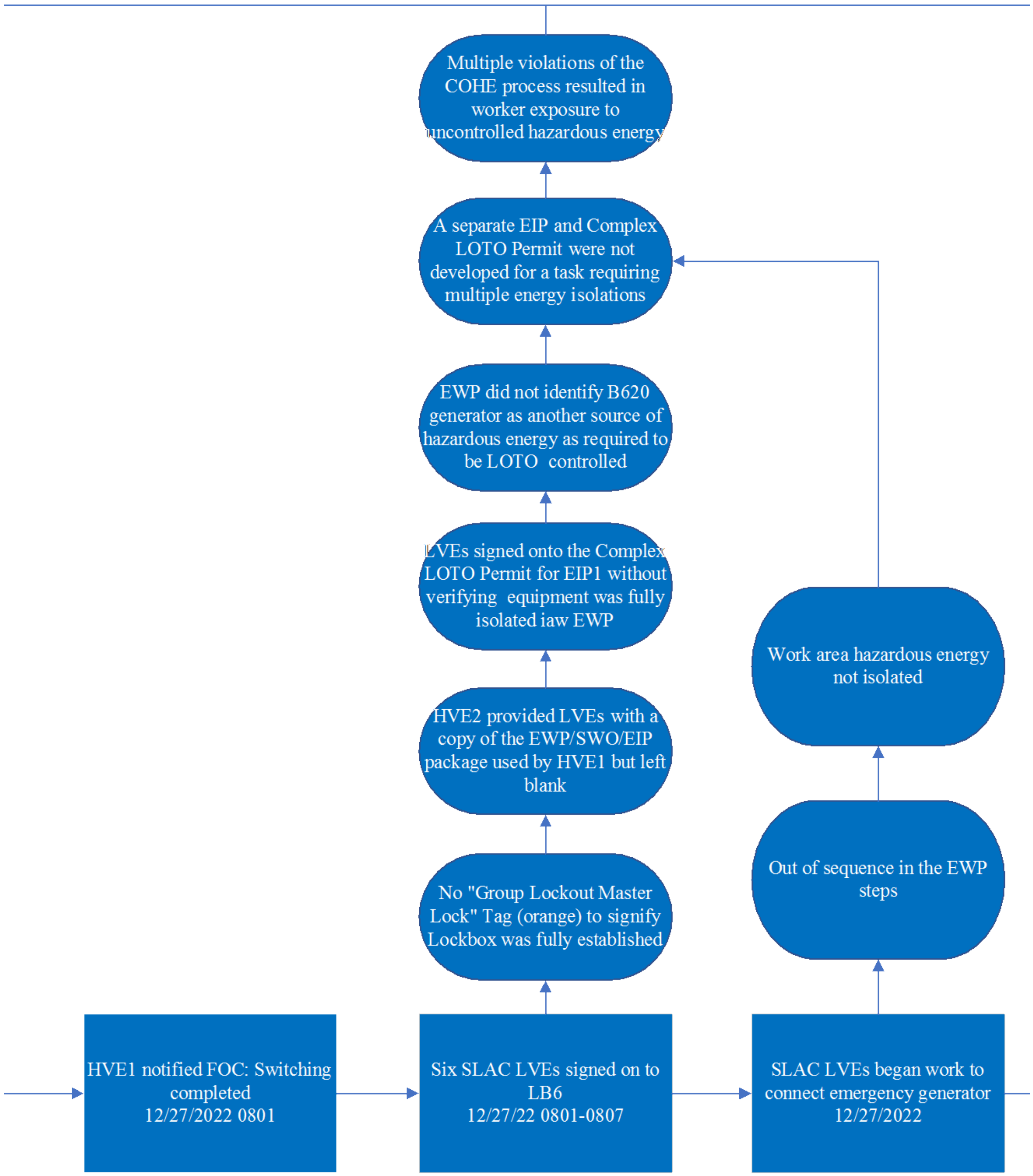

Hazards missed or not identified. Premature placement of grounds (CC-1, CC-8)
HVEs deviated from approved EWP; did not stop to questions deviations; did not analyze hazards (CC-1, CC-8)
Hazard controls not tailored to work performed (CC-4)
Working to Skill-Based Mode vice approved procedures
SWO2 and EIP2 directed placement of ground at BRK360
Lack of questioning attitude
Work executed outside of scope activities (CF-14)
Stop/Pause Work not instituted
Workers not aware of hazard of placing grounds prior to all isolations controlled by LOTO
SWO1 does not identify the placement of ground (EIP1 does)
Work step added to approved EWP without additional HA/Approval (CF-16)
Grounds at BKR360 installed prior to all isolation established and controlled by LOTO
Field conditions do not match expected/briefed conditions (BRK360 racked-out) (CF-15)
Upon arrival, work crew found BRK360 physically removed
HVE1, HVE2, and HVE3 arrived at IR-12 B726 to LOTO on BKR360, ZVV check, and install grounds in back of BKR360 12/27/2022 0700
HVE1 established Group LB8 with Lock #112 12/27/22 0730

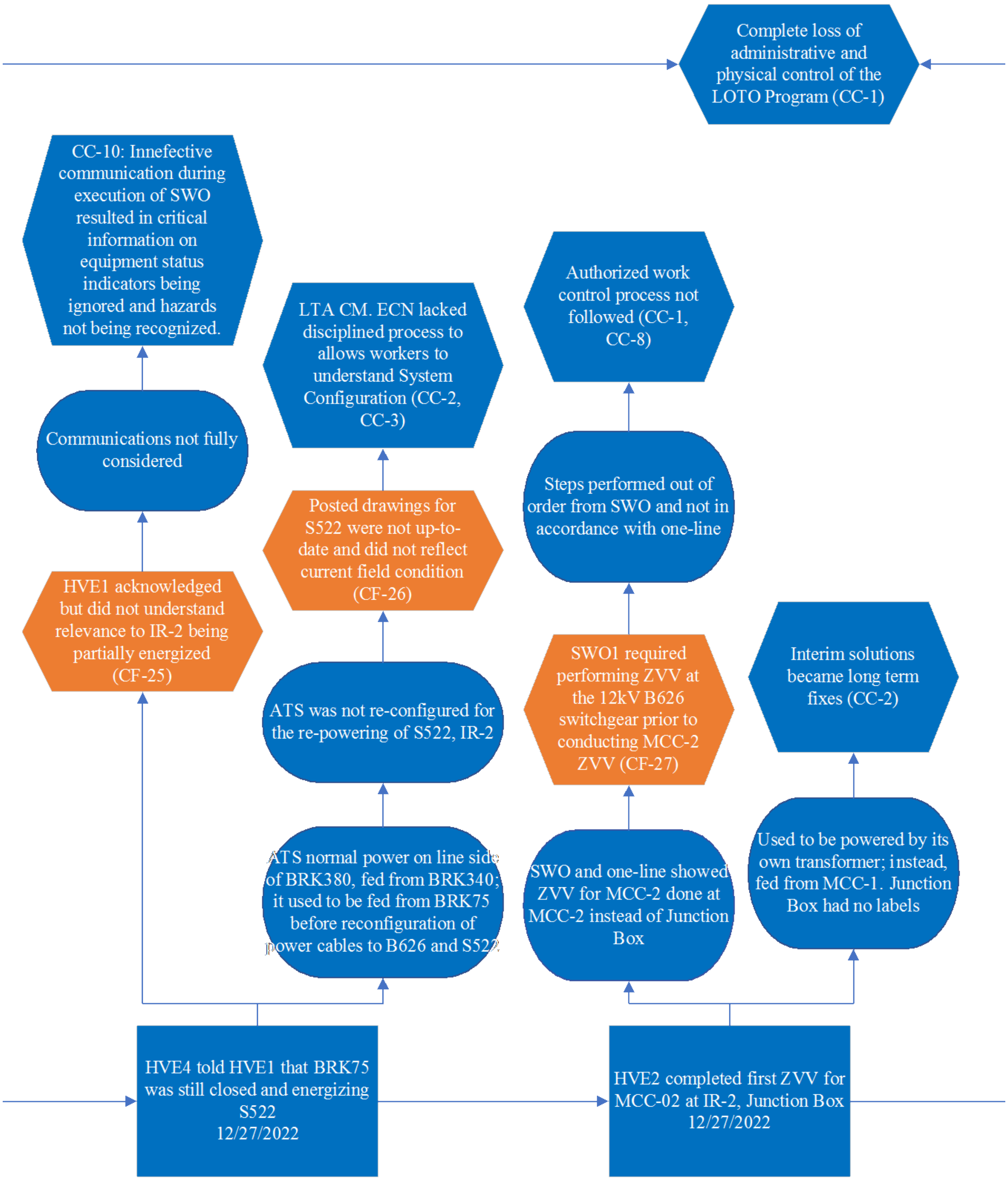

Work plan did not include an arc flash risk assessment for remote racking (CF-17)
SWO#1 only stated to use remote racking device and did not mention wearing PPE
Workers were inside the arc flash boundary of 55 feet without wearing appropriate arc flash PPE
Remote racking performed about 15 feet away in arc-rated daily wear
HVE1 and HVE2 arrived at S522, followed by HVE3 and HVE4 12/27/2022
HVE1 and HVE2 rackout BRK380 and LOTO Lock #101 12/27/2022 0735
HVE1 and HVE2 departed for B626. HVE3 and HVE4 remained at S522 12/27/2022

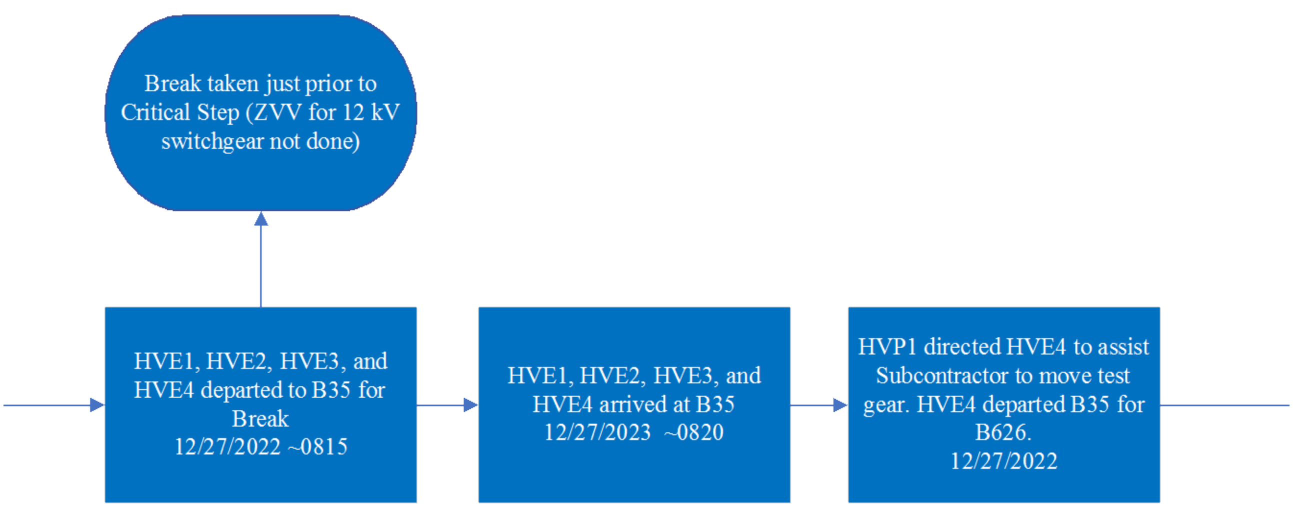

CC-9: Workers and Planners do not understand how to apply and control the arc flash boundary, resulting in worker exposure without appropriate PPE. (CC-1)
Work plan did not include an arc flash risk assessment for remote switching (CF-18)
Work plan did not include an arc flash risk assessment for remote racking (CF-19)
HVE1 and HVE2 were inside the arc flash boundary and not wearing appropriate PPE
HVE1 and HVE2 were inside the arc flash boundary and not wearing appropriate PPE
HVE3 and HVE4 called HVE1 and asked whether this was an expected response. HVE1 replied: yes. HVE4 asked HVE1 to come to S522
No house lighting in the work environment
Arc Flash label incorrect: It showed 64" boundary instead of 59ft
Arc Flash label incorrect: It showed 64" boundary instead of 59ft
HVE3 and HVE4 observed lights went off in S522. After short delay, ATS transfered and lights came back on in S522
Lights went out in B626 and did not come back on. IR-2 is not equipped with an ATS for control power.
SWO1 only stated to use "chicken switch" and did not mention wearing PPE
SWO1 only stated to use remote racking and did not mention wearing PPE
HVE1 and HVE2 opened BRK342 at B626 using remote switching. 12/27/2022 0742
HVE1 and HVE2 racked out BKR342 using remote racking and applied Group LOTO lock #73, and put key into LB8 12/27/2022

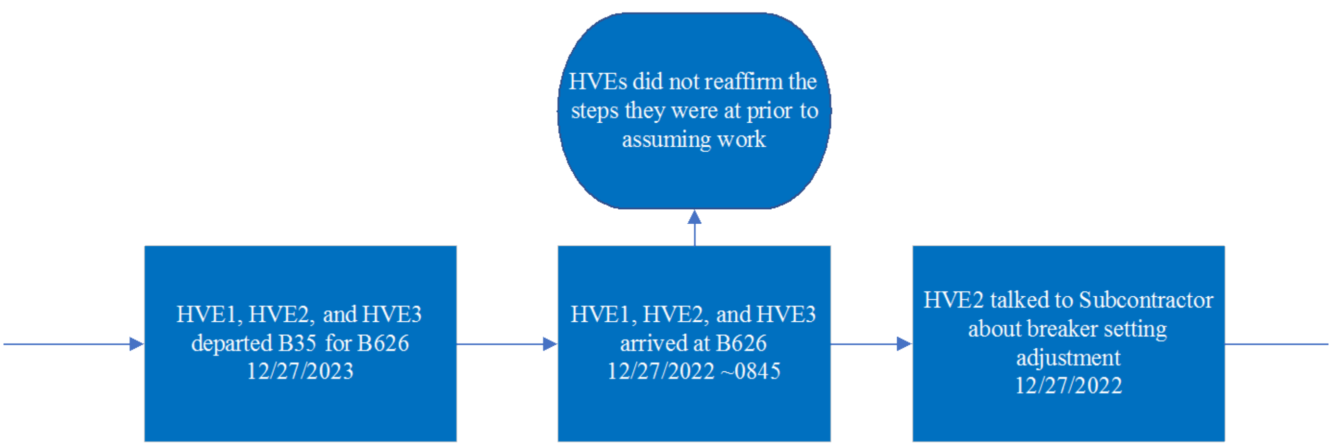

CC-3: Multiple configuration changes to the electrical distribution system feeding IR-2 and S522 during previous years did not include the updating of applicable drawings, equipment identifications tags, and arc flash labels to reflect actual field conditions. (CC-2)
CC-10: Innefective communications during the execution of the SWO resulted in critical information on equipment status indicators being ignored and hazards not being recognized.
Posted drawings for IR-2 were not up-to-date, did not reflect current condition (CF-21)
Incorrect assumption for system configuration (CC-3, CC-8)
Signs, postings, and communications not fully considered
IR-2 previously fed from MSS BRK33 to BRK340
IR-2 was still energized from BRK75 to the back of BRK342
HVE2 verbalized arc flash label concern to HVE1. No recognition or further communication by HEV1 (CF-20)
HVE2 is not aware of the configuration changes to IR-2, where BRK75 now feeds BRK342
Lights out, 0V at receptacle. HVEs believed IR-2 was deenergized. Improper ZVV and understanding of energy isolation boundary (CF-22)
HVE2 informed HVE1 that arc flash label on BRK342 has two separate power sources: 1) BRK75 at MSS at B016; 2) BRK360 at IR-12 B726. 12/27/2022
HVE1 tested a 120 V receptacle inside B626 for absence of voltage 12/27/2022

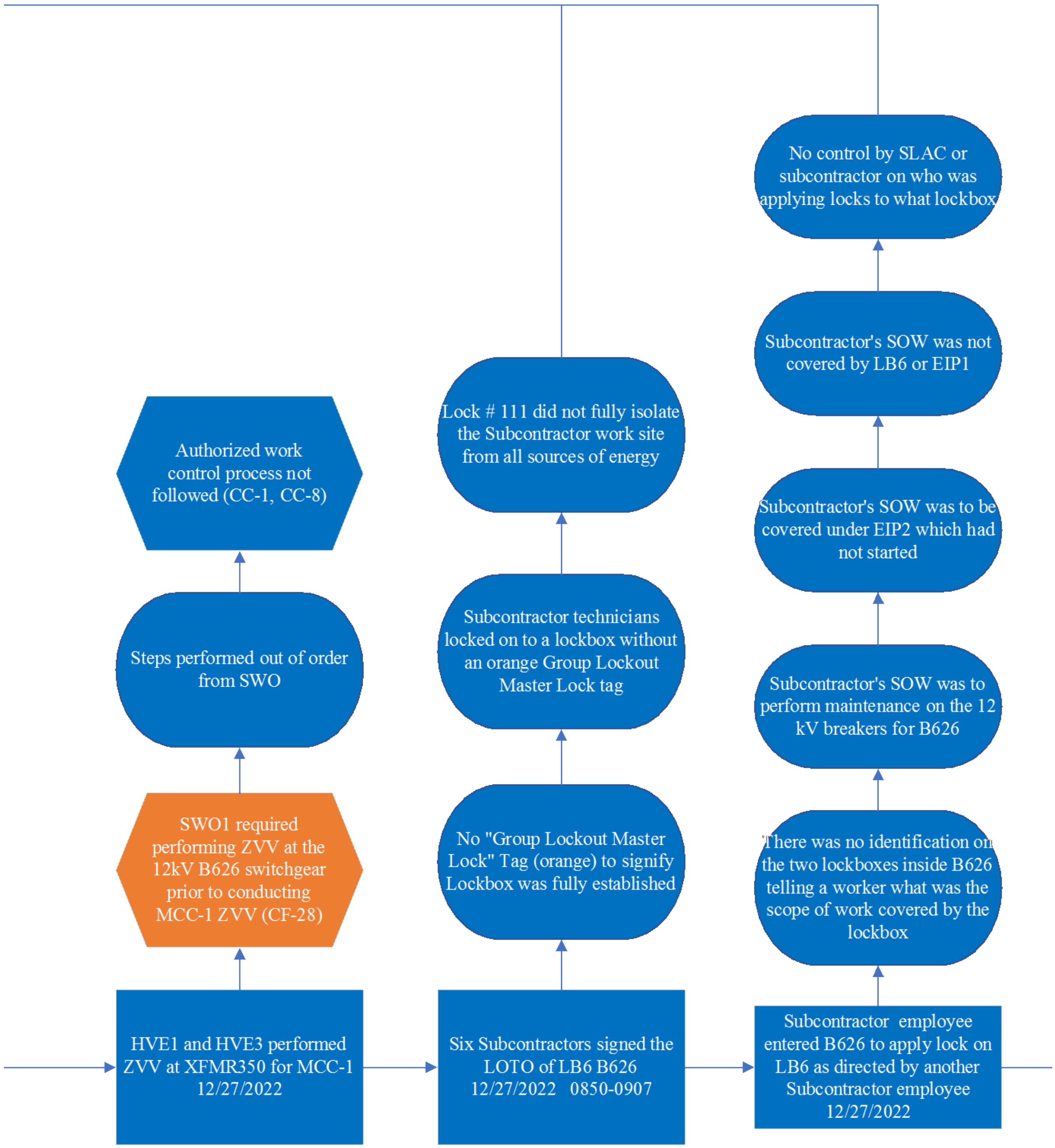

Incorrect system configuration reinforced (CC-3)
Performance of work heavily reliant on Skill-Base Mode (CC-8)
Two LAEW's with unclear roles and responsibilities (CF-24)
Operating in Skill-Base Mode without visual keys such as meters or indicating lights
Two lockboxes partially established for the overlapping scope of work
System Status not readily identifiable
Deviated from EWP without evaluating hazards (CC-8)
Neither the Group LOTO tags nor the lockboxes had identifying information, and no EIP was used for LB6.
Disabled all front panel indicators, meters, and status lights (CF-23)
Step not in EWP
HVE1 did not want LVEs to apply locks to LB8 for what HVE1 considered a simple LOTO. HVE1 directed HVE2 to establish LB6
BRK342 alone does not isolate all sources of normal power for the LV scope of work. No other isolations or locks were used for LB6.
HVE1 isolated battery rack inside B626 to prevent draining of batteries before Subcontractor PM on breakers 12/27/2022
HVE2 applied additional group LOTO lock #111 to BKR342 and initiated LB6 for LVEs to perform generator installation/ connection 12/27/2022 0800

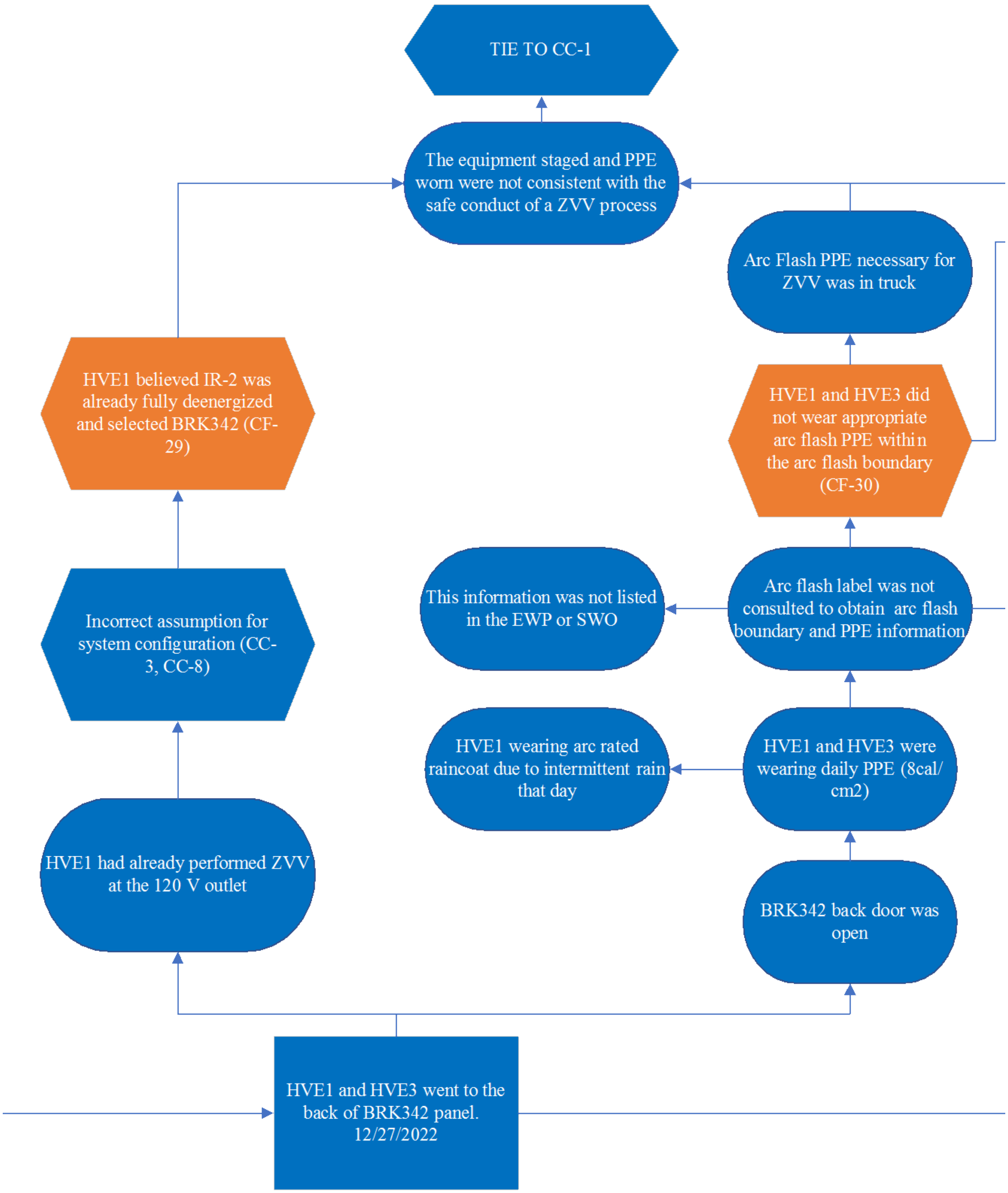

Multiple violations of the COHE process resulted in worker exposure to uncontrolled hazardous energy
A separate EIP and Complex LOTO Permit were not developed for a task requiring multiple energy isolations
EWP did not identify B620 generator as another source of hazardous energy as required to be LOTO controlled
LVEs signed onto the Complex LOTO Permit for EIP1 without verifying equipment was fully isolated iaw EWP
HVE2 provided LVEs with a copy of the EWP/SWO/EIP package used by HVE1 but left blank
No "Group Lockout Master Lock" Tag (orange) to signify Lockbox was fully established
Work area hazardous energy not isolated
Out of sequence in the EWP steps
HVE1 notified FOC: Switching completed 12/27/2022 0801
Six SLAC LVEs signed on to LB6 12/27/22 0801-0807
SLAC LVEs began work to connect emergency generator 12/27/2022

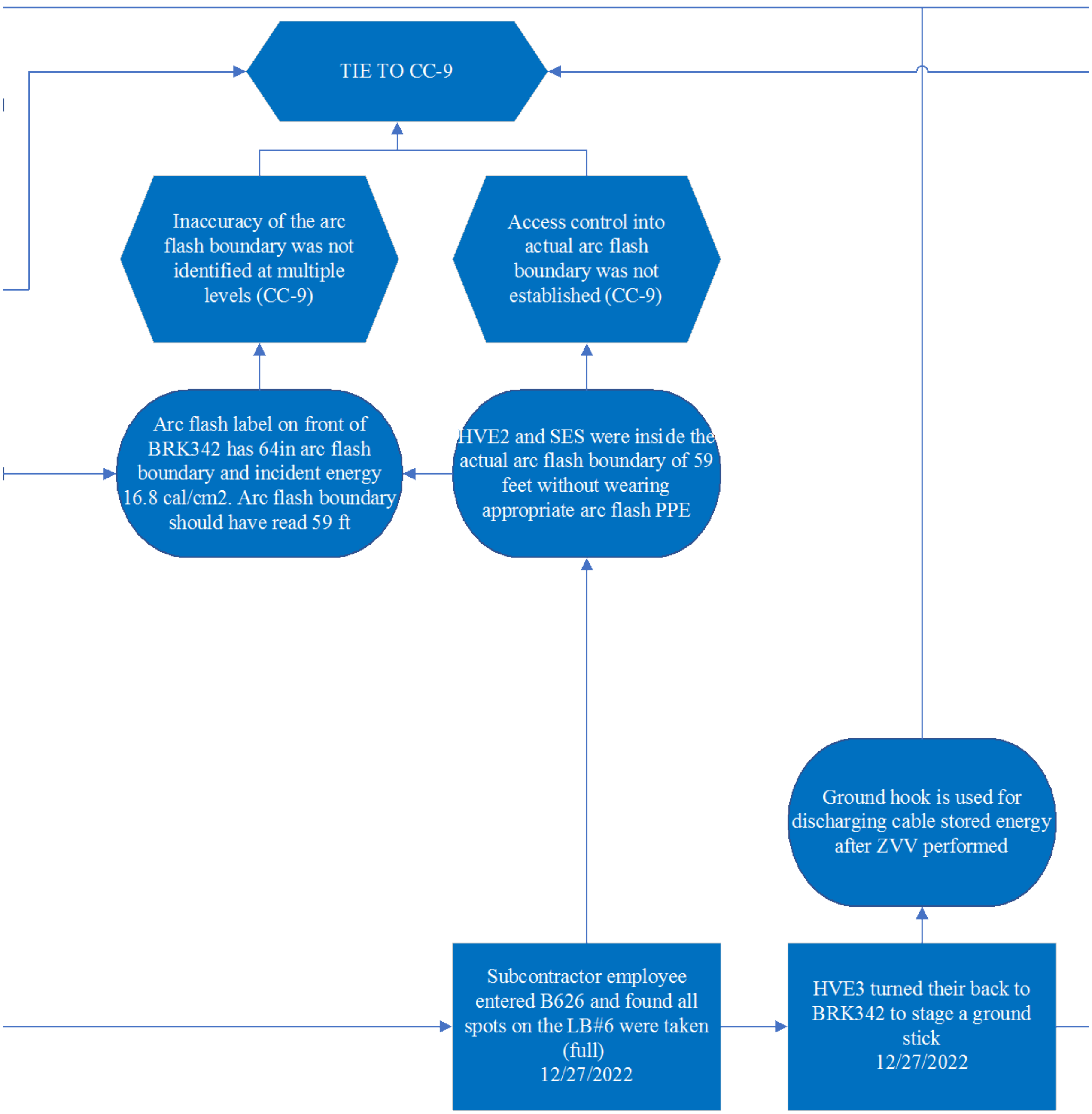

Complete loss of administrative and physical control of the LOTO Program (CC-1)
CC-10: Innefective communication during execution of SWO resulted in critical information on equipment status indicators being ignored and hazards not being recognized.
LTA CM. ECN lacked disciplined process to allows workers to understand System Configuration (CC-2, CC-3)
Authorized work control process not followed (CC-1, CC-8)
Communications not fully considered
Posted drawings for S522 were not up-to-date and did not reflect current field condition (CF-26)
Steps performed out of order from SWO and not in accordance with one-line
HVE1 acknowledged but did not understand relevance to IR-2 being partially energized (CF-25)
ATS was not re-configured for the re-powering of S522, IR-2
SWO1 required performing ZVV at the 12kV B626 switchgear prior to conducting MCC-2 ZVV (CF-27)
Interim solutions became long term fixes (CC-2)
ATS normal power on line side of BRK380, fed from BRK340; it used to be fed from BRK75 before reconfiguration of power cables to B626 and S522
SWO and one-line showed ZVV for MCC-2 done at MCC-2 instead of Junction Box
Used to be powered by its own transformer; instead, fed from MCC-1. Junction Box had no labels
HVE4 told HVE1 that BRK75 was still closed and energizing S522 12/27/2022
HVE2 completed first ZVV for MCC-02 at IR-2, Junction Box 12/27/2022

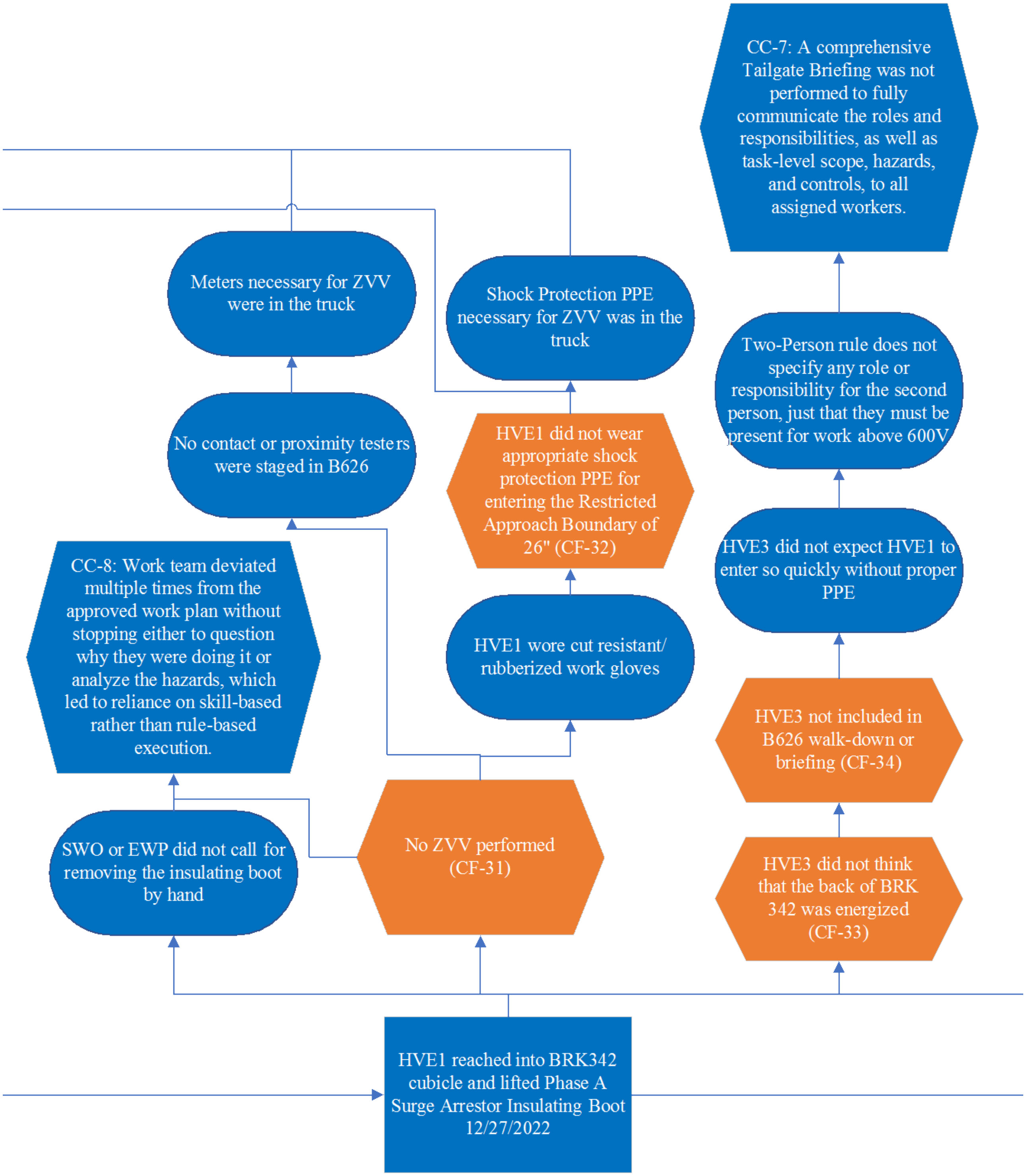

Break taken just prior to Critical Step (ZVV for 12 kV switchgear not done)
HVE1, HVE2, HVE3, and HVE4 departed to B35 for Break 12/27/2022 ~0815
HVE1, HVE2, HVE3, and HVE4 arrived at B35 12/27/2023 ~0820
HVP1 directed HVE4 to assist Subcontractor to move test gear. HVE4 departed B35 for B626. 12/27/2022

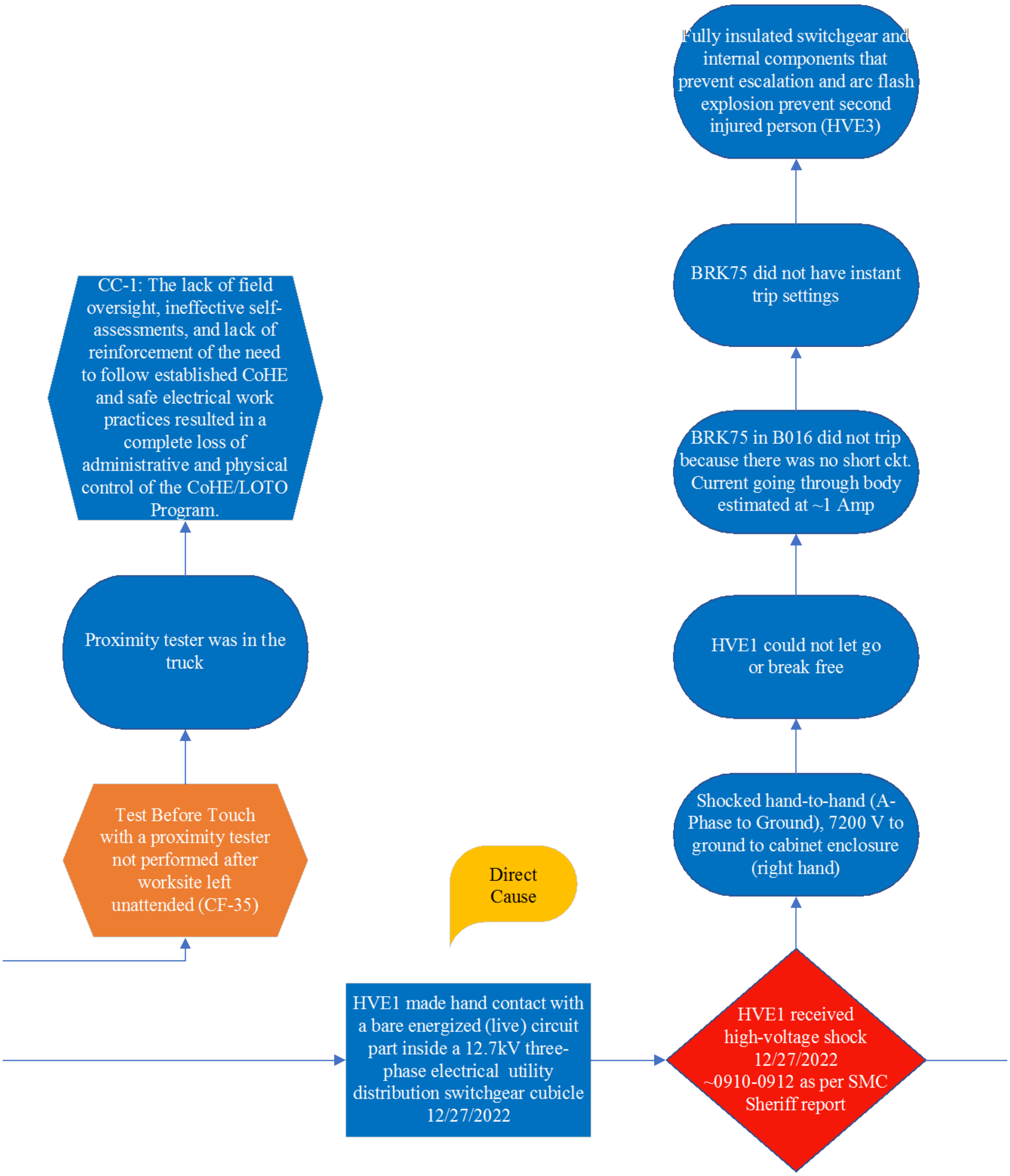

HVEs did not reaffirm the steps they were at prior to assuming work
HVE1, HVE2, and HVE3 departed B35 for B626 12/27/2023
HVE1, HVE2, and HVE3 arrived at B626 12/27/2022 ~0845
HVE2 talked to Subcontractor about breaker setting adjustment 12/27/2022

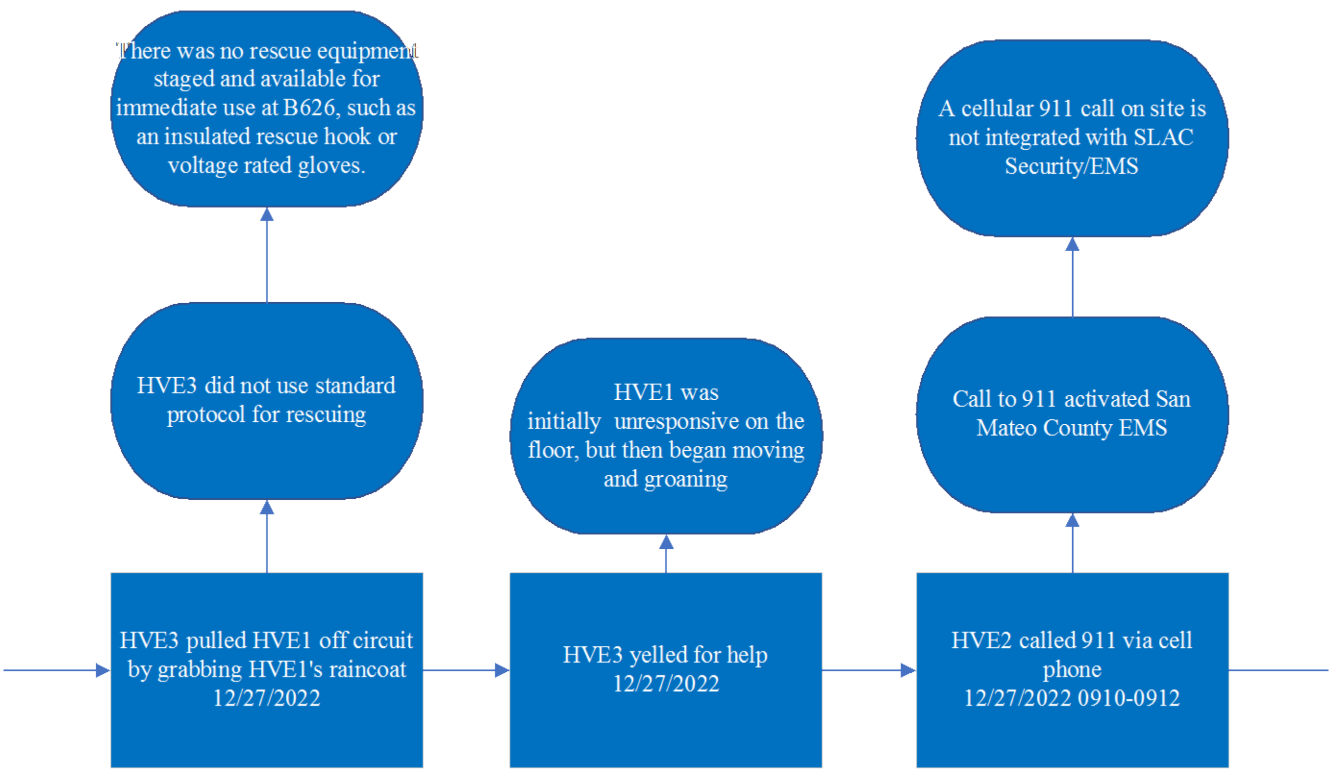

No control by SLAC or subcontractor on who was applying locks to what lockbox
Subcontractor's SOW was not covered by LB6 or EIP1
Subcontractor's SOW was to be covered under EIP2 which had not started
Subcontractor's SOW was to perform maintenance on the 12 kV breakers for B626
There was no identification on the two lockboxes inside B626 telling a worker what was the scope of work covered by the lockbox
Subcontractor employee entered B626 to apply lock on LB6 as directed by another Subcontractor employee 12/27/2022
Lock # 111 did not fully isolate the Subcontractor work site from all sources of energy
Subcontractor technicians locked on to a lockbox without an orange Group Lockout Master Lock tag
No "Group Lockout Master Lock" Tag (orange) to signify Lockbox was fully established
Six Subcontractors signed the LOTO of LB6 B626 12/27/2022 0850-0907
Authorized work control process not followed (CC-1, CC-8)
Steps performed out of order from SWO
SWO1 required performing ZVV at the 12kV B626 switchgear prior to conducting MCC-1 ZVV (CF-28)
HVE1 and HVE3 performed ZVV at XFMR350 for MCC-1 12/27/2022

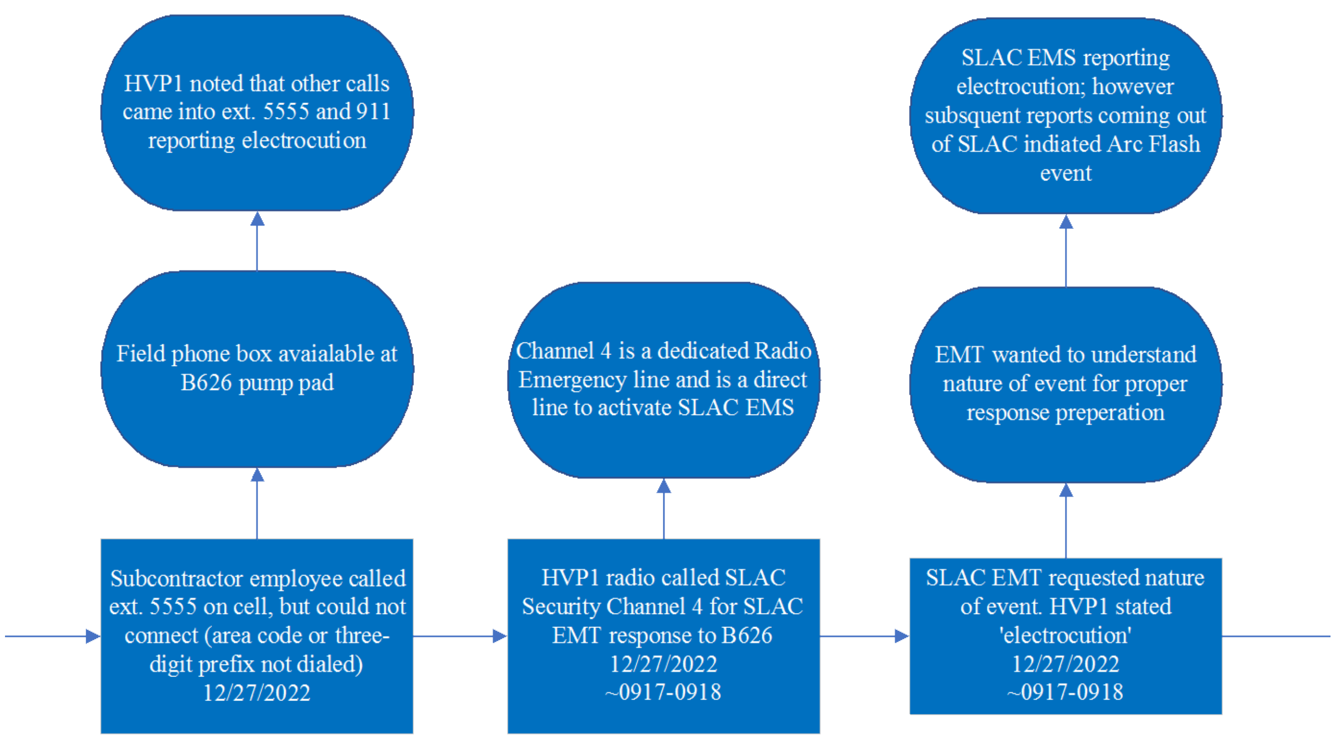

TIE TO CC-1
The equipment staged and PPE worn were not consistent with the safe conduct of a ZVV process
Arc Flash PPE necessary for ZVV was in truck
HVE1 believed IR-2 was already fully deenergized and selected BRK342 (CF-29)
HVE1 and HVE3 did not wear appropriate arc flash PPE within the arc flash boundary (CF-30)
This information was not listed in the EWP or SWO
Arc flash label was not consulted to obtain arc flash boundary and PPE information
Incorrect assumption for system configuration (CC-3, CC-8)
HVE1 wearing arc rated raincoat due to intermittent rain that day
HVE1 and HVE3 were wearing daily PPE (8cal/cm2)
HVE1 had already performed ZVV at the 120 V outlet
BRK342 back door was open
HVE1 and HVE3 went to the back of BRK342 panel. 12/27/2022

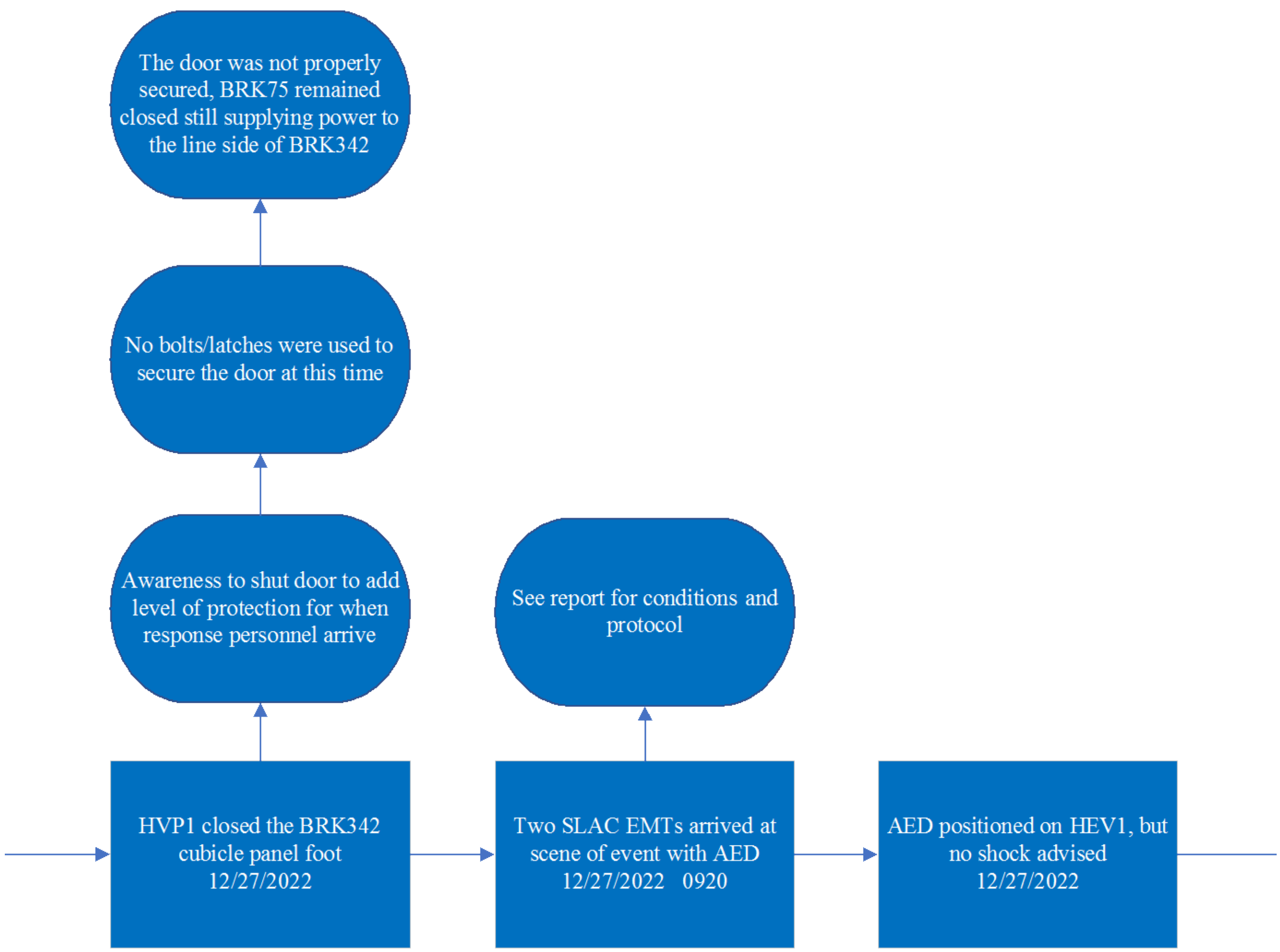

TIE TO CC-9
Inaccuracy of the arc flash boundary was not identified at multiple levels (CC-9)
Access control into actual arc flash boundary was not established (CC-9)
Arc flash label on front of BRK342 has 64in arc flash boundary and incident energy 16.8 cal/cm2. Arc flash boundary should have read 59 ft
HVE2 and SES were inside the actual arc flash boundary of 59 feet without wearing appropriate arc flash PPE
Ground hook is used for discharging cable stored energy after ZVV performed
Subcontractor employee entered B626 and found all spots on the LB#6 were taken (full) 12/27/2022
HVE3 turned their back to BRK342 to stage a ground stick 12/27/2022


CC-7: A comprehensive Tailgate Briefing was not performed to fully communicate the roles and responsibilities, as well as task-level scope, hazards, and controls, to all assigned workers.
Meters necessary for ZVV were in the truck
Shock Protection PPE necessary for ZVV was in the truck
Two-Person rule does not specify any role or responsibility for the second person, just that they must be present for work above 600V
No contact or proximity testers were staged in B626
HVE1 did not wear appropriate shock protection PPE for entering the Restricted Approach Boundary of 26" (CF-32)
HVE3 did not expect HVE1 to enter so quickly without proper PPE
CC-8: Work team deviated multiple times from the approved work plan without stopping either to question why they were doing it or analyze the hazards, which led to reliance on skill-based rather than rule-based execution.
HVE1 wore cut resistant/ rubberized work gloves
HVE3 not included in B626 walk-down or briefing (CF-34)
SWO or EWP did not call for removing the insulating boot by hand
No ZVV performed (CF-31)
HVE3 did not think that the back of BRK 342 was energized (CF-33)
HVE1 reached into BRK342 cubicle and lifted Phase A Surge Arrestor Insulating Boot 12/27/2022

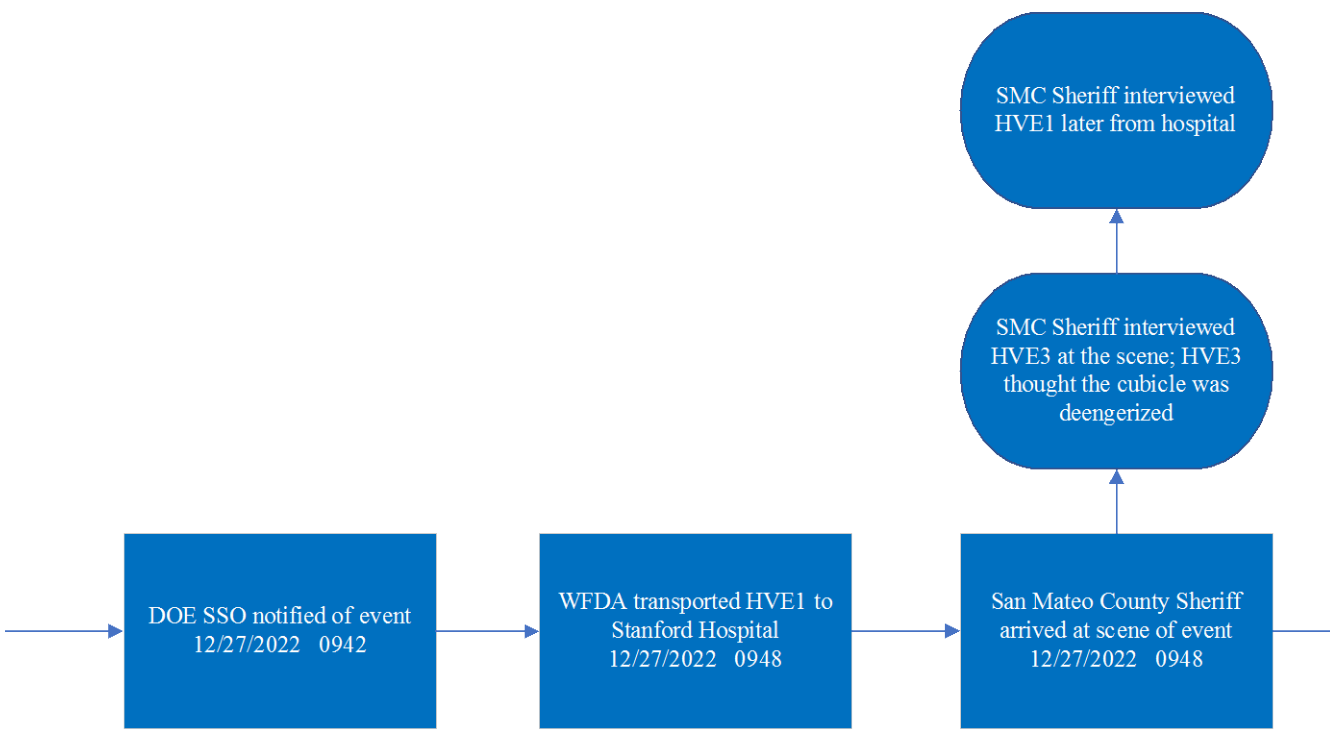

Fully insulated switchgear and internal components that prevent escalation and arc flash explosion prevent second injured person (HVE3)
BRK75 did not have instant trip settings
CC-1: The lack of field oversight, ineffective self-assessments, and lack of reinforcement of the need to follow established CoHE and safe electrical work practices resulted in a complete loss of administrative and physical control of the CoHE/LOTO Program.
BRK75 in B016 did not trip because there was no short ckt. Current going through body estimated at ~1 Amp
Proximity tester was in the truck
HVE1 could not let go or break free
Shocked hand-to-hand (A-Phase to Ground), 7200 V to ground to cabinet enclosure (right hand)
Test Before Touch with a proximity tester not performed after worksite left unattended (CF-35)
Direct Cause
HVE1 made hand contact with a bare energized (live) circuit part inside a 12.7kV three-phase electrical utility distribution switchgear cubicle 12/27/2022
HVE1 received high-voltage shock 12/27/2022 ~0910-0912 as per SMC Sheriff report


There was no rescue equipment staged and available for immediate use at B626, such as an insulated rescue hook or voltage rated gloves.
HVE3 did not use standard protocol for rescuing
HVE3 pulled HVE1 off circuit by grabbing HVE1's raincoat 12/27/2022
HVE1 was initially unresponsive on the floor, but then began moving and groaning
HVE3 yelled for help 12/27/2022
A cellular 911 call on site is not integrated with SLAC Security/EMS
Call to 911 activated San Mateo County EMS
HVE2 called 911 via cell phone 12/27/2022 0910-0912


HVP1 noted that other calls came into ext. 5555 and 911 reporting electrocution
SLAC EMS reporting electrocution; however subsquent reports coming out of SLAC indiated Arc Flash event
Field phone box avaialable at B626 pump pad
Channel 4 is a dedicated Radio Emergency line and is a direct line to activate SLAC EMS
EMT wanted to understand nature of event for proper response preperation
Subcontractor employee called ext. 5555 on cell, but could not connect (area code or three-digit prefix not dialed) 12/27/2022
HVP1 radio called SLAC Security Channel 4 for SLAC EMT response to B626 12/27/2022 ~0917-0918
SLAC EMT requested nature of event. HVP1 stated 'electrocution' 12/27/2022 ~0917-0918


The door was not properly secured, BRK75 remained closed still supplying power to the line side of BRK342
No bolts/latches were used to secure the door at this time
Awareness to shut door to add level of protection for when response personnel arrive
See report for conditions and protocol
HVP1 closed the BRK342 cubicle panel foot 12/27/2022
Two SLAC EMTs arrived at scene of event with AED 12/27/2022 0920
AED positioned on HEV1, but no shock advised 12/27/2022


Menlo Park Fire District Engine 4 and Woodside Fire District Ambulance arrived at SLAC Main Gate 12/27/2022 0924
MPFDE4 and WFDA arrived at scene of event 12/27/2022 0925
SLAC ES&H Division Director notified of event 12/27/2022 0929


SMC Sheriff interviewed HVE1 later from hospital
SMC Sheriff interviewed HVE3 at the scene; HVE3 thought the cubicle was deengerized
DOE SSO notified of event 12/27/2022 0942
WFDA transported HVE1 to Stanford Hospital 12/27/2022 0948
San Mateo County Sheriff arrived at scene of event 12/27/2022 0948


MPFDE4 departed
San Mateo Sheriff departed
SLAC Security locked and barricaded B626 12/27/2022 1230