Type B Accident Investigation Board Report

Arc Flash at Brookhaven National Laboratory April 14, 2006

August 2006

Brookhaven Site Office
U.S. Department of Energy
Upton, New York

Acronyms and Abbreviations

AC	Alternating Current
AGS	Alternating Gradient Synchrotron
AHJ	Authority Having Jurisdiction
ASE	Accelerator Safety Envelope
ASSRC	Accelerator System Safety Review Committee
ATS	Action Tracking System
BNL	Brookhaven National Laboratory
BNL PE	BNL Plant Engineering
BHSO	Brookhaven Site Office
C-AD	Collider-Accelerator Department
CAS	Collider Accelerator Support
CRD	Contractor Requirements Document
DC	Direct Current
DOE	Department of Energy
EMT	Emergency Medical Technician
ESFD	Experimental Support and Facilities Division
ESH&Q	Environment, Safety, Health, and Quality
ES&H	Environment, Safety, and Health
ESRC	Experimental Safety Review Committee
FR	Flame-Resistant
FRA	Facility Risk Assessment
GE	General Electric
GFCI	Ground Fault Circuit Interrupter
ISM	Integrated Safety Management
ISMSD	Integrated Safety Management System Description
JON	Judgment of Need
JRA	Job Risk Assessment
JTA	Job Training Assessment

LIPA	Long Island Power Authority
LOTO	Lockout/Tagout
NASA	National Aeronautics and Space Administration
NEC	National Electrical Code
NFPA	National Fire Protection Association
OMC	Occupational Medical Clinic
OPM	Operating Procedure Manual
ORR	Operational Readiness Review
OSHA	Occupational Safety and Health Administration
PPE	Personal Protective Equipment
PT	Potential Transformer
QAM	Quality Assurance Manual
QAP	Quality Assurance Program
RHIC	Relativistic Heavy Ion Collider
SAD	Safety Assessment Document
SBMS	Standards-Based Management System
SC	Office of Science
SEAPPM	Safety and Environmental Administrative Policy and Procedures Manual
S&EP	Safety and Environmental Protection
SLAC	Stanford Linear Accelerator Center
SME	Subject Matter Expert
STAR	Solenoidal Tracker at RHIC
UL	Underwriters Laboratories

Disclaimer

This report is an independent product of the Type B Accident Investigation Board appointed by Michael Holland, Manager, Brookhaven Site Office, U.S. Department of Energy.

The Board was appointed to perform a Type B investigation of this accident and to prepare an investigation report in accordance with DOE O 225.1A, *Accident Investigations*, and DOE G 225.1-A, *Implementation Guide for Use with DOE 225.1A,* Accident Investigations.

The discussion of 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 April 17, 2006, I established a Type B Accident Investigation Board to investigate the April 14, 2006, arc flash incident at the Brookhaven National Laboratory (BNL) that resulted in first- and second-degree burns to a BNL electrical engineer. The Board's responsibilities have been completed with respect to this investigation. The analysis process, identification of causal factors, and development of judgments of need were performed during the investigation in accordance with DOE O 225.1A, *Accident Investigations*. I accept the findings of the Board and authorize the release of this report for general distribution.

Michael D. Holland
Manager, Brookhaven Site Office

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Executive Summary

The Accident

At 10:20 a.m., on April 14, 2006, a BNL Collider-Accelerator Department (C-AD) electrical engineer was injured by an arc flash at the Brookhaven National Laboratory (BNL) Relativistic Heavy Ion Collider (RHIC) when an arcing ground fault occurred across all three phases of a 480-volt, fused-disconnect switch. The C-AD electrical engineer was in the process of restoring electrical power to the magnet power supplies for the Solenoidal Tracker at RHIC (STAR) detector and had just closed a switch in Building 1006A. The C-AD electrical engineer was not wearing the appropriate clothing and personal protective equipment (safety glasses) required for this work activity, and he received first- and second-degree burns to his face and body. The extent of burns included first-degree burns on his face, scalp, and chest and first- and second-degree burns on his hands and forearms. Additionally, he received a corneal abrasion on his left eye and his hair was set on fire. After receiving medical treatment at a local hospital, the C-AD electrical engineer was released the same day.

The Board concluded that the three-phase arcing ground fault was produced by an overvoltage condition resulting from a ground fault in a cable at the resonant frequency of the system. The Board could not rule out the possibility that a failure of the switch's internal structure may have been a contributing cause to the arc flash. The existence of a ground fault was discovered 3 days before the accident, but this condition was not communicated to the RHIC Main Control Room, Chief Electrical Engineer, or Collider Accelerator Support (CAS) personnel. The overvoltage condition on the ungrounded delta power system was determined to be the direct cause of the accident.

On April 17, 2006, the Site Office Manager for the U.S. Department of Energy (DOE) Office of Science (SC), Brookhaven Site Office (BHSO) appointed a Type B Accident Investigation Board to analyze the causal factors, identify the root causes, and determine judgments of need to preclude similar accidents in the future. The Board arrived onsite at BNL on April 17, 2006, and began the investigation.

Background

BNL is a multi-program national laboratory, established in 1947 on Long Island, Upton, New York. BNL operates under the programmatic direction of SC at DOE Headquarters, and is operated by Brookhaven Science Associates, LLC. The injured employee was a systems engineer for the STAR detector magnet power supplies.

On the day of the accident, a power dip on the incoming power from the local utility caused fuses to blow in the magnet power supplies for the STAR detector. The RHIC Main Control Room received alarms from the STAR facility and requested support from CAS. The work activity to be conducted was to troubleshoot the magnet power supplies to determine what had caused the outage. The STAR Magnet power supplies were susceptible to blown fuses caused by power dips, which were a common occurrence.

The power distribution system for RHIC and STAR is a three-phase, ungrounded delta system. The advantage to using an ungrounded delta electrical distribution system is that a line-to-ground fault does not result in the operation of the overcurrent device, and the system continues to operate (as opposed to a solidly grounded system in which a ground fault would result in the operation of the overcurrent protection device). If a ground fault is not detected, the system continues to operate; but, if another fault occurs, it results in a line-to-line-to-ground fault, which has the potential for more severe damage to the electrical equipment and personnel exposure to electrical hazards. When ground-fault detection is installed and monitored, it allows steps to be taken to isolate the ground fault and make repairs in a safe and timely manner. BNL has had approximately 50 years of operating experience with ungrounded delta power systems.

Disadvantages of ungrounded delta power supply systems include their vulnerability to switching surges and transient and resonant overvoltages. The power distribution system for the STAR Magnets was installed in 1997. RHIC requirements at the time of the STAR design, as well as current C-AD operating requirements, require remote monitoring of ground-fault conditions. Alarm response procedures for the RHIC Main Control Room specified prompt determination of the source of the ground fault (within 8 hours) and notification to the Chief Electrical Engineer if the source was not found. The *National Electrical Code* (NEC) at the time of the design recommended the use of monitoring equipment; the August 2004, NEC required that ungrounded electrical systems be provided with ground-fault monitoring.

Substation 6C provides power to the electrical panel involved in the arc flash. This substation had a ground-fault detection relay installed, but it was inoperable because it did not have the required power source. The STAR control room and RHIC Main Control Room staff and the Chief Electrical Engineer were unaware that substation 6C did not have the capability to monitor ground-fault conditions. A surveillance of the voltages of substation 6C was performed 3 days before the accident; and, although a slight ground fault was recorded on the inspection form, no corrective action was taken. A ground fault on one of these cables resulted from a cut in the insulation and from the cable being submerged in a flooded manhole.

Results and Analysis

The accident resulted from a number of deficiencies in the implementation of a series of management systems and related processes. These weaknesses involved elements of the line organization, including the RHIC Project, C-AD, and Plant Engineering; the Environment, Safety, and Health Division; and BHSO.

BNL had established design and operability requirements for the monitoring of ground-fault conditions on ungrounded power systems. However, BNL failed to ensure that these requirements were implemented in the design; verified in the engineering and environment, safety, and health design review and approval processes; tested following installation; confirmed in the Operational Readiness Reviews; and validated in commissioning activities. Although the ground-fault monitoring detection was a stated requirement in the RHIC Safety Assessment Document, this function was not verified to be operable. Ground-fault relays are important to the proper functioning of a safety feature; however, they were not included in a preventive maintenance program.

The safe operation of ungrounded delta systems requires facility operators to take prompt action to determine the source of a ground fault and to take appropriate corrective actions. BNL failed to implement formal work controls for working on ungrounded delta systems that could have a ground-fault condition.

BNL failed to implement National Fire Protection Association (NFPA) 70E, *Standard for Electrical Safety in the Workplace*. Arc flash calculations for Building 1006A were not completed. Upon completion of the arc flash calculations, BNL would have posted the appropriate personal protective equipment (PPE) on the electrical panel. The injured worker was not wearing the prescribed clothing and safety glasses while performing the work task. BNL failed to adequately monitor the implementation of NFPA 70E.

BNL failed to implement NFPA 70, *National Electrical Code* (NEC) 2005 for ground-fault detection. The versions of the NEC prior to 2005 only recommended that ground-fault detection be provided for some specific applications of ungrounded electrical systems. NEC 2005 requires ground-fault detectors to be provided for ungrounded electrical systems. This code became effective in August 2004.

BNL failed to ensure adequate implementation of the C-AD Conduct of Operations Program. Pre-job briefs were not held; personnel did not enforce stop work when a worker was not wearing proper protective equipment; surveillances of ground-fault conditions were not formalized through an approved procedure; and results were not communicated to operations and engineering management.

BHSO failed to adequately validate BNL's implementation of corrective actions from the Laboratory's self-assessment and the Office of Science Energized Electrical Work.

The Board could not rule out the possibility that the arc flash might have been caused by a switch failure; however, there was insufficient evidence to conclude that this was a likely failure mode.

Conclusions

The Board concluded that the accident was preventable. The overvoltage condition was the result of an undetected ground fault on an ungrounded system. The C-AD electrical engineer and the CAS electronic technicians were assigned to perform troubleshooting and fuse replacement tasks on a power system while it was in a ground-fault condition.

The Board identified the root cause as BNL's failure to ensure that good industrial practices, as well as Laboratory and applicable NFPA 70, *National Electrical Code*, requirements for the design, test, operation and maintenance of ungrounded delta electrical power distribution systems, were used at RHIC. The Board concluded that if these management processes and quality assurance requirements had been implemented, and if BNL had ensured that NFPA 70 E was effectively implemented, BNL workers would have been better protected in the event of an arc flash. The Laboratory and BHSO need to increase their emphasis on reducing worker exposure to electrical hazards.

Table ES-1. Judgments of Need and Causal Factors

No.	Judgment of Need	Causal Factor
JON 1	BNL needs to conduct the following engineering evaluations of ungrounded delta electrical systems throughout the site: • Ensure that instantaneous trip settings for power circuit breakers are reduced to the lowest value possible consistent with in-rush and load considerations and coordination with other overcurrent devices. • Evaluate the installation of a dampening resistor across the broken delta points of all three-phase wye broken delta connected potential transformers that are connected to ungrounded 480-volt systems. • Evaluate increasing the sensitivity of the ground-fault detecting relays in all 480-volt ungrounded substations. • Evaluate the installation of surge suppressors on all 480-volt ungrounded panel boards to suppress common-mode overvoltages and their related phase-to-ground flashovers. • Perform an engineering evaluation on the continued use of ungrounded 480-volt power systems and consider conversion to high-resistance ground systems. • Verify that all potential transformers connected to ungrounded 480-volt systems are provided with ground-fault monitoring.	BNL failed to ensure that good industrial practices, as well as Laboratory and applicable NFPA 70, *National Electrical Code,* requirements for the design, test, operation, and maintenance of ungrounded delta electrical power distribution systems, were used at RHIC.
JON 2	BNL needs to immediately verify that all ground-fault monitoring devices are connected to remote alarms in the RHIC Main Control Room.	BNL failed to ensure that ground-fault detector relays, as well as monitoring and alarm systems, were properly designed, installed, tested, and maintained.
JON 3	BNL needs to determine and review the specific factors by which RHIC and Plant Engineering design reviews and approval processes failed to ensure installation of a functional ground-fault monitoring and alarm system as specified in BNL standards and DOE requirements. Additionally, BNL needs to implement the corrective actions identified by this review to prevent recurrence.	BNL failed to ensure that a ground-fault monitoring system provided prompt notification to the Main Control Room for safe and reliable operation.
JON 4	BNL needs to improve the rigor and formality of the engineering design and design review processes to ensure that the functional specifications identified in DOE Directives and BNL standards are addressed.	

No.	Judgment of Need	Causal Factor
JON 5	BHSO needs to monitor BNL's evaluation of the design review and approval processes.	
JON 6	BNL needs to improve the rigor and formality in acceptance testing, operational readiness review, and commissioning activities to ensure that the functional and performance specifications identified in DOE Directives and BNL Standards have been implemented.	
JON 7	BNL needs to ensure that all equipment necessary for safe and reliable operations of the RHIC (as described in the current Safety Assessment Document) has been verified to meet design specifications.	
JON 8	BNL needs to develop, train, and implement formal work controls to address receipt of initial ground-fault alarms at RHIC.	BNL failed to ensure that formal work controls were established for working on ungrounded delta electrical systems that could have a ground-fault condition.
JON 9	BNL needs to establish the precautionary actions for safe work on ungrounded delta electrical systems that have a ground fault.	
JON 10	BNL needs to inspect all GE Spectra Series switches to ensure their mechanical integrity.	BNL failed to establish a preventive maintenance inspection program for fused-disconnect switches and ground-fault relays.
JON 11	BNL needs to establish a preventive maintenance inspection program for electrical distribution system equipment to include fused-disconnect switches and ground-fault relays.	
JON 12	BNL needs to establish a formalized project management process for arc flash calculations that establishes priorities, resources, and accountabilities.	BNL failed to implement NFPA 70E.
JON 13	BNL needs to conduct an independent effectiveness review of the implementation of the personal protective equipment and training requirements of NFPA 70E.	
JON 14	BHSO needs to monitor the status of the corrective actions for the following: • SC Energized Electrical Work Review; • BNL self-assessment of energized electrical work; and • Performance of BNL's effectiveness review.	BNL failed to adequately monitor the progress of its implementation of NFPA 70E requirements. BHSO failed to adequately validate BNL's implementation of corrective actions from BNL's self-assessment and the SC Energized Electrical Work Review.

No.	Judgment of Need	Causal Factor
JON 15	BNL needs to strengthen the C-AD Conduct of Operations Program to ensure procedural adherence, formality of operations, performance of required job briefings, and the exercise of stop-work authority.	BNL failed to ensure adequate implementation of the C-AD Conduct of Operations Program.
JON 16	BNL needs to issue a lessons learned to the DOE Corporate Lessons Learned Program Web site on the issues surrounding the GE Spectra Series switches.	
JON 17	BNL needs to establish a formal process for making modifications to nationally recognized testing laboratory-listed and labeled electrical equipment for the installation of Kirk Key interlock systems.	BNL failed to establish a formal process for making modifications to nationally recognized testing laboratory-listed equipment.

1.0 INTRODUCTION

1.1 Background

On April 14, 2006, Michael Holland, Manager of the U.S. Department of Energy (DOE), Office of Science (SC), Brookhaven Site Office (BHSO), informed the management of Brookhaven National Laboratory (BNL) that a Type B Investigation Board would be initiated to investigate an April 14, 2006, arc flash incident at BNL that resulted in first- and second-degree burns to a BNL electrical engineer. On April 17, 2006, the Type B Accident Investigation Board was formally appointed (Appendix A). This report documents the facts of the accident and the analyses and conclusions of the Board.

1.2 Facility Description

BNL, established in 1947 on Long Island, Upton, New York, is a DOE Office of Science, multi-program national laboratory operated by Brookhaven Science Associates, LLC. BNL support to four DOE strategic missions includes the following:

- To conceive, design, and operate complex, leading-edge, user-oriented facilities in response to the needs of DOE and the international community of users;
- To carry out basic and applied research in long-term, high-risk programs at the frontier of science;
- To develop advanced technologies that address national needs and transfer them to other organizations and to the commercial sector;
- To disseminate technical knowledge; to educate new generations of scientists and engineers; to maintain technical capabilities in the nation's workforce; and to encourage scientific awareness in the general public.

In support of these missions BNL operates several user facilities, including the Relativistic Heavy Ion Collider (RHIC). The Laboratory is situated on a wooded, 5,265-acre site in central Long Island, New York (Figure 1-1). Brookhaven has a staff of approximately 3,000 scientists, engineers, technicians, and support staff and hosts over 4,000 guest researchers annually.

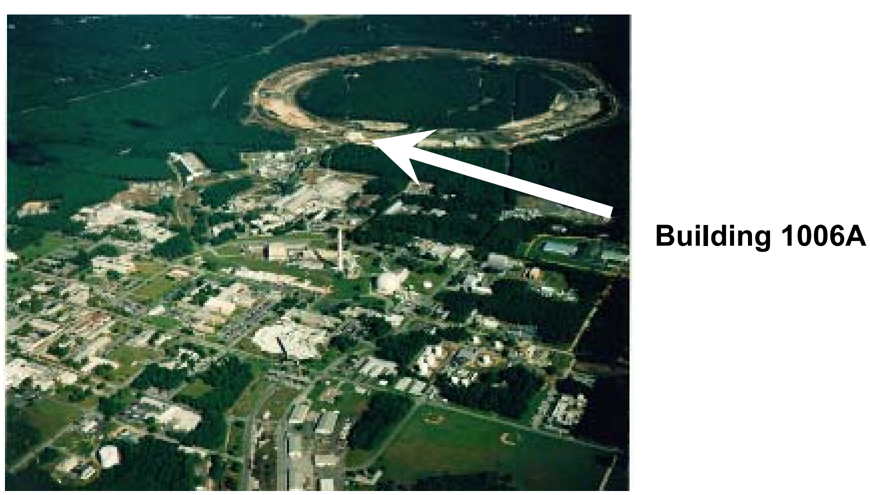


Figure 1-1. Brookhaven National Laboratory

The electrical arc flash occurred in Building 1006A, one of the support facilities for the RHIC (Figure 1-2). This facility houses equipment associated with the Solenoidal Tracker at RHIC (STAR). STAR is a detector that is designed to track the thousands of particles produced by each ion collision at RHIC and is used to search for signatures of the form of matter that RHIC was designed to create (i.e., the quark-gluon plasma). The Mechanical Equipment Loft in Building 1006A houses magnet power supplies and pumps used to cool magnets. The arc flash occurred in electrical panel PB-1, which houses five, fused-disconnect switches (Figure 1-3). The switches are used to control four power supplies for magnets on the STAR detector. The switches and power supplies use a Kirk Key interlock system, as shown in Figures 1-3 and 1-4, in lieu of lockout/tagout (LOTO). Two of the fused-disconnect switches are three-pole, 600-volt, 400-amp (switches 2A and 3A) and three are three-pole, 600-volt, 100-amp-rated fused-disconnect switches (switches 4A, 5A, and a spare).

Figure 1-2. Building 1006A
(Arc flash occurred in the Mechanical Equipment Loft on the east side of the building)

The 400-amp switches feed the load to the Pole Tip Trim East and Pole Tip Trim West magnet power supplies; the 100-amp switches control the Space Trim magnet power supplies. Also located in this area is a 13.8-kV circuit breaker that controls the main solenoid magnet power supply. The Mechanical Equipment Loft is provided with ionization and photoelectric smoke detection, as well as with automatic sprinkler protection. Building 1006A is an insulated metal-panel building, and the floor of the Mechanical Equipment Loft is poured concrete on steel.

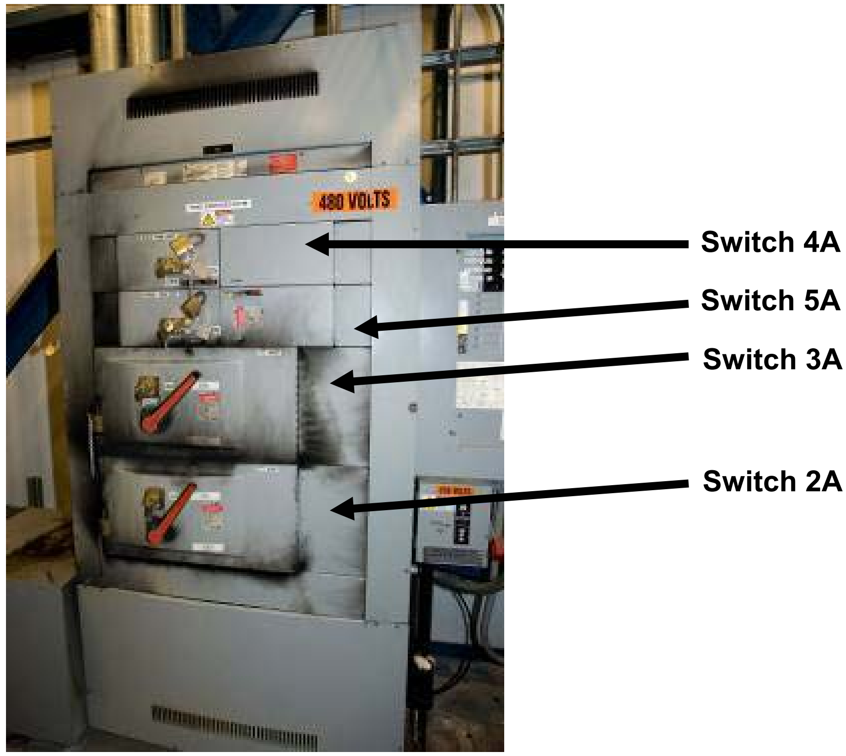


Figure 1-3. Electrical panel PB-1

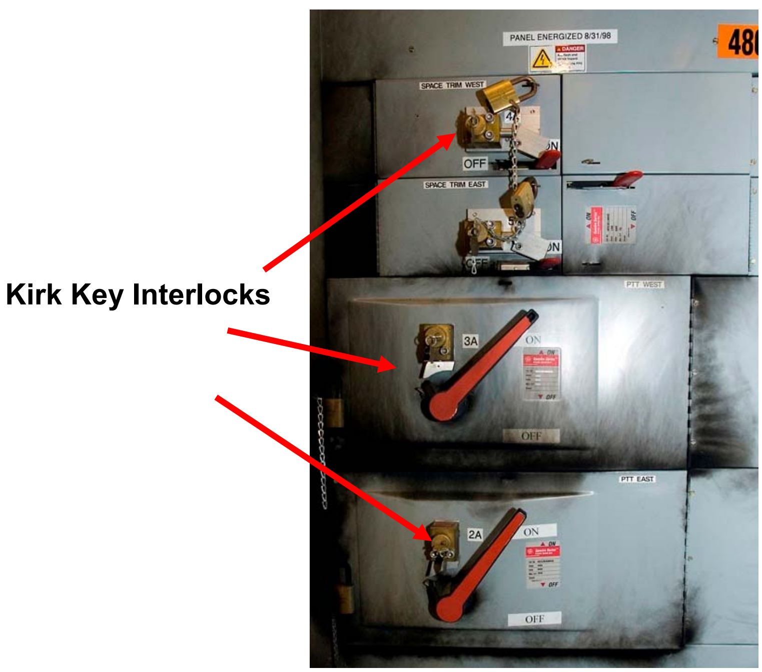


Figure 1-4. Kirk Key interlocks on switches 2A, 3A, 4A, and 5A

1.3 BNL Organizational History

The time span covered by the investigation ranged from the start of the RHIC Project in January 1991 to the date of the accident on April 14, 2006. During this time, various BNL organizations influenced the activities surrounding the RHIC and STAR design, construction, and subsequent operation. Additionally, changes occurred within the BNL organization during this time. The major organizational changes included the following.

- Brookhaven Science Associates, LLC, became the new prime contractor (taking over from Associated Universities, Inc.) in March 1998.
- The RHIC Project merged with the BNL Alternating Gradient Synchrotron (AGS) Department in October 1999 to form the Collider-Accelerator Department (C-AD).

The following summarizes the BNL organization, their roles, and their responsibilities.

1.3.1 BNL Organization and the RHIC Project

The RHIC Project started in January 1991 and ended with the start of operations in July 1999. Figure 1-5, Interim Organization Chart (1997), shows the typical overall BNL organization, including the RHIC Project, during this period. Figure 1-6, RHIC Project Organization (1997), shows the detail of the RHIC Project.

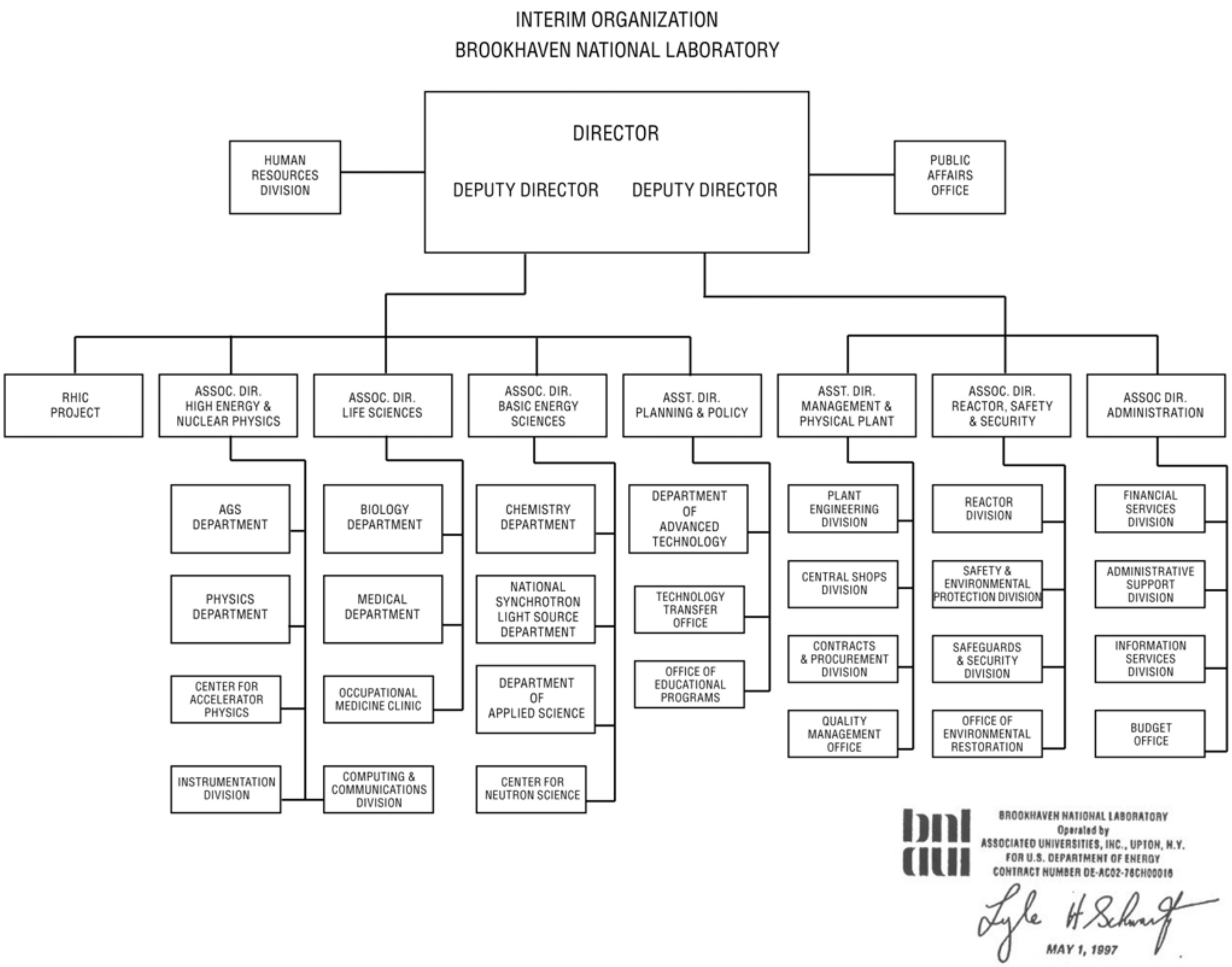


Figure 1-5. Interim Organization Chart (1997)

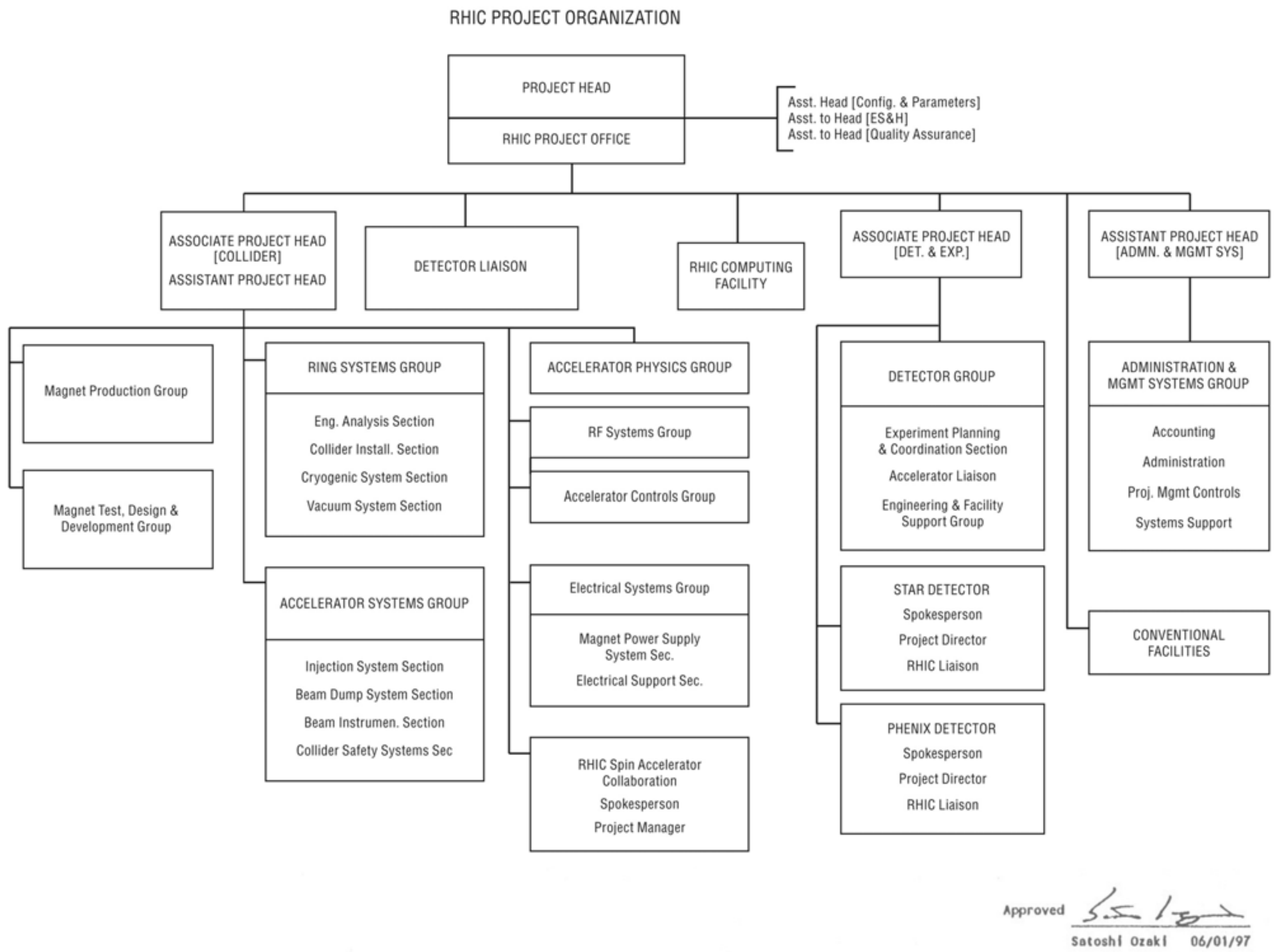


Figure 1-6. RHIC Organization Chart (1997)

The BNL RHIC Project Head provided the overall scientific and managerial leadership for the RHIC organization and was responsible for assembling the scientific and management team responsible for design, construction, and commissioning of the RHIC facility. The RHIC Project Head, while responsible for the entire execution of the RHIC design and construction program, had two principal Associate Heads (one for the Collider systems and one for Detectors and Experiments), who exercised technical control of these areas.

The RHIC Project also included a Special Assistant to the Project Head for Environment, Safety, and Health (ES&H) as part of the RHIC ESH Implementation Plan. Responsibilities for this position included developing the Project ES&H program, implementing the *Safety and Environmental Administrative and Procedures Manual* (SEAPPM), ensuring ESH reviews of the ESH portion of the RHIC commissioning documents, and performing as editor-in-chief for the RHIC *Safety Assessment Document* (SAD).

Additionally, an RHIC Safety and Environmental Protection (S&EP) Systems Safety Engineer was assigned to provide independent ESH overview, review, and analysis of RHIC systems from conceptual design to operational readiness. The Systems Safety Engineer was integrated into the day-to-day engineering design activities (e.g., design reviews, safety committees).

1.3.2 BNL Organization and the Collider-Accelerator Department

At the end of the RHIC Project in July 1999, the RHIC Project began to merge with the existing AGS Department to form the C-AD. The merge was completed in October 1999. Figure 1-7, 2006 Laboratory Organization Chart, shows the present day BNL organization, including the C-AD.

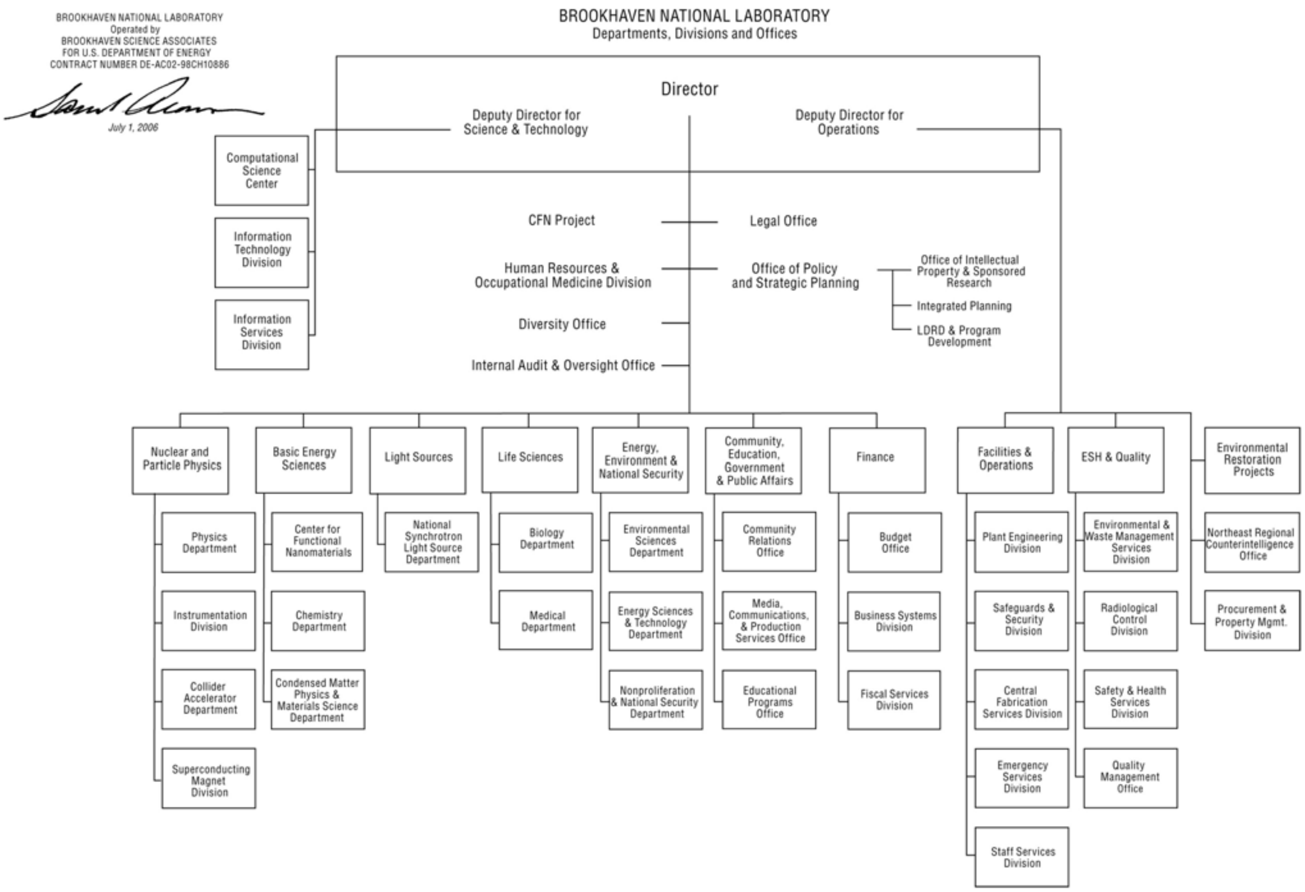


Figure 1-7. BNL Organization Chart (2006)

The C-AD is headed by a Chairman and several Associate Chairs. The two major divisions within C-AD are the Accelerator Division and the Experimental Support and Facilities Division (ESFD). The Accelerator Division includes organizations such as operations, electrical, vacuum, mechanical, and others necessary to operate and maintain the various C-AD accelerators to provide beam to the end users. The ESFD provides support to the end users at the experiment locations.

Collider Accelerator Support (CAS) is under the ESFD and provides round-the-clock coverage of C-AD facilities. The CAS shift usually consists of two technicians who deploy to respond to alarms, unusual conditions, or other issues. They get direction from, and maintain close contact with, the RHIC Main Control Room. Although technicians are not experts on the C-AD systems, they are able to provide limited or minimal service to equipment to reset or maintain its operability. Should the equipment problem be more complex, CAS personnel will contact the RHIC Main Control Room so the system specialist can be informed. The STAR power supply system specialist works under the Accelerator Division in the Electrical Systems Group.

There is a boundary, or separation of work and ownership, once inside the STAR detector building (Building 1006). C-AD personnel are responsible for all activities required to bring the beam into the building and up to the STAR detector itself, including ensuring that the STAR power supplies are operable. However, any operations involving the STAR detector itself (e.g., tuning) are controlled by the STAR operating and technical staff. The STAR operating and technical staff are associated with the BNL Physics Department, not C-AD. The STAR Control Room (within the STAR Building 1006) is staffed by these STAR personnel. While the activities between the STAR Control Room and RHIC Main Control Room need to be (and are) coordinated, the STAR operations group has their own STAR-group procedures and does not rely on C-AD Operating Procedures Manual (OPM) procedures.

1.3.3 DOE Organization and the RHIC Project

Concurrent with the BNL RHIC Project organization, a DOE Project Manager was assigned for the duration of the project. Following the transition to operations in 1999, BHSO assigned a full-time facility representative to oversee the operations of RHIC operations.

1.4 Scope, Conduct, and Methodology

The Board began its activities on April 17, 2006, and submitted the final report to the DOE-BHSO Manager on August 11, 2006. The scope of the Board's investigation was to identify all relevant facts; analyze the facts to determine the direct, contributing, and root causes of the accident; develop conclusions; and determine the actions that, when implemented, should prevent the recurrence of a similar accident. The terminology applicable to this accident investigation is shown in Table 1-1.

The investigation was performed in accordance with DOE O 225.1A, *Accident Investigations*, using the following methodology.

- Facts relevant to the accident were gathered through interviews and reviews of documents and evidence.
- The event scene and equipment involved were inspected, and photographs of them
- Facts were analyzed to identify the causal factors, using event and causal factors analysis, barrier analysis, root cause analysis, change analysis, and Integrated Safety Management (ISM) analysis.
- Judgments of Need (JONs) for corrective actions to prevent recurrence were developed to address the causal factors of the event.

Table 1-1. Accident Investigation Terminology

A ***causal factor*** is an event or condition in the accident sequence that contributes to the unwanted result. There are three types of causal factors: direct, which is the immediate event(s) or condition(s) that caused the accident; root cause(s), which is the causal factor(s) that, if corrected, would prevent recurrence of the accident; and the contributing causal factors, which are the causal factors that, collectively with the other causes, increase the likelihood of an accident, but which did not cause the accident.

Events and causal factors analysis includes charting, which depicts the logical sequence of events and conditions (causal factors that allowed the event to occur), and using deductive reasoning to determine the events that contributed to the accident.

Barrier analysis is a review of 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.

Root cause analysis is a technique that identifies the underlying deficiencies that, if corrected, would prevent the same or similar accidents from occurring.

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

Requirements verification analysis is a forward/backward analysis process to ensure that all portions of the report are accurate and consistent in the flow of facts to analysis to conclusions to the Judgments of Need.

2.0 THE ACCIDENT

2.1 ACCIDENT OVERVIEW

2.1.1 Accident Description

On April 14, 2006, at approximately 10:20 a.m., a C-AD electrical engineer closed fused-disconnect switch 3A of panel PB-1, located on the east wall of the Mechanical Equipment Loft in Building 1006A, and an arc flash occurred. The arc flash resulted from an arcing ground fault across all three phases of fused-disconnect switch 3A and all three phases of fused-disconnect switch 2A.

Most of the radiant heat energy and molten aluminum created by the arc flash was contained within the cabinetry of panel PB-1 or was vented away from the C-AD electrical engineer. However, the radiant heat and molten aluminum that was expelled out of the front of the panel toward the C-AD electrical engineer set his hair on fire and caused first-degree burns on his face, scalp, and chest. He also received first- and second-degree burns on his hands and forearms. In addition, because he was not wearing safety glasses, the C-AD engineer received a corneal abrasion on his left eye. The C-AD electrical engineer was wearing a non-flame-resistant, short-sleeved polo shirt and an undershirt, both of which were slightly burned, as evidenced by a number of singed pock marks. Technical documents adjacent to the north side of panel PB-1 were also set on fire. No metal panel sections were blown loose, but some distortion of the panel covers occurred from the high pressures produced.

2.1.1.1 Background

Electrical power is supplied to the RHIC mainly through an ungrounded delta electrical system. The advantage to using an ungrounded delta electrical distribution system is that a line-to-ground fault does not result in the operation of the overcurrent device, and the system continues to operate (as opposed to a solidly grounded system in which a ground fault would result in the operation of the overcurrent protection device). If a ground fault is not detected, the system continues to operate; but, if another fault occurs, it results in a line-to-line-to-ground fault, which has the potential for more severe damage to the electrical equipment. When ground-fault detection is installed and monitored, it allows steps to be taken to isolate the ground fault and make repairs in a safe and timely manner. Nevertheless, as designed, a number of well-known characteristics of ungrounded systems remain that makes the system vulnerable to switching surges and transient and resonant overvoltages. These vulnerabilities can be addressed by (1) installing surge suppressors on all 480-volt, ungrounded panel boards to suppress common-mode overvoltages and their related phase-to-ground flashovers and (2) installing zigzag grounding transformers and neutral grounding resistors that convert the 480-volt ungrounded systems to high-resistance grounded systems. The conversion to high-resistance grounded systems will stabilize the phase-to-ground-potential, mitigate overvoltages, and generally provide the advantages of grounded systems while maintaining the reliability inherent to ungrounded systems.

In a 1978 Technical Note prepared by BNL, *Continuity of Electric Power at the AGS* (No.148), BNL evaluated the advantages of operating the proposed ISABELLE colliding accelerator addition to the AGS with ungrounded delta electric distribution systems. This Technical Note advanced the arguments for the continuation of an ungrounded delta electric distribution system for the ISABELLE colliding accelerator. The Technical Note also stated that "fault detectors in all 33 AGS substations with ungrounded delta 480-volt systems are annunciated at a central panel" and indicated that "all ground alarms are checked out immediately and faults are isolated within a few hours." The ungrounded delta electrical distribution system was also chosen for the RHIC electric distribution system design because of its operational advantages.

Research and development, construction, and pre-operations for the RHIC were under the control of the RHIC Project. The RHIC Project was organizationally separated from the AGS Department and reported to the Laboratory Director. On October 1, 1999, the RHIC Project and the AGS Department were combined to create the C-AD.

The RHIC Project developed its own procedures and standards. One of these standards, *Supplemental Electrical Safety Standards RHIC Project*, OPM 5.1.5.0.1, dated March 20, 1997, required that "ungrounded Delta connections shall have ground detection devices for each building served." The standard further states: "If a ground on a substation is detected, the cognizant Division Head, ES&H Coordinator, and other appropriate affected personnel shall be notified immediately. Actions to remediate the grounded conductor shall be addressed promptly." On November 27, 2000, C-AD promulgated this standard as the *Supplemental Electrical Safety Standard*. The expressed purpose of the standard was "to augment the National Electrical Code [NEC] and OSHA [Occupational Safety and Health Administration] standards where they do not address the design and operation of a research accelerator complex." This standard continued the requirement for ground-fault detection and mitigation on ungrounded delta connected electrical systems.

The RHIC Project *Quality Assurance Manual* (QAM) was developed to give overall structure for RHIC quality activities and responsibilities. Included in the QAM was the RHIC Quality Assurance Program (QAP), which addressed the basic requirements of DOE Order 5700.6C, *Quality Assurance*. The QAP required, in part, that design criteria define the requirements for safety as well as the appropriate codes and standards in the design documentation. The QAP also stated that specifications, drawings, and other design documents were to be prepared to define the design parameters and were to be reviewed and approved before issuance. The RHIC SAD identified a requirement that ground-fault detection be installed and monitored.

RHIC-QAP-601, *Design Control*, required design reviews during various stages of the design life. During the preliminary design phase, a preliminary review was to include code compliance and safety considerations. During the detail design phase, additional, detailed reviews were required in the area of code compliance and safety requirements.

RHIC Design Standard DS-1 (QAP Appendix) also required processes to be developed before the release of engineering drawings. These included verifying compliance with appropriate design standards, review for conformance to basic design, and reviews by the cognizant engineer, engineering supervisor, and quality assurance.

The RHIC QAP also included requirements for inspection and testing of equipment. RHIC-QAP-801, *Inspection and Test*, required performing inspection and testing of equipment, components, and subsystems with the objective of promptly detecting nonconformances that could adversely affect performance, safety, and reliability.

The engineering design reviews did not identify the omission of the ground-fault detection. Additionally, more detailed or thorough research for testing of the power supplies may have resulted in identifying the omission of the ground-fault detection.

When the STAR power supplies were being designed, the 1996 version of the National Fire Protection Association (NFPA) NEC Standard (NFPA 70) was applicable. The versions of the NEC prior to 2005 only recommended that ground-fault detection be provided for some specific applications of ungrounded electrical systems. NEC 2005 requires ground-fault detectors to be provided for ungrounded electrical systems. This code became effective in August 2004. BNL did not provide evidence that NEC edition changes; specifically, the change requiring ground-fault detection, were evaluated against existing operations and facilities.

In accordance with the DOE contracting policy, DOE submitted revised DOE O 440.1A, *Worker Protection Management for DOE Federal and Contractor Employees* (approved March 27, 1998), to BNL for their review. In a May 4, 1998, letter to the BHSO Contracting Officer, BNL stated that they had reviewed the subject directive and concluded that the requirements were essentially the same as required in the previous version of the Order and that the new/revised requirements had already been incorporated in previous BNL ESH standards and/or procedures. BNL also stated that "therefore, no additional impacts were identified and a new compliance action plan is not required." Relevant to this investigation, the following two requirements were added to the Contractor Requirements Document (Attachment 2 of the Order): item 12 k, NFPA 70, *National Electrical Code*; and 12 l, NFPA 70E, *Electrical Safety Requirements for Employee Workplaces*. In the previous DOE O 440.1, *Worker Protection Management for DOE Federal and Contractor Employees*, approved September 30, 1995, neither NFPA 70 nor 70E requirements were referenced, nor were portions of them required.

The Board requested that BNL C-AD provide a listing of the ground-fault detection systems for their ungrounded substations. A summary of their results is provided in Table 2-1 below.

Table 2-1. Status of Ground-Fault Detection Alarms for C-AD Substations

Status of Ground-Fault Detection Alarms for C-AD Substations	Number
C-AD Ungrounded Substations	49
C-AD Ungrounded Delta Transformers with Local and Remote Alarms	28
C-AD Ungrounded Delta Transformers with Remote–Only Alarms	2
C-AD Ungrounded Delta Transformers with Local–Only Alarms (does not include 6C since it was not operable)	14
C-AD Ungrounded Delta Transformers with No Alarms	4

BNL determined that four ungrounded substations had neither local nor remote alarms. The location and substation designation are as follows: Bldg 912, substations B and C; Building 914, substation D; and Building 1004, substation 1004D.

Two substations, designated as 6A and 6C, provide power to the STAR facility in Building 1006. The local-only ground fault indication for the 6B substation is for Building 1005E. Substation 6A has both local indication and remote alarms. The local ground-fault indicator is observable only when an operator sees that a flag is in the tripped condition on the ground-fault relay in the unmanned substation enclosure. There are no audible alarms, and the only other visual indication of a ground fault would be to read the voltmeter readings on each phase. The one-line diagram for substation 6A (Figure 2-1) shows that the ground-fault alarm (relay 64) is sent to the RHIC Main Control Room, where it is displayed on LCD monitors.

The display consists of a one-line description of the fault. In this case, the alarm would be identified as 1006BGFMOD.RHIC-SUB-6A, denoting that a ground-fault alarm exists at Building 1006, substation 6A. Upon receipt of this alarm, the Main Control Room operator can determine the response required for the alarm by mouse-clicking on the line item. The required response is also documented in the alarm response procedure. For most ground-fault alarms, the alarm response is the same:

> *Support One (CAS) shall determine the source of the ground fault within 8 hours if necessary with the help of electricians. After 8 hours, notify the Chief Electrical Engineer.*

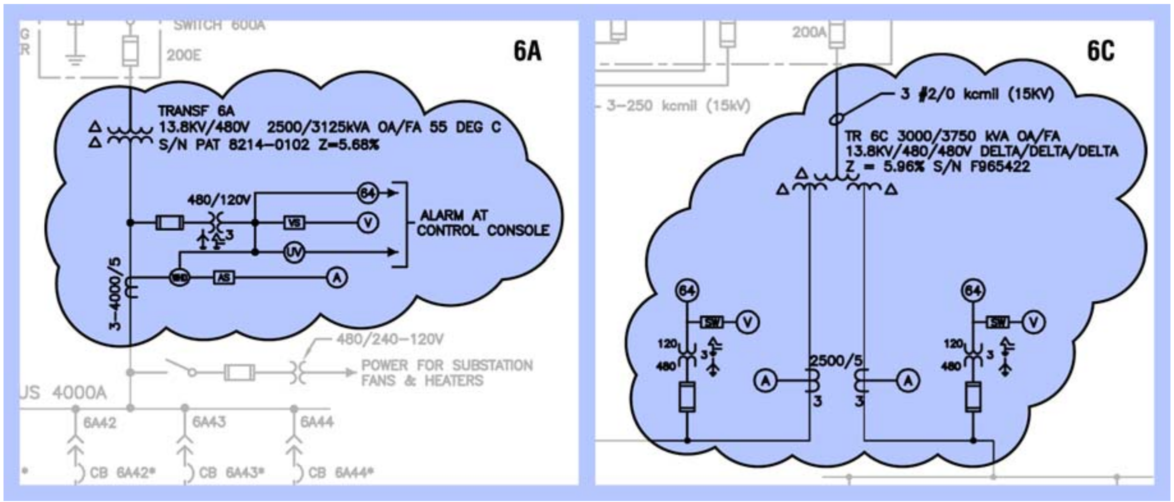


Figure 2-1. Circuit 64 designs for the 6A transformer (with alarm to control console) and 6C (without alarm to control console).

The RHIC Main Control Room operators would inform CAS of the ground-fault alarm and request that they respond accordingly. CAS also receives notifications of similar alarms or off-normal conditions in their shop via a monitor, so they know of the condition at the same time as the RHIC Main Control Room. CAS learns of the condition at the same time. Support One (CAS) will start making preparations in the shop to resolve the alarm (e.g., assembling tools), but CAS will not proceed until directed by the RHIC Main Control Room. In general, CAS personnel are not considered experts on the equipment or systems they may work on. CAS personnel resolve the ground fault (or any abnormal condition) based on their past experience with the equipment and by observing conditions found when they arrive at the location; reviewing any documents, procedures, logs, or notes that may be available from previous ground faults; and asking questions of system specialists or others who have more knowledge of the equipment. There is no documented process for establishing controls, such as restricting the operation of additional equipment (e.g., switches or breakers).

The 64 relay on the one-line diagram for substation 6C (Figure 2-1) shows that this relay is not connected to either a local or remote alarm. The 64 relay design for substations 6A and 6C were on the same C-AD main one-line diagram (A2030600).

The design, specification, procurement, and installation of electrical power for the STAR detector magnets were all performed under STAR Job Number 906-03-01. (See Section 2.2.1.1, "Electrical System Description.") This work was managed by the BNL Plant Engineering (PE) organization for the RHIC Project. The work included installation of substation 6C and other electrical and mechanical equipment. BNL PE staff evaluated bid proposals for the electrical panels and switches and chose those that would be installed as electrical panel PB-1 for the control of the STAR Magnet power supplies. The panel and switches purchased were General Electric (GE) Spectra Series and included the fused-disconnect switches identified as 3A and 2A, which were involved in the arc-flash accident. These medium-duty switches are 400-amp, fused switches (GE Catalog No. ADS36400HB) that supplied electrical power to the East and West Pole Tip Trim power supplies. The Underwriters Laboratories (UL) listing for these switches tests them for 1,000 operations with current and 5,000 operations with no load. BNL estimates that the switches in panel PB-1 have been operated approximately 1,000 times with no-load.

The RHIC Project BNL PE staff generated drawings and specifications for the STAR detector magnet power systems electrical power distribution in 1997. In August 1997, the S&EP Division reviewed the drawings and specifications for this work. The result of this review was issued on September 4, 1997. Comments generated by this review did not include an indication that ground-fault detection was not being monitored or that the "#64 relays" were not connected. Drawing No. 906-03-01-E13, "One Line Diagrams, 13.8 kV and 480V Substation," identifies relay #64 with a note "Ground Fault Relay." This drawing was issued for bids on September 5, 1997, and contractor bids were received in September 1997. This drawing covered the 6C substation. Work started on the installation of the electrical power and cooling water project in November 1997. The drawings and specifications for the STAR detector magnet power systems did not include monitoring or connecting the # 64 relay on the 480-volt ungrounded delta electrical systems. The substations were provided with three voltmeters. The specifications did require that megger testing be performed on installed cables and that the tests be made in the presence of BNL personnel.

The 6C substation includes two #64 relays, one for each of the transformer secondary windings. These are voltage-sensing relays that are used to detect grounds on the normally ungrounded 480-volt system. Each relay is connected to its respective 480-volt, three-phase circuit through three potential transformers (PTs), which are connected in a grounded wye to the 480-volt bus and broken delta to the #64 relay. Under normal operating conditions the voltages from the three PTs will be equal and balanced and will cancel each other out so that the #64 relay sees no voltage. If one of the phases becomes grounded, however, the three voltages will no longer be equal; therefore, they will not cancel each other out. The #64 relay senses the unbalanced voltage and closes its alarm contact. The #64 relay also includes a flag that will drop to indicate the presence of a momentary or intermittent ground condition. The flag for the #64 relay is located in the substation enclosure and is not visible from outside the enclosure. Because the relay was not connected, this feature was not available on the 6C substation. During the investigation the Board noted that, had the #64 relays been operable, the sensitivity setting might have been set too high to detect some ground faults. BNL does not have a formal preventive maintenance program for the ground-fault detection relays in the substation enclosures. Within commercial industry, it is typical to have a 2-year inspection interval for these relays, with verification of functional contacts.

The Laboratory considered the three voltmeters on the substation in an enclosed cabinet as ground-fault monitoring. Using the three voltmeters, a ground-fault condition could be identified only if an inspector entered the locked substation yard, opened the locked substation enclosure, and observed the voltages on the three phases. At the time of the accident the visual inspections were scheduled monthly, but they were performed only twice in the previous year. The last "monthly" inspection was performed 3 days before the accident, and the inspector recorded a slight ground-fault condition, but took no action (see Section 3.4.5).

Installation of the electrical systems for the STAR Magnet power supplies began in November 1997; electrical substation 6C was energized in April 1998; and the cables supplying power to panel PB-1 were installed in February 1998. On June 15, 1998, the ES&H Services Division (formerly S&EP) conducted an Operational Readiness Review (ORR) of the new substations at Building 1006. The stated purpose of the ORR was to "determine if all environment, safety, and health requirements have been met to allow for routine operation of the two substations." The scope of the review was "limited to the feeder switchgear, transformer, and substation located in a fenced-in yard east of Building 1006." The magnet power supplies installation was not completed at the time of this ORR; therefore, it was not included in the review. The ORR identified 15 Post-Start Findings; none concerned the lack of ground-fault detection monitoring. STAR power panel PB-1 was energized on August 31, 1998. The ORR did not identify that the #64 relay was not connected. The "one-line" drawing for substation 6C, approved on July 1, 1999, identified the "64" contact points for substation 6C, but did not indicate any connection for the contacts.

STAR Description

The RHIC accelerator has four detectors at four of its six intersection regions. One of the larger detectors is STAR. STAR weighs about 1,200 tons and is built around a large solenoid main magnet. The STAR detector assists in the RHIC mission of researching the quark-gluon plasma that existed in the first few microseconds of the universe.

The STAR main magnet is cylindrical and about 24 feet long and 24 feet in diameter; the RHIC beam pipe goes through the center or axis of the cylinder. The main magnet needs to provide a uniform and straight magnetic field to perform its detection function. To compensate for the typical non-uniformity and bending of magnetic field lines along the length and ends of the main magnet, two types of coils are installed (Space Trim coils and Pole Tip Trim coils). The power to both the Space Trim and Pole Tip Trim coils can be varied to influence, unify, and straighten the magnetic field generated by the main magnet as needed.

There are two Space Trim coils (East and West) located on the outer diameter of the main magnet cylinder, one at each end. Each Space Trim coil has an inside diameter of about 17 feet and an outside diameter of about 20 feet, and each weighs about 3.5 tons. There are also two Pole Tip Trim coils (East and West); one coil is located near each end of the axis of the cylinder. Each Pole Tip Trim coil has an inside diameter of about 6 feet, an outside diameter of about 9 feet, and weighs about 1.2 tons.

The STAR power supply systems are made up of the following five, 12-pulse, thyristor-controlled alternating current (AC) to direct current (DC) converters.

- The Main Power supply (825 volts, 5,300 amps)
- Two Pole Tip Trim power supplies (140 volts, 1,600 amps)
- Two Space Trim power supplies (50 volts, 600 amps)

The transformers, thyristor assemblies, filters, and regulators are all in one package and are located in the STAR power supply room. Substation 6C feeds 480 volts to the 100-amp, fused-disconnect switches in the power supply room. This voltage goes directly to the Space Trim power supplies, where it is converted into a regulated, controllable DC voltage and fed to the Space Trim coils on the detector magnet. BNL built the regulators and assembled the power supplies onsite.

Substation 6C feeds 480 volts to the 400-amp, fused-disconnect switches in the power supply room. This power is then fed to the "ON/OFF" contacts in the Pole Tip Trim rectifier assembly. When the contactors are closed, the power is fed from the rectifier assemblies to the step-down rectifier transformers in the STAR transformer yard. This power is then fed back into the rectifier assembly and converted into a regulated, controllable DC voltage and fed to the Pole Tip Trim coils on the detector magnet.

For the main power supply, 13.8 kV is brought into the circuit breaker in the power supply room. When this breaker is closed, power is fed to the step-down rectifier transformers in the STAR transformer yard. The secondaries of these transformers then supply power to the main rectifier assembly in the STAR power supply room, where it is converted into regulated, controllable DC voltage and fed to the STAR main solenoid magnet coil.

Each power supply contains a filter choke, filter capacitors, overvoltage and overcurrent protection, and free-wheeling diodes.

2.1.1.2 Environmental Conditions

On April 14, 2006, the BNL Meteorologist reported generally mild weather conditions. Exterior temperatures on central Long Island at the time of the accident were measured at 67°F. This temperature was approximately 20°F above the 30-year historical mean high temperature.

The Mechanical Equipment Loft of Building 1006A houses STAR Magnet electrical service equipment, cooling water pumps, and associated piping. Ambient conditions in the area were found to be generally clean and uncluttered, adequately illuminated, sufficiently ventilated, and of comfortable temperature, but extremely noisy. As part of the BNL hearing conservation program, a February 1, 2006, survey conducted by the C-AD Environment, Health, Safety and Quality Division (ESH&Q) reaffirmed noise levels in this location to be above the OSHA 8-hour permissible noise-exposure limit of 85 dBA. Signs posted at the door leading into the area require the wearing of hearing protection for entry.

2.1.1.3 Personal Protective Equipment and Clothing Requirements

NFPA Standard 70E, *Standard for Electrical Safety in the Workplace*, establishes the personal protective equipment (PPE) and clothing requirements for the work being performed at the time of the accident. Note 1 to Table 130.7(C)(9)(A) of NFPA 70E identifies the hazard/risk category classifications listed for "Panelboards or Switchboards Rated >240V and up to 600V (with molded case or insulated case circuit breakers)" as being appropriate only for short-circuit current 25 kA with 0.03-second clearing time. The fault current, which was calculated for panel PB-1 after the accident, is 36 kA, with a clearing time of 0.20 seconds. NFPA 70E identifies the hazard/risk category as 0. Protective systems for hazard/risk category 0 are untreated, natural-fiber, long-sleeved shirt and pants and safety glasses.

Racking of the 13.8-kV circuit breaker for the STAR main magnet has been modified to allow for remote mechanized operation. The pendent control for the remote racking motor is located several feet outside the limited approach boundary established by NFPA 70E, Table 130.2(C); therefore, there are no specialized clothing or PPE requirements for the remote racking operation. However, there are other switches located within the limited approach boundary. Anyone operating the panel PB-1 switches during the circuit breaker racking operation would be required to be appropriately protected from arc flash.

The CAS electronic technicians were provided with flame-resistant (FR) long-sleeved shirts, natural-fiber denim jeans, and safety glasses. They are not required to wear this protective clothing at all times. CAS personnel do not have to continuously wear their FR clothing throughout their work shift. They are permitted to change into their FR clothing when performing work on energized electrical equipment. Bargaining employees wanted the same privileges afforded non-bargaining employees who were allowed to wear short pants, and in a March 1980, arbitration hearing, it was decided (against the Laboratory) that bargaining employees need only wear appropriate protective clothing when the work task actually required doing so. The Board could not confirm that appropriate clothing was worn on the day of the accident, although the CAS electronic technicians indicated they were wearing appropriate clothing that day.

During interactions with the CAS electronic technicians, the Board noticed that their protective clothing was not worn appropriately. Some had shirt tails outside of their pants, shirt sleeves were rolled up, and all had open collars. The Board did not observe the CAS technicians performing work on energized circuits, but the technicians stated they were not aware of the NFPA 70E clothing coverage requirements (i.e., shirt sleeves fastened at the wrist and shirts closed at the neck).

The C-AD electrical engineer was offered the opportunity to be provided with appropriate FR clothing, but he declined the offer. At the time of the accident he was wearing a 100 percent cotton, short-sleeved polo shirt; a cotton undershirt; and cotton, denim jeans. The C-AD electrical engineer was not wearing safety glasses at the time of the accident. The C-AD electrical engineer's supervisor did not ensure that he wore the necessary protective clothing or PPE to operate the switches.

It was reported that at the time of the accident the C-AD electrical engineer and the two CAS electronic technicians were wearing hearing protection in accordance with posted hearing conservation program requirements.

2.1.1.4 Description of Events Preceding Accident

At 7:05 a.m., on April 14, 2006, the Long Island Power Authority (LIPA) experienced a power dip, which caused a reduction in the electrical power being fed to BNL. LIPA reported that the power dip occurred because an insulator at their Ruland Road substation failed. As a result of this power dip, the RHIC Main Control Room was simultaneously receiving several alarm signals because of failed systems. In response, RHIC Main Control Room staff contacted the CAS to report that one of the STAR Space Trim power supply units had failed.

CAS electronic technicians 1 and 3 responded to the STAR Control Room at Building 1006A to view monitors and determine the status of the STAR Space Trim power supply units. After confirming the failure, CAS electronic technicians 1 and 3 proceeded to the Mechanical Equipment Loft in Building 1006A, where the STAR Space Trim power supply units are located. When they arrived at the Mechanical Equipment Loft, the two technicians began shutting down the STAR Main Magnet, the Pole Tip Trim East, the Pole Tip Trim West, the Space Trim East, and the Space Trim West. The CAS electronic technicians were provided with the needed protective clothing and PPE for NFPA 70E hazard/risk category 0.

All of these power supplies are required to be de-energized when work is performed on any individual power supply. C-AD OPM 11.4.3, *STAR Power Supply Operating Procedure*, is to be followed for shutdown and startup of the STAR Magnet power supplies. The CAS electronic technicians do not use the procedure as a step-by-step procedure, but rather as a guide, and they indicated that they normally fill out the procedures checklists after the work is completed. CAS electronic technicians 1 and 3 used the Kirk Key interlock system as their electrical lockout for each of these power supplies.

Although they believe they performed the zero-voltage checks in accordance with established procedures, the electronic technicians were unable to recall all of the specific work tasks performed. If the capacitors had not had sufficient time to decay, and the technicians had not performed a zero-voltage check, the technicians would have been exposed to a potential electric shock hazard. The CAS electronic technicians did not perform any pre-job briefing to carry out this work safely. Troubleshooting is considered skill-of-the-worker and did not require a pre-job briefing.

CAS electronic technicians 1 and 3 discovered one blown silicon control rectifier fuse in the Space Trim West power supply, one blown silicon control rectifier fuse in the Space Trim East power supply, and five blown capacitor-bank trigger fuses in the STAR Main Magnet power supply. Believing this to be the cause of the failure reported by the RHIC Main Control Room, the technicians replaced seven fuses, sequentially reversed the Kirk Key interlock system to release the electrical lockouts, and restored electrical power. CAS electronic technicians 1 and 3 then turned on the five power supplies serving the STAR Main Magnet, the Pole Tip Trim East, the Pole Tip Trim West, the Space Trim East, and the Space Trim West at low values; returned to the STAR Control Room; and brought the system back on line. After determining that the system was operating properly, CAS electronic technicians 1 and 3 returned to their shop in Building 940.

Soon after arriving at Building 940, CAS electronic technician 1 was notified by STAR Control Room personnel of another failure of a STAR power supply. Monitors were indicating the existence of high-current ripple in the Space Trim West power supply. (High-current ripple is an undesirable oscillation of DC voltage mimicking AC voltage.) In response to this failure, CAS electronic technicians 1 and 3 returned to Building 1006A and proceeded to the Mechanical Equipment Loft, where they performed diagnostic evaluations of the Space Trim West power supply and a comparative diagnostic evaluation of the Space Trim East power supply through plug-in points to confirm the problem was caused by high-current ripple. Because they were not sure about the actual cause of the high-current ripple, CAS electronic technician 1 decided at 9:45 a.m. to contact the C-AD electrical engineer to gain his technical assistance to resolve the problem. In the meantime, CAS electronic technician 4 responded to the Building 1006A Mechanical Equipment Loft to see if additional assistance was needed. Because the C-AD electrical engineer was responding to Building 1006A in response to the high-current ripple problem, CAS electronic technicians 3 and 4 determined their assistance was no longer needed, and they decided to return to their shop in Building 940.

When the C-AD electrical engineer and CAS electronic technician 2 arrived at Building 1006A, the C-AD electrical engineer confirmed through repeated diagnostics that additional blown silicon control rectifier fuses in the Space Trim West power supply were causing the high-current ripple. To correct this problem, CAS electronic technician 1 went to the STAR Control Room to shut the system down using an associated computer. When CAS electronic technician 1 arrived at the STAR Control Room, he learned that the computer had crashed and was inoperable. At this same time, the C-AD electrical engineer went to the STAR Control Room while CAS electronic technician 2 remained outside the entrance to the Mechanical Equipment Loft. When the C-AD electrical engineer arrived at the STAR Control Room and learned of the computer problems, he decided that he and CAS electronic technicians 1 and 2 would turn off the system locally. The C-AD electrical engineer and CAS electronic technician 1 then returned to the Mechanical Equipment Loft. Again, no pre-job briefing was conducted to discuss how this work would be accomplished safely.

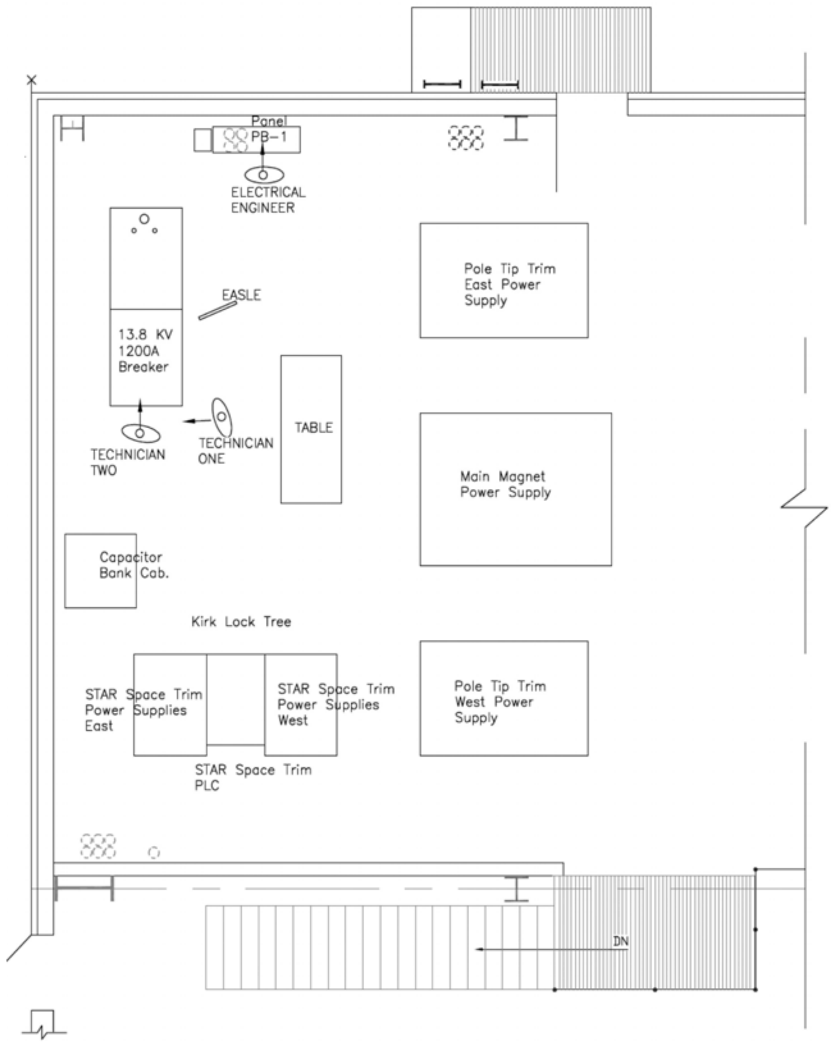
The C-AD electrical engineer and CAS electronic technicians 1 and 2 began shutting down the power supplies serving the STAR Main Magnet, Pole Tip Trim East, Pole Tip Trim West, Space Trim East, and Space Trim West. The CAS electronic technicians were provided with proper clothing and PPE for this task. The CAS electronic technicians did not invoke stop-work authority to prevent the C-AD electrical engineer from operating the panel PB-1 switches. The C-AD electrical engineer was not dressed to comply with NFPA 70E Hazard/Risk Category 0 clothing requirements or wearing safety glasses. CAS electronic technician 2 racked out the circuit breaker for the STAR Main Magnet power supply while CAS electronic technician 1 prepared the tools needed to perform the work.

The C-AD electrical engineer opened fused-disconnect switches on panel PB-1 (2A) for the Pole Tip Trim East power supply, (3A) for the Pole Tip Trim West power supply, (4A) for the Space Trim West power supply, and (5A) for the Space Trim East power supply. Because these switches have a strong spring action, the operator must stand directly in front switches 2A and 3A of panel PB-1 and use both hands to operate the switch lever. (This is contrary to C-AD training, which directs workers to stand to the side when operating a switch or circuit breaker.) The C-AD electrical engineer and CAS electronic technician 2 then used the Kirk Key interlock system as their electrical lockout for each of the five power supplies. Although they believe they performed zero-voltage checks in accordance with established procedures, the electronic technicians were unable to recall all of the specific work tasks performed.

CAS electronic technician 1 identified and replaced two blown, silicon control-rectifier fuses in the Space Trim West power supply. To ensure that the Space Trim West power supply was operating properly, it had to be energized and turned on to perform diagnostic testing. This required the C-AD electrical engineer and CAS electronic technicians 1 and 2 to partially reverse the sequence required to release the electrical lockouts established by the Kirk Key interlock system. The C-AD electrical engineer and CAS electronic technician 1 tested the Space Trim West power supply and determined it was operating correctly. Confident that the problem was solved, the C-AD electrical engineer asked CAS electronic technician 1 to call the RHIC Main Control Room to get approval to run the STAR Main Magnet. An additional call was made by CAS electronic technician 1 to the STAR Control Room to gain similar approval. After obtaining these approvals, the electrical engineer and CAS electronic technicians 1 and 2 decided to begin restoring electrical power to the five power supplies and began completing the reverse sequence required to totally release the electrical lockouts established by the Kirk Key interlock system.

CAS electronic technician 1 began cleaning up the tools used. CAS electronic technician 2 began positioning the screw-drive motor for re-racking the13.8-kV circuit breaker for the STAR Main Magnet power supply. The C-AD electrical engineer initiated the closing of the fused-disconnect switches on panel PB-1. Following the closing of switches 4A and 5A, the C-AD electrical engineer first closed fused-disconnect switch 2A for the Pole Tip Trim East power supply. The C-AD electrical engineer then positioned himself to close fused-disconnect switch 3A for the Pole Tip Trim West power supply. As the C-AD electrical engineer stood directly in front of panel PB-1 and used both hands to push up the lever of fused-disconnect switch 3A for the Pole Tip Trim West power supply, he heard a very loud noise and observed smoke and sparks emanating out of panel PB-1. Likewise, CAS electronic technicians 1 and 2, who were both working on positioning the screw-drive motor for re-racking the circuit breaker for the STAR Main Magnet power supply, heard the very loud noise, looked to determine its source, and saw sparks falling down around the C-AD electrical engineer. Figure 2-2 shows the location of the BNL personnel when the arc flash occurred.

Figure 2-2. Location of BNL personnel when the arc flash occurred



A timeline of significant events is detailed in Appendix B, *Arc Flash Accident Event Chronology*.

2.1.1.5 Emergency Response

At 10:24 a.m. on April 14, 2006, the smoke generated by the arc flash actuated an ionization-type smoke detector that is located at the ceiling level above panel PB-1. The detector caused a local fire alarm (bell) to sound and sent an alarm signal to BNL Emergency Services (BNL Fire/Rescue Group and BNL Police) and to the C-AD Main Control Room. CAS electronic technician 1 saw that the C-AD electrical engineer was on fire and used his hand to smother the engineer's burning hair. The C-AD electrical engineer and both technicians left the Mechanical Equipment Room. After CAS electronic technician 1 exited the Mechanical Equipment Room, he dialed the site emergency response number to report the accident. The emergency phone system was answered by a BNL Police dispatch operator. The message given to the BNL Police dispatch operator was "We need some assistance, maybe an ambulance, 1006A. We had a breaker explosion." The BNL Police dispatcher acknowledged the call but failed to note any additional information pertinent to the emergency because it did not involve safeguards and security issues. CAS electronic technician 2 escorted the C-AD electrical engineer to the parking lot.

The fire dispatcher, who also listened in on the emergency phone call, broadcasted a tone and the message, "Fire alarm, explosion with injuries at 1006" on the BNL fire radio band. The acting Fire Chief was at Boiler Plant Building 610 issuing a cutting and welding permit when he heard the radio call for the Fire/Rescue Group to respond Building 1006A. The acting Fire Chief immediately responded to this call using a BNL Fire/Rescue vehicle he had driven to Building 610. The Fire/Rescue Group began their response from the firehouse with a command car, two pumper trucks, and an ambulance. Those responding were the acting captain, a captain who was onsite for training, three firefighters (one serving as an acting lieutenant), and three Emergency Medical Technicians (EMTs).

The C-AD electrical engineer asked CAS electronic technician 2 to drive him directly to the BNL Occupational Medicine Clinic (OMC) in a BNL pickup truck. While the acting Chief was driving to the accident scene he was flagged down by CAS electronic technician 2 in the vicinity of Railroad Avenue and Fifth Avenue, about ¾ mile from Building 1006A. The C-AD electrical engineer exited the BNL pickup truck and approached the acting Fire Chief. The acting Fire Chief made a quick assessment of the C-AD electrical engineer's medical status. In doing so, he learned that the C-AD electrical engineer was the only injured person from Building 1006A, and he redirected the ambulance to respond to his location.

The ambulance and three EMTs arrived at the acting Fire Chief's location, and the acting Fire Chief proceeded to Building 1006A. At 10:28 a.m., the injured C-AD electrical engineer was placed in the BNL Fire/Rescue ambulance where his vital signs were assessed and immediate care was initiated. A radio message was sent to the Stony Brook Hospital (the location of the nearest burn unit) to alert them of the condition of the C-AD electrical engineer. At 10:29 a.m., BNL issued a sitewide page text message concerning the accident at Building 1006A.

Members of the DOE BHSO also received this message. At 10:35 a.m., the ambulance with the C-AD electrical engineer left for Stony Brook University Hospital where it arrived at 10:56 a.m. The engineer was transferred to the Stony Brook University Hospital for medical treatment and released later that same day.

The acting captain and the two pumper trucks arrived at Building 1006A. The acting captain assumed the role of incident commander. One of the firefighters was directed to return to the fire house and exchange the pumper truck for the heavy rescue truck. The other responding firefighters began to put on their turnout equipment, including self-contained breathing apparatus. The responding firefighters met a C-AD employee who directed them to the Mechanical Equipment Loft where the arc flash had occurred. Three firefighters entered Building 1006A with two, 17-pound, halon 1211 fire extinguishers and one, 10-pound, dry-chemical fire extinguisher. When the acting Fire Chief arrived at the scene, the incident commander role was transferred to him from the acting captain. The heavy rescue truck arrived at the incident scene at 10:31 a.m. At 10:32 a.m., the acting Fire Chief issued an emergency call-in page to off-duty firefighters requesting that three firefighters respond for backup, since all available firefighters and EMTs were actively involved in this emergency response.

The firefighters used one, halon 1211 fire extinguisher to extinguish the burning papers (e.g., drawings, schematics, notes) that had been set on fire by the arc flash. At 10:34 a.m., the fire was extinguished and building venting began. The BNL PE Line Crew arrived at 10:35 a.m. to secure electrical power to the area of Building 1006A affected by the arc flash. At 10:40 a.m., the BNL Crisis Manager arrived at the scene and met with the incident commander. The BNL Line Crew secured the electrical power at 10:50 a.m. The BNL Crisis Manager declared an operational emergency at 10:52 a.m., and BNL notified the DOE Emergency Operations Center by fax. While the emergency was still in progress, many bystanders from various organizations and varying levels of management also arrived at the accident scene. Crowd control at the incident command center became a minor problem, but when the individuals were asked to step back they obeyed the request. The initial emergency response and medical response were timely and well coordinated.

2.2 EVALUATION OF THE ARC FLASH

2.2.1 Electrical System Description and Damage Analysis

2.2.1.1 Electrical System Description

The STAR Magnet power supplies receive 13.8-kV electrical power at substation 6C, which is located outside Building 1006A (Figure 2-3). Transformer 6C is a three-winding transformer rated at 3,000 kVA, 13.8 kV/480-volt/480-volt, delta/delta/delta, as shown in the one-line diagram (Figure 2-4). Transformer 6C has two 480-volt secondaries. One of the 480-volt secondaries feeds circuit breakers 6C41 and 6C42 in the outdoor substation as shown in Figure 2-3.

Figure 2-3. Substation 6C outside Building 1006A

Circuit breaker 6C42 provides power to electrical panel PB-3, which was not under load at the time of the accident. Circuit breaker 6C41, which provided power to electrical panel PB-1, is a draw-out power circuit breaker, GE type AK-2A-50-1. This circuit breaker has been retrofitted with a solid-state "Versa Trip" tripping unit that has long-time, short-time, and instantaneous tripping elements. Panel PB-1, a standard GE Spectra Series, APN plug-in style panel board manufactured in November 1997, is rated 600 volts, three-phase, three-wire, with aluminum main vertical bus. Panel PB-1 does not have a main overcurrent device; it has two, 100-amp fused switches feeding the East and West Space Trim magnet power supplies, plus a spare 100-amp fused switch. Panel PB-1 also has two, 400-amp fused switches (GE Catalog No. ADS36400 HB) that feed the East and West Pole Trip Trim magnet power supplies.

These switches have been equipped with Kirk Key interlocks with two bolts that attach the interlock mechanism to the switch doors through holes that had been drilled through the doors. The UL evaluation of the equipment installed as panel board PB-1 did not include the Kirk Key interlock installations; therefore, these installations voided the applied UL listing and labeling. However, unless it is explicitly stated as required by NFPA 70, use of non-listed or non-labeled equipment is not prohibited. NFPA 70 only requires that when listed and labeled equipment is installed it be used in accordance with any instructions included in the listing or labeling. The NFPA does point out that it is expected that considerable evaluation of non-listed or non-labeled equipment will be performed to determine compliance with NFPA 70 Article 110.3(a) for approval by the Authority Having Jurisdiction (AHJ). BNL Standard, ESH 1.5.0, *Electrical Safety*, establishes the Laboratory Electrical Safety Officer as being responsible for acting as the AHJ in the field, reporting back to the Laboratory Electrical Safety Committee. BNL does not have a formalized procedure for evaluating and approving the modification to listed and labeled equipment. Review of the Kirk Key installation was described as consisting of verbal approval by an electrical engineer after discussing installation methods. It was learned through discussions with GE, that GE recommends that, if a Kirk Key interlock system is installed, it should be part of the purchased equipment, so the manufacturer can install the equipment. If GE is aware that Kirk Key interlocks will be installed by the end user, they will include a waiver of liability indicating that GE is not responsible for any problems that may occur after the Kirk Key interlocks are installed.

Each of the 480-volt circuits has an ammeter and three voltmeters in the outdoor switchgear. The ammeter is connected to the three-phase buses through a selector switch and three current transformers. Three potential transformers are connected in a grounded wye–broken delta configuration. The broken delta secondaries of each set of PTs are connected to voltmeters and are also designed to connect to a GE Type IAV voltage-sensing protective relay (#64 relay), which is used to detect ground faults on the system. These voltage-sensing relays detect grounds on the normally ungrounded 480-volt system. Each relay is connected to its respective 480-volt, three-phase circuit through three PTs. The PTs are connected in a grounded wye to the 480-volt bus and broken delta to the #64 relay. Under normal operating conditions, the voltages from the three PTs will be equal and balanced and will cancel each other out so that the #64 relay sees no voltage. If one of the phases becomes grounded, however, the three voltages will no longer be equal. In that case, the voltages will not cancel each other out, and the #64 relay senses the unbalanced voltage and closes its alarm contact. The #64 relay also has a mechanical flag that will drop to indicate the presence of a momentary or intermittent ground condition. Because the relay was not connected to a local or remote alarm device, this feature was not operational on the 6C substation. The mechanical flag needs a power source from the alarm device to be operational.

Following the accident, BNL calculated the phase-to-ground fault current available at panel PB-1 as 36 kA for bolted faults and 16.7 kA for arcing faults. A bolted fault is caused when either a phase-to-phase or a phase-to-ground is directly connected together (bolted). Arcing faults occur when electrical clearances are reduced or compromised by deteriorating insulation or human error, causing an arc to form phase-to-phase or phase-to-ground. The arc burns in open air, releasing a large amount of energy until an upstream overcurrent protection device opens to clear the fault. Since this was an arcing fault, the current was limited to a maximum of 16.7 kA, which is below the 24-kA instantaneous trip setting of

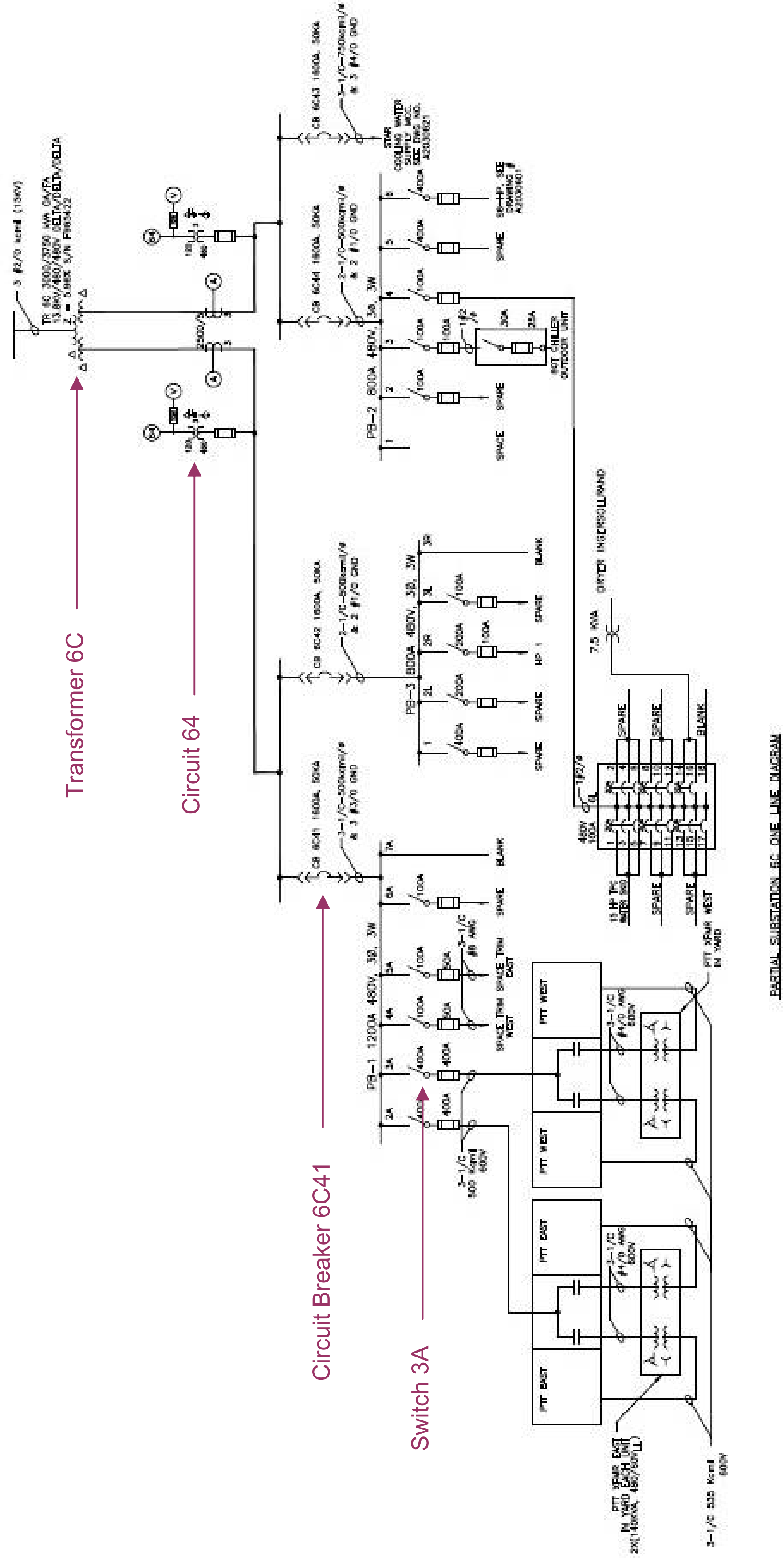


Figure 2-4. Partial one-line diagram substation 6C

the upstream circuit breaker (6C41). The short time-setting for circuit breaker 6C41 was 5,760 A, with an intentional 0.15-second time delay. This circuit breaker requires an additional 0.05 seconds to clear a fault, making the total clearing time about 0.2 seconds. Clearing time is the period of time required for the circuit breaker to open, thus "clearing" the fault.

2.2.1.2 Description of Damage

The inside of the two 400-amp switches 2A and 3A was coated with a thick layer of black soot. The switch components appeared from the front to be intact, except for thin plastic insulating sheets at the left end of the switches, opposite the load terminals. The left ends of the 400-amp switches were partially blown out, and the adjacent wiring insulation was melted from the heat of the arc flash. The vent panels on the ends of the switches were completely seared by the heat and blown off. The front covers were deformed and would have failed eventually if the fault persisted beyond the 0.2-second clearing time (see Figure 2-5 and Figure 1-4).

Figure 2-5. Bowed cover of Switch 3A

The heavy-duty padlock and hasp likely restrained switch doors 2A and 3A from being forced open toward the C-AD electrical engineer. The back of the switches have aluminum bus bars that run the length of the switch and connect the spring-loaded contact jaws to the switching elements on the left side of the switch. The sheet metal plate that covers the bus bars had a semicircular hole melted in the top and bottom of the rear cover plates, as shown in Figure 2-6.

Figure 2-6. Back of switch 3A bus cover plate

Figure 2-7 shows the bus on an undamaged switch in another location that was not involved in the accident. As shown in Figure 2-8, arcing heavily eroded the ends of the switch bus bars, and the head of the attaching bolts were melted. The arcing had enveloped all six busses of the two adjacent switches 3A and 2A.

Figure 2-7. Undamaged bus on undamaged switch

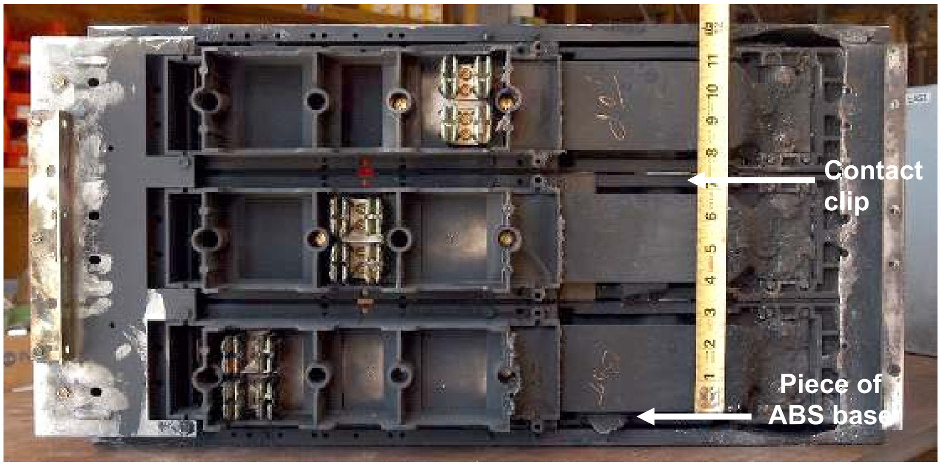


Figure 2-8. Damaged Switch 3A
(Note location of contact clip and piece of ABS base)

The removal of the bus bars disclosed that an arc had occurred between the aluminum bus and the adjacent steel switch frame. This was observed on the B-phase of switch 3A. (See small yellow arrow on Figure 2-9.) The bus bar is held about ¾ inch from the steel frame by its plastic support with two opposing screws (see yellow arrows on Figure 2-9), which are approximately ½ inch apart (Figure 2-10). The screw end on the right (Figure 2-9) connects the bus bar to its plastic support and is in full contact with the 480-volt bus. The screw on the left (screw removed in Figure 2-9) holds a switch assembly on the front onto the steel support piece, and is at ground potential.

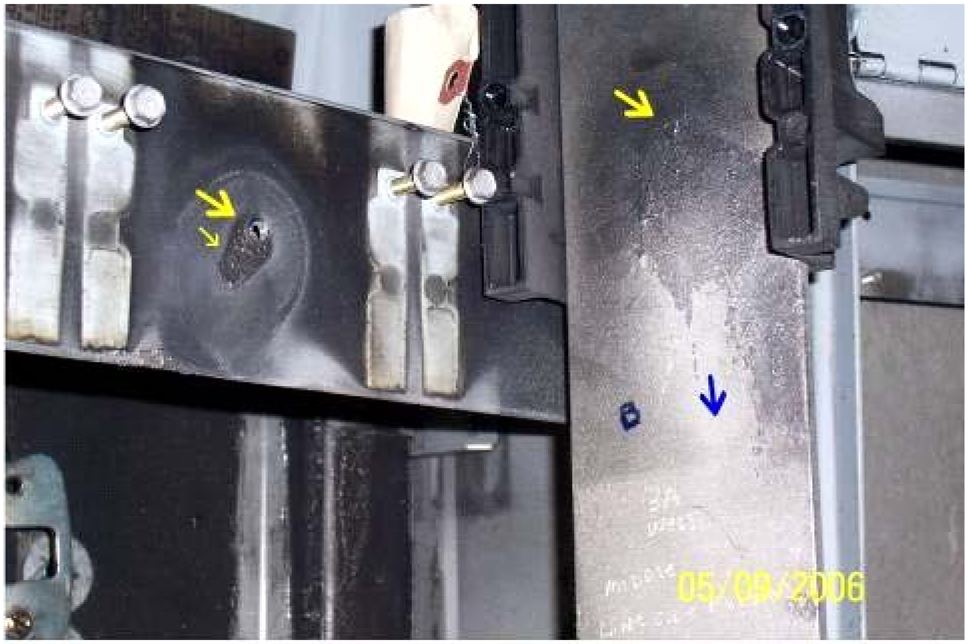


Figure 2-9. Evidence of arcing between base and Phase B Switch 3A

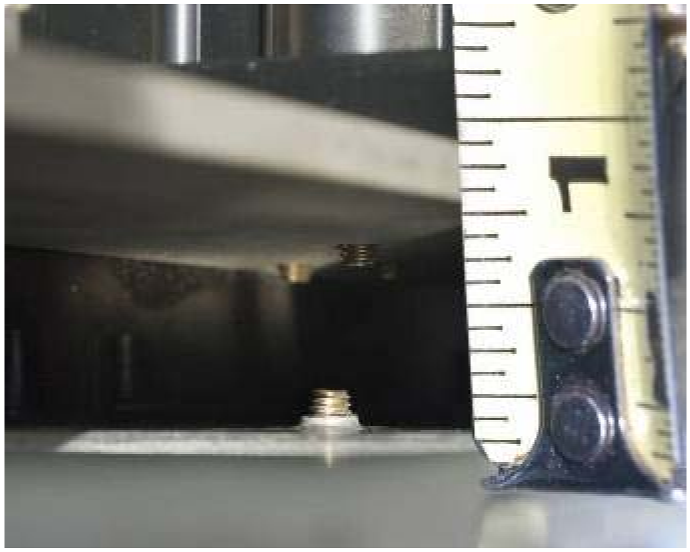


Figure 2-10. Space between screw ends on undamaged switch

The removal of the bus bars also disclosed that on switch 3A the ABS base had failed and a circular piece was displaced (Figure 2-11). The ABS base holds the contact clips, which are used to maintain contact pressure for the moving and stationary contacts. The examination of switch 2A revealed that Base had been displaced and two of the contact clips were displaced (Figure 2-12), one of which could not be found. Upon examination of identical switches purchased at the same time as those for the STAR Magnet power supplies, cracks were found in a pattern similar to the switches involved in the arc flash, as can be seen in Figure 2-13.

Figure 2-11. Switch 3A ABS base Phase B displaced piece

Figure 2-12. Switch 2A ABS base Phase A and C displaced pieces (Only one contact clip could be found)

Figure 2-13. Crack developing in ABS base of switch not involved in the accident

The feeder cables serving electrical panel PB-1 are enclosed in an underground conduit that runs between substation 6C (through a manhole) into Building 1006A. When the accident occurred, the manhole was flooded and the cable was underwater. The cables, which supply electrical power to panel PB-1, were tested, and a ground fault was identified in the C-phase feeder. The cable was tested with a 600-volt megger, and was found to have unacceptable leakage current to ground. The cable with the ground fault was removed for inspection. As shown in Figure 2-14, a nick was found in the cable insulation that contained a pinhole, exposing the copper conductor.

Figure 2-14. Damaged cable which was underwater in manhole from substation 6C to panel PB-1

The pinhole was surrounded by a small, volcano-shaped mound of carbonized insulation. When the insulation was removed, the copper wire in the area of the nick was found to be oxidized and discolored (Figure 2-15), an indication that this condition had been present for an extended period of time. When the manhole was drained, the ground fault cleared. A new cable was installed and no ground faults were detected.

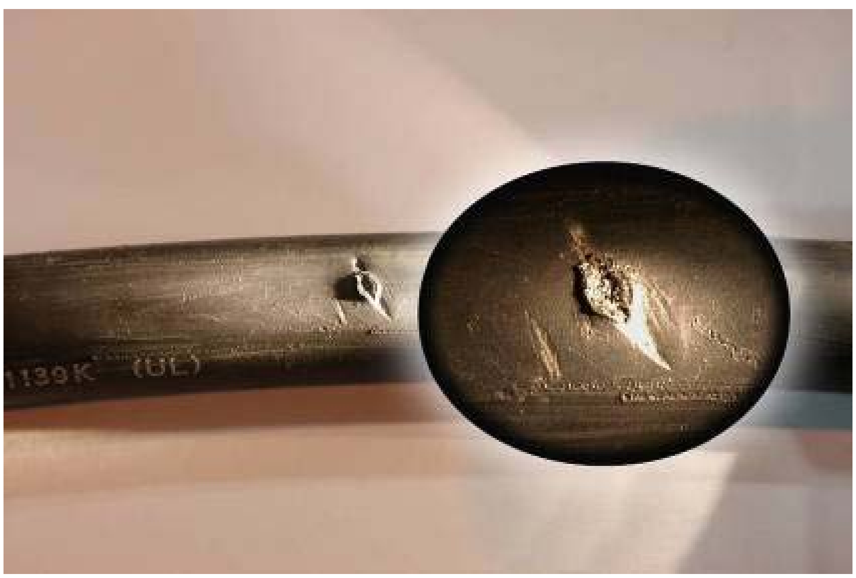


Figure 2-15. Damaged cable with oxidized copper

2.2.1.3 Possible Arc Flash Causes

Overvoltage

The Board concluded that there are several possible conditions that could cause overvoltage to the electrical system. Ungrounded delta electrical systems are susceptible to overvoltages from lightning strikes, switching surges, intermittent ground faults or resonant conditions. Because the weather was clear and warm, there were no lightning strikes at the time of the accident. The Board also considered a second condition, switching surges, and determined that there was no load on switches 2A and 3A in panel PB-1 when they were closed.

The third condition considered was the effect of the ground fault in the underground feeder conductor. The insulation for the C-phase feeder cable, which supplies panel PB-1, was damaged. This could have resulted in sputtering or a restriking ground. When the restrike frequency approaches the power system frequency, the line-to-ground voltage can ratchet up to a very high level with each successive arc because the trapped charge that accompanies arc current flow is unable to discharge between restrikes. There is no theoretical limit to the increase in voltage; however, in practice, the voltage will not exceed 6 to 8 times normal, or in this case 3,840 volts to ground on this 480-volt system. After the accident, BNL tested a similar switch to 5,000 volts, and no arcing occurred. However, the condition of the switch was severely compromised by the blast of the fault, making this test of questionable value.

A fourth scenario involves the use of potential transformers. The application of grounded wye PTs on ungrounded systems with a wye or broken-delta secondary connection can be responsible for damaging overvoltages as a result of resonant or ferroresonant action because the magnetizing reactance of the potential transformers becomes connected from the phase conductors to ground. This inductive reactance is connected to the distributed capacitance of the power system, creating a tuned circuit with some naturally occurring resonant frequency. This system used grounded wye potential transformers with a broken delta.

The final situation considered for creating overvoltages would be the introduction of harmonic voltages onto the cable over a wide range of frequencies, caused by the arcing ground fault in the underground cable. This would be similar to the spark gap transmitter first used for radio communications. If one of these voltage frequencies matches the resonant frequency of the power distribution system, very high common-mode voltage (in excess of 10,000 volts) can be developed.

Substation 6C has two sets of three-phase potential transformers that are connected in a grounded-wye, broken-delta configuration. The potential transformers are not provided with dampening resistors that can attenuate damaging overcurrents and overvoltages from resonant and ferroresonate oscillations. The inductance of the potential transformers is in series with the distributed capacitance of the feeder cables, which form a tuned circuit with a definite resonant frequency. Normally this is not a problem because this frequency is far removed from the 60-Hz power frequency; but, with an arcing ground fault, high-frequency harmonic voltage could have been provided near the systems resonant frequency. As the switches in panel PB-1 were closed after the fuses were replaced in the power supplies, the capacitance increased with each switch closure. When switch 3A was closed, enough capacitance was introduced to shift the resonant frequency of the system to the same as that being produced by the grounded arc in the water-filled manhole. This produced voltage sufficient to strike a phase-to- ground arc in switch 3A. This arc occurred between the screw tips shown in Figures 2-9 and 2-10. The conductive gasses were blown to the bends at the ends of the bus bars where the main phase-to-phase arc then occurred.

Mechanical Damage or Foreign Object

Mechanical damage, and a resulting ground fault or phase- to-phase fault, could have been caused by a mechanical fault of the switch or a foreign object in the switch. The release of the contact clip, if the cracked ABS Base material was displaced, could have contacted the phase bus located behind the switch contact. The contact clip could have created a phase-to-phase or phase-to-ground short circuit. The observed damage to the switches by the failure of the ABS Base led to the inspection of other Spectra 400-amp fused-disconnect switches at BNL. These inspections identified cracking of the ABS Bases of the switches that were installed at the same time as those in panel PB-1. BNL has subsequently removed a switch from service and cycled the switch. The ABS Bases cracked, but failed to release the contact clips, after more than 4,000 switch operations. BNL inspected all of the GE Spectra-type switches in use and found that the arc chutes were broken on a 600-amp switch and the arch chute had been displaced on one switch. (See Figure 2-16)

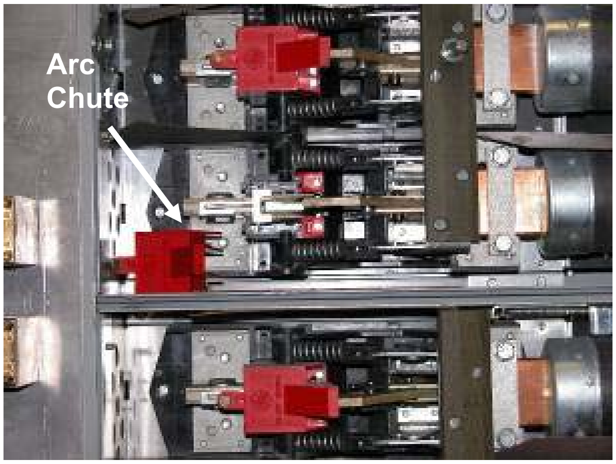


Figure 2-16. Loose arc chute from 600-amp Spectra-fused disconnect switch

A single contact clip of switch 3A was found on the side of the phase B bus after the switch was removed from panel PB-1(Figures 2-17 and 2-18). The contact clip from switch 3A was partially damaged by arcing, as show in Figure 2-19. On switch 2A, which had two pieces of the ABS base displaced (Figure 2-20), only one of the contact clips could be found. There was no evidence that the contact clips from either switch 2A or 3A had contacted the buses; however, this could not be proven with any certainty. Had the contact clip from switch 3A caused the arc flash, it might have been completely destroyed in the ensuing arc, but evidence of arcing would have been left on the aluminum bus at the point of contact. No such evidence was seen, and the bus bar would have been damaged where grounding occurred.

Figure 2-17. Switch 3A (note location of contact clip)

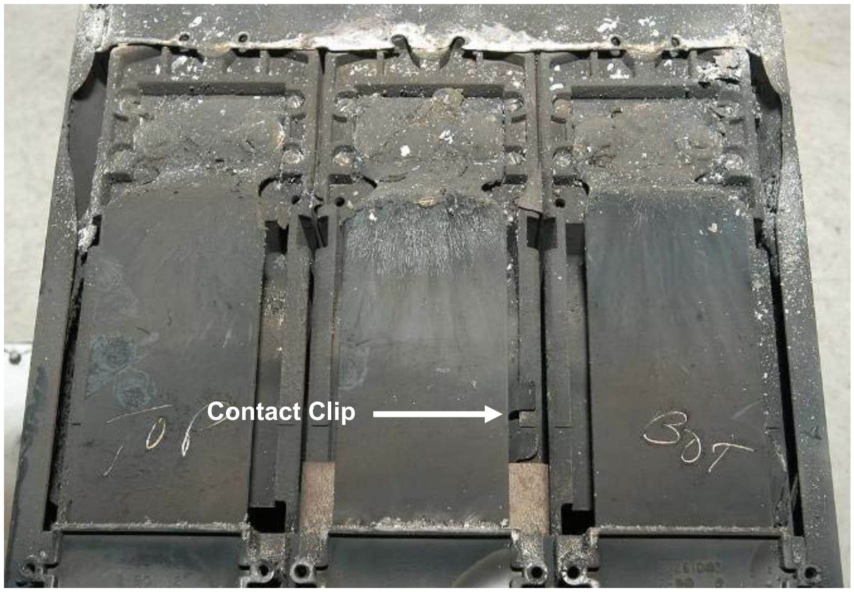


Figure 2-18. Location of contact clip on Switch 3A after backing plate removed

Figure 2-19. Contact clip from Switch 3A

Possible sources of foreign objects entering into the switches were found in panel PB-1. These consisted of conduits openings that entered panel PB-1. The conduits that had cables installed in them did not have the void spaces filled, and an empty conduit was not capped. No foreign objects were found during the inspection and removal of the failed switches. The switch cabinets covers were in place and locked closed before the arc flash occurred (see Figures 1-3 and 1-4).

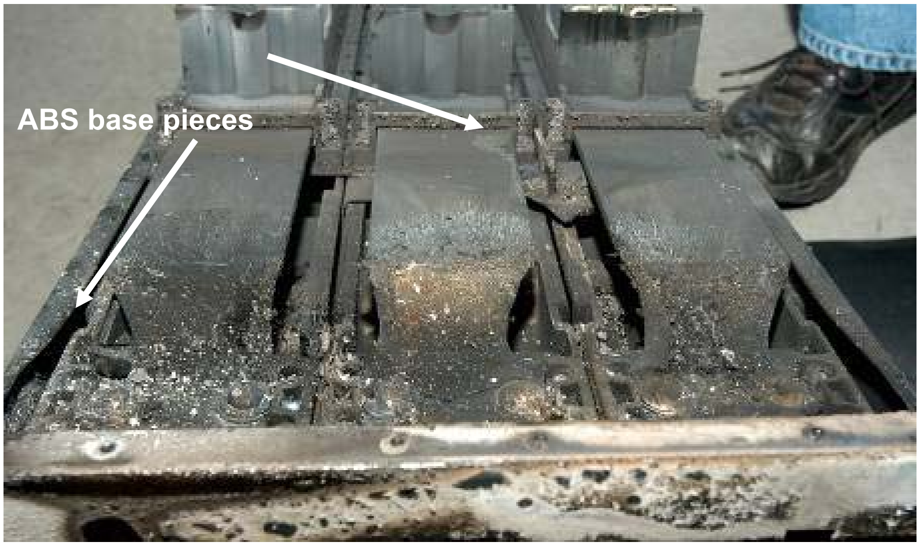


Figure 2-20. Switch 2A (note the ABS base pieces)

Probable Cause of the Arc Flash

It is the Board's opinion that an initial arc occurred between the grounded steel frame and the phase B bus on the back of switch 3A. This was caused by an overvoltage, which is believed to be tied to the underground cable ground fault and resonant frequency of the system. This arcing then caused the phase-to-phase arcing in switch 3A, which in turn caused the failure of switch 2A. This all occurred in a very short period of time. Although this is the Board's opinion, we could not positively rule out the possibility that the arc flash could have been caused by the switch failure. However, since the contact clip on switch 3A was only partially damaged, and there was no evidence of arcing on the aluminum bus near the contact clip, this mode of failure is less likely. It is not understandable how the failure could have begun in switch 2A, which had the missing contact clip, because the C-AD electrical engineer stated that he closed switch 3A after he closed switch 2A. The Board postulates that the displacement of the ABS base pieces was due to the pressure of the arc flash, not the result of mechanical failure.

Damaged fused-disconnect switch 3A was sent to GE Industrial Systems for evaluation. The manufacturer evaluated the damage to the switch and conducted tests on a new switch that was machined to simulate the damage noted on the ABS base of switch 3A. In their tests, the contact clip was contained by the ABS base, and the contact clip could not cause arc initiation. When the modified new switch was tested at 600 volts, the make/break arc was observed traveling towards the two mounting screws. GE could not replicate the failure, but they believe the arc event started between the two mounting screws and traveled away from the line to the load side of the bus. This is consistent with the conclusions of the Board.

2.3 TRAINING AND QUALIFICATION

Management of employee training and qualification needs is established through the BNL Standards-Based Management System (SBMS) Training and Qualification Management System. The Laboratory uses a Job Training Assessment (JTA) to develop a training and qualification plan for each employee. This allows managers to tailor ES&H training and qualification requirements applicable to the hazards associated with their specific operations. Through the Brookhaven Training Management System, supervisors have on-screen access to the current JTA for each subordinate employee. Managers are required to evaluate the adequacy of these training and qualification requirements on an annual basis or as an individual's duties are changed. The BNL Human Resources Services Training Office is responsible for ensuring that line organizations complete the annual JTA evaluations.

The C-AD OPM establishes needed training for individuals based on the specific locations where they will be working. C-AD OPM Procedure 14.32.2, *Occupational Safety and Health Operational Training for C-AD Experiment Construction, Operations, Testing, Maintenance and Emergency Response*, communicates that electrical energy represents a significant hazard during the performance of this work. To address the electrical energy hazard, Procedure 14.32.2 identifies the following work controls.

- Working on or near energized equipment work permits
- Two-man rule where appropriate
- Use of shorting bars for electrical safety
- Maintaining electrical flash and shock boundaries
- Lockout/tagout
- Voltage-rated gloves
- Clothing to protect against arc flash hazard
- Use of equipment that meets UL or equivalent standards
- Ground fault circuit interrupters (GFCIs)
- Kirk Keys
- Grounding

Procedure 14.32.2 establishes C-AD OPM Procedure 1.5, *Electrical Safety Implementation Plan*, as the means for providing employee awareness of these controls. Procedure 1.5 requires supervisors to ensure that all subordinate employees have current verified training and that proper technique is being followed in the performance of work assignments. Procedure 1.5 further requires all C-AD personnel working on electrical equipment or apparatus connected to electrical energy sources to be trained in the content of Procedure 1.5, as well as in BNL ES&H standards 1.5.0, *Electrical Safety*; 1.5.1, *Lockout/Tagout Requirements*; 1.5.3, *Interlock Safety for Protection of Personnel*; and in the equipment on which they will be working. The requirement for this training is also communicated in the electrical safety section of C-AD Access Training; Radiation Safety, Conventional Safety Access Control; Information Guide. This document also requires all workers be trained in electrical safety, LOTO, and C-AD-specific electrical safe work practices.

The Board reviewed the JTAs for the C-AD electrical engineer and the three CAS electronic technicians who were working in the Building 1006A Mechanical Equipment Loft on April 14, 2006. They found that each of the workers was current with required electrical safety training. The courses that all four workers had completed included those shown in Table 2-2 below.

Table 2-2. Electrical Safety Training

Course Code	Course Title	Frequency
TQ-HP-ESR-W	Electrical Safety Review	12 months
HP-OSH-151B-W	Lock Out/Tag Out – Authorized	12 months
AD-ELECSAFETY	Electrical Safe Work Practices	36 months
TQ-ELECSAF1	Electrical Safety 1	24 months
AD-CA-ACCESS	Collider-Accelerator Access Training	24 months

The respective JTAs for each of the three CAS electronic technicians showed they were also current in course AD-LOTO-OJT, *Department-Specific Lockout/Tagout*. Although the C-AD electrical engineer used the Kirk Key system to lock out electrical energy sources in the Building 1006A Mechanical Equipment Loft on April 14, 2006, this course was not listed as required training on his JTA. The AD-LOTO-OJT, *Department-Specific Lockout/Tagout*, requires a supervisor to provide annual written indication (i.e., memo) to the C-AD Training Coordinator that a specific individual is capable and or knowledgeable of performing LOTO tasks. There are no specific requirements for the individual to meet prior to the supervisor sending the memo. Upon completion of the Web-based LOTO training, the individual is authorized to perform LOTO activities when the supervisor provides a memorandum to the C-AD Training Coordinator.

2.4 DOE OVERSIGHT

DOE line oversight has nearly exclusively been performed by BHSO. The BHSO Manager serves as the local Federal official responsible for ensuring BNL contractual compliance with ES&H requirements. The BHSO Manager reports directly to the DOE SC Chief Operating Officer, who in turn reports to the Director of DOE SC. BNL contractual requirements include DOE Order 440.1A, which requires compliance with OSHA requirements, NFPA 70, and NFPA 70E.

The BHSO Operations Management Division has established six facility representative positions for performing day-to-day operational awareness oversight of BNL operations. This oversight is conducted in accordance with BHSO Procedure OA-1, *Conduct of Environment, Safety and Health (ESH) Assessments*, and BHSO Procedure OA-2, *Conduct of Environment, Safety and Health Surveillances and Walkthroughs*. BHSO facility representatives are qualified in accordance with BHSO Procedure OA-13, *Facility Representative Qualification and Training*. This procedure is consistent with the process of qualification established by DOE-STD-1063-2000, *Facility Representatives*, and DOE-STD-1151-2002, *Facility Representative Functional Area Qualification Standard*.

A qualified BHSO facility representative has been appointed to oversee work being performed in conjunction with RHIC operations. The BHSO facility representative assigned to RHIC operations also covers the C-AD organization and their other facilities (e.g., AGS, Tandem, Linear Accelerator, and the National Aeronautics and Space Administration (NASA) Space Radiation Research Laboratory).

In response to the 2004 arc flash accident at the Stanford Linear Accelerator Center (SLAC), the Director of SC commissioned independent review teams to determine conformance with contractual requirements for performing energized electrical work at each SC laboratory. The BNL review was accomplished on April 18 through April 21, 2005. The review team concluded that BNL recognizes the hazards associated with performing energized work and that the Laboratory is fully committed to compliance with the NFPA 70E. The review team concluded that BNL had demonstrated significant implementation of the NFPA 70E requirements, but noted 16 recommendations for BNL "to consider in finalizing the BNL electrical safety process." The review also acknowledged the actions identified by the March 2005, BNL Electrical Safety Self-Assessment. The SC Review endorsed these BNL actions.

One of the BNL self-identified actions was to complete the arc flash calculations for BNL. The arc flash calculations were not completed for Building 1006A at the time of the accident. The actions for the self-assessment committed to labeling all electrical panels that require a warning about the potential for arc-flash hazards by the end of 2007. At the time of the accident, the schedule given to management for completion of these self-assessment actions was not accurate, and the status of the actions was undetermined. BHSO has scheduled a status review of the recommendations from the SC Energized Electrical Safety Review and the BNL Electrical Safety Self-Assessment. At the time of the accident, only the National Synchrotron Light Source arc-flash calculations were completed.

2.5 BNL OVERSIGHT

Formal BNL ES&H oversight is driven by SBMS, *Worker Safety and Health Management System*, subject area "Environment, Safety, Health and Quality (Tier 1) Inspections." Tier 1 inspections are line organization oversight activities conducted periodically for the purpose of self-identifying ES&H vulnerabilities. The C-AD OPM further refines the performance of Tier 1 inspections through Procedure 9.4.1, *Procedure for Conducting Safety Inspections*.

The last Tier 1 inspection conducted by C-AD that included Building 1006A occurred on March 29, 2006. This Tier 1 inspection included thermal scanning of all electrical panels, cables, and motors for possible locations of overheating. No such locations were identified. Of the 23 documented findings, none was noted as being found in Building 1006A. Similarly, semiannual Tier 1 inspections conducted on September 21, 2004, March 31, 2005, and September 30, 2005, did not document any issues for Building 1006A. The next Tier 1 inspection to include Building 1006A is scheduled for September 27, 2006. These Tier 1 inspections noted only physical hazards; they did not indicate any observations of work or include notations pertaining to unsafe acts.

There was no visual inspection of the operating mechanisms of the fused-disconnect switches. Although the manufacturer does not list recommended maintenance or inspections, it is good industrial practice to perform periodic visual inspections of the switch mechanism. Based on interviews, BNL had not performed any inspections or maintenance on the fused-disconnect switches.

In December 2002, the BNL Office of Independent Oversight led a comprehensive electrical safety review that included participation by the BNL Electrical Safety Committee. A follow-up review was slated to occur during 2004, but due to other priorities it was postponed until 2005. When it was learned that SC was going to be conducting an energized electrical work review at BNL in April 2005, this follow-up review was cancelled. In preparation for the SC Energized Electrical Safety Review at BNL, the Laboratory conducted an electrical safety program self-assessment during March 2005 (see Section 3.4.5).

2.6 INVESTIGATIVE READINESS

The Contractor Requirements Document of DOE O 225.1A, *Accident Investigations*, mandates that contractors will support Type A and B accident investigations, establish and maintain readiness to respond to accidents, mitigate the consequences, assist in collecting and preserving evidence, and assist with the conduct of the investigation by providing office space and equipment; meeting regularly to discuss issues surrounding the accident; and providing general administrative assistance.

The BNL Crisis Manager terminated the operational emergency at 11:35 a.m. At this time, the BNL Fire/Rescue Group turned the accident scene over to the BNL Associate Laboratory Director for High Energy and Nuclear Physics. Access was limited to the accident scene and a guard was posted. Photographs of the accident scene were taken, initial interview statements were collected, and the accident scene evidence was preserved. The Laboratory also conducted a critique of the event to make an initial determination of what happened. At 5:00 p.m., the BNL Director halted all work involving 480-volt switches pending approval from the BNL Assistant Laboratory Director for Facilities and Operations. At the same time, BHSO notified BNL of the BHSO Manager's decision to convene a Type B Accident Investigation Board. On April 17, 2006, the Accident Investigation Board took control of the accident scene. BNL took effective measures to collect and preserve evidence and maintain the accident scene.

3.0 ANALYSIS

3.1 BARRIER ANALYSIS

Barrier analysis is based on the premise that hazards are associated with all tasks. A barrier is any management or physical means used to control, prevent, or impede the hazard from reaching the target (i.e., persons or objects that a hazard may damage, injure, or harm). The results of the barrier analysis are integrated into the events and causal factors chart to support the development of causal factors. Appendix C contains the Board's Barrier Analysis of physical and management barriers that did not perform as intended and thereby contributed to the accident.

3.2 CHANGE ANALYSIS

Change analysis examines planned or unplanned changes that caused undesirable results related to the accident. This process analyzes the difference between what is normal or expected and what actually occurred before the accident. The results of the change analysis conducted by the Board are integrated into the events and causal factors chart to support the development of causal factors. Appendix D contains the Board's Change Analysis and reinforces the Barrier Analysis.

3.3 EVENTS AND CAUSAL FACTORS ANALYSIS

The Events and Causal Factors Analysis (Table 3-1) is a systematic process that uses deductive reasoning to determine causal factors of an accident. Causal factors are the significant events and conditions that produced or contributed to the direct cause, the contributing causes, and the root cause(s) of the accident. The Board created an Events and Causal Factors Chart (Appendix E) to assist in determining the causal factors of this accident.

Table 3-1. Summary of Causal Factor Analysis

Root Cause	Discussion
BNL failed to ensure that good industrial practices, as well as Laboratory and applicable NFPA 70 requirements, for the design, test, operation, and maintenance of ungrounded delta electrical power distribution systems, were used at RHIC.	• Ground-fault monitoring was not provided. • Circuit breaker 6C41 settings allowed higher incident energy. • Surge suppressor was not provided on panel PB-1. • Use of ungrounded delta electrical distribution on substation 6C without ground-fault detection. • Zigzag grounding transformers and neutral grounding resistors was not installed on the electrical distribution system. • Engineering evaluation was not performed to determine if use of ungrounded delta electrical distribution system remains appropriate. • Conversion to high-resistance grounded system was not evaluated against the ungrounded delta system. • OPM 5.1.5.0.1 (RHIC and C-AD) requirements for ground-fault detection for ungrounded delta power supply were not implemented for substation 6C. • RHIC SAD requirement for ground-fault detection and monitoring was not met for substations 6C. • RHIC-QAP-601 was not implemented for the ground-fault relay for substation 6C. • RHIC Design Standard DS-1 was not implemented for the ground-fault relay for substation 6C. • RHIC-QAP-801 was not implemented for the ground-fault relay for substation 6C. • BNL did not evaluate changes in NFPA 70 against existing operations and facilities.
Contributing Causes	**Discussion**
BNL failed to ensure that ground-fault detector relays, monitoring, and alarm systems were properly designed, installed, tested, and maintained.	• Substation 6C ground-fault relay is not operational or monitored by RHIC or STAR control rooms. • Substation 6C one-line diagram indicates that the ground-fault relay is not connected. • The design drawings for Substation 6C did not indicate ground-fault relays would be monitored. • The ground-fault relay could not operate because the contact for the #64 relay was not connected. • No periodic testing of the ground fault circuits was conducted. • Design reviews conducted did not identify that ground-fault detection monitoring was not included for substation 6C. • The ORR conducted did not identify that substation 6C ground-fault detection would not operate and was not monitored. • RHIC-QAP-601 was not implemented for the ground-fault relay for substation 6C. • RHIC Design Standard DS-1 was not implemented for the ground-fault relay for substation 6C. • RHIC-QAP-801 was not implemented for the ground-fault relay for substation 6C.

Contributing Causes	Discussion
BNL failed to ensure that a ground-fault monitoring system provided prompt notification to the main control room for safe and reliable operation.	• Substation 6C ground fault circuit is not monitored by the RHIC main control room or STAR Control Room • The ground-fault relay target (#64 relay) is not connected and cannot operate.
BNL failed to ensure that formal work controls were established for working on ungrounded delta electrical systems which may have a ground-fault condition.	• Work conducted without pre-job briefing. • C-AD does not have formal expectations for planning and conducting troubleshooting and repair activities. • Roles, responsibilities, and accountabilities for system specialists not defined. • Risk assessments have not identified the hazards associated with ground faults on an ungrounded delta power system. • Employees are not required to review Job Risk. Skill-of-the-worker tasks allow hazardous work activities to be conducted without adequate planning, controls, or procedures. • There was no documented process for establishing controls, such as restricting the operation of additional equipment upon the receipt of a ground-fault alarm.
BNL failed to establish a preventive maintenance inspection program for fused-disconnect switches and ground-fault relays.	• Fuse failures on the STAR Magnet power supplies were not trended, increasing exposure of C-AD personnel to hazards of operating the fused-disconnect switches on an ungrounded delta power system. • Fused-disconnect switches are not on a preventive maintenance schedule. • Spectra Switches inspected at BNL (as well as those involved in the arc flash) were also found to have structural damage. • There is no periodic inspection or testing of ground-fault circuits so that the lack of monitoring on 6C would have been identified.
BNL failed to implement NFPA 70E.	• C-AD electrical engineer was not wearing appropriate clothing. • C-AD electrical engineer supervisor did not ensure that he had appropriate clothing and PPE for operating switch. • C-AD electrical engineer was not wearing safety glasses. • CAS electronic technicians are only required to wear FR clothing when performing work. This practice can lead to performing work without appropriate clothing. • Arc flash calculations had not been performed for the PB-1 electrical equipment. • Pre-job briefing was not conducted (zero-voltage check considered energized electrical work). • Correct use of protective clothing not included in NFPA 70E training (collar closed, sleeves not rolled up, shirt tucked into pants). • Operation of fused-disconnect switches 2A and 3A required use of both hands, not as instructed in BNL training.
BNL failed to adequately monitor the progress of its implementation of NFPA 70E requirements.	• Progress on arc flash calculations not being adequately monitored by BNL. • Correct use of protective clothing not included in NFPA 70E training (collar closed, sleeves not rolled up, shirt tucked into pants).

Contributing Causes	Discussion
BHSO failed to adequately validate BNL's implementation of corrective actions from BNL's self-assessment and the SC Energized Electrical Work Review.	• Status report provided BHSO was not accurate. • The SC Energized Electrical Work Review's limited scope did not identify appropriate status of arc flash calculations for C-AD or that FR clothing was not provided to all exposed employees.
BNL failed to ensure adequate implementation of the C-AD Conduct of Operations Program.	• Pre-job briefing not conducted before work was begun. • Workers did not use procedure while conducting work. • Blown fuses were not trended, which allowed continued and increased exposure to the hazards of operating magnet power supply switches. • System operating performance other than the accelerator was poorly documented. • CAS technicians failed to stop work of engineer who was not wearing appropriate PPE. • Monthly substation inspection not conducted with formal procedure. • Monthly substation inspections not being performed monthly. • C-AD Chief Engineer not notified of "slight ground" condition of 6C substation. • The acceptance testing documents for the STAR power distribution system could not be retrieved for Board review. Documents that could impact safety, reliability, and operation of the accelerator were not available.
BNL failed to establish a formal process for making modifications to nationally recognized testing laboratory-listed equipment.	• BNL does not have a formal process for evaluation of Kirk Key interlocks to nationally recognized testing laboratory-listed cabinets.

3.3.1 Direct Cause

The direct cause is the immediate event or condition that caused the accident or event. **The Board concluded that the direct cause of the accident was the overvoltage condition on the ungrounded delta power system.**

3.3.2 Contributing Causes

Contributing causes are the events or conditions that, collectively with the other causes, increased the likelihood of the event but which did not cause this event. **Table 3-1 shows the nine contributing causes and associated facts identified for this accident.**

3.3.3 Root Cause

Root causes are the events or conditions that, if corrected, will prevent recurrence of this and similar events. **The Board identified the root case of this event as BNL's failure to ensure that good industrial practices, as well as Laboratory and applicable NFPA 70, *National Electrical Code*, requirements for the design, test, operation and maintenance of ungrounded delta electrical power distribution systems, were used at RHIC.** The Board concluded that if these management processes and quality assurance requirements had been implemented, and if BNL had ensured that NFPA 70E was implemented effectively, BNL workers would have been better protected in the event of an arc flash.

3.4 INTEGRATED SAFETY MANAGEMENT SYSTEM ANALYSIS

The BNL ISMSD is documented in the SBMS, which is the primary system of setting institutional standards and requirements at BNL. The ISMSD is required to be maintained as a living document that is reviewed annually and updated as necessary to reflect the current status of the operating contract, system improvements, and changed conditions and requirements.

The major components in the SBMS are the management systems. Currently, there are 31 management systems in the SBMS, which are further divided into subject-specific areas. The Board reviewed the current SBMS management systems and subject areas that provide requirements and expectations for planning, conducting, authorizing, and controlling work, as well as C-AD implementing procedures. The review was conducted to ensure that gaps in requirements or implementation did not contribute to, or fail to adequately control, the hazards associated with the STAR power-supply arc flash accident.

The SBMS management systems and subject areas were phased-in during July 1999. In August 1999, RHIC and STAR commenced the commissioning activities that would authorize operation, and that October, RHIC and AGS merged to become C-AD. The Board also reviewed the OPMs that existed for RHIC at the time of the design and review of the STAR Magnet power supply. Most of the design work, acceptance testing of equipment and systems, and construction was performed under these OPMs. Work planning for maintenance activities, as well as troubleshooting of STAR systems, must meet the current SBMS requirements and the C-AD implementing procedures in the OPMs.

3.4.1 Define the Scope of Work

SBMS management system, *Work Planning and Control*, is used for planning and conducting work safely. The subject area, "Work Planning and Control for Experiments and Operations," provides the requirements for planning and controlling the work, as well as direction for implementing controls. Work planning for the STAR Magnet and its power supply was part of the overall RHIC project and began in 1991, with construction commencing in 1992. Before initiating work planning on a project or experiment, the SBMS subject area requires a description of customer requirements, specifications, and constraints.

The design of the STAR power supplies was performed under the RHIC requirements identified in the following procedures.

- RHIC OPM 9.1, *Conventional ES&H Review of an Accelerator System*
- RHIC OPM 9.16, *Conventional ES&H Review of RHIC Experiments*
- RHIC OPM 5.1.5.0, *Supplemental Electrical Safety Standard RHIC Project*, March 20, 1997

These procedures provide direction for management oversight reviews for compliance with ES&H requirements. The Board requested documentation in support of these management oversight reviews, but only received copies of the design review comments from S&EP (now known as Environment Safety and Health Division). Reviews conducted within the RHIC organization were not available. The S&EP design review did not identify omission of the ground-fault monitoring.

Safety requirements for accelerator facilities are defined in DOE O 420.2B, *Safety of Accelerator Facilities*. When the STAR experimental facilities were under design, the DOE requirements were those in DOE Order 5480.25, *Safety of Accelerator Facilities*. The SAD and the ASE identify and implement the hazard controls. The 1999 SAD for RHIC specified that ungrounded systems would be monitored to meet the requirements of the RHIC Chief Electrical Engineer's Supplemental Electrical Safety Standard RHIC Project, March 20, 1997 (RHIC OPM 5.1.5.0.1). This standard required RHIC to provide ground-fault detection in the power distribution system for the ungrounded delta systems. The design reviews failed to identify that ground-fault detection was not adequately designed. The design drawings were not compliant with RHIC OPM 5.1.5.0. Since the design reviews missed that ground-fault monitoring was not provided because the deficiency was not identified, project management and the Chief Electrical Engineer were not aware of the omission.

At each stage of the RHIC project, project engineers and scientists are required to develop procedures or work plans in accordance with the approved commission and authorization scheme. These procedures are reviewed by the Accelerator System Safety Review Committee (ASSRC) as well as the Experimental Safety Review Committee (ESRC). When the RHIC was commissioned, the use of formal procedures would have been at the professional discretion of members on the various committees involved in the review process. The Board requested documentation used in the installation and acceptance testing on the STAR power systems and ground-fault detection, but no documentation other than the heat-load test was provided. The line organization review process is described in RHIC OPM 9.1, *Conventional ES&H Review of an Accelerator System*, as well as its current version, C-AD OPM 9.2.1, *Procedure for Reviewing Environmental, Health and Safety Aspects of an Experiment*. The procedure describes a process whereby the ASSRC reviews the design if the project engineer determines it does not meet the requirements. The ASSRC did not review the drawings for the STAR power systems.

Work tasks are required to be defined at a level such that planners, supervisors, and workers can readily identify the hazards and risks. The current requirements for implementing the SBMS procedure *Work Planning and Control for Experiment and Operations* and for work execution in C-AD is OPM 2.28, *Procedure for Work Planning and Control for Operations*. C-AD classifies all non-office work as having low, moderate, or high ES&H risks based on the examples in OPM 2.28d, "Work Screening Guidance." Work that is low hazard can be addressed as skill-of-the-worker; other jobs, classified as moderate to high hazard, must be planned and controlled through a procedure or the enhanced work control process. Based on interviews with senior management within C-AD, the Board learned that approximately 40 percent of the work at C-AD is skill-of-the-worker. The work conducted by CAS is regarded as having a low ES&H risk; therefore, skill-of-the-worker is considered sufficient. Discussion with CAS personnel indicated that the majority of maintenance and troubleshooting work is conducted without procedures and considered skill-of-the-worker.

Operating the STAR power supply switches was a routine, proceduralized task. The system specialist is regarded as the expert in the C-AD skill-of-the-worker hierarchy, and the C-AD electrical engineer is considered the system specialist for the STAR electrical power systems. Once the C-AD electrical engineer arrived, as the expert or system specialist, he took over as the authority for the work, as well as the work planning. Although the position of system specialist and its authority in planning or directing the work of CAS personnel is not documented, it is understood and accepted by management and CAS personnel. On the day of the accident, the C-AD electrical engineer also performed work, operating Kirk Keys and switches in panel PB-1.

No formal specific expectations or boundaries exist for providing guidance to workers or system specialists for planning or conducting troubleshooting. No pre-job briefings were held on the day of the accident. The role of C-AD electrical engineer is not formally defined when he is involved in a troubleshooting task.

The Board concluded that the design, design review, acceptance testing, and commissioning failed to identify the absence of ground-fault detection.

The Board concluded that C-AD did not provide formal expectations for planning and conducting troubleshooting and repair.

The Board concluded that roles, responsibilities, authorities, and accountabilities are not defined for system specialists.

3.4.2 Analyze the Hazards

BNL Technical Note No. 148, *Continuity of Electrical Power of the AGS*, documented the hazards in ungrounded delta electrical systems. RHIC OPM 5.1.5.0.1, *Supplemental Electrical Safety Standard RHIC Project*, requires ground-fault detection on ungrounded delta electrical systems, as well as the immediate notification of the appropriate personnel and elimination of the ground fault. The 1999 RHIC SAD also identifies the requirements for ground-fault monitoring. The C-AD electrical engineer and CAS electronic technicians were not aware that ground faults were not monitored on the STAR power supply, nor were they aware of any ground faults on the system. BNL has not analyzed the hazards associated with ungrounded delta power supplies with ground faults.

A Job Risk Assessment (JRA) is used as a management tool for documenting hazards and ensuring adequate controls are identified for reducing risks. JRAs are not used to educate or train the workers on the hazards and controls identified in them, and there is no requirement for them to be reviewed during work planning. The actual preparation of the JRA is performed by personnel from the C-AD ESH&Q group. Decisions about the types of jobs for which JRAs will be developed are made by the C-AD ESH&Q personnel given that responsibility, with input from supervisors and some workers. Once the JRAs are developed, they are reviewed by supervisors and by some, but not all, workers impacted by the potential hazards of the job.

The purpose of the JRA is to address each discrete step (task) for a given job by identifying the severity of the hazards, the number of workers involved, the frequency with which the task is accomplished, the severity of an accident, and the likelihood that an accident would occur. JRA 13-05B, *LOTO of the STAR Magnet Power Supplies in Building 1006*, rated the risks of this job as "negligible" for each of the steps, based on the listed controls. In addition to the hazards directly encountered with the work, indirect or other co-located work or environmental hazards, such as noise, are addressed. JRA 13-05B fails to consider ground fault as a potential hazard.

A Facility Risk Assessment (FRA) is used as a management tool for documenting and assessing all significant risks that exist within a given type of operational area or given type of operational room within a facility. BNL recommends that all areas and facilities that may present hazards to the worker be considered for risk assessment. The April 27, 2005, FRA in place at the time of the accident, FRA 12-06, *STAR Area-Wide*, does not specifically identify ground faults as a hazard, but does recognize arc flash and electric shock or electrocution as potential hazards under multiple circumstances involving electricity. The controls identified for these hazards as they may pertain to ground faults are typically shown as "procedures, training, PPE as per NFPA 70E," and "grounding standards," respectively. FRA 12-06 rates these risks as either "negligible" or "acceptable."

Criteria for determining whether a job requires enhanced work planning is outlined in OPM 2.28, *Procedure for Work Planning and Control for Operations*. All moderate- and high-hazard work requires enhanced work planning. Low-hazard work can be assigned as skill-of-the-worker and requires no formal work planning (or enhanced work planning) unless work control coordinators feel the tasks are complex or have concerns with the level of coordination. OPM 2.28d, "Work Screening Guideline," and SBMS provide examples of low, moderate, and high ES&H risks. However, activity complexity and coordination level are not formally defined, and no detailed direction is provided. In interviews with CAS electronic technicians and work control coordinators, the only element that was consistently mentioned as an example of complexity was coordination between multiple workers or interface issues with other organizations. All CAS personnel interviewed stated that the work was rated as having a low ES&H risk. Decisions to use a procedure (or other enhanced work planning) were based on personal professional judgment.

The Board concluded that risk assessments have not identified the hazards associated with ground faults on an ungrounded delta power system.

The Board concluded that all C-AD employees conducting work covered by a JRA should be required to review the JRA with their supervisor prior to commencing work.

3.4.3 Develop and Implement Hazard Controls

The Board evaluated the engineering controls for the circuit breaker providing power to panel PB-1. The instantaneous trip settings for circuit breaker 6C41, which protects panel PB-1, were set at 24,000 amperes. Had these trip settings been below the actual fault current, the clearing time, and consequently the incident energy, would have been greatly reduced. Had the settings been reduced and the circuit breaker tripped instantaneously, without a 0.15-second, short-time delay, it could have cleared the arc flash in 0.05 seconds instead of 0.2 seconds. The reduction would have reduced the incident energy from 16.9 cal/cm^2 to 4.46 cal/cm^2 with substantially less damage. These reductions were not identified during the design or review cycles for the STAR power systems, nor was the lack of a ground-fault alarm, which is registered at an attended location (i.e., RHIC Main Control Room). The C-AD electrical engineer and CAS electronic technicians were unaware of the potential hazards of this system, and the RHIC Control Room operators were unaware that the ungrounded delta power system for substation 6C of STAR was not monitored for ground faults and that this could create a hazardous condition.

The operation of the STAR Magnet power supply switches is controlled with procedure C-AD OPM 11.4.3, *STAR Power Supply Operating Procedure*. This procedure requires the use of checklists when shutting down and starting up power. The procedure does not identify the required level of PPE to be worn when operating the switches in panel PB-1, and identifies requirements only for the control of energized systems with the Kirk Key interlock system and the procedure for operation of the power switches. Panel PB-1 was not labeled with the hazard risk level as required by BNL's commitment to its March 2005 self-assessment and the SC Energized Electrical Work Review. The arc flash calculations for this panel also had not yet been conducted.

The C-AD electrical engineer for the STAR Magnet power supplies had been actively involved in the design and installation of the system and trained the CAS electronic technicians on the operation of the

STAR Magnet power supplies. This training included performing diagnostic techniques to resolve system failures. On April 14, 2006, no pre-job briefing was conducted because the C-AD electrical engineer and CAS electronic technicians had frequently performed the troubleshooting and fuse replacement tasks. OPM 2.28 requires that all work must be planned; OPM 2.28.i, "Conducting Effective Pre-job Briefing, Walk-downs, and Post-Job Reviews," provides guidance on conducting these activities, including required PPE and roles and responsibilities for a task. The shutdown and startup of the STAR Magnet power supplies are also covered by procedure (C-AD OPM 11.4.3).

The C-AD electrical engineer and CAS electronic technicians did not discuss how the diagnostic and fuse replacement tasks were to be performed and did not discuss the hazards or any PPE requirements necessary for the work to be performed. They also did not discuss who was going to perform which task. They stated that, because of their familiarity with performing the task, they simply conducted the work without the procedure checklist. A STAR manager indicated that in some instances, the CAS electronic technicians completed the checklist upon their return to the Control Room before filing the checklist and that it was a common practice to fill out the checklist after the work was completed. The Board reviewed the binder of completed checklists stored in the STAR Control Room against the Control Room Logbook, compared the completed checklists that had been filed, and found that they did not always match.

NFPA 70E 110.7(G) requires that a job briefing be held before each job. The briefing is required to cover such topics as hazards associated with the job, work procedures, special precautions, energy source controls, and PPE requirements.

The Board concluded that the decision process used for determining when a pre-job brief should not be conducted is not in compliance with NFPA 70E requirements; the work conducted on April 14, 2006, had the potential to expose personnel to energized circuits.

The Board concluded that CAS technicians are not completing the C-AD OPM 11.4.3 checklist when the steps are performed. This can lead to unsafe conditions and loss of configuration control.

3.4.4 Perform Work within Controls

According to the C-AD Associate Chair for ES&H/QA, 40 percent of the work at C-AD, including troubleshooting and corrective maintenance, is skill-of-the-worker. The C-AD electrical engineer directed or coordinated the work of others on April 14, 2006, under assumed authority. The troubleshooting for the STAR Magnet power supplies is considered to be a low-risk, skill-of-the-worker task. However, troubleshooting does expose workers to significant hazards such as de-energizing circuits, zero-voltage checks, and work on capacitor banks. The troubleshooting work that was being conducted was performed without discussion, planning, or coordination between the C-AD electrical engineer and the CAS electronic technicians (see section 3.4.3).

At the time of the accident, skill-of–the-worker activities did not require pre-job briefings. Well-defined protocols or procedures are not in place to address changes in work scope and identification of new hazards when routine corrective maintenance becomes troubleshooting.

Employees are empowered with stop-work authority, as described in the SBMS subject area "Stop Work." Although the C-AD electrical engineer did not have adequate PPE to perform the task of operating the switches in panel PB-1, the CAS electronic technicians took no action to stop the work. It is unclear from testimony who opened the switches in panel PB-1. The technicians were present when the engineer closed the switches and did not discuss his failure to wear appropriate PPE. They claimed they were unaware that he was going to close the switches.

The Board concluded that employees do not understand when to use stop-work authority, as evidenced by the failure to stop the C-AD electrical engineer from performing work when not wearing appropriate PPE.

The Board concluded that the bounding definition used for skill-of–the-worker tasks allows hazardous work activities to be conducted with inadequate planning, control, or procedures.

3.4.5 Provide Feedback and Improvement

The purpose of the C-AD ASSRC is to review conventional safety aspects and hazard control of new and modified C-AD systems, including equipment systems obtained from outside universities or other accelerators for use at BNL. A procedure provides instructions for C-AD group leaders to evaluate which new and modified C-AD systems require an ASSRC review. This procedure also provides instructions for ASSRC members, line managers, and designated project engineers and project physicists for reviewing new and modified C-AD systems. Feedback on review items is provided through "Action Items." Electrical drawings are not subject to review by the ASSRC unless in the opinion of the project engineer they have not met the identified requirements in OPM 9.1, *Conventional ES&H Review of an Accelerator System*. Because the project engineer believed he had met all requirements, there was no reason for him to take the ungrounded delta electrical system design to the ASSRC for their review.

Design specifications for the transformers and rectifiers for the STAR power supply contained adequate inspection and acceptance testing criteria to aid in ensuring that the power supply met the design specifications. The Board requested documentation used in the installation and acceptance testing on the STAR power systems and ground-fault detection. No documentation other than the heat-load test was provided. C-AD personnel stated that the power supply cables were meggered by the contractor after installation, but no documentation on this or any other operability testing and commissioning documentation has been found.

Trouble reports are generated when power disruption to the accelerator is greater than an hour; however, disruptions of experiments such as STAR would not result in a trouble report even if loss of power to the magnet lasted over an hour. STAR is a responsibility of the Physics Department, not C-AD; therefore, the requirements for trouble reporting are not applicable. Blown power fuses have been occurring on the STAR power supply regularly since its commissioning. The fuse failures and the work associated with replacing the fuses have not been evaluated against the increased exposure to CAS employees. According to BNL, the switches on panel PB-1 have been operated more than 1,000 times since the installation.

The SBMS subject area "Environment, Safety, Health and Quality (Tier 1) Inspections," requires the line organizations to identify and track to closure ESH&Q deficiencies and observations identified during walkthough inspections of work areas. Administrative areas are inspected annually, and laboratory and work areas are inspected quarterly unless a basis for less frequent inspections are documented. Semiannual inspections are being conducted in Building 1006A by C-AD. Due to the scope and purpose of the Tier 1 inspections, it is unlikely that these inspections would have identified the issues surrounding this accident.

The Power Distribution Supervisor was responsible performing inspections of the C-AD power substation transformers and switchgear. The Power Distribution Supervisor stated that although these inspections are scheduled monthly, due to demands on his time, only two inspections (October 21, 2005 and April 11, 2006) had been performed over the past year. On both dates the inspector noted a "slight ground" on 1006C as determined by reading the bus voltage meters (October 21, 2005 – "1006C2 slight grd," April 11, 2006 – "1004A slight grd, 1006C slight grd Bus1"). The significance of the slight ground notation cannot be evaluated since the bus voltage readings were not noted on the form. It is not known how long the slight ground condition had existed on the system. The inspections were performed to observe metering for ground faults; monitor oil levels; look for oil leaks, proper ground connections, and condition of enclosures (e.g., rusting); and examine the condition of insulators. On several occasions these inspections identified insulators that were starting to fail, but the existence of the slight ground conditions were not communicated to the Chief Electrical Engineer for his evaluation. There is no procedure for conducting the inspections.

In December 2002, the BNL Office of Independent Oversight led a comprehensive electrical safety review which included participation by the BNL Electrical Safety Committee. A follow-up review was slated to occur during 2004, but was postponed to 2005 because of other priorities. When it was learned that SC was going to be conducting an energized electrical work review at BNL in April 2005, this follow-up review was cancelled. In preparation for the SC Energized Electrical Work Review at BNL, the Laboratory conducted an electrical safety program self-assessment during March 2005 Also, a self-assessment of energized electrical work was conducted in March 2005 in preparation for the April 2005 SC Energized Electrical Work Review. This self-assessment identified 10 nonconformances with NFPA 70E. The nonconformances were in areas such as training and hazard recognition in regards to approach boundaries and in PPE, work permits, and one-line drawings.

Corrective actions to the nonconformances were developed and tracked in the BNL Action Tracking System (ATS). Most of the actions were completed in 2005. At the time of the accident a significant open corrective action was the performance of the arc-flash calculations for many buildings, including 1006A. The completion of the arc flash calculations is dependent on the verification and correction of inaccurate one-line electrical drawings, as well the collation of information necessary for input to the calculations. It should be noted that the one-line drawing for the STAR Magnet power systems in Building 1006A was found to be inaccurate. The work required to complete the arc flash calculations has been impeded because of organizational coordination and the application of resources. The C-AD engineer responsible for conducting the calculations stated that he has not had worked on these calculations in more than 1½ years due to conflicting priorities. Overall responsibility to ensure the arc flash calculations across the Laboratory are completed on a prioritized basis has not been established.

The April 2005 SC Energized Electrical Work Review presented a summary of the Laboratory's implementation of NFPA 70E. The report identified a noteworthy practice in provision of FR clothing and PPE for all electrical workers and appropriate supervisors. It also had a noteworthy practice for the engineering controls being taken for flash hazard analysis for the entire site to reduce the hazard level of electrical tasks. The C-AD electrical engineer did not wear appropriate PPE for the activity he was conducting. He had been offered the FR clothing but did not request it, and his supervisor was unaware that he did not have the appropriate clothing.

C-AD had not been conducting arc flash calculations at least 6 months prior to the SC review. The state of the arc flash calculations in C-AD was not identified in the SC review because of the limited sampling of data taken in a short period of time.

BNL and C-AD developed training for electrical workers and supervisors in response to the SLAC arc flash accident. This training instructed the workers to stand to one side of the pane when operating a disconnect switch or circuit breaker. Switches 2A and 3A could not be operated with one hand due to the spring strength of this type of switch. The supervisors of the CAS electronic technicians and electrical engineer were not aware that personnel were operating the switches with both hands. Additionally, these workers did not inform their supervisors that they could not operate the switches with one hand.

Although the Laboratory had provided training on approach boundaries and appropriate PPE, the portion of the training that addressed PPE did not address the necessity to ensure that protective clothing is properly worn (i.e., collars buttons fastened, sleeves rolled down and buttoned, and shirt tucked into pants). The CAS electronic technicians interviewed were not knowledgeable of these requirements. In addition, the CAS electronic technicians interviewed did not have a full understanding of approach boundaries.

The Board concluded that BNL's inability to provide documents related to acceptance testing could impact the safety, reliability, and operation of the accelerator.

The Board concluded that the failure to trend the blown fuses in the STAR Magnet power systems created a missed opportunity for increased management attention to correct the situation. This failure increased the exposure of CAS personnel to the hazards of operating the magnet power supply switches.

The Board concluded that the monthly inspections of substations and transformers were performed without procedures detailing the conduct of inspection, acceptance criteria, and notification protocol.

The Board concluded that BNL management has not aggressively pursued completion of arc flash calculations throughout the site. This leaves employees potentially exposed to dangerous arc flash energy releases.

The Board concluded that the April 2005 SC Energized Electrical Work Review led to an inaccurate understanding by BNL management and SC line management of the state of implementation of NFPA 70E.

The Board concluded that the NFPA 70E training provided to BNL employees was not effective in ensuring that workers were properly wearing protective clothing.

4.0 JUDGMENTS OF NEED

Judgments of Need are managerial controls and safety measures believed necessary to prevent or minimize the probability of recurrence. They flow from the causal factors and are directed at guiding managers in developing corrective actions. The Executive Summary identifies the Board's Judgments of Need. Judgments of Need and causal factors are provided in Table 4-1 below.

Table 4-1. Judgments of Need and Causal Factors

No.	Judgment of Need	Causal Factor
JON 1	BNL needs to conduct the following engineering evaluations of ungrounded delta electrical systems throughout the site: • Ensure that instantaneous trip settings for power circuit breakers are reduced to the lowest value possible consistent with in-rush and load considerations and coordination with other overcurrent devices. • Evaluate the installation of a dampening resistor across the broken delta points of all three-phase wye broken delta connected potential transformers that are connected to ungrounded 480-volt systems. • Evaluate increasing the sensitivity of the ground-fault detecting relays in all 480-volt ungrounded substations. • Evaluate the installation of surge suppressors on all 480-volt ungrounded panel boards to suppress common-mode overvoltages and their related phase-to-ground flashovers. • Perform an engineering evaluation on the continued use of ungrounded 480-volt power systems and consider conversion to high-resistance ground systems. • Verify that all potential transformers connected to ungrounded 480-volt systems are provided with ground-fault monitoring.	BNL failed to ensure that good industrial practices, as well as Laboratory and applicable NFPA 70, *National Electrical Code,* requirements for the design, test, operation, and maintenance of ungrounded delta electrical power distribution systems, were used at RHIC.
JON 2	BNL needs to immediately verify that all ground-fault monitoring devices are connected to remote alarms in the RHIC Main Control Room.	BNL failed to ensure that ground-fault detector relays, as well as monitoring and alarm systems, were properly designed, installed, tested, and maintained.
JON 3	BNL needs to determine and review the specific factors by which RHIC and Plant Engineering design reviews and approval processes failed to ensure installation of a functional ground-fault monitoring and alarm system as specified in BNL standards and DOE requirements. Additionally, BNL needs to implement the corrective actions identified by this review to prevent recurrence.	BNL failed to ensure that a ground-fault monitoring system provided prompt notification to the Main Control Room for safe and reliable operation.
JON 4	BNL needs to improve the rigor and formality of the engineering design and design review processes to ensure that the functional specifications identified in DOE Directives and BNL standards are addressed.	

No.	Judgment of Need	Causal Factor
JON 5 JON 6 JON 7	BHSO needs to monitor BNL's evaluation of the design review and approval processes. BNL needs to improve the rigor and formality in acceptance testing, operational readiness review, and commissioning activities to ensure that the functional and performance specifications identified in DOE Directives and BNL Standards have been implemented. BNL needs to ensure that all equipment necessary for safe and reliable operations of the RHIC (as described in the current Safety Assessment Document) has been verified to meet design specifications.	
JON 8 JON 9	BNL needs to develop, train, and implement formal work controls to address receipt of initial ground-fault alarms at RHIC. BNL needs to establish the precautionary actions for safe work on ungrounded delta electrical systems that have a ground fault.	BNL failed to ensure that formal work controls were established for working on ungrounded delta electrical systems that could have a ground-fault condition.
JON 10 JON 11	BNL needs to inspect all GE Spectra Series switches to ensure their mechanical integrity. BNL needs to establish a preventive maintenance inspection program for electrical distribution system equipment to include fused-disconnect switches and ground-fault relays.	BNL failed to establish a preventive maintenance inspection program for fused-disconnect switches and ground-fault relays.
JON 12 JON 13	BNL needs to establish a formalized project management process for arc flash calculations that establishes priorities, resources, and accountabilities. BNL needs to conduct an independent effectiveness review of the implementation of the personal protective equipment and training requirements of NFPA 70E.	BNL failed to implement NFPA 70E.
JON 14	BHSO needs to monitor the status of the corrective actions for the following: • SC Energized Electrical Work Review; • BNL self-assessment of energized electrical work; and • Performance of BNL's effectiveness review.	BNL failed to adequately monitor the progress of its implementation of NFPA 70E requirements. BHSO failed to adequately validate BNL's implementation of corrective actions from BNL's self-assessment and the SC Energized Electrical Work Review.

No.	Judgment of Need	Causal Factor
JON 15	BNL needs to strengthen the C-AD Conduct of Operations Program to ensure procedural adherence, formality of operations, performance of required job briefings, and the exercise of stop-work authority.	BNL failed to ensure adequate implementation of the C-AD Conduct of Operations Program.
JON 16	BNL needs to issue a lessons learned to the DOE Corporate Lessons Learned Program Web site on the issues surrounding the GE Spectra Series switches.	
JON 17	BNL needs to establish a formal process for making modifications to nationally recognized testing laboratory-listed and labeled electrical equipment for the installation of Kirk Key interlock systems.	BNL failed to establish a formal process for making modifications to nationally recognized testing laboratory-listed equipment.

5.0 BOARD SIGNATURES

Justin T. Zamirowski, Chairperson* August 11, 2006
DOE Accident Investigation Board Date
U.S. Department of Energy
Office of Science Chicago Office

Thomas McDermott, Member* August 11, 2006
DOE Accident Investigation Board Date
U.S. Department of Energy
Office of Science Chicago Office

Karl Moro, Member* August 11, 2006
DOE Accident Investigation Board Date
U.S. Department of Energy
Office of Science Chicago Office

Peter Kelley, Member August 11, 2006
DOE Accident Investigation Board Date
U.S. Department of Energy
Office of Science Brookhaven Site Office

*DOE Trained Investigator

6.0 BOARD MEMBERS AND ADVISORS

Chairperson	Justin T. Zamirowski, DOE Chicago Office
Member	Thomas McDermott, DOE Chicago Office
Member	Karl Moro, DOE Chicago Office
Member	Peter Kelley, BHSO
Advisor	Joseph Drago, DOE Chicago Office
Technical Consultant	David O'Neill – MAS Engineering Consultants
Technical Consultant	Keith Forstell – Management Concepts
Legal Advisor	Irene Atney, BHSO – OCC
Laboratory Liaison	Andrew McNerney – BNL
Technical Writer	Catherine Brown – Parallax, Inc.
Graphics Designer	John Norton – Parallax, Inc.

Appendix A
Board Appointment Memorandum

Department of Energy
Brookhaven Site Office
P.O. Box 5000
Upton, New York 11973

APR 17 2006

Justin T. Zamirowski
Safety and Technical Services
Office of Science
Chicago Office

SUBJECT: APPOINTMENT OF INVESTIGATION BOARD

I hereby establish a Type B Accident Investigation Board to investigate the personal injury accident which occurred at the Brookhaven National Laboratory (BNL) site on April 14, 2006. The injured person was operating a 480 VAC switch associated with the STAR detector at RHIC. An apparent arc flash occurred causing skin burn injury and starting a small fire which was extinguished. The person was transported to the hospital and hours later released with first and second degree burns to his hands, forearms, face and an irritated eye. I have determined that a Type B Investigation is appropriate for this accident investigation.

You are hereby appointed Accident Board Chairperson. The Board members will be Tom McDermott and Karl Moro from your office, and Peter Kelley from my office. The Board will be assisted by advisors, consultants, and other support personnel as determined by you.

The scope of the Board's investigation will include but is not limited to identifying all relevant facts; analyzing the facts to determine the direct contributing and root causes of the accident; developing conclusions; and determining the actions that when implemented should prevent the recurrence of a similar accident. The investigation will be conducted in accordance with DOE O 225.1 and will specifically address the role of DOE and Contractor organizations and management systems as they may have contributed to the accident.

The Board will provide my office with periodic reports on the status of the investigation but will not include any conclusions until an analysis of all the causal factors has been completed. Draft copies of the factual portion of the investigation report should be provided to the Brookhaven Site Office (BHSO) officials and BNL for a factual accuracy review prior to report finalization.

The report should be provided to me for acceptance by May 31, 2006. Discussions of the investigation and copies of the draft report will be controlled until I authorize release of the final report.

If you have any questions, please contact me at (631) 344-3424, or Robert Desmarais of my staff at (631) 344-5434.

M. Holland

Michael D. Holland
Site Manager

cc:
L. Dever, SC-31, FORS.
D. Erbschloe, SC-2, FORS.
D. Kovar, SC-26, GTN.
R. Staffin, SC-25, GTN.
P. Dehmer, SC-22, GTN.
L. Vann, SC-CH
K. Moro, SC-CH
T. McDermott, SC-CH
C. Nealy, SC-CH
P. Kelley, SC-BHSO
R. Desmarais, SC-BHSO
M. Bebon, BSA
P. Chaudhari, BSA

Appendix B
Arc Flash Accident Event Chronology

Date	Time	Event
April 14, 2006	0705	Long Island Power Authority (LIPA) experiences a power dip due to failed insulator at the LIPA Ruland Road Substation.
April 14, 2006	-	Brookhaven National Laboratory (BNL) Relativistic Heavy Ion Collider Project (RHIC) Main Control Room experiences several system failures due to power dip.
April 14, 2006	-	RHIC Main Control Room contacts the Collider-Accelerator Support Group (CAS) to report a failure of one of Solenoidal Tracker at RHIC (STAR) Space Trim power supplies.
April 14, 2006	-	CAS electronic technician 1 and CAS electronic technician 3 respond to Building 1006A.
April 14, 2006	-	CAS electronic technician 1 and CAS electronic technician 3 go to the STAR Control Room to view monitors for help in determining the source of the problem.
April 14, 2006	-	CAS electronic technician 1 and CAS electronic technician 3 leave the STAR Control Room and go to the Building 1006A Mechanical Equipment Loft.
April 14, 2006	-	CAS electronic technician 1 and CAS electronic technician 3 shut down the STAR Main Magnet power supply, Pole Tip Trim East power supply, Pole Tip Trim West power supply, Space Trim East power supply, and Space Trim West power supply.
April 14, 2006	-	CAS electronic technician 1 and CAS electronic technician 3 use the Kirk Key interlock system to lock out electrical power to the STAR Main Magnet power supply, Pole Tip Trim East power supply, Pole Tip Trim West power supply, Space Trim East power supply, and Space Trim West power supply. (Although they believe they had performed zero-voltage checks in accordance with established procedures, the electronic technicians were unable to recall all of the specific work tasks performed.)
April 14, 2006	-	CAS electronic technician 1 replaces a one silicon control rectifier fuse in the Space Trim West power supply and one silicon control rectifier fuse in the Space Trim East power supply; CAS electronic technician replaces five capacity bank trigger fuses in the STAR Main Magnet Power Supply.
April 14, 2006	-	CAS electronic technician 1 and CAS electronic technician 3 release the lockout to restore electrical power by reversing the sequence of the Kirk Key interlock system to the STAR Main Magnet power supply, Pole Tip Trim East power supply, Pole Tip Trim West power supply, Space Trim East power supply, and Space Trim West power supply.
April 14, 2006	-	CAS electronic technician 1 and CAS electronic technician 3 return to the STAR Control Room and bring the system back on line.

Date	Time	Event
April 14, 2006	-	After determining that the system is operating properly, CAS electronic technician 1 and CAS electronic technician 3 return to Building 940.
April 14, 2006	-	RHIC Main Control Room reports to CAS electronic technician 1 the occurrence of a direct current fault on the STAR power supply and an indication of high current ripple in the Space Trim West power supply.
April 14, 2006	-	CAS electronic technician 1 and CAS electronic technician 3 return to Building 1006A and proceed to the Mechanical Equipment Loft.
April 14, 2006	-	CAS electronic technician 1 and CAS electronic technician 3 perform comparative diagnostic testing of the Space Trim East and the Space Trim West power supplies and confirm high current ripple in the Space Trim West power supply, but are uncertain as to cause.
April 14, 2006	-	CAS electronic technician 4 arrives at Building 1006A Mechanical Equipment Loft to provide additional assistance.
April 14, 2006	0945	CAS electronic technician 1 pages C-AD electrical engineer to provide additional support to determine cause and corrective action for eliminating high current ripple in the Space Trim West power supply.
April 14, 2006	-	CAS electronic technician 3 and CAS electronic technician 4, knowing that the C-AD electrical engineer is responding to eliminate high current ripple in the Space Trim West power supply, leave Building 1006A and return to Building 940.
April 14, 2006	-	C-AD electrical engineer and CAS electronic technician 2 leave Building 912 and drive in BNL vehicle to Building 1006A.
April 14, 2006	-	C-AD electrical engineer and CAS electronic technician 2 arrive at Building 1006A Mechanical Equipment Loft; CAS electronic technician 1 goes to the STAR Control Room to shut down system through associated computer.
April 14, 2006	-	C-AD electrical engineer performs diagnostics and determines the high current ripple is caused by additional silicon control rectifier fuses blown in Space Trim West power supply.
April 14, 2006	-	CAS electronic technician 1 learns that the needed computer has crashed and at that time is inoperable.
April 14, 2006	-	C-AD electrical engineer goes to RHIC Main Control Room; CAS electronic technician 2 stays at the Building 1006A Mechanical Equipment Loft.
April 14, 2006	-	C-AD electrical engineer arrives at STAR Control Room, learns of computer problems, and informs CAS electronic technician 1 that they will return to the Mechanical Equipment Loft to restore the system locally.
April 14, 2006	-	C-AD electrical engineer and CAS electronic technician 1 return to the Building 1006A Mechanical Equipment Loft.

Date	Time	Event
April 14, 2006	-	C-AD electrical engineer, CAS electronic technician 1, and CAS electronic technician 2 start shutting down the STAR Main Magnet power supply, Pole Tip Trim East power supply, Pole Tip Trim West power supply, Space Trim East power supply, and Space Trim West power supply. (It is unclear from testimony who opened the switches in Panel PB-1.)
April 14, 2006	-	CAS electronic technician 2 racks out the circuit breaker for the STAR Main Magnet power supply; CAS electronic technician 1 is preparing tools to perform work.
April 14, 2006	-	C-AD electrical engineer opens the fused-disconnect switch (2A) for the East Pole Tip Trim power supply and the fused-disconnect switch (3A) for the West Pole Tip Trim power supply at panel PB-1
April 14, 2006	-	C-AD electrical engineer and CAS electronic technician 2 use Kirk Key interlock system to lockout electrical power to the Pole Tip Trim East power supply, Pole Tip Trim West power supply, Space Trim East power supply, and Space Trim West power supply, and the STAR Main Magnet Power Supply. (Although they believe they had performed zero-voltage checks in accordance with established procedures, the electronic technicians were unable to recall all of the specific work tasks performed.)
April 14, 2006	-	CAS electronic technician 1 replaces two silicon control rectifier fuses in the Space Trim West power supply.
April 14, 2006	-	C-AD electrical engineer, CAS electronic technician 1, and CAS electronic technician 2 partially reverse the sequence of the Kirk Key interlock system to the STAR Main Magnet power supply, Pole Tip Trim East power supply, Pole Tip Trim West power supply, Space Trim East power supply, and Space Trim West power supply to permit diagnostic testing of the Space Trim West power supply.
April 14, 2006	-	CAS electronic technician 1 and CAS electronic technician 2 close switch for Space Trim West power supply.
April 14, 2006	~1015	C-AD electrical engineer and CAS electronic technician 1 turn on Space Trim West power supply and find it operating normally.
April 14, 2006	-	CAS electronic technician 1 obtains approvals from the RHIC Main Control Room and STAR Control Room to start up system.
April 14, 2006	-	C-AD electrical engineer, CAS electronic technician 1, and CAS electronic technician 2 release the lockout to restore electrical power by finalizing the reversal of the sequence of the Kirk Key interlock system to the STAR Main Magnet power supply, Pole Tip Trim East power supply, Pole Tip Trim West power supply, Space Trim East power supply, and Space Trim West power supply.
April 14, 2006	-	CAS electronic technician 2 positions self to re-rack the circuit breaker for the STAR Main Magnet power supply.
April 14, 2006	-	CAS electronic technician 1 is positioned next to CAS electronic technician 2 cleaning up tools and equipment.

Date	Time	Event
April 14, 2006	-	C-AD electrical engineer positions self to close the fused-disconnect switch (2A) for the East Pole Tip Trim power supply and the fused-disconnect switch (3A) for the West Pole Tip Trim power supply.
April 14, 2006	-	CAS electronic technician 2 is kneeling down in front of the STAR Main Magnet power supply preparing to re-rack its circuit breaker.
April 14, 2006	-	C-AD electrical engineer is standing in front of panel PB-1 and closes the fused-disconnect switch (2A) for the East Pole Tip Trim power supply.
April 14, 2006	-	CAS electronic technician 2 is demonstrating to CAS electronic technician 1 the process for re-racking the circuit breaker for the STAR Main Magnet power supply.
April 14, 2006	~1020	C-AD electrical engineer is standing in front of panel PB-1 and closes the fused-disconnect switch (3A) West Pole Tip Trim power supply and hears a loud noise and observes smoke and sparks emitted from panel due to arc flash.
April 14, 2006	-	The arc flash sets the C-AD electrical engineer's hair on fire, he experiences first-degree burns to scalp, face, chest; first- and second-degree burns to forearms and hands; receives corneal abrasion on left eye; and his non-flame-resistant short-sleeved polo shirt and t-shirt are slightly burned.
April 14, 2006	-	System drawings and specification documents situated next to panel PB-1 are set on fire from arc flash.
April 14, 2006	-	CAS electronic technician 1 and CAS electronic technician 2 are positioned with their backs to the C-AD electrical engineer when they hear a loud noise – they turn and see a shower of sparks over the C-AD electrical engineer.
April 14, 2006	-	CAS electronic technician 1 and CAS electronic technician 2 note that the smoke detectors in the Mechanical Equipment Loft activate Building 1006A fire alarm.
April 14, 2006	-	CAS electronic technician 1 uses his hands to smother the burning hair on the C-AD electrical engineer's head.
April 14, 2006	-	C-AD electrical engineer, CAS electronic technician 1, and CAS electronic technician 2 immediately rush out of the Building 1006A Mechanical Equipment Loft.
April 14, 2006	1024	RHIC Main Control Room and BNL Emergency Services receives fire alarm signal.
April 14, 2006	1024	CAS electronic technician 1 dials site emergency phone number (2222) from telephone (2994) at ground floor level in high bay and notifies BNL Emergency Services of an explosion in Building 1006A and the need for an ambulance.
April 14, 2006	-	CAS electronic technician 2 and C-AD electrical engineer exit from Building 1006A to parking area.
April 14, 2006	-	At his own request, C-AD electrical engineer is taken in BNL vehicle by CAS electronic technician 2 to the BNL Occupational Medicine Clinic; CAS electronic technician 1 remains at Building 1006A.

Date	Time	Event
April 14, 2006	1025	CAS electronic technician 1 notifies RHIC Main Control Room of event from telephone (2994) at ground floor level in high bay in Building 1006A.
April 14, 2006	-	BNL Fire/Rescue acting chief, while issuing a cutting and welding permit at Building 610, hears tone on fire/rescue radio announcing fire and explosion at Building 1006A.
April 14, 2006	-	BNL Fire/Rescue command vehicle, two pumper trucks, and ambulance leave BNL Fire House.
April 14, 2006	-	BNL Protective Force watch commander is notified of event and two officers are dispatched to Building 1006A to provide traffic control.
April 14, 2006	-	BNL Fire/Rescue acting chief, driving BNL vehicle to Building 1006A is waved down on Railroad Avenue, just south of East Fifth Avenue by CAS electronic technician 2 driving BNL vehicle.
April 14, 2006	-	C-AD electrical engineer exits BNL vehicle driven by CAS electronic technician 2 and approaches BNL vehicle driven by BNL Fire/Rescue acting chief.
April 14, 2006	-	BNL Fire/Rescue acting chief performs cursory medical evaluation of C-AD electrical engineer, learns that there is the only one injured person, and redirects BNL Fire/Rescue ambulance to Railroad Avenue, just south of East Fifth Avenue.
April 14, 2006	1026	BNL Fire/Rescue command vehicle and two pumper trucks arrive at Building 1006A.
April 14, 2006	-	BNL Fire/Rescue acting captain returns one pumper truck to BNL Fire House in exchange for the heavy rescue truck.
April 14, 2006	-	BNL Fire/Rescue Firefighters are met at Building 1006A by Collider-Accelerator Department employee who directs them to Mechanical Equipment Loft.
April 14, 2006	-	Three dressed-out BNL Fire/Rescue firefighters enter Building 1006A with two 17-pound halon 1211 portable fire extinguishers and one 10-pound dry chemical portable fire extinguisher.
April 14, 2006	1028	C-AD electrical engineer is placed into BNL Fire/Rescue ambulance and starts receiving emergency medical care.
April 14, 2006	-	BNL Fire/Rescue acting chief responds to Building 1006A and is transferred role of incident commander.
April 14, 2006	1029	Brookhaven Site Office notified of event through BNL sitewide page text message.
April 14, 2006	1030	BNL Pager Group message announces an “electrical accident” at Building 1006A, “command post” at Building 1006A, and patient being transported to Stony Brook Hospital.
April 14, 2006	1031	BNL Fire/Rescue heavy rescue truck arrives at Building 1006A.
April 14, 2006	1032	BNL Fire/Rescue acting chief issues an “Emergency Call In” page requesting three off-duty firefighters to respond to Building 1006A for backup.

Date	Time	Event
April 14, 2006	1034	BNL Fire/Rescue firefighter uses one 17-pound halon 1211 portable fire extinguisher to extinguish burning paper; declares the fire extinguished; begins venting the immediate are of byproducts of combustion.
April 14, 2006	1035	BNL line crew arrives to secure electrical power.
April 14, 2006	1035	BNL Fire/Rescue ambulance departs for Stony Brook University Hospital.
April 14, 2006	1039	BNL Pager Group message announces BNL Fire/Rescue on-scene at Building 1006A, there is one injury, and the fire is out.
April 14, 2006	1040	BNL Crisis Manager arrives on-scene.
April 14, 2006	1047	RHIC Main Control Room ceases all operations.
April 14, 2006	1049	BNL Pager Group message announces the BNL Fire/Rescue ambulance is transporting the C-AD electrical engineer to Stony Brook University Hospital.
April 14, 2006	1050	BNL line crew secures electrical power.
April 14, 2006	1052	BNL Crisis Manager declares operational emergency.
April 14, 2006	1052	BNL Pager Group message announces the identification of C-AD electrical engineer taken to Stony Brook Hospital.
April 14, 2006	1056	BNL Fire/Rescue ambulance arrives at Stony Brook University Hospital.
April 14, 2006	1124	BNL Fire/Rescue conducts air monitoring for potential toxic by-products of combustion in Building 1006A Mechanical Equipment Loft.
April 14, 2006	1135	BNL Crisis Manager terminates operational emergency.
April 14, 2006	-	BNL Fire/Rescue turns scene over to the BNL Associate Laboratory Director for High Energy and Nuclear Physics.
April 14, 2006	1205	Associate Laboratory Director for High Energy and Nuclear Physics terminates event.
April 14, 2006	1220	BNL Fire/Rescue vehicles arrive back at BNL Fire House.
April 14, 2006	1230	BNL Photographs accident scene.
April 14, 2006	1330	C-AD electrical engineer is released from Stony Brook University Hospital and is brought back to work by co-workers to retrieve his car before a coworker drives him home.
April 14, 2006	1430	BNL performs critique for initial gathering of facts surrounding arc flash.
April 14, 2006	1530	BHSO informs BNL of possibility of Type B Accident Investigation and directs BNL to preserve accident scene and begin collecting evidence.

Date	Time	Event
April 14, 2006	1630	As an outcome of critique, BNL Assistant Laboratory Director for Facilities and Operations requests BNL Protective Force to continue to secure access to the Building 1006A Mechanical Equipment Loft.
April 14, 2006	1700	BNL Director halts all work involving 480-volt switches pending approval from BNL Assistant Laboratory Director for Facilities and Operations.
April 14, 2006	1700	BHSO notifies BNL of intent to conduct a Type B Accident Investigation.
April 17, 2006	-	BHSO Issues Type B Accident Investigation Board appointment memo.
April 17, 2006	1730	Type B Accident Investigation Board arrives at BNL.

Appendix C
Barrier Analysis

Hazard: Energy release from arc flash **Target:** Engineer

	What were the barriers?	How did each barrier perform?	Why did the barrier fail?	How did the barrier affect the accident?
Design Controls				
1	BNL Technical Note 148, dated Dec. 14, 1978	Failed	Technical Note 148 affirms the continued use based on 30+ years of BNL's experience with ground-fault detection on all ungrounded 480-volt delta systems. Management processes failed to ensure that RHIC Project and PE personnel verified that the requirements in Technical Note 148 were included in STAR design, installation, and testing.	There is no remote monitoring system installed to detect a ground-fault condition. Control Room Operators and troubleshooting team of technicians and system specialist were not aware that there was a ground fault on the system when they responded to the failure of the Space Trim power supply units.
2	Supplemental Electrical Standard RHIC OPM 5.1.5.0.1, dated March 20, 1997	Failed	This standard required that ungrounded delta connections shall have ground-fault detection devices for each building served. RHIC Project and PE personnel did not ensure that this requirement was incorporated into the design.	Operations, maintenance, and engineering personnel were not aware that a ground-fault detection circuit was not installed.
3	One-line drawing approved, dated July 1999	Failed	The designer, reviewer, approver, and QA personnel did not identify that the one-line drawing showing the "#64" contact points for the 6C substation were not connected.	The engineering drawing design and review process missed the opportunity to identify that there was no local or remote means to monitor the existence of a ground fault.
4	DOE Contract DOE O 440.1A	Failed	BNL does not have a process by which it evaluates changes to the NEC to determine the impact on current installations. The DOE contract requires compliance with NFPA 70, in accordance with DOE O 440.1A. The 2005 NEC, with an effective date of August 5, 2004, required ungrounded delta systems to be monitored. This was a change from an FPN in the previous edition. The Subject Matter Expert (SME) for electrical codes and standards determines whether SBMS needs to be updated. The SME stated that the change to the NEC requiring monitoring of ungrounded systems would not require updating SBMS. The SBMS revision history indicates that in August 2005, SBMS procedure, ESH 1.5.0 "was revised to bring the standard into conformance with the current NEC."	The Engineering and C-AD organizations missed an opportunity to verify that a ground-fault monitoring system had been installed in substation 6C.
5	RHIC QAP	Failed	The engineering design reviews were inadequate in that they did not identify the omission of ground-fault detection. Additionally, more detailed or thorough research for testing of the power supplies may have enabled the ground-fault detection	The RHIC Project missed an opportunity to verify that a ground-fault monitoring system had been installed in substation 6C, as described in the SAD.

	What were the barriers?	How did each barrier perform?	Why did the barrier fail?	How did the barrier affect the accident?
			omission to be identified.	
6	Design of 480-volt ungrounded delta electrical power system	Failed	Design features such as instantaneous trip setting, dampening resistor across broken delta points, ground-fault detection relays, sensitivity installation alarm, and installation of surge suppressors were not adequate.	Installation of these features would have either detected ground-fault conditions, notified operators, or reduced the available energy in the arc flash.
			BNL Oversight Barriers	
1	S&EP Department Drawing Review, August 1997	Failed	The #64 relays on the engineering drawings are not connected (powered). There was no indication when a ground fault occurred. The design reviews failed to identify this omission. The design reviews were not formalized.	S&EP missed an opportunity to verify that a ground-fault monitoring system had been installed in substation 6C.
2	BNL ORR, June 15, 1998	Failed	The scope of the ORR was "limited to the feeder switchgear, transformer, and substation located in a fenced-in yard east of Building 1006." Since the magnet power supplies installation was not completed at the time this ORR was conducted, they were not included in the review. None of the findings identified the lack of ground-fault detection monitoring (i.e., circuit 64 not connected or absence of remote ground-fault monitoring).	The BNL ORR was incomplete and missed an opportunity to identify that the ground-fault monitoring circuit was not connected.
3	RHIC Commissioning, July 1999	Failed	At the time RHIC was commissioned, the use of formal procedures would have been at the professional discretion of members on the various committees involved in the review process. There were no procedures, checklists, or formal guidelines used in the installation and acceptance testing other than the heat load test. RHIC personnel did not verify that this SAD requirement was addressed in operational documents, such as alarm procedures and maintenance procedures.	The RHIC commissioning process missed the opportunity to identify that there was no local or remote means to monitor the existence of a ground fault.
4	RHIC SAD	Failed	RHIC SAD specified that ungrounded systems would be monitored to meet the requirements of the C-AD Chief Electrical Engineer's Supplemental Electrical Safety Standard RHIC Project, OPM 5.1.5.0.1, March 20, 1997, which required that the RHIC follow the longstanding BNL practice for installing ground-fault detection in the power distribution system for ungrounded delta systems. The review team did not verify that this requirement was met.	The failure to ensure that the monitoring of ungrounded systems was implemented allowed a ground-fault condition to go undetected.
5	Substation	Failed	Plant Engineering performed monthly	Monthly inspection of the substation

	What were the barriers?	How did each barrier perform?	Why did the barrier fail?	How did the barrier affect the accident?
	monthly inspections (voltage monitoring of the three phases)		inspections of the transformer equipment. The purpose of the inspection included observing voltage meter readings for ground faults, transformer oil levels, inspection for oil leaks, proper ground connections, condition of enclosures (rusting, etc.) and examining the condition of insulators. Due to insufficient resources, PE had conducted only two monthly inspections in the last calendar year. Although the recorded information recorded is "slight ground on 1006C," there were no quantitative acceptance criteria. The supervisor did not inform the Chief Electrical Engineer of this condition because he thought that the condition was not significant.	voltages is not adequate to detect all ground-fault failure modes such as the sputtering type that was likely to have occurred in this accident.
6	Management observations of workers' performance	Failed	Supervisors had not observed workers operating the failed switch. Management did not ask workers if there were difficulties with operating the switch under the current policy.	Management missed an opportunity to verify that the revised switch operating policy was being properly executed either by direct observation of work or by inquiring following completion of the work. Supervisor did not ensure that employee was wearing PPE as required by BNL requirements.
			DOE Oversight Barriers	
1	DOE Review of BNL's Implementation of NFPA 70E, dated April 2005	Failed	The scope of the review focused on the planning and execution of work conducted on energized equipment. The review evaluated programmatic elements of NFPA 70E. The report documented that BNL had been provided or ordered FR clothing and PPE for all electrical workers and their supervisors. The review was not comprehensive and did not identify that some workers were not wearing the proper PPE and appropriate clothing. The report does not state whether the team observed performance of work.	The review was not comprehensive and did not identify that some workers were not wearing the proper PPE and clothing. The C-AD electrical engineer was not wearing appropriate PPE (safety glasses and long-sleeved, natural fiber shirt) as was required.
			Physical Barriers	
1	Local ground-fault detection	Failed	Circuit 64 was not connected. Installation personnel did not identify that the indicator flag for the Circuit 64 relay would not function because the relay was not connected to a power source.	There was no local indication of a ground fault.
2	Cable insulation	Failed	The cable was inadvertently cut, and the defect was not noticed.	When the manhole in which the cable was installed became flooded, the cut insulation became submerged, resulting in a sputtering

	What were the barriers?	How did each barrier perform?	Why did the barrier fail?	How did the barrier affect the accident?
				ground fault.
3	Remote ground-fault detection	Failed	There was no remote indication of ground fault.	The ground-fault detection relay on the engineering drawing was not connected to the transformer circuit. There was no remote indication of ground fault status transmitted to either the STAR or Main Control Rooms. Personnel were not aware of the ground fault when restoring power.
4	Appropriate clothing and PPE	Failed	The C-AD electrical engineer did not bring his safety glasses to the work site prior to commencing troubleshooting.	Safety glasses would have provided additional eye protection by preventing exposure to foreign material. The C-AD electrical engineer sustained a corneal abrasion in his left eye.
5	GE Spectra Series fused-disconnect switches	Failed	Cracks develop in the switch's ABS base. It has been operated over 1,000 times (UL testing consists of 6,000 cycles).	The make/break arc could have traveled to the opposing screws on the switch, initiating an arc from an overvoltage condition.
			Training Barriers	
1	Control Room Operator Training	Failed	Operators do not have a comprehensive understanding of the instrumentation and design features of the power systems. Control Room Operators' training is to monitor the board and contact the electronic technicians to troubleshoot the system when a system goes into alarm.	Operators did not know that the BNL practice is to install remote monitoring for ground faults on ungrounded electrical systems.
2	SLAC Lessons Learned Sessions	Failed	BNL and C-AD developed training in response to the SLAC Type A Accident Investigation. This training instructed the worker to stand off to one side of the panel when operating a disconnect switch or circuit breaker. Because the worker had to use both hands and stand directly in front of the panel, this operation could not be implemented as instructed for switch 3A.	Operating the switch in this position placed the unprotected worker in a more vulnerable location relative to the energy released.
			Administrative Barriers	
1	Stop-work authority	Failed	The CAS electronic technicians observed the C-AD electrical engineer opening switches without proper clothing and PPE and did not initiate a stop-work action.	The C-AD electrical engineer was allowed to continue to work without the proper clothing and PPE.
2	STAR power supply shutdown and startup procedures	Failed	The procedure did not list proper PPE.	The C-AD electrical engineer was not wearing proper PPE (long-sleeved natural fiber shirt, long pants, and safety glasses)
3	Pre-job briefing	Failed	The CAS electronic technicians had performed these troubleshooting tasks on several occasions. They were familiar with	The C-AD electrical engineer was not wearing the proper PPE for the troubleshooting tasks that he had anticipated

	What were the barriers?	How did each barrier perform?	Why did the barrier fail?	How did the barrier affect the accident?
			the steps in the procedure, and no pre-job brief was conducted. BNL and C-AD procedures do not require a pre-job brief for all tasks. The role of the C-AD electrical engineer when working with the CAS electronic technicians in the troubleshooting task was unclear to all involved.	to perform.
4	Implementation of NFPA 70E	Failed	The C-AD electrical engineer declined the supervisor's provision of FR clothing. He was not wearing safety glasses at the time of the accident. Management did not ensure personnel wore NFPA 70E-compliant clothing when performing work. BNL workers were not required to wear FR clothing at all times although they were assigned energized electrical work.	The C-AD electrical engineer conducted work without the proper clothing and PPE.
5	Preventive maintenance of ground-fault relay	Failed	The ground-fault relay for 6C was not in a preventive maintenance program	Typical preventive maintenance program of this relay would have been on a 2-year schedule. Failure to perform the preventive maintenance was a missed opportunity to identify that the relay was not operable.

Appendix D

Change Analysis

Factors	Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
WHAT: Conditions, occurrences, activities, equipment	Electrical cable has a pinhole in the insulation.	Insulation is intact.	The cut insulation created the potential for an electrical ground.	Potential ground fault but not detectable.
	Flooded manhole.	Manhole is dry.	A flooded manhole provides a ground path.	Potential ground fault but not detectable.
	Electrical cable has a pinhole in the insulation that is submerged in a flooded manhole.	Insulation is intact and manhole is dry.	Insulation is cut, and the location of the cut is submerged in a flooded manhole.	Ground-fault condition exists.
	LIPA has power dip.	Stable power supply to RHIC.	Power dip causes electronic components and systems to fail, resulting in system troubleshooting, shutdown, and restart.	Electronic technicians and engineers are potentially exposed to electrical hazards associated with trouble-shooting, shutdown, and restart of electrical components.
	Remote monitoring of initial ground fault not provided.	Remote monitoring provides alarm in control room for ground faults.	Operations personnel do not know if a ground-fault condition exists and do not notify technicians to troubleshoot system.	There is no warning of a potentially unsafe electrical condition should a second ground fault occur.
	First ground fault is undetected when second ground fault occurs.	Remote monitoring identifies initial ground fault, and it is isolated prior to second ground fault occurring. Personnel performing work on components wear proper PPE for arc flash potential.	Without warning, a second ground fault causes the ungrounded delta system to become a grounded system.	Failure to know of initial ground fault creates the potential for an unsafe electrical condition and system shutdown in the event of a second ground fault. Personnel are at risk to arc flash.
	Design reviews, commissioning, and readiness review of RHIC STAR fails to identify missing ground-fault monitoring as specified in RHIC documents and the RHIC SAD.	Operations, engineering, readiness review, and safety assessments identify missing ground-fault monitoring.	Ground-fault monitoring system is not connected as specified in project documents.	There is no warning of a potentially unsafe electrical condition should a second ground fault occur.

Factors	Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
	Ungrounded delta power supply systems	High-resistance grounded power supply systems	Conversion to high-resistance grounded systems will stabilize the phase-to-ground potential, mitigate overvoltages, and generally provide the advantages of grounded system while maintaining the reliability inherent to ungrounded systems.	Overvoltage from ground fault prevented.
WHERE: Physical location, environment, conditions	Local indication of ground-fault relay in transformer enclosure not operable	Local indication of ground-fault relay connected and visually signals ground fault.	Periodic inspection would observe tripped visual indicator, identifying the existence of a ground-fault condition.	There is no warning of a potentially unsafe electrical condition should a second ground fault occur.
WHO: Staff involved, training, qualification, supervision	Engineer and technicians have not performed a pre-job brief.	Engineer and electronic technicians perform pre-job brief to discuss work to be performed, associated hazards and needed controls, as required by NFPA 70E.	Roles and responsibilities of the engineer and electronic technicians were not understood, nor were safety requirements discussed.	Electronic technicians and engineer missed an opportunity to establish work plan and assurance of safety precautions.
	Inspector notes slight ground fault on one of the phases and does not notify supervisor.	Inspector notes slight ground fault on one of the phases and notifies supervisor. Troubleshooting to determine location of ground fault proceeds.	Initial ground is allowed to continue to exist.	Ground-fault condition exists.
	Engineer operated switches for magnet power supplies without safety glasses and proper protective clothing without knowing of initial ground-fault condition.	Engineer operated switches for magnet power supplies with safety glasses and proper protective clothing. No ground-fault condition exists.	Engineer not wearing safety glasses and wears untreated natural fiber, long-sleeved shirt.	Overall injuries are minimized or prevented.

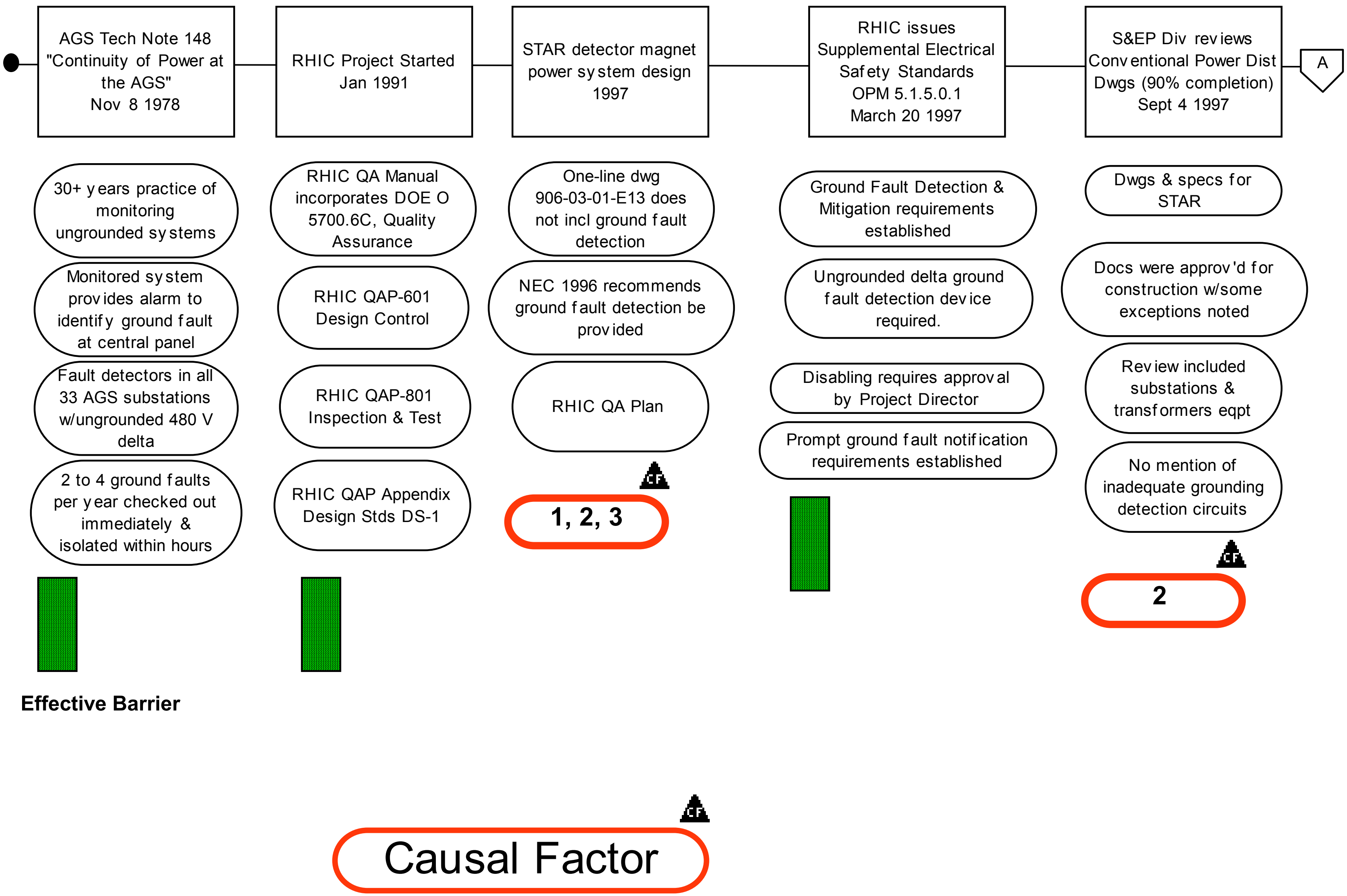
Factors	Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
	RHIC Project failed to comply with 1978 AGS Technical Note 148 for monitoring of ungrounded delta 480-volt electrical systems. Standard RHIC and C-AD OPM 5.1.5.0.1 (March 1997) requires that ungrounded Delta connections shall have ground-detection devices for each building served.	Remote ground-fault monitoring for RHIC STAR is installed.	No remote ground-fault monitoring system for Substation 6C for RHIC STAR.	Unsafe electrical condition went undetected from 1999 through to April 2006.
	Main Control Room operators do not question why there is no ground-fault monitoring indicator for Substation 6C for RHIC STAR.	Main Control Room operators know that all ungrounded delta systems should have alarm indications for safety and reliability should a ground fault occur.	Main Control Room operators are not knowledgeable of ground-fault situations in substation 6C for RHIC STAR.	There is no warning of a potentially unsafe electrical condition should a second ground fault occur.
	Main Control Room operators dispatch electronic technicians to troubleshoot system failures without communicating the existence of a ground fault.	Main Control Room operators communicate to the electronic technicians the existence of a ground fault alarm when notifying them of the need to troubleshoot system failures.	Main Control Room operators are not knowledgeable of ground-fault situations in substation 6C for RHIC STAR.	Electronic technicians and engineer were at risk of arc flash situation in the performance of their troubleshooting activities.
	Main Control Room operators were unaware that ground-fault detection was not provided on substation 6C.	All ground-fault conditions for ungrounded delta power systems monitored at the Main Control Room. Main Control Room operators receive alarm for ground fault. Operators take action to eliminate ground-fault condition by contacting C-AS personnel.	Main Control Room operators are not knowledgeable of ground-fault situations in substation 6C for RHIC STAR. Operators are aware that ground fault alarms for substation 6A are displayed on the Main Control Room monitors.	Electronic technicians and engineer were at risk of arc flash situation in the performance of their troubleshooting activities
HOW: Control chain, hazard analysis, monitoring	BNL fails to identify that RHIC STAR is noncompliant with NEC 2005. NEC 2005 is changed to require ground-fault monitoring of ungrounded delta electrical systems. (August 2004)	NEC compliance is a DOE contract requirement. BNL evaluates NEC 2005 changes and identifies no remote ground-fault monitoring system at RHIC STAR.	NEC elevated ground-fault monitoring of ungrounded electrical system from a recommendation to a requirement.	BNL and DOE are not aware that RHIC STAR is noncompliant with current NEC as required per the contract.

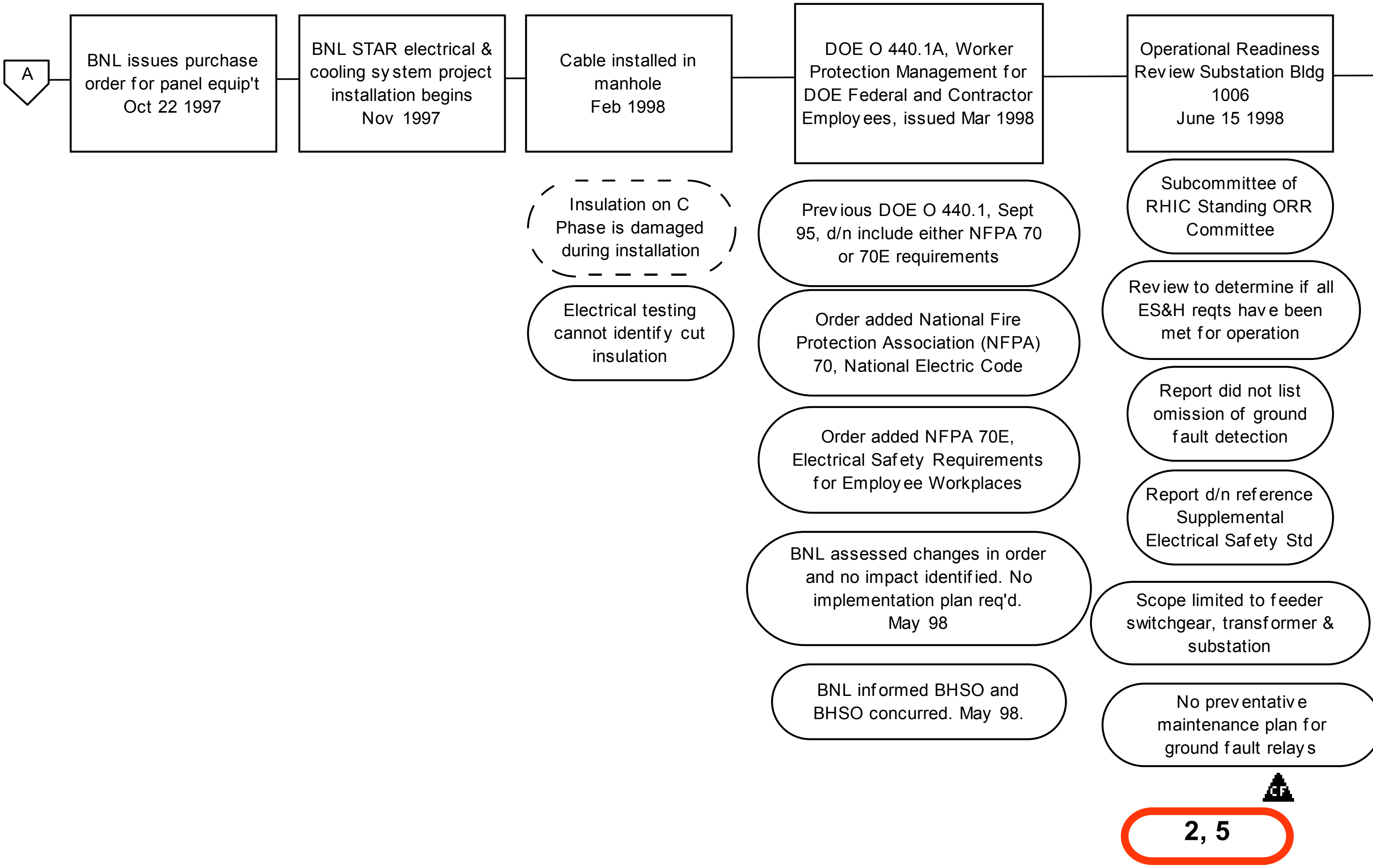
Appendix E

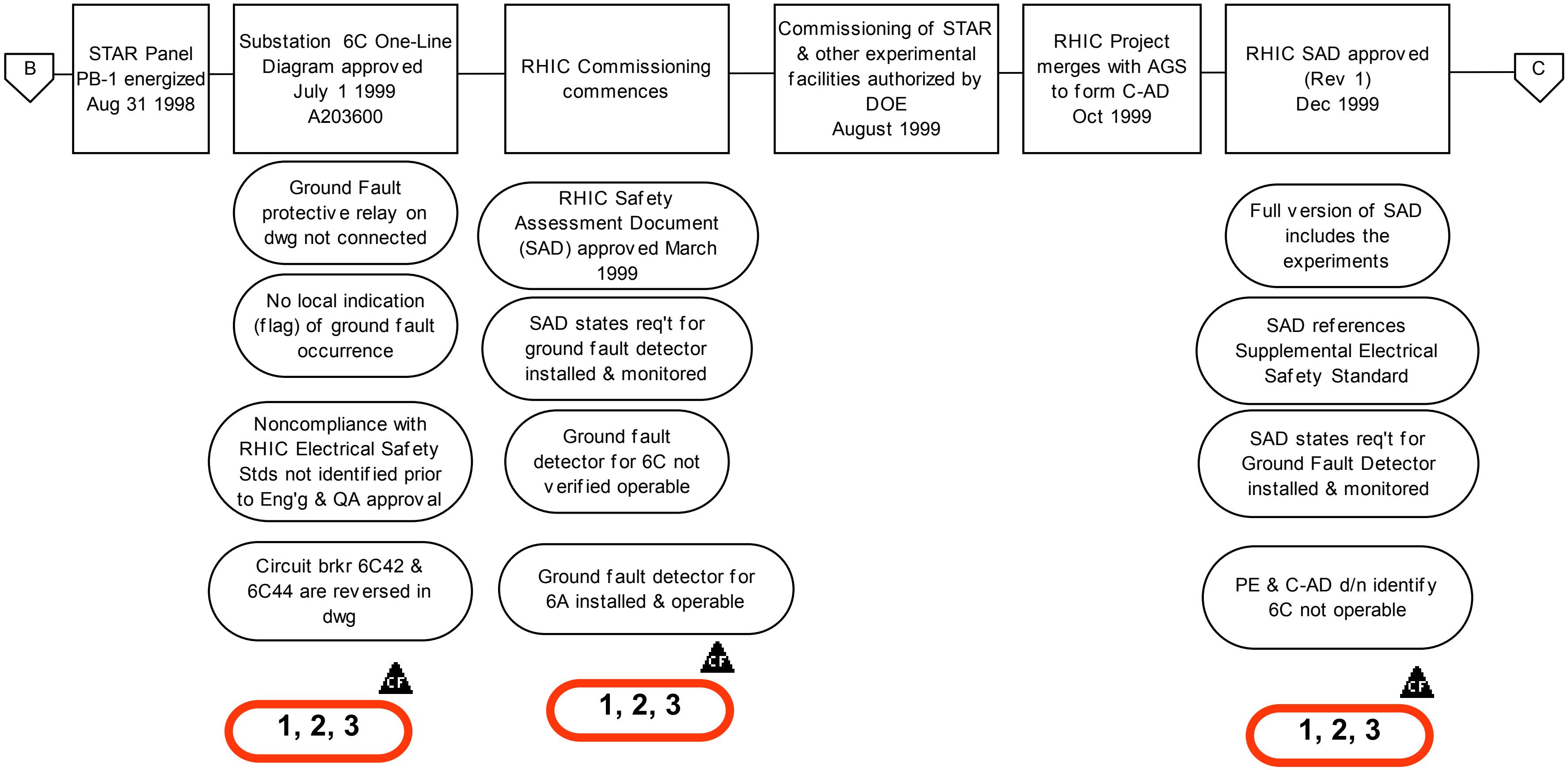
Events and Causal Factors Chart

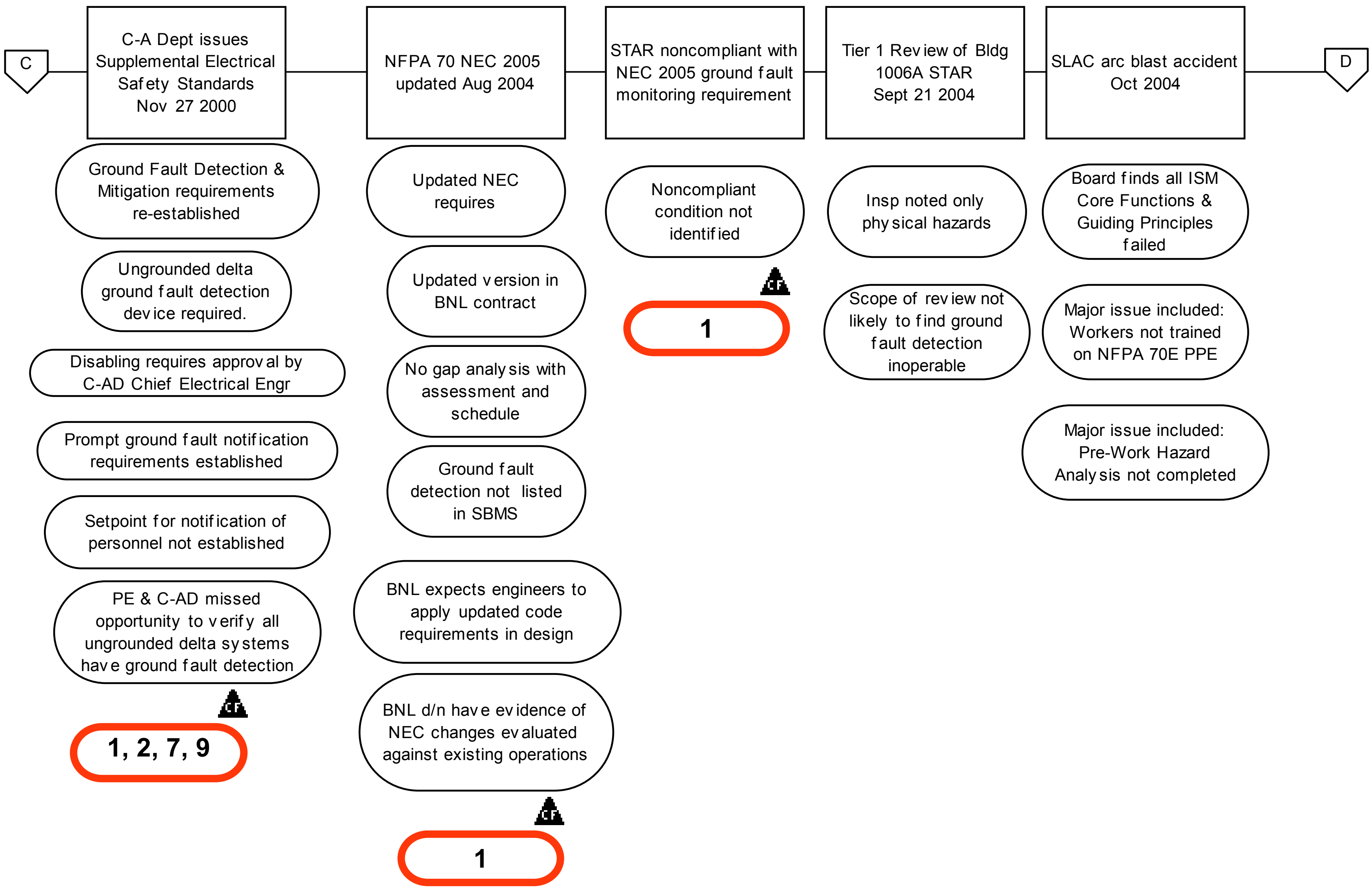
Causal Factors Identified on the Events and Causal Factors Chart

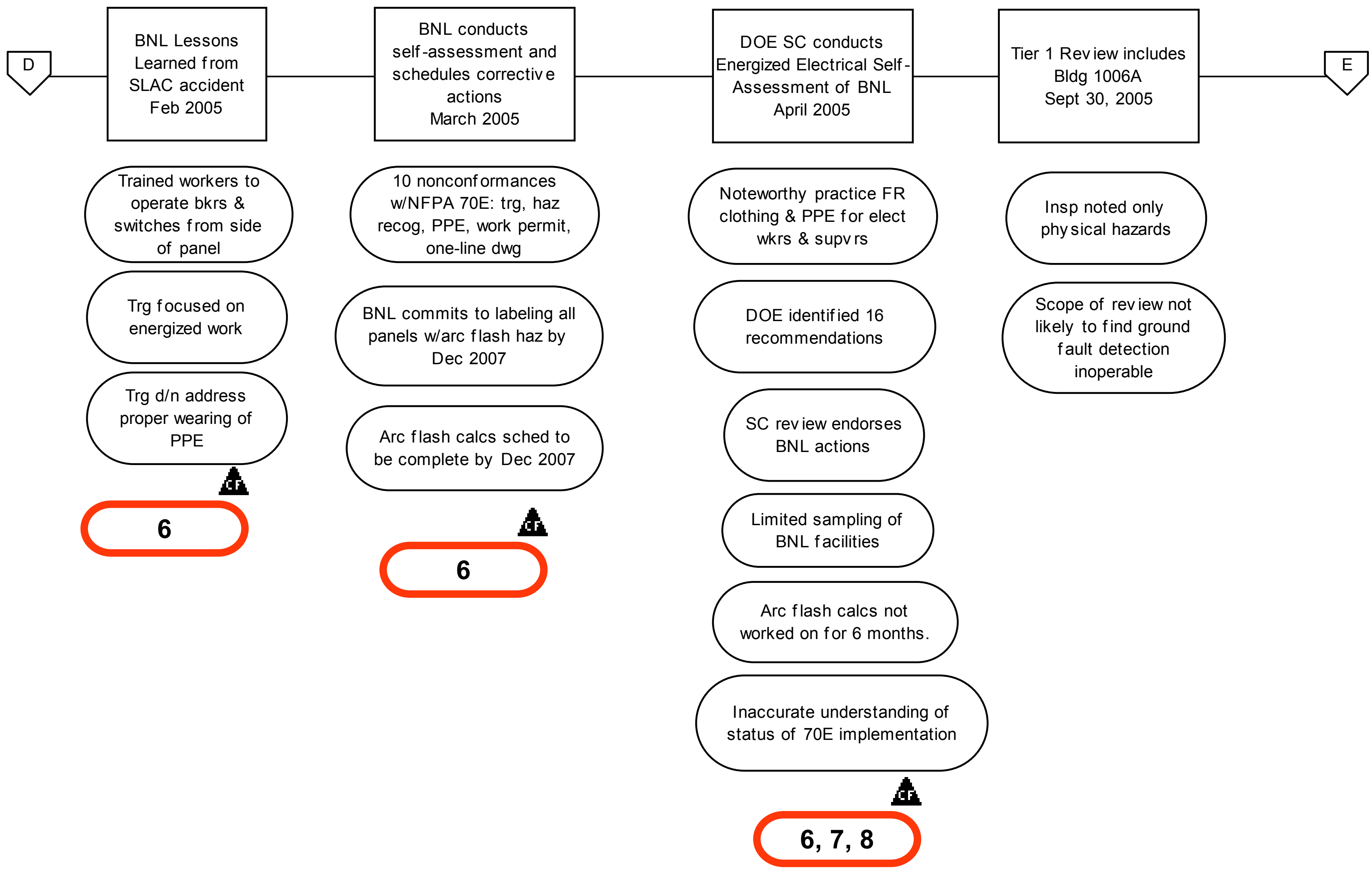
CF	Causal Factor
1	BNL failed to ensure that good industrial practices, as well as Laboratory and applicable NFPA 70, *National Electrical Code*, requirements for the design, test, operation and maintenance of ungrounded delta electrical power distribution systems were used at
2	BNL failed to ensure that ground-fault detector relays, as well as monitoring and alarm systems, were properly designed, installed, tested, and maintained.
3	BNL failed to ensure that a ground-fault monitoring system provided prompt notification to the Main Control Room for safe and reliable operation.
4	BNL failed to ensure that formal work controls were established for working on ungrounded delta electrical systems that might have a ground-fault condition.
5	BNL failed to establish a preventive maintenance inspection program for fused-disconnect switches and ground-fault relays.
6	BNL failed to implement NFPA 70E.
7	BNL failed to adequately monitor the progress of its implementation of NFPA 70E requirements.
8	BHSO failed to adequately validate BNL's implementation of corrective actions from BNL's self-assessment and the SC Energized Electrical Work Review.
9	BNL failed to ensure adequate implementation of the C-AD Conduct of Operations Program.
10	BNL failed to establish a formal process for making modifications to nationally recognized testing laboratory-listed equipment.

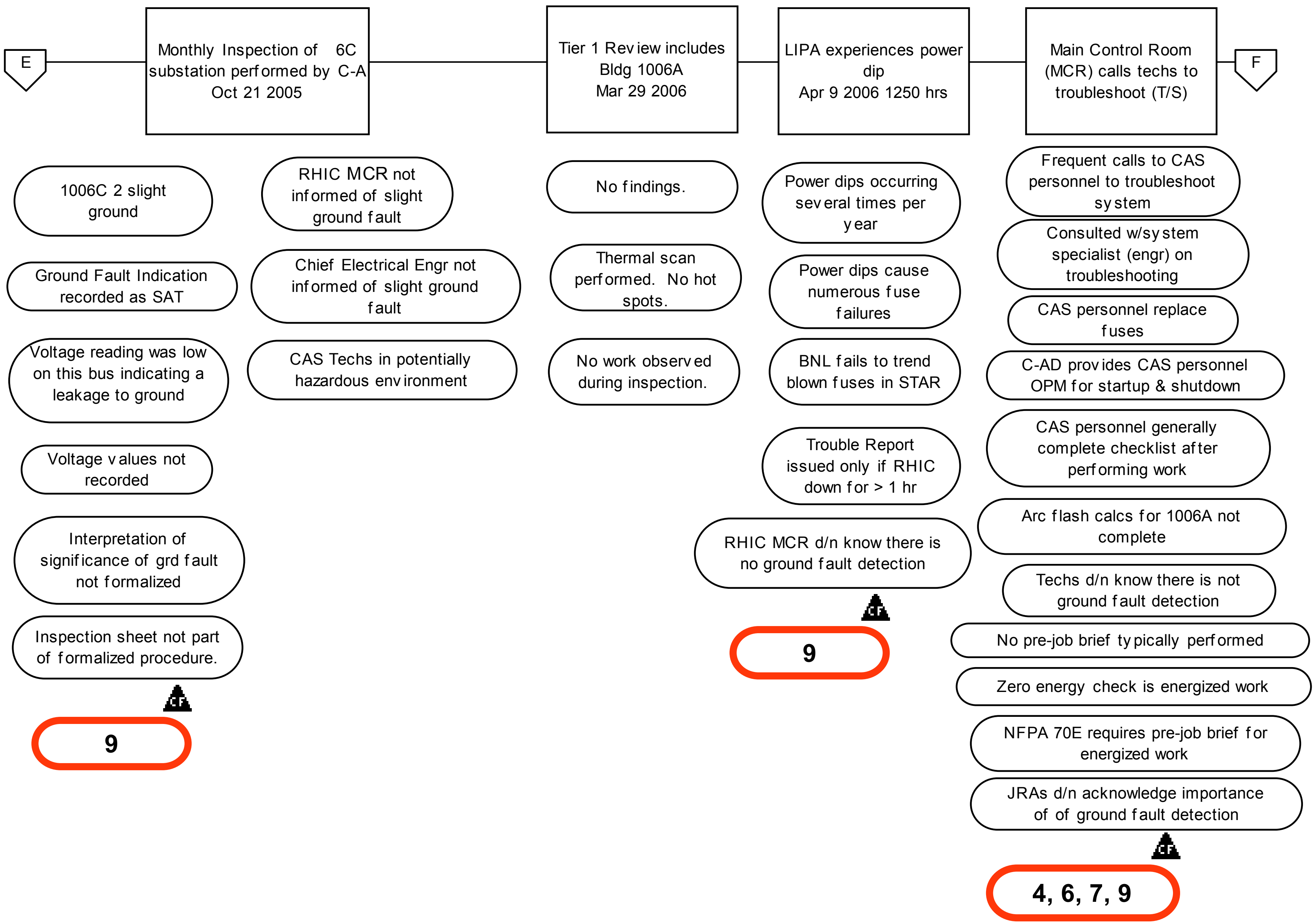

AGS Tech Note 148 "Continuity of Power at the AGS" Nov 8 1978
RHIC Project Started Jan 1991
STAR detector magnet power system design 1997
RHIC issues Supplemental Electrical Safety Standards OPM 5.1.5.0.1 March 20 1997
S&EP Div reviews Conventional Power Dist Dwgs (90% completion) Sept 4 1997
A
30+ years practice of monitoring ungrounded systems
Monitored system provides alarm to identify ground fault at central panel
Fault detectors in all 33 AGS substations w/ungrounded 480 V delta
2 to 4 ground faults per year checked out immediately & isolated within hours
RHIC QA Manual incorporates DOE O 5700.6C, Quality Assurance
RHIC QAP-601 Design Control
RHIC QAP-801 Inspection & Test
RHIC QAP Appendix Design Stds DS-1
One-line dwg 906-03-01-E13 does not incl ground fault detection
NEC 1996 recommends ground fault detection be provided
RHIC QA Plan
1, 2, 3
Ground Fault Detection & Mitigation requirements established
Ungrounded delta ground fault detection device required.
Disabling requires approval by Project Director
Prompt ground fault notification requirements established
Dwgs & specs for STAR
Docs were approv'd for construction w/some exceptions noted
Review included substations & transformers eqpt
No mention of inadequate grounding detection circuits
2
Effective Barrier
Causal Factor

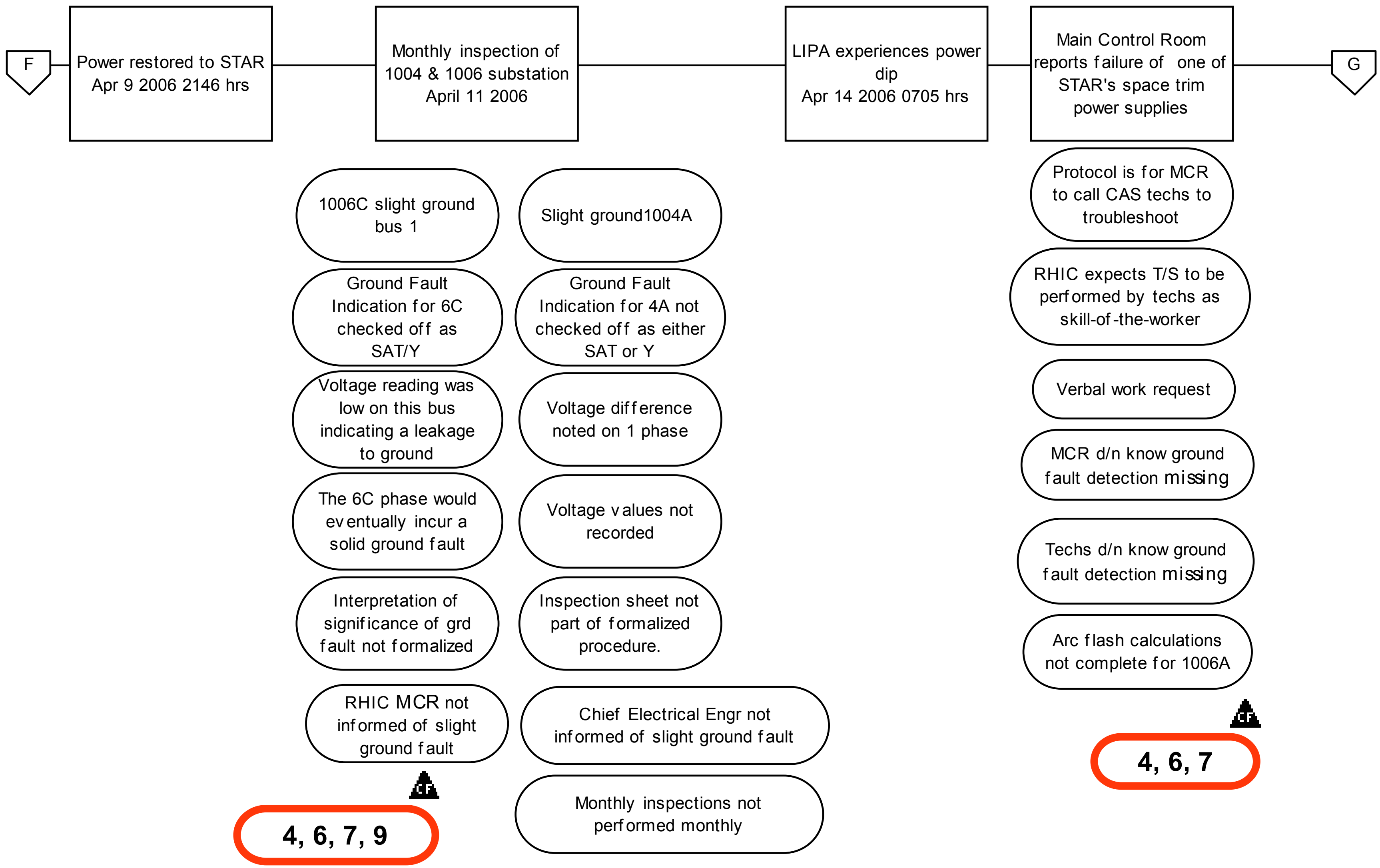

A
BNL issues purchase order for panel equip't Oct 22 1997
BNL STAR electrical & cooling system project installation begins Nov 1997
Cable installed in manhole Feb 1998
Insulation on C Phase is damaged during installation
Electrical testing cannot identify cut insulation
DOE O 440.1A, Worker Protection Management for DOE Federal and Contractor Employees, issued Mar 1998
Previous DOE O 440.1, Sept 95, d/n include either NFPA 70 or 70E requirements
Order added National Fire Protection Association (NFPA) 70, National Electric Code
Order added NFPA 70E, Electrical Safety Requirements for Employee Workplaces
BNL assessed changes in order and no impact identified. No implementation plan req'd. May 98
BNL informed BHSO and BHSO concurred. May 98.
Operational Readiness Review Substation Bldg 1006 June 15 1998
Subcommittee of RHIC Standing ORR Committee
Review to determine if all ES&H reqts have been met for operation
Report did not list omission of ground fault detection
Report d/n reference Supplemental Electrical Safety Std
Scope limited to feeder switchgear, transformer & substation
No preventative maintenance plan for ground fault relays
CF
2, 5
B

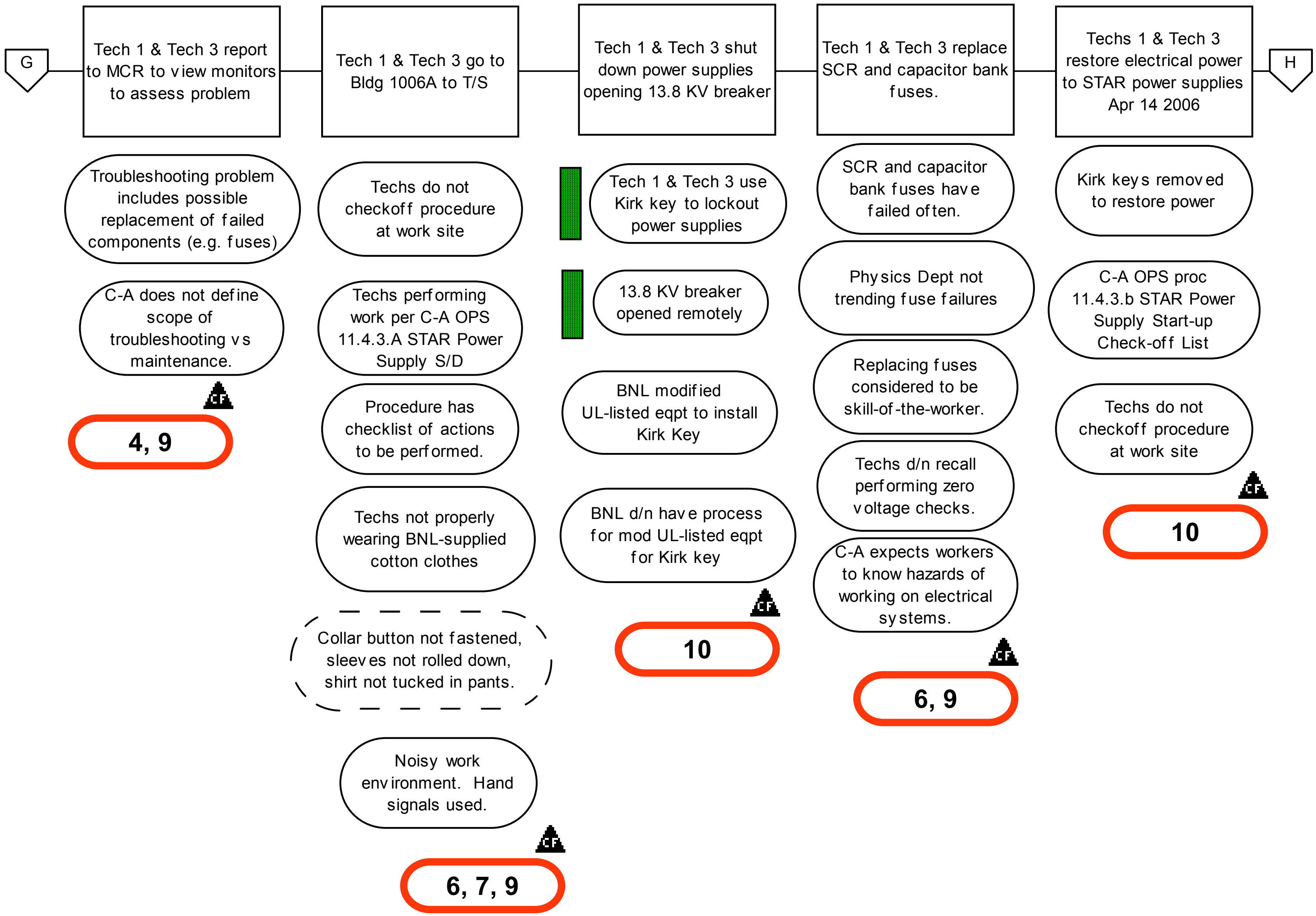

B
STAR Panel PB-1 energized Aug 31 1998
Substation 6C One-Line Diagram approved July 1 1999 A203600
RHIC Commissioning commences
Commissioning of STAR & other experimental facilities authorized by DOE August 1999
RHIC Project merges with AGS to form C-AD Oct 1999
RHIC SAD approved (Rev 1) Dec 1999
C
Ground Fault protective relay on dwg not connected
No local indication (flag) of ground fault occurrence
Noncompliance with RHIC Electrical Safety Stds not identified prior to Eng'g & QA approval
Circuit brkr 6C42 & 6C44 are reversed in dwg
CF
1, 2, 3
RHIC Safety Assessment Document (SAD) approved March 1999
SAD states req't for ground fault detector installed & monitored
Ground fault detector for 6C not verified operable
Ground fault detector for 6A installed & operable
CF
1, 2, 3
Full version of SAD includes the experiments
SAD references Supplemental Electrical Safety Standard
SAD states req't for Ground Fault Detector installed & monitored
PE & C-AD d/n identify 6C not operable
CF
1, 2, 3

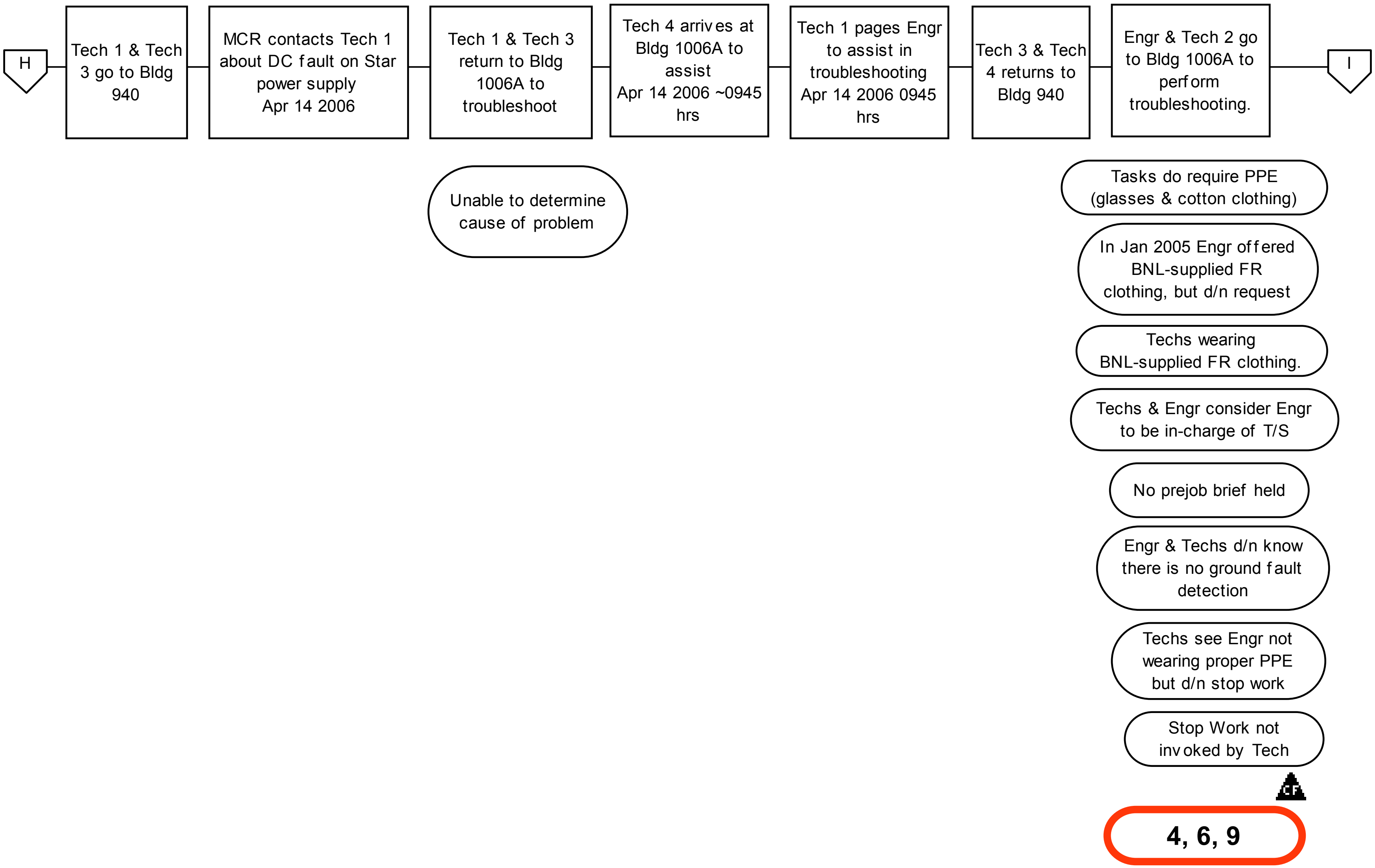

C
C-A Dept issues Supplemental Electrical Safety Standards Nov 27 2000
Ground Fault Detection & Mitigation requirements re-established
Ungrounded delta ground fault detection device required.
Disabling requires approval by C-AD Chief Electrical Engr
Prompt ground fault notification requirements established
Setpoint for notification of personnel not established
PE & C-AD missed opportunity to verify all ungrounded delta systems have ground fault detection
CF
1, 2, 7, 9
NFPA 70 NEC 2005 updated Aug 2004
Updated NEC requires
Updated version in BNL contract
No gap analysis with assessment and schedule
Ground fault detection not listed in SBMS
BNL expects engineers to apply updated code requirements in design
BNL d/n have evidence of NEC changes evaluated against existing operations
CF
1
STAR noncompliant with NEC 2005 ground fault monitoring requirement
Noncompliant condition not identified
CF
1
Tier 1 Review of Bldg 1006A STAR Sept 21 2004
Insp noted only physical hazards
Scope of review not likely to find ground fault detection inoperable
SLAC arc blast accident Oct 2004
Board finds all ISM Core Functions & Guiding Principles failed
Major issue included: Workers not trained on NFPA 70E PPE
Major issue included: Pre-Work Hazard Analysis not completed
D

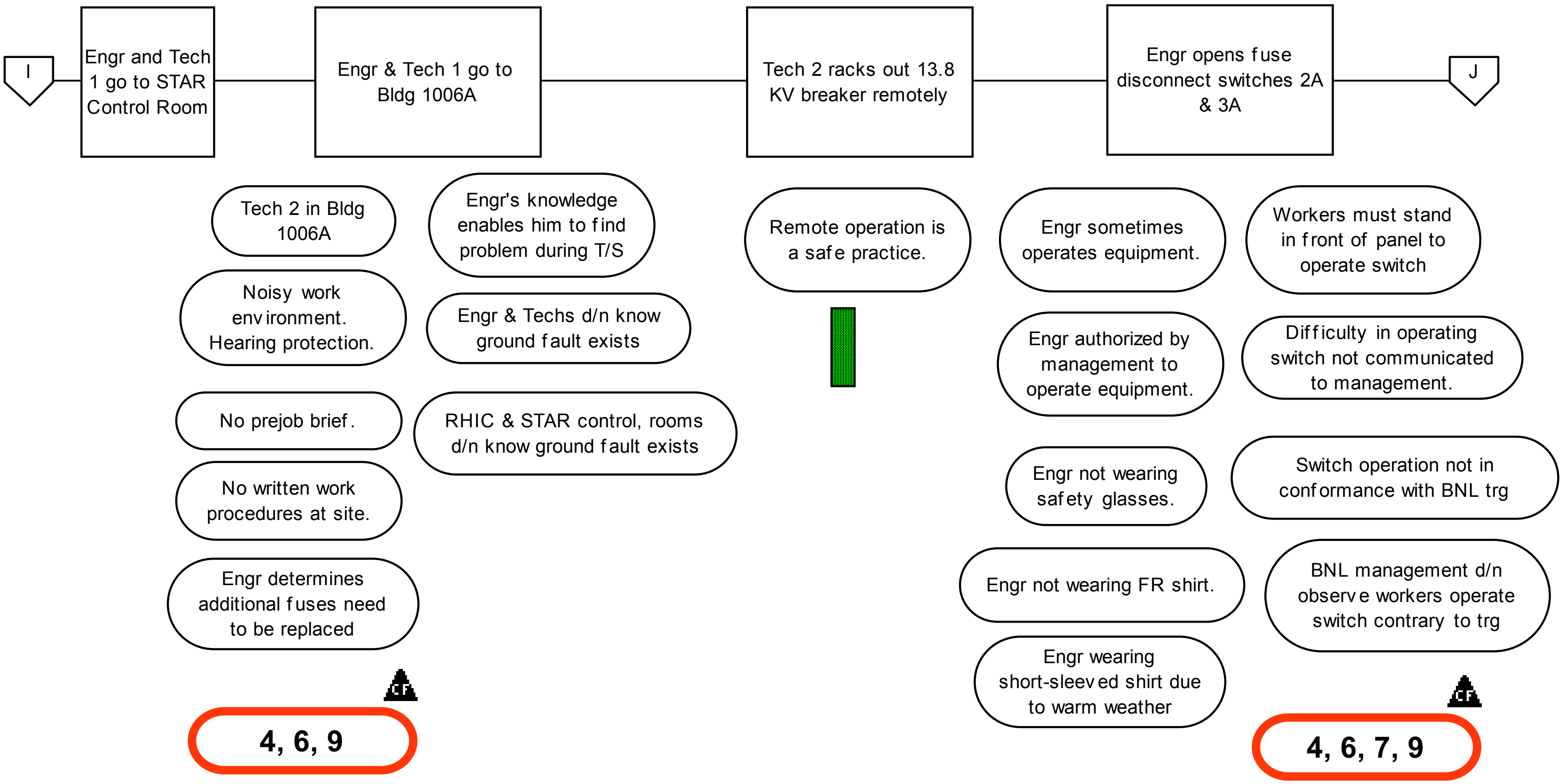

D
BNL Lessons Learned from SLAC accident Feb 2005
Trained workers to operate bkrs & switches from side of panel
Trg focused on energized work
Trg d/n address proper wearing of PPE
CF
6
BNL conducts self-assessment and schedules corrective actions March 2005
10 nonconformances w/NFPA 70E: trg, haz recog, PPE, work permit, one-line dwg
BNL commits to labeling all panels w/arc flash haz by Dec 2007
Arc flash calcs sched to be complete by Dec 2007
CF
6
DOE SC conducts Energized Electrical Self-Assessment of BNL April 2005
Noteworthy practice FR clothing & PPE for elect wkrs & supvrs
DOE identified 16 recommendations
SC review endorses BNL actions
Limited sampling of BNL facilities
Arc flash calcs not worked on for 6 months.
Inaccurate understanding of status of 70E implementation
CF
6, 7, 8
Tier 1 Review includes Bldg 1006A Sept 30, 2005
Insp noted only physical hazards
Scope of review not likely to find ground fault detection inoperable
E

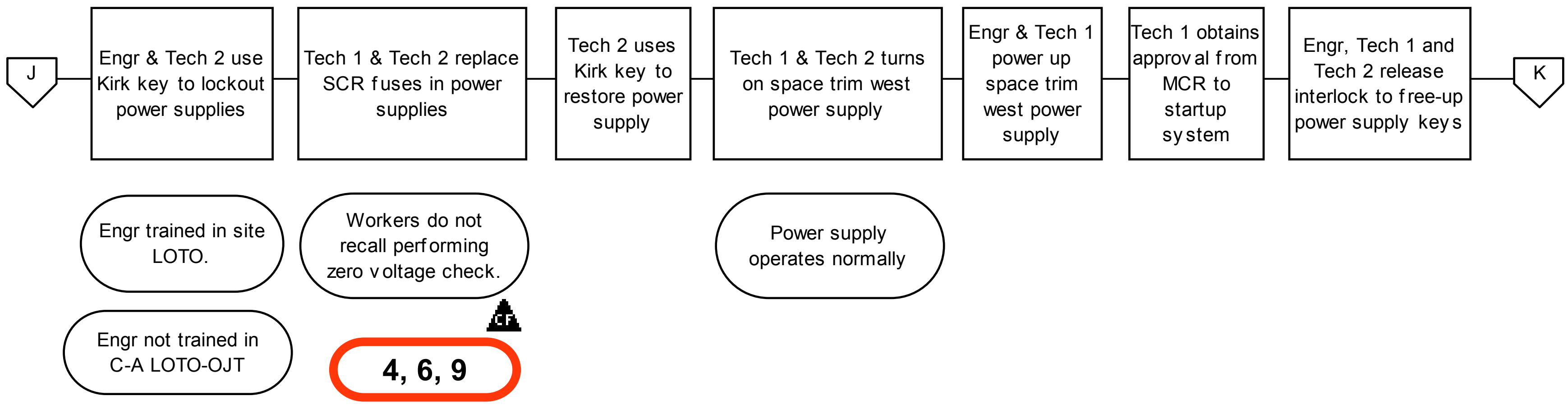

E
Monthly Inspection of 6C substation performed by C-A Oct 21 2005
Tier 1 Review includes Bldg 1006A Mar 29 2006
LIPA experiences power dip Apr 9 2006 1250 hrs
Main Control Room (MCR) calls techs to troubleshoot (T/S)
F
1006C 2 slight ground
Ground Fault Indication recorded as SAT
Voltage reading was low on this bus indicating a leakage to ground
Voltage values not recorded
Interpretation of significance of grd fault not formalized
Inspection sheet not part of formalized procedure.
CF
9
RHIC MCR not informed of slight ground fault
Chief Electrical Engr not informed of slight ground fault
CAS Techs in potentially hazardous environment
No findings.
Thermal scan performed. No hot spots.
No work observed during inspection.
Power dips occurring several times per year
Power dips cause numerous fuse failures
BNL fails to trend blown fuses in STAR
Trouble Report issued only if RHIC down for > 1 hr
RHIC MCR d/n know there is no ground fault detection
CF
9
Frequent calls to CAS personnel to troubleshoot system
Consulted w/system specialist (engr) on troubleshooting
CAS personnel replace fuses
C-AD provides CAS personnel OPM for startup & shutdown
CAS personnel generally complete checklist after performing work
Arc flash calcs for 1006A not complete
Techs d/n know there is not ground fault detection
No pre-job brief typically performed
Zero energy check is energized work
NFPA 70E requires pre-job brief for energized work
JRAs d/n acknowledge importance of of ground fault detection
CF
4, 6, 7, 9

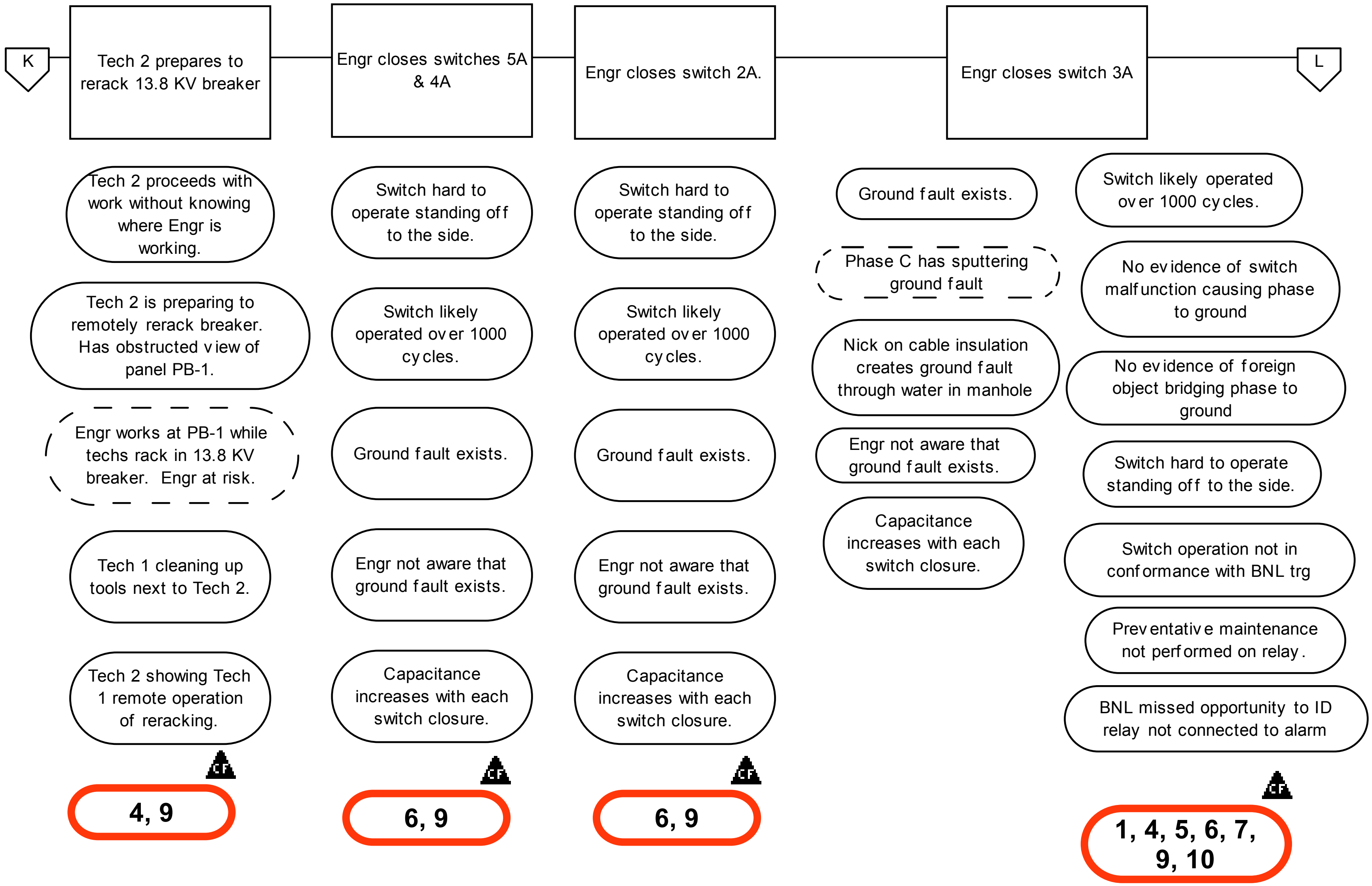

F
Power restored to STAR Apr 9 2006 2146 hrs
Monthly inspection of 1004 & 1006 substation April 11 2006
LIPA experiences power dip Apr 14 2006 0705 hrs
Main Control Room reports failure of one of STAR's space trim power supplies
G
1006C slight ground bus 1
Ground Fault Indication for 6C checked off as SAT/Y
Voltage reading was low on this bus indicating a leakage to ground
The 6C phase would eventually incur a solid ground fault
Interpretation of significance of grd fault not formalized
RHIC MCR not informed of slight ground fault
CF
4, 6, 7, 9
Slight ground1004A
Ground Fault Indication for 4A not checked off as either SAT or Y
Voltage difference noted on 1 phase
Voltage values not recorded
Inspection sheet not part of formalized procedure.
Chief Electrical Engr not informed of slight ground fault
Monthly inspections not performed monthly
Protocol is for MCR to call CAS techs to troubleshoot
RHIC expects T/S to be performed by techs as skill-of-the-worker
Verbal work request
MCR d/n know ground fault detection missing
Techs d/n know ground fault detection missing
Arc flash calculations not complete for 1006A
CF
4, 6, 7

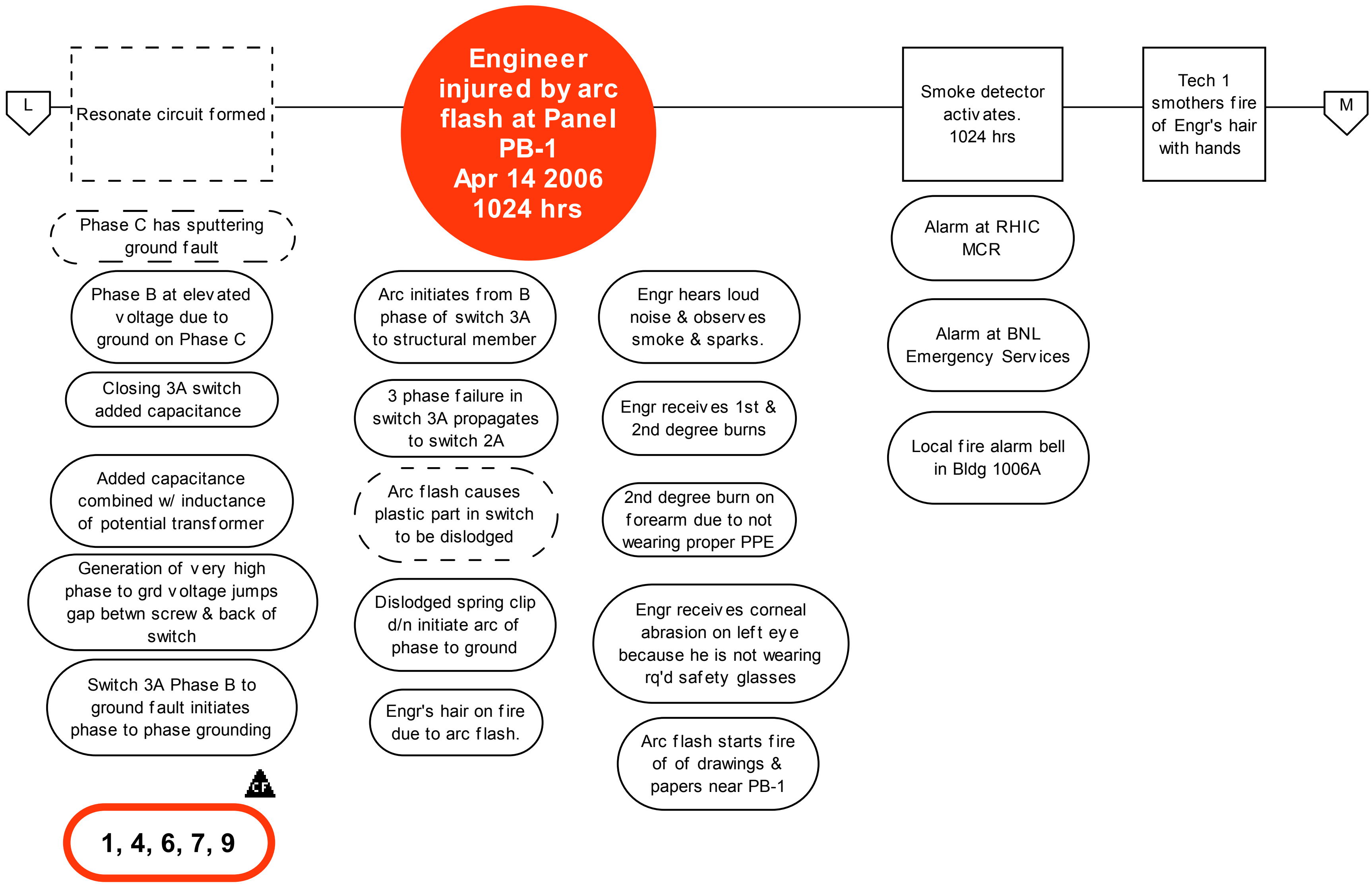

G
Tech 1 & Tech 3 report to MCR to view monitors to assess problem
Tech 1 & Tech 3 go to Bldg 1006A to T/S
Tech 1 & Tech 3 shut down power supplies opening 13.8 KV breaker
Tech 1 & Tech 3 replace SCR and capacitor bank fuses.
Techs 1 & Tech 3 restore electrical power to STAR power supplies Apr 14 2006
H
Troubleshooting problem includes possible replacement of failed components (e.g. fuses)
C-A does not define scope of troubleshooting vs maintenance.
4, 9
Techs do not checkoff procedure at work site
Techs performing work per C-A OPS 11.4.3.A STAR Power Supply S/D
Procedure has checklist of actions to be performed.
Techs not properly wearing BNL-supplied cotton clothes
Collar button not fastened, sleeves not rolled down, shirt not tucked in pants.
Noisy work environment. Hand signals used.
6, 7, 9
Tech 1 & Tech 3 use Kirk key to lockout power supplies
13.8 KV breaker opened remotely
BNL modified UL-listed eqpt to install Kirk Key
BNL d/n have process for mod UL-listed eqpt for Kirk key
10
SCR and capacitor bank fuses have failed often.
Physics Dept not trending fuse failures
Replacing fuses considered to be skill-of-the-worker.
Techs d/n recall performing zero voltage checks.
C-A expects workers to know hazards of working on electrical systems.
6, 9
Kirk keys removed to restore power
C-A OPS proc 11.4.3.b STAR Power Supply Start-up Check-off List
Techs do not checkoff procedure at work site
10

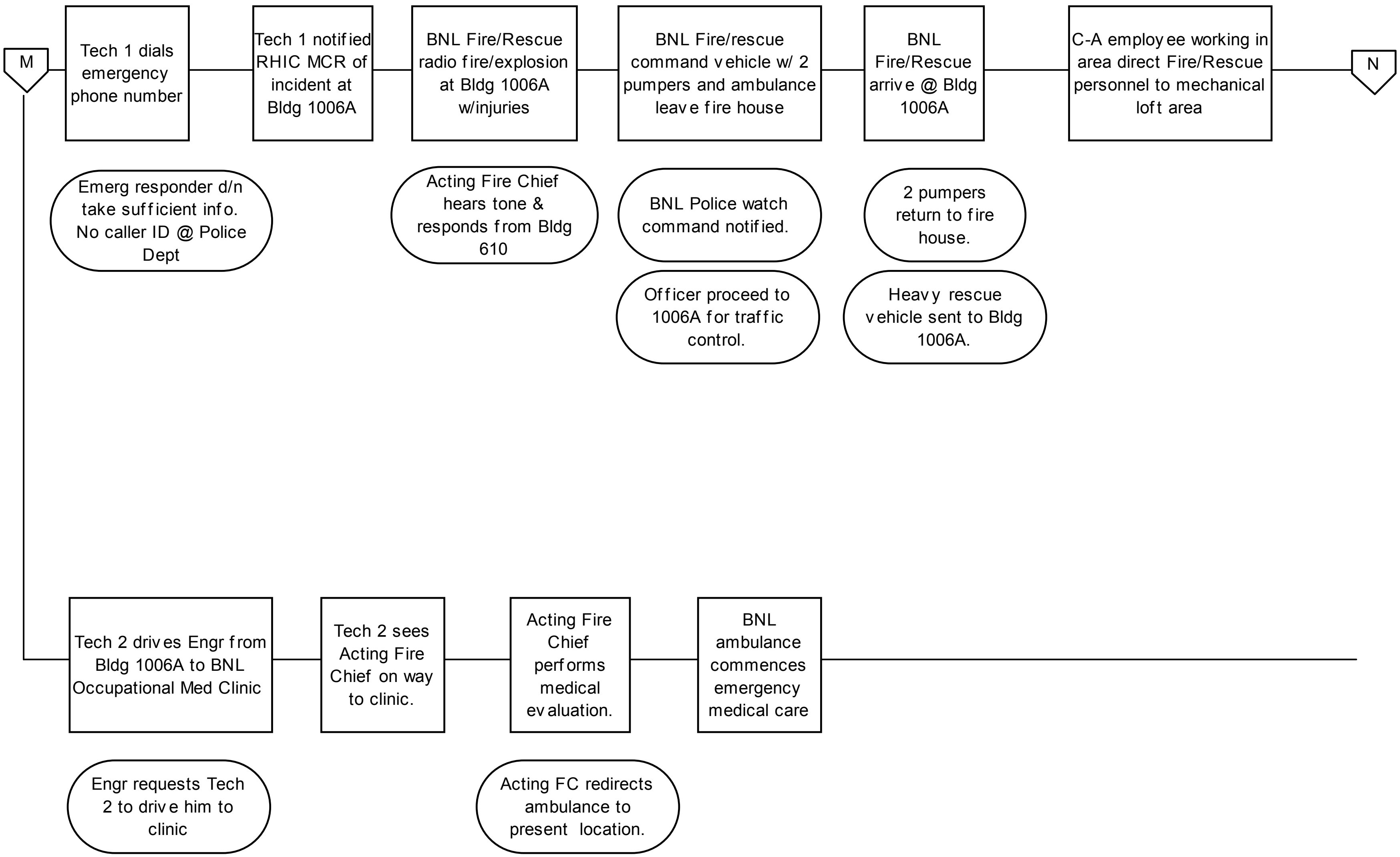

H
Tech 1 & Tech 3 go to Bldg 940
MCR contacts Tech 1 about DC fault on Star power supply Apr 14 2006
Tech 1 & Tech 3 return to Bldg 1006A to troubleshoot
Tech 4 arrives at Bldg 1006A to assist Apr 14 2006 ~0945 hrs
Tech 1 pages Engr to assist in troubleshooting Apr 14 2006 0945 hrs
Tech 3 & Tech 4 returns to Bldg 940
Engr & Tech 2 go to Bldg 1006A to perform troubleshooting.
I
Unable to determine cause of problem
Tasks do require PPE (glasses & cotton clothing)
In Jan 2005 Engr offered BNL-supplied FR clothing, but d/n request
Techs wearing BNL-supplied FR clothing.
Techs & Engr consider Engr to be in-charge of T/S
No prejob brief held
Engr & Techs d/n know there is no ground fault detection
Techs see Engr not wearing proper PPE but d/n stop work
Stop Work not invoked by Tech
CF
4, 6, 9

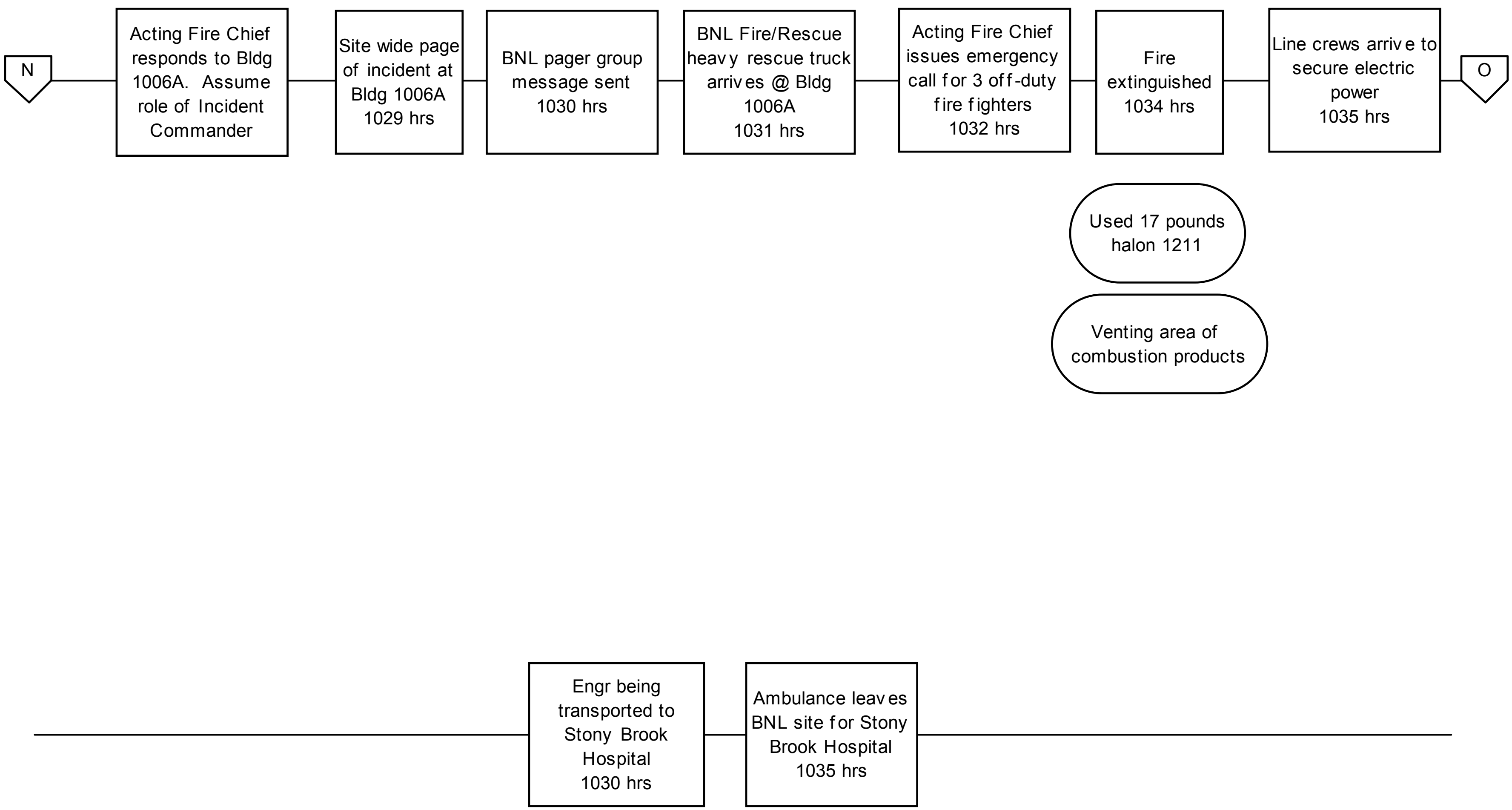

I
Engr and Tech 1 go to STAR Control Room
Engr & Tech 1 go to Bldg 1006A
Tech 2 racks out 13.8 KV breaker remotely
Engr opens fuse disconnect switches 2A & 3A
J
Tech 2 in Bldg 1006A
Noisy work environment. Hearing protection.
No prejob brief.
No written work procedures at site.
Engr determines additional fuses need to be replaced
CF
4, 6, 9
Engr's knowledge enables him to find problem during T/S
Engr & Techs d/n know ground fault exists
RHIC & STAR control, rooms d/n know ground fault exists
Remote operation is a safe practice.
Engr sometimes operates equipment.
Engr authorized by management to operate equipment.
Engr not wearing safety glasses.
Engr not wearing FR shirt.
Engr wearing short-sleeved shirt due to warm weather
Workers must stand in front of panel to operate switch
Difficulty in operating switch not communicated to management.
Switch operation not in conformance with BNL trg
BNL management d/n observe workers operate switch contrary to trg
CF
4, 6, 7, 9

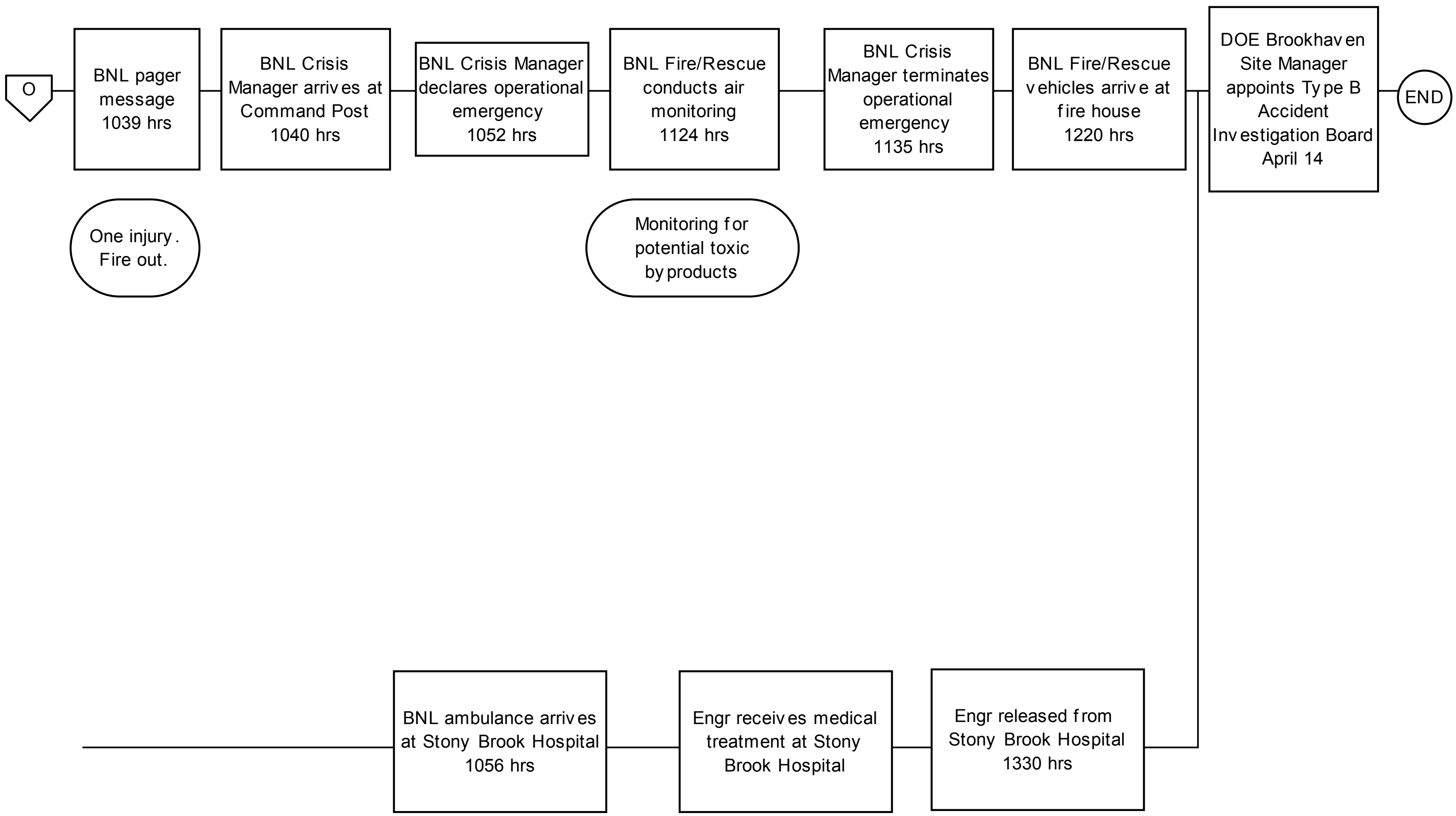

J
Engr & Tech 2 use Kirk key to lockout power supplies
Tech 1 & Tech 2 replace SCR fuses in power supplies
Tech 2 uses Kirk key to restore power supply
Tech 1 & Tech 2 turns on space trim west power supply
Engr & Tech 1 power up space trim west power supply
Tech 1 obtains approval from MCR to startup system
Engr, Tech 1 and Tech 2 release interlock to free-up power supply keys
K
Engr trained in site LOTO.
Engr not trained in C-A LOTO-OJT
Workers do not recall performing zero voltage check.
CF
4, 6, 9
Power supply operates normally


K
Tech 2 prepares to rerack 13.8 KV breaker
Engr closes switches 5A & 4A
Engr closes switch 2A.
Engr closes switch 3A
L
Tech 2 proceeds with work without knowing where Engr is working.
Tech 2 is preparing to remotely rerack breaker. Has obstructed view of panel PB-1.
Engr works at PB-1 while techs rack in 13.8 KV breaker. Engr at risk.
Tech 1 cleaning up tools next to Tech 2.
Tech 2 showing Tech 1 remote operation of reracking.
CF
4, 9
Switch hard to operate standing off to the side.
Switch likely operated over 1000 cycles.
Ground fault exists.
Engr not aware that ground fault exists.
Capacitance increases with each switch closure.
CF
6, 9
Switch hard to operate standing off to the side.
Switch likely operated over 1000 cycles.
Ground fault exists.
Engr not aware that ground fault exists.
Capacitance increases with each switch closure.
CF
6, 9
Ground fault exists.
Phase C has sputtering ground fault
Nick on cable insulation creates ground fault through water in manhole
Engr not aware that ground fault exists.
Capacitance increases with each switch closure.
Switch likely operated over 1000 cycles.
No evidence of switch malfunction causing phase to ground
No evidence of foreign object bridging phase to ground
Switch hard to operate standing off to the side.
Switch operation not in conformance with BNL trg
Preventative maintenance not performed on relay.
BNL missed opportunity to ID relay not connected to alarm
CF
1, 4, 5, 6, 7, 9, 10


L
Resonate circuit formed
Engineer injured by arc flash at Panel PB-1 Apr 14 2006 1024 hrs
Smoke detector activates. 1024 hrs
Tech 1 smothers fire of Engr's hair with hands
M
Phase C has sputtering ground fault
Phase B at elevated voltage due to ground on Phase C
Closing 3A switch added capacitance
Added capacitance combined w/ inductance of potential transformer
Generation of very high phase to grd voltage jumps gap betwn screw & back of switch
Switch 3A Phase B to ground fault initiates phase to phase grounding
1, 4, 6, 7, 9
Arc initiates from B phase of switch 3A to structural member
3 phase failure in switch 3A propagates to switch 2A
Arc flash causes plastic part in switch to be dislodged
Dislodged spring clip d/n initiate arc of phase to ground
Engr's hair on fire due to arc flash.
Engr hears loud noise & observes smoke & sparks.
Engr receives 1st & 2nd degree burns
2nd degree burn on forearm due to not wearing proper PPE
Engr receives corneal abrasion on left eye because he is not wearing rq'd safety glasses
Arc flash starts fire of of drawings & papers near PB-1
Alarm at RHIC MCR
Alarm at BNL Emergency Services
Local fire alarm bell in Bldg 1006A


M
Tech 1 dials emergency phone number
Tech 1 notified RHIC MCR of incident at Bldg 1006A
BNL Fire/Rescue radio fire/explosion at Bldg 1006A w/injuries
BNL Fire/rescue command vehicle w/ 2 pumpers and ambulance leave fire house
BNL Fire/Rescue arrive @ Bldg 1006A
C-A employee working in area direct Fire/Rescue personnel to mechanical loft area
N
Emerg responder d/n take sufficient info. No caller ID @ Police Dept
Acting Fire Chief hears tone & responds from Bldg 610
BNL Police watch command notified.
Officer proceed to 1006A for traffic control.
2 pumpers return to fire house.
Heavy rescue vehicle sent to Bldg 1006A.
Tech 2 drives Engr from Bldg 1006A to BNL Occupational Med Clinic
Tech 2 sees Acting Fire Chief on way to clinic.
Acting Fire Chief performs medical evaluation.
BNL ambulance commences emergency medical care
Engr requests Tech 2 to drive him to clinic
Acting FC redirects ambulance to present location.


N
Acting Fire Chief responds to Bldg 1006A. Assume role of Incident Commander
Site wide page of incident at Bldg 1006A 1029 hrs
BNL pager group message sent 1030 hrs
BNL Fire/Rescue heavy rescue truck arrives @ Bldg 1006A 1031 hrs
Acting Fire Chief issues emergency call for 3 off-duty fire fighters 1032 hrs
Fire extinguished 1034 hrs
Line crews arrive to secure electric power 1035 hrs
O
Used 17 pounds halon 1211
Venting area of combustion products
Engr being transported to Stony Brook Hospital 1030 hrs
Ambulance leaves BNL site for Stony Brook Hospital 1035 hrs


O
BNL pager message 1039 hrs
BNL Crisis Manager arrives at Command Post 1040 hrs
BNL Crisis Manager declares operational emergency 1052 hrs
BNL Fire/Rescue conducts air monitoring 1124 hrs
BNL Crisis Manager terminates operational emergency 1135 hrs
BNL Fire/Rescue vehicles arrive at fire house 1220 hrs
DOE Brookhaven Site Manager appoints Type B Accident Investigation Board April 14
END
One injury. Fire out.
Monitoring for potential toxic byproducts
BNL ambulance arrives at Stony Brook Hospital 1056 hrs
Engr receives medical treatment at Stony Brook Hospital
Engr released from Stony Brook Hospital 1330 hrs