LCLS Safety Assessment Document
SLAC-I-010-30100-016
## Revision Record

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<thead>
<tr>
<th>Revision</th>
<th>Date Revised</th>
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<th>Description of Change</th>
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<tr>
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<td>Original release.</td>
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</table>
LCLS Safety Assessment Document

Approved by (signature/date)

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Table of Contents

1. INTRODUCTION ......................................................................................................................... 4

2. SUMMARY .................................................................................................................................. 6
   2.1 ANALYSIS CONCLUSIONS .............................................................................................................. 6
   2.2 MISHAP RISK ASSESSMENT ............................................................................................................ 6

3. DESCRIPTION OF THE LCLS UNDULATOR COMPLEX AND NEAR EXPERIMENTAL HALL, AND THEIR OPERATIONS ............................................................................................................. 13
   3.1 LCLS UNDULATOR COMPLEX SUBSYSTEMS ......................................................................................... 13
      3.1.1 The Beam Transport Hall .............................................................................................................. 13
      3.1.2 The Undulator ............................................................................................................................... 13
      3.1.3 The Electron Beam Dump ............................................................................................................ 13
      3.1.4 The Front End Enclosure ............................................................................................................. 14
   3.2 THE NEAR EXPERIMENTAL HALL (NEH) ....................................................................................... 14
   3.3 OPERATING ORGANIZATION ........................................................................................................... 15
      3.3.1 Accelerator Operations Organization ............................................................................................. 15
      3.3.2 Experimental Facilities Operations Organization ............................................................................ 17

4. HAZARD ANALYSIS ......................................................................................................................... 19
   4.1 HAZARD ANALYSIS METHODOLOGY ............................................................................................. 19
      4.1.1 Identification of Potential Hazards .................................................................................................. 19
      4.1.2 Evaluation of Potential Hazards ..................................................................................................... 20
   4.2 RISK MINIMIZATION ...................................................................................................................... 21
   4.3 ENVIRONMENTAL HAZARDS IDENTIFICATION AND ANALYSIS ....................................................... 21
      4.3.1 Seismic ....................................................................................................................................... 21
      4.3.2 Environmental .............................................................................................................................. 22
   4.4 CONVENTIONAL HAZARDS IDENTIFICATION AND ANALYSIS ...................................................... 22
      4.4.1 Chemical .................................................................................................................................... 23
      4.4.2 Biohazards ................................................................................................................................... 24
      4.4.3 Cryogenics .................................................................................................................................. 24
      4.4.4 Oxygen Deficiency ..................................................................................................................... 24
      4.4.5 Noxious Gases ............................................................................................................................ 25
      4.4.6 Electrical .................................................................................................................................... 25
      4.4.7 Fire ............................................................................................................................................. 27
      4.4.8 Magnetic Fields ............................................................................................................................ 28
      4.4.9 Mechanical ................................................................................................................................ 29
      4.4.10 Noise ....................................................................................................................................... 31
      4.4.11 Vacuum and Pressure .................................................................................................................. 31
   4.5 RADIATION HAZARDS IDENTIFICATION AND ANALYSIS .............................................................. 32
      4.5.1 Non-ionizing Radiation Hazards .................................................................................................... 32
      4.5.2 Ionizing Radiation Hazards ........................................................................................................ 33

5. ACCELERATOR SAFETY ENVELOPE ............................................................................................... 33

6. QUALITY ASSURANCE .................................................................................................................... 43

7. POST OPERATION .......................................................................................................................... 44

APPENDIX A. REFERENCES .................................................................................................................. 45

SLAC INTERNAL DOCUMENTS .............................................................................................................. 45

APPENDIX B. ABBREVIATIONS USED IN THIS DOCUMENT ..................................................................... 47
1. Introduction

This Safety Assessment Document (SAD) identifies potential hazards associated with operations and credible accidents in the Linac Coherent Light Source (LCLS) Undulator Complex and Near Experimental Hall at the SLAC National Accelerator Laboratory. The purpose of this SAD is to assure line managers, workers, users, and reviewers that all significant hazards presented by this complex and its operations have been adequately assessed and can be managed and controlled to an acceptable level of risk (see *SLAC Guidelines for Operations, Chapter 25: Safety Assessment Documents*).

This SAD addresses the LCLS Undulator Complex and Near Experimental Hall. The Undulator Complex is comprised of the following subsystems, as shown in Fig. 1-1:

- The Beam Transport Hall which houses the electron beam transport line to the Undulator.
- The Undulator Hall which houses the LCLS Undulator.
- The Electron Dump Enclosure which houses the main electron dump.
- The Front End Enclosure which houses x-ray diagnostics.

The Undulator Complex accepts a high energy electron beam from the SLAC Linear Accelerator. The beam is transported through the Beam Transport Hall to the Undulator. In the Undulator, the electrons generate the LCLS x-ray beam. After exiting the Undulator, the electrons are deflected to the main electron dump while the x-rays continue into the Front End Enclosure (FEE).

![Figure 1-1 LCLS Undulator Complex Subsystems](image)

From the Front End Enclosure, the LCLS x-ray beam can be transported into the Near Experimental Hall (NEH) (see Figure 1-2). There the beam can be directed to three instruments, AMO, SXR, and XXP, each contained in a separate experiment hutch on the bottom floor of the NEH.

Downstream of the Near Experimental Hall, the LCLS facility will in future be expanded to allow x-rays to be directed into the X-Ray Tunnel and ultimately the Far Experimental Hall. The Tunnel and Far Hall are currently under construction. Analysis of operation in the X-Ray Tunnel and Far Experimental Hall will be added to an updated Safety Assessment Document at an appropriate future date.
This SAD will be reviewed and updated as needed, but no less frequently than every two years. It will also be revised whenever major modifications are made to the facility (see SLAC Guidelines for Operations, Chapter 25: Safety Assessment Documents).
2. **Summary**

The results of this Safety Analysis Report are consistent with the conclusion that LCLS is a complex facility with negligible offsite impacts based on guidance defined in [DOE O 420.2-1, Accelerator Facility Safety Implementation Guide](https://www.energy.gov/). The conclusion of this assessment is that the engineered and administrative controls adequately mitigate the risk for operations and credible accident scenarios.

2.1 **Analysis Conclusions**

This conclusion is based on the following findings:

- LCLS operations are well within existing safety and operating envelopes of the SLAC facility. While the peak brightness of the LCLS x-ray beam is unprecedented, due to its intense, ultrashort pulses, the average power is modest. The average power of the LCLS x-ray beam, the energy and power of the electron beam, and hence the radiation hazard they pose are all well within the range of applicability for SLAC shielding and safety systems. Radiation shielding analysis revealed that the LCLS presents some complex geometry questions, but the models used to provide minimum shield wall thickness are well understood and adequate shielding is in place.

- The risk (probability and severity) of all hazards are similar in nature and magnitude to those already found in the present accelerator and storage ring experimental programs at SLAC. The impact of any hazard is minor onsite and negligible off-site to people or the environment.

- Existing and mature programs (citizen safety committees, ES&H division, LCLS Division Safety Officers) have been engaged to ensure that all aspects of the design, installation, and testing phases of the LCLS project will be properly managed and that they conform to the applicable Work Smart Standards that SLAC has adopted and written into its contract with the DOE.

- That Integrated Safety and Environmental Management System (ISEMS) has been fully implemented at SLAC via the DEAR clause and incorporated through the contract between Stanford University and DOE in 1998.

- The LCLS Environmental Assessment did not identify any previously unrecognized hazards or conditions that would adversely affect worker safety and health or the environment during the assembly and installation of the instruments being constructed by the LCLS Ultrafast Science Instruments Project, slated for future installation into the LCLS facility.


2.2 **Mishap Risk Assessment**

The Risk Assessment Value is a numerical expression of comparative risk determined by an evaluation of both the potential severity of a mishap and the probability of its occurrence. The Risk Assessment Value is assigned a number from 1 to 20 from the Mishap Risk Assessment Matrix (see Table 2-5). The Risk Assessment Value can be used to prioritize hazards for risk...
mitigation actions and to group hazards into risk categorizes. The Risk Assessment Values identify chemical hazards, electrical hazards, and ionizing radiation hazards as having the highest risk at LCLS. In all cases, the mitigated risk levels are acceptably low.

This section contains a summary of the hazard analyses detailed in Section 4. The mitigated risk is derived from the probability (Table 2-2) and consequence (Table 2-3) of each type of hazard, as shown in Table 2-4. The assessments of the mitigated probability and consequence levels for each identified risk were reviewed and verified by appropriate SLAC safety experts.

Some hazard prevention/mitigation strategies are employed for all work at SLAC:

- Work Planning and Control processes (see SLAC ES&H Manual, Chapter 2)
- ISEMS implementation in all work.
- Training appropriate for work, for all LCLS Staff and Users.
- Use of appropriate PPE.

In addition, LCLS mitigates hazards by providing continuous shift coverage during operations by staff trained in emergency response. Specific hazards associated with LCLS research are identified and addressed through the LCLS Experiment Safety Review process. A hazard analysis is conducted for every experiment planned for LCLS.

### Table 2-1 Hazard Analysis Summary

<table>
<thead>
<tr>
<th>Section in SAD</th>
<th>Hazard</th>
<th>Prevention/ Mitigation</th>
<th>Mitigated Probability Level</th>
<th>Mitigated Consequence Level</th>
<th>Mitigated Risk Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.3.2</td>
<td>Environmental</td>
<td>Environmental impact reviews for new construction. Oversight, disposal, and restoration services of SLAC Environmental Protection Dept. Ref: SLAC ES&amp;H Manual Ch. 17, Hazardous Waste and Ch. 43, Industrial Wastewater</td>
<td>Extremely Low</td>
<td>Extremely Low</td>
<td>Level 19 Acceptable</td>
</tr>
<tr>
<td>4.4.1</td>
<td>Chemical</td>
<td>Minimize quantities of chemicals used. Use proper procedures for storing and working with chemicals. Ref: Chemical Process Hazard Analyses; and SLAC ES&amp;H Manual Ch. 40, Hazardous Materials &amp; Ch. 16 Spills</td>
<td>Low</td>
<td>Low</td>
<td>Level 11 Acceptable</td>
</tr>
<tr>
<td>4.4.2</td>
<td>Biohazards</td>
<td>Work at biosafety level 3 or higher not permitted at SLAC. Oversight by SSRL and Stanford experts. Follow prescribed protocols. Ref: SLAC ES&amp;H Manual Ch. 34, Biohazards</td>
<td>Extremely Low</td>
<td>Extremely Low</td>
<td>Level 19 Acceptable</td>
</tr>
<tr>
<td>Section in SAD</td>
<td>Hazard</td>
<td>Prevention/ Mitigation</td>
<td>Mitigated Probability Level</td>
<td>Mitigated Consequence Level</td>
<td>Mitigated Risk Level</td>
</tr>
<tr>
<td>---------------</td>
<td>--------</td>
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<tr>
<td>4.4.3</td>
<td>Cryogenic</td>
<td>Use proper PPE including gloves and face shields. Ref: SLAC ES&amp;H Manual Ch. 36, Cryogenic and Oxygen Deficiency Hazard Safety &amp; Ch.19, Personnel Protective Equipment</td>
<td>Extremely Low</td>
<td>Low</td>
<td>Level 14 Acceptable</td>
</tr>
<tr>
<td>4.4.4</td>
<td>Oxygen Deficiency</td>
<td>Limit volumes of gases and liquefied gases in tunnels and buildings Use OD monitor if required. Ref: SLAC ES&amp;H Manual Ch. 36, Cryogenic and Oxygen Deficiency Hazard Safety</td>
<td>Extremely Low</td>
<td>Low</td>
<td>Level 14 Acceptable</td>
</tr>
<tr>
<td>4.4.5</td>
<td>Noxious Gases</td>
<td>Implementation of controls, including exhaust ventilation.</td>
<td>Extremely Low</td>
<td>Low</td>
<td>Level 14 Acceptable</td>
</tr>
<tr>
<td>4.4.6</td>
<td>Electrical</td>
<td>Implementation of building and structural codes (UBC) SLAC Electrical Safety Committee reviews and inspections, when required. All equipment used in LCLS installations must be EEIP certified. Certain conventional equipment must be UL listed. Energized bus bars and terminals covered to prevent contact. Lock and Tag training for workers at risk. Specific LOTO procedure (EEIP) for each power supply. Electrical hot work permits, where applicable. Ref: SLAC ES&amp;H Manual, Chapter 8, Electrical Safety</td>
<td>Low</td>
<td>Low</td>
<td>Level 11 Acceptable</td>
</tr>
<tr>
<td>4.4.8</td>
<td>Magnetic</td>
<td>Magnetic field notification postings. Make exposed high magnetic fields inaccessible. Posting for pacemakers.</td>
<td>Extremely Low</td>
<td>Extremely Low</td>
<td>Level 19 Acceptable</td>
</tr>
<tr>
<td>Section in SAD</td>
<td>Hazard</td>
<td>Prevention/ Mitigation</td>
<td>Mitigated Probability Level</td>
<td>Mitigated Consequence Level</td>
<td>Mitigated Risk Level</td>
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<td>---------------</td>
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</tr>
<tr>
<td>4.4.11</td>
<td>Vacuum and Pressure</td>
<td>Vacuum chambers with a potential of being pressurized during an experiment are fit with low positive pressure burst disks that are compliant with 10CFR851 to prevent them from being over pressurized. Ref: SLAC ES&amp;H Manual Ch. 38 Compressed Gas Cylinders &amp; Ch.14 Pressure and Vacuum Vessels</td>
<td>Extremely Low</td>
<td>Low</td>
<td>Level 14 Acceptable</td>
</tr>
<tr>
<td>Section in SAD</td>
<td>Hazard</td>
<td>Prevention/ Mitigation</td>
<td>Mitigated Probability Level</td>
<td>Mitigated Consequence Level</td>
<td>Mitigated Risk Level</td>
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Table 2-2 Hazard Probability Rating Levels

<table>
<thead>
<tr>
<th>Probability Level</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>High</td>
<td>Event is likely to occur several times in a year.</td>
</tr>
<tr>
<td>Medium</td>
<td>Event is likely to occur annually.</td>
</tr>
<tr>
<td>Low</td>
<td>Event is likely to occur during the life of the facility or operation.</td>
</tr>
<tr>
<td>Extremely Low</td>
<td>Occurrence is unlikely or the event is not expected to occur during the life of the facility or operation.</td>
</tr>
<tr>
<td>Incredible</td>
<td>Probability of occurrence is so small that a reasonable scenario is inconceivable. These events are not considered in the design or SAD analysis.</td>
</tr>
</tbody>
</table>

Table 2-3. Hazard Consequence Rating Levels

<table>
<thead>
<tr>
<th>Consequence Level</th>
<th>Potential Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>A condition that may cause death or permanently disabling injury, facility destruction, major systems during the operation</td>
</tr>
<tr>
<td>Medium</td>
<td>A condition that may cause severe injury or occupational illness, or major property damage to facilities, systems, equipment, or hardware.</td>
</tr>
<tr>
<td>Low</td>
<td>A condition that may cause minor injury or occupational illness, or minor property damage to facilities, systems, equipment, or hardware.</td>
</tr>
<tr>
<td>Extremely Low</td>
<td>A condition that could cause the need for minor first aid treatment though would not adversely affect personal safety or health. A condition that subjects facilities, equipment, or hardware to more than normal wear and tear.</td>
</tr>
</tbody>
</table>
### Table 2-4: Mishap Risk Assessment Matrix

<table>
<thead>
<tr>
<th>Severity</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
<th>Extremely Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>Medium</td>
<td>2</td>
<td>5</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>Low</td>
<td>4</td>
<td>6</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>Extremely Low</td>
<td>8</td>
<td>10</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td>Incredible</td>
<td>12</td>
<td>15</td>
<td>17</td>
<td>20</td>
</tr>
</tbody>
</table>

MIL-STD-882D

### Table 2-5: Mishap Risk Assessment Value

<table>
<thead>
<tr>
<th>Risk Assessment Value</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>1-5</td>
<td>Unacceptable</td>
</tr>
<tr>
<td>6-9</td>
<td>Undesirable</td>
</tr>
<tr>
<td>10-17</td>
<td>Acceptable</td>
</tr>
<tr>
<td>18-20</td>
<td>Acceptable</td>
</tr>
</tbody>
</table>
3. Description of the LCLS Undulator Complex and Near Experimental Hall, and their Operations

3.1 LCLS Undulator Complex Subsystems
The LCLS Undulator Complex is comprised of the Beam Transport Hall (BTH) which houses the Linac-to-Undulator (LTU) beamline, the Undulator Hall (UH) which houses the Undulator, the Electron Beam Dump Enclosure where the electron beam terminates, and the Front End Enclosure (FEE). These areas are located within the Linac radiological control area to the east of the SLAC Linac. The areas lie between the Linac’s Beam Switchyard (BSY) and the Near Experimental Hall (NEH).

The LCLS Undulator Complex performs the following:

- Accepts a 3 to 17 GeV electron beam from the Linac.
- Transports and characterizes that beam to the Undulator.
- Generates a high brightness 800 – 8000 eV x-ray beam in the Undulator.
- Deflects and dumps the electron beam allowing the photon beam to be transported to the experimental areas.

The LCLS Undulator Complex operates at rates up to 120 pulses per second.

3.1.1 The Beam Transport Hall
The Beam Transport Hall (BTH) is located immediately east of the Linac BSY. Electron beams from the linac are transported through the BSY to the LTU beamline in the BTH. A set of horizontal and vertical bending magnets directs the beam onto a line through the center of the undulator magnets downstream. A set of wire scanners in the LTU allow the emittance of the beam to be measured. At the east end of the LTU there is a tune-up dump onto which the beam can be temporarily parked. Three service buildings above the BTH house controls for the LTU beamline.

3.1.2 The Undulator
The LCLS Undulator consists of thirty-three undulator segments placed end-to-end along the beam line. Each segment is 3.3m long. Between segments are a quadrupole magnet, a beam position monitor and a beam finder wire. The undulator segments are mounted on cam-driven girders so that they can be held in alignment with respect to the electron beam to high precision. The alignment is monitored with wire position monitor and hydrostatic level systems. To maintain the precision of the undulator system, the temperature in the Undulator Hall must be held to 20.0±0.5°C. As the electron beam passes through the undulator it produces, via self-amplified spontaneous emission, a high brightness x-ray FEL beam. The controls for the LTU beamline are housed in two service buildings, one above the Beam Transport Hall (BTH), and one above the Undulator Hall.

3.1.3 The Electron Beam Dump
Following the undulator, the beam entering the electron beam dump area is a superposition of electrons and x-rays. The electron beam is separated from the photons and deflected down into the main electron dump, which is designed to take the full beam power. The x-rays are not deflected and remain directed toward the experimental areas through the Front End Enclosure.
(FEE). Two electron/photon stoppers, located in the photon beam line above the main electron
dump, are part of the personnel protection system for entry into the FEE.

3.1.4 The Front End Enclosure
The Front End Enclosure (FEE) is the first room downstream of the Electron Beam Dump
Enclosure. The beamline in it is designed to transport photons only. Personnel are permitted in
the FEE while electron beam is stopped on the electron dump providing the electron/photon
stoppers in the electron dump area are inserted. The FEE is separated from the electron beam
dump by a 7 foot thick wall of steel and concrete to protect personnel in the FEE from prompt
radiation from the electron dump. The Front End Enclosure contains apertures, attenuators,
diagnostics and optics. The photon beam first passes through a mask and adjustable slit system
that is remotely operated. Next are two independent attenuator systems, one designed for
operation below 2 keV and one for operation above 2 keV. The photon beam then passes into a
series of diagnostics which are capable of monitoring position and energy on a single pulse basis.
Then the photon beam passes into the optics section. There are two independent mirror systems;
one for photon energies below 2 keV and the other for photon energies up to 25 keV. Each
mirror system includes collimators with B\textsubscript{4}C to ensure that the photon FEL beam cannot damage
equipment and Bremsstrahlung cannot go into the NEH. The mirror systems will generate three
different photon beam paths that diverge from each other as they pass into the Near Experimental
Hall. Following the mirrors there is also a steel “shadow wall” which helps to shield the NEH
experimental hutches from Bremsstrahlung.

3.2 The Near Experimental Hall (NEH)
The Near Experimental Hall (NEH) is SLAC Building 950. The x-ray beamline and experiment
stations are located on the bottom floor of the building. An associated laser hall is located on the
upper floor of the building. FEL x-rays can enter the NEH experiment stations from the FEE to
the west. A set of x-ray mirrors in the FEE is used to direct the photon beam into one of three
beam pipes that penetrate the shield wall between FEE and NEH. Photon stoppers just upstream
of the wall (in FEE) are controlled by an interlocked PPS system to prevent exposure to people
working in NEH. Within the NEH, the photon beam pipes lead to 3 shielded experiment hutches
located on the bottom floor, where the experiment stations are located. The PPS system used for
the hutches has just two states for each hutch, “searched no access” and “access permitted”, and
is referred to as a Hutch Protection System (HPS).

Laser beams can be directed from the laser hall down into the experiment hutches through
evacuated laser beam tubes. The laser beam transport includes shutters which are controlled by a
certified Laser Safety System (LSS), allowing remote laser operation in the hutches when they
are in searched no access mode. Interlocked laser doors on the hutches and laser hall permit
trained laser operators working within a defined laser Standard Operating Procedure to work in
the presence of laser beams.

The X-ray Tunnel lies to the east of the NEH. A photon stopper located just east of the shield
wall between NEH and Tunnel serves as the final beam stop for the LCLS in its current
configuration. There is no radiation hazard in the Tunnel or Far Experimental Hall (which lies
further east).
3.3 Operating Organization

The LCLS Undulator Complex and the NEH are operated and managed within an organization that adheres to the SLAC Work Planning and Control process, and reliably identifies safety standards and implementation guidance applicable to maintenance work and modifications. This process includes Experiment Safety Review for all experiments carried out in the NEH. The technical managers have been trained to understand the need to address ES&H requirements before authorizing work on this facility. Policies and procedures governing the operation of this facility have been established to minimize any potential adverse environmental effects while accomplishing the facility's mission.

Responsibility for operating the Undulator Complex rests with the LCLS Accelerator Systems Division. Responsibility for operating the NEH rests with the LCLS Experimental Facilities Division. Both divisions report to the LCLS Directorate of SLAC.

3.3.1 Accelerator Operations Organization

Operation of the LCLS Undulator Complex is under the control of the Accelerator Systems Division, which reports to the LCLS Directorate. The Accelerator Operations Department is charged with the day-to-day running of the accelerator facility.

The Engineering Operator-in-Charge is responsible for the safe and efficient running of the accelerator facility in order to execute the scheduled program on a shift-by-shift basis. The EOICs are assisted in the Main Control Center (MCC) control room by Accelerator Systems Operators (ASOs).

All operations are carried out in compliance with SLAC Guidelines for Operations and the Accelerator Systems Division Operations Directives. These documents are used by the operating, safety, and maintenance groups to ensure that activities are conducted in a safe and effective manner.

3.3.1.1 Operations

SLAC Guidelines for Operations and the Accelerator Systems Division Operations Directives are the controlling documents for facility operations. These documents, together with the more detailed procedures which implement them, are intended to ensure that a high level of performance is achieved in the operation of the accelerator, and that operations are carried out safely. The Accelerator Division Operations Directives define the roles and responsibilities of the EOIC and the on-duty control room staff and specify applicable detailed procedures.

The procedures required for operation of the LCLS Undulator Complex are maintained in a hierarchical documentation system by the Accelerator Operations Department. The level of review and approval required for each procedure depends on its position in the hierarchy, with critical safety procedures being subject to the most rigorous control and approval processes. Critical accelerator safety procedures are updated whenever operational requirements change. The approving authority for each document is listed with the document, and the governing policies are described in the Accelerator Division Operations Directives.

3.3.1.2 Safety

Safe operation of the accelerator facility is achieved through adherence to administrative procedures as described in SLAC Guidelines for Operations and Accelerator Division Operations Directives, as well as the SLAC ES&H Manual and the Radiation Safety Systems Technical Basis Document. While the EOIC has the primary responsibility for the safe operation of the LCLS
Undulator Complex, the Accelerator Division Safety Office (ADSO) provides an overview function for all activities that have an impact on safety.

### 3.3.1.3 Maintenance

Accelerator maintenance and installation activities are managed by the Accelerator Systems Division following processes and procedures described in the *Accelerator Division Operations Directives* and *SLAC Guidelines for Operations*. The area manager is responsible for coordinating all maintenance activities in his or her area.

Short-term maintenance required for the daily operation of the accelerator during a running cycle is coordinated by the Accelerator Division Maintenance Office (ADMO) in the Accelerator Systems Division. Staff members from this group collect maintenance requests and schedule the work for the next available maintenance period. Maintenance activities requiring immediate action are coordinated and controlled by the EOIC with the assistance of the area manager for the particular area.

### 3.3.1.4 Training

All employees who have reason to perform work in the LCLS Undulator Complex are required to complete safety training programs tailored to their job responsibilities. For example, all employees who work in Controlled Areas are required to complete Employee Orientation to Environmental Safety and Health (EOESH) and General Employee Radiological Training (GERT). This training is administered by the ES&H Division using formal course material and written tests. This requirement applies to outside contractors as well. Only appropriately trained and qualified personnel, or trainees under the supervision of trained and qualified personnel, are permitted to perform tasks that may affect safety and health.

Responsibility for training lies with line managers and supervisors. This includes periodically reviewing the duties of each person to assess the hazards he or she may encounter, determining the appropriate training requirements, and verifying that the employee has completed the requisite training. This is normally done as part of the Activity and Training Authorization (ATA) process and is reviewed each year in conjunction with the annual employee performance evaluation process.

The ES&H Division offers training courses covering the hazards encountered by most employees. Employee records for these courses are maintained in a central database, with provisions for notifying employees and their supervisors when refresher training is due. Specialized training required by particular employees or groups is managed by each employee’s department, which is also responsible for record keeping.

The training requirements for EOICs and accelerator operators are more extensive and detailed than for most other employees, and certain safety-critical tasks may only be carried out by EOICs and operators who have completed specified training requirements. In addition to general ES&H safety training, operators and EOICs are trained and qualified in accordance with a strictly controlled program administered by the Accelerator Operations Department of the Accelerator Systems Division as specified in the *Accelerator Division Operations Directives*. Three levels of Accelerator Systems Operators: ASO-1, ASO-2, and ASO-3 are defined for control room work assignments, in addition to the EOIC. The training requirements increase in difficulty at each succeeding level.

Operator training is conducted by senior staff in the Accelerator Operations Department using detailed workbooks which are signed off as the operator-in-training demonstrates competence in each specific task.
New personnel are assigned the qualification level of “New Operator” and begin training with the *ASO-1 Qualification Workbook*. Until they complete this workbook, they may only carry out work activities under the supervision of a qualified operator or EOIC. Beyond the ASO-1 level, operators may progress through the ASO-2, ASO-3, and EOIC training using the corresponding qualification workbooks.

Each workbook describes in detail the requirements for obtaining the qualification level being attempted. In general, the trainer may be any control room operator who has a higher qualification or another senior operations staff member. Final sign off on each section is done by the operator’s supervisor. The major elements of the training program include safety, technical procedures, documentation, and operating procedures. Under safety training, operators are given a safety orientation and a hazard communication briefing, and must complete courses conducted by the ES&H Division covering radiation safety, electrical safety, and emergency preparedness.

To operate the PPS controls for a specific area, control room operators and EOICs are required to complete the corresponding PPS certification workbook. Workbooks are available for each of the major PPS areas (LCLS Injector Vault, Linac, BSY, and Undulator Complex). The workbooks contain training information on the operation of the PPS controls. There are requirements for demonstration of proficiency in operation of PPS controls, as well as in execution of *Search Procedures, Exit and Entry Procedures, Safety Inspection Checklists, and PPS Interlock Checklists*.

Records of operator training in critical safety-related tasks are summarized in the *Shift Schedules and Training Record Summaries*. This document lists the current qualification level and PPS certifications for each operator and is used by the EOIC to schedule operator task assignments.

### 3.3.2 Experimental Facilities Operations Organization

Operation of the LCLS NEH is under the control of the Experimental Facilities Division (XFD), which reports to the LCLS Directorate. The XFD Operations Department is charged with the day-to-day running of the x-ray facility.

All operations are carried out in compliance with [SLAC Guidelines for Operations](#) and the [Experimental Facilities Division Operations Directives](#).

#### 3.3.2.1 Operations

[SLAC Guidelines for Operations](#) and [Experimental Facilities Division Operations Directives](#) are the controlling documents for NEH operations. These documents, together with the more detailed procedures which implement them, are intended to ensure that a high level of performance is achieved in the operation of the NEH facilities, and that operations are carried out safely. The XFD Operations Directives define the roles and responsibilities of the Users and Experimental Facilities Division staff, and specify applicable detailed procedures.

The procedures required for operation of the LCLS NEH are maintained in a hierarchical documentation system by the Experimental Facilities Division Operations Department. The level of review and approval required for each procedure depends on its position in the hierarchy, with critical safety procedures being subject to the most rigorous control and approval processes. Critical experimental facilities safety procedures are updated whenever operational requirements change. The approving authority for each document is listed with the document, and the governing policies are described in the Experimental Facilities Division Operations Directives.
3.3.2.2 Safety
Safe operation of the NEH facility is achieved through adherence to administrative procedures as described in SLAC Guidelines for Operations and Experimental Facilities Division Operations Directives, as well as the SLAC ES&H Manual and the Radiation Safety Systems Technical Basis Document. The Experimental Facilities Division Safety Office provides an overview function for all activities that have an impact on safety.

3.3.2.3 Maintenance
Maintenance and installation activities within the NEH are coordinated by the Experimental Facilities Division, following the Experimental Facilities Division Operations Directives.

3.3.2.4 Training
All who work in the NEH (Experimental Facilities Division employees, other SLAC employees, contractors, and Users) are required to complete safety training programs tailored to their functions and activities. Only appropriately trained and qualified personnel, or trainees under the supervision of trained and qualified personnel, are permitted to perform tasks that may affect safety and health. For example, employees who have reason to work in Controlled Areas are required to complete Employee Orientation to Environmental Safety and Health (EOESH) and General Employee Radiological Training (GERT). This training is administered by the ES&H Division using formal course material and written tests. This requirement applies to outside contractors as well. Users who perform experiments using LCLS x-ray beams are also required to take appropriate safety training, including EOESH and GERT training for all Users. User training is administered by the LCLS User Administration.

Responsibility for determining the appropriate level of training lies with line managers and supervisors. This includes periodically reviewing the duties of each person to assess the hazards he or she may encounter, determining the appropriate training requirements, and verifying that the employee has completed the requisite training. Each LCLS User and visitor is assigned a supervisor who is responsible for determining appropriate training requirements, and assuring that the User/visitor has appropriate training for all activities they undertake at SLAC.

The ES&H Division offers training courses covering the hazards encountered by most employees. Employee records for these courses are maintained in a central database, with provisions for notifying employees and their supervisors when refresher training is due. Specialized training required by particular employees or groups is managed by each employee’s department, which is also responsible for record keeping. The ES&H Division keeps records of the training status of LCLS staff and Users.
4. Hazard Analysis

This section identifies and evaluates the potential hazards associated with the operation of the LCLS Undulator Complex and Near Experimental Hall. The design and development of the LCLS and its technical components have been the result of an iterative review process established during the conceptual stages of the project. Throughout the design of the LCLS, regular meetings were held to address the safety of the design and the effects of the operation of the technical components. This process began with the identification of hazards, their evaluation, development of control or alternative mechanisms to address the identified hazards and, where necessary, a revision of the design to assure that the hazards were eliminated or appropriately mitigated. As designs progressed and became more detailed, the safety review and revision process continued. This self assessment exercise has been supplemented by several independent reviews called by both DOE and LCLS itself. The result is a design in which all safety concerns have been addressed.

The hazard and safety analysis process is governed by Safety of Accelerator Facilities, DOE Order 420.2B. Detailed guidance to implement the order is provided in the Accelerator Facility Safety Implementation Guide for DOE O 420.2B, Safety of Accelerator Facilities, DOE G 420.2-1.

Safety issues that are not covered in this document, and for which a safety analysis has not been performed, could arise. Such an issue would constitute an Unreviewed Safety Issue under DOE Order 420.2B Section 4c. Activities that involve unreviewed safety issues will not be performed if significant safety consequences could result from either an accident or a malfunction of equipment that is important to safety. When unreviewed safety issues are identified, they will be formally reviewed and be subject to the approval of the appropriate safety officers and citizen committees, as required by SLAC Guidelines for Operations, Chapter 23. Activities involving identified unreviewed safety issues must not commence before DOE has provided written approval.

Within the LCLS facility some hazards include those commonly found in general industry. These hazards are addressed in the SLAC ES&H Manual, which provides guidance in the applicability of federal and state regulations (e.g., Cal/OSHA) and professional and engineering standards (e.g., American National Standards Institute (ANSI), American Society of Mechanical Engineers (ASME), and NFPA70E). Specific standards, including DOE Orders, are established in the Work Smart Standards (WSS) and are included in the Stanford/DOE contract.

4.1 Hazard Analysis Methodology

4.1.1 Identification of Potential Hazards

Most potential hazards have been identified or anticipated and studied from the earliest days of SLAC. In addition, facility inspections, area manager walk-throughs, safety reviews and audits, and discussions with the engineers and potential users of the facilities have been used to identify other potential hazards.

Progressively, a more general list of potential hazards associated with radiation sources, energy sources, and hazardous materials, as well as those hazards arising from natural phenomena that could occur during commissioning and during normal operations, has evolved. These hazards are evaluated in terms of their potential on- or off-site consequences and associated risk and generally addressed in the SLAC ES&H Manual.
Potential hazards in accelerator facilities include:

- chemical
- cryogenics and oxygen deficiency
- electrical
- environmental
- fire
- ionizing radiation
- non-ionizing radiation
- ladders
- magnetic fields
- mechanical
- noise
- noxious gases
- occupational safety
- seismic
- vacuum and pressure
- biohazards

Hazards within the LCLS Undulator Complex and NEH have been analyzed and mitigated to a level judged to be acceptable.

4.1.2 Evaluation of Potential Hazards

The hazard evaluation process is a qualitative assessment of potential impacts in terms of hazards, initiators, likelihood estimates, preventive or mitigating features and public, environmental, and worker consequence estimates. The results of these evaluations confirm that the potential risks from operations and maintenance are acceptable.

The scope and design of the LCLS was reviewed by the SLAC Safety Overview Committee (SOC), which coordinates and assigns safety review responsibility to SLAC citizen committees. The members of these committees, appointed by the Director or Chief Safety Officer, have relevant knowledge in applicable subject matter areas. In some cases, they review the system safety documentation and the equipment before new systems are energized. Comments and guidance from each of these reviews are incorporated into the safety design and procedures.

The SLAC citizen committees involved in the review of the LCLS facility design were:
- As Low as Reasonably Achievable (ALARA) Committee
- Earthquake Safety Committee (EqSC)
- Electrical Safety Committee (ESC)
- Environmental Safety Committee (EnvSC)
- Fire Protection Safety Committee (FPSC)
- Hazardous Experimental Equipment Safety Committee (HEEC)
- Hoisting and Rigging Safety Committee (HRC)
- Radiation Safety Committee (RSC)
- Safety Overview Committee (SOC)

During the design and construction of technical components, reviews were conducted to ensure that safety issues had been adequately addressed. This process began with the identification of hazards and the development of controls or alternative mitigation mechanisms. Where necessary, designs were revised to ensure that the hazards were eliminated or appropriately mitigated. Throughout their design and construction, the safety of the x-ray beamline and instrument components has been evaluated. When assembled and ready for commissioning, a major
beamline component or instrument will be subject to an Instrument Readiness Review (IRR), which will include input from the appropriate SLAC Safety Committees. The Instrument Readiness Review Committee will conduct its evaluation in a systematic manner using the expertise of the committee members as well as the committee advisors. The estimated effect of each hazard is evaluated by the IRR Committee with regard to its potential impact on personnel and on the operation of the facility.

All accelerator system and experimental beamline risk analyses were based on a bounding event approach, where the most severe of each particular category of credible accident was analyzed to obtain worst-case results. Each event analysis included determination of the initiating occurrence, possible detection methods, the safety features that would prevent or mitigate the event, the probability of the event occurring, and the possible consequences.

The probability rating levels are shown in Table 2-2. The consequence rating levels are shown in Table 2-3. The hazard risk was determined using the matrix shown in Figure 2-1. The analysis was used to determine the adequacy of the facility and systems designs and formed the basis for the development of needed administrative controls. The following text provides a narrative description of the hazards. The consequences of LCLS operations, including conceivable accidents, would lead to barely-detectable off-site or environmental impacts.

To ensure ongoing compliance with all applicable safety standards, each accelerator facility is audited at least once every five years under a program managed by the Safety Overview Committee and described in the SLAC ES&H Manual, Chapter 31.

4.2 Risk Minimization

Many of the hazards within the LCLS are already well understood, are covered by recognized industrial codes and standards, and have been mitigated to acceptable levels. The hazards addressed in this section are mainly those that present a potential to cause illness or injury to personnel, damage to the facility or its operation, or cause environmental damage due to causes not fully addressed by standard industrial safety practices.

4.3 Environmental Hazards Identification and Analysis

A detailed overview of the SLAC site including geology, hydrology, seismicity, and climate is available in Annual Site Environmental Report. The geology and hydrogeology of SLAC is further described in The Geology of the Stanford Linear Accelerator Center.

4.3.1 Seismic

The design of the physical structure of the LCLS Undulator Complex and NEH addresses hazards posed by seismic activity. Among the potential site-wide emergency situations that could occur at SLAC, a major earthquake is the most likely.

Using newly-collected data and evolving theories of earthquake occurrence, U.S. Geological Survey (USGS) and other scientists now conclude that there is a 62% probability of at least one magnitude 6.7 or greater quake, capable of causing widespread damage, striking somewhere in the San Francisco Bay region before 2032 (see Is a Powerful Quake Likely to Strike in the Next 30 Years? U.S. Geological Survey Fact Sheet 039-03).

SLAC structures have been designed to reduce the effects of a major earthquake to acceptable levels. The design of experimental equipment, including cable trays and large experimental apparatus, as well as shielding modifications and new conventional construction, is reviewed by
the SLAC Earthquake Safety Committee. This facility is subject to both internally developed seismic standards and conventional building codes. Detailed seismicity information is available in *Seismic Design Specification for Buildings, Structures, Equipment, and Systems*. Technical systems (infrastructure support, experimental instruments, support tables, etc.) are installed only after having been subject to a review by the SLAC Earthquake Safety Committee (EqSC).

**4.3.2 Environmental**

The *Environmental Assessment for the LCLS Experimental Facility* addressed the details of the environmental issues associated with LCLS construction and operation, from the Gun all the way through the final instrument in the Far Experiment Hall. A Finding of No Significant Impact (FONSI) was reached by the DOE following their review of the Environmental Assessment in which they concluded that the continued operation, construction and upgrades of the LCLS at SLAC do not constitute a major federal action significantly affecting the quality of the human environment within the meaning of the National Environmental Policy Act of 1969.

The Environmental Protection Department at SLAC provides technical and regulatory guidance and disposal services, and manages environmental restoration projects on the site. A *National Emissions Standards for Hazardous Air Pollutants (NESHAPs)* evaluation was conducted for the LCLS by the SLAC Radiation Physics Department, to estimate the potential for radioactive airborne emissions. Calculations of the radioactivity vented to the atmosphere were performed at 14 release points at SLAC, including several sections of LCLS. (See *Radiation Safety Aspects of LCLS Electron Beam Line Operation*.) The effects were calculated for nominal beam losses onto a target yielding the maximum number of photons. For all calculations saturation activity was used and all of the radionuclides were assumed to be released at each discharge. The dose impact from LCLS has been calculated to be 2.7E-04 mrem/yr for the BTH (single beam dump), 2.5E-03 mrem/yr for the undulator (tune up dump) and 1.7E-03 mrem/yr for the Dump and FEE areas. The calculated dose is well below the 10 mrem/yr annual limit specified in *National Emission Standards for Hazardous Air Pollutants: Subpart H: Department of Energy Facilities*, Title 40 CFR, Part 61, Subpart H, and the 0.1 mrem/yr SLAC design goal.

Therefore, the risk to members of the public is minimal, and an annual administrative review of the facility is sufficient to evaluate any changes in operations, processes, beam intensity, or any other factors that may increase emissions to the environment.

**4.4 Conventional Hazards Identification and Analysis**

SLAC strives to keep its workplace free from recognized hazards and promotes Integrated Safety and Environmental Management Systems. The LCLS facility design, fabrication, construction, installation, testing, and beamline operations fall under the normal SLAC occupational safety requirements as stated in the *SLAC ES&H Manual*. Applicable safety regulations are listed in the WSS set, based on known or anticipated facility hazards.
4.4.1 Chemical

SLAC maintains an inventory of hazardous chemicals in compliance with requirements imposed by San Mateo County. Flammable materials and chemical storage cabinets are provided throughout the facility. Satellite waste accumulation areas are established as needed. This provides control over the types and volume of chemicals stored and used in work areas. All operations and maintenance personnel are trained in the proper use of MSDSs and receive training, as necessary, in specific chemical handling and use. Reviews of the conventional safety aspects of the facilities show that use of these chemicals does not warrant special controls other than appropriate signs, procedures, appropriate use of personal protective equipment, and hazard communication training.

Proposals for experiments in the NEH will include a review of the materials to be brought to the facility. These proposals are required to identify the hazardous materials, quantities, and the nature of the hazards to be brought to SLAC. The XFD Safety Officer (XFDSO), assisted by SLAC safety subject experts and other SLAC staff, assesses the chemical hazards and designs mitigation techniques and special controls required for their safe use. Approved procedures for handling chemicals used in LCLS experiments must be in place before the chemicals are brought to SLAC.

Site and facility specific procedures are also in place for the safe handling, storing, transporting, inspecting and disposing of hazardous materials. These are contained in the SLAC ES&H Manual, Chapter 17, Hazardous Waste Management, and Chapter 40, Hazardous Materials Management, which describes the standards necessary to comply with the Code of Federal Regulations, Occupational Safety and Health Standards, Hazard Communication, Title 29 CFR, Part 1910.1200.

During the operation of the LCLS NEH, materials such as paints, epoxies, solvents, oils, beryllium windows, and lead shielding are used. The industrial hygiene program, which is detailed in the SLAC ES&H Manual, Chapter 5, addresses potential hazards to workers using such materials. The program identifies how to evaluate workplace hazards when planning work and the controls necessary to eliminate or mitigate these hazards to an acceptable level.

Beryllium (Be) – Beryllium fragments, such as shards from broken beamline windows, present a potential health hazard different from that of many other toxic materials in that some individuals can develop a sensitivity to Be following inhalation exposure. Continuing studies of chronic beryllium disease and the availability of sophisticated testing for sensitization have raised the question of whether or not an exposure limit can be set that will prevent sensitization in all individuals. Chronic beryllium disease (CBD) has occurred subsequent to what was previously considered acceptable exposure. The Department of Energy has published a regulation in the U.S. Code of Federal Regulations (10 CFR 850) covering health protection procedures for working with beryllium.

Lead (Pb) – Lead is used for radiation shielding at LCLS. Lead brick, shot, and wool are used as shield material in beam stops, penetrations, and supplemental shielding. Lead will need to be relocated periodically. There are no specific OSHA standards for surface lead contamination. However, the General Industry Lead Standard [29 CFR 1910.1025 (h) (1)] and Lead Exposure in Construction Standard [29 CFR 1926.62 (h) (1)] require surfaces to be maintained as free as practicable of lead accumulation. OSHA’s Compliance Directive CPL 2-2.58 uses 400 μg/ft² (44 μg/100 cm²) as acceptable for Work areas and change areas. All lead handling operations comply...

**Chemical storage** -- Storage cabinets for chemicals and flammable materials are required at all applicable beamline locations. These are confirmed during the IRR process. Waste accumulation areas are established as needed, and the responsible XFD personnel are required to receive the appropriate training. Strict requirements are placed on the XFD Operations Dept. to control the types and volume of chemicals stored and used in work areas. Material Safety Data Sheets (MSDSs) are required to be made available for all chemicals brought to the facility by Users. All beamline personnel are trained in the proper use of the MSDSs and receive training, as necessary, in specific chemical handling and use.

Any components that have the potential for containing an oxygen-deficiency hazard are reviewed during the IRR or experiment review process. Appropriate protection, training, and procedures are required to be put in place to ensure that the hazard is appropriately mitigated.

### 4.4.2 Biohazards

There are no biohazards associated with the operation of the LCLS Undulator Complex. Operation of the User experimental program in the NEH may involve biohazards which are brought to SLAC as part of an experimental study. All work involving biohazards is controlled by the User safety process, and adheres to the requirements of the [SLAC ES&H Manual, Chapter 34: Biohazards](#).

### 4.4.3 Cryogenics

Small quantities of liquid nitrogen are used for maintenance and testing in accelerator enclosures. The main hazard occurs while filling small dewars from large liquid storage tanks. PPE is worn when transferring liquid nitrogen. Face shields, gloves, and protective clothing must be used to prevent liquid spatter from hitting exposed skin or eyes.

Cryogenic systems may be utilized as part of the operation of the beamlines. Primary applications consist of liquid nitrogen transfer from various size dewars for use in vacuum leak detectors, cryogenic vacuum pumps, etc. The LCLS provides appropriate procedures, as well as insulated gloves and safety goggles and/or face shields, at main transfer locations. All personnel involved in these operations are required to take a cryogenic safety course and to comply with both the LCLS and the beamline safety procedures. Any other nonstandard cryogenic systems that may be included in a beamline design will be reviewed by the LCLS beamline review process. Operator and User training and operating procedures are in place.

### 4.4.4 Oxygen Deficiency

Liquid nitrogen is used to service components in both the accelerator and experimental hutchess. Liquid nitrogen presents cryogenic and oxygen deficiency hazards. The [SLAC ES&H Manual, Chapter 36](#), defines the requirements for the safe use of liquid nitrogen in accelerator housings and experimental hutchess. Although cryogens are used extensively at SLAC, there are strict limitations on quantities that may be used in the accelerator housing or experiment hutchess. Uses beyond defined limits require analyses and the use of ventilation, oxygen deficiency monitoring, or other controls.
Compressed nitrogen, helium, and argon are also used in the LCLS NEH. These gases are not toxic, but can displace oxygen if released in spaces without adequate ventilation. The accelerator enclosures are well ventilated and contain no materials in sufficient quantity to contribute to an oxygen-deficient atmosphere.

4.4.5 Noxious Gases
Toxic gases such as ozone and nitric oxides can be produced by ionization of air created by intense radiation fields. These gases can be a problem in accelerators where charged particle beams pass through air or where high-energy Bremsstrahlung beams have significant path lengths in air. These conditions are not a significant hazard in the LCLS Undulator Complex because the beams are well contained within gas-tight vacuum chambers, and the small amounts of toxic gases produced in surrounding air is rapidly and safely dissipated.

The operation of beamlines and equipment within the NEH will not generate noxious gases, since the intense x-ray beams are also contained in vacuum chambers. However, noxious gases may be brought to the facility by experiments. Use of such gases is controlled and the hazards mitigated through the experiment safety review process.

Ozone is produced in air by sources emitting ultraviolet (UV) radiation at wavelengths below 250 nm. All operation of lasers at these wavelengths must use ventilation, enclosed beams, or other means to limit exposure to ozone to as low as practical below the established time-weighted average (TWA) of 0.05 ppm and 0.1 mg/m³.

Hydrochloric acid will be produced in the unlikely event of a cable fire since most cable insulating material is PVC. The fire suppression system is designed to minimize the spread of a fire and therefore minimize the production of hydrochloric acid resulting from a cable fire. Individuals caught in a location where they might breathe these noxious gases could experience respiratory damage. Special precautions (such as using self-contained breathing apparatus) will be used by the SLAC Fire Department in the event of a cable fire.

4.4.6 Electrical
Electrical systems are found throughout accelerator and experimental facilities. High voltages, high currents, or high levels of stored energy present hazards if not managed properly. Mitigation of electrical hazards is achieved through engineered controls such as isolation and insulation, combined with policies, procedures and training for work on these systems. Work performed on electrical systems includes controls such as the use of Control of Hazardous Energy (CoHE) (also known as Lockout/Tagout (LOTO)) procedures, SLAC Control of Hazardous Energy Program: ES&H Manual Ch 51. Laboratory policy prohibits work on energized systems, except in extraordinary circumstances under very limited and controlled conditions.

The design, upgrade, installation, and operation of electrical equipment are conducted in compliance with the following:

- National Electrical Code, National Fire Protection Association (NFPA) 70
- SLAC ES&H Manual, Chapter 8, Electrical Safety

Prevention of injuries to personnel through electrical shock and arc flash burns is of paramount concern. Also important to the scientific mission of the LCLS and its user community is the prevention of electrical faults that could damage equipment or impact operations.
Proper engineering design is used for systems and components over 50 V to eliminate any accidental contact while they are energized. Where practical, systems are designed to operate at lower voltages.

Much of the equipment in use at the facility has been designed and built for a specific purpose and is not commonly found in other industrial facilities. Although workplace experience with this equipment has been very good from both safety and operational perspectives, a program has been established to inspect all equipment that is not labeled by a Nationally Recognized Testing Lab (NRTL). These inspections are performed by trained staff members who examine all unlabeled equipment to confirm that it is free from reasonably foreseeable risk due to electrical hazards. This program applies to all electrical equipment built, acquired, or brought to the LCLS NEH by workers, guests, experimenters, and contractors.

- All personnel working with electrical equipment must be qualified by their supervisors to work safely with the equipment. For each employee or user, the supervisor prepares a training assessment which specifies the training requirements for the worker.
- Any work requiring access to energized circuits is subject to the requirements of SLAC electrical safety procedures and Standard for Electrical Safety in the Workplace, NFPA 70E.

All CoHE activities or work with exposed energized conductors must be performed in accordance with an electrical work permit. Written procedures are established for more complicated activities to guide personnel in the operation and maintenance of equipment involving electrical hazards.

- Safety interlock systems are used where appropriate to ensure that access to high voltage and/or high current equipment takes place only under controlled circumstances. A labeling program has been developed to identify distribution panels and disconnect switches and their sources of power.
- A labeling program has been developed to identify hazardous equipment (electrical and mechanical) throughout the facility. All new LCLS equipment has been labeled with appropriate hazard labels.
- Electrical systems undergo preventive maintenance as scheduled by the Facilities Department.
- Solid electrical grounding has been implemented throughout the LCLS systems, per Uniform Building Code (UBC), NFPA and National Electrical Code (NEC) requirements, and pre-existing facilities are being evaluated and upgraded as part of an aggressive safety program.

All new equipment in the LCLS complex is installed with mechanical barriers that mitigate the risk of exposure to electrical shock. CoHE procedures are defined in SLAC ES&H Manual, Chapter 5, Control Of Hazardous Energy. Electrical safety training and Lock and Tag training are provided for those personnel who may work on or near potential electrical hazards and for their supervisors.

### 4.4.6.1 AC Distribution

The primary AC distribution to the site is at 12.47 kV. For most systems, substation transformers convert the 12.47 kV to 480 volts AC for subsequent distribution. Because of the very high hazards, the substations are fenced, and access is limited to qualified high-voltage electricians. Other personnel do not normally have access to these areas.
Most secondary distribution is 480 V, 3 phase, 60 Hz, ungrounded delta. This is used directly in motors, pumps, power supplies, and other equipment. It is further transformed to 208/120 V, 3 phase for lights, utility outlets, and other general needs. The 480/277 V neutral is grounded. The hazard at 480 V is not only from electric shock, but also from possible arc formation at a short circuit. Short circuit currents can be extremely high, and the resulting arc flash can spray molten copper and other materials. The procedures followed for work on 480 V circuits include training, CoHE or key lockout, circuit voltage testing, and the use of proper personnel protective equipment.

4.4.6.2 High Voltage, Direct Current
Some electronic devices contain high voltage, low current power supplies. While the current in some cases may present a direct shock hazard, in others it is too low to cause a direct injury, but may lead to indirect injuries, such as falls, bumps or other physical mishaps. Accelerator and experimental components are prominently marked for a high-voltage hazard.

Currents of a few tens of mA passing through the body may result in physical injury. Various pulsed magnets, kickers, and other devices, use potentially lethal power supplies. All such power supplies are properly marked. Access panels are interlocked where appropriate, local status indicators are provided, and local lockout switches are provided where more than one turn-on location is used. Shorting devices are included when hazardous stored charges may be present.

4.4.6.3 High Current, Low Voltage
Electromagnets within the Undulator Complex often operate at high currents, up to several thousand amperes, but at relatively low voltages. In some cases, the shock hazards are low but a short circuit can create an arc flash hazard. CoHE policies and procedures are used to control work on or near such hazards. In addition, barriers and warning signs are often used for enhanced safety.

4.4.7 Fire
The potential fire hazards associated with the LCLS are:

- Ignition of electrical cable insulation.
- Overheating or electrical breakdown in power supplies or electronic components.
- Transient combustible materials.

Fire hazards in LCLS areas were analyzed as described in Title II Fire Hazard Analysis for the Linac Coherent Light Source, as required by *Facility Safety*, DOE O 420.1A, and *Nonreactor Nuclear Safety Design Criteria and Explosives Safety Criteria Guide*, DOE G 420.1-1. The conclusions developed through this analysis were reflected in the final facility design. The Fire Protection system has been installed in the area to be occupied by the LCLS equipment is classified as an “improved risk” system, meeting the objectives of DOE Order 420.1. The Fire Hazards Analysis of the LCLS Project included recommendations regarding the type of cabling to be used on the LCLS project to minimize the fire hazard and associated risks. These recommendations were followed. Experiment instrumentation is contained within enclosures. In the NEH, the enclosures have standard smoke detector coverage and sprinklers. The selection of cable used on the project and fire breaks in cable trays were chosen with the view of reducing the fire exposure in the LCLS. The design of the facility includes features to de-energize the experiment station enclosures in the event of a fire. Packing material and chemicals are administratively controlled to minimize their presence.
The probability of a fire in the LCLS areas is similar to that in other SLAC accelerator facilities. X-ray beamline and experimental equipment components are fabricated primarily from non-flammable materials and combustible materials are kept to a minimum through administrative controls. The most likely fire with any substantial consequences would be in the insulating material of the electrical cable plant caused by an overload condition.

New cables for the LCLS are installed consistent with current SLAC standards for cable insulation and comply with National Electrical Code (NEC) standards concerning cable fire resistance. This reduces the probability of a fire starting and the deleterious health effects of combustion products of cables containing halogens.

Smoke detection systems were installed in the NEH area for early fire detection. The use of tray-rated, low-smoke zero halogen cable and of fire breaks in the cable trays mitigate fire spread potential. Support buildings for power supplies and electronic equipment are protected by automatic heat activated wet sprinkler systems. Fire extinguishers are located in all buildings and accelerator housings. The combination of smoke detection systems, sprinklers and the on-site fire department ensures a rapid response to any fire or smoke related incident.

The LCLS conventional facilities, including the new beamline housings, have been designed within the framework of the model Uniform Building Code (UBC). The LCLS design complies with NFPA Standard 101, the Life Safety Code (LSC), for life safety compliance. Area Managers maintain housekeeping standards to minimize the amount of transient flammable materials from their areas. Overall, the beamline areas present low fire hazards because of the minimal amount of combustible material.

Manual fire alarm stations (see Fire Alarm System Reference Manual) are located throughout the LCLS facility and are connected to the site-wide fire alarm system. Additionally, portable fire extinguishers are provided throughout the structures. PAFD maintains an on-site fire station equipped with one 1,250-gpm fire engine and one wild land truck. PAFD is an International Standards Organization (ISO) Class 2 rated department which can deliver six vehicles and 15 fire fighters in response to a fire at any SLAC facility.

The Undulator Complex is classified as “special purpose industrial occupancies” by the Life Safety Code, NFPA 101 (2006), which allows a maximum of 300 feet travel distance to an exit. Within the linac tunnel and support buildings, stairways or ladders leading directly to exits are spaced such that no point is more than 165 feet from an exit.

The Beam Dump, the FEE and the NEH sub-basement are also classified as a special purpose industrial occupancy. These areas fully comply with Life Safety Code requirements, except that an equivalency was approved for the FEE to accommodate a common path of travel distance throughout the single exit that is approximately 50 feet in excess of the code allowance. Compensating factors include additional fire/smoke barrier walls, VESDA high sensitivity smoke detection throughout, and controls on combustible materials.

### 4.4.8 Magnetic Fields

Devices generating magnetic fields have numerous and diverse uses in the LCLS Undulator Complex. Sets of dipole, quadrupole, sextupole, and trim electromagnets guide electrons through the beamline. The electron beam passes through undulator magnets to generate the LCLS x-ray beam. Vacuum ion pumps contain magnets with typical fields of 1800 gauss at contact.
Magnets are used in the accelerator to bend and focus the positron or the electron beam. The high magnetic fields produced by each magnet are primarily contained inside the bore and are inaccessible to personnel. The magnets do have fields greater than 10-3 T (10 G) extending less than 10.2 cm (4in) beyond the core ends.

The concern with all of these devices is the strength and extent of the fringe fields and how these may impact persons and equipment in their vicinity. Fringe fields in excess of 5 gauss could adversely impact medical electronic devices (pacemakers), and fields in excess of 600 gauss strongly attract ferromagnetic implants (artificial joints), steel materials, and tools. The American Conference of Government Industrial Hygienists (ACGIH) recommends that people with cardiac pacemakers or other medical implants not be exposed to magnetic fields exceeding 5 gauss (0.5 mT).

Magnetic fields in excess of that limit are present but are not accessible to personnel in normal work areas. Postings in publicly accessible areas alert personnel to local magnetic field hazards and conditions. Access to areas containing magnets is coordinated with the Operations group. Personnel involved in operating, maintaining, and testing of magnets are trained in the hazards and precautions associated with magnetic energy, including those relating to ferrous metals, health effects, and medical implants.

LCLS permanent magnet assemblies contain strong static magnetic field assemblies capable of pulling ferromagnetic tools from hands and can also cause injury if hands or fingers are trapped against the assembly by the action of the magnetic field on a ferromagnetic object. The permanent magnets are brittle and may shatter when struck, producing flying debris with sharp edges. The high magnetic fields can influence the performance of implanted ferromagnetic devices such as cardiac pacemakers, suture staples, aneurysm clips, artificial joints, and prostheses.

The use of ferrous metal tools is not allowed near the gaps of energized electromagnets. The hazards and safeguards appropriate to these magnets are identical to those described below for insertion devices.

No magnetic devices, other than standard small motors or vacuum pumps, are expected to be used in beamlines. However, specialized beamlines may include devices capable of producing magnetic fields capable of posing a safety hazard. These devices will be reviewed by the LCLS, and, if required, the XFD Operations Dept. will prepare posting plans and any other necessary methods for mitigating the hazards. Accessibility to magnetic fields is limited. Operator training and operating procedures are in place.

### 4.4.9 Mechanical

The maintenance of accelerator components often involves moving massive objects requiring special lifting fixtures and procedures. While the objects being moved are sometimes unique or specialized technical components, the procedures for moving and installing them employ conventional rigging techniques. At SLAC, rigging is done only by trained and authorized technicians, and all cranes, hoists, and rigging fixtures are subject to formal testing and approval processes. These requirements are covered in the *SLAC ES&H Manual, Chapter 41*.

Mechanical hazards associated with the rupture of vacuum vessels or piping and hoses containing high-pressure fluids are discussed separately.

The other mechanical hazards found in the LCLS NEH are devices that move under remote control. The motion of vacuum valves and x-ray optics introduce potential pinch hazards;
however, each of these devices has been covered with a protective barrier or has been demonstrated to move slowly enough or in such a way that no credible pinch hazard could arise. LCLS buildings contain rotating machinery such as pumps, blowers, and fans. Proper guarding is in place and procedures require the equipment to be locked out before guards are removed for servicing of the equipment. Pinch points are required to be covered or labeled. Assembly pinch points have been reasonably addressed during design.

Pneumatic actuators shall have the cylinder vented and cycled to its rest state before maintenance. All pneumatic devices shall have local shut-off valves. Positioning of much of the equipment and components at LCLS requires the use of forklifts, moveable tables, cranes, and specialized lifting equipment.

Magnets are supported by the steel girder assemblies. The design criteria for the girder assemblies were based on desired deflection characteristics, resulting in low stresses with applied magnet loads. Dynamic response to vibration tests of the girder assembly showed acceptable results, indicating a safe capacity for the static magnet loads. The design criteria for the support assemblies were based on desired deflection characteristics, resulting in low stresses with applied dynamic loads. Dynamic response to vibration tests of the support tables showed acceptable results, indicating a safe capacity for the static loads. Use of lifting equipment is governed by SLAC safety standards and procedures. Where required, handling and operating procedures have been documented on drawings, reviewed with personnel, and distributed.

Use of lifting equipment is governed by SLAC standards and procedures. Rigging operations are performed by properly trained and licensed operators using certified lifting equipment. When required, handling and operating procedures have been documented, reviewed with personnel, and distributed. Personnel responsible for performing these activities have received relevant SLAC training courses.

Component pinch points have been reasonably addressed during design. Where required, specialized tooling and tools have been identified and have been fabricated or procured. Pinch points are labeled and, if possible, covered. Beamline components are supported on girders. The girders have to provide positional stability to the components; therefore, the designs need to be conservative. A mechanical hazard event may occur when these components are installed or relocated as part of beamline installation or modification. Use of lifting equipment is governed by SLAC safety requirements and procedures. Hoisting operations will only be performed by properly licensed operators using certified lifting equipment. Beamlines may contain rotating machinery, such as pumps, blowers, and fans. Proper guarding will be required to be in place, and the Beamline Management will be required to prepare procedures requiring the equipment to be locked/tagged out before guards are removed for servicing of the machinery.

**Remote Controlled Robot Arm** – The XPP instrument which will be placed in Hutch 3 of the NEH plans to include an anthropomorphic robot for the detector mover. The robot arm has a maximum one meter radius and is capable of moving the detector around a spherical surface at a prescribed radius. The remote manipulation of the robot arm creates a potential for entrapment, pinching or striking of equipment or personnel. The robot is large and powerful enough to cause physical injury or damage. The OSHA technical manual, section IV, chapter 4; “Industrial Robot and Robot System Safety” and ANSI/RIA R15-06; “American National Standard for Industrial Robots and Robot Systems.” will be used as guides to developing a safe robot arm system. The safety measures will include, but are not limited to the following:

- Personnel protection systems
- Hardware systems - docking interlocks to robot power and control systems switching, force sensor interlocks.
- Software system - training & maintenance modes.

Detailed operational procedures for this robot will be examined by the IRR process and certified safe before the robot is energized.

4.4.10 Noise
The SLAC ES&H Manual, Chapter 18, Hearing Conservation contains requirements for reducing noise and protecting SLAC personnel who may be exposed to excessive noise levels. Warning signs are posted where hazardous noise levels may arise, and hearing protection devices are readily available.

4.4.11 Vacuum and Pressure
The SLAC ES&H Manual, Chapter 14, Pressure and Vacuum Vessels, contains requirements for the safe use of vacuum and pressure vessels at SLAC. Vacuum vessels are used extensively at LCLS. In order to maintain an adequate particle beam lifetime and to prevent contamination, the vacuum system is generally constructed with metal tube using bolted, all-metal seals. However, there are several locations that have glass windows or ceramic-to-metal seals.

The beamline will generally be maintained and operated under vacuum. The operational level of vacuum for the beamline generally lies between 1 X 10^-4 and 1 X 10^-9 Torr.

Risks associated with high-vacuum systems include the risk of flying debris from an implosion, the similar risk of debris from an explosion if the system is unintentionally over-pressured, and other risks from ancillary activities associated with operating the system, such as risk from hot surfaces during vacuum baking and electrical risk from equipment inside a metal vacuum chamber.

In general, implosion and explosion risks are mitigated through good design practices, using properly-rated components and often including the strategic placement of burst disks in the system. Requirements and safety evaluation processes are given by the SLAC ES&H Manual, Chapter 14. Specific requirements for handling compressed gas cylinders are given by the SLAC ES&H Manual, Chapter 38.

After venting of a vacuum chamber, the vacuum system must often be baked out for proper UHV operation. The bakeout temperature for these systems is typically 130 degrees C. This is done using heat tapes installed by trained personnel. Signs notifying personnel that the system is hot are posted and access restricted.

Cooling water and compressed air are distributed throughout the LCLS Undulator Complex for a variety of purposes. The cooling water, which is plumbed through a system of rigid pipes, flexible pipes, and hoses, introduces a rupture hazard. The rapid release of water would be a startle hazard and could cause a person to fall, but is unlikely to cause any major injury directly. These water systems are conservatively designed to reduce the likelihood of structural failure from stress cycles that occur during normal operations. Flexible pipe is chosen based on the operating pressure, and fittings are attached following the manufacturer’s specifications.

Compressed air is used to actuate various valves and other pneumatic devices in the LCLS Undulator Complex, and introduces a risk of a startle hazard similar to a water hose rupture. The compressed air systems are also conservatively designed using high quality hoses and fittings. The tubing used to distribute the compressed air is typically small diameter, thereby impeding
the flow of air and limiting the volume that could be released rapidly. All new or modified pressure vessels are designed and built to conservative engineering standards, and are subject to formal engineering reviews. Acceptance testing of pressurized systems is done where applicable.

4.5 Radiation Hazards Identification and Analysis

Linear Accelerator Facility operations generate both ionizing and non-ionizing radiation. Non-ionizing radiation sources include lasers and pulsed klystron high-power RF systems which generate electromagnetic radiation in the microwave range (2.856 and 11.424 GHz). Neither the LCLS Undulator Complex nor the NEH contain pulsed high power RF systems. The Undulator Complex contains one enclosed laser in the FEE, while the NEH contains a complex system of high-power lasers.

Ionizing radiation hazards associated with high-energy electron beams can be severe, and therefore are carefully studied and subject to formal reviews. In the LCLS Undulator Complex beams are transported within vacuum enclosures, but significant fractions of the beams can be lost. When high-energy electrons or positrons strike matter, whether on a beam collimator or the side of vacuum pipe, secondary fields of photons, neutrons, and other particles are produced. In general, the unshielded secondary radiation fields from such losses are dominated by photons, particularly in the more forward direction from beam loss points. Passive shielding and PPS-controlled exclusion zones are necessary for ensuring that persons are not exposed to this radiation.

The LCLS FEE and NEH do not contain high-energy electron beams, but the FEE does admit the radiation products of the electron beams from the Undulator Complex, while the NEH has minimal probability of admitting any secondary radiation from the electron beam. The primary ionizing radiation in the NEH consists of the x-ray beam generated through the Free-Electron Laser (FEL) process in the LCLS Undulator. In addition to this radiation, small amounts of other radiation generated in the Undulator Complex (broadband synchrotron radiation, Bremsstrahlung radiation, muons, neutrons) are present at the beam entrance point into the NEH. Passive shielding is used to reduce this other radiation to negligible levels in the NEH. PPS-controlled exclusion zones are used to reduce the risk of exposure to the FEL x-rays, and to further reduce exposure to the other types of ionizing radiation.

4.5.1 Non-ionizing Radiation Hazards

A high-powered Class 4 laser is used in the experiments in NEH. The laser is located in the laser room, directly above the NEH hutch. Laser light can be directed into any hutch through an evacuated beam transport tube connecting the laser upstairs with an enclosed laser table inside the hutch. Laser equipment is located on the laser tables, surrounded by opaque enclosures. The beam is transported to the experimental chambers through tubes and enter the vacuum system through viewports.

Laser hazards associated with the LCLS accelerator systems are mitigated through engineering controls which exclude most workers from the laser areas, and through training, procedures, and PPE for workers who must work directly with the laser beams.

Low power lasers for survey do not present a safety hazard.

Low-power communications radio transmitters are used in the LCLS Undulator Complex and NEH. These transmitters are commercial devices with FCC certification. Their installation and use are reviewed for safety by SLAC subject matter experts, see the LCLS Communications
Radio Non Ionizing Radiation Hazard Analysis [SLAC-I-030-30800-002] The associated risk is generally very low, though in certain areas a small risk to wearers of cardiac pacemakers may exist, and if so warning signs are posted.

4.5.1.1 Control Measures for Class 3b and Class 4 Lasers

All Class 3b and Class 4 lasers at SLAC must be controlled so that the hazards that they present are mitigated. The mitigation is performed primarily through engineering controls. The control measures must be approved by the SLAC Laser Safety Officer (LSO) before the lasers can be operated. Specific requirements for laser engineering controls are given in the SLAC ES&H Manual, Chapter 10 Laser Safety, and the requirements of the American Standards for the Safe Use of Lasers, ANSI Z136.1. Laser controls may include protective housings and enclosed beam paths, Laser Controlled Areas, interlocks, PPE requirements, etc. The safety controls for a hazardous laser system are known as the Laser Safety System (LSS).

The NEH LSS is designed so that laser light is completely contained at all times when untrained people are present. Untrained experimenters can control the laser beams remotely for their experiments. A specification for the NEH LSS can be found in the LCLS Requirement, Specification and Interface documents, number 1.6-115.

Only workers with specific laser training and medical surveillance, and using established procedures and PPE, can be in an area that contains unenclosed hazardous laser radiation. Workers qualified to work in the vicinity of unenclosed laser radiation are known at LCLS as Laser Operators. Laser Operators are qualified to work with a specific laser system by the System Laser Safety Officer (SLSO).

4.5.1.2 Laser Controlled Areas, Interlocks, and Automated Warning Devices

In general, a Laser Controlled Area (LCA) includes the following features:

- No visual access into the LCA at the wavelength of the laser light.
- Prevention of unexpected or unauthorized entry into the LCA by engineering controls or, alternatively, the accessible laser beam is automatically cut off upon such entry.

Normally, only work directly connected with the laser may be performed in an LCA when the laser is operating. In extraordinary circumstances, other work may be performed with permission of the LSO, provided that the persons performing such work have received laser safety training and have had the required medical examination.

Interlocks and automated warning devices must be tested as a unit, as well as in their component parts; testing of interlocks for LCAs located inside of the accelerator enclosures must be performed at least semiannually. All other interlocks and automated warning devices must be tested at least quarterly. All test results must documented. If a malfunction is found, it must be corrected immediately, or equivalent temporary controls must be substituted.

Invisible beam Class 3b and Class 4 laser systems must incorporate an automatic warning light, or other suitable device, to indicate the presence of a beam. The warning device must be visible through laser safety eyewear and must be located so that a person working near the beam path will see it.

4.5.2 Ionizing Radiation Hazards

The Occupational Radiation Protection regulations, 10 CFR 835, specify an annual total effective dose equivalent limit of 5 rem to workers from both internal and external radiation
sources. This is reflected in the Radiation Safety Systems Technical Basis Document. To ensure high standards of safety, SLAC maintains an administrative threshold control level of 0.5 rem per year. To protect against any possible radiation accident, however unlikely, it is customary at SLAC to carry out a detailed analysis of each mode of operation, including all plausible failure modes, and to demonstrate that transient events, such as beam faults, cannot cause annual radiation dose limits to be exceeded. The special status of radiation hazards is exemplified in the requirement in the Radiological Control Manual that exposure to radiation should be minimized and driven as far below the statutory limits as is practicable. As a result, the risk of a serious radiation injury at SLAC accelerators and experiments is extremely low.

Expected radiation sources in addition to the primary beams have been identified and analyzed to determine the required radiation safety systems. These sources produce high-energy Bremsstrahlung and particle radiation from the interaction of the primary electron beam with protection collimators, beam diagnostic devices, the electron stoppers and dumps, and interaction with the residual gases in the vacuum chambers. A radiation safety system consists of shielding, the BCS, and the PPS, along with a system of rigorously applied safety procedures and a lab-wide personal dosimetry program.

The radiation safety program is designed to ensure that radiation doses received by workers and the public are “As Low As Reasonably Achievable” (ALARA), as well as to prevent any person from receiving more radiation exposure than is permitted under federal regulations. The ALARA program is designed to ensure that access to high radiation areas is controlled, that the accelerator facilities are adequately shielded, and that designs for new facilities and significant modifications incorporate dose reduction, contamination reduction, and waste minimization features in the earliest planning stages. Technical and administrative systems exist to implement the program, as described in the Radiation Safety Systems Technical Basis Document and the SLAC Guidelines for Operations.

The following criteria are described in the Radiation Safety Systems Technical Basis Document:

- The integrated dose equivalent outside the surface of the shielding barriers must not exceed 1 rem in a year for normal beam operation.
- In the event of a Maximum Credible Incident (MCI), the dose equivalent-rate is less than 25 rem/h, and the integrated dose equivalent is less than 3 rem.
- The maximum dose equivalent rates in accessible areas at 1 foot from the shielding or barrier should not exceed 400 mrem/h for missteering conditions, defined as conditions that are comprised of infrequent or short-duration events in which the maximum allowable beam power, limited by BCS devices, is lost locally or in a limited area.
- The dose equivalent for the maximally exposed member of the public due to ionizing radiation from all SLAC-produced pathways must be less than 100 mrem/yr. The design goal for the dose equivalent at the site boundary due to the operation of the Linear Accelerator Facility (including the LCLS NEH) due to sky-shine and direct exposure must be below the design goal of 5 mrem/year.

Some areas at SLAC are designated as Controlled Areas or Radiologically Controlled Areas (RCAs) and are subject to special policies and procedures, with the intent of minimizing radiation exposures to people who work in these areas. These areas are established with the expectation that radiation levels will not exceed certain specified maxima depending on the type of zone. The Radiation Protection Field Operations Group maintains web-accessible lists of controlled areas with classification details and radiation safety work control requirements.
The probability of significant contamination and ingestion of radionuclides within the LCLS NEH arises only from possible radioactive samples brought for experimental purposes, not from the operation of the LCLS facility itself. This risk is controlled through the User safety process. In addition to shielding, the radiation protection systems use a Personnel Protection System (PPS) and a Beam Containment System (BCS). The PPS ensures that the accelerator and other interlocked hazards are off whenever people are present in the accelerator housing. SLAC uses the name Hutch Protection System (HPS) to describe the subset of PPS systems that are used to control x-ray beam hazards inside the LCLS experimental hutches in the NEH. HPS systems are distinguished from standard accelerator PPS systems at SLAC in that HPS systems have a standard, small set of configurations. Non-SLAC employees (LCLS Users) are permitted to operate HPS systems, after training.

The BCS is designed to protect people outside the accelerator housing by limiting beam parameters, by ensuring the integrity of PPS stoppers and critical collimators, and by monitoring radiation levels outside the accelerator enclosure. These systems are subject to SLAC citizen committee reviews and technical implementation reviews by experts from within and outside of SLAC. These systems are implemented with hardware redundancy and are subject to configuration control requirements as defined in SLAC Guidelines for Operations. As part of the configuration control program, these systems are subject to periodic inspections and check out. Further, these systems undergo rigorous periodic certification as defined in SLAC Guidelines for Operations.

### 4.5.2.1 Shielding Requirements for Ionizing Radiation

The radiation shielding policy at SLAC, applicable to the LCLS Undulator Complex and NEH, is documented in the *Radiation Safety Systems Technical Basis Document*. SLAC’s internal design criteria require that the effective dose equivalent must not exceed 400 mrem/h under a missteering scenario, and that under an accident scenario, the maximum dose equivalent does not exceed 25 rem averaged over a 1 hour period.

Records of shielding calculations are maintained in the minutes of the Radiation Safety Committee and in the archives of the Radiation Protection Department. Details of the LCLS NEH shielding analysis and requirements can be found in *Radiation Safety Aspects of LCLS Electron Beam Line Operation*.

### 4.5.2.2 Personnel Protection System (PPS)

The PPS is designed to prevent beams and beam-generated radiation from being delivered to areas where people could be present, and to automatically turn off beams and other interlocked hazards if someone tries to enter a secured PPS zone when the accelerator is on. The PPS also provides a means of ensuring that everyone who has entered a zone under Controlled Access conditions has come out before beam operations resume. The PPS is composed of beam stoppers, interlocked entryways, and beam-control switches including emergency shutoff buttons (see the *Radiation Safety Systems Technical Basis Document*). In general, entry to a PPS zone requires that three PPS stoppers all be in a state that prevents the beam and beam generated radiation from reaching the zone. A special class of PPS systems known as a Hutch Protection System (HPS, see below) has slightly less restrictive requirements.

The operation of PPS controls is governed by formal procedures:

- **Search Procedures**
- **Exit and Entry Procedures**
- Online/Offline Procedure
- Safety Inspection Checklists
- PPS Interlock Checklists

4.5.2.2.1 PPS Zones in the LCLS Undulator Complex

PPS Zone details are illustrated in PPS Zone Maps. Beamline devices for each area are detailed in Beamline Maps.

The LCLS Undulator Complex is made up three PPS zones: The Beam Transport Hall (BTH) zone, which includes the BTH and the Undulator Hall Tunnel, the Electron Dump Enclosure zone, and the the Front End Enclosure zone. Just downstream of the LCLS Undulator Complex are the three x-ray hutches of the Near Experimental Hall (NEH). These hutches are HPS Zones, as described below in section 4.5.2.2.4.

![Figure 4-1. LCLS Undulator Complex PPS Zones and the NEH hutches.](image)

4.5.2.2.2 PPS Zone Interconnections

The PPS has been designed to allow entry into one zone or enclosure without breaking the security of adjacent zones. This is an important feature, because searching these areas is time-consuming and labor-intensive. Thus, while the design is modular in the sense that zones are independent of each other, all zones must be properly interconnected for safe beam operation and for safe entry when the beams are off. In order to deliver the electron beam to the Main Electron Dump in the Electron Dump Enclosure, both the BTH and the Electron Dump Enclosure zones must be secure. In addition, the FEE must be secure, or the electron/photon stoppers protecting it must be inserted.

4.5.2.2.3 PPS Zone Entry Requirements

Certain beam stoppers must be closed, depending on the particular zone, before the PPS logic will generate permissive signals to release keys and to operate door latches. In addition to the requirement that stoppers be inserted, any interlocked electrical hazards in the area must be turned off before door latch and key permissives are given. The hazards and stoppers for each area are listed in the Entry and Exit Procedures.

4.5.2.2.3.1 Security Violation

A security violation in any zone that is receiving or is ready to receive the beam, while the associated PPS stoppers are out, immediately turns off the interlocked electrical hazards and removes beam-related radiation by inserting the PPS stoppers and turning off the Variable
Voltage Substations (VVSs). The *Entry and Exit Procedures* list the specific stoppers that are inserted or turned off when security is lost in a zone and the electrical hazards that are turned off.

### 4.5.2.2.4 Hutch Protection System (HPS)

A Hutch Protection System (HPS) is a special designation for a PPS system which protects personnel from synchrotron and FEL x-ray beams in an experimental hutch. An HPS system is conceptually simpler than most PPS systems, in that it controls a relatively small area (one room), and has only two operational modes: No Access, and Access Permitted. As configured for LCLS, in the Access Permitted HPS mode, upstream stoppers prevent x-ray beams from entering the hutch. The hutch must be searched and secured before it can be placed in No Access mode, and cannot then be entered without breaking the search and going to Access Permitted mode.

Each NEH hutch has an HPS system. An entry into an HPS-protected hutch requires that two HPS stoppers be inserted to prevent the x-ray beam from entering the hutch.

Non-SLAC personnel (LCLS Users) can be authorized to operate the LCLS HPS systems, after training. HPS training records are posted at the beamline during the experiment, and archived by the XFD documentation office.

### 4.5.2.2.5 Administrative Responsibilities and Procedures

Even the most carefully engineered interlock system can fail to provide protection if not augmented by administrative rules and procedures covering operation, testing, and modifications. The LCLS ASD has administrative responsibility for the PPS systems in the Undulator Complex, and the XFD has administrative responsibility for the HPS systems in the NEH. The separation of responsibility occurs at the shield wall between FEE and NEH, as per the *LCLS XFD and ASD Jurisdictional Boundary Treaty* [SLAC-I-020-20200-002]. Both LCLS divisions, ASD and XFD, separately control keys to the PPS stoppers which allow x-rays to pass from FEE to NEH.

ASD and XFD procedures and their identifying numbers are listed in Appendix A. Summaries of the PPS-related administrative procedures follow:

- **Search Procedures**: The *Search Procedures* are formal documents that must be strictly followed to ensure that no person is left in a PPS zone when the hazards are enabled.
- **Entry and Exit Procedures**: The *Entry and Exit Procedures* are formal documents that list the radiation stoppers that must be closed and electrical hazards that must be turned off.
- **Safety Assurance Tests**: Tests of the PPS are done annually, following detailed procedures and checklists prepared by the Controls Department and approved by the ADSO or XFDSD. The procedures include radiation interlock tests.
- **Testing**: Specific tests are done periodically, normally in conjunction with searches, to verify that door microswitches and emergency off buttons are working properly. These tests are described in the Accelerator Systems Division *PPS Interlock Checklists*. Safety inspection of the radiation protection devices are also made in accordance with written procedures following personnel access to any zone. These are described in the *Safety Inspection Checklists* issued by the Accelerator Systems Division.
- Configuration Control: Policies governing the modification and retesting of PPS systems are described in the *SLAC Guidelines for Operations*. All changes must be carefully reviewed and approved, and retesting must be done in accordance with an approved procedure.

- *Beam Authorization Sheet*: For each beam running cycle, specific limits on beam parameters and required safety devices are listed in the *Beam Authorization Sheet*. This is a formal document prepared by the Radiation Protection Department and subject to the approval of the ADSO and the Head of the Accelerator Operations Department. Beam parameters are sometimes limited to levels significantly below the accelerator safety envelope.

- *Beam Line Authorization*: Required safety devices for an x-ray hutch in the NEH are listed in the BLA. This document is prepared by the SLAC Radiation Protection Department and subject to the approval of the XFDSO and the head of the XFD Operations Department.

- Incident and Alarm Response: Incident Response Procedures and Alarm Response Procedures must be followed by XFD staff and Users whenever warning or alarm signals are received.

Accelerator Operators and XFD staff are trained in the use of the PPS. The progress and status of their training is carefully monitored and recorded in PPS certification workbooks for each area. Floor Coordinators qualified in the operation of the HPS are also qualified to train users in the search procedure and operation of the HPS system. HPS training records are posted at the beamline during the experiment, and archived by the XFD documentation office.

**4.5.2.3 Beam Containment System (BCS)**

SLAC’s beam containment policy, described in the *Radiation Safety Systems Technical Basis Document*, requires that beamlines be designed to limit the incoming beam power and detect beam losses to prevent excessive radiation in occupied areas. The containment of the beam is achieved by implementing a system of redundant fail-safe electronic and mechanical devices, which are subject to strict administrative controls. A typical BCS consists of mechanical devices such as collimators, magnets, electron beam stoppers, and dumps, and devices that shut off the beam when out-of-tolerance conditions are detected, such as average current monitors, burn-through monitors, and BSOICs. The specific BCS configuration required for a particular period of accelerator operation is described in the corresponding *Beam Authorization Sheet* (BAS). The specific x-ray beamline BCS configuration required during a particular operating period for x-ray experiments is described in the corresponding *Beam Line Authorization* (BLA).

The BCS for the LCLS Undulator Complex uses toroid current monitors to limit the incoming average beam power to less than an approved level, long ion chambers to limit normal beam losses, protection collimators to limit the range of trajectories of miss-steered beams, and ion chambers and flow switches to protect collimators, stoppers and dumps.

The MCC is the primary collection point for the signals from LCLS. Signals originating at beamline devices are connected by cables to processing electronics in locked racks in the control room. When a fault condition is detected, beam processing modules in MCC withdraw beam permissive signals, which immediately rate-limit or stop the beam.
The BCS equipment in MCC is under strict configuration control, and is checked daily or weekly in accordance with *Beam Containment System Procedures*, issued by the Accelerator Systems Division.

4.5.2.3.1 Beamline Design and Implementation

Devices along the beamline are designed either to absorb the maximum credible beam power or are protected with ionization chambers, flow switches, temperature detectors, or burn-through monitors as required. The beam containment policy and guidelines for beam containment implementation are specified in the *Radiological Control Manual* and the *Radiation Safety Systems Technical Basis Document*. These provide the beamline designer with minimum requirements for the safe design of beamlines. The final design is reviewed by the Radiation Safety Committee.

4.5.2.3.2 Administrative Procedures

Beam Authorization Sheet: *The Beam Authorization Sheet* (BAS) prescribes a specific operating envelope for the LCLS accelerator. It specifies accelerator running parameters, BCS requirements and special shielding requirements for the beamline for the duration of a run cycle. It is a controlled document managed within the Accelerator Systems Division, and also approved and signed by the Head of the Experimental Facilities Division.

Beam Line Authorization: The *Beam Line Authorization* (BLA) specifies the beam containment devices that must be active for the x-ray beamline during a running cycle. It is a controlled document managed within the Experimental Facilities Division. The BLA is prepared by the responsible radiation physicist and is subject to approval by the XFDSO and the head of the XFD Operations Department.

Validation Procedures: Before each beam running cycle, the electronic devices that are required for each beamline are validated using procedures developed by the Beam Containment and Machine Protection Systems Group.

Daily and Weekly Test Procedures: Most of the BCS sensors and modules use self-test signals or similar features to ensure system integrity. In addition, daily and weekly checks are carried out on the BCS systems required to be active by the BAS. These include daily checks that systems are active and weekly checks that trip point settings are correct. These routine checks are described in the *Beam Containment System Procedures*, prepared and maintained by the Accelerator Systems Division.

Configuration Control: Procedures that control the modification and retesting of the BCS are described in the *SLAC Guidelines for Operations*. All changes must be reviewed and approved, and retesting must be done in accordance with an approved procedure.

4.5.2.3.3 Beam Shut-off Ion Chamber System

The linear accelerator beam produces negligible radiation at ground level along the linac, even when beam missteering or equipment failure causes significant beam loss in the tunnel. When the beam emerges from the BSY at the end of the two-mile tunnel, it is directed into experimental areas such as the LCLS. These concrete enclosures are not as thick as the earth shielding along the linac, and if a beam is miss-steered or intercepted in an unintended way, elevated radiation levels may exist in occupied areas. To prevent these elevated levels from remaining unnoticed for any length of time, a number of interlocked radiation monitors, known as Beam Shut-off Ion Chambers (BSOICs), have been installed in the research yard and other
locations. The number of active BSOICs varies, depending on the experimental program. Each BSOIC provides an analog signal proportional to the actual radiation level at the BSOIC and a fail-safe interlock signal which acts to shut off the beam when the upper set point is exceeded. Typically, beam shut-off is achieved by automatic insertion of beamline stoppers.

The location for each BSOIC is specified by a radiation physicist based on considerations such as the thickness of the shielding and the likelihood of beam losses at various locations. Most BSOICs for LCLS are set at 10 mrem/hr, but individual set points may vary. The BSOICs are not intended to monitor dose accumulation in occupied areas, but rather to detect and alarm in the case of a failure of the BCS.

4.5.2.3.3.1 Configuration Control

In accordance with the requirements of the SLAC Guidelines for Operations, all work on the BSOIC system is performed using Radiation Safety Work Control Forms. Personnel who work on these systems are specifically assigned and authorized to do this work.

4.5.2.3.3.2 Acceptance Testing

Acceptance testing of sub-assemblies and of each fully assembled BSOIC is the responsibility of the Radiation Protection Department. Testing includes calibration of each unit using a radioactive source. Defective units are repaired by the Controls Department. The procedures used by the Radiation Protection Department for the testing and calibration of BSOICs can be found in RP Department BSOICs Procedure [RP# FO 024].

4.5.2.3.3.3 Field Certification

When a BSOIC has been replaced in the field, Radiation Protection Department technicians, working with control room operators, confirm that the BSOIC and the appropriate shutoff paths are operating correctly. These tests are described in the BSOIC Certification Checklists. The checklists are prepared and maintained by the Accelerator Systems Division.
5. Accelerator Safety Envelope

This section describes and refers to the Linear Accelerator Facility Accelerator Safety Envelope (ASE), a SLAC configuration-controlled document. The ASE describes the engineered and administrative bounding conditions that define and ensure the safe operations of the SLAC Linear Accelerator facility.

No operation is allowed which violates the ASE. If such a violation occurs, the offending activity must be terminated immediately and not restarted without Department of Energy approval. The ASE will be reviewed and updated as needed, but no less frequently than every two years. The ASE will also be revised as needed whenever major modifications are made to the facility (see SLAC Guidelines for Operations, Chapter 25: Safety Assessment Documents).

The allowed running conditions for each mode of operation of the accelerator are listed explicitly in the corresponding Beam Authorization Sheet (BAS), which is issued for each running period and which is subject to a formal approval process. Compliance with the requirements of the BAS ensures that operational parameters remain within the bounds set by the ASE and that the level of risk to all persons is maintained at an acceptably low level. The BAS typically specifies allowed beam parameter limits, settings of radiation sensors, special shielding configurations, and lists of safety certifications, interlock checks, initial beam tests, and other requirements that may depend on particular experimental configurations.

Allowed running conditions for the x-ray beamline in the NEH are described in a Beam Line Authorization (BLA) document. A BLA is issued for each running period, for each experimental hutch and instrument, before the photon beam can be brought to the instrument. A BLA is subject to a formal approval process. The BLA typically specifies settings of radiation sensors, shielding configurations, interlock checks, initial beam tests, and other requirements for the beamline in the NEH.

Engineered safety systems are employed to ensure that the accelerator components operate within their predetermined parameters or operating ranges, that no beam can be introduced into an area occupied by people, and that radiation levels in occupied areas do not exceed predetermined limits. The safety envelope also includes administrative policies and procedures to ensure that all required safety devices are in place and functioning properly. These include procedures for verifying by inspection that the required safety devices are in place, initial beam tests to calibrate sensors and demonstrate the efficacy of shielding, and documented work control procedures and authorization policies for maintenance, replacement, or modification of safety devices. The specific devices required for each mode of operation are listed in the Beam Authorization Sheet.

The Personnel Protection System (PPS) is subject to testing as specified in SLAC Guidelines for Operations, Chapter 27: Testing of Personnel Protection Systems.

Variations in operating conditions are permitted as long as the consequences of the variations do not exceed the bounds imposed by the safety envelope. These variations of the operating conditions may be introduced during machine development study periods, special tests, or as part of the ongoing efforts to improve the performance of the facility. Variations of operating conditions are controlled through the BAS. Unplanned events, such as power outages, may interrupt operations but do not compromise the safety of the facility.
Shielding is designed to limit integrated radiation doses to acceptable levels, as defined in the *Radiation Safety System Technical Basis Document*. The maximum acceptable radiation levels are summarized in Table 5-1.

### Table 5-1 Ionizing Radiation Shielding Design Limits

<table>
<thead>
<tr>
<th>Condition</th>
<th>Limit</th>
<th>Beam Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure to worker</td>
<td>1 rem/year</td>
<td>Normal operations</td>
</tr>
<tr>
<td>Exposure to public from skyshine at site boundary</td>
<td>0.1 rem/year</td>
<td>Normal operations</td>
</tr>
<tr>
<td>Exposure to worker during safety system failure</td>
<td>25 rem/hour or 3 rem/event</td>
<td>Maximum beam power with BCS failure</td>
</tr>
</tbody>
</table>

Three modes of operation are envisioned for the Linear Accelerator facility in the next few years:

- Electron or positron beam to End Station A.
- Electron beam to the LCLS main dump, with photons to FEE and NEH.
- Electron and positron beams to the NIT and SIT Systems.

When electron beam is delivered to the LCLS main dump, x-rays can be delivered to the Front End Enclosure and the NEH.

In addition, a beam of secondary particles can be generated in the BSY and delivered to ESA. Secondary beams of this kind are necessarily much lower in power and average energy than the primary beam used to produce them. Therefore, this mode can be considered a subset of the primary beam mode. These modes of operations are covered in the ASE.
6. Quality Assurance

The quality assurance (QA) program is described in the *SLAC Assurance Program Description*. SLAC’s QA program places a high priority on safety as well as on ensuring that equipment procurement, installation, and operations are carried out in an efficient and cost-effective manner.

The LCLS QA program ensures the availability, functionality, and configuration control of key engineered controls such as PPS, fire detection and suppression, shielding, and laser safety systems.

SLAC’s line management organization is responsible for providing appropriate resources to ensure that the facility meets its long-term performance goals in a safe and effective manner consistent with high standards of quality assurance. At all levels, management communicates high expectations and goals for the attainment of quality, and makes decisions to ensure that performance objectives for both construction and operation are met. Management also seeks out and uses, as applicable, modern quality assurance, manufacturing, and reliability approaches.

LCLS maintains a comprehensive document control system for all policies and procedures required for the safe operation of the LCLS Undulator Complex and NEH. *SLAC Guidelines for Operations*, the *Accelerator Systems Division Operations Directives* and the *Experimental Facilities Division Operations Directives* are the controlling documents for facility operations. The guidelines and directives, together with the more detailed procedures which implement them, are intended to ensure that a high level of performance is achieved in the operation of the accelerator, and that operations are carried out in a safe and effective manner.
7. **Post Operation**

Decommissioning of the LCLS NEH will be a major engineering task. Large volumes of reinforced concrete will have to be disassembled and removed, and large volumes of backfill will be required to restore the terrain.

SLAC has developed programs to minimize contamination by reducing the generation of contaminants, to contain spills, and to dispose of contaminants. Decommissioning will require extensive soil sampling to evaluate the need to scrape and replace soil in order to achieve the goal of restoring the site to unrestricted residential standards.

The decommissioning plan will delineate the applicable California and federal laws, consensus standards, DOE directives, and other requirements applicable to the activities at the time of decommissioning.
## Appendix A. References

<table>
<thead>
<tr>
<th>Reference</th>
<th>Reference Number</th>
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<tr>
<td>Code of Federal Regulations, Electrical</td>
<td>OSHA 29, Part 1910, Subpart S</td>
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<tr>
<td>Environmental Assessment for the LCLS Experimental Facility</td>
<td>DOE/EA-1426</td>
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<td>Facility Safety</td>
<td>DOE O 420.1A</td>
</tr>
<tr>
<td>Is a Powerful Quake Likely to Strike in the Next 30 Years?</td>
<td>U.S. Geological Survey Fact Sheet 039-03</td>
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<td>NFPA 101</td>
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<td>NFPA 70</td>
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<td>Safety Analysis and Review System</td>
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<td>Safety of Accelerator Facilities</td>
<td>DOE O 420.2B</td>
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<td>Standard for Electrical Safety in the Workplace</td>
<td>NFPA 70E</td>
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## SLAC Internal Documents

<table>
<thead>
<tr>
<th>Document</th>
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<tbody>
<tr>
<td>Experimental Facilities Division Operations Directives</td>
<td>SLAC-I-030-00100-001</td>
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<td>Accelerator Systems Division Operations Directives</td>
<td>SLAC-I-040-00100-001</td>
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<td>Alarm Response Procedures</td>
<td>SLAC-I-040-30700-002</td>
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<tr>
<td>Warning Response Procedures</td>
<td>SLAC-I-040-30700-002</td>
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<td>Floor Coordinator Alarm and Warning Response Procedures</td>
<td>SLAC-I-030-30300-001</td>
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<td>Annual Site Environmental Report 2007 (Environmental Reports Page)</td>
<td>SLAC-R-894</td>
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<td>ASO-1 Qualification Workbook</td>
<td>SLAC-I-040-50400-001</td>
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<td>Floor Coordinator Qualification Workbook</td>
<td>SLAC-I-030-50200-001</td>
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<td>Beam Authorization Sheets</td>
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<td>Beam Line Authorization</td>
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<tr>
<td>Beam Containment System Procedures</td>
<td>SLAC-I-040-30200-007</td>
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<td>Beamline Maps</td>
<td>SLAC-I-030-20200-001</td>
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<td>BSOIC Certification Checklists</td>
<td>SLAC-I-040-30400-011</td>
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<td>Entry and Exit Procedures</td>
<td>SLAC-I-040-30400-003</td>
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<td>NEH Entry and Exit Procedures</td>
<td>SLAC-I-030-30200-003</td>
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<td>Fire Alarm System Reference Manual</td>
<td>SLAC-I-040-30500-003</td>
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<td>Geology of Stanford Linear Accelerator Center</td>
<td>SLAC-I-750-3A33X-002</td>
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<td>Incident Response Procedures</td>
<td>SLAC-I-040-30700-001</td>
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<td>Linear Accelerator Facility Safety Envelope</td>
<td>SLAC-I-010-30100-000</td>
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<td>PPS Interlock Checklists</td>
<td>SLAC-I-040-30400-005</td>
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<tr>
<td>PPS and HPS Interlock Checklists</td>
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<td><strong>PPS Zone Maps</strong></td>
<td>SLAC-I-040-30200-002</td>
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<td><strong>PPS and HPS Zone Maps</strong></td>
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<td><strong>Radiation Safety Aspects of LCLS Electron Beam Line Operation</strong></td>
<td>RP-08-07</td>
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<td><strong>Radiological Control Manual</strong></td>
<td>SLAC-I-720-0A05Z-001</td>
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<td><strong>Safety Inspection Checklists</strong></td>
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<td><strong>Search Procedures</strong></td>
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<td><strong>NEH Hutch 1 Search Procedure</strong></td>
<td>SLAC-I-030-30200-002</td>
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<td><strong>Shift Schedules and Training Record Summaries</strong></td>
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<td><strong>Training and Qualification Summaries for XFD Staff</strong></td>
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<td><strong>SLAC Accelerator Facilities: Implementation Plans for DOE Order 5480.25</strong></td>
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<td>SLAC-I-730-0A14A-001</td>
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<td><strong>SLAC Control of Hazardous Energy Program: Interim Procedure</strong></td>
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<td><strong>SLAC Guidelines for Operations</strong></td>
<td>SLAC-I-010-00100-000</td>
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<td><strong>SLAC Integrated Safety and Environmental Management (ISEM) Program Description</strong></td>
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<td><strong>Standard Operating Procedure for the LCLS Injector Laser</strong></td>
<td>LCLS 1.2-001</td>
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<td><strong>Summary of Requirements for Work in Accelerator Housings</strong></td>
<td>SLAC-I-010-00100-002</td>
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<td><strong>Title II Fire Hazards Analysis for the Linac Coherent Light Source, October 20, 2006</strong></td>
<td>SLAC-I-010-30100-016_R002</td>
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## Appendix B. Abbreviations used in this Document

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>ACGIH</td>
<td>American Conference of Government Industrial Hygienists</td>
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<tr>
<td>ADMO</td>
<td>Accelerator Division Maintenance Office</td>
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<tr>
<td>ADSC</td>
<td>Accelerator Division Safety Committee</td>
</tr>
<tr>
<td>ADSO</td>
<td>Accelerator Division Safety Officer</td>
</tr>
<tr>
<td>AE&amp;CM</td>
<td>Architect Engineer-Construction Manager</td>
</tr>
<tr>
<td>AEC</td>
<td>Atomic Energy Commission</td>
</tr>
<tr>
<td>ALARA</td>
<td>As Low As Reasonably Achievable</td>
</tr>
<tr>
<td>ASE</td>
<td>Accelerator Safety Envelope</td>
</tr>
<tr>
<td>ASO</td>
<td>Accelerator Systems Operator</td>
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<td>BAS</td>
<td>Beam Authorization Sheet</td>
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<td>BAS-II</td>
<td>Beam Analyzing Dump</td>
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<td>BC</td>
<td>Bunch Compressor</td>
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<td>BCS</td>
<td>Beam Containment System</td>
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<td>BLA</td>
<td>Beam Line Authorization</td>
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<td>BSOIC</td>
<td>Beam Shutoff Ion Chamber</td>
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<td>BSY</td>
<td>Beam Switchyard</td>
</tr>
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<td>BTH</td>
<td>Beam Transport Hall</td>
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<td>BTM</td>
<td>Burn-Through Monitor</td>
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<td>CID</td>
<td>Collider Injection Development Injector</td>
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<tr>
<td>CoHE</td>
<td>Control of Hazardous Energy</td>
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<td>DOE</td>
<td>U.S. Department of Energy</td>
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<td>ELP</td>
<td>Equipment Lockout Procedure</td>
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<td>Environmental Safety Committee</td>
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<td>EOIC</td>
<td>Engineering Operator-in-Charge</td>
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<td>ESC</td>
<td>Electrical Safety Committee</td>
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<td>FONSI</td>
<td>Finding of No Significant Impact</td>
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<td>FPSC</td>
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<td>GERT</td>
<td>General Employee Radiation Training</td>
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<tr>
<td>GeV</td>
<td>Gigaelectron-volt</td>
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<td>Hutch Protection System</td>
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<td>HRC</td>
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<td>IR</td>
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<td>ISEMS</td>
<td>Integrated Safety and Environmental Management System</td>
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<td>LCLS</td>
<td>Linac Coherent Light Source</td>
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<td>LCW</td>
<td>Low Conductivity Water</td>
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<td>Linac</td>
<td>Linear Accelerator</td>
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<td>LOTO</td>
<td>Lock Out, Tag Out</td>
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<td>LSC</td>
<td>Laser Safety Committee or Life Safety Code</td>
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<td>Abbreviation</td>
<td>Full Form</td>
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<td>LSO</td>
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<td>LTU</td>
<td>Linac-to-Undulator</td>
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<td>MCC</td>
<td>Main Control Center</td>
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<td>MCI</td>
<td>Maximum Credible Incident</td>
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<td>NEC</td>
<td>National Electrical Code</td>
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<td>NEH</td>
<td>Near Experimental Hall</td>
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<td>NESHAP</td>
<td>National Emissions Standards for Hazardous Air Pollutants</td>
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<td>NFPA</td>
<td>National Fire Protection Association</td>
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<td>NiRSC</td>
<td>Non-ionizing Radiation Safety Committee</td>
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<td>Personnel Protection System</td>
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<td>Quality Assurance</td>
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<td>RCA</td>
<td>Radiologically Controlled Area</td>
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<td>Radio frequency</td>
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<td>RTD</td>
<td>Resistance Thermometer Device</td>
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<td>Threshold Limit Value</td>
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<td>UBC</td>
<td>Uniform Building Code</td>
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<td>UH</td>
<td>Undulator Hall</td>
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<td>UV</td>
<td>Ultraviolet</td>
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<td>VESDA</td>
<td>Very Early Smoke Detection Appliance</td>
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<td>VVS</td>
<td>Variable Voltage Substation</td>
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<td>WSS</td>
<td>Work Smart Standards</td>
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