LCLS Injector
Safety Assessment Document

Document Approved by (signature/date)

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1. Introduction

This Safety Assessment Document (SAD) summarizes the hazards associated with the operation and maintenance of the Linac Coherent Light Source (LCLS) Injector. The injector is the first component of the complete LCLS, and was commissioned starting January 2007. The LCLS is a component of the Stanford Linear Accelerator Center (SLAC) Linear Accelerator Facility which is documented in the *Linear Accelerator Facility Safety Assessment Document*.

This SAD considers only the hazards and mitigating systems associated with the LCLS injector and its operation in conjunction with the referenced linear accelerator facility. Hazards capable of causing injury to personnel or damage to the environment have been considered in this analysis. Both engineering and administrative control elements are used to mitigate the hazards. This SAD will be revised, reviewed, and approved as additional components of the LCLS are installed and become ready for commissioning in the coming years.

This SAD provides a detailed view of the safety hazards and systems for employees who work at the LCLS injector facility. It is listed as a reference document in employee training materials.

1.1 Linac Coherent Light Source

The LCLS is a fourth-generation light source at SLAC. The LCLS project is the world's first "hard" X-ray laser, producing X-ray beams of unprecedented brightness in the wavelength range 1.5 – 15 angstroms (800 – 8,000 eV photon energy).

The project scope includes:

- Facilities for production and transport of a bright, high-current electron beam.
- An undulator system in which the electron beam will generate the X-ray beam.
- Facilities for transport, diagnostics and optical manipulation of the X-ray beam.
- End stations and related facilities for X-ray experiments.
- Conventional facilities for the accelerator systems and X-ray experiments.
- An office and laboratory building to house support staff and researchers.

The LCLS project is building an X-ray Free Electron Laser (FEL) facility at SLAC based on the existing SLAC linac. The LCLS requires a new 135 MeV injector at Sector-20 of the existing 30-sector linac to create the high brightness electron beam required to produce the coherent x-ray beam. The last kilometer of the linac, which accelerates the electrons to 14 GeV, has been modified by adding two magnetic bunch compressors. An electron beam transport line that crosses the research yard at the end of the linac passes below the berm at the east end of the research yard through a tunnel housing a 120 meter undulator. A shielded electron beam dump is located approximately 67 meters downstream of the undulator.

Two new experimental halls are being constructed. The Near Experimental Hall (NEH) is approximately 100 meters downstream of the undulator and contains experimental stations in shielded hutches. The NEH is the bottom floor of a planned Central Laboratory and Office Complex (CLOC), which provides laboratory and office space to house the LCLS support staff and research groups. The Far Experimental Hall (FEH) is an underground facility located approximately 386 meters downstream of the undulator hall. It contains three experiment hutches with adjacent support and office areas for experimenters and support staff.

The completed LCLS will include systems to transport the X-ray beam from the undulator to the experiment halls. This system provides the ability to attenuate the X-ray beam and measure its properties (intensity, photon energy and energy spread, pulse duration, transverse dimensions, divergence) in the NEH. Since the unprecedented intensity of the X-ray beam poses special challenges in the design of X-ray optics, the development of prototypical optical elements is also in the project scope. These optical elements are intended to permit basic manipulations of the X-ray beam that are important for the first LCLS experiments.

The parameters of the LCLS Self-Amplified Spontaneous Emission (SASE) Free Electron Laser (FEL) are:

- X-ray Photon Energy 0.8 - 8 keV
- Electron Beam Energy 4.4 – 14.1 GeV from SLAC Linac
- Peak Power in SASE Bandwidth 8 GW
- Peak Brightness 1 x 10^{33} photons/s (mm^2 $mrad^2$ 0.1% BW)
- Pulse Duration 230 femtoseconds
- Pulse Repetition Rate 120 Hz

Detailed information can be found in the *Linac Coherent Light Source Conceptual Design*, SLAC-R-593 (http://www-ssrl.slac.stanford.edu/lcls/cdr/) document.

The LCLS project is a joint effort of SLAC, Lawrence Livermore National Laboratory (LLNL), and Argonne National Laboratory (ANL). Project management for LCLS design and construction is conducted by the SLAC LCLS directorate.

1.2 LCLS Injector Safety Assessment Document

The LCLS injector system described in this document consists of the following:

- RF gun
- GTL spectrometer
- L0 accelerating region
- SAB spectrometer
- Insertion region
- L1 accelerating region
- X-band accelerating region
- Bunch compressor #1
- Drive Laser System

The maximum credible beam power of the LCLS injector system is much smaller than the established safety envelope of the linear accelerator facility, which ensures that LCLS injector commissioning can be carried out safely. Later revisions of this SAD will include details of the safety envelope for the undulator, the X-ray beamlines, and other downstream systems.

The purpose of this SAD is to identify potential hazards to individuals and to the environment from both normal operations of this facility and credible accident scenarios. This information has been used during the design phase of the project to minimize hazards where possible and to develop administrative controls for any remaining hazards to ensure that they can be managed to an acceptable level of risk. A detailed analysis of the technical systems, consistent with core Integrated Safety Management System (ISMS) functions, has been conducted during the safety analysis of the machine’s components. The SAD describes the engineered controls and administrative measures taken to eliminate, control, or mitigate risks from operation of the completed facility.

The LCLS project has developed and implemented a Quality Assurance (QA) program that places as much priority on safety as on other management concerns, with regard to equipment procurement, installation, and operations. Concern for safety is also evident in the procurement system's ES&H approval process, which is the mechanism used to track review requirements and to communicate safety approval to personnel processing procurement packages. Safety is also addressed in the QA requirements covering equipment to be brought to the facility to support experiments.

A determination of a “Finding of No Significant Impact” was made on the *LCLS Environmental Assessment* developed for this project.

SLAC management realizes that the hazard analysis process must be ongoing, taking proper account of, and adapting to changes in planned procurement plans as well as future technical operations.

1.3 LCLS Safety Systems

SLAC’s ES&H program is standards-oriented; the LCLS Project has a system in place that reliably identifies standards and implementation guidance applicable to planned work and purchases. Moreover, the technical managers understand the need to address ES&H requirements before authorizing work or purchases. SLAC's accomplishments to date demonstrate a commitment to minimizing adverse environmental impacts. Plans for ensuring a sustainable design and energy efficiency reflect a reasonable balance between minimizing potential adverse effects and accomplishing the operating facility's mission. The ES&H requirements of the LCLS project are defined in *Project Management for the Acquisition of Capital Assets; Contractor Requirements Document* Attachment 1, DOE O 413.3 Chg 1 which states that the prime contractor's project management system is to meet the following requirement:

- An ISMS has been developed and implemented for the contract scope of work in compliance with *Integration of Environmental, Safety and Health into Work Planning and Execution*, DEAR 970-5204-2. The SLAC ISMS program description can be viewed at www.group.slac.stanford.edu/esh/isms/.
- This document also addresses *Safety of Accelerator Facilities*, DOE O 420.2B Section 4 Requirements, which defines the required contents for the development of a SAD.

2. Summary / Conclusions

2.1 Purpose

The Linear Accelerator Facility, of which the LCLS is a part, was designated a Low Hazard Facility by the Director of the Office of Energy Research, Department of Energy, on October 5, 1995.

This chapter provides a summary of the information contained within this safety assessment document. The safety unique operational hazards of the Linac Coherent Light Source (LCLS) have been analyzed and mitigated to "low risk." A Risk Analysis Summary is provided in Table 2.1 and described in Chapter 4.

The LCLS also has hazards commonly found in general industry. These hazards are addressed in the *SLAC ES&H Manual* which implements pertinent federal regulations (e.g. Cal/OSHA) and professional and engineering standards (e.g., ANSI, ASME and NFPA70E). Specific standards, including DOE Orders, are established in the Work Smart Standards and are included in the Stanford/DOE contract.

2.2 Scope

This document covers the LCLS Injector and Linac commissioned in 2007. The beamlines commissioned early in calendar 2007 are; the RF Gun and its associated drive laser, the GTL Spectrometer, the L0 Accelerating Region, the SAB Spectrometer, the Insertion Region, the L1 Accelerating Region, the X-band Accelerating Region, and Bunch Compressor #1. The Safety Envelope and the Operating Envelope of the SLAC Linear Accelerator Facility can accommodate a much higher beam power than the maximum credible beam that can be produced with the LCLS systems, so the anticipated LCLS operations are well within the SLAC Linac Operating Envelope. Later revisions of this SAD will include details of the safety envelope for LCLS Linac accelerator systems, the Undulator, and the X-ray beamlines.

2.3 Scope and Emphasis

The scope and emphasis of this report have been guided, in part, by expectations set forth in the following documents:

- *Program and Project Management for the Acquisition of Capital Assets* DOE 0 413.3
- *Project Management for the Acquisition of Capital Assets* DOE M 413.3-1
- *Environment, Safety and Health (ES&H) Considerations for Planning and Reviewing SC Projects* (CD-1 and CD-2), available at: http://www.science.doe.gov/SC-80/sc-81/PDF/cd1&2.html; and http://www.science.Doe.gov/opa/PDF/cd1&2.html
- *SLAC Integrated Safety Management Program Description*, which can be viewed at: http://www.group.slac.stanford.edu/esh/isms/

2.4 Applicable Standards

This document identifies SLAC's approach to implementing ES&H standards, and how risks are identified and managed. Control of safety hazards is based on compliance with NFPA, NEC, UPC, ASHRAE, UBC and seismic codes and standards.

SLAC applies and implements an Integrated Safety Management System (ISMS) approach throughout all levels of the LCLS project.

2.5 Hazard Analysis Summary

Table 2.1 Hazard Analysis Summary

Section	Risk Source	Cause	Unmitigated Risk	Control/Mitigation	Potential Impact	Mitigated Risk
4.4.2	Seismic	Falling objects during earthquake	Low	Implementation of building and structural codes Design standards and Safety Committee review and inspections Ref: *Specification for Seismic Design of Building, Structures, Equipment, and Systems*	Personnel struck by or pinched between equipment during an earthquake	Extremely Low
4.4.2	Environmental	Spills Discharges to sanitary or storm drains	High	Training	Personnel exposure Release of liquids to drain system	Low
4.5.1.1	Chemical	Cleaning chemical during installation Acid flushing of magnet coils generates mixed waste.	Low	Personnel Protective Equipment (PPE), Secondary chemical containment CEF and RPFO procedures Ref: *Chemical Process Hazard Analyses*; and *SLAC ES&H Manual*	Injection	Extremely Low

Section	Risk Source	Cause	Unmitigated Risk	Control/Mitigation	Potential Impact	Mitigated Risk
4.5.1.2	Oxygen Deficiency	Release of gases on accelerator enclosures	Extremely high	Limit volumes of gasses in accelerator enclosures. Review by HEEC and application of the requirements in Ch. 36 Safe work procedures. Ref: *SLAC ES&H Manual*	Asphyxiation	Extremely low
4.5.1.3	Electrical	Installation of standard industrial distribution (< 210 V) systems. Contact with energized cables during installation of instrumentation	High	New equipment complies with all applicable electrical codes and standards. All equipment used in LCLS installations must be UL listed. Project reviewed by the SLAC electrical safety committee review LOTO training for all individuals working on exposed electrical systems. Specific LOTO procedure (ELP) for each power supply. Electrical hot work permits, where applicable. Ref: *SLAC ES&H Manual* *Requirements for Work in SLAC Accelerator Housing*	Shock or arc (flash)	Extremely Low
4.5.1.4	Fire	Cable Plant Combustible material in enclosure	Medium	VESDA smoke detection system reporting to the Pyrotronics MXL panel. Fire sprinklers in some areas. Proper selection of cable plant. Fire breaks in cable trays. On-site fire department. Ref: *SLAC ES&H Manual*	Loss of technical equipment Partial loss of cable plant Shut down of operations Personnel Injury	Low
4.5.1.5	Magnetic	High magnetic fields will not be present in or at points	Low	Training – SLAC magnetic field	Personnel injury or	Low

Section	Risk Source	Cause	Unmitigated Risk	Control/Mitigation	Potential Impact	Mitigated Risk
		accessible to individuals assembling or installing Injector equipment.		notification postings Use of SLAC IH program for monitoring exposed individuals	exposure	
4.5.1.6	Mechanical	Vacuum chambers LCW feed & return lines Compressed air and gas lines	High	Engineered systems designed to conservative standards.	Personnel exposure	Low
4.5.1.10	Ladder	Fall from tall ladders in linac access penetrations.	Medium	Fall Protection training courses 200, 201, and 202. *SLAC ES&H Manual* Chapter 45 Fall Protection.	Personnel injury	Low
4.5.1.11	Vacuum and Pressure	Pressure devices fail.	Medium	SLAC safety reviews, acceptance testing of pressure devices	Personnel injury	Extremely Low
4.6.1	Nonionizing Radiation: Rf Radiation	High power rf exposure to personnel	Medium	Confinement to klystron, waveguide, accelerator structures vacuum enclosure; safety interlock system based on waveguide pressure sensors.	Personnel injury	Extremely Low
	Nonionizing Radiation: Laser	Laser exposure to eyes and skin	Medium	Laser system design Ref: *SLAC ES&H Manual* *Standard Operating Procedure for the LCLS Injector Laser* *ANSI Standards Z136.1-2000* sg PPE (gloves and laser goggles)	Eye and skin injury	Extremely Low
4.6.2	Ionizing radiation exposure inside the accelerator enclosure (greater than 25 rem/hr): 1. Prompt	PPS failure or inadequate search	High	Personnel Protection System (PPS). PPS operator training. Periodic testing of PPS. Radiation safety training. Ref: *SLAC Guidelines for Operations*, Search Procedures, Entry and Exit Procedures, PPS Interlock Checklists	High radiation exposure	Extremely Low
	Ionizing radiation exposure inside the accelerator enclosure	Work on or near activated components.	Medium	Radiation surveys and use of Radiological Work Permits	Exposure to residual radiation.	Extremely Low

Section	Risk Source	Cause	Unmitigated Risk	Control/Mitigation	Potential Impact	Mitigated Risk
	(greater than 25 rem/hr): 2. Residual			Ref: *Radiation Safety Systems*, *Radiation Physics procedures.*		
4.6.3	Ionizing radiation exposure (greater than 25 rem/hr) outside the Linac enclosure	Shielding error combined with BSOIC failure	High	Beam Containment System (BCS), Beam Shut-off Ion Chambers (BSOICs), Ref: *Radiological Control Manual* *Beam Authorization Sheet, Prerun Checks, PPS Safety Inspection Checklists*	Personnel radiation exposure	Extremely Low

2.6 Hazard Consequence Rating

The hazards have been rated based on the following criteria.

Table 2.2 Risk Probability Rating Levels

Category	Category Estimated Range of Occurrence Probability (per year)	Description
High	>10-1	Event is likely to occur several times in a year.
Medium	10-2 to 10-1	Event is likely to occur annually.
Low	10-4 to 10-2	Occurrence is likely to occur, during the life of the facility or operation.
Extremely Low	10-6 to 10-4	Occurrence is unlikely or the event is not expected to occur during the life of the facility or operation.
Incredible	<10-6	Probability of occurrence is so small that a reasonable scenario is inconceivable. These events are not considered in the design or SAD analysis.

Table 2.3 Risk Consequence Rating Levels

Consequence Level	Maximum Consequence
High	Serious impact on-site or off-site. May cause deaths or loss of the facility/operation. Major impact on the environment.
Medium	Major impact on-site or off-site. May cause deaths, severe injuries, or severe occupational illness to personnel or major damage to a facility/ operation or minor impact on the environment. Capable of returning to operation.
Low	Minor on-site with negligible off-site impact. May cause minor injury or minor occupational illness or minor impact on the environment.
Extremely Low	Will not result in a significant injury or occupation illness or provide a significant impact on the environment.

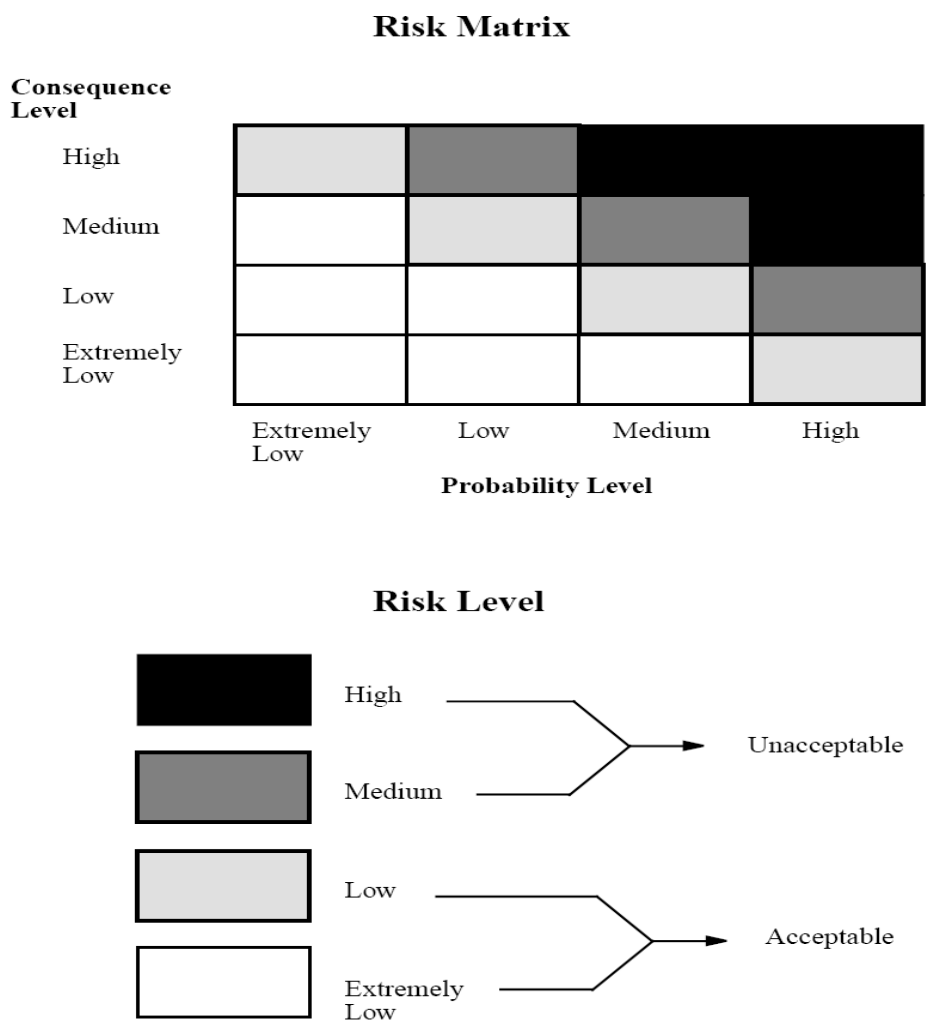


Figure 2.1 Risk Determination

3. Description of Site, Facilities, and Operations

This chapter describes the LCLS construction environment, the facility characteristics that are related to safety and the management methods used in operating the accelerator facility.

3.1 Site Description

A detailed overview of the SLAC site including geology, hydrology, seismicity, and climate is available in *SLAC Annual Site Environmental Report, January-December 2001*.

The geology and hydrogeology of SLAC is further described in *The Geology of the Eastern Part of Stanford Linear Accelerator Center*.

Detailed seismicity information is also available in *Specification for Seismic Design of Buildings, Structures, Equipment and Systems at the Stanford Linear Accelerator Center*.

3.2 LCLS Facility Description

The Linac Coherent Light Source (LCLS) is a free electron X-ray laser which represents a generational advance in X-ray laser science and technology. The electron beam used to generate the X-ray laser will be produced by the existing Stanford Linear Accelerator (Linac).

Physically, the LCLS is an extension of the Linac. The extended beam path is contained within six separate connected structures; the Beam Transfer Hall (BTH) tunnel, the Undulator Hall (UH) tunnel, the Beam Dump and Front End Enclosure (FEE), the Near Experimental Hall (NEH) building, the X-ray tunnel, and the Far Experimental Hall (FEH) building. The BTH is an above-ground, poured-concrete bunker. The other structures are underground. A final tunnel provides access to the FEH from outside. Many of the structures have one or more above-ground utility buildings servicing them. The NEH is part of a building complex that includes an offset, above-ground, structure called the Central Laboratory and Office Complex (CLOC).

The Stanford Linear Accelerator is an electron linear accelerator using room temperature, 2856-MHz radio frequency (rf), copper, disk-loaded waveguide structures, driven by SLAC-built klystrons and energy-doubling cavities. The linear accelerator is located in a tunnel 25 feet underground. Above the tunnel is the gallery, which houses the klystrons and energy-doubling cavities. The linac is segmented into thirty 101.6-meter-long sectors, with Sector 1 on the west end, and Sector 30 on the east end. The LCLS Injector is located underground in an adjacent annex to the linac tunnel near Sector 20. The beam is injected into the linac and accelerated before being transported through the Undulator system.

The linac was originally built in 1966 as a 20-GeV accelerator, but the energy-doubling system and the development of more powerful klystrons has increased the energy capability to 50 GeV. The maximum repetition rate for the reconfigured linac is 120 pulses per second (pps or Hz). For the LCLS project, the linac has been altered to include two four-dipole-magnet bunch compressor chicanes: one at Sector 21 and one at Sector 24. Additional quadrupole magnet focusing is added in Sector 21 to accommodate the lower energy beam of the LCLS Injector, which is about 100-times lower energy than the 30-GeV SLC beam at that point.

3.3 LCLS Technical Systems

This Safety Assessment Document covers those parts of the LCLS commissioned in the period between January 2, 2007 and September 30, 2007. These are the Drive Laser, the Electron Gun, the Injector, and the Linac through Bunch Compressor 1 (BC1). Activities will include testing and commissioning these new systems to achieve the design parameters of the electron beam.

During this time, the parts of the LCLS downstream of the Beam Switch Yard will not yet be installed; there will be no FEL operation and no experimental activities.

3.3.1 LCLS Injector

The LCLS Injector is a new electron beamline incorporating a photocathode rf gun for the production and transport of low-emittance electron beam pulses to the Linac. UV light from a drive laser, pulsed at up to 120 Hz, impinges on the gun cathode, producing the electron bunches. The electrons are captured by the rf in the gun and accelerated to 135 MeV through two rf accelerating structures (L0a and L0b). The electrons are then steered onto the SLAC linac axis for acceleration to high energy. The Injector includes conditioning optics and diagnostic systems for characterization of both the electron and laser beams. Engineered safety systems are included to ensure the safety of the workers.

3.3.1.1 Controls

A new controls system utilizing the commercial Experimental Physics and Industrial Control System (EPICS) will operate the Injector. Racks for the controls are located in the laser alcove and in the existing SLAC Klystron Gallery. Timing electronics are housed in a temperature-controlled room located in the Klystron Gallery. Normal operation of the Injector is remotely controlled from the SLAC Main Control Center (MCC). The Controls include the Personnel Protection System and the Laser Safety System which are engineered systems which control access to the Injector to protect people from direct exposure to prompt radiation and laser hazards.

3.3.1.2 Drive Laser

The Class IV laser to drive the gun is located in the Sector-20 service building at ground level. The UV laser light is transported down to the Injector tunnel through dedicated laser penetrations. Operation of the laser is regulated by the Standard Operating Procedure, a reviewed document which details the conditions under which the Laser system may be run. The Laser Safety System is comprised of hardware interlocks, which prevent nonqualified personnel from accessing the laser beam in the alcove or in the housing. Special access conditions allow qualified personnel to access the laser during operation for alignment purposes.

3.3.1.3 Magnets

Magnets in the injector system include solenoids, dipoles, quadrupoles and dipole corrector magnets of both water-cooled and air-cooled design. Most magnets are not considered electrical hazards due to low voltage; however, all exposed conductors on new magnets will be covered to eliminate access. Long-haul cables connect the magnet loads to power supplies located in the Klystron Gallery. Power supplies for previously installed magnets in the Linac beamline, which are considered electrical hazards, are interlocked to the Personnel Protection System. Work on or near any electrical system requires the completion of an Electrical Safety Work Control form which specifies Lock-Out Tag-Out (LOTO) requirements.

3.3.1.4 Vacuum

Beamline and waveguide vacuum are maintained by discreet ion pumps located along the beamline. Vacuum is monitored using gauges placed between pumps. Pump and valve controls are located in racks in the Klystron Gallery. Vacuum hardware is designed to present no electrical or mechanical hazards.

3.3.1.5 Diagnostics

Individual devices and systems of devices are installed to fully characterize the electron beam at all critical points along the electron path. Systems include Beam Position Monitors (BPMs), toroid bunch charge monitors, insertable beam screens and motion-controlled wire-scanners for transverse beam size and shape measurements. The hardware is designed to present no electrical or mechanical hazards.

3.3.1.6 Radio Frequency (RF) Systems

Microwave power to generate and accelerate electrons, and to perform time-resolved beam measurements is provided by existing SLAC Linac klystrons located in Sector-20 of the Klystron Gallery. Klystron 20-5 powers the injector transverse deflecting structure. Klystron 20-6 powers the RF Gun. Klystron 20-7 and Klystron 20-8 power accelerating structures L0a and L0b. Klystron 21-1 powers the L1 accelerating structures. An X-band klystron at location 21-2 powers a single X-band structure in the Linac.

New waveguide runs connect the output of the klystrons to the loads specified above. Timing and feedback control components for the RF-powered devices are housed in a temperature-stabilized “RF Hut.” The Hut is centrally located and encloses penetration 20-17 at the end of Sector 20. This location allows easy cable access to the tunnel and minimizes the distances to the Linac klystrons. RF signal cables run down penetration 20-17 and through the tunnel, from the Hut to the components.

No personnel are allowed access to the Injector or the Linac tunnel while RF power is enabled. The Personnel Protection System (PPS) has redundant interlocks which permit RF power to be present only when the tunnels are secure.

3.3.2 Linac

The LCLS is built on the final one km of the existing SLAC Linac, beginning in Sector 21 and extending through Sector 30. Linac Sectors 21 and 24 include two magnetic-chicane electron bunch compressors, with diagnostics to characterize the short electron bunch. These divide the Linac Sectors 21-30 into five functional LCLS areas; Linac-1 (L1), Bunch Compressor-1 (BC1), Linac-2 (L2), Bunch Compressor-2 (BC2) and Linac-3 (L3). This Safety Assessment Document covers the Linac through Bunch Compressor 1 (BC1).

3.3.2.1 L1 First Accelerating Region

L1 is the first accelerating region in the linac following the injection point. The L1 linac section is composed of an existing 10-ft long RF accelerating structure (21-1d), and two new 9.5-ft sections that allow the addition of two new quadrupole magnets. All new magnets have covers over their conductors. Existing linac magnets in this area have power supplies which are interlocked to the PPS. The RF power for the accelerating structures is interlocked as discussed above.

3.3.2.2 BC1 First Bunch Compressor and X-band RF Section

Bunch Compressor 1 is located in linac Sector-21. This region contains a new four-dipole chicane, a new 2-ft long X-band RF accelerating structure, new quadrupoles, and diagnostic devices, and a pneumatically controlled insertable electron dump. Power supplies and diagnostic device controllers have been added, as well as cables to power and control these units. Cooling water for the magnets is obtained from the existing Low-Conductivity Water (LCW) system. All new magnets have covered conductors. The RF power for the accelerating structure is interlocked as discussed above.

3.4 Operating/Commissioning Organization

3.4.1 Precursors to Commissioning

The LCLS Injector will complete a period of beam commissioning before routine operations commence. A precursor to commissioning will be the successful completion of an Accelerator Readiness Review (ARR) for commissioning, as stipulated in *Safety of Accelerator Facilities* DOE Order 420.2B.

Before an accelerator facility can operate, a *Beam Authorization Sheet* (BAS) listing conditions on beam operations must be prepared and validated. The BAS establishes the pre-running and running conditions necessary to ensure that beam operations will not introduce unacceptable risks. These conditions include checking the physical integrity of shielding, testing of Beam Containment Devices (BCS), testing and certifying the PPS system, specifying BCS settings to limit the maximum allowable beam current and energy, and specifying any other operating conditions that may affect the safe operation. The operation of the LCLS, from an operational safety standpoint, is an extension of current accelerator operations practices. The BAS will be updated as necessary to reflect changes in shielding configurations, the addition of active beam containment devices, and other modifications.

3.4.2 Maintenance

Maintenance of the accelerator is managed by the Accelerator Systems Division, which ensures that the accelerator systems are ready for operation when needed and that repair work is dispatched and coordinated efficiently. During maintenance and shutdown periods, the Accelerator Systems Division coordinates all maintenance and installation work involving the accelerator.

3.4.3 Operating Organization

Operation of the Linear Accelerator Facility is under the control of the Accelerator Systems Division in the SLAC Particle and Particle Astrophysics (PPA) Directorate. Within this division, the Accelerator Operations Department is charged with the day-to-day running of the accelerator facility. The Engineering Operator-in-Charge (EOIC) is responsible for the safe and efficient running of the accelerator facility on a shift-by-shift basis. The EOICs are assisted in the Main Control Center (MCC) control room by Accelerator Systems Operators. All operations are carried out in compliance with *SLAC Guidelines for Operations* and the *Accelerator Division Operations Directives*. These documents are used by the operating, safety, and maintenance groups to ensure that operations are carried out in a safe and effective manner.

Safety responsibility during scheduled operation of the accelerator facilities rests primarily with the EOIC. The Accelerator Division Safety Officer (ADSO) has an oversight role over all operations that have a bearing on safety, including the authority to terminate operations that are in violation of safety rules.

Operator training is carried out by senior operations staff as specified in the *Accelerator Division Operations Directives*. Operators are not permitted to work on a system or in an area without supervision until all training for that system or area has been completed and appropriately signed off. Training of persons outside the Accelerator Systems Division is the responsibility of each person's department.

Long-term maintenance is coordinated by senior staff in the Accelerator Systems Division. 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 items that arise during the shift are coordinated and controlled by the EOIC, with the assistance of the Area Manager for the particular area. The Area Manager is responsible for overseeing all maintenance in his or her area in accordance with the Integrated Safety Management System (ISMS) (see the SLAC Integrated Safety Management Program Description). The EOIC has the authority to call for maintenance assistance from any support group in the PPA Directorate, Operations Directorate, or the ES&H Division at any time, including off-shift hours and weekends.

3.4.4 Operations

SLAC Guidelines for Operations and *Accelerator 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. The *Accelerator Division Operations Directives* define the roles and responsibilities of the key operating personnel and specify the applicable detailed procedures.

A summary of the roles and responsibilities of key operating personnel follows:

- A Program Coordinator is appointed for the duration of each approved program cycle. Responsibilities include managing the short-term schedule, assigning Program Deputies, assisting the Deputies when needed, and keeping the staff focused on the program goals for the running cycle.
- The Program Deputy position is filled by an accelerator physicist or a senior member of the Accelerator Operations Department in the Accelerator Systems Division. The Program Deputy usually serves for a few days at a time and is responsible for all shifts during that time. Duties include daily scheduling to make optimal use of the accelerator at all times, and the preparation of an alternative program in the event it becomes impossible to carry out the scheduled program.
- The Engineering Operator-in-Charge (EOIC) is responsible for managing the Control Room staff so as to carry out the assigned program in a safe and effective manner. The EOIC is also the Person-in-Charge (PIC) of the laboratory during emergency situations, unless relieved by the Director or a designated Deputy or Acting Director of the laboratory. Control Room duties include executing the alternative program whenever necessary, following established procedures in achieving program goals, and maintaining a complete and accurate Operations Log.

- Accelerator System Operators control and monitor the accelerator systems to deliver the beams required for the scheduled accelerator program.
- Control Room Physicists may occasionally operate the accelerator controls to commission new hardware or software. At all times, the physicists must comply with the Control Room directives. They are expressly prohibited from operating any safety-related controls.

3.4.5 Safety

Safe operation of the accelerator facility is achieved by strict 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 facility, the ADSO provides an overview function (quality assurance) for all activities that have an impact on safety.

The ADSO is in the Accelerator Systems Division, reporting to the Division Head. The ADSO has the following responsibilities:

- Ensure that the MCC control room staff operates the machine safely.
- Prepare safety rules and procedures such as *Search Procedures* and *PPS Interlock Checklists*.
- Interpret and clarify safety rules and procedures that are specified in documents such as the *SLAC ES&H Manual*, and the *Radiation Safety Systems Technical Basis Document*.
- Direct the EOIC or other members of the on-duty control room staff to stop operations that are in violation of safety rules.
- Order the discontinuation of any activity at the accelerator facility until the unsafe condition has been rectified.
- Approve all repairs and modifications to safety systems.

The Accelerator Division Safety Committee (ADSC) provides guidance and expertise to the ADSO in matters of ionizing radiation, nonionizing radiation (microwave, laser), cryogenics, and electrical safety, as well as OSHA-related topics. The ADSO is the chairman of the Safety Committee. When necessary, the committee seeks advice from safety experts in the ES&H Division.

The EOIC, assisted by the on-duty Control Room staff, is responsible for carrying out the scheduled program in a safe and effective manner. In addition to duties such as program coordination, supervision, and training, the EOIC has specific safety responsibilities as follows:

- Monitor all control room activities to ensure that they are being carried out in a safe manner.
- Be familiar with current safety rules and procedures.
- Read and sign off any new items in the Hot Sheet at the start of the shift. The Hot Sheet contains safety items of immediate interest that have arisen within the past few shifts.

- Read and sign the *Beam Authorization Sheet* (BAS). This is the controlling document that specifies the safe operating parameters of the machine for the current running cycle.
- Respond to alarm signals from the safety interlock systems such as the Personnel Protection System, the Beam Containment System, and the interlocked radiation monitors called Beam Shut-off Ion Chambers (BSOICs).
- Sign out the Personnel Protection System (PPS) keys and other safety keys to authorized personnel.
- Assume the role of Person-in-Charge (PIC) for responding to site-wide emergencies.

Accelerator System Operators perform system start up and beam operation tasks and have the following safety responsibilities:

- Read and sign *Hot Sheet* items
- Notify the EOIC of any safety problem or emergency condition involving a medical emergency, fire, hazardous gas, oxygen deficiency, or radiation
- Initiate a response to hazardous situations if the EOIC or deputy is unavailable
- Issue PPS keys and other safety keys, search and secure all PPS areas before beam operation, and monitor and control entry and exit from PPS enclosures

3.4.6 Training

All employees and users are required to complete safety training programs tailored to their job responsibilities. For example, all employees and users who work in Radiological Control Areas are required to complete General Safety Training and General Employee Radiation Training. This training is administered by the ES&H Division using formal course material and written tests. This requirement applies to outside contractors as well.

The training requirements for accelerator operators are more extensive and detailed than for most other employees. Operators are trained and qualified in accordance with a strictly controlled program administered by the Accelerator Operations Department of the Accelerator Systems Division. There are three levels of accelerator operators below the EOIC: ASO-1, ASO-2, and ASO-3. The training requirements increase in difficulty at each succeeding level.

Operator training is conducted by senior staff in the Accelerator Operations Department using detailed checklists which are signed off when the operator-in-training demonstrates competence in a 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. Beyond the ASO-1 level, operators may progress through the ASO-2, ASO-3, and EOIC training using the corresponding qualification workbook.

Each workbook describes in detail the requirements for obtaining the qualification level being attempted. The trainer may be any control room operator who has a higher qualification. Final sign off on each section is done by the operator’s supervisor. The major elements of the training program include safety training, technical training, 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 on the Personnel Protection System, Radiation Safety, Electrical Safety, and Emergency Preparedness.

To operate the PPS controls for a specific area, control room operators are required to complete the corresponding PPS certification workbook. There is a workbook for each of the major PPS areas. The workbooks contain training information on the operation of the PPS controls, as well as on *Search Procedures, Exit and Entry Procedures, Safety Inspection Checklists,* and *PPS Interlock Checklists*.

The training program summarized above is described in the *Accelerator Division Operations Directives*. 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.

4. 4. Safety Analysis

4.1 Introduction

The sections of this chapter identify potential hazards that may occur in the course of operation of the LCLS Injection System and Linac beamline. For this SAD, the LCLS Injection System and Linac is comprised of those beamlines which will be commissioned in calendar year 2007, specifically; the RF Gun and its associated drive laser, the GTL Spectrometer, the L0 Accelerating Region, the SAB Spectrometer, the Insertion Region, the L1 Accelerating Region, the X-band Accelerating Region, and Bunch Compressor #1, terminating at electron stopper TD11 at the end of Bunch Compressor #1. This chapter addresses the procedures and equipment used to control the hazard and reduce the risk levels to ensure safe operation. Later revisions of this SAD will include details of the safety envelope for LCLS Linac accelerator systems, the Undulator, and X-ray beamlines.

The Hazards/Safety analysis process is governed by DOE Order 420.2A, Safety of Accelerator Facilities. Detailed guidance to implement DOE Order 420.2A is provided in the “Accelerator Facility Safety Guidance Document.” Accelerator facilities are exempt from the regulations provided in Title 10 of the Code of Federal Regulations Part 830 (10 CFR 830), Nuclear Safety Management. As a nonprofit educational institution, is also exempt from Subpart B, Enforcement Process, of 10 CFR 820, Procedural Rules for DOE Nuclear Activities. 10 CFR 820, Subpart B, establishes the procedures for investigating the nature and extent of violations of the DOE Nuclear Safety Requirements and for adjudicating the assessment of a civil penalty.

Included in this analysis are hazards generally recognized to be present in accelerator facilities including: ionizing radiation, nonionizing radiation, electrical, fire, vacuum and pressure, magnetic fields, chemical, cryogenic, oxygen deficiency, noxious gases, mechanical, and environmental concerns.

The DOE Office of Energy Research (now Office of Science) classified SLAC as a “Low-Hazard Radiological Facility” in response to the “SLAC Accelerator Facilities; Implementation Plans for DOE Order 5480.25” prepared by John Harris, et al. of the Technical Division on 12/15/95.

As a result of this analysis the LCLS facility has been determined to be a “low” hazard class facility as defined in DOE Order 5481.1B, *Safety Analysis and Review System*.

4.2 Hazard Analysis Methodology

The identification of potential hazards has been a consideration from the conceptual stages of the LCLS project. During the development of technical components, regular reviews were held during their design that included consideration for safety in the assembly, operation and subsequent maintenance of their associated systems. This process began with the identification of hazards, their evaluation, and development of control or alternative mechanisms to address the identified hazards. Where necessary, a revision of the design was made to ensure that the hazards were eliminated as a first priority, where possible, 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 evaluations and reviews called by both DOE and by the LCLS project managers. The result is a design in which all recognized safety concerns have been addressed.

From the outset, the safety of components was evaluated as the components were designed. When assembled, the components were inspected by the independent SLAC Safety Overview Committee, which coordinates and assigns safety reviews of new projects to SLAC Citizen Committees (safety committees). The members of these committees, appointed by the Laboratory Director, have hazard knowledge or skills in specific subject matter areas. They also review the system safety documentation and the equipment before the systems are energized. Comments and guidance from each of these reviews provided input to the iterative process of safety design and procedures improvement. Once the facility enters into operation the Safety Overview Committee Coordinates and assigns safety reviews of new experiments/projects or facility modifications to other citizen committees. The committee assigned to review the experiment/project or modification gives its approval before the activity can proceed.

The SLAC safety committees that were involved in the review of the LCLS project were:

- Safety Overview Committee
- As Low as Reasonably Achievable Committee
- Earthquake Safety Committee
- Electrical Safety Committee
- Environmental Safety Committee
- Fire Protection Safety Committee
- Hazardous Experimental Equipment Safety Committee
- Hoisting and Rigging Safety Committee
- Laser Safety Committee
- Nonionizing Radiation Safety Committee
- Radiation Safety Committee

The hazard identification process applied in the development of the LCLS facility was based on design and operating information; facility walk-downs to identify potential hazards within the complex that could adversely affect the workers and environment; and discussions with the engineers and potential users of the facilities. The hazard evaluation process is a largely qualitative assessment of potential impacts in terms of hazards, initiators, likelihood estimates, preventive or mitigating features and public, environmental and worker consequence estimates. A maximum credible accident scenario for each part of the Injector is presented later in this chapter. The results of these evaluations confirm that the potential risks from operations and maintenance are low. The hazards involve those present at all high-energy accelerators and experiments; radiation, chemical, biological, electrical, magnetic fields, radio frequency (rf) fields, energy sources, pressure and vacuum, material handling and lifting, heights, rotating equipment, fire, explosions, natural phenomena, steam, heat and cold, confined spaces, lasers, compressed gas, and hazardous materials handling.

A Hazard and Operability Study (HAZOP) was not performed to look at conceivable malfunctions. Shielding design explicitly accounts for the effects of a missteered electron or photon beam, which could be a result of improper operations or system failure. Mitigation for these events comes in the form of shielding, Beam Containment Systems, and Personnel Protection Systems, which are all part of the LCLS Radiation Protection requirements.

4.3 General Approach to Risk Minimization

Hazard identification produces a comprehensive list of hazards present in a process or facility. Screening of these removes those hazards which are already well understood and acceptable, and those that are covered by recognized industrial codes and standards. As a result, the hazards addressed in this chapter are limited to those that present a potential to cause illness or injury to personnel, damage to the facility or its operation, or cause environmental damage.

For each hazard analysis, the unmitigated risk is first evaluated in terms of likelihood and consequence. This evaluation is performed using professional engineering judgment based on machine and experiment design and operating history. The following assumptions govern the determinations of unmitigated risk:

- The unmitigated risk does not include safety or control systems.
- Assigned frequencies are based on engineering judgment.
- Assigned consequence can be qualitative, but must be conservative.
- If the unmitigated risk is extremely low, then the analysis can stop at this point. Otherwise, one proceeds to the evaluation of mitigated risk as described below.

The unmitigated risk is reevaluated considering the preventive and mitigating factors in place that would either reduce the consequence or reduce the frequency. This should move the location on the risk matrix based on assumed conditional probabilities of failure for the mitigating systems. At this point, the mitigated risk should be either low or extremely low. For low risk, the evaluation of the hazard is reviewed to determine if there are additional preventive or mitigating features that could be credited to bring the risk to extremely low. The last step is to determine if it is necessary to designate any Safety-Significant equipment, make commitments for formal administrative controls, or specify limits for operation. Safety-Significant equipment is designated as such because it actively or passively protects workers and/or staff from significant hazards.

The purpose of Safety-Significant designation is to highlight a minimum number of structures, systems or components needed to ensure safety. An effective system design has as one of its objectives to minimize the number of administrative controls and limits required of such a system. The remaining controls are incorporated into the Accelerator Safety Envelope (ASE), appropriate procedures and/or quality assurance documents.

If the unmitigated consequence is fatal for one or more persons, or if a significant environmental impact can occur, then a Safety-Significant designation, in general, should be made. If there are several mitigating or preventive features, and any single one can control the hazard adequately, then it may not be necessary to designate a Safety-Significant feature.

4.4 Hazard Identification and Hazards Analysis

4.4.1 Environmental Hazards

4.4.1.1 Natural Phenomena Hazards Mitigation

The design of the LCLS addresses mitigation of hazards posed by natural phenomena. It has been estimated by the U. S. Geological Survey that the chance of one or more large earthquakes (magnitude 7 or greater) in the San Francisco Bay area in the coming 30 years is about 67 percent. This represents the emergency situation most likely to arise at SLAC.

SLAC structures are designed and constructed to minimize the effects of a major earthquake to acceptable levels. To ensure and maintain a safe and healthful workplace, the design and installation of experimental equipment for the LCLS (magnet supports, klystron installation, cable tray installation etc.) as well as shielding modifications and new construction (buildings, tunnels, and infrastructure) are reviewed by the SLAC Earthquake Safety Committee. Design and construction activities with respect to seismic loads are covered by internally developed standards and conventional building codes.

Flooding is not considered to be a likely hazard since the facility is not in a flood zone and is on high ground.

Severe weather events such as lightning or rainstorms, do occasionally occur, and have the potential to cause significant damage resulting in an operational emergency. However, such events at the LCLS would not involve a significant release of or loss of operational control of a hazardous or radiological material. Typical severe weather-related phenomena affect the stability of the electrical power supplied to the SLAC facility. Shielding protects personnel from beam losses due to electrical power instability. If SLAC were to declare a weather-related operational emergency recommending that staff evacuate the site, accelerator operators would shut down all accelerators. To date the SLAC complex has suffered minimal impacts from extreme weather. These include the incursion of rainwater (roof leaks and under doors) and loss of some exterior wall panels. Excess storm water could increase the potential for electrical hazards. Depending on the extent of the flooding, in area and in height, there is some potential for chemical and lead contamination of the water. There would be no potential for radiological contamination of that water. Chemical hazards are mitigated by having chemicals stored in cabinets and on shelving above the floor away from the potential water. In addition, custodians damp mop the facility’s floor surfaces to reduce the build-up of dust and other materials.

4.4.1.2 Environmental

The LCLS Environmental Assessment examined environmental concerns associated with LCLS operations. DOE reviewed this document and has issued a Finding of No Significant Impact (FONSI) in which it determined 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 preparation of an Environmental Impact Statement was not required.

A National Emissions Standards for Hazardous Air Pollutants evaluation (NESHAPs; based on guidance in the Radioactive Airborne Emissions Subject Area) for the LCLS has been conducted by the SLAC Radiation Physics group. The total dose to the Maximally Exposed Individual (MEI) resulting from the activation of air due to bremsstrahlung and neutron emission from the

LCLS operation was estimated to be 6×10-4 mrem/year (see RP note RP-05-15). The calculated dose is well below the 10 mrem/year annual limit as specified in the 40 CFR 61, subpart H, and the 0.1 mrem/year SLAC design goal. Therefore, the dose/risk to the 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.

4.4.1.3 Emergency Preparedness

SLAC has a comprehensive emergency preparedness program. The program is defined in the *SLAC Emergency Preparedness Plan* and associated procedures.

At least once each year, per the *SLAC ES&H Manual*, the Emergency Management Coordinator reviews and as necessary updates a Hazard Assessment discussing all known hazards that could impact the SLAC site. This document includes information on natural hazards such as tornadoes, earthquakes, etc. Other known potential technological or man-made hazards on-site or near-site are also discussed in this document. This document also summarizes unclassified emergency planning information regarding security events which could lead to an Operational Emergency on-site. The LCLS management provides needed information to the Emergency Management Coordinator so the document accurately characterizes risks posed by LCLS activities and serves as a source of information containing pertinent non-LCLS hazard information that could impact the LCLS facilities.

4.5 Conventional Hazards

4.5.1 Chemical

SLAC maintains an inventory on all its hazardous materials and is required by the County of San Mateo and the SLAC Business Plan to keep it current. In addition to the inventory of chemicals at the facility, copies of the respective manufacturer’s Material Safety Data Sheets are also maintained. Required 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. Reviews are carried out before work begins, via the ISEMS work planning process.

Use of any hazardous material in a system that has the potential for causing exposure or facility damage (i.e., outside of daily use such as solvents, oils and greases) are reviewed by the Hazardous Experiment and Equipment Committee (HEEC) at SLAC. The proposal would identify materials, quantities, nature of the hazard and mitigation techniques and controls required for safe operation.

During the operation of the LCLS, materials such as paints, epoxies, solvents, oils and lead in the form of shielding will be used. There are no current or anticipated activities at the LCLS that would expose workers to contaminants above acceptable levels. The SLAC Industrial Hygiene Program, which is detailed in chapter 5 of the *SLAC ES&H Manual*, 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.

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 Part 29, 1910.1200.

4.5.2 Cryogenics and Oxygen Deficiency

Liquid nitrogen boil-off lines and/or portable dewars will be used to service components in both the accelerator and experimental housings. The *SLAC ES&H Manual*, Chapter 36 defines the requirements for the safe use of liquid nitrogen in accelerator housings. Although cryogens are used extensively at SLAC there are strict limitations on how much cryogen can be used in accelerator housing or experiment hutches. Uses beyond defined limits require analysis and the use of ventilation, oxygen deficiency monitoring or other controls. The first safety control will be to limit quantities and the use of PPE when handling cryogens.

Compressed gases in use at the LCLS are projected to include nitrogen, helium and argon. The use of these gases will be reviewed and approved on a case by case basis by the Hazardous Experimental Equipment Committee (HEEC). Consistent with Chapter 36 of the ES&H Manual, HEEC may require additional engineering safeguards and monitoring to mitigate the risk of any ODH accident to an extremely low level.

4.5.3 Electrical

High voltage and high current systems are found throughout accelerator facilities. Either of these can present a hazard if not managed properly. Primary mitigation of electrical hazards is through engineered controls such as isolation and insulation, i.e., termination covers. Work performed on electrical systems includes controls such as the use of Lock-Out Tag-Out (LOTO) procedures. Laboratory policy prohibits work on energized systems, except in extraordinary circumstances. Work on energized systems is conducted under very limited and controlled conditions, using qualified employees and under approval of the Laboratory Director.

The design, upgrade, installation and operation of electrical equipment is conducted in compliance with the National Electrical Code, NFPA, the Code of Federal Regulations, Subpart S Electrical and SLAC's policy on Electrical Safety in the *SLAC ES&H Manual*, Chapter 8.

Prevention of injuries to personnel through electrical shock and arc flash burns is of paramount concern and importance. Also important to the scientific mission of the LCLS and its user community is the prevention of electrical faults that could damage equipment to the extent of impacting operation. A number of controls are in place to prevent the above conditions and to minimize electrical hazards.

Proper engineering design is utilized for systems and components over 50 V to eliminate any accidental contact with them while they are energized. Where possible, systems are designed to operate at low voltage, e.g., interlock control systems at 24 V.

Much of the equipment in use at the facility is special purpose and not commonly found in typical industrial facilities. Although workplace experience with this equipment has been very good from a safety and operational perspective, a program has been established to inspect all equipment that is not labeled by a Nationally Recognized Testing Lab (NRTL). These inspections will be performed by trained staff members who will 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 by workers, guests 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 will be subject to the requirements of SLAC electrical safety procedures and NFPA 70E.
- All LOTO 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 to safe operation, maintenance or access for areas with electrical hazards.
- An electrical safety interlock system ensures that access to high voltage and/or high current equipment takes place under controlled circumstances. A labeling program is used to identify distribution panels and disconnect switches and their sources of power. This information is maintained in the Master Equipment List database.
- A labeling program is also used to identify hazardous equipment (electrical and mechanical) throughout the facility. The equipment has been labeled with the appropriate hazard label and the equipment has been inventoried in a database.
- Electrical systems undergo preventive maintenance as scheduled by the SLAC CEF group.
- Grounding has been included in the design for the entire facility, per UBC, NFPA and NEC requirements.

Entry into the accelerator housing requires (through the PPS) that all exposed electrical hazards be de-energized. All new equipment in LCLS beamlines will have mechanical barriers that mitigate the risk of exposure to electrical shock. LOTO procedures are defined in the *SLAC Lock and Tag Program for the Control of Hazardous Energy*. Electrical safety training and Lock and Tag training is provided by SLAC for those personnel who may work on or near potential electrical hazards.

Chapter 3 identifies various electrical devices, magnets, power supplies, vacuum systems, rf systems, beam instrumentation and controls, that are parts of the LCLS.

4.5.3.1 AC Distribution

- The primary AC distribution to the site is at 13.8 kV. Transformers convert the 13.8 kV to 480 volts AC for subsequent distribution. Because of the very high hazard, the substations are fenced with controlled access by the SLAC CEF personnel. Operations 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 many pieces of equipment, motors, pumps, power supplies, etc. It is further transformed to 220/120 V, 3 phase for lights, utility outlets and all general needs. The LCLS tunnel lighting is 277 V which is fed from 480 V to 480/277 V isolation transformers to reduce the fault current magnitude. The 480/277 V neutral is grounded. The hazard at 480 V is not only from a 480 V shock, but also from possible arc formation

at a short circuit. The short circuit currents are extremely high and an arc can spray molten copper and other materials. The procedures followed on 480 V circuits include training, LOTO or key lockout, circuit voltage testing, and the use of proper personnel protective equipment.

4.5.3.2 High Voltage, Direct Current

- Low Current - In many pieces of electronic equipment there are high voltage, low current, power supplies. While the current in some cases may present a direct shock hazard, in others it will be too low to cause a direct injury, but may lead to indirect injuries, such as, falls, bumps or other physical or electrical mishaps. Accelerator and experimental components are prominently marked for a high voltage hazard and may also be interlocked if a direct shock hazard exists.
- High Current – High current in the range of 10-50 mA passing through the body may result in significant physical harm. The rf systems, as well as various pulsed magnets, kickers, and other devices, use potentially lethal power supplies. All such power supplies are properly marked; interlocks actuated on entry to the supply are hard wired to the power source; panel indicator lights show the power supply status; local-remote lockout switches are provided where more than one turn on location is used. Shorting devices are provided, manual or automatic, especially on capacitor storage devices.

4.5.3.3 High Current, Low Voltage

Many devices use high currents, up to several thousand amperes, at relatively low voltages. In most cases the shock hazards are low but a short circuit on the lines, just as in the 480 V AC case, can create a physical hazard. Proper warnings, enclosing of conductors and interlock devices are used. If work is required closer than the distances specified in the *Summary of Requirements for Work in Accelerator Housings*, LOTO must be performed with appropriate PPE, specific Equipment Lockout Procedure, and verification.

4.5.3.4 RF Voltages

Rf voltages in the many kilovolt level are present in the accelerating systems. Contact can result in shock and deep rf burns. Procedures are used such as those for the high voltage DC case.

4.5.4 Fire Safety

The LCLS has in place a Fire Hazards Analysis (FHA), *LCLS Title II Fire Hazard Analysis*, as required by DOE Order 420.1A, Facility Safety, and described in DOE Guide 420.1-1, *Nonreactor Nuclear Safety Design Criteria and Explosives Safety Criteria Guide*. The observations developed by this analysis were included by the Architect Engineer into the facility design.

The probability of a fire in the LCLS facility is similar to that in other SLAC accelerator facilities. Accelerator components are fabricated primarily from non-flammable materials; combustible materials are kept to a minimum. The most likely fire incident with any substantial consequences would be a fire in the insulating material of the electrical cable plant caused by an overload condition.

New cables for the LCLS are being installed consistent with current SLAC standards for cable insulation and comply with National Electric 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.

Beam type smoke detection systems are installed in the new beamline housing for early fire detection. The use of tray-rated, low-smoke zero halogen (LSZH) 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 for use by trained personnel. The combination of smoke detection systems, sprinklers and an on-site fire department (response time ~5 minutes) affords an early warning and timely response to fire or smoke related incidents.

Accelerator housings and other tunnel areas comply with the Life Safety Code with respect to exit distances.

The LCLS conventional facilities have been designed within the framework of the model Uniform Building Code® (UBC®). The LCLS design basis also cites NFPA Standard 101®, the Life Safety Code® (LSC), for life safety compliance. Structures have been designed and reviewed for compliance with the life safety features of NFPA 101 in lieu of the UBC®. In the design of the LCLS Front End Enclosure, where compliance with the LSC common path of travel requirement is not directly achievable, compensatory measures have been provided to achieve an equivalent level of life safety.

4.5.5 Magnetic Fields

Devices generating magnetic fields have numerous and diverse uses at the LCLS. Sets of dipole, quadrupole, sextupole and trim electromagnets guide electrons through the Linac. Klystron assemblies employ permanent magnets of 1000 gauss at contact. Ion pumps in use on all evacuated accelerator and beamline pipes and chambers contain magnets of 1800 gauss at contact. 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. Of particular concern are fringe fields in excess of 5 gauss that could impact medical electronic devices (pacemakers) and fields in excess of 600 gauss that could impact ferromagnetic implants (artificial joints) and other materials (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 alert personnel to local magnetic field hazards and conditions.

4.5.6 Mechanical

There exist several mechanical systems in the accelerator complex that could have potential hazards associated with them if they were to fail. They are:

- Vacuum chambers
- Low conductivity water feed and return lines
- Compressed air and gas lines
- Diagnostic systems

Failure of any of these systems could lead to implosion (in the case of the vacuum chamber) or explosion (in the case of gas or liquid-filled pipes) from poor design or inferior installation, and pinch hazards resulting from motor-actuated diagnostic systems.

Vacuum systems tend to fail less catastrophically; usually a leaking weld or an improperly fitted flange is the cause of a loss of vacuum pressure. These systems are designed with a factor of safety. Pressurized systems also contain safety relief devices set at approximately 120% of the operating pressure of the system. If personnel were to be close when one of these systems fails there is the potential for serious injury in the form of flying debris.

Catastrophic failure of LCW flexible pipe from main headers feeding the magnet cooling systems is a second source of mechanical failure. This event does not consider the possibility of leakage from fittings, age, etc. These systems are also designed with a safety factor, which lowers 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 per the manufacturer's specifications by qualified staff. If personnel were close to a flexible line as it failed, the potential for injury would be low.

4.5.7 Noise

The LCLS uses a wide variety of noisy equipment. Pumps, fans, and machine shop devices, among others, are possible sources of noise levels that might exceed the SLAC noise action level. Noise surveys will be conducted in working areas, as well as near individual pieces of equipment. Based on the results of the surveys, engineering or administrative controls, hearing conservation personal protective equipment, training, postings and additional medical surveillance may be required.

- A Noise and Hearing Conservation Training CBT will be provided to those who qualify based on their work in noise areas.
- The work planning assessment will consider noise hazards in ISEMS work authorization evaluation and will implement hearing protection requirements as needed. Noise levels are also considered as part of beamline and experiment reviews.
- The SLAC ES&H Division industrial hygienists will provide noise level monitoring services.

4.5.8 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 electron beams pass through air or where bremsstrahlung beams have significant path lengths in air. Neither of these cases is present in the LCLS because of the following design and operating characteristics:

- The electron beam is contained in vacuum at all times.
- The most intense bremsstrahlung beam is produced by electron beam interactions in the faraday cup at the end of the beam line.
- Bremsstrahlung beams at wider angles are reduced in intensity by a factor greater than 1000 compared to the forward-directed beam and are significantly reduced in intensity by shielding around all beam stops.

4.5.9 Occupational Safety

SLAC strives to keep its workplace free from recognized hazards and promotes Integrated Safety Management Systems in its pursuit to identify and mitigate new hazards that may appear as a function of a project, task, or engineered system. All LCLS system design, fabrication/construction, installation, testing and finally accelerator beamline operations fall under the normal SLAC occupational safety requirements as stated in the *SLAC ES&H Manual*. Safety requirements are identified through the SLAC Work Smart Standards and are based on known and identified facility hazards.

4.5.10 Ladder Safety

The Sector 21 penetration has a 35-foot vertical fixed ladder which is used to access the Linac housing. Accessing the Linac in this way requires fall protection training. See the SL*AC ES&H Manual* Chapter 45 Fall Protection. Specific entry and exit procedures and use of the fall protection equipment in the linac is documented in *Entry and Exit Procedures*.

4.5.11 Vacuum and Pressure

Proper beamline vacuum maintains electron beam properties and minimizes the generation of bremsstrahlung radiation. Proper beamline vacuum minimizes the loss of beam intensity and reduces corrosion to beamline component surfaces. If a vacuum fault is detected, interlocks close valves to limit contamination (from air) to as small an area as possible. This automatically stops the beam.

Beamline and waveguide vacuum will be maintained by discreet ion pumps located along the beamline. Vacuum will be held at 10-10 to 10-6 torr. Vacuum will be monitored using gauges placed between pumps. Pump and valve controls will be located in racks in the Klystron Gallery.

4.6 Radiation Hazards

LCLS operations will generate both ionizing and nonionizing radiation. Nonionizing 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).

Ionizing radiation hazards associated with a high-energy electron beam are also significant and must be carefully considered. The electron beam is accelerated and transported within vacuum systems, but significant fractions of the beam are lost. When high-energy electrons strike matter, whether on a beam collimator or the side of vacuum pipe, secondary fields of photons and neutrons 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. Therefore, shielding is particularly important as the principal mechanism to reduce secondary radiation fields around beam loss points.

4.6.1 Nonionizing Radiation Hazards

4.6.1.1 Rf Radiation

The emission of nonionizing radiation is controlled to prevent the radio frequency (RF) power generated by the klystrons in the system from becoming a source of personnel hazard. Each klystron is capable of producing pulses of RF power at 2856 MHz with a peak power of 60 MW. The RF system is designed so that the RF fields, generated by both the klystrons and the electron beam, are completely contained within the vacuum enclosure of the klystrons, waveguides, and accelerator structures and do not pose a personnel hazard. An RF safety program for the purpose of protection from the RF exposure hazards has been developed. This program consists of engineering and administrative controls that insure the containment of the RF fields during normal machine operation and control of the sources of the hazards during system maintenance. The system uses vacuum interlocks, which are periodically tested, to disable the RF power source in the event of a break in the vacuum integrity of the system. The trip level of these interlocks is set sufficiently low that the RF power will be disabled before any gap in the enclosure is large enough to allow significant RF power to escape. Surveys have been made which confirm that the RF fields are confined within the vacuum enclosure and are negligible compared to the safety levels set by the industry standards IEEE Standard C95.1 and the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLVs). .

4.6.1.2 Laser Radiation

Lasers will be used for alignment and as a drive source for the Photocathode Gun. The use of lasers at SLAC is regulated via the ANSI Z136.1(2000)"Safe Use of Lasers" standard the requirements of which have been included within the *SLAC ES&H Manual* Chapter 10, "Laser Safety", which establishes hazard classifications based on the laser's ability to cause biological damage to the eye or skin. As required by SLAC policy, written approval is required from the SLAC Laser Safety Officer (LSO) to energize the injector lasers. The Laser Safety Officer requires, in accordance with ISMS policy, that an Injector System Laser Safety Officer be delegated the responsibility for the safety of the Injector Laser System. This System Laser Safety Officer prepares a Standard Operating Procedure (SOP) document detailing all engineering and administrative controls used to mitigate the hazards. In addition, the Laser Safety Committee reviews the SOP and training documents and advises the LSO prior to his approval to operate the lasers. SLAC requires Laser Operators to be trained in General Laser Safety practices and also to be trained in the safety procedures specific to the LCLS drive lasers. Only Qualified Laser Operatosr will have keys giving access to the Laser Room and will be the only personnel present when the lasers are operating. Protective eyewear will be worn at all times during operation. Interlocked shutters will close, turning off the laser beams, upon unauthorized entry. Specially engineered access conditions in the Injector Vault will allow Qualified Laser Operators to be present for alignment purposes with IR and UV beams present. Again, Protective Eyewear are required.

Stability and timing requirements necessitate that laser light be relayed though controlled environments. The transport line between the laser room and gun hutch is a stainless steel tube. Similar enclosed beam paths will be utilized for transporting Class IV laser light. In normal operation, the laser components are covered on their tables to improve stability. The integrated system is effectively a Class IV laser as defined in the ANSI Standard Z136.1.

A Master Control Key can be removed from the Master Control Panel disabling the shutters in the closed position. The System Laser Safety Officer controls the availability of this key. The Photocathode system installation and operation is governed by the approved Standard Operating Procedure for the LCLS Injector Laser. Installation and operation of additional laser systems will be addressed by updating the laser Standard Operating Procedure, with approval of the SLAC Laser Safety Officer. Protection systems (protective housings, interlocks, beam stops, eye protection, etc.) appropriate to the classification of the laser will be implemented consistent with ANSI standards and prescribed in the SOP. Administrative controls include the use of operational safety procedures and designation of laser areas with warning signs. Training and participation in a medical surveillance program are also prescribed for all laser operators and users.

4.6.2 Ionizing Radiation inside the Accelerator Enclosure

The radiation protection considerations for the LCLS are similar to those encountered at both high-energy electron linacs and synchrotron radiation facilities. The *Radiation Safety Systems Technical Basis Document* specifies an annual total effective dose equivalent limit to workers from both internal and external radiation sources of 5 rem. In addition, SLAC maintains an administrative threshold control level of 1.5 rem.

The risk of a serious radiation injury at SLAC accelerators and experiments is very low. However, for radiation exposure it is customary to go beyond the scope of Hazard Analysis to demonstrate that transient events, such as credible beam faults, do not cause annual radiation dose goals or requirements to be exceeded. The special status of radiation hazards is exemplified in the As Low As Reasonably Achievable (ALARA) requirement in the *SLAC Radiological Control Manual* that exposure to radiation is to be minimized and driven as far below the statutory limits as is practicable.

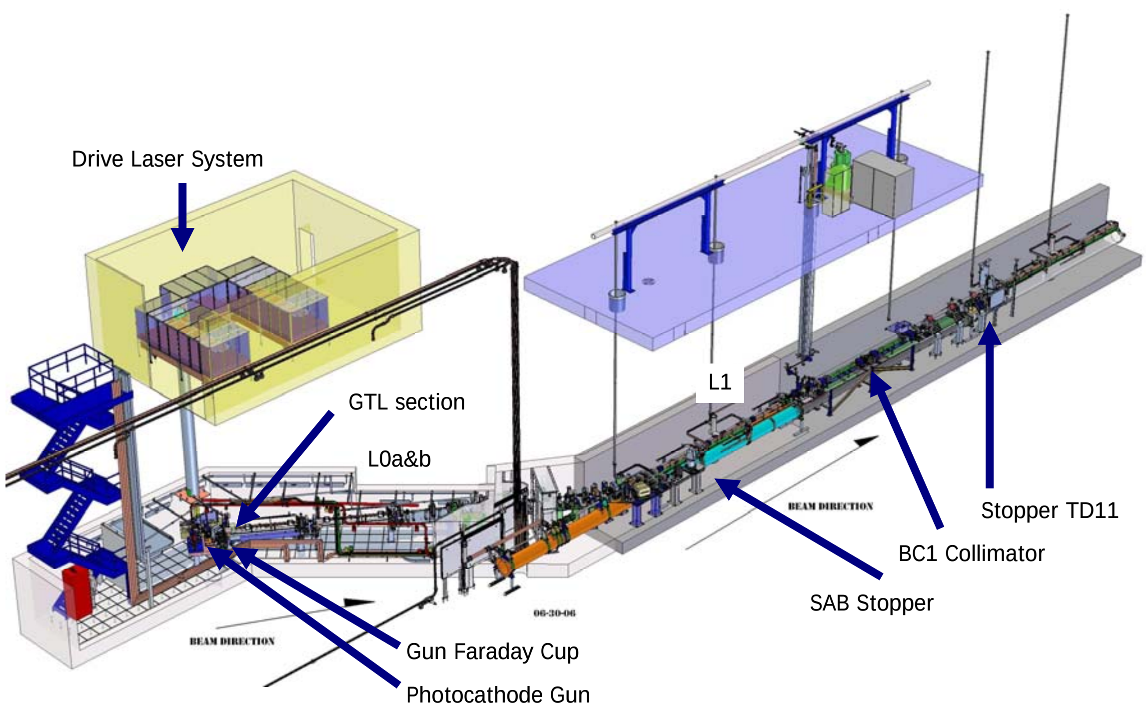
Some areas at SLAC are Radiologically Controlled Areas. These areas (Controlled Area, Radiation Area, etc.) are established to control the flow and behavior of workers in each area such that workers receive the minimum radiation exposure coincident with operating and maintaining the facility, which is the risk, to achieve its authorized research mission, which is the benefit. These areas are set with the expectation that radiation levels will not exceed certain specified maxima depending on the type of zone. The designated area maxima will be satisfied considering both the base level of residual radiation fields and the integrated effect of the short bursts typical of credible beam faults. The *Accelerator Division Operations Directives*, in compliance with the *SLAC Radiological Control Manual*, lists the different areas, and includes the required controls for minimizing exposure to external radiation.

The probability of significant contamination and internal uptake of radionuclides within LCLS facilities is very low. This is so based on the following criteria, from the *Radiation Safety Systems Technical Basis Document*:

- Radiation dose criteria used in design of the LCLS radiation safety systems are the same as those required for other SLAC facilities.
- 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, the dose equivalent-rate will be less than 25 rem/h, and the integrated dose equivalent will be 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 situations in which the maximum allowable beam power, limited by Beam Containment System (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 LCLS due to sky-shine and direct exposure must be below the design goal of 5 mrem/year.

Expected radiation sources 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 vacuum. A radiation safety system comprised of shielding, the Beam Containment System (BCS), and the Personnel Protection System (PPS) has been designed for the LCLS Injector. The issues considered in the design of these systems are described in this section. The LCLS Injector system that has been evaluated by the SLAC Radiation Physics Department is comprised of those beamlines commissioned in calendar 2007; specifically, the RF Gun and its associated drive laser, the GTL Spectrometer, the L0 Accelerating Region, the SAB Spectrometer, the Insertion Region, the L1 Accelerating Region, the X-band Accelerating Region, and Bunch Compressor #1.



The LCLS Injector for 2007 Commissioning

Nominal Beam Parameters

Gun FC	6 MeV	0.7 W
SAB Stopper	135 MeV	16 W
BC1 collimator	250 MeV	30 W
Stopper TD11	250 MeV	30 W
MCI beam power	16 GeV (average)	100 kW

4.6.2.1 Radiation Sources

During the commissioning of the LCLS Injector, high energy photons and neutron radiation are generated from the interaction of the primary electron beam with collimators, beam dumps, and beam diagnostic devices. The radiation initiated in these reactions is the main sources of radiation that needs to be considered in the design of shielding. The particle radiations of concern are neutrons and high energy photons. The electron beam in the LCLS Injector will be delivered at energies up to 250 MeV at 1 nC and 120 Hz.

The specific sources of concern are the Gun Faraday cup, the SAB beam stopper, the BC1 collimator, and the TD11 beam stopper. These sources have been analyzed and additional shielding designed around them as necessary.

4.6.2.2 Radiation Safety System

The SLAC Radiation Safety Program is designed to ensure that radiation doses above background 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 government regulations. The main provisions of the ALARA program ensure that access to high radiation areas is controlled; the accelerator facilities are provided with adequately shielded enclosures for times when the possibility exists for a radiation field to be present; and designs for new facilities and significant modifications incorporate dose reduction, contamination reduction, and waste minimization features in the earliest planning stages.

Several technical, operations, and administrative systems exist to implement the program, as described in the *Radiation Safety Systems Technical Basis Document* and the *SLAC Guidelines for Operations*.

In addition to shielding (bulk and local), the LCLS radiation protection systems uses a Beam Containment System (BCS) and a Personnel Protection System (PPS). These are both Safety Significant Systems. These systems are subject to SLAC Citizen Committee reviews and technical implementation reviews by experts from within and outside of SLAC. The design of both the PPS and BCS systems are based on Technical Basis Documents that define principals and requirements to be followed when designing, installing, commissioning and operating them.

These systems are redundant. They are also subject to SLAC configuration control requirements as defined in *SLAC Guidelines for Operations*. These systems can not be modified without approval and review. As part of the configuration control program, these systems are additionally subject to access-driven inspections and check out. Further, these systems undergo rigorous annual certification as defined in *SLAC Guidelines for Operations*.

The BCS is designed to ensure that beam parameters do not exceed the operational envelope, to ensure the integrity of PPS stoppers and crucial collimators, and to prevent beam losses that may result in unacceptable radiation levels outside the accelerator enclosure. The PPS controls entry to the tunnel, ensuring that personnel are excluded from the tunnel during beam operation, and when hazards are present.

4.6.2.2.1 Shielding Requirements

Shielding for the LCLS Injector conforms to the *Radiation Safety Systems Technical Basis Document*. SLAC's internal design criteria also require that the effective dose equivalent not exceed 400 mrem/h under a missteering scenario, and that under an accident scenario human intervention is required to turn off the beam, ensuring the maximum dose equivalent shall not exceed 25 rem averaged over a 1 hour period.

Shielding for the LCLS has been designed to meet or be more conservative than the aforementioned criteria in conformance with the SLAC ALARA policy. Radiation hazards identified during this process are mitigated to acceptable values through the addition of localized shielding, the use of engineered controls, and active electron beam loss monitoring systems. Details of the shielding analysis and requirements can be found in *Shielding and BCS Requirements for LCLS Injector Phase 1 Operation*.

4.6.2.2.2 Beam Containment System

SLAC's beam containment policy, described in the *Radiation Safety Systems Technical Basis Document*, requires that beam lines be designed to contain the beam, limit the incoming beam power to the beam line, and limit the beam losses to prevent excessive radiation in occupied areas. The containment of the beam in its channel is achieved by implementing a system of redundant, tamper-proof, and fail-safe electronic and mechanical devices, which are subject to strict administrative controls. A typical BCS consists of passive mechanical devices such as collimators, magnets, electron beam stoppers, and dumps, and active devices that shut off the beam when out-of-tolerance conditions are detected, such as average current monitors, burn-through monitors, and beam-shut-off ion chambers (BSOICs).

The BCS for the LCLS (see LCLS Beam Containment System Requirements) will use current monitor toroids to limit the incoming average beam power to less than an allowed level, toroids and long ion chambers to limit normal beam losses to 1 watt, protection collimators to limit the range of trajectories of misteered beams, and ion chambers and flow switches to protect collimators, stoppers and dumps.

4.6.2.2.3 Personnel Protection System (PPS)

The PPS is designed to prevent beams 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 PPS zone when the accelerator is on. The PPS also provides a means for 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, entry modules, and emergency shutoff buttons (see the *Radiation Safety Systems Technical Basis Document*). Entry to a zone requires that three PPS stoppers all be in a state that prevents the beam from reaching the zone. The entrance to the LCLS Injector vault is through the Sector 20 service building (see LCLS Personnel Protection System Requirements). The entry point is equipped with an outer door, inner gate, key bank, access annunciator panel, door control boxes, search reset box, intercom, and TV camera. The outer door has an electromagnetic lock and redundant switches that sense when the door is closed. The inner gate also has two closed-sensing switches to provide further redundancy.

4.6.2.2.4 Burn-Through Monitors

A Burn-Through Monitor (BTM) mechanism is built into each PPS stopper at a depth corresponding to the maximum energy dissipation of an electromagnetic shower in the stopper. The purpose of this system is to automatically terminate beam operations in the event that excessive beam power reaches the stopper. A typical BTM consists of a pair of cavities separated by a copper diaphragm. The first cavity is pressurized with dry N2. Its return line contains a pressure switch with the trip level set to 15 psig. The second cavity is open to atmospheric pressure on the outside. Should excessive beam power be deposited in the stopper such that it begins to burn through, the diaphragm will perforate, allowing the N2 to escape into the second cavity. The pressure switch will sense this condition and open an interlock circuit, which will turn off the beam.

4.6.2.3 Induced Activity

The system components susceptible to activation are the main beam dump, Tune-up Dump and the Single Beam Dump. The main beam dump will not be readily accessible and the other dumps will be locally shielded. The immediate areas around such components are posted and access to them administratively controlled. Other components will intercept significant amount of beam. As the beam will not pass through air there will be no air activation. The main electron beam dump is in a covered enclosure. The local shielding at high loss points attenuates the bremsstrahlung photons significantly.

Low conductivity cooling water systems with potential for residual activity are identified, and monitoring and handling procedures are required.

4.6.3 Ionizing Radiation Exposure (greater than 25 rem/h) outside the linac enclosure

4.7 Maximum Credible Incident (MCI)

The MCI for the LCLS is based on an estimate of the maximum charge that can be extracted from the cathode and accelerated by the injector, with the pulse duration constrained self-consistently by the stored energy in the gun. In this way, longer-than-normal current pulses have been considered.

4.7.1 Beam Excursion

4.7.1.1 Beam Excursion Scenario – Injector Facility

The worst case scenario in an accelerator facility is the excursion of a beam out of the confines of its transport chamber and the impingement of a beam in a localized region resulting in high radiation doses to a worker or the public. Given the location of the injector system, in the underground vault of Sector 20, the loss of a beam in this area will be contained and will not pose a hazard to workers, the public or the environment.

4.7.1.2 Analysis and Corrective Measures

Shielding requirements for the LCLS Injector were calculated based on maximum credible incident beam scenarios. These are shown in Table 4 of the *LCLS Physics Requirement Document* LCLS 1.1-011. This analysis shows a theoretical maximum beam power at the end of the SLAC Linac of 100 kW. As the SLAC Linear Accelerator Facility was designed to operate up to 5.77E + 05W, any LCLS beam excursion within existing SLAC shielded enclosures would fall well within SLAC MCI scenarios.

SLAC Radiation Physics defined requirements for LCLS shielding to assure that radiation generated by the LCLS stays below levels defined in SLAC radiation safety policy. Details of the shielding analysis and requirements can be found in *Shielding and BCS Requirements for LCLS Injector Phase 1 Operation*.

5. Accelerator Safety Envelope

This chapter describes the engineered and administrative bounding conditions that define the Accelerator Safety Envelope (ASE). These conditions are listed explicitly in the *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 the level of risk to all persons is maintained at an acceptable level.

5.1 Accelerator Safety Envelope

The safety envelope conditions listed in the BAS govern the operation of the LCLS Injector System. The LCLS Injector System described in this chapter consists of the RF Gun and its associated drive laser, the GTL Spectrometer, the L0 Accelerating Region, the SAB Spectrometer, the Insertion Region, the L1 Accelerating Region, the X-band Accelerating Region, and Bunch Compressor #1. The maximum credible beam power of the LCLS Injector System is much smaller than the established safety envelope of the Linear Accelerator Facility, which ensures that LCLS Injector commissioning can be carried out safely. Later revisions of this SAD will include details of the safety envelope for the Undulator, the X-ray beamlines, and other downstream systems.

The safety envelope is a set of physical and administrative conditions that define the bounding conditions for safe and environmentally sound operations. 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 levels. Procedures provide specific instructions for carrying out activities that are critical for ensuring that the accelerator can be operated safely.

Variations in operating conditions are permitted as long as consequences of the variations do not exceed the bounds imposed by the safety envelope. These variations of the operating conditions include unplanned events, such as power outages, which may interrupt operations but do not compromise the safety of the facility.

Shielding is designed to limit integrated radiation dose to acceptable levels, as defined in the *Radiation Safety System Technical Basis Document*.

Personnel doses resulting from operation of the Linear Accelerator Facility, often at power levels far in excess of the maximum possible LCLS beam power, have remained below the limits listed in Table 5.1 for many years. The maximum possible LCLS beam power is derived by assuming that the maximum possible electron current from the gun is accelerated to the maximum possible energy with a repetition rate of 120 pps.

Table 5.1. Safety Exposure Limits

Condition	Limit	Beam Loss
Normal Operation	1 rem/y	Local + Distributed
Exposure at Fence line	0.1 rem/y	Maximum Credible Beam
Accident	25 rem/h, 3 rem/event	Maximum Credible Beam

5.2 Safety Envelope – Technical Requirements

Beam losses during normal operations of the LCLS Injector System, and the maximum credible beam power are calculated in *LCLS Physics Requirement Document* 1.1-011. Estimates are made for beam loss at a number of locations including beam dumps, and under a variety of normal operating conditions, including an estimate for dark current.

The maximum credible beam power is calculated by assuming the total stored energy in the gun is directed to the acceleration of electrons (Explosive Electron Emission). The acceleration of this large current in the accelerator structures is then simulated at the highest gradient consistent with beam loading effects. An energy spectrum for the beam is produced, and beam losses are calculated based on the physical aperture of the beamline. This analysis is done for the beam stopping at the TD11 stopper, and also for the beam accelerated down the Linac to the Beam Switch Yard.

Nominal operating conditions:	
At TD11: 120 nA at 250 MeV	30 W
At the end of SLAC Linac: 120 nA at 14.1 GeV	1692 W
Maximum beam power for operations:	5 kW
Maximum credible LCLS beam power:	
At TD11: 6 μA at 250 MeV (max)	1.5 kW
At the end of SLAC Linac: 6 μA at 16 GeV (average)	100 kW

Table 5.2. LCLS Safety Envelopes

Envelope	Beam Power
LCLS Safety Envelope	100 kW
LCLS Operation Envelope	5 kW
LCLS Nominal Operating Power	1.7 kW

These values for power deposition have been used in the analysis of shielding requirements for the LCLS Injector and Linac.

5.3 Safety Envelope – Administrative Requirements

The safety envelope includes administrative as well as engineered requirements to assure that all required hardware (toroids, beam stoppers, beam loss monitors, supplemental shielding, etc.) is in place and functioning properly. These requirements include initial review of the adequacy of the system, procedures for verifying by inspection that the required safety devices are in place, initial beam tests to calibrate controls and demonstrate the efficacy of shielding, and documented inspections following removal/replacement or modification of specified shielding.

The Personnel Protection System is subject to a documented Safety Assurance Test before interlocked hazards are energized and every six months during extended running periods. Requirements for configuration control and periodic system testing are described in *SLAC Guidelines for Operations*.

6. Quality Assurance

The LCLS project management provides the appropriate resources to ensure that the LCLS meets its long-term performance goals. It is the responsibility of project management to maintain the project's direction and to make decisions that encourage quality assurance considerations. At all levels, project management will communicate high expectations and concrete goals for the attainment of quality, and make decisions to ensure that performance objectives for both construction and operation are met. Project management will also seek out and use, as applicable, modern quality assurance, manufacturing, and reliability approaches.

Quality Assurance (QA) is an integral part of the design, procurement, fabrication, construction, commissioning, and operations phases of the LCLS project. Special attention is given to items and services that affect the safety and operational reliability of the project facilities. The intent of project management is for the LCLS quality assurance program to:

- Describe a fully integrated and functioning quality assurance organization at all levels.
- Provide practical guidance on implementing a quality assurance plan for critical activities on the project, and provide support to core group/service organizations.
- Designate specific quality assurance elements in the processes of engineering, procurement, construction and operations.
- Provide consistent and distinct levels of quality assurance to respond accurately to project needs.
- Facilitate the implementation of project-wide quality assurance measures, with emphasis on problem prevention

The LCLS Quality Assurance Manager is responsible for development, implementation, assessment, and improvement of the *Linac Coherent Light Source Quality Assurance Plan*. The QA plan is implemented through the use of QA/quality control (QC) procedures and guidelines and management systems.

All LCLS components, systems, installation and start-up activities are subject to the LCLS Design Review process as described in LCLS document 1.1-324, *LCLS Design Review Guidelines*. The primary objective of the LCLS Technical Design Review Program is to enhance the probability of success by the early identification of potential design problems associated with function, safety, construction, installation, or operations to minimize cost, schedule, performance and safety hazard impacts.

The LCLS Project Office QA group maintains oversight of the architect engineer-construction manager (AE & CM) and of the partner laboratories' quality systems as used for LCLS work, including formal assessments. In addition, the Project Office QA group provides guidance and support to the partner laboratories to maintain common and effective quality assurance practices throughout the entire LCLS Project.

SLAC Guidelines for Operations and *Accelerator 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 will be a major engineering task. Large volumes of reinforced concrete will have to be disassembled and removed. Also large volumes of backfill will be required to restore the terrain.

During operations, programs are in place to minimize contamination by reducing the generation of contaminants and by secondary containment and disposal of contaminants. Post operations will require extensive soil sampling to evaluate the need to scrape and replace soil in order to achieve the goal of achieving an unrestricted residential standard for the post operations site.

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, especially those required to meet the end-point criteria.

Appendix A. References

Site-Wide Documentation

SLAC Guidelines for Operations	SLAC-I-010-00100-000
Summary of Requirements for Work in Accelerator Housings	SLAC-I-010-00100-002
Linear Accelerator Facility Safety Assessment Document	SLAC-I-010-30100-009
High Powered Microwave Systems Safety	SLAC-I-010-30400-002
SLAC Radiological Control Manual	SLAC-I-720-0A05Z-001
Radiation Safety Systems Technical Basis Document	SLAC-I-720-0A05Z-002
SLAC ES&H Manual	SLAC-I-720-0A29Z-001
SLAC Emergency Preparedness Plan	SLAC-I-720-70000-105/ESH-105
SLAC Lock and Tag Program for the Control of Hazardous Energy	SLAC-I-730-0A10Z-001
The Geology of the Eastern Part of the Stanford Linear Accelerator Center	SLAC-I-750-3A33X-001
Annual Site Environmental Report 2004	SLAC-R-789
SLAC Work Smart Standards	www-group.slac.stanford.edu/esh/general/isems/wss/
SLAC Integrated Safety Management (ISM) Program Description	www-group.slac.stanford.edu/esh/isms/

LCLS Documents

LCLS Title II Fire Hazard Analysis	SLAC-I-010-30400-001
LCLS Physics Requirement Document	LCLS 1.1-011
Linac Coherent Light Source Conceptual Design (http://www-ssrl.slac.stanford.edu/lcls/cdr)	SLAC-R-593
LCLS Design Review Guidelines	LCLS 1.1-324
LCLS Quality Assurance Plan	PMD-003
LCLS Environmental Assessment	DOE/EA-1426
Standard Operating Procedure for the LCLS Injector Laser	LCLS 1.2-001
Shielding and BCS Requirements for LCLS Injector Phase 1 Operation	RP-05-15
LCLS Personnel Protection System Requirements	LCLS 1.1-310
LCLS Beam Containment System Requirements	LCLS 1.1-311

Accelerator Systems Division Documents

https://www-internal.slac.stanford.edu/ad/addo/addo.html

Accelerator Division Operations Directives	SLAC-I-040-00100-001
Shift Schedules and Training Record Summaries	SLAC-I-040-20100-004
Search Procedures	SLAC-I-040-30400-001
Entry and Exit Procedures	SLAC-I-040-30400-003

Safety Inspection Checklists	SLAC-I-040-30400-004
PPS Interlock Checklists	SLAC-I-040-30400-005
ASO-1 Qualification Workbook	SLAC-I-040-50400-001

Appendix B. Abbreviations Used in this Document

ADSO	Accelerator Division Safety Officer
ALARA	As Low As Reasonably Achievable
ARR	Accelerator Readiness Review
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BC	Bunch compressor
BPM	Beam Position Monitor
BSOIC	Beam Shutoff Ion Chamber
BTH	Beam Transfer Hall
CLOC	Central Laboratory and Office Complex
DOE	U.S. Department of Energy
EOIC	Engineering Operator-in-Charge
EPICS	Experimental Physics and Industrial Control System
FEH	Far Experimental Hall
FEL	Free Electron Laser
GeV	Gigaelectron-volt
GTL	Gun To Linac
HEEC	Hazardous Experimental Equipment Committee
ISEMS	Integrated Safety and Environment Management System
ISMS	Integrated Safety Management System
L1 – L30	Linac Sector-1 to Linac Sector-30
LCLS	Linac Coherent Light Source
LOTO	Lock Out, Tag Out
NEC	National Electrical Code
NEH	Near Experimental Hall
NFPA	National Fire Protection Association
PPA	Particle and Particle Astrophysics Division
PPS	Personnel Protection System
Rf; RF	Radio frequency
SAB	Straight Ahead Beamline
SAD	Safety Assessment Document
SASE	Self-Amplified Spontaneous Emission
UBC	Uniform Building Code
UPC	Universal Product Code