Investigation of Incident

"Accidental Electrical Shock at U4A"

Prepared by W. R. Casey

5/22/02

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Purpose - This investigation was conducted to establish the sequence of events and determine the causal factors that resulted in the accidental electrical shock of a visiting physicist at beam line U4A. An initial meeting on was held 4/29/02 to gather information and evaluate circumstances surrounding the event. This meeting was attended by: A. Ackerman (NSLS), R. Biscardi (NSLS), R. Casey (NSLS), R. Church (NSLS), N. Gmur (NSLS), S. Hulbert (NSLS), S. Layendecker (RCD), T. Monahan (SHSD), S. Musolino (RCD), S. Scocca (QP&SO), E. Sierra (QP&SO), L. Quiros (SHSD). Additional meetings to finalize the causal factors and corrective actions were held with a review team made up of R. Casey, E. Zitvogel, T. Monahan, J. Aloi, N. Gmur, M. Ali (DOE) and S. Hulbert.

Introduction - On 4/19/02 during the set up of an experiment at beam line U4A, a physicist (User A) experienced an accidental electrical shock while setting up his experiment. The shock resulted from his disconnecting an electrical connector energized at 1000 VDC. Maximum current available from the power supply was 100 mA. User A experienced a small (~ 0.5 mm) blister on his right thumb and four pinpoint size blisters on the palm of his left hand. It is his opinion and that of a doctor that he consulted[1] that he did not experience any serious injuries or lasting effects from his exposure.

Sequence of Events (see Attachment 1 for schematic)

- User A has worked regularly at the NSLS for the last 15 months and currently serves as a Local Contact[2] for the U4A beam line. On Friday 4/20/02, he connected a multimeter in series with a 1000 VDC power supply capable of providing up to 100 mA current (see diagram in Attachment 2). A second person, User B, assisted in the experiment. User A was planning to use the multimeter to measure the current to his sample at a more precise level than he could by using the meter built into his power supply. Unable to successfully make the measurement, he pulled the connector to the multimeter and experienced the electrical shock (see Attachment 3 for a detailed description provided by the user.) In reaction to the shock, he jumped back pushing against a rack behind him for balance. The power supply was then turned off by User B. User A reported later that he experienced no unusual beating of his heart nor experienced any trouble breathing. After concluding that he had not harmed himself, he and his colleague evaluated the set-up that had been configured and quickly realized that connector shell was energized at 1000 VDC. User A then disassembled the setup and devised another method to regulate the current heating his sample. He continued to work throughout the day.
- On Saturday the user called the NSLS Control Room and reported that he had been shocked the day before. The Control Room dispatched an Operations Coordinator who discussed the incident with the user and reviewed the equipment. It was

[1] The user declined on 4/22/02 to visit the BNL Occupational Clinic for a medical exam and EKG.
[2] In NSLS terminology, the Local Contact has day to day responsibility for the functioning of a beam line. This particular beam line has 2 local contacts, one of whom will be present when the beamline is in operation.

concluded that there was no remaining safety issue. Control Room personnel also contacted the NSLS Safety Officer and the NSLS ESH Coordinator by phone and discussed the issue with them. Based on these discussions, it was concluded that there was no imminent safety concerns and that further review of the incident could wait until Monday, 4/22. The Safety Officer asked that User A prepare a brief report summarizing the incident (see Attachment 3).

- The ESH Coordinator went to interview the user early during the work day on 4/22. When he determined that User A had experienced pain in both forearms, had received a shock across his chest and had received minor burns to both thumbs, the ESH Coordinator realized that the event was more serious than he had perceived on Saturday 4/20. He contacted the BNL Occurrence Categorizer and it was agreed that the incident would be reported as a "Near Miss" event. In addition, the Safety Officer and others interviewed User A, and reviewed the equipment that had been used. They again concluded that there was no remaining safety concern. However, there was concern that the user should receive a medical evaluation and the NSLS ESH staff members requested that he visit the BNL Clinic for a medical examination and EKG. User A was leaving the Lab mid-morning and was pressed for time. Because he had not experienced symptoms or distress from the shock three days earlier, he was unwilling to miss a plane flight in order to receive medical evaluation. He was requested to receive a medical evaluation from a private physician when he returned to his home (See email in Attachment 3 from the doctor).

Discussion

Background

- User A is a post-doctoral experimental physicist at a major U.S. university and had been working at U4A for about 15 months at the time of the incident. User A does not work full-time at the NSLS and commutes to the facility (~ 8 times/year) when running at the line. He serves as a co-Local Contact for the beam line. In this role, he is responsible for administration of beam line training, as well as day to day management of beam line activities. The U4A beam line is managed by a collaboration of two universities. Each of the two managing organizations has designated a responsible Local Contact for their operating periods. At the time of the incident, all of User A's required training was current, which includes electrical safety orientation.
- Prior to the beginning of any new experiment, a review consistent with the requirements of BNL Experimental Safety Review Subject Area is performed. The safety review examines the materials and other issues introduced by the research activity, but does not review the supporting equipment normally present at the beam line. Instruction in the proper use of beam line equipment is provided by beam line staff. User A is in fact the person who would provide any needed training on the use of the power supply to an inexperienced user. The adequacy of the safety conditions within the infrastructure of the beam line is reviewed during the NSLS beam line safety reviews and is routinely monitored on the

experimental floor through safety inspections conducted 4 times a year at each beam line.

- Each user gaining access to the experimental floor receives safety instructions relating to a number of conditions that may exist within the building. Electrical safe work practices are specified in this training and are shown in Attachment 4. It should be noted that working with exposed energized electrical surfaces is prohibited. In addition, users are asked to report all electrical shocks to the NSLS Operations Coordinator.

The Shock

- The power supply involved in this incident is used to heat a sample that is in the evacuated main chamber of the beam line. During this run, the thermocouple that is normally attached to the sample had fallen off. To compensate for the lack of a thermocouple, User A was seeking to measure the DC current more precisely by using a multimeter rather than using the gross reading available from the meter on the power supply. The thermocouple could have been replaced, but that would have created a significant delay since the main chamber of the experiment would have had to be brought up to atmospheric pressure, opened up and then pumped down before operation could recommence.
- User A reconfigured the normal electrical connections between the power supply and the sample by using signal coaxial cables, BNC connectors, alligator clips and a banana plug as shown in Attachment 2. As a result he introduced equipment that was appropriate for low current and low voltage applications into a high voltage circuit. Both users were clearly aware that several of the surfaces had exposed voltages and sought to minimize the risks by using partially insulated alligator clips and positioning connections on insulated surfaces. However, in their preparation they overlooked the fact that the BNC used to connect to the multimeter was floating at 1000 VDC. The users assembled the components and their connections without review or discussion with NSLS Safety or other beam line personnel.
- Immediately following the electrical shock, User B turned off the power to the supply. User A checked himself for physical symptoms of dangerous electrical shock. Other than minor blisters on his thumbs, he concluded that he had not suffered injury. After settling himself, he and User B reconsidered what they were doing and recognized that the arrangement shown in Attachment 2 produced a high voltage on the connector to the multimeter. He realized that when he had touched the BNC connector with his other hand on ground that he had experienced electrical current flow through his body. They immediately disassembled the unsafe arrangement and sought another method to control the heating of the sample. After further review of their equipment, they determined that a variable current limiting adjustment provided by the power supply regulated the DC current output well and continued with their experiment.
- Members of the Laboratory Electrical Safety Committee reviewed the existing wiring configuration between the power supply and the heating filaments several days after the incident. They noted that the high voltage cable was not explicitly

rated for its service and recommended that the cable be replaced with one rated for service up to at least 2000 volts (the maximum output of the power supply). The cable was replaced with a RG-59 cable rated at 5000 V. They also noted the use of MHV connectors and recommended that they be replaced with SHV connectors. SHV connectors provide better isolation of the high voltage terminal and cannot be connected to low voltage rated BNC connectors. In this incident, the MHV connectors in the original high voltage cable were mated with BNC connectors, which made possible the mixing of high voltage and signal cable equipment.

Reporting of the Event

- User A initially judged that reporting the shock to the Operations Staff was not needed since he was unhurt and because he had corrected the unsafe condition. He considered the shock to be minor and therefore, did not need reporting. After reflecting on the incident overnight, he decided to report it the next day since the NSLS instructions were clear (see Attachment 4) and because the incident could have been more dangerous in another situation.
- The Laboratory has an occurrence reporting system which requires a determination of reportability within 2 hours of the discovery of the incident. Based on the phone call discussions with the Control Room, NSLS ESH personnel believed that the shock was a minor event which did not meet the reporting criteria established by the DOE. It was not until Monday that the ESH Coordinator realized that this event was potentially more serious than he had understood on Saturday, and contacted the BNL Occurrence Categorizer. The event was then reported under the category of a "near miss". There had been no discussion with the categorizer on Saturday when it was perceived that a minor shock had taken place. It should also be noted that the NSLS ESH Coordinator has served as an Occurrence Categorizer and is fully knowledgeable of the reporting criteria.

Medical Follow-up

It is the opinion of the BNL Occupational Medicine Clinic that medical evaluation of User A's condition was important after the shock to fully ensure that he had received no significant injury. They have also stated that this evaluation would have been important even on Monday, 3 days after the shock. NSLS personnel strongly advised User A to visit the Clinic for evaluation prior to his return to home, but felt that it was his prerogative to decline the visit if he desired, particularly since he is not a BNL employee. It may be important for BNL to clarify Laboratory policies regarding required medical evaluation following certain events, and also define the obligations of our visitors at the site.

Causal Analysis

The sequence of events depicted in Attachment 1 was established in consultation with all involved parties. A causal analysis was conducted preliminarily through a formal process utilizing "Taproot", a commercial computer program developed to support this process. The causal analysis was confirmed through a detailed discussion of the event and its causes at a meeting of NSLS beam line and ESH personnel, members of the Laboratory Electrical Safety Committee, and members of the ESH/Q Directorate.

Direct Cause

In an effort to address an operational issue, User A developed a measurement technique that created exposed energized components. When he sought to disconnect the assembly without turning off the power, he contacted a surface energized at 1000 VDC and created a current flow through his body to ground.

Contributing Causes

1. There was inadequate consideration of the potential hazards associated with the measurement technique that User A was attempting to perform.
2. Wiring and connectors introduced by User A were designed for low voltage applications and were inappropriate for this activity.

Root Cause

There is inadequate emphasis provided in NSLS facility specific training regarding electrical safety requirements and the need for review of significant configuration changes in beam line experimental equipment.

Corrective Actions

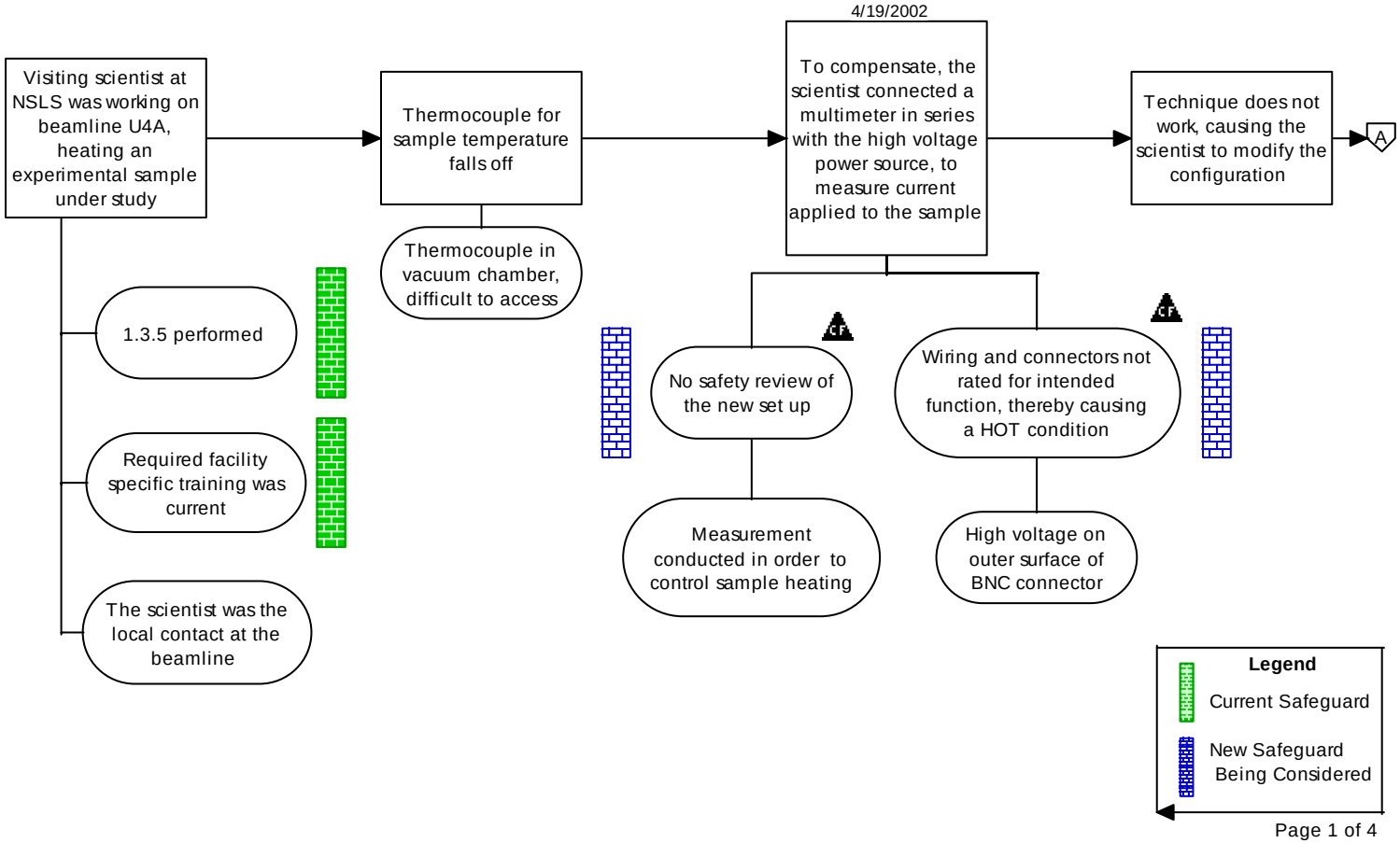
1. Distribute summary information to NSLS staff and users to inform personnel of the lessons-learned from this incident.
2. Enhance the current NSLS facility specific training to provide improved understanding of:
    a. electrical safety requirements, particularly with regard to working "hot".
    b. the need for safety review following significant configuration changes in beam line experimental equipment infrastructure, and
    c. reporting requirements for electrical shock and other operational events with safety implications.
3. Establish guidance for researchers and staff with regard to design of high voltage connectors and wiring for equipment and systems.

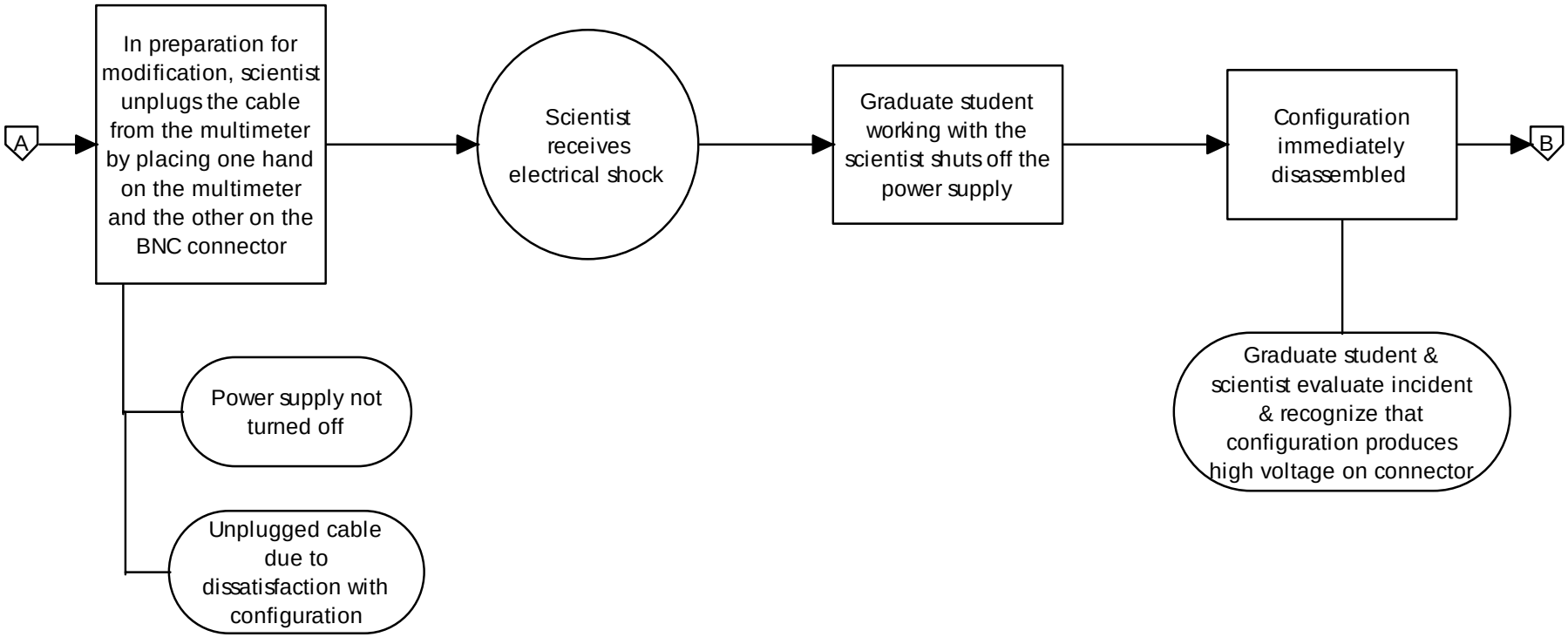
Although not related to the causal factors leading to the electrical shock event, there are two other issues that warrant follow-up.

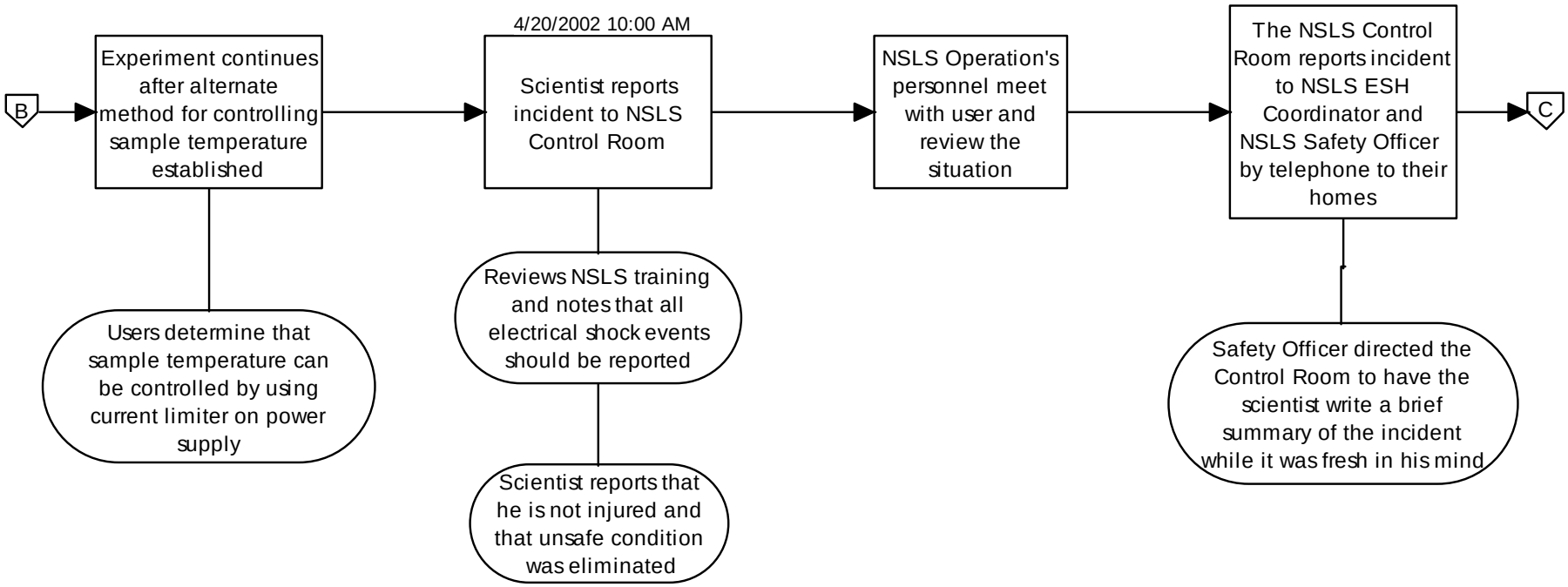
4. Provide additional guidance to NSLS personnel regarding the BNL Occurrence Reporting System and the process that should be followed to determine if an event is reportable.
5. Clarify the department's responsibilities for addressing medical evaluation of non - BNL personnel following a potentially harmful event.

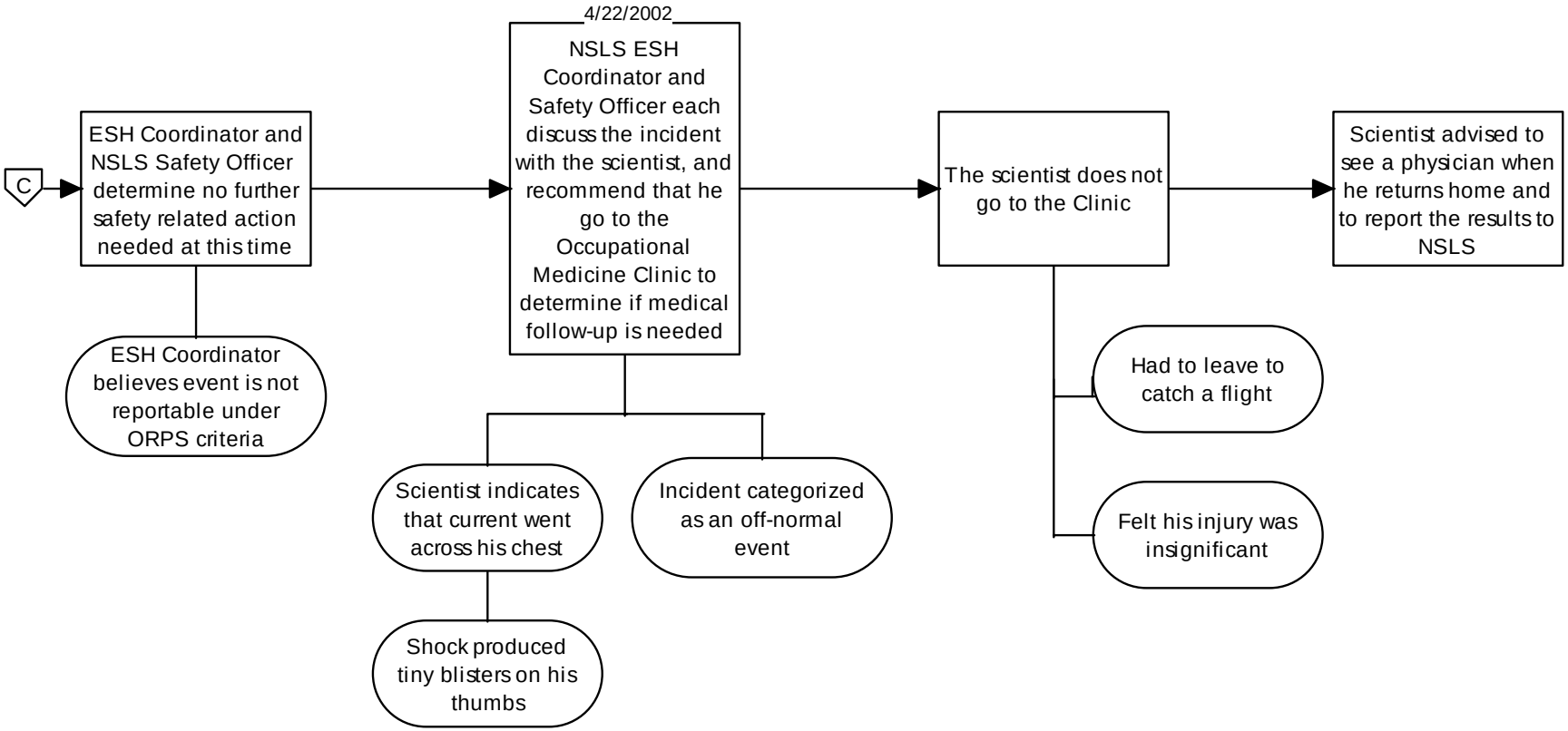
Attachment 1

Sequence of Events for Electrical Shock at National Synchrotron Light Source

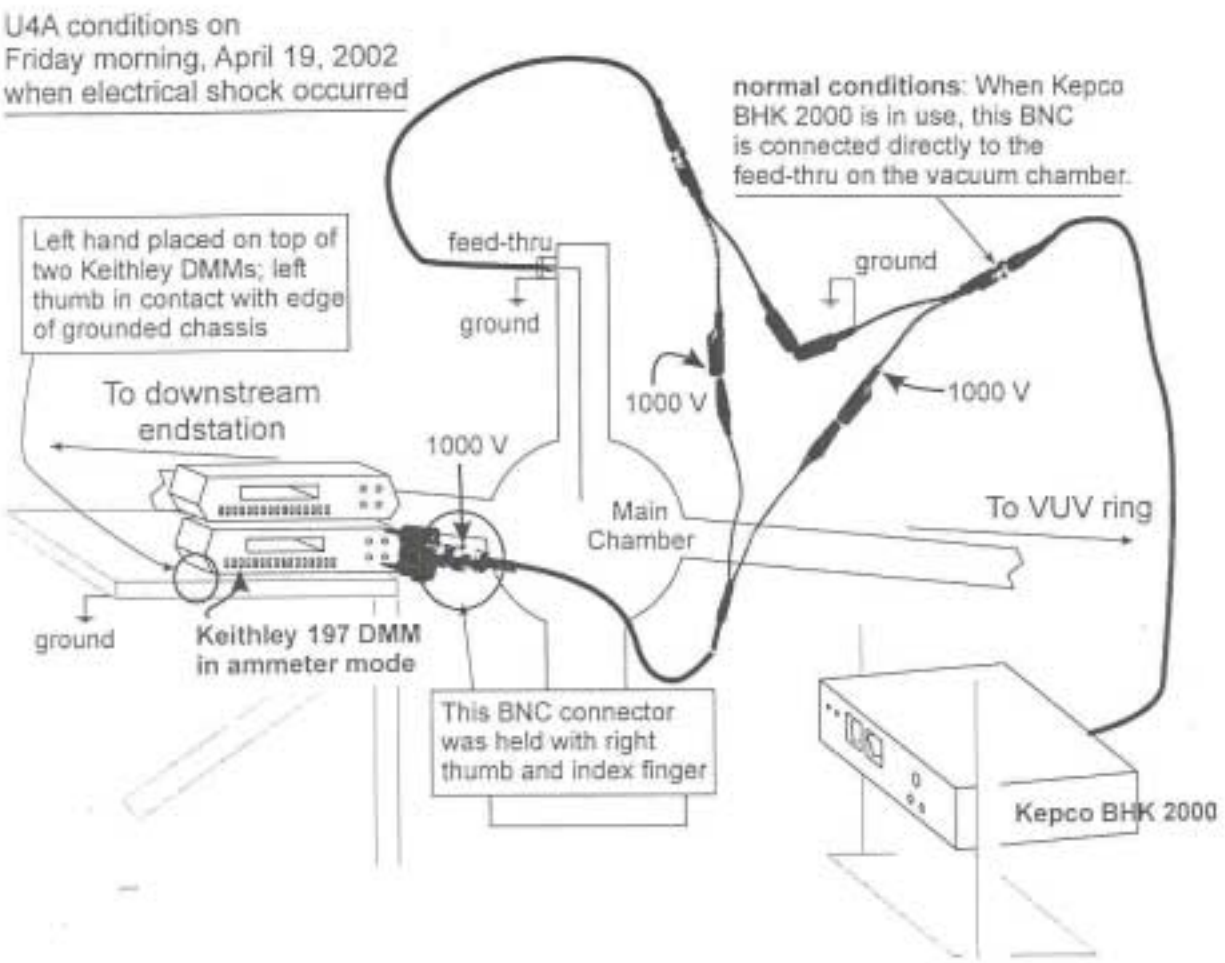



A
In preparation for modification, scientist unplugs the cable from the multimeter by placing one hand on the multimeter and the other on the BNC connector
Scientist receives electrical shock
Graduate student working with the scientist shuts off the power supply
Configuration immediately disassembled
B
Power supply not turned off
Unplugged cable due to dissatisfaction with configuration
Graduate student & scientist evaluate incident & recognize that configuration produces high voltage on connector


B
Experiment continues after alternate method for controlling sample temperature established
Users determine that sample temperature can be controlled by using current limiter on power supply
4/20/2002 10:00 AM
Scientist reports incident to NSLS Control Room
Reviews NSLS training and notes that all electrical shock events should be reported
Scientist reports that he is not injured and that unsafe condition was eliminated
NSLS Operation's personnel meet with user and review the situation
The NSLS Control Room reports incident to NSLS ESH Coordinator and NSLS Safety Officer by telephone to their homes
Safety Officer directed the Control Room to have the scientist write a brief summary of the incident while it was fresh in his mind
C


C
ESH Coordinator and NSLS Safety Officer determine no further safety related action needed at this time
ESH Coordinator believes event is not reportable under ORPS criteria
4/22/2002
NSLS ESH Coordinator and Safety Officer each discuss the incident with the scientist, and recommend that he go to the Occupational Medicine Clinic to determine if medical follow-up is needed
Scientist indicates that current went across his chest
Shock produced tiny blisters on his thumbs
Incident categorized as an off-normal event
The scientist does not go to the Clinic
Had to leave to catch a flight
Felt his injury was insignificant
Scientist advised to see a physician when he returns home and to report the results to NSLS

Attachment 2- Schematic of Circuit



Attachment 3

Note from User A describing Event

To NSLS ESH Staff

I will do my best here to provide all the requested information. I consulted with my father (who is a physician) regarding the electrical shock. Apparently understanding the need for something fairly official in government related business, he emailed me the result of my consultation with him. He did not think it important to visit a doctor at this point and mentions that in his email which I have forwarded / attached at the end of my message here.

I will attempt to describe the incident in detail with words. If necessary, I can draw a picture or something of this nature. I am thinking that because the error was due to poor wiring procedures on my part (I should have known better than to wire things up as I did) that a picture will not be necessary. If one is needed, please let me know and I will do my best to provide that as well.

My personal assessment of the incident is as follows. I spent some time looking for information regarding the danger of electrical shocks on the internet, with the most useful information coming from a part of the University of Illinois's website. It mentioned that with DC, as was my shock, 100mA is about what is necessary to affect the heart. I also found various places mentioning that a body's resistance with dry skin is anywhere from 100k to 500k Ohms. After the incident happened, I measured my body's resistance from thumb to thumb with an Ohmmeter and no matter how hard I squeezed the leads, I could not get the measured resistance to drop below 1MOhm. My contact with the high voltage and ground would have had less contact than this. I have very dry skin and bring Lubriderm to the NSLS when I come because of that. I had not been using any on this visit, my hands were not wet or damp when the shock occurred and my skin was not broken during the incident. The power supply cannot supply more than 100mA of current, but I assess from the pain I felt and the lack of anything like difficulty breathing that I probably received between 10mA and 20mA.

Detailed description of incident:

The unit that supplied the high voltage is a Kepco BHK Regulated DC supply Model BHK2000. The voltage we had chosen was 1000 Volts (DC). Current was limited to 100mA. To measure the current through the high voltage power source, I connected a Keithley 197 multimeter (I am fairly certain of the model number but not 100% sure) in series with the high voltage using coax cable and BNC connectors. I used partially insulated alligator clips to connect the coax cable in series with the high voltage source. These were set carefully on a folded felt cloth. At the Keithley multimeter, the coax cable had a BNC connector attached to a dual banana plug. This was plugged into the Keithley multimeter. This arrangement placed high voltage on the metal BNC connector. User B was with me. After several tests and being dissatisfied with the arrangement, I went to unplug the cable from the Keithley multimeter without first ensuring that the Kepco power supply was turned off. I unplugged the cable as follows. I placed my left hand on top of the Keithley multimeter to hold it in place when I pulled on the plug. Doing so placed my left thumb in casual contact with the beamline chassis which would necessarily have been grounded. I then grabbed the metal BNC connector with my right thumb and index finger. I then pulled the plug out of the Keithley multimeter and received the shock at that time. Upon feeling the shock, I jumped back, and yelled, "Ouch!" instantly dropping the cable. It is most likely that my left hand came away from the chassis before I dropped the cable. My reaction left me off balance so I pushed against the rack mount behind me to regain balance. I remained standing where I was to assess if anything else was going to happen either to me or to the dangling cable. Nothing did and Ivan had shut off the high voltage power supply as well. I had felt pain shoot up my arms during the shock. I did not have trouble breathing either during or after the shock. I also did not notice any

unusual beating of my heart. There was a blister on my right thumb with dimensions of 2 millimeters by 0.5 millimeters and four blisters on the side of my left thumb each barely larger than a pinpoint. (Perhaps the size of a 10pt Times New Roman period symbol.) After a minute or two of assessing what I did wrong, I went and sat down to think about what should be done. Afterward, having seen the error of the arrangement (having high voltage on the outside of a coax cable and having high voltage exposed) we immediately disassembled the arrangement. None of the equipment involved in the incident was BNL equipment.

Below is the message from my father who is a doctor as well.

User A

Note from a medical doctor who evaluated User A following the event

To Whom It May Concern:

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User A discussed with me the incident referred to above in which he momentarily contacted 1000 volts of direct current at an estimated current of 20 to 100 milli-amperes for about 0.2 second (fast enough to react). He sustained a small blister on his right thumb and about four punctate burns on his left thumb which were the points of contact. He jumped back the instant he was shocked. There was no obvious injury or of abnormal cardiac rhythm.

The calculated energy from such an incident is about 50 joules. This is well below the threshold of vascular or neurological injury (such as would be seen in electrocution by lightning or industrial power applications). Typical power settings for medical treatment of cardiac arrhythmias are 200 - 300 joules.

He has noticed no significant sequelae, and I would not expect any. I would not expect that any physical exam diagnostic tests (such as cardiac EKG) to reveal anything related to this incident.

XXXXXXXXX, MD
USAF MC USAF (ret)
Flight Surgeon
Ophthalmologist

Electrical Safe Work Practices

Beamline operation requires considerable signal and power distribution. Equipment requires primary 110, 208, and 480 Volt AC power sources. Secondary power sources are high voltage DC magnet supplies and high voltage supplies to vacuum pumps, lasers, and other equipment.
Ask for help with systems you do not understand! Be careful not to work on systems which are maintained by others. However, if you do need to work on an electrical equipment, then follow safe work practices:

- **Do NOT work hot. (Do not work on energized equipment - make sure it is turned off and disconnected from any power source.)**
- **Isolate the circuit from its power source.**
- **Use test equipment and confirm that the equipment is properly grounded.**
- **Minimize the use of extension cords.**
- **Avoid circuit overloads.**
- **Use only NRTL-approved cords. (National Recognized Testing Laboratory- for example, UL or CSA)**
- **Do not make any modifications to the building power distribution systems. Only authorized electricians are allowed to perform this type of work.**
- **If you do get a shock, no matter how small, inform the Operations Coordinator.**

Additional training in electrical safety may be required; Basic Electrical Safety is available on the Web http://training.bnl.gov under "Web Courses". Contact an Experiment Review Coordinator or the NSLS Training Coordinator if you have any questions about training requirements for your experiment.