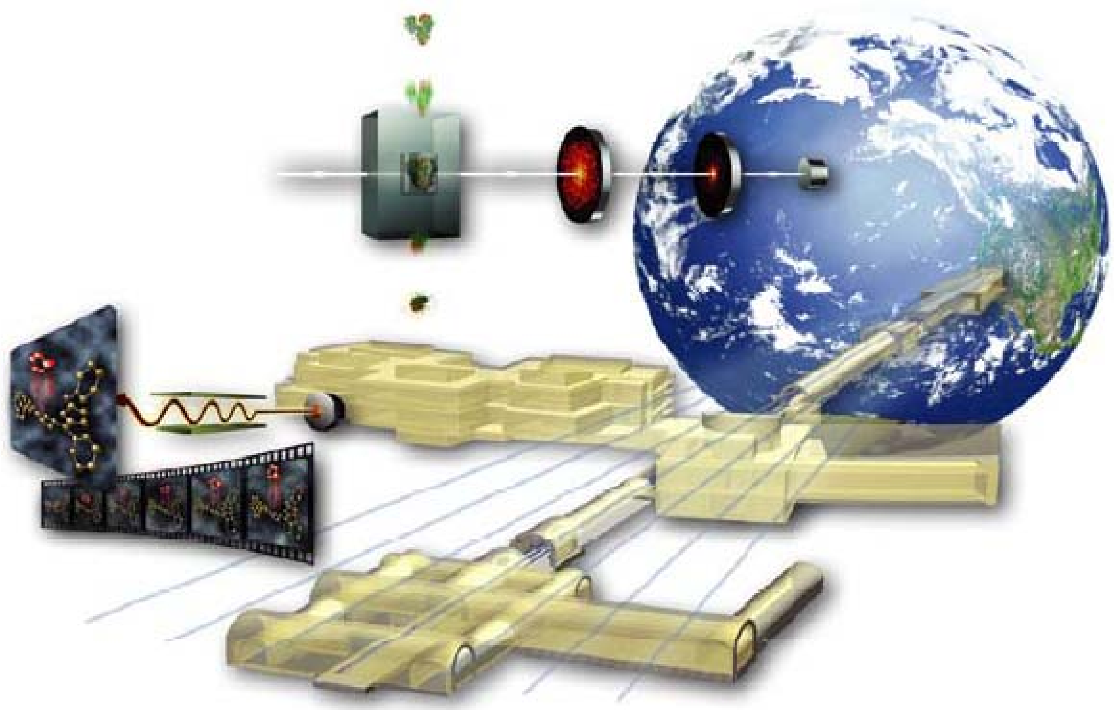
Stanford Linear Accelerator Center
Stanford Synchrotron Radiation Laboratory

Linac Coherent Light Source



Preliminary Safety Assessment Document

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Preliminary Safety Assessment Document

1. Introduction

According to DOE Program and Project Management Practices, the SLAC Integrated Safety Management Plan (ISM) and the DOE Safety of Accelerator Facilities Order requirements this Preliminary Safety Assessment Document (PSAD) was initially developed as part of the Critical Decision 2 (CD-2) process for the Linac Coherent Light Source (LCLS) and subsequently up-dated to support the CD-3b decision to start construction.

The LCLS project is a joint effort of Stanford Linear Accelerator Center (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. The architect/engineer for the project is Jacobs Engineering and the Construction Manager is Turner Construction Company.

The purpose of this PSAD is to identify potential hazards presented by the operation of this facility to individuals both onsite and offsite, and to the environment from both normal operations and credible accident scenarios. This information will be used during the design phase of the project to engineer out hazards where possible and subsequently develop procedural controls for any remaining hazards such that they can be managed to an acceptable level of risk. A detailed analysis of the technical systems, consistent with core ISMS function will be conducted during the safety analysis of the machine's components and will be documented in the SLAC Linac Facility Safety Assessment Document (SAD). This assessment will not duplicate other activities carried out in the development of a facility's overall environment, safety, and health program such as the development of Work Smart Standards or redefine the information in the SLAC or LCLS ISMS Plan.

The SAD will document the engineered controls (e.g., interlocks and physical barriers) and administrative measures (e.g., training) taken to eliminate, control, or mitigate hazards from operation of the completed facility

Taking into account both the current project schedule and the accomplishments reported below, the Laboratory and LCLS management are confident that an effective program, appropriate to current activities, will be in effect throughout project's construction, equipment installation and user operation phases of the facility.

The required National Environmental Protection Act (NEPA) documentation has been endorsed and is in place.

With regard to conventional facilities construction:

- LCLS management is designing the facility to ensure that it incorporates and provides for engineered hazard controls.
- LCLS management and SLAC staff played an active role in identifying and addressing building code issues.
- LCLS management understands the program elements that require attention and implementation in the near future to ensure that the conventional facilities will be constructed and the equipment will be installed without unnecessary risk.

With regard to equipment procurement, installation, and operations, the project has developed and implemented a quality assurance (QA) program that places as much priority on safety as other management concerns. Concern about safety is also evident in the procurement system's ES&H approval system, the mechanism that LCLS management will use to track review requirements and communicate safety approval to personnel processing procurement packages. Safety will be addressed in QA requirements covering equipment and experiment safety review requirements covering equipment to be brought to the facility to support experiments.

The LCLS has a hazard analysis program covering planned operations-phase activities, but, more importantly, LCLS management realizes that the analysis process must be ongoing, taking proper account of and adapting to changes in planned procurement plans as well as future technical operations.

The LCLS's ES&H program planning was (and will continue to be) standards-oriented; the LCLS Project has a system in place that reliably identifies standards and implementation guidance applicable to planned work and purchases. (SLAC Work Smart Standards are found in Appendix E). Moreover, the LCLS Project understands the need to require its technical managers to address requirements in ES&H standards in their work planning before authorizing work (or purchases) to proceed. LCLS's accomplishments to date demonstrate its commitment to minimizing adverse environmental impact. Its plans for ensuring a sustainable design and energy efficiency reflect a good balance between minimizing potential adverse effects and accomplishing the operating facility's mission. The ES&H requirements of the LCLS project as defined in DOE O 413.3 Chg 1, *Project Management for the Acquisition of Capital Assets*; Contractor Requirements Document Attachment 1, which states that the prime contractor's project management system is to meet the following requirement:

12. An Integrated Safety Management system must be developed and implemented for the contract scope of work in compliance with DEAR 970-5204-2, Integration of Environmental, Safety and Health into Work Planning and Execution.

This document also addresses DOE O 420.2B *Safety of Accelerator Facilities* Section 4. Requirements. This defines the required contents for the development of a Safety Assessment Document. Based on these criteria the LCLS Project is ready for CD-3b, “Approve expenditure of funds for construction”

2. Overview

2.1. Purpose

This document reports the LCLS's progress in developing its ES&H program since the June 2002 Preliminary Hazards Analyses (PHA). It builds on all previous ES&H assessment activities, not only those previously reported in the PHA and the EA, but also findings resulting from external and internal reviews. In particular, this document shows that, at a level of detail appropriate to its current phase of planning, LCLS management:

- Understands the work that will be done during construction and operations,
- Understands the hazards associated with construction and planned R&D activities,
- Has identified and understands mandatory standards and standards of good practice applicable to planned activities,
- Has plans for reasonable and reliable approaches for controlling risks in a manner conforming to requirements,
- Has work monitoring plans that will promptly and reliably detect work not being conducted properly,
- Has plans for control mechanisms that can effectively deal with nonconformance, and
- Will not authorize work or purchases until safety reviews have been completed and controls have been implemented.

The report describes not only accomplishments related to ES&H planning, equipment procurement and building construction, but also the LCLS's plans for future efforts needed to ensure that an effective ES&H program will be in place when the LCLS is ready to begin operations.

2.2. Scope and Emphasis

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

- DOE 0 413.3, Program and Project Management for the Acquisition of Capital Assets;
- DOE M 413.3-1, Project Management for the Acquisition of Capital Assets;
- 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; & www.science.Doe.gov/opa/PDF/cd1&2.html
- SLAC Integrated Safety Management (ISM) Program Description, which can be viewed at: www.group.slac.stanford.edu/esh/isms/

2.3. Applicable Standards

The PHA contains the Work Smart Standards relevant to the LCLS's ES&H planning efforts. As planning has progressed and issues have become better defined, the LCLS, with input from several SLAC support and oversight organizations, has focused its attention on the most relevant standards and codes. In general, readers will find relevant standards identified in context, such as in this report's discussion of identified ES&H concerns. This document identifies LCLS management's approach to implementing ES&H and how it will address and help manage associated risks. Design work considered both construction and operational safety of paramount importance. Safety considerations during design include compliance with NFPA, NEC, UPC, ASHRAE, UBC and seismic codes and standards and addressed emergency planning and access throughout the facility.

2.4. LCLS Organization

The LCLS's Project Execution Plan (PEP), which is a separate document, provides a detailed description of organizational structure. The responsibilities reflected in assignments implied in this report reflect the organizational structure set forth in the PEP and LCLS management's plans for position descriptions and prerequisite competencies for each role.

The PSAD was developed following guidelines provided in DOE O 420.1A Facility Safety (Sections 4.2 & 4.4), DOE O 420.2B Safety of Accelerator Facilities, DOE O 413.3 Program and Project Management for the Acquisition of Capital Assets. The objective of this PSAD has been to identify potential hazards through the evolution of the project from the conceptual design stage through to the completion of Title II drawings. This compendium of hazards and associated observations will serve as the basis for the development of the SAD for the balance of the project.

The LCLS is a low hazard facility as formerly defined in DOE Order 5480.1B. Mitigation of identified hazards has been incorporated into the design and planning of the project, ensuring that during the construction and proposed operation of the LCLS, potential hazards are eliminated or controlled to the point that they pose only minor on-site and negligible off-site impact to people and the environment.

Those hazards identified during the analysis for both the construction and operation phases of this project (i.e. fire, industrial, construction, electrical, radiation, environmental etc.) are well recognized at SLAC. Experience with these hazards during construction of PEPII, upgrade of SPEAR3 and operation of the Stanford Synchrotron Radiation Laboratory at its present level, combined with SLAC’s Integrated Safety Management System , will allow SLAC to provide a world class facility to its Users and staff with maximum safety.

SLAC applies and implements an Integrated Safety Management System (ISMS) approach throughout all levels of the LCLS project. ISMS Core Functions and Guiding Principals are viewed as the best way of doing business, consistent with the LCLS approach to hazards identification and mitigation.

3. Description of Site, Facilities and Operation Requirements

3.1. Facilities

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 free electron beam used to generate the x-ray laser will be produced by the Stanford Linear Accelerator (Linac). Physically, the LCLS is therefore an extension of the Linac. The extended beam path is contained within six separate connected structures—Beam Transfer Hall (BTH) tunnel, underground Undulator Hall (UH) tunnel, Beam Dump and Front End Enclosure, Near Experimental Hall (NEH) building, X-Ray tunnel, and Far Experimental Hall (FEH) building. One final tunnel provides access to the FEH from outside. Many of the major structures have one or more above-ground utility buildings associated with it. The NEH is part of a larger building the other part of which is an offset, above-ground structure called the Central Laboratory and Office Complex (CLOC).

3.1.1. Sector 20 (S20)

The S20 modifications will include Alcove Improvements and a 200 square foot RF Hut. The Alcove Improvements shall include a Laser Room, Load Lock and Control Room. This total gross square footage consists of 2,000 square feet of space at grade level adjacent to the Klystron Gallery. The existing space requires new construction, including structural supports for seismic compliance of roofing, siding, lighting, power, utilities, and HVAC. The Laser Room will be environmentally controlled.

The RF Hut will be a temperature stabilized enclosure with a ceiling approximately 9 feet high. It will be located inside the existing Klystron Gallery over two existing penetrations which lead down to the accelerator tunnel below. The RF Hut will house temperature and vibration sensitive equipment and controls, and will have other special utility needs.

Cable trays will run from SLAC provided power conversion and RF racks located in the Klystron Galley over the top of the Laser Room and down the existing stairwell access to the injector area below. The S20 Injector facilities shall be provided with heating, cooling, ventilation and smoke purge systems. A fire sprinkler system shall be provided throughout the area.

3.1.2. Magnetic Measurement Facility (MMF)

The MMF will be an enclosed area approximately 4500 square feet located within existing SLAC Building 81. The primary conventional facilities requirements are for the enclosure structure (walls and ceiling), foundation, HVAC, electric power, cable trays and supports, equipment cooling water and compressed air.

The existing building is a steel frame structure with an average ceiling height of 25 feet. In the vicinity of the future MMF, the bay is 40 feet wide with columns spaced at 25 feet. The floor is a 6-inch thick reinforced concrete slab. The vicinity of the future MMF is currently used for storage. The MMF shall be provided with heating, cooling, ventilation and smoke purge systems. A fire sprinkler system shall be provided throughout the MMF.

3.1.3. Research Yard Modifications

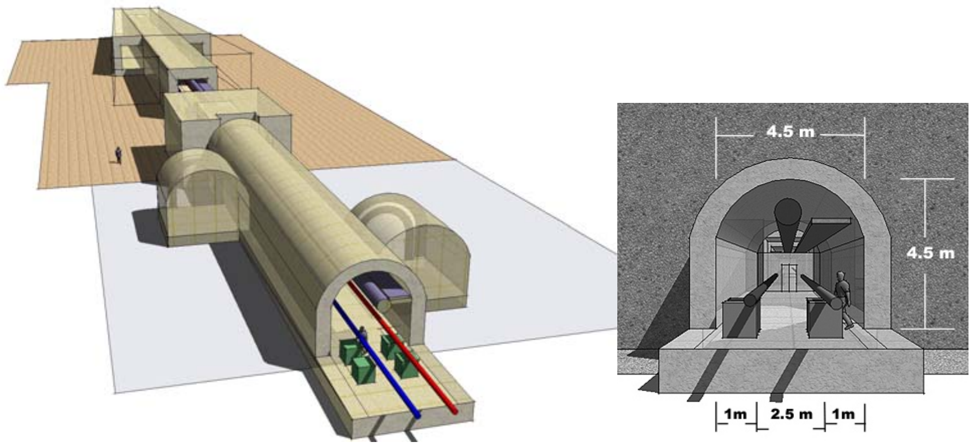
Modifications to the existing Research Yard shall be limited to buildings and road work directly impacted as a result of the LCLS project; these buildings are #064, #102, and #113. Various storage unit sea-trains and temporary trailers will also be relocated. Some utilities shall be relocated and or modified as a result of the modifications required within the Research Yard.

3.1.4. Beam Transport Hall (BTH)

The BTH shall consist of an above ground concrete tunnel like structure bisecting the SLAC Research Yard that will house the LCLS electron beam line. The purpose of the BTH is to continue the electron beam from the Linac into the Undulator Hall, Front End Enclosure and Beam Dump. The interior dimensions are 15 feet wide x 10 feet high. The walls shall be 72” thick and the ceiling shall be 48” thick (except where service buildings placed on roof). The BTH extends from the end of the Beam Switch Yard wall downstream in the direction of the beam for approximately 230 meters. The final eight (8) meters of the BTH shall house the Tune-Up Dump which contains a solid copper block with localized shielding. The downstream end of the BTH shall include a physical thermal barrier separating the BTH from the Undulator Hall. The BTH shall be provided with ventilation and smoke purge systems. A fire sprinkler system shall be provided throughout the BTH. The floor elevation shall be maintained at 247.25 feet and will remain constant throughout the entire LCLS facilities.

3.1.5. Undulator Hall (UH)

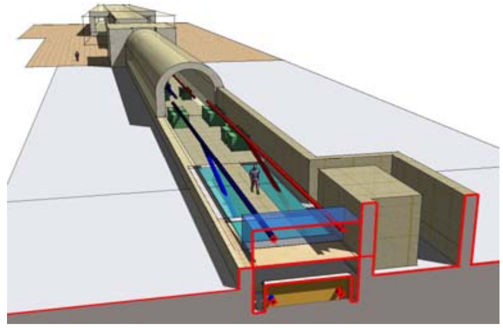
The UH shall be a tunnel commencing from the downstream end of the BTH thermal barrier. The UH shall extend 170 meters in the direction of the beam to the downstream end of the UH where it shall be enclosed by another physical thermal barrier separating the UH from the Beam Dump/Front End Enclosure. The purpose of the UH will be to contain 33 undulator magnets and associated equipment as it continues the electron beam to the Front End Enclosure and Beam Dump, therefore temperature and foundation stability are critical to a successful design. The interior dimensions are 4.5 meters wide by approximately 4.0 meters high. Access into the UH will be through an entry provided from the BTH. Within the UH shall be multiple alcoves staggered on both sides to house mechanical equipment and air handling units. The construction of these alcoves shall be of similar construction as the tunnel. The UH shall be provided with heating, cooling, ventilation and smoke purge systems. A fire sprinkler system shall be provided throughout the UH. The floor elevation shall be maintained at 247.25 feet and will remain constant throughout the entire LCLS facilities.



175 Meter Undulator with Alcoves - Cross Section

3.1.6. Beam Dump (BD)

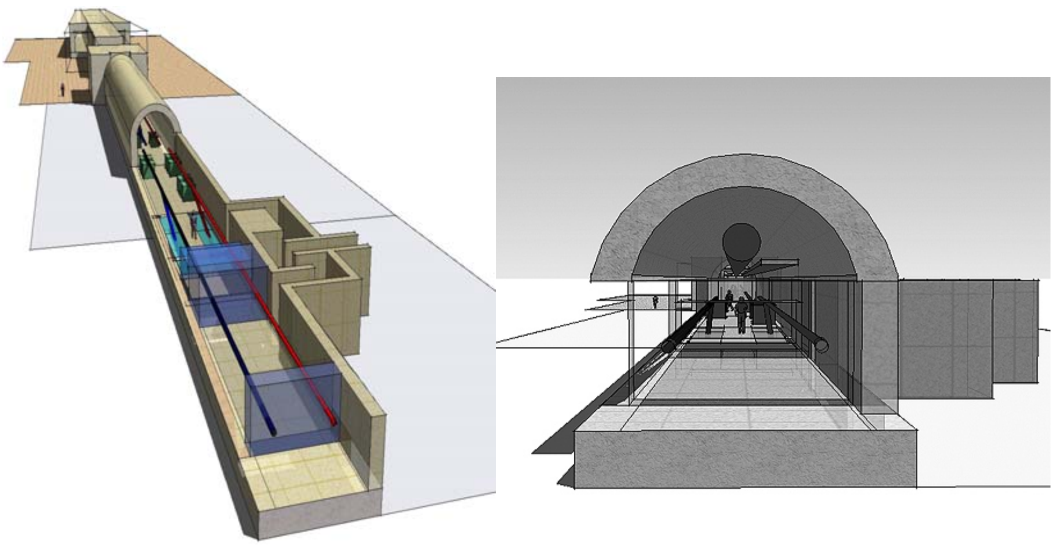
The Beam Dump structure shall be similar in configuration to the UH and in its appearance shall be continuous. The purpose of the BD shall be to separate the electron and x-ray beams. The electron beam shall curve downward and terminate its path in the Beam Dump, and the x-ray beam shall continue into the Front End Enclosure and other facility components further downstream. The actual dump is located on a lower level, below the level of the rest of the beamline, and will have provisions for occasional access for maintenance. Within the BD shall be a massive metal/steel block which will act as part of the radiation shielding. The block is 7 feet thick. The BD shall be provided with ventilation and smoke purge systems. A fire sprinkler system shall be provided throughout the BD. The main floor elevation shall be maintained at 247.25 feet and will remain constant throughout the entire LCLS facilities; the lower floor where the dump itself is located will be at an elevation of 247.25 feet.



Beam Dump

3.1.7. Front End Enclosure (FEE)

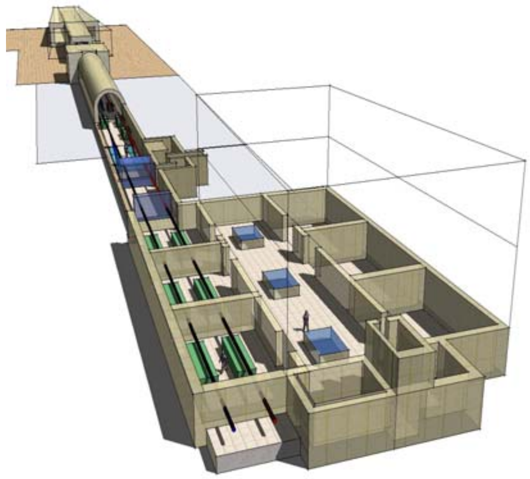
The Front End Enclosure shall be located in a tunnel immediately downstream from the Beam Dump, separated from it by steel and concrete shielding. The x-ray beam will enter the FEE through a small beam pipe penetrating the shielding. The FEE shall be 33 m in length, and shall be accessible through a shielding maze with interlocked doors. At its downstream end, the FEE shall be separated from the Near Experimental Hall by steel shielding (4 ft thick) and concrete shielding (3 ft thick). The x-ray beam will pass through this shielding in a small beam pipe. The FEE shall be provided with heating, cooling, ventilation and smoke purge systems. A fire sprinkler system shall be provided throughout the FEE. The floor elevation shall be maintained at 247.25 feet and will remain constant throughout the entire LCLS facilities.

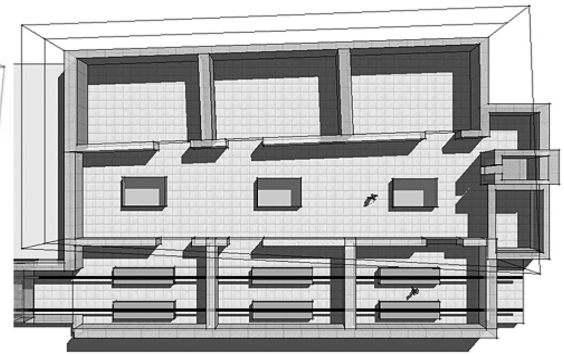


Front End Enclosure & Beam Dump - Cross Section

3.1.8. Near Experimental Hall (NEH)

The NEH is a two-story structure (below grade) that will begin downstream of the FEE and will extend approximately 47 meters in the direction of the beam. The primary function of the NEH is to house three experimental hutches. Each hutch shall have its independent PPS entry. Adjacent to the hutches shall be floor space to accommodate Prep and Control areas. Provisions shall be made for a unisex restroom and 5-ton freight elevator. The entire facility shall include hutches, minimal office space, machine shop, vacuum shop, electronic shop, mechanical shop and an optics lab. The second floor shall house a Laser Bay at approximately 6 meters by 32 meters. The NEH shall be provided with heating, cooling, ventilation and smoke purge systems. Provisions shall be made for the hutches to have process exhaust fans. A fire sprinkler system shall be provided throughout the NEH. The floor elevation shall be maintained at 247.25 feet and will remain constant throughout the entire LCLS facilities.





NEH (below grade) **NEH Floor Plan**

3.1.9. X-Ray Transport Tunnel

The X-Ray Tunnel shall extend 200 meters downstream of the NEH and shall span to the FEH. A fire sprinkler system shall be provided throughout the X-Ray Tunnel. The floor elevation shall be maintained at 247.25 feet and will remain constant throughout the entire LCLS facilities.

3.1.10. Far Experimental Hall (FEH)

The FEH shall be located 600 feet downstream of the NEH. It shall be located approximately 100 feet below grade and shall be constructed using conventional tunneling applications. The primary function of the FEH is to house experimental hutches. Each hutch shall have its independent PPS entry. Adjacent to the hutches shall be floor space to accommodate Prep and Control areas. The FEH shall be provided with heating, cooling, ventilation and smoke purge systems. Provisions shall be made for the hutches to have process exhaust fans. A fire sprinkler system shall be provided throughout the FEH. The floor elevation shall be maintained at 247.25 feet and will remain constant throughout the entire LCLS facilities.

3.1.10.1. Central Lab Office Complex (CLOC)

A CLOC will be constructed to house the research offices and laboratory space to accommodate LCLS users, scientific and support staff. Parking will be provided adjacent to the office building and the area should be moderately landscaped. . Capacity of the CLOC is currently estimated at 275 persons with approximately 78,000 square feet of office and lab space. This facility can be located on grade and adjacent to the east edge of PEP Ring Road. Site and roadway redevelopment may be required to provide access to the ground level from the existing driveway leading to Bldg #750 for access of large semi trailers. The facility shall be heavily utilized during normal business hours but shall also have the ability to function in a normal building status during “off-hours”. Provisions shall be made for all groups to perform activities efficiently, safely and comfortably. General office space shall be designed to be flexible with a combination of hard-walled offices and open landscaped systems furniture. An exhibition area shall be designed to provide spatial allowance to feature the LCLS research. Provisions for laboratory space shall include (6) six laser labs. Additional space shall include a computational center, storage rooms, mail room, reproduction room, conference rooms, and other general amenities (i.e. kitchen, lounge, etc). Parking shall be provided adjacent to or in the immediate surrounding area. Provisions for moderate landscaping shall be provided.

3.2. LCLS Injector

The LCLS Injector is a new electron beamline incorporating a photocathode RF gun for the production and transport of low emmitance electron beam pulses to the LCLS Linac. A UV laser, pulsed at 120 Hz, impinges on the gun cathode timed to the RF pulses to produce the electron bunches. The electrons are captured and accelerated to 135 MeV through two RF accelerating structures. The electrons are then steered onto the SLAC Linac axis for acceleration and delivery to the FEL Undulator. The Injector includes conditioning optics and diagnostics systems for characterization of both the electron and laser beams. Safety systems are included in the design to prevent unauthorized access to the laser and electron beamlines.

3.2.1. Injector Controls

A new controls system utilizing EPICS will be constructed to run the Injector. New racks for the controls will be located in the laser alcove and in the existing Klystron Gallery. Timing electronics will be housed in a temperature controlled room located in the Klystron Gallery. Normal operation of the Injector will be remotely controlled from the existing Main Control Center. Operation of the machine may be enhanced using locally stationed scientists and technicians monitoring sensitive equipment.

3.2.2. Injector Drive Laser

The class IV gun drive laser is located in the Sector 20 alcove at ground level. The UV laser light is transported down to the below-grade Sector 20 off-axis injector housing through dedicated laser penetrations. Operation of the laser is regulated by a laser safety system which prevents non-qualified 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. No personnel are allowed access to the injector housing while RF is on.

3.2.3. Injector RF

Power to produce electrons, accelerate and to perform time correlated measurements will be provided by existing RF Klystrons located in Sector 20 of the Klystron Gallery.

- Tube 20-5 will power the Transverse Deflecting Structure.
- Tube 20-6 will power the RF Gun.
- Tube 20-7 will power accelerating structure L0A.

- Tube 20-8 will power structure L0B.

New waveguide runs will be installed to connect the output of the tubes to loads specified above. Timing and feedback control components for the RF powered devices will be housed in a temperature stabilized “RF Hut.” The Hut is centrally located and encloses Penetration 20-17 at the end of Sector 20.

3.2.4. Injector Magnets

Magnets in the injector system include solenoids, dipoles, quadrupoles and dipole corrector magnets of both water cooled and air-cooled varieties. Most magnets are not considered electrical hazards due to low voltage; however, all exposed conductors will be covered. New long-haul cables will connect the magnet load to new power supplies located in new racks in the Klystron Gallery.

3.2.5. Injector Vacuum

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

3.2.6. Injector Diagnostics

Individual devices and systems of devices will be installed to fully characterize the electron beam at all critical points along the electron path. Systems include measurement stations for transverse beam shape, emmitance, and time dependant characteristics.

3.2.7. Injector Installation

Part of the injector will be installed in the off-axis injector housing at Sector 20. The portion of the injector that inserts electrons into the main linac and a 135MeV spectrometer are located in the main linac enclosure. Installation of the portion in the linac enclosure must be coordinated with SLAC Operations Group to support current SLAC programmatic needs.

3.3. RF System

The RF Hut is a temperature stabilized enclosure which will house the RF systems used to monitor and control the RF systems for the LCLS Linac 0 and Linac 1. The Hut is centrally located and encloses Penetration 20-17 at the end of Sector 20. The Hut will be about 10 by 12 feet with a height of about 8 feet. This location allows easy access to the tunnel and minimizes the distances to the following Linac klystrons:

20-5 Transverse Deflector Structure
20-6 RF Gun
20-7 Linac 0 Accelerator 1
20-8 Linac 0 Accelerator 2
21-1 Linac 1 S-Band Structure
21-2 Linac 1 X-Band Structure

The LCLS RF driven components in the tunnel are as follows:
RF Gun
Linac 0 Accelerator 1
Linac 0 Accelerator 2
Linac 0 Transverse Deflector Structure
Linac 1 S-Band Accelerator
Linac 1 X-Band Accelerator

All the RF cables from the HUT to the components will be run down penetration 20-17 and through the tunnel. Temperature stabilized Heliax cables will be used with temperature coefficients less than 5ppm/degC. The furthest component from the enclosure is the RF gun, which is less than 100 feet away, down the penetration and into the off axis injector. At 5ppm/degC, 100 ft of Heliax will vary 500fS/degC. The phase accuracy of the LCLS is about 70fS in several places as seen in Table 1. In order to achieve this accuracy the cables and RF electronics must be held to about 0.1degC rms changes. The accelerator tunnel achieves this type of stability after several days of being closed.

3.4. Linac

The LCLS Linac System is comprised of the existing SLAC Linac from sectors 21 through 30, the central beam line through the SLAC Beam Switchyard (BSY), the Linac to Undulator Beamline (LTU) housed in the new Beam Transport Hall and the Main Electron Dump (E-Dump). Linac sectors 20 through 30 will be modified to include two magnetic chicane electron bunch compressors and diagnostic devices which will characterize the short electron bunch. The beamline through the SLAC BSY will remain unchanged. The LTU is a new beamline but will re-use some of the decommissioned Final Focus Test Beam (FFTB) components. The E-Dump will be a new beamline. Components are similar to those discussed in the Injector section. New support buildings will house the power supplies and controls components for the LTU and E-Dump beamlines.

3.4.1. The Main Linac,

SLAC Sectors 21-30 are divided into five functional areas; Linac 1 (L1), Bunch Compressor 1 (BC1), Linac 2 (L2), Bunch Compressor 2 (BC2) and Linac 3 (L3). Each of these areas incorporates modifications to the existing SLAC Linear Accelerator. The existing vacuum system, RF system, cable plant and power distribution system will be retained with modifications as outlined below.

3.4.2. L1 First Accelerating Region

L1 is the first accelerating region in LCLS following the injection of electrons into the SLAC Linac. In L1, located in Sector 21, two ten foot accelerator sections will be replaced by 9.5 foot sections. Quadrupoles, BPMs and corrector magnets will be added. New power supplies and BPM controllers will be added. Cables will be added to the existing cable plant to power and control these units. Cooling water for the magnets will be obtained from the existing LCW cooling water system.

BC1 is also located in Linac sector 21. Five S-band accelerator sections will be removed to accommodate an X-Band section, a four-bend magnetic chicane, quadrupoles, BPMs, profile monitors, toroids, wire scanners and a tune-up dump. New power supplies and diagnostics device controllers will be added. Cables will be added to the existing cable plant to power and control these units. Cooling water for the magnets will be obtained from the existing LCW cooling water system.

3.4.3. BC1 First Bunch Compressor and LX

BC1 is also located in Linac sector 21. Five S-band accelerator sections will be removed to accommodate an X-Band section, a four-bend magnetic chicane, quadrupoles, BPMs, profile monitors, toroids, wire scanners and a tune-up dump. New power supplies and diagnostics device controllers will be added. Cables will be added to the existing cable plant to power and control these units. Cooling water for the magnets will be obtained from the existing LCW cooling water system.

3.4.4. L2 Second Accelerating Region

L2 is the accelerating region between the two bunch compressor chicanes. L2 starts in Linac Sector 21 and ends in Linac Sector 24. The only changes to the existing SLAC Linac will be the removal of three accelerating structures in Sector 24 where wire scanners will be installed and new BPM electronics modules will be installed for all BPM's in the region. New cabling for the BPM's and cabling for the control of the wire scanners will be added to the existing cable plant. Modifications to the cooling water system will be required where the three accelerator sections are removed.

3.4.5. BC2 Second Bunch Compressor

BC2 is located in Linac sector 24. Eight S-band accelerator sections will be removed to accommodate a four-bend magnetic chicane, quadrupoles, BPM's, profile monitors, toroids and a tune-up dump. New power supplies and diagnostics device controllers will be added. Cables will be added to the existing cable plant to power and control these units. Cooling water for the magnets will be obtained from the existing LCW cooling water system.

3.4.6. L3 Accelerating Region

L3 is the accelerating region between the second bunch compressor chicane and the transport line to the undulator. L3 starts in Linac Sector 24 and ends in Sector 30 at the beginning of the SLAC Beam Switchyard. Linac Sectors 26, 29 and 30 will remain unchanged. In Linac Sector 25, the decommissioned NPI gun will be removed and two accelerating structures will be restored. A transverse deflecting RF structure and a profile monitor will be added. In Linac Sector 27, the Li27-6D accelerator structure will be removed and a wire scanner will be moved from Li27-9 to Li27-6. In Linac Sector 28, the accelerating structure at Li 28-5d will be swapped with the wire scanner and drift at Li28-7d. New BPM controllers will be required for all BPM's in this region. New cables will be added to the existing cable plant to power and control the BPM's, the new wire scanners, and new profile monitor. Modifications to the cooling water system will be required where accelerator sections are removed or installed.

3.4.7. LTU transport line

The LTU is the transport line from the SLAC Linac to the LCLS Undulator. The LTU begins at the end of Sector 30 and includes the existing central beamline through the SLAC Beam Switchyard and a new beamline extending from the muon shielding plug, across the research yard and into the hillside under the master alignment tower. The FFTB beamline equipment and supports will be removed and the FFTB housing will be demolished. A new housing will be constructed crossing the research yard. One new magnet will be installed in the BSY region. The new beamline region will include dipoles, quadrupoles, steering correctors, a wiggler magnet, BPMs, profile monitors, bunch length monitors, toroids, collimators, ion chambers, a single beam dumper and a tune-up dump. The new beamline will also require vacuum drift sections, pumps, gages and valves. BCS and MPS systems will be linked to the above diagnostics devices. A new PPS system will be installed in the new housing. Power supplies and control modules will be located in the MCC building, building 406, building 407 and in a new support building located above the new beamline enclosure on the East side of the research yard. A new cable plant will be installed for the new beamline. An LCW water system will be installed in the new housing to provide cooling for the new magnets. Thermal interlocks will be installed on all magnets.

3.4.8. Electron Dump Line

The electron dump line follows the X-Ray FEL Undulator and is in a new beamline enclosure. The dump line uses electromagnetic bend magnets to separate the electron beam from the X-Ray beam. The electron beam is steered into a pit in the enclosure floor where it is stopped in a beam dump. The beamline also includes quadrupoles, BPMs, profile monitors, collimators, burn through monitors, ion chambers, pumps, chambers and valves. In addition to the dump line, there will be equipment in the straight ahead X-Ray beamline including residual field permanent magnet safety bends and a safety dump, collimators, burn through monitors, toroids and ion chambers. The purpose of the equipment in the straight ahead line is to stop propagation of the electron beam in the case of a failure of the electromagnets in the dump line. Electromagnets are required in the dump line to provide energy measurement at all available beam energies. BCS and MPS systems will incorporate the above diagnostics in both beamlines. A new PPS system will be installed in the new enclosure. Power supplies and control modules will be located in a new support building located above the new beamline enclosure. A new cable plant will be installed for the new beamline. An LCW water system will be installed in the new housing to provide cooling for the new magnets. Thermal interlocks will be installed on all magnets.

3.5. Undulator System

3.5.1. Magnets

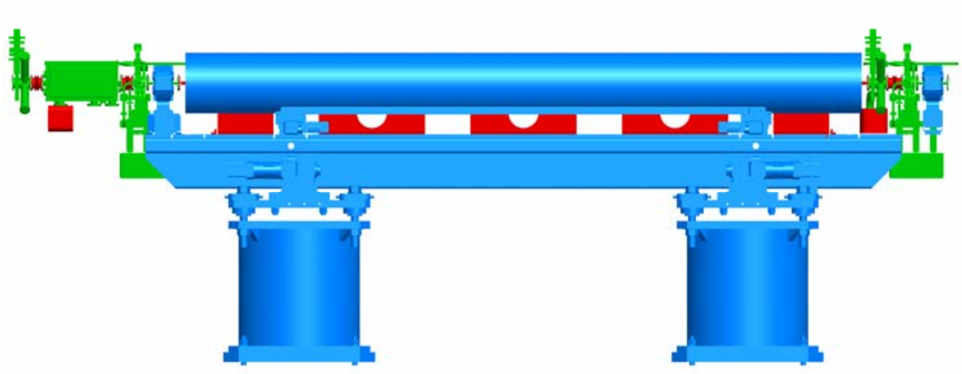
There are two types of magnets used in the LCLS undulator system, quadrupole/corrector magnets and undulator magnets. The undulator magnets are powered by NdFeB permanent magnet blocks, whereas the quadrupole/corrector magnets are conventional electromagnets.

3.5.1.1. Undulator Magnets and Supports

Each undulator magnet consists of an array of alternating dipole fields. These fields are produced by a sandwiched array of NdFeB blocks and vanadium permendur blocks clamped firmly to an aluminum base. The aluminum base is mounted firmly into a 3.4-m long fixed gap titanium strongback. The pole-to-pole gap in the undulators is approximately 6.5 mm and the peak on-axis field is 1.3 T. These fields fall off to zero beyond 10 cm from the gap. There is access to the gap from only one side. Each undulator weighs roughly 2000 kg. There will be thirty three 3.4-m undulators installed in the LCLS undulator tunnel. Seven additional undulators will be constructed and used as operational spares. A rigid girder will be used as the basic platform to hold all components related to each individual undulator. These girders rest on support pedestals that have locally adjustable positioner used for initial survey alignment and these pedestals are rigidly mounted to the concrete undulator hall floor. On the girder the undulators will rest on a horizontal slider system that will allow the undulator to be moved 8 cm horizontally outward from the vacuum chamber. The girder will be supported on a five point eccentric cam mounting system that rests on the support pedestals. This cam mounting system will allow very accurate remote positioning of each of the 33 undulators.

3.5.1.2. Quadrupole Magnets and Supports

The quadrupole/correctors are roughly 10 cm by 10 cm by 5 cm long. They are electrically powered with three separate circuits, one to control the quadrupole field and the other two to control the horizontal and vertical steering fields. Cooling is provided by air. The aperture is 1.1 cm in diameter and the peak field at the pole tips is 0.3 T. The effective length of these quadrupoles is roughly 8 cm with the field going to zero outside this region. The maximum voltage drop and current in quadrupole circuit of the magnet are 3.1 Volts and 6 Amps and in the corrector circuits these numbers are 0.1 Volt and 1.0 Amps. The maximum power dissipation in the magnets is 19 Watts. The quadrupole/correctors are supported on a fixed support that is rigidly attached to the girder which also carries the undulator magnet.



Side view of a single undulator on its girder and support pedestals

3.5.2. Vacuum System

Under standard operation conditions the Undulator Vacuum System is an all-metal ion pumped system operating in the low 10^{-8} Torr pressure region. The electron beam, while in the undulator system, passes through in a specially designed vacuum chamber that has an aluminum coating on polished stainless steel. In the breaks between the undulators are electron beam diagnostic devices and vacuum components that are used to measure properties of the beam, maintain the vacuum, provide machine protection instrumentation and also provide a continuous vacuum system from undulator to undulator.

During maintenance periods there can be additional equipment attached to the undulator vacuum system. Mobile pumping stations will be used that will pump on the vacuum system until the pressure is sufficiently low that the ion pumps can take over. The stations can be connected through pump-out valves located in the front, back, and long diagnostics regions. There will be an in situ pumping station in the exit section.

3.5.3. Undulator Chamber

This chamber will be inserted into the undulator magnet and inside of it have vacuum pressure of approximately 10^{-7} Torr. The chamber will weigh approximately 200 lbs.

3.5.3.1. Bellows Assembly

The Bellow performs two tasks: one it has movable ends to adjust to the actual length and position of adjacent components while acting as a vacuum barrier, and it also has a central liner used to electromagnetically shield the electron beam from the bellows corrugations as the beam travels through it. This assembly weighs approximately 10 lbs.

3.5.3.2. Short Diagnostic Break

There are 22 short break sections between undulators. The short break has some vacuum spools, a Tee fitting, an RF beam position monitor, and an ion pump in the assembly. The ion pump will be powered by a 5.5 KV power supply that at short circuit can produce as much as a few hundred mA of current.

3.5.3.3. Long Diagnostic Break

There are 10 long break sections between undulators (every third undulator). This has a similar assortment of components as the Short Diagnostics break with the addition of a vacuum pump-out valve and the Diagnostics Station. The manual valve is used to pump out the interior of the Long Diagnostic Break and the all-metal valve is planned to have an indicator when the stem reaches proper torque when tightening it. The diagnostics station will enclose a future suite of e-beam and x-ray.

3.5.3.4. Entrance Section

The entrance section to the undulator system contains vacuum spools, ion pumps, vacuum gauges, residual gas analyzers (RGA), pump-out valves, and gate valves. The vacuum gauge connector has on one leg 4,000 V. This is used to set the potential inside of the gauge. The RGA connector has legs that are at 250 V with one leg of the electron multiplier being adjustable to 1,500 Volts. The gate valve is planned to be a manually operated unit with limit switches to signal with the valve is fully open and fully closed.

3.5.3.5. Exit Section

This has many of the same components as the Entrance Section with the inclusion of a Turbo Pump, Roughing Pump, and a Pneumatic Gate valve. The mag lev Turbo Pump will be spinning at approximately 50,000 rpm and when the cable is disconnected at that speed the pump can act like a generator that can put out something like 100 V. There is no gas purge on this pump and it will be vented from the top to equalize the pressure in the case of replacement. The dry roughing pump has a rotating mechanism and is powered by either 110 V AC or 208 V AC electric motor. The pneumatic valve that works in conjunction with the turbo pump will close in the event of power loss. The 90 psi that it will take to seal the valve will only get used in those times that the undulator system is being pumped and operations does not want people in the tunnel.

3.5.3.6. Baking System

This will be used to bake the vacuum components to 250 deg C while being pumped under vacuum. It will use a vacuum gauge, an RGA, a turbo pump, a roughing pump, and a pneumatically operated gate valve. The outside of the system will have to be insulated but the heaters will have to operate at voltages as high as 110 VAC while being controlled by a PID type temperature controller.

3.5.4. Diagnostics

There are four types of diagnostics used within the undulator: RF beam position monitors, beam finder wires, beam loss monitors, and charge monitors.

3.5.4.1. RF BPMs

The RF beam-position monitors are copper cavities fixed to the vacuum chamber. An RF field is generated in the cavities when the electron beam passes. This small field is detected by electrodes and processed with a local low-level RF detector. The processed signal is digitized and sent to the control system for further processing into beam position data. There are 34 RF BPM's along the length of the undulator system.

3.5.4.2. Beam Finder Wires

Beam Finder Wires are used to locate the one end of the undulator relative to the electron beam. In a beam finder wire a thin wire is swept through the electron beam. These energetic electrons knock electrons off the wire and create a current in the thin wire. Detection of the current provides information of the electron beam density at the position of the wire. A secondary signal is also detected by monitoring the beam loss monitors downstream of the wire. This current (or beam loss) and position information will be sent to the control system for processing into beam distribution and position information. The beam finder wires in the undulator system will be very similar in basic concept to those employed throughout the rest of the LCLS linac. The modifications required are due to the difference in the vacuum chamber design of the undulator system and that these are two position devices as opposed to a scanning wire. There will be a total of 11 beam finder wires along the length of the undulator system.

3.5.4.3. Beam Loss Monitors

Thirty three beam loss detectors are installed at regular intervals along the length of the undulator system as a means to detect unwanted beam losses. Each device consists of a simple piece of plastic and a sensitive photodiode. If the electron beam is miss-steered and strikes the vacuum chamber secondary emission electrons are generated and some of these escape the chamber. These escaping secondary emission electrons are intercepted by the plastic. When they do a small burst of light is generated and detected by the photodiode. This signal is processed and sent off to the controls system for further processing.

3.5.5. Controls

The controls within the undulator hall of the LCLS can be further divided into different control subsections as follows:

3.5.5.1. Motion

The cam movers beneath the undulators will be driven with servo motors. These motors do not require current to hold their position. Control will be via local integrated "smart motor" interfaces. There are five cam motors per undulator. The undulator horizontal slider motion requires two motors. These are similar to the motors used for the cam motion. The beam finder wire motion will be done using a combination of an integral two position mechanism (in the beam, out of the beam) and the cam motors. This combination will allow placing the beam finder wire into the beam and sweeping it through. There are 33 beam finder wires systems.

3.5.5.2. Signal Analysis

A variety of diagnostic signals need to be captured and analyzed by the control system. Signals from these devices will be run over shielded high-frequency low loss cables (such as Heliax) to the equipment alcoves. At the equipment rack, these signals will be further amplified/processed before being connected to ADCs within the control crate. The 34 BPMs each have 4 signals which require this analysis. Each of the 11 beam finder wire systems also require this type of analysis.

3.5.5.3. Temperature

Temperature monitoring of the undulators will be done with thermocouple sensors on the undulators connected to controllers in the equipment alcoves.

3.5.5.4. Vacuum Equipment

All vacuum equipment will interface to the control system via serial or Ethernet communications cable. These cables will be from the vacuum equipment to the controls crate within a specific alcove (it is expected the vacuum equipment will occupy the racks within the same equipment alcove). Equipment expected to be interfaced to the control system include vacuum pump controllers, vacuum gauges controllers, and the residual gas analyzer.

3.6. X-ray Transport Optics and Diagnostics

XTOD Scope - The X-Ray Transport, Optics, and Diagnostics (XTOD) WBS section encompasses most of the x-ray beamline elements starting from the electron dump at the end of the undulator, to the 3 x-ray beam pipes terminating in the FEH. In addition to the pumps and pipes that transport the x-ray beam through the facility XTOD also provides several pieces of optical and diagnostic components located throughout the facility.

3.6.1. Electron Dump Systems

3.6.1.1. Fast Close Valve

The fast-close-valve is a fast (< 0.1 sec) vacuum valve, to protect the upstream vacuum system in the event of vacuum failure in the experimental area. The sensors that trigger this valve will be interlocked with the linac controls, so that the valve will not be subjected to FEL radiation.

3.6.2. FEE Systems

3.6.2.1. Fixed Mask

The Fixed Mask insure that all radiation allowed downstream is confined to within a small angular region. The mask is a thick block of hi-z material with a TBD (~5 mm) clear aperture in the center.

3.6.2.2. Slit A

Slit A consists of a two movable jaws defining an adjustable horizontal aperture, and two movable jaws defining an adjustable vertical aperture. The purpose of the slit is to allow the users to remove the halo of spontaneous radiation surrounding the FEL.

3.6.2.3. Gas Attenuator

The gas attenuator is a 5-10 m long section of pipe filled with gas whose purpose is to attenuate the FEL beam especially at low photon energies. The gases under consideration are N2, and Ar at pressures up to 20 Torr. The gas attenuator must be windowless because of damage and absorption issues with the FEL beam. This means that gas will leak into the beam pipe and must be differentially pumped. Gas that is pumped out of the system will be recycled.

3.6.2.4. Solid Attenuator

The solid attenuators reside in a vacuum tank directly downstream of the gas attenuator. The attenuators are mounted on a series of wheels inside the tank allowing various combinations of attenuators to be selected. The attenuators will be made of low-Z materials such as Be, Li, and/or B4C in thicknesses raging from 100 microns to 5 cm. Their use is limited to photon energies above TBD (3-4 KeV) to prevent dangerous vaporization of the solids.

3.6.2.5. Windowless ion chamber

The windowless ion chamber is a short version of the gas attenuator operating at lower pressures and with additional electronic to measure the ionization of the gas to infer x-ray intensity.

3.6.2.6. Imaging Diagnostic tank

This tank is a 2 m x 1 m stainless steel (ss) tank and vacuum system housing the imaging diagnostics and associated rails and stages for positioning them.

3.6.2.7. Direct Imager

The Direct Imager is an insertable, high-resolution scintillator viewed by a CCD camera for measuring spatial distributions and for alignment and focusing of optical elements. The imager utilizes a thin crystal of LSO or YAG to convert x-rays into visible photons and will be damaged by the full FEL.

3.6.2.8. Indirect Imager

The Indirect Imager overcomes the FEL damage problems of the Direct Imager by utilizing a thin foil of a low-Z material such as Be to act as a beam splitter to partially reflect a portion of the beam onto the YAG imaging camera which remains out of the beam. The reflected intensity can be adjusted by changing the angle of incidence.

3.6.2.9. Commissioning Diagnostic Tank

This tank is a 2 m x 1 m ss tank and vacuum system housing the commissioning diagnostics and associated rails and stages for positioning them.

3.6.2.10. Spectrometer

The commissioning diagnostic tank is converted into a spectrometer by adding a crystal at 8 keV or a grating at 0.8 keV. In either case the optic disperses the radiation onto an x-ray sensitive region of a fast readout position-sensitive detector.

3.6.2.11. Calorimeter

The calorimeter is a small volume x-ray absorber (probably Be) which absorbs all of the x-ray energy resulting in a rapid temperature rise which may be used to infer the intensity of the FEL pulse. The heat capacity and mass of the absorber determine the temperature rise.

3.6.3. Tunnel Systems

3.6.3.1. Tunnel Beam Pipes

The beam transport mechanical and vacuum system contains approximately 600 meters of vacuum beam pipe maintained at 10-7 Torr by approximately 10 Ion pumps. The basic design of a section of beam pipe has TBD (2”) stainless-steel electroplated inside and out and connected with metal sealed gaskets and welded 4 5/8” conflats. The pumping section consists of a stainless-steel cross with 8” flanges top and bottom to accommodate the ion pumps. The section terminates with an isolation valve and a bellows for alignment. The isolation valves are all metal gate valves such as manufactured by Vat. The stands have cross bracing for earthquake protection. These sections are repeated through the halls and tunnel, except in places where the pipe is replaced by one of the tanks or other instruments in the beam line.

3.6.3.2. System Monochrometer

Some experiments in the FEH will require a bandwidth narrower than the intrinsic bandwidth of the FEL. The system monochrometer is a standard monochromator using Si and diamond crystals and should not suffer any damage due to the peak power.

3.6.3.3. Pulse-split-and-delay System

This system, located in the end of the tunnel, will use crystal diffraction to split the FEL pulse, direct the two x-ray pulses around unequal path lengths, and bring them back onto the primary beam path with a time delay between them. The beam splitting is accomplished by a very thin (10 μm) silicon crystal.

3.6.4. Near Experiment Hall (NEH)

3.6.4.1. Flipper Mirror

The flipper mirrors are a set of two or more mirrors, located in a differentially pumped tank at the end of the NEH. The mirrors can be set to allow the x-ray beam to be introduced into one of the 3 x-ray paths leading to the FEH.

3.7. X-Ray End station Systems

X-Ray End Station Systems comprise the interface between the LCLS radiation and the experimental users. This interface takes place mainly in the x-ray hutches in the NEH and FEH. Section 1.6 also includes experimental equipment for Atomic Physics experiments, including an ultra-fast optical laser in the NEH. All x-ray PPS/MPS activity for LCLS is included in section 1.6, along with laser PPS and other experiment-related user safeguards.

3.7.1. Conventional Facilities

The x-ray hutches are essentially large laboratory rooms. As part of their conventional construction, they must be protected by standard safeguards for fire, electrical hazards, and ventilation-related hazards. In addition, they will contain large equipment items which will require seismic bracing. The x-ray hutches must include PPS interlocks to prevent entry while radiation is present. Radiation shutters and beam stops will allow the radiation to be used in upstream hutches while downstream hutches are safely open. The laser rooms and x-ray hutches will sometimes contain high-power laser radiation, and must include laser PPS systems.

3.7.2. Instrumentation

Much of the instrumentation used in the x-ray hutches will be commercial lab equipment. Electrical, vacuum, and chemical hazards may exist and must be mitigated. The experimental configuration may change over time, bringing new hazards which must be recognized and addressed. Most LCLS experiments will involve high-power (Class-IV) ultra-fast laser systems. One such system will be permanently installed in the NEH. Additional laser systems may be installed in the x-ray hutches in the future. Laser safety mechanisms and procedures must be developed for these laser systems.

3.7.3. Vacuum System

The LCLS x-ray beam will be transported through a high-vacuum pipe (typically 4" diameter stainless pipe). Many of the experiments will take place in vacuum chambers attached to this pipe (typically <10 cubic ft volume). Also, the high-power laser beams may be transported through vacuum pipes. Puncture of the LCLS vacuum system in the experimental areas could potentially damage the accelerator upstream. An MPS system must be included to valve off the vacuum in case of an accidental venting.

3.7.4. Cable Plant

The End station Systems will involve an extensive cable plant, transporting data signals from experiments to remote computers, and between sensors and actuators distributed along the LCLS beamline. A potential exists for fire to spread via the cable plant; cable specifications should be made accordingly.

4. Project Management

This section describes the LCLS's planning for the implementation of ES&H program elements specific to construction of the LCLS project.

4.1. Overview of Construction

The LCLS project includes the, site preparation, tunneling, construction of the conventional facilities, utilities and fixtures in accordance with applicable codes and standards. Upon project completion, the facility will be ready for the installation of technical equipment and furnishings. The scope of the LCLS project includes:

- Demolition of existing structures;
- Site preparation and tunneling, and landscaping;
- Construction of buildings (i.e., foundation, walls), including all required utilities (electrical, water, gas, wastewater, HVAC);
- Installation of all necessary basic wiring for computing, telecommunication, security, personnel and equipment safety monitoring systems;
- Fire alarm systems, and security systems; and
- Installation and commissioning of technical and scientific equipment.

SLAC Citizens Committees, ES&H Division and subject matter experts have been actively involved in planning the conventional facilities. In addition to the engineering firms and independent review committees to evaluate the project design for code compliance, constructability and value engineering the project also hired a fire protection engineer to evaluate the Fire Protection and Life safety considerations of the architect's design.

4.2. ES&H Hazards and Risks

Environmental hazards specific to, or of notable concern to, construction of the LCLS building have been given detailed treatment in later subsections.

LCLS and SLAC construction safety personnel have evaluated anticipated hazards associated with the LCLS facility. They found many hazards common to all building and tunnel construction of this scale, but no unusual hazards. The Hazard Identification and Risk Determination Summary found in Appendix A identifies hazards associated with the facility, in general. The Construction Safety Regulatory Linkage in Appendix C is a table that summarizes the determination of construction specific hazards.

The LCLS project will manage construction hazards and risks according to a project-specific ES&H plan based on the SLAC Policy Manual requirements and procedures set forth in the LCLS Site Safety Plan. LCLS will require that its contractors develop job safety analysis (JSA) for each work activity. The JSAs must identify the various hazards associated with performing a task and the precautions that will be used to control identified hazards. SLAC procedures call for the JSA review by the managing contractor before the start of on-site work. The management of subcontractor performance is included in the Construction Manager's contract. This contract has been awarded to Turner Construction Co. Their site specific safety program will reflect all SLAC safety requirements.

Turner Construction Company has submitted the first draft of their site specific safety program. Both the SSO and LCLS Project Office provided comments. The document will be reviewed until it meets all party's approval.

4.3. Applicable ES&H Requirements

LCLS management acknowledges that the construction of the LCLS project must comply with requirements set forth in:

- DOE Order 413.3, Program and Project Management for the Acquisition of Capital Assets;
- 48 CFR 970.5204-2, Integrating Environment, Safety and Health into Work Planning and Execution;
- DOE Order 440.1A, Worker Protection Management for DOE Federal and Contractor Employees; and
- DOE Order 450.1, Environmental Protection Program.

The LCLS Project Safety Plan defines in practical terms the work practices to be followed that implement the requirements contained in these documents. The LCLS recognizes that, at the level of day-to-day work, the worker protection standards most relevant to the construction activities are those listed under Section 12 of the "Contractor Requirements Document" attached to DOE Order 440.1 A, particularly:

- Cal OSHA
- 29 CFR 1926, Safety and Health Regulations for Construction and
- 29 CFR 1910, Occupational Safety and Health Standards.

4.4. Organization/Role Interfaces

At SLAC, safety is a line management responsibility, and several line organizations will be involved in the construction of the LCLS. This section defines the organizational interfaces needed to ensure the success of the LCLS. The section reflects discussions within the LCLS, discussions with the DOE's LCLS Federal Project Director, discussions with SLAC's ESH and Quality Assurance groups, and Laboratory policies and procedures.

Stanford Site Office - The DOE's Federal Project Director, who functions as the chairperson of the Integrated Project Team, and SLAC's LCLS Project Manager will be the primary and official interface between the DOE and Laboratory on day-to-day ES&H issues relating to the project. To facilitate communications, the persons in these roles have each designated qualified, experienced ES&H representatives and authorized them to communicate directly with one another while keeping their respective management informed. The LCLS anticipates that there will be occasions when other DOE personnel communicate LCLS ES&H concerns to the Federal Project Director or to SLAC's ESH Division. Likewise, there may be occasions when SLAC ESH personnel share observations with points of contact in the DOE's Stanford Site Office (SSO). The LCLS expects that the informal communications among these groups will contribute to strong ES&H performance and awareness. LCLS's management will remain responsible for formal ES&H decision making and for keeping other laboratory entities informed.

LCLS Project Management Team - The LCLS's Work Breakdown Structure (WBS) 1.9 System Manager will direct LCLS conventional facilities design and construction staff. This position reports to the LCLS Project Manager. The planned WBS 1.9 staff includes a LCLS "construction manager" and construction field representatives.

The qualifications for the construction manager and construction field representative roles will include significant on-the-job construction safety experience and at least 30 hours of OSHA construction safety training.

The LCLS recognizes that it is subject to routine ES&H oversight conducted by SLAC personnel and DOE personnel. The LCLS's official point of contact for SLAC communications is the LCLS Director, but the Director may routinely be represented by the LCLS's ES&H Coordinator.

The personnel in these roles will be the day-to-day points of contact with the construction management firm, general contractor and construction subcontractors.

Turner Construction Co. - Within this structure is a Construction Manager who will manage the day-to-day aspects of field construction. Turner Construction Company has been retained to perform this function. They were selected following a competitive review of several prospective bidders. The basis upon which they were ultimately awarded the contract was their past track record of successful projects with low injury and incident rates as well as the experience of their underground construction partner.

General - All project personnel will be responsible for immediately informing LCLS management, including the WBS 1.9 System Manager, about any contact with Turner, SLAC, or DOE personnel regarding ES&H issues. During the absence of the LCLS ES&H Coordinator and the WBS 1.9 System Manager, the Construction Manager will be responsible for bringing ES&H matters to the attention of the LCLS Project Director. The LCLS ES&H Coordinator, unless otherwise instructed, will represent the LCLS in construction safety discussions with SLAC and DOE personnel.

In addition, the LCLS will, prior to the start of construction activities, have an agreement with the adjoining SLAC facilities defining actions to be taken to ensure that construction activities do not adversely affect the health or safety of personnel in the adjoining areas or the scientific operations conducted therein.

To promote communication and clear understanding of collective goals, construction partnering sessions are being conducted between Turner, SLAC and the DOE which have included attention to safety. This will further enhance project safety and potentially reduce claims and litigation

4.5. Construction Safety Goals and Incentives

LCLS management has established a construction safety goal for the LCLS project of zero lost workday injuries (that is, a lost workday incidence rate of zero for every year of the project). In addition, LCLS management has set an environmental stewardship goal of zero reportable environmental incidents. The LCLS may choose to include incentives/penalties for safety performance in construction contracts, while absolutely requiring reporting of injuries and potentially unsafe conditions. Subcontractors will be required to report injuries and illness to the SLAC contract officer and the LCLS contract manager.

Included in the contract with the Managing Contractor, Turner Construction Company, is a safety incentive clause.

SLAC construction experience demonstrates that subcontractors can achieve these goals if the project follows established safety procedures. The LCLS will facilitate implementation of the procedures by:

- Placing attention on proper work planning;
- Effectively involving qualified personnel from various SLAC organizations in ES&H risk evaluations, specification writing and preparation of contractor bid documents, evaluation of contractors' qualifications, and selection of contractors;
- Conducting internal (LCLS personnel and construction management firm) surveillance that begins with an emphasis on cooperative identification and control of risk, but progresses, if necessary, to the application of sanctions;
- Cooperating with external (SLAC, DOE, and regulatory agency) oversight efforts; and clearly communicating this goal (expectation) to subcontractor organizations.

4.6. Tunneling Design and Management

This section is an introduction to the considerations addressed when evaluating the underground siting, design and planning of the construction of underground facilities. In anticipation of the selection of the tunneling contractor this section is limited to a discussion of the more general aspects of tunnel construction in rock.

4.6.1. Factors Impacting Rock Tunnel Behavior

The design of a tunnel must be developed with due regard to the constraints of the construction (tunneling) process to ensure realistic requirements are established to not only come up with an affordable design, but to reduce the risk associated with tunnel construction.

While the tunneled excavation must satisfy the space demands of the end user it must also be designed with an adequate safety margin to assure the stability of the tunnel. Stability in tunnel design is affected by both the size and shape of the excavation. Tunnel instability is dictated by the density and shear strength of natural fractures, the larger the opening excavated the greater the likelihood of more frequent, larger rock fallouts occurring and the greater the density and size of the supporting structures needed to counter such fall-outs. Where in situ stresses are relatively high compared to the strength of the rock mass, a tunnel profile that is elliptical or circular is desirable to a more angular one. Elliptical or circular designs avoid corners which create high stress concentrations.

4.6.2. Tunneling Methods and Means

In all but the weakest rock, three basic types of excavation methods are commonly considered to be feasible for tunnel work. Two of these methods rely on mechanically breaking the rock, namely the tunnel boring machine system (TBM-system), and the roadheader. The third method is “drill and blast” (D&B) which obviously relies on the use of explosives.

The TBM system, which includes not only the cutterhead machine but also the ground support and muck evacuation systems, is often used to good effect in the excavation of longer, smaller diameter, relatively straight tunnels with uniform cross-sectional requirements, mined under more uniform rock mass conditions. In such applications, the TBM-system has the ability to tunnel faster and cheaper than either of the other two mining methods. However, for many tunnel projects the TBM is not an automatic choice. It has a relatively high capital cost and requires an extended period for fabrication/refurbishment, mobilization and demobilization. Its tunneling capacity is limited to fixed, circular cross-section and cannot mine tight bends or corners.

In shorter, larger and/or more complex tunnel layouts including tight turns, steep gradients, multiple cross-sections and variations in ground support and treatment en route, roadheader or drill and blast excavation methods are chosen. The roadheader and drill and blast methods have similar degrees of flexibility. Roadheader viability is severely compromised in harder, more abrasive and massive rock masses conditions where progress rate is reduced and the abrasive wear on the cutting tools increased significantly.

Drill and blast tunneling offers the user the most flexible excavation system that can be used economically in even the hardest, most abrasive, rocks. However, drill and blast methods result in additional fracturing of the rock. Where explosives are used as the means of excavating more support is generally required over that of a mechanically-mined tunnels.

For the LCLS project the roadheader has been selected as the most efficient and safest approach.

4.6.3. Rock Support and Treatment

In all but the most stable rock mass, some support is needed in the tunnel. Rock supports are installed to stabilize the tunnel periphery and ensure that the tunnelers can work safely within the confines of the newly excavated tunnel. The supports can be either temporary (during construction) or a permanent (for the life of the project). Rock supports installed at the heading will be adjusted locally in response variations in the “as-encountered” ground conditions. Rock supports may be supplemented by ground treatment work performed around and/or at the face as necessary. Treatment of the rock mass may be needed to improve the tunneling conditions and reduce the impact of construction on the surrounding area (for example, water table draw-down or surface settlement). Treatment (freezing, grouting etc.) may be used to achieve a temporary or permanent increase in rock mass strength or a reduction or increment in rock mass permeability. Rock mass zones that require significant amounts of such treatment should be identified early in the site investigation process in order that their presence, characteristics, extent and mining impacts can be fully evaluated during the siting process.

4.6.4. Underground Design Requirements

At the conceptual stage of design, initial estimates of ground shielding, clearance envelopes (including tolerances), and general layout/environmental criteria required for the construction, installation, operation and maintenance phases the Project must be defined in drawing sets that show the tunnel in plan and section (longitudinal and cross). The tunnel excavations should be laid-out in a manner that is compatible with the selected construction means and methods. The tunnel (plan and section) should show key geologic and hydrologic information. Some underground requirements that should be estimated during this conceptual period include:

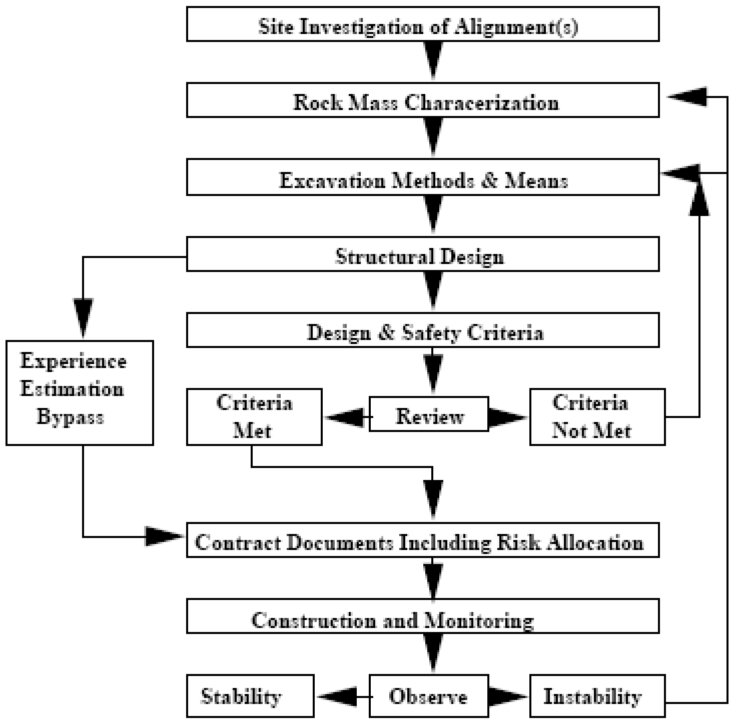
- External loading of floors, wall and crown anchorages including detector supports, transportation and lifting system
- Electrical, electronic, communications networks (cables and cable trays)
- Heating, cooling, ventilation and air conditioning (duct work, fans, door and louvers, drip ceilings and underground chilling/heating units etc.)
- Groundwater collection and evacuation systems (excavations, drains, pumps and pipes)
- Survey controls (including stations and lines of sight)
- Environmental requirements (spoil disposal, groundwater protection.)
- Neighborhood issues (mitigation of construction/operation impacts on and off-site).

4.6.5. Phases of a Tunnel Project

The principle design and construction phases of a tunnel project are outlined in the flowchart below. The flowchart is modeled after the International Tunneling Association guidelines for tunnel design [1]. The flowchart reflects a stepwise progression from site investigation through to construction and monitoring. In practice, the site investigation activity overlaps other planning activities to allow for the detailed investigation of design and the mapping of the excavated geology. As the project progresses periodic reviews

[1] Lowe, P.T. (1993), "The Planning and Design of the Prospect to Pipehead Tunnel." Proceedings, 8th Australian Tunneling Conference, Sydney, Australia, 24-26 August, pp. 21-27.

should be held to evaluate progress, improve management confidence in budget and time goals and enhance the practicality and economy of the tunnel work itself.



Flow Chart for Tunnel Design

4.6.6. Site Investigation and Rock Mass Conditions

To evaluate a site's suitability for tunneling both regional and location-specific geologic information regarding information on rock units, structural folds and faults, groundwater and stress regimes need to be gathered. This basic geological information must be interpreted to characterize the rock mass along the alignment(s) and provide input for the constructability and engineering analyses. Early acquisition of site investigation data can help quickly identify difficult or showstopper situations along an alignment and expedite the short-listing of the more serious alignment issues. As the design progresses from the conceptual to the alignment-specific stage, site-specific information is needed to support the validation of the means and methods to be used in the tunneling operation. At this stage a modicum of alignment specific data is need, which is typically acquired from trench and borehole investigation and laboratory testing. A general engineering description of the rock mass for tunneling purposes will typically include a geologic classification of the rock units (ideally with % minerals), an estimate of the intact rock strength, and a description of the natural block structure (condition, roughness, orientation, size and shape). The potential for the presence of atypical rock mass conditions also needs to be studied.

Atypical conditions that merit investigation include soil-like zones within the rock mass, zones of faulting, shears, open fractures, solution zones, hydrothermal alteration, weathering and buried valleys. Efforts should also be made to evaluate the potential for encountering zones of high water inflow that may or may not be associated with soil-like zones of weakness within the rock mass. The potential for more pervasive rock-unit or regional adverse tunnel conditions, including the presence of relatively high in situ stresses, high ambient rock temperatures and more pervasive fluid/gas inflows should also be investigated.

4.6.6.1. Excavation Methods and Means and Structural Design

Once a preferred alignment has been identified and basic rock engineering characteristics determined, the selection of an initial set of baseline means and methods can be selected. Throughout the planning period, and most importantly when determining the selection of means and methods, contractor input is highly desirable. Practicing contractors are best positioned to provide state of-the-industry input for selection of safe, practical and cost-effective methods and means for tunnel construction. This was done on the LCLS project.

However, even the most thorough site investigation of geologic conditions will not be able to completely define the scope of an underground construction contract. Some surprises from the natural material must be anticipated. Risk analyses should be conducted to characterize the likelihood and severity of the impact of surprises on both the construction work and the project as a whole. Unacceptable risks should be mitigated by design, specification, contract provisions or insurance measures before the contract is let. The level of risk that tunnel construction brings to the overall project can be high, and is strongly influenced by factors, including the:

- Complexity of the geology,
- Thoroughness of the site-specific investigation,
- Amount and relevance of accumulated case history information,
- Flexibility of the mining system and, perhaps most importantly of all,
- Skill-set of the owner's design and construction team that is assembled to plan and execute the work.

A strong argument should be made to actively involve the excavation contractor or one intimately familiar with local conditions, in the design process. The involvement of the contractor in the planning of the tunnel project often favors the adoption of a more integrated design and build approach, where responsibility for design of the tunnel (design and build) passes to the contractor. Cording [2] notes "The separation of design and specifications from the contractor's planning creates unnecessary impediments and adds

[2] Cording, E.J. (1985), "Constraints on Tunneling Technology," Proceedings, Tunneling and Underground Transport, Future Developments in Technology, Economics, and Policy, Boston, MA., US., April, pp. 121-141.(132)

unnecessary costs to the project." Ultimately, an integrated design strategy that involves the contractor can provide for a more integrated and innovative approach to tunneling [3].

However, to assure the success of the project the owner must assemble a core project team that has a thorough understanding of both the end-user needs and tunneling means and methods. In the case where the owner does not initially have all the requisite skill-set in-house, the project management team should be supplemented with outside expertise. During design and construction the owner's management team should take full responsibility for project planning and be endowed with adequate responsibility and commensurate authority to be able to effectively administer all related design and construction activities [4]. This too was done on the LCLS project.

4.6.7. Safety Planning

When planning a high risk construction project including tunneling safety must be a paramount concern addressed by incorporating the following principles in the project at every stage:

- A Working Atmosphere of Safety
- Integrated Safety Management

A hazard/risk analysis should be developed and documented for each phase of the project to systematically identify the hazards that may be associated with it. This analysis should ensure that matters of environmental protection and worker health and safety related to the project are identified and that they are thoroughly addressed in the design, construction and subsequent operation of the project.

The major cost driver for LCLS project will be the construction of the tunnel for the undulator and experiment hall. This will require substantial civil construction by a contractor responsible for building the underground facility. Civil construction of an underground site offers special challenges. Some of these involve use of heavy construction equipment, while simultaneously dealing with fire protection and confined space issues. At the onset of the project a set of procedures for instituting safety rules must implemented and agreed to by all involved parties. These procedures were developed for this project *LCLS Project Environmental Safety and Health Plan*. Once the tunneling contractor has been retained for the LCLS project this planning for safe construction will be conducted by Turner/Hatch Mott MacDonald with LCLS project involvement. This Tunnel Safety planning will conform to Cal-OSHA Title 8, Subchapter 20, Tunnel Safety Orders, Articles Nos. 1 through 19.

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[3] Songer, A.D., and K.R. Molenaar (1996), "Selecting Design-Build: Public and Private Sector Owner Attitudes," Journal of Management in Engineering, November - December, pp. 47-53. 3

[4] McCreath, Dougall. Lehman Review of the NuMI Project. Fermilab May 2001.

4.6.8. Emergency Response

Tunnel Rescue protocols will be in place per Cal-OSHA Title 8, Subchapter 20, Article 10, §8430. This regulation requires that there be in place at least two 5-person rescue teams. The near team is currently planned to be provided through the SLAC on-site fire Department (PAFD), who will receive training in tunnel rescue. Investigation is in-progress to establish the far rescue team, which may be provided through the San Jose Fire Department. The tunnel subcontractor, HMM, will provide referent technical rescue expertise, and will have on-site personnel also trained in tunnel rescue."

4.7. Environmental Management

This section identifies three issues that SLAC and the LCLS recognize as requiring careful management. Other sections of this report identify issues and provide more detail on these Issues.

4.7.1. Spoils Pile Management

The LCLS has identified spoils pile management as a necessary and important environmental control for the construction phase of the project. Project management has identified the location of all spoils management. To provide for effective control of hazards, the LCLS will ensure that:

- Silt fencing is installed (and maintained) around the entire perimeter of the spoils pile,
- Covering spoils piles where needed,
- Soils dropped on roadways by trucks and construction equipment is controlled and cleaned up promptly after the LCLS becomes aware of the spillage, and
- Collected runoff water is managed according to provisions included in and implemented according to the SLAC Storm Water Pollution Prevention Plan (SWPPP).

4.7.2. Lay-Down Areas Management

LCLS management has identified the management of lay-down areas as a concern warranting special attention because the areas must be located so the activity does not impact any of the identified environmentally sensitive areas. LCLS management will ensure that the project includes all provisions required in the SLAC site-wide SWPPP to protect the surrounding areas from contaminant incursion arising from equipment, liquids, and supplies located in the lay-down area.

4.7.3. Storm Water Pollution Prevention Plan Maintenance

The LCLS management will cooperatively work with the ESH Division Environmental Protection Department to develop and implement a comprehensive and complete SWPPP that will protect all sensitive environments. The plan will incorporate and implement monitoring and maintenance elements intended to ensure that all provisions of the SWPPP are functioning as designed and planned.

4.8. Waste management

Appendix D, Construction Waste Management, contains a detailed description of SLAC policies and procedures pertinent to management of LCLS construction wastes. These policies and procedures promote minimizing the amount of waste generated and reusing, salvaging, or recycling waste wherever possible. They also call for the LCLS to require contractors to remove accumulated construction debris as the work progresses and, upon completion, to remove from the Laboratory all remaining construction debris, excess material, equipment, tools, and temporary construction.

The CMGC has been asked to define specific controls for potential effluents such as ready mix concrete truck "Wash-out" areas. Past practice on the project has been the provision of washout boxes which was effective. The CMGC has also been asked to define its proposed means of managing it tunnel de-watering effluent.

5. Safety Analysis

5.1. Methodology

Identification of hazards for LCLS began with a review by the 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 a specific subject matter areas. This process was then followed by an internal review of the project's infrastructure and an assessment of proposed activities to identify potential hazards associated with the project. This process will be an on-going one to identify potential hazards and mitigate them. Each component, sub-system and system is subject to a peer review of the technical aspects of its design. Included in this review is a safety assessment. As a result all the project personnel will have been involved in identifying and mitigating hazards that might exist on this project.

5.2. Facility Design

This section provides an overview of the efforts the LCLS has taken to ensure that the LCLS building and experiment halls will meet applicable facility safety requirements and will have the infrastructure needed provide for safe operations while the building is being used to house LCLS activities.

5.2.1. Codes and Standards

The firm providing architecture and engineering (AE) services for the LCLS undertook a codes analysis and produced a design narrative that listed many codes and standards addressing natural hazards and safety concerns. Among the codes were:

Uniform Building Code, Uniform Plumbing Code, Uniform Mechanical Code

National Fire Codes (latest edition of each standard), including National Fire Protection Association (NFP A) 70, National Electrical Code® and NFPA 101, Life Safety Code®.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62-2001, Ventilation for Acceptable Indoor Air Quality

More comprehensive listings of applicable codes can be found in the codes analysis report and the design narrative.

The AE also identified DOE 420.1A as establishing design requirements.

5.2.2. Building Programming

The design requirement calling for compliance with codes and standards applied not only to the building proper, but also the support systems and utilities required to accommodate planned LCLS operations. To ensure that the A/E could fulfill this requirement, LCLS staff members, including the WBS System Managers, have helped feed needed information characterizing planned activities and associated equipment and materials to the AE. Their familiarity with planned building operations have enabled them to provide the AE with the information needed to reliably and methodically compile a room-by-room characterization of the facility. The AE was then able to compile a Program Requirements document containing the datasheets reflecting LCLS input and layouts reflecting the space needed to accommodate planned research and support activities and the relative locations of emergency exits, ventilation systems, safety equipment, etc.

5.2.3. Design Reviews

The AE has periodically provided the maturing layouts and specifications for the LCLS building to the LCLS for review and comment. In turn, the LCLS has called upon SLAC subject matter experts and an independent group of safety experts associated with a construction manager to review the design and identify weaknesses and noncompliance. Comments about apparent noncompliance with standards and codes have been fed back to the AE and tracked until resolved.

5.2.4. Fire Hazards Analysis

The LCLS contracted for the development of a fire hazards analysis (FHA) as required in 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 analysis is underway and observations have been fed back to the AE as the work was being conducted. Reported FHA conclusions will be incorporated into the LCLS's final safety analysis report. Appendix D includes a Fire Hazards analysis as reflected through 60% of Title II design.

The probability of a fire in the LCLS is expected to be similar to that for present operations, as accelerator components are primarily fabricated out of similar non-flammable materials and combustible materials are kept to a minimum. The most "reasonably foreseeable" incident or event with any substantial consequences would be a fire in the insulating material of the electrical cable plant caused by an overload condition. This differs from the maximum credible fire loss, which assumes proper functioning of the smoke detector system and a normal response from the fire department. In this case, losses would be confined to a single section, but includes magnets, vacuum chamber and associated cabling. A comprehensive Fire Hazard Analysis document is being developed and will be delivered on completion of the Title II design.

Installation of new cables for the LCLS will meet the current SLAC standards for cable insulation and comply with National Electric Code (NEC) standards concerning cable fire resistance. While this reduces the probability of a fire starting, an aspiration type smoke detection system (VESDA) in the accelerator housing and fire breaks in the cable trays will mitigate fire travel. Support buildings for power supplies and electronic equipment are protected by automatic heat activated wet sprinkler systems and smoke detectors. Fire extinguishers are located in all buildings and accelerator housings for use by trained personnel. The combination of smoke detection systems, sprinklers and on-site fire department (response time ~5 minutes) affords an early warning and timely response to fire or smoke related incidents.

New accelerator housings and tunnel area will comply with the Life Safety Code with respect to exit distances.

As of the 60% design review stage, life safety features of the LCLS conventional facilities have been designed solely within the framework of the model Uniform Building Code (UBC). However, DOE guidance and the LCLS design basis also cite NFPA Standard 101, the *Life Safety Code*, for life safety compliance. This report, 8. Appendix C, analyzes the 60% design submittal against NFPA 101 requirements. In the design of unusual structures, such as the LCLS tunnel and building complex, full NFPA 101 compliance is not always directly achievable. In these cases, DOE requires that measures be put in place to achieve a "comparable level of life safety."

5.2.5. Natural Phenomena Hazards Mitigation

The design of the LCLS addressed 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 to be 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, infrastructure) are reviewed by the SLAC Earthquake Safety Committee, as mandated by the SLAC Safety Program. Design and construction activities with respect to seismic loads are covered by internally developed standards and conventional building codes.

Earthquake design requirements for LCLS structures (per the IBC) are specified in the structural design, calculations and specifications, as well as being specified for all exterior enclosure systems for the building.

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

Grounding has been included in the design for the entire facility, per UBC, NFPA and NEC requirements.

5.2.6. Emergency Preparedness

SLAC has a comprehensive emergency management program. The program is defined in the SLAC *Comprehensive Emergency Management Plan* and associated *Emergency Plan Implementing Procedures*. The Director of the LCLS project will assign an individual to serve as the Area Emergency Supervisor (AES) for the LCLS facilities. The AES will advise the LCLS management on emergency response and preparedness. The AES will take technical direction from the SLAC Emergency Management Officer.

AES responsibilities include ensuring that:

- All aspects of the LCLS program are:
  - Properly administered to support emergency response and preparedness
  - Documented in the building emergency plan, and
  - Documented in the associated hazard survey.

- All information regarding hazards at CNM facilities is provided to the site's Emergency Management Officer and the SLAC Fire Chief.
- Appropriate information is incorporated into site planning and training activities.

At least once each year, the Emergency Management Officer prepares 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 onsite or near site are also discussed in this document. This document also summarizes non-classified emergency planning information regarding security events which could lead to an Operational Emergency onsite. When built, the LCLS will provide needed information to the Emergency Management Officer so the document will accurately characterize risks posed by LCLS activities as well as a source of information containing pertinent non-LCLS hazard information that could impact the LCLS facilities.

5.3. Radiation Physics

5.3.1. Introduction

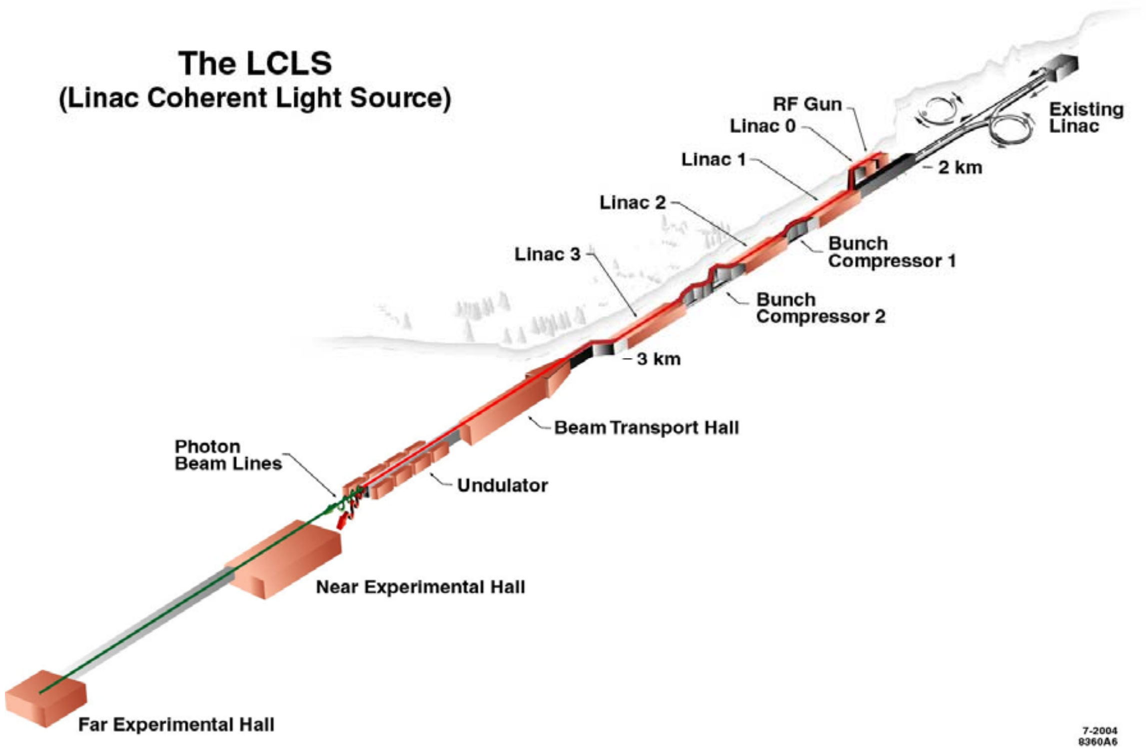
The radiation protection considerations for the LCLS are similar to those encountered at both high-energy electron linacs and synchrotron radiation facilities. The SLAC Radiological Control Manual [1] specifies an annual total effective dose equivalent limit to workers from both internal and external radiation sources of 5 rem. In addition, SLAC maintains an administrative threshold control level of 1.5 rem.

1. Radiation dose criteria used in design of the LCLS radiation safety systems are those required for SLAC facilities.
2. The integrated dose equivalent outside the surface of the shielding barriers must not exceed 1 rem in a year for normal beam operation [1].
3. The integrated dose equivalent to personnel working inside and around the experimental hutch shielding barriers must not exceed 0.1 rem in a year for normal beam operation. [2].
4. The dose equivalent-rate in the event of the Maximum Credible Incident is limited to less than 25 rem/h , and integrated dose equivalent of less than 3 rem [1].
5. The maximum dose equivalent rates in accessible areas at 1 foot from the shielding or barrier should not exceed 400 mrem/h for mis-steering 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.

6. The dose equivalent for the maximally exposed member of the public exposed to ionizing radiation from SLAC produced pathways must be less than or equal to 10 mrem/yr [3]. The dose equivalent at the site boundary from the operation of the LCLS must be a small fraction of that total for normal beam operation.

The 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, main LCLS dump, and interaction with the residual vacuum. A radiation safety system comprised of shielding, Beam Containment System (BCS), Personnel Protection System (PPS) and Hutch Protection System (HPS) [1] has been designed for the LCLS. The issues considered in the design of these systems are described in this section. The specific LCLS systems that have been evaluated by the SLAC Radiation Physics group were the following:

- LCLS Injector
- LINAC
- BSY/LCLS
- Beam Transport Hall (BTH)
- Undulator Hall (UH)
- Electron Dump
- Front End Enclosure (FEE)
- Near Experimental Hall (NEH)
- X-ray Transport Optics Diagnostic (XTOD)
- Far Experimental Hall (FEH)



Nominal Beam Parameters

Injector:	e-	135 MeV,	16 W
LINAC:	e-	15 GeV,	5 kW
MCB:	e-	15 GeV,	150 kW
X-ray:	photon	140 keV (Ec),	2.7 W
FEL:	photon	8.2 keV (1st Harmonic),	0.3 W

5.3.2. Radiation Sources

During machine operation, high energy bremsstrahlung and particle radiation is generated from the interaction of the primary electron beam with protection collimators, beam diagnostic devices, main LCLS dump, and interaction with the residual vacuum.

The radiation initiated in these reactions as well as the forward directed and scattered coherent x-ray and synchrotron radiation are the main sources of radiation that need to be considered in the design of the LCLS shielding. The particle radiations of concern are neutrons and muons. The electron beam will be delivered at energies up to 17 GeV at 1 nC and 120 Hz.

5.3.2.1. Bremsstrahlung from Collimators

Two copper collimators, each 10 cm long and with an internal diameter of 0.2 cm, will be placed up beam of the undulator. The purpose of the first collimator is to reduce the electron beam halo, while the second is designed to intercept any mis-steered beam that could hit and damage the undulator. The first collimator, continuously intercepting about 1% of the beam, will be a constant source of forward-directed bremsstrahlung and muon radiation. The second collimator should interact with the beam only in exceptional cases and is not expected to contribute substantially to the radiation field under normal operating conditions.

Bremsstrahlung radiation produced in the collimators will present a hazard to personnel in downstream experimental areas. Consequently photon stoppers are required as part of the Personnel Protection System. The first of these stoppers, which must be inserted into the beamline when access is allowed in any downstream enclosure, will intercept this bremsstrahlung radiation.

Details of the calculation are given in [5]. For a 1% loss of a 15-GeV, 2-kW electron beam the energy deposition in the PPS stopper ST1 (see Fig. 14.3), which must be inserted into the beamline when access is allowed in Hutch 1, was 17 mW, calculated using the EGS4 code. The energy deposition in the PPS stopper ST3, which must be inserted into the beamline when access is allowed in Hutch 2, was 12 mW [6].

However, bremsstrahlung from collimators is neither the only nor the main source of radiation to be considered for shielding design: other radiation components (bremsstrahlung from profile monitors, neutrons, muons, x-rays) must also be taken into account.

5.3.2.2. Bremsstrahlung from On-Axis Diagnostic X-Ray Stations

The electron beam will be intercepted by monitoring devices at several locations in the on-axis diagnostic x-ray stations along the undulator. There will be 10 or 12 of these stations, but calculations have been made for the one located in the last 10 m section of the undulator. The material is diamond, 0.5 mm thick, but because the beam strikes it at an angle of 45°, the effective thickness traversed is 0.707 mm. For a 15-GeV and 2-kW electron beam the energy deposition in the BCS stopper, which is interlocked with the monitor, was 6.5 W calculated using the EGS4 code [5,6]. If it is assumed that the monitor will be used about 10% of the beam time, this is equivalent to a continuous energy deposition of 650 mW in the BCS stopper.

5.3.2.3. Synchrotron Radiation

The synchrotron x-rays will be absorbed in the BCS or PPS stoppers when they are inserted to the beam. The total power in the LCLS synchrotron spectrum was calculated to be 2.78 W [6]. When the beam line is open, this power will be absorbed in the hutch stopper.

5.3.2.4. Electron Beam Dump

The distance from the front face of the first bending magnet to the front face of the dump will be 28 meters. The distance from the center of the dump to the ground level will be 1.5 meters. The shielding design for the dump was based on this arrangement

5.3.2.5. Gas Bremsstrahlung

Interaction of the electron beam with residual low-pressure gas molecules in the vacuum pipe will give rise to forward-directed gas bremsstrahlung. This type of radiation has been thoroughly investigated at circular storage rings, where the beam current is much more intense. However, at LCLS the straight length over which bremsstrahlung is produced will be much longer (120 m between the dog-leg and the first bending magnet before the electron dump). The residual gas pressure and the electron energy will also be higher.

Radiation levels from the interaction of gas-bremsstrahlung photons generated in the LCLS undulator with a tungsten stopper were calculated using the FLUKA code and compared with results from two analytical methods [7]. The total dose rate at a distance of 1 meter from the stopper was estimated at 6.3 μrem h^{-1}, dominated by secondary photons from the stopper.

5.3.2.6. Muons

Muons produced by electron interactions in the Beam Switchyard and upstream of it are ranged by 55 feet of iron and cannot constitute a concern. Muons can be created in the diagnostic area (by losses upstream of and inside the dog-leg, in the collimators and in the profile monitors); there are other possible muon sources inside the undulator (x-ray intensity monitors) and the electron dump. These muons will be either bent away by magnets downstream of the undulator or shielded by iron shielding located on the top of the electron dump.

5.3.2.7. Neutrons

Photo-neutrons can be generated on the zero-degree line in any object hit by electrons and by bremsstrahlung. Such objects include the electron dump, the transport line to the dump, photon stoppers outside and inside the experimental Halls, and any optical device in the x-ray line. Neutrons generated outside the Near-Field Hall can penetrate to the Hall through the concrete shielding or streaming through the x-ray beam pipe. A preliminary analysis of the neutron radiation levels has been made using the analytical code SHIELD11 [12].

5.3.3. Radiation Safety System

The SLAC Radiation Safety Program is designed to ensure that radiation doses above background received by workers and the public are be 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 and the associated detectors 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 SLAC Radiological Control Manual [2] and the SLAC Guidelines for Operations [13] and Radiation Safety Systems, Technical Basis Document [1].

In addition to shielding (bulk and local), the LCLS radiation protection systems will have Beam Containment System (BCS) and Personnel Protection System (PPS) in the Tunnel, and the Hutch Protection System (HPS) in the beam lines to achieve the designed goals.

The BCS is designed to ensure that beam parameters do not exceed the preset values, and that the beam is delivered to the main dump with minimal loss. The PPS controls entry to the tunnel, ensuring that personnel are excluded from the tunnel during the FFTB beam operation and the HPS control access to the experimental hutches.

5.3.4. Minimum Shielding Requirements

Shielding for the LCLS will conform to the Radiation Safety Systems Technical Basis Document, Chapter 1 Radiological Guidelines for Shielding and Barriers (SLAC-I-720-0A05Z-002). The LCLS design objective is to design to accommodate non-radiological workers (Users) whose annual effective dose equivalent must be maintained below 0.1 rem/yr. SLAC's internal design criteria also requires that under a system failure the effective dose equivalent not exceed 3 rem for a broad beam and 12 rem for a narrow beam, and that under an accident scenario that requires human intervention to turn off the beam 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 will be mitigated to acceptable values through the addition of localized shielding, the use of engineered controls, active electron beam loss monitoring systems. This is a summary of the radiation sources used for shielding calculations:

Radiation Source	Power	Brief Explanation
Single beam dump (SBD)	5 kW	5 kW beam parks on SBD during tuning up beam
e-beam transport line	5 W	5 W could be lost at any point on e- beam transport line.
Tune-up dump	417 W	417 W beam parks on Tune-up dump when tuning the beam.
Gas bremsstrahlung	Negligible	Is negligible because the average e- beam current is low.
Beam loss in dump	30 W	30 W could be lost at any point of the dump line.
Electron beam dump	5 kW	5kW beam parks on the dump during operation
Spontaneous radiation	2.78 W	Spectrum provided by Roman Tatchyn. The average power up to the 180^{th} harmonic is 2.78 W (2.73×10^{14} photons/s). The critical energy is 140 keV. The following beam parameters were used to calculate the spectrum: 14.35 GeV, 0.95 nC/pulse, 120 Hz, e-beam power of 1.6 kW, 4000 periods in undulator (120 meter), K=3.71

Based on these radiation sources the following shielding requirements have been specified:

BTH Head House:
Requirements [5]: 72 to 67 inches concrete on the sides as the distance to the BSY wall increases from 0 m to 63 m.
Non-occupied area on the roof: 43 inches concrete.
Occupied area on the roof: 63 inches concrete.

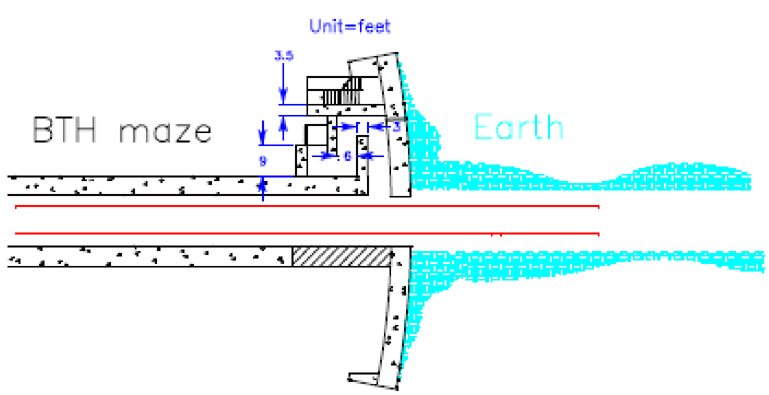
End of the flared sections of BTH Head Hall (endplug):
The shielding requirements for the end-plug are dominated by accident cases. It is assumed that a 15-GeV and 2-kW nominal beam hits the endplug.
Requirements [5] [6]: 7' concrete endplug.

BTH tunnel:
Requirements [5]: 72 inches on the sides.
Requirements for the roof are the same as BTH house.

Service Stations
There are one service station on the roof of BTH Head House and two service stations on the roof of BTH tunnel. The shielding requirements are 63 inches concrete on the roof. Additional concrete needs to be installed on the sides of the stations and on the top of non-occupied area since the service stations have no concrete shielding walls to cover the beam losses upstream or downstream of the stations (Figure 3). It is assumed in the calculations that 5 W could be lost at any point. It is required that 77"-long and 157"-long concrete blocks are placed upstream and downstream of the stations, respectively.

The vent in the concrete roof:
There are three vents located underneath of the service stations inside the BTH roof (Figure 1). The vent open is 20" × 150". To meet the dose rate of 0.5 mrem/hr, additional 10" iron shielding is required above and below the vent.

Maze to BTH tunnel:
A maze is located in the end of BTH tunnel.



Single beam dump (SBD):
Requirements: 9’ long, 0.40” ID, 8” OD, lead collimator downstream of the SBD.

Tune-up stopper:
Requirements: 3’ long, 0.25” ID, 12” OD, lead collimator upstream of the undulator.

e- beam dump:
Requirements:
Above the dump, 2 feet iron + 3 feet concrete, 2 feet concrete tunnel roof, 8’ earth above the roof. The occupied area is on the hill.

Muon shielding:
Requirements:
3’ long toroidal magnetic spoiler is located downstream of the dump magnets. The outside diameter of the spoiler is 24”, the inside diameter is 0.6” including the current winding. (The distance from the front face of the spoiler to the Near Hall is 50 m). A 3’ thick iron muon shield which fills the tunnel is located downstream of the electron dump. The beam hole through the muon shield is 3 cm diameter. (The distance from the front face of the muon shield to the Near Hall is 33 m). 4’ iron and 3’ concrete is used as the up-beam wall of the first Near Hall hutch [18]

Maze to the e- dump and Front End:
Requirements: The maze wall is 2’ concrete.

Near Hall hutch (see Figure 3):
Requirements: 2 feet concrete wall on the north side, 4” iron local shielding after PPS stopper, 3 feet concrete wall down beam, 3 feet concrete on the roof.
3 feet concrete wall on the north side of the reflect mirror tank.

5.3.5. Beam Containment System

The Beam Containment System (BCS) prevents accelerated beams from diverging from the desired channel and detects excessive beam energy or intensity that could cause unacceptable radiation levels. A typical BCS consists of passive mechanical devices such as slits, collimators, magnets, electron beam stoppers, dumps, photon beam stoppers, injection beam stoppers and active devices such as electronic monitors that shut off the beam when out of tolerance conditions are detected. Active electronic devices include average current monitors, burn through monitors, and beam shut off ion chambers. The LCLS will incorporate all of these.

SLAC’s beam containment policy 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 [1]. 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 that are enforced by strict operational requirements. The BCS for the LCLS will use most, if not all, of the FFTB BCS, which is comprised of devices that limit the incoming average beam power to less than the allowed beam power (torroids of current monitors 14 and 15); devices that limit normal beam loss to 1 W (torroids 16 and 17, long ion chambers); protection collimators that ensure that errant beams do not escape containment; and devices that protect collimators, stoppers and dumps (ion chambers and flow switches). The permanent dipole magnets in the beam line that assure that the electron beam reaches the main dump are the final component of the BCS.

5.3.6. Personnel Protection System (PPS) and Hutch Protection System (HPS)

The PPS and HPS are designed to prevent access to experimental areas when beams are present and to prevent beams from entering an area during personnel access. Thus, the PPS and HPS function as access control systems and are based on standard designs at SLAC.

The PPS is composed of beam stoppers, entry module, and emergency shutoff buttons. Entry to the tunnel requires that all three PPS stoppers (D2, ST60 and ST61) be in the IN state. The main entrance to the FFTB tunnel is through a maze in the research yard. It is equipped with the standard access module of an outer door, an inner door, a key bank, an access enunciator panel, door control boxes, search reset boxes, a telephone, and a TV camera. The outer door has an electromagnetic lock and two door-position sensing switches that are used to monitor the status of this door and to activate a relay that permits or prevents a beam. The inner door provides redundancy and has two position sensing switches as well. A similar maze will be added at the entrance to the front end.

The experimental hall shielding, which prevents access to beam areas, will consist of fixed and moveable parts. The experimental hall perimeter walls and central beamline walls are planned to be fixed shielding consisting of appropriate material for the energy spectra of expected radiation. The experimenter hutches may have movable walls to adjust for experimental requirements. The moveable wall configuration will activate the current radiological configuration control system when changing the hutch shielding [13]. The experimental walls will have the capability of adjusting to the different angles of any hutch branch lines. The access control system (PPS and HPS) will be capable of retaining integrity and reliability, while compensating for wall placement.

The HPS will control access to the experimental hutches and will be modeled after existing SSRL HPS. The key parts of the HPS are a keyed access door, photon stopper interlocks, and area security system. The HPS allows either permission for personnel access or for beam to enter the hutch. It contains the logic interlock circuits that govern the sequence of access operations centered on the status of the stoppers. It also captures or releases the hutch door keys, acknowledges completion of a personnel security search, and keys the experiment enclosure on-line or off-line. Access to the hutch is permitted only if all photon stoppers are closed.

For access permission to any experimental hutch, the LCLS HPS will control the operation of photon stoppers in other areas or hutches that are required to be in. Two ion chambers and a burn-through monitor are required to protect each stopper.

5.3.6.1. Stoppers

Two up beam PPS beam stoppers will be required to allow entry into an experimental hutch to make changes that require disruption of the x-ray beam line while the e- beam is being delivered to the undulator and deflected into the dump. The function of these stoppers is to block and absorb any coherent or incoherent γ or X-radiation from the undulator, as well as bremsstrahlung from anywhere in the beam transport system. These stoppers are patterned after an SLC design used in Sector 10 of the SLAC linac and in the PEP-II extraction lines [14]. The design energy is 12-15 GeV and the assumed power for continuous exposure is Pav ~5 kW. The absorbing element in each stopper provides 30 cm copper, or the equivalent in radiation length of other material. The stoppers will be designed to meet the safety criteria.

5.3.6.2. Burn-Through Monitors

A built-in burn-through monitor is located at the depth of shower maximum in each stopper. It consists of a pair of cavities separated by a Cu diaphragm. The first cavity is pressurized with dry N2. Its return line contains a pressure switch with the trip level set to 15 psig. Should excessive beam power be deposited in the stopper block, the diaphragm will perforate, allowing the N2 to escape into the second cavity, which is open to atmospheric conditions on the outside. The pressure switch will interrupt beam delivery within 2-3 linac pulses.

5.3.7. Induced Activity

Personnel exposure from radioactive components in the beam line is of concern mainly around beam dumps, targets, or collimators where the entire beam or a large fraction of the beam is dissipated continuously.

Another source of potential exposure is to personnel working on the undulator after it has been in service for a period of time. Calculations based on methods developed by [15] and on [16] Swanson's (1979) tabulations express the rate of radionuclide production in terms of saturation activity A_s, i.e., the activity, at the instant that the irradiation has stopped, of a target that has been steadily irradiated for a time long compared with the half-life of the produced radionuclides. For these calculations, it was assumed that the permanent magnets are made of natural iron and natural cobalt, 50% each. To calculate the exposure rate, A_s is multiplied by γ, the specific gamma ray constant which gives the exposure rate in air at a fixed distance (1 m) per unit of activity (Ci).

Natural iron is comprised of $_{54}$Fe, $_{56}$Fe, $_{57}$Fe, $_{58}$Fe isotopes. Reactions (γ,n) (γ,2n) (γ,np) (γ,p) (γ,spallation) were considered. The product radionuclides that contribute the largest fraction of the dose are Mn isotopes. Natural cobalt is 100% $_{59}$Co, and the reactions (γ,n)$_{58}$Co, (γ,2n)$_{57}$Co were considered. Reactions (γ,p), (γ,pn), (γ,p2n) (γ,p4n) all lead to stable iron isotopes, and (γ,p3n) leads to Fe with a 5.9 keV x-ray which would be self shielded in the target.

The total exposure rate from an activated magnet immediately after shut-down is conservatively estimated to be 5 mrad hr $_{-1}$ W$_{-1}$ at 1 m. The exposure is dominated by a 0.8 MeV gamma from $_{58}$Co with a half-life of 71 days. With the expected low level of beam losses in the undulator, the activation of the unit and resulting personnel exposure are expected to be very low.

5.3.8. Non-Ionizing Radiation

5.3.8.1. RF Radiation

The LCLS will use radio frequency range energy which when not controlled could have an adverse health effect on personnel near the system. The LCLS will incorporate safety measures to enforce the strict adherence to procedures for installation, testing and the operation of the RF system. RF energy will be contained in wave guides under Ultra High Vacuum (10E-8 torr). A vacuum leak in the wave guide will result in the actuation of a pressure switch interlock which will shutdown the RF producing devices. Running the system under vacuum guards against it being operated with a piece of wave guide missing or an improperly assembled flange joint. Although the most likely cause of RF leakage under operating conditions is where a wave guide joint is loose or undone, it is possible for the system to be gas tight but not RF leak tight. This occurs when flange bolts are not properly tightened and the gasket is not fully compressed. This is avoided by ensuring all bolts are torqued to a predetermined value and RF leak testing after all installations and maintenance activities, and periodically before start up of the system after scheduled shutdowns.

5.3.9. Lasers Radiation

Lasers will be used for alignment and as a drive source for the Photo Cathode Gun. Several lasers will be placed throughout the facility, in the Near Experiment Hall, the Far Experiment Hall and the Central Lab Office Complex. The use of lasers at SLAC is regulated via the ANSI standard whose requirements are contained 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 by the SLAC Laser Safety Officer to energize the injector laser. SLAC also requires Laser Operators to be trained in Laser Safety, so that personnel can identify and categorize laser hazards and understand the required controls.

Protection (protective housings, interlocks, beam stops, eye protection, etc.) appropriate to the classification of the laser under the ANSI standard is required. 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 required in certain cases.

5.4. Electrical Safety

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 will be engineered controls such as termination covers. Work performed on electrical systems will include controls such as de-energization and the use of Lock and Tag procedures.

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

Entry into the accelerator housing will require the complete lock down of all electrical hazards. In some specific cases electrical hazards may be mitigated by the selective use of mechanical barriers that are interlocked to further reduce the risk of exposure to electrical shock. Lock and tag procedures as defined in the SLAC Lock and Tag Program for the Control of Hazardous Energy (Ref. Document ID # SLAC-I-730-0A10Z-001-R0001, dated July 6, 2005. Electrical safety training and Lock and Tag training are provided by SLAC for those personnel who may work on or near potential electrical hazards.

Infrequently it may be necessary to complete work on energized equipment. This is conducted under very limited and controlled conditions, using qualified employees and under the full approval of the appropriate Associate Director.

Special procedures will be used to permit authorized personnel to occupy areas adjacent to energized magnets. These procedures are called RASK, for "Restricted Access Safety Key". Under these procedures, a special RASK authorization form must be completed to obtain a key that enables (turns on the power supply) the electrical power supply for a single magnet, or unique string of magnets to be tested. During this time the emergency-off buttons remain active and will crash off the power supply when activated.

5.5. Hazardous Materials

During the installation and operational phases of the LCLS it is anticipated that a minimal amount of hazardous materials such as paints, epoxy's, 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 contaminants above acceptable levels.

The SLAC Industrial Hygiene Program, which is detailed in the SLAC ES&H Manual, addresses potential hazards to workers from the use of hazardous materials. The program identifies how to evaluate workplace hazards at the earliest stages of the project and implement controls 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 (CH 17, Hazardous Waste Management & CH 40, Hazardous Materials Management) which describes minimum standards to maintain for compliance with Code of Federal Regulations Part 29, 1910.1200.

The UTR or Project Engineer has added responsibilities with respect to the management of hazardous materials. They ensure subcontractor personnel are aware of, and remain in compliance with SLAC's written Hazard Communication Plan, also keeping affected SLAC personnel informed of hazardous material usage and the associated hazards and risk.

5.6. Construction Safety

Construction, which on the LCLS project incorporates demolition, conventional construction and tunneling, is a high risk activity with potentially serious consequence of losses, unless managed judiciously. To that end the project has retained personnel with in-depth experience in both heavy construction and tunneling operations to develop and oversee the implementation of an effective project safety program.

During construction, oversight of subcontractor activities and safety compliance is a line organization responsibility. Although the project has retained a CMGC to coordinate and schedule contracted work the LCLS project management team will oversee the development and implementation of the safety program developed by the CMGC.

Experience to date indicates that communication is the key element to maintaining a "safe" workplace during this active period. The project management personnel will have an active presence on the job site with stop work authority where they identify imminent danger situations. The hazards matrix in Appendix 3 itemizes hazards that may be associated with construction activities, their possible cause(s) and means of mitigation.

Detailed activities and job functions are clearly set forth in the LCLS ISMS Plan and the SLAC Quality Assurance and Compliance Design Assurance and Construction Inspection Procedure (SLAC-I-770-0A22C-001). Responsibilities of project management personnel include, but are not limited to:

- Apprising subcontractors about SLAC and DOE safety criteria prior to construction.
- Informing subcontractors of the hazards routinely found at SLAC.
- Conducting daily inspections of subcontractor construction areas to evaluate the quality of the subcontractor's safety compliance program and quality of work.
- Providing information to SLAC Citizen Safety Committees as required or requested.
- Communicating and resolving safety or quality deficiencies identified by SLAC personnel with the subcontractor.
- Receiving subcontractor accident reports and compiling information for reporting to the DOE.

A project specific site safety plan LCLS Document Number: PMD 1.1-011 titled *LCLS Project Environment, Safety, and Health Plan* was developed for the project based on the safety program of other DOE projects such as the National Ignition Facility and Spallation Neutron Source. There-in are the specific details of the requirements of the CM/GC and their respective contractors regarding safe work.

5.7. Environmental Protection

Constructing the LCLS entails the removal of some of the present magnets and vacuum chambers, utilization of the present electrical distribution system with minor modifications and expansion as required, minor modifications to the Low Conductivity Water (LCW) system and major construction and site work as outlined in Section 2. Removal of materials and the subsequent construction activities will produce small quantities of hazardous, non-hazardous and radioactive waste that needs to be managed through defined channels. Past history indicates that normal operation of the accelerator does not typically produce waste, however, some hardware may have induced radioactivity associated with it from its proximity and time close to the beam. Other components may contain hazardous materials as part of their design, e.g. mineral oil in electrical components, or have radioactive contamination from the LCW system. Core samples of the asphalt, concrete and soil in and around the accelerator housing show no signs of radioactivity, however detectable levels of PCB's and lead have been found. Contaminated excavation debris is sent off-site for disposal in an appropriately classed landfill. All material removed from within the accelerator housing will be surveyed for residual radioactivity or contamination. If none is detected, items will be salvaged for re-use as recyclable scrap material or disposed of as non hazardous waste in an approved off-site landfill. Items that show residual radioactivity or contamination would be stored on site in the Radioactive Material Storage Yard (RAMSY) for future reuse or ultimate disposal. Any hazardous waste would be disposed of in accordance with SLAC procedures and ultimately to a permitted Treatment , Storage and Disposal Facility, under regulations set forth in the Resource, Conservation and Recovery Act (RCRA). Component manufacturing and system installation may also produce hazardous wastes such as used solvent from degreasing baths or spent cutting fluids. These are ongoing operations at SLAC. Disposal of wastes is routine and in full compliance with SLAC's policies on the management of hazardous materials and waste minimization. All activities will be managed to prevent adverse impact on ground water, storm water, and air quality as well as to minimize any ground disturbing activities.

5.7.1. Gases, Vapors, and Mist

Construction activities commonly involve use of engines, asphalt heaters, paints, fuels, fires, chemicals, and other sources that emit gases, vapors, mists, fumes, and smoke capable of adversely affecting air quality. Emitted pollutants can endanger the health of construction personnel, as well as other people, and plant and animal life. The LCLS and SLAC recognize their responsibility to help ensure that noxious fumes, odors, and smoke are eliminated, where feasible, or minimized. To carry out this responsibility, the LCLS will require contractors to identify all anticipated air pollutant emissions, including, but not limited to, vehicle and other combustion equipment exhaust, dust generating activities, organic vapor generating activities (e.g., surface coating, parts cleaning, vehicle refueling, and fuel storage), toxic emissions (e.g., asbestos, benzene, radionuclides), and odor-causing activities (e.g., roofing, asphalt paving). Contractors must also provide:

- Some indication of the scale of such emissions, such as the number of vehicles, gallons of solvent to be used, surface area of exposed soil which may generate dust, amount of asbestos to be removed, etc.

- An indication how they will meet applicable regulations.

- An indication how emissions from each of these sources will be minimized. At a minimum, contractors will be expected to address the following regulatory requirements:

    - All vehicles and construction equipment shall be maintained to remain in compliance with applicable sections of IEP A regulations governing mobile emission sources (35 Illinois Administrative Code (lAC) 240).

- o Any degreaser used at the construction site shall comply with 35 lAC 181183, where applicable.

- o Any architectural coating employed at the site shall contain less than 20% by volume photochemically reactive materials, as required by 35 lAC 215.561.

- o Solvents used for cleaning painting equipment or other surfaces shall be stored in closed containers and disposed of appropriately. Evaporation of solvents as a means of disposal shall not be allowed. The means of storage and disposal of solvents shall result in less than 20% evaporation losses, as required by 35 lAC 215.630.

- o Cutback asphalt shall not be used for paving purposes, except as allowed by 35 lAC 215.563.

5.7.2. Dust

Grading, plowing, grinding, crushing, conveying, dry material mixing, demolition, and traffic on unpaved roads can generate airborne dust, some of which can be expected to have hygienically significant levels of free crystalline silica. The LCLS and SLAC recognize this potential and will help ensure that dust control methods, including applying water to unpaved roads, placing a layer of drain rock and/or wood chips on vehicle use areas and pedestrian paths, using water to wet down demolition items, etc., are used when needed. In addition abrasive blasting will be minimized and carried out only with acceptable agents and controls e.g., vacuum systems, plastic sheet coverings, wet sand, or water sprays. Spoils piles will also be covered (tarp cover) for dust control. Applicable regulations include:

- 35 lAC 212.301, which requires that emitted dust not be visible to the naked eye at the construction site boundary.

- 35 lAC 212.315, which requires covering vehicles transporting dust-producing materials

5.7.3. Burning

Stanford Linear Accelerator Center prohibits open burning.

5.7.4. Water Quality

Placement of concrete, storage and use of liquid chemicals, cleaning of equipment and other surfaces and pumping of groundwater are examples of construction activities that can give rise to water pollution. Contractor is required to provide plans identifying activities that can cause water pollution and their approach to control that effluent. The plans will be expected to provide:

- Some indication of the scale of risks posed by activities, such as the volume of concrete, gallons of chemicals to be stored or used, surface areas of exposed soil which may contribute to erosion, the estimated amount of groundwater to be pumped, etc.

- An indication as to how the release of pollutants to streams or sewers from each of these activities will be prevented.

5.7.5. Drainage

Concrete and mortar mixing, cooling water, dust control spraying, and equipment washing are just a few of the construction operations that use water. Most of these operations use enough water to produce runoff. In sloping areas, the runoff quantity and velocity also may be high enough to pick up sediment, causing erosion when the sediment reaches the main stream, thereby producing muddy, cloudy water. Erosion and sediment damage may also occur from rainfall on graded or excavated areas. To prevent erosion damage and to preserve the water quality in streams, runoff needs to be controlled. Drainage from construction areas, storage yards, and other use areas shall be regulated to prevent erosion and to preserve the water quality in streams. Methods to control this drainage include velocity barriers, baled straw, drainage ditches, and down drains.

5.7.6. Erosion Controls

Erosion control plans and permits shall be in place where practical, prior to the start of earthwork. When the above is not practical, excavation and backfill operations shall not proceed beyond erosion control measures when inclement weather is forecasted, or by more than twenty four (24) hours during fair weather. The contractor(s) shall inspect their work areas prior to the close of business each day to ensure that erosion controls are in place and not damaged from the day's activities.

5.7.7. Accidental Spills

Streams need to be protected from direct or indirect accidental spills of pollutants such as refuse, garbage, cement, concrete, lime, sewage, chemicals, industrial waste, fuels, radioactive substances, oil products, mineral salts, and organic material. Sources of these pollutant spills include: waste water from core drilling; spills and waste from curing compounds; salt,; disposal of concrete curing water; waste from cleanup of mixers and batch trucks; waste from equipment washing; and, use of fuel lubricants and chemicals.

Flammable and/or combustible liquids, hazardous materials, and/or oil(s) brought onto the site in quantities greater than those needed for one day's use must have approval by the Laboratory. The Plan shall require that the Laboratory be notified of the presence of any liquid chemicals or other hazardous material stored or used in quantities greater than 5 gallons. Hazardous liquids or waste materials shall be stored in appropriate storage cabinets or other devices, which provide adequate secondary containment capacity to retain a spill or leak of the largest conceivable volume. All storage containers must be appropriately labeled. Before any wastewater or other liquids are disposed of into sewers, poured on land or dumped into surface streams or ditches, written approval from the Laboratory shall be obtained.

If pollutants are accidentally spilled, the Laboratory emergency response group shall be notified immediately (dial 9-1-1 on any Laboratory phone) so that emergency cleanup operations can begin promptly, reducing the spread and harmful effects of the spill. After notification, the contractor shall immediately identify the materials involved in the spill and obtain whatever information is available regarding the potential hazards identified in the Material Safety Data Sheets (MSDS) or other product literature. The contractor shall then stand by to provide the Laboratory other information that may be required, i.e., construction dikes, removal of contaminated soils, traffic control, etc .. The Laboratory will maintain control of the spill site until the site is certified clean. The contractor shall be responsible for cleaning up the spilled material and decontaminated soil or other surfaces involved. The clean-up procedures shall be reviewed and approved by the Laboratory prior to the start of clean-up activities. The contractor shall pay the cost of cleaning up such a spill.

5.8. Occupational Safety

SLAC strives to keep its workplace free from recognized hazards and promotes ISMS 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 ES&H Manual and numerous other ES&H Documents. Safety requirements are identified through the Work Smart Standard process employed at SLAC and are based on known and identified facility hazards.

5.9. Cryogenic Safety

Liquid nitrogen boil off line and/or portable dewars will be used to service components in both the accelerator and experimental housings. SLAC Guideline for Operations, Chapter 26 clearly mandates requirements for the safe use of liquid nitrogen in accelerator housings. It emphasizes limiting quantities as a primary measure before the use of early warning O2 monitoring and other PPE.

5.10. Maximum Credible Incident (MCI)

The two worst case scenarios typically envisioned prior to the start of construction of accelerator facilities are a construction accident and a beam loss scenario. Within the construction arena the most unfamiliar activity on the LCLS project will be the tunneling operation. Within accelerator operations the MCI scenario is typically an undetected errant beam excursion.

5.10.1. Tunneling Incident

5.10.1.1. Tunneling Accident Scenario

High consequence accident scenarios specific to tunneling are roof collapses, encounters with flammable gases and adequate emergency response.

5.10.1.2. Analysis and Corrective Measures

Background - Experience has shown a weakness in tunneling and construction site safety, in general, is the way potential hazards are identified, analyzed, and mitigated before work is started. The tendency has been to rely on the expertise and experience of the contractor to keep out of trouble, rather than assuring that the project team carefully walks through planned activities with an eye toward "what if's." The root cause of major construction incidents is more often than not inadequate pre-job planning.

Execution - LCLS project emphasis has been to clearly define “Owner” safety program expectations, staffing the project with individuals with strong backgrounds in tunnel and construction safety and establish demanding contractor safety selection criteria. Key to the safety program is the implementation of the requirement for preliminary hazard analysis (PHA) prior to commencement of construction by both the Laboratory and the CM/GC. Also, a Job Safety Analysis (JSA) is necessary prior to commencement of work on any phase of the project.

Training - About 90 percent of all construction injuries occur within the first 12 months that a worker reports to a new worksite, and about 20 percent occur within the first month. Past program assessments and accident investigations indicate that inadequate training is probably the most common root cause. In an underground tunnel assessment at one site, no procedures existed for training workers on tunnel construction equipment. At many sites, there is an emphasis on classroom-style general safety training with too little hands-on exercises. In many instances, defined training performance objectives, coupled with testing or observation to validate training effectiveness, are not found.

The construction contractor needs to ensure that each employee entering a worksite has--through experience, training and certification (if required)--the skill and knowledge necessary to safely perform his or her assigned tasks. A comprehensive safety program at a construction site should include: 1) worksite safety and health orientation; 2) pre-phase training (prior to each phase of construction); and 3) regular "tool box" safety and health meetings at the job site.

Procedures tend to change from job to job. It is common practice for these skills and procedures to be largely learned on-the-job, with a trainee under an experienced worker. The adequacy of the training, as with most on-the-job training, tends to vary with the trainer involved and the amount of time available to learn necessary skills. There is little assurance that new workers will be adequately prepared and experienced workers will not bring any bad habits to the new job.

5.10.1.3. Emergency preparedness

Given the unique challenge of safely evacuating workers from a tunnel setting in the event of fire, cave-in, or injury, a comprehensive emergency preparedness program is an absolute necessity. The program must provide clear procedures, thorough training, and the availability and use of protective equipment.

A number of valuable lessons from the October 30, 1992, N-Tunnel flammable gas flashover accident, at the Nevada Test Site, were learned. Although the contractor had good operational procedures in place, this accident, involving three workers at a tunnel face several hundred feet underground, exposed weaknesses in emergency planning. The investigation of that incident found that the placement of equipment in the tunnel impeded egress. Similarly, air hoses were tied off by the workers to the tunnel walls, impeding egress with protective equipment intact. No provision was made for the positioning of rescue workers and equipment. A co-worker rushed into the tunnel to assist the injured workers without benefit of protective equipment, thereby potentially risking his life.

- **Better accountability for safety**--accountability that does not stop with the subcontractor, but instead flows between the LCLS project, the prime contractor, and the various subcontractors, will strengthening how safe practices are instilled and safe behavior is practiced in the way business is conducted in construction safety.
- **Improving how we conduct construction operations from a safety standpoint**--"conduct of operations" signifies the philosophy and systematic process which guides safety in everyday operations and provides the necessary margins of protection against the inevitable human errors that take place. Conduct of operations encompasses hazard analysis, procedures, training, pre-job planning, and emergency planning. These safety provisions must be both formally defined, trained against, and made an integral part of routine operations.

Coupled with safety-based engineering design and review, good conduct of operations provides what could be called "defense in depth." The approach to safety is one which provides sufficient design and operational safety provisions so that if one or even two safety features fail--a hazard analysis fails to predict flammable gases or a piece of personal protective equipment fails to function--the situation remains recoverable, i.e., other options and backups exist to prevent worker injury or death.

Given the inherent hazards involved in underground construction management attention to identifying and analyzing workplace hazards, developing appropriate procedures, and training workers on safe practices is key to motivating the implementation and exercise of safe work practices.

Specific to tunnel projects, change control is a vulnerability that deserves attention. Any time change is introduced, whether between two work shifts, two different phases of construction, different construction jobs, or even with the entry of new workers, the likelihood of mishaps increases dramatically. Change control is a critical and often overlooked aspect of what, again, can be called conduct of operations. It is also an aspect of work practice that is amenable to improvement through a behavior-based safety approach.

The concept of approaching hazardous construction work -- particularly, the often unconventional work required in tunneling -- from a systems safety standpoint, making sure all the right bases are "touched" -- is key in what is one of the most hazardous occupations in the world.

5.10.2. Beam Excursion Incident

5.10.2.1. Beam Excursion Scenario

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.

5.10.2.2. Analysis and Corrective Measures

The following beam parameters are used in the calculations:

- Electron beam: 15 GeV, 5 kW (unless otherwise specified).
- Maximum theoretical beam power: 17 GeV, 150 kW.

Calculated shielding requirements for the LCLS were based on maximum credible incident (MCI) scenarios for the LCLS facility from the injector through to the experiment stations based on a theoretical maximum beam power of 150 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 well within SLAC MCI scenarios.

Dose consequences of MCI scenarios were calculated for new construction from the BSY through to the experiment stations. As stated in the former Guidance to DOE Order 5480.25 (DOE 1993d), the dose consequences are given in terms of dose rate (0.25 Sv/h [25 rem/h]), indicating the maximum dose for a 1-hour exposure, although the LCLS does not expect any loss scenario to last more than a few pulses. Shielding requirements specified for new LCLS construction was based on the aforementioned calculations in order to contain radiation levels in accessible areas within defined DOE limits.

5.10.2.3. Conclusion

Operating Envelope	Power
SLAC Linear Accelerator Facility current Safety Envelope	2 MW
SLAC Linear Accelerator Facility current Operation Envelope	577 kW
LCLS Safety Envelope	150 kW

LCLS Operation Envelope	5 kW
LCLS Nominal Operating Limit	1.6 kW

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. The LCLS Radiation Physics Group will include LCLS specific MCI scenarios in the final Safety Assessment Document in which the LCLS is included. However, based on the aforementioned energy levels of the beam any beam excursions do not appear to be a problem.

6. Operational Safety Requirements

6.1. Operational Safety

Upon completion of the LCLS, the accelerator will enter a period of commissioning before routine operations commence. A precursor to commissioning will the successful completion of an Accelerator Readiness Review for commissioning as stipulated in DOE Order 420.2B Safety of Accelerator Facilities. Further at SLAC before an accelerator facility can operate, a Beam Authorization Sheet (BAS) must be in place. The BAS establishes the pre-running and running conditions that need to be met before beam can be put into the machine. This would include checking the physical integrity of shielding, testing of Beam Containment Devices, testing and certifying the PPS system, identification of BCS settings, defining/limiting the maximum beam current and energy and specifying any other operating conditions that may affect the safe operation.

The operation of the LCLS, from a safety standpoint, will not differ from present accelerator operations at SLAC. The BAS will be updated to reflect the change in shielding configurations, the addition of active beam containment devices, and other modifications as necessary.

During "run" cycles, maintenance of the beam falls under the responsibility of the Accelerator Operations Manager, whose task is to assure that the facility operates within specified parameters, that accelerator components remain functional and that the facilities and infrastructure of the area are in good repair. During maintenance and shutdown periods, the Accelerator Engineering and Technical Services Manager are responsible for the accelerator and its components and infrastructure, and assure that work is performed in accordance to established ES&H regulations.

6.2. Accelerator Safety Envelope

The Accelerator Safety Order allows for the safety envelope to be based on specific radiation levels or potential maximum exposures derived from extrapolation of empirical data and operational experience. Correspondingly, shielding design and installation will limit integrated radiation dose under normal operating conditions, mis-steering conditions and MCI conditions to those limits specified by SLAC in the Radiation Safety System, Technical Basis Document. This then constitutes the physical limits of the Accelerator Safety Envelope for prompt ionizing radiation at the LCLS facility. Various administrative and engineered systems provide assurance that the safety envelope will not be exceeded.

Accelerator Safety Envelope - Limits for Shielding Design

Condition	Limit	Beam Loss
Normal Operation	1 rem/y	Local + Distributed
Accident	25rem/h, 3rem/even	Maximum Credible Beam

To satisfy the physical limits defined in Table 1, the LCLS has chosen the maximum power capability of the accelerator as the Safety Envelope boundary for all applications. In as much, no operator action can cause the LCLS to exceed the beam power limits of the Safety Envelope.

The nominal operating conditions are:

120 nanoamperes of 14.1 GeV electrons, a beam power of 1692 watts.

Maximum beam power for operations: 5 Kw

Maximum credible incident (MCI) beam power: 150 kW

6.3. Accelerator Operations Envelope.

Assurance of the safe conduct of operations within the boundaries of the safety envelope relies on both engineered safety systems and operational procedures to prevent or mitigate unwarranted conditions.

Procedures are written to provide specific direction for operating systems and equipment during normal, abnormal and emergency conditions.

Engineered safety systems are employed to assure systems operate within their pre-determined parameters or operating ranges.

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8. Approvals

This Preliminary Safety Assessment Document is concurred and approved by:

SLAC LCLS Project Manager

John Galayda

SSRL Division Associate Director

Keith Hodgson

Appendix A - Hazard Identification and Risk Determination Summary

Item	Hazard	Causes	Prevention/ Mitigation Means	Potential Impact	Consequences	Likelihood	Risk
1	Ionizing Radiation Exposure, outside Accelerator Housing	Electron losses during normal operation Interlock failure	Shielding Appropriate operating envelope Access restrictions Training	Personnel exposure	Low	Anticipated	Acceptable
2	Ionizing Radiation Exposure, inside Accelerator Housing	PPS or administrative failure Induced activity in accelerator components	Design, maintenance and routine inspection or radiation safety systems. Fail safe designed hardware systems Forced search procedures Audible & Visual Warnings Entry radiation surveys Training	Personnel exposure	Moderate	Extremely Unlikely	Acceptable

Item	Hazard	Causes	Prevention/ Mitigation Means	Potential Impact	Consequences	Likelihood	Risk
3	Fire, Accelerator Housing	Electrical – via shorting or over heating and insulation breakdown Cable plant fire Planned maintenance Responding to un-planned maintenance	VESDA smoke detection system reporting to the Pyrotronics MXL panel Proper selection of cable plant Fire breaks in cable trays On-site fire department	Complete loss of an LCLS section Partial loss of cable plant Shut down of operations until corrected Personnel Injury	Low	Unlikely	Acceptable
4	Fire, Equipment & Controls Area	Electrical – via shorting or over heating and insulation breakdown Cable plant fire Planned maintenance Responding to un-planned maintenance	Smoke detectors Fire sprinklers Proper selection of cable plant Fire breaks in cable trays On-site fire department Manned full-time during operations	Total loss of control room electronics would shut down operations until corrected Personnel Injury	Low	Unlikely	Acceptable

Item	Hazard	Causes	Prevention/ Mitigation Means	Potential Impact	Consequences	Likelihood	Risk
5	Non-Ionizing Radiation Exposure	Leaking wave-guide flange joints Laser light Visible & UV light	Vacuum wave-guide system interlocked locally through RF Routine surveys of flange joints after interventions PPE Engineered interlocks Training	Personnel exposure	Low	Extremely Unlikely	Acceptable

Item	Hazard	Causes	Prevention/ Mitigation Means	Potential Impact	Consequences	Likelihood	Risk
6	Electrical Hazards	Access to energized systems or components due to failure of interlock systems or failure of administrative system (LOTO)	Installation in accordance with NEC Interlocked cabinets Un-insulated conductors interlocked through PPS Current limiting device and circuit breakers Lock & Tag RASK Training	Personnel exposure	Low	Unlikely	Acceptable

Item	Hazard	Causes	Prevention/ Mitigation Means	Potential Impact	Consequences	Likelihood	Risk
7	Construction Hazards	Construction activities: Major recognized construction hazards are: Falls Electrical Excavation Scaffolding Cranes/Rigging Welding/ Hot Work Confined space	Pre-work hazards analysis Subcontractor kick off meetings Periodic inspections of work-site Daily meetings with ES&H as a line item Implementation of SLAC subcontractor oversight program Permits (Fire, excavation etc.)	Personnel injury Stop activity until safety issues resolved	Low	Unlikely	Acceptable
8	Seismic Hazards and Other NPHs	Earthquake	Implementation of building and structural codes Design standards Field inspections	Personnel injury Property loss	Moderate	Probable	Acceptable

Item	Hazard	Causes	Prevention/ Mitigation Means	Potential Impact	Consequences	Likelihood	Risk
9	Exposure to Hazardous Materials	Exposure to: Solvents, paints, epoxies, oils & greases Compressed gases Cryogens Lead Nuisance dusts	Use of SLAC IH program for monitoring exposed individuals Minimize quantities Engineered fluid transport systems Training	Personnel exposure	Low	Unlikely	Acceptable
10	Thermal Hazards	Use of cryogens Vacuum bakeout	Training PPE	Personnel exposure	Low	Unlikely	Acceptable
11	Mechanical Hazards	Failure of: Vacuum chamber LCW feed & return lines Compressed air and gas lines	Engineered systems designed to accept daily stress cycles Relief valves Training	Personnel exposure	Low	Unlikely	Acceptable

Item	Hazard	Causes	Prevention/ Mitigation Means	Potential Impact	Consequences	Likelihood	Risk
12	Effects on the Environment	Spills Discharges to sanitary or storm drains Noise Air emissions Soil contamination Transformer oil	Training Secondary containment Minimize quantities Management of waste waters from discreet operations (i.e., purging LCW systems, coolant from concrete-saw cutting) Pre-work hazards analysis IH monitoring Dust management	Personnel exposure Release to drain system Air quality	Low	Unlikely	Acceptable

Item	Hazard	Causes	Prevention/ Mitigation Means	Potential Impact	Consequences	Likelihood	Risk
13	Industrial Hazards	Any activity involving personnel	Training Employee Training Assessment Pre-work hazards Analysis Stop work/activity program Periodic work-site inspections Implementation of SLAC ISMS program	Personnel injury or exposure Property loss	Low	Unlikely	Acceptable
14	Material Handling	General construction Excavation Transportation of machine parts.	Training Enforcement of traffic rules and regs. Construction oversight	Personnel injury or exposure Property loss	Low	Unlikely	Acceptable

Item	Hazard	Causes	Prevention/ Mitigation Means	Potential Impact	Consequences	Likelihood	Risk
15	High Magnetic Fields Fringe fields	Routine or unplanned maintenance of undulator system	Training Use of SLAC IH program for monitoring exposed individuals PPE Barriers	Personnel injury or exposure Property loss	Low	Unlikely	Acceptable
16	Oxygen Deficiency	Accumulations of gas in confined spaces	Limit volumes of gasses in accelerator housings and research areas O2 monitoring Equipment/Process review Procedures	Personnel injury or exposure	Low	Unlikely	Acceptable

All of the above hazards have been identified in the SLAC Work Smart Standard set. There are many documents within the ES&H realm that addresses the above listed activities, allowing supervisor to make correct end educated decisions when attempting to mitigate of control hazards or hazardous situations. These documents include, the SLAC ES&H Manual, the SLAC Safety Management System, ES&H bulletins, site specific and activity specific procedures, Employee Training Assessment, etc. LCLS project has a system in place that can address and mitigate hazards on a real time basis.

Appendix B – Fire Safety

B.1 Introduction

Three general features must be present to justify a comparable level of safety to NFPA 101 for the LCLS facility: **compartmentation, awareness, and communication**.

Compartmentation: The long LCLS tunnel complex must be subdivided into a sufficient number of fire compartments to allow occupants time to move away from the fire and reach the outside safely.

Awareness: There must be reliable automatic means to provide early awareness of a fire or smoke condition to a central command post and to LCLS occupants.

Communication: An emergency communications system must exist to alert occupants in neighboring compartments to the existence of a fire and its location. In the absence of prompt and effective communication, occupants in neighboring compartments could unwittingly move towards the fire in response to an evacuation alarm.

This Appendix is focused on Fire Safety Design for the completed facility. However, during construction there certainly is a concern for the control of fires during the tunneling operation. Details of fire protection and Tunnel Emergency Response will be forthcoming with the Turner Site Specific Safety Program. As of the February 2006 review the requirement of the tunneling contractor is compliance with Cal/OSHA Tunnel Safety requirements.

Awareness and communication to allow quick and effective evacuation are particularly important for the LCLS; in the unlikely event of a large, uncontrolled fire in an underground compartment, thermal pressurization of the enclosed space can quickly degrade the ability of fire walls to resist passage of smoke and hot gas. Section V of this report suggests specific measures to address life safety code deficiencies. Measures include fire wall upgrades, smoke detection systems and emergency communication systems.

This report is being issued in preliminary form to allow for discussion with LCLS management and design team members, as well as coordination with the Fire Protection Engineer preparing the Fire Hazard Analysis. The report will be updated and reissued in final form following the 100% design review.

B.2 Conduct, Purpose and Scope of Review

Conduct of Analysis

This review document was prepared by Ralph Kerwin, P.E., Assistant Fire Marshal and Staff Fire Protection Engineer for Stanford Linear Accelerator Center.

Ralph Kerwin, P.E is a qualified fire protection engineer under DOE criteria. For the LCLS project, he is acting under the direction of the SLAC Fire Marshal, Robert Reek, as the LCLS fire protection authority having jurisdiction as of the 60% submittal stage. This report was written in early December, 2005, immediately following the expedited 60% design submittal review. He prepared this report based on the 60% drawing set and design basis provided by Jacobs Engineering. There was insufficient time to prepare this analysis as a part of the 60% review, so it is being offered as a separate study.

Purpose

Although both the NFPA Life Safety Code and the Uniform Building Code are cited in the design basis documents in Title I and Title II, the life safety code design work has been provided entirely in terms of the UBC 1997 model code. DOE Order 420.1 does require general fire protection design in compliance, at minimum, with the appropriate regional model building code. However, additional guidance in DOE Standard 1066-99 requests design for life safety provisions in accordance with NFPA Standard 101 and waives further detailed code basis justification when NFPA 101 is used as the design standard for life safety. It is Ralph Kerwin's judgment as SLAC Fire Protection Authority Having Jurisdiction that a parallel code review under NFPA 101 is required to assure that DOE life safety requirements and preferences are being met for this significant federal facility design.

To support the expedited design schedule, he provided fire protection/life safety review in terms of UBC 1997 compliance for the 60% submittal and stated that in support of the LCLS project I would provide a subsequent detailed review of the design against NPFA 101 criteria no later than December 22, 2005. This preliminary report fulfills that requirement.

The purpose of this review is to determine if the LCLS project 60% design (as modified by design review comments) meets or exceeds the requirements of NFPA 101. A second purpose is to propose a conceptual framework for establishing a comparable level of life safety and to suggest possible compensatory measures for achieving it. Once compensatory measures have been established, an equivalency request will be sent to DOE to document its acceptance of them.

Ralph Kerwin has provided specific engineering suggestions made in this report to provide a comparable level of life safety in my role as staff fire protection engineer. They demonstrate one possible set of acceptable methods of achieving a comparable level of life safety. They also demonstrate the level of fire protection analysis detail that he would need to judge equivalent compliance. Alternative measures which are properly documented by an independent, experienced fire protection engineer are acceptable for consideration; however, schedule constraints may inhibit the solicitation of such measures.

Scope

This report is based on a 60% design submittal and review which was conducted immediately prior to this study. Comments which have already been made within the scope of the 60% review are assumed to be addressed for the purposes of this report.

This report includes construction of major structures that are included within the scope of the current design effort, including the Beam Transfer Hall, Undulator Hall, Beam Dump, Front End Enclosure, Near Experimental Hall, X-Ray Tunnel, Far Experimental Hall and Far Experimental Hall Access Tunnel. This report conforms with the preliminary fire hazard analysis recommendation to ensure that underground facilities conform to NFPA life safety criteria. Since the Central Laboratory and Office Complex are treated in the 60% design as a part of the Near Experimental Hall, it is also included in this review.

The following facilities associated with the LCLS project are <u>not</u> a part of this review:

1. <u>Sector 20</u>: The Linac is being modified to provide laser driven injection of electrons at Sector 20. This facility is under a separate design and construction track and is not included in the scope of this review.

2. <u>MMF</u>: An environmentally controlled Magnet Maintenance Facility is being constructed in Building 081 to calibrate the custom-built Undulator permanent magnets from SLAC for the LCLS. This facility is also under a separate design and construction track and is outside the scope of this review.

3. <u>Off-Site Work</u>: All facilities for off-site work in support of LCLS—including x-ray laser support at LLNL and undulator magnet construction at ANL—is outside the scope of this review.

4. <u>Above-Ground Utility Buildings</u>: Most of the major LCLS structures addressed in this study have above-ground utility buildings associated with them. These single-room buildings tend to be small and pose only conventional life safety considerations. They are sprinklered and provided with emergency lighting and signage. Egress distances are short. In these cases, I consider compliance with the UBC as comparable to compliance with NFPA 101.

Requirements for accessible means of egress have been reviewed only to the extent that they appear in NFPA 101-2003.

No toxic or flammable materials are expected to be present in the tunnel spaces in quantities requiring special treatment. However, asphyxiant gases such as nitrogen or possibly argon will be present. Safety measures for such gases, including the possible use of oxygen deficiency monitors, will be evaluated and included in the Safety Assessment Document. However, I anticipate that the conceptual framework established to address equivalencies for fire life safety would also be effective for analyzing and establishing safety measures for asphyxiant gas release scenarios.

The design basis for an upset condition is a single fire event. Although sprinklers are given credit for controlling most fires, the failure of a sprinkler system (for instance, a closed valve) is considered as a secondary scenario because of the strong life safety effects created by an uncontrolled fire in a confined underground space. In particular, the potential effects of an uncontrolled fire in either the NEH or FEH were informally considered based on the higher potential in these spaces for concentration and continuity of combustibles.

This study is based on code research and careful application of engineering reasoning and judgment. No computer-based fire modeling was deemed necessary or conducted as a part of this study.

B3. Code Basis

DOE Requirements and Guidance

DOE Order 420.1, *Facility Safety,* last updated 11-22-00, provides the contractually enforceable requirements between DOE and SLAC for life safety design basis for the LCLS. Order 420.1 requires that, as a minimum, new construction shall conform to the Model Building Codes applicable for the state or region, supplemented by additional safety requirements associated with specific hazards (420.1, Para. 4). A separate section requires meeting “the applicable building code” and “National Fire Protection Codes and Standards.” (420.1, Para. 4.2.3)

Supporting the Order 420.1 requirements is DOE Standard 1066-99. This document discusses acceptable methods rather than setting mandatory requirements. Alternative methods may also be acceptable. However, such methods must be justified to ensure that there is an adequate level of safety commensurate with the identified hazards (420.1, Para. 4).

STD-1066-99 states that “Life safety provisions should be provided for all facilities in accordance with NFPA Standard 101, “Life Safety Code” (LSC). . . . Compliance with the LSC is considered by DOE to satisfy the exit requirements of the applicable building code and 29CFR1910.” (Para. 10.1)

LCLS Code Basis – UBC vs. NFPA Standard 101

The project designer, Jacobs Engineering, has designed and attempted to justify life safety aspects for all structures in accordance with the UBC 1997 model code. In conventional structures, compliance with UBC life safety standards will often provide a level of safety comparable to that achieved with NFPA 101. Because the unusual features of a large accelerator facility are not well addressed in the UBC requirements, however, precisely identifying code deviations and justifying equivalencies becomes very difficult. (The architect/engineer has not yet done this in a manner satisfactory to the SLAC fire protection authority having jurisdiction.) In contrast, NFPA 101 provides a far more detailed breakdown of life safety requirements specifically geared for special industrial occupancies. This permits a far more precise identification of deficiencies and subsequent justification of equivalencies to assure a comparable level of life safety.

To support the expedited LCLS design schedule, Ralph Kerwin elected to pursue a parallel strategy of allowing the architect/engineer's design effort to proceed on the basis of a UBC life safety design basis while at the same time independently conducting an NFPA 101 design basis review. In cases where compliance is not clear, he proposes alternative measures to provide a comparable level of safety (101, Section 1.4). This report is preliminary and will be finalized following review of the 100% design submittal.

Consideration of NFPA Standard 520, *Subterranean Structures*

Both the DOE 30% contract fire protection reviewer and the fire protection engineer who prepared the preliminary fire hazard analysis have suggested the NFPA 520, *Standard on Subterranean Spaces*, be applied to the underground portions of the LCLS. After careful review of this standard he decided against including it within the scope of this review. While the wording of many portions of the standard read as if it were directly applicable to the LCLS project, there is an underlying sense that it is intended to be applied to the specific situation of buildings constructed within larger caverns. (e.g. NFPA 520-2005, Para. 3.3.133 and 3.3.13.1.1, definitions of "subterranean space" and "common space," respectively.) The text and drawings seem to anticipate a cavern space large enough to anticipate roadways, railways, fire hydrants and parking lots (e.g. Para. 3.3.9, 6.2.2, 6.3.1, 6.3.2, Annex B – particularly Figure B.1(b)). In contrast, LCLS consists of a linear arrangement of tunnels and tunnels modified directly into buildings. The buildings (NEH, FEH) are connected to each other only by a sequence of tunnels designed to accommodate the LCLS beam line. There is no larger "cavern" space within which the LCLS structures are located. The applicability of designating the beam tunnels as "common areas" under NPFA 520 is therefore unclear.

In theory, this issue could be clarified via formal correspondence with the NFPA 520 committee. he contacted two long-time members of the committee to discuss this issue, and their personal opinion was that the LCLS application did **not** fall under the intended scope of the standard (Phone conversation between R. Kerwin, P. Villotti and A. Meister, 12/20/05.) This contact does not represent a formal committee opinion but does cast some doubt on the success of a formal petition for consideration. Given the compressed schedule of the LCLS design and construction process, he does not see such a petition as a feasible alternative in any event. Instead, this report establishes that NFPA 101, used in conjunction with the DOE equivalency process, provides an adequate framework for addressing all LCLS structures

A Conceptual Framework For Addressing Comparable Life Safety

Although specific code compliance deviations can be addressed in a piece-meal fashion by individual compensatory measures or justifications, it is better to have a larger conceptual framework to judge the significance of the various compensatory measures as a whole. Such a framework would look at what is special about the occupancy in question, both in terms of its potential life safety strengths and weaknesses. NFPA 101A, *Guide on Alternative Approaches to Life Safety*, provides one organized method to do this. Unfortunately, NFPA 101A guidance is occupancy specific and does not include industrial occupancies in its current scope. For the LCLS application, a framework must be created from scratch. This can be done by comparing life safety strengths and weaknesses for the LCLS complex. Life safety strengths include: massive non-combustible construction, controlled access by trained personnel, a lack of combustible and flammable liquids and gases, controls on exposed combustible materials, provision of sprinklers, and a linear tunnel layout that lends itself to strong fire compartmentation and remote egress capability. Life safety weaknesses include: lack of frequent exits, obstructions due to machine assemblies (e.g. beam lines), lack of awareness by occupants of conditions in adjoining compartments (occupied or unoccupied) that may form a part of the path of egress, excessive travel distances to reach exterior exits, lack of smoke venting capability or automatic smoke management systems for underground structures, and the relatively limited air volumes and one-dimensional shape of the tunnels (significant when considering smoke filling behavior).

Careful analysis is required to achieve appropriate life safety measures under these conditions without imposing undue cost or functional limitations. The accepted design basis is a single upset (fire) condition. Three general features must be present to justify a comparable level of safety to NFPA: compartmentation, awareness, and communication. Compartmentation means that this long, connected tunnel space must be subdivided into separate fire/smoke compartments to allow occupants time to move away from a fire and reach the outside safely. The current design has done a good job of this through use of two-hour fire barriers. (Additional compartmentation is needed around the Undulator Hall area). Awareness means that there must be sufficient automatic means to provide early awareness of a fire condition to a central command post and to LCLS occupants. Manual detection and notification is not sufficiently reliable. Quick response sprinklers are an excellent start, but a secondary detection system is the best way of achieving equivalency for Life Safety requirements. Standard smoke detectors pose maintenance and operability concerns in the tunnels; high sensitivity aspirated systems pose a cost burden difficult for LCLS management to support under the current construction budget and estimates. (An appropriate alternative for supplementing life safety in long, straight tunnel spaces that will address both maintenance and cost concerns is a linear beam smoke detection system.) Communication means that occupants outside the compartment of fire origin must be made aware of the fire condition. They must also be informed of where the fire is occurring, so that they can move in the opposite direction to exit safely to the outside. In the absence of prompt and effective communication, occupants in neighboring compartments could be unaware of the fire condition which has cut off one of their means of egress, or they could even unwittingly move towards the fire in response to an evacuation alarm.

Measures to compensate for life safety code deficiencies must be judged against these three features to determine if they provide a comparable measure of life safety. The emphasis on awareness and communication to effect quick and effective evacuation is particularly important for the LCLS. The underground portion of the design does not use automatic smoke management systems. In the unlikely event of an uncontrolled fire occurring in an area with a higher combustible loading (for example the NEH sub-basement or FEH), the thermal pressurization effects of the fire will work to compromise the effectiveness of the fire barriers. In addition, the one-dimensional nature of the LCLS tunnel structure will tend to accelerate smoke filling effects in an adjacent compartment once a barrier is breached.

B.4 Findings and Recommendations

Findings

A detailed review of various NFPA 101 requirements is summarized in Appendix A for each of the major LCLS structures examined in this report. Most design features at this 60% submittal stage are at least potentially in compliance with NFPA 101 requirements. (Some design details are lacking and have been noted as part of the 60% review.) The predominant deficiency relates to excessive lengths of travel to exits. Other deficiencies include an excessive common path of travel situation and an instance of "extraneous" utilities penetrating an access tunnel being used as an exit passageway.

General Conclusions

It is Ralph Kerwin's conclusion that most but not all of the 60% design for the LCLS complex meets the design criteria of NFPA 101. The few specific deficiencies can be compensated for within the context of a logical set of criteria. A version of this report making recommendations to address these deficiencies to provide a comparable level of life safety to NFPA 101 was provided to the A/E to be incorporated into the design.

Detailed application of these recommendations is given in Section B below.

Compartmentation: In most locations, sufficient fire compartmentation is achieved in the existing design through the use of 2-hour fire barrier walls. Special attention should be paid to cable tray penetrations to ensure they provide a combination of flexibility and effectiveness while maintaining the 2-hour rating of the wall. (Give consideration to cable transits, particularly for the FEH/Access Tunnel wall. See Recommendation .) Provide additional compartmentation to isolate the Undulator Hall from neighboring tunnel spaces. Make walls 3-hour rated to address associated DOE equipment value separation concerns.

Awareness: Rapid automatic detection of flaming or smoky fires is essential to ensure that occupants in neighboring compartments can exit promptly. Quick-response sprinklers throughout tunnel spaces provide rapid detection of flaming fires as well as suppression capability. However, sprinkler flow switches can fail, or a smoky condition without sufficient heat may not be detected. Linear beam smoke detectors are recommended to provide cost-effective, supplementary detection in most tunnel areas. Two-component systems (sender/receiver) can provide smoke detection for up to 100 m, so there should not be a need for more than two detectors in any given tunnel area. The Front End Enclosure warrants a highly sensitive smoke detection system due to the single exit, and the Near Experimental Hall sub-basement area and FEH hutches are better served with conventional smoke detectors.

Communication: A formal plan is recommended to provide for emergency communication with tunnel and underground building occupants. In beam tunnel areas, where access is controlled to trained personnel, radio communication is recommended as a simple and inexpensive solution already in use in other SLAC tunnels. Procedures must be in place to ensure that information can be promptly reported by radio to any tunnel occupants. An emergency voice communication system is also a possibility. In the Far Experimental Hall, an emergency fire alarm voice system or the use of special graphic annunciators is recommended. No special communication measures are necessary for the Near Experimental Hall, as occupants can exit directly to the outside without passing through adjoining compartments.

Recommendations for Design Changes

Unless noted otherwise, all parenthetical references below refer to NFPA 101-2003.

Non-Compliance: Excessive travel distance in Undulator Hall. (Table 40.2.6)

Suggested Solution: Upgrade Undulator Hall east end wall to provide a 3-hour fire resistance rating to isolate the east end of the Undulator Hall from the Beam Dump area. (This change also addresses a DOE value separation requirement in addition to LSC compliance. See DOE-STD-1066-99, Para. 5.1.2.) Provide linear beam smoke detection in BTH, Undulator Hall and possibly Beam Dump (see Item 2 below).

Non-Compliance: Excessive common path of travel in Front End Enclosure. (Para. 40.2.4.1.2, Table 40.2.5)

Suggested Solution: Provide a high sensitivity smoke detection system for the Front End Enclosure. Upgrade a vestibule doorway in the beam dump corridor to a one-hour fire rating to isolate the Beam Dump Area from the Front End Enclosure and provide beam smoke detection in Beam Dump Area. As an alternative to beam smoke detection and 1-hour isolation, provide high sensitivity smoke detection system in the Beam Dump area as well.

Non-Compliance: After exiting west from the FEH into X-ray Tunnel through 2-hour rated horizontal exit, excessive length of travel through X-Ray Tunnel combined with need to pass through NEH sub-basement workspace to reach NEH exit stair enclosure. (Section 7.2.4, Table 40.2.6)

Suggested Solution: Provide standard smoke detection throughout the sub-basement of the Near Experimental Hall, so that workers in the adjoining utility areas can receive early notification of a fire condition in the NEH sub-basement based on automatic detection. This is necessary because passage through the NEH sub-basement is a key part of the required exit access route of the FEH through the X-Ray Tunnel, and X-Ray Tunnel air is supplied from NEH. Standard smoke detectors are suitable for this application.

Non-Compliance: FEH access tunnel must be used as exit passageway but does not qualify due to presence of extraneous FEH utilities. The wide (about 20 feet) corridor also introduces the future possibility for storage, which is not allowed in an exit passageway. (Para. 7.1.3.2.1(6), Section 7.2.6, Para. 40.2.2.7)

Suggested Solution: (a) Provide strict controls on any exposed combustibles within the FEH access tunnel equivalent to those provided within a plenum space. (b) Provide administrative controls to prevent storage of combustible materials in the access tunnel, (c) Eliminate the 36” x 48” air transfer opening in the FEH/access tunnel wall. Provide manual smoke evacuation through the existing duct system, possibly supplemented by portable air trunk lines. The advantages of manually evacuating smoke more quickly in the aftermath of a fire are outweighed by the serious NFPA 101 deficiency present in having such a large air transfer device in an exit enclosure wall. (d) The need to isolate this critical exit passageway from smoke intrusion from the FEH is particularly important. I recommend the use of a cable transit for cable tray penetrations through the wall. A cable transit provides a seal for multiple individual cables that is highly effective, accommodates future changes in cable number and configuration, and is easily inspectable.

Non-Compliance: Need for early notification of smoke production in FEH egress paths due to excessive lengths of travel. (Table 40.2.6.)

Suggested Solution: Provide linear beam smoke detection systems in FEH access tunnel, in FEH and in X-Ray tunnel. Provide standard smoke detectors in FEH hutches. These smoke detection systems will provide prompt FEH occupants with prompt notification of smoke conditions in these critical access routes.

Non-Compliance: Inability of tunnel workers to know which area is affected by fire in event of a fire alarm may compromise equivalent level of life safety in certain locations, due to long travel distances to reach exterior exits. (Para. Table 40.2.6.)

Suggested Solution: Provide approved NFPA 72 private mode notification for fire alarm signals within utility tunnel areas that would allow for continued radio communications in the event of a fire alarm, so that workers in the tunnel could be told of the approximate location of the alarm prior to deciding on an evacuation direction. As an alternative, provide pre-recorded voice messaging throughout the tunnel areas to identify the fire location throughout the tunnel complex.

Non-Compliance: Inability of FEH occupants to know which area is affected by fire in event of a fire alarm may compromise equivalent level of life safety due to long travel lengths to exterior exits. (Para. Table 40.2.6.)

Suggested Solution: Provide an emergency voice alarm system or other approved means for occupants of the Far Experimental Hall to positively identify the building or tunnel location of a fire alarm prior to evacuation.

Recommendations for Requests for Equivalency

Ralph Kerwin has recommended that the following non-compliant conditions could be addressed through a formal set of equivalency requests. Application of the design measures listed above would be used to justify them. Parenthetical citations refer to NFPA 101-2003 unless otherwise noted.

1. Acceptance of excessive common path of travel for Front End Enclosure (subject to provision of high sensitivity smoke detection). (Table 40.2.5.)

2. Acceptance of certain FEH utilities being routed through the FEH access tunnel, while still treating the tunnel as an exit enclosure for code purposes (subject to control of exposed combustibles and installation of beam-type smoke detection in adjacent tunnels and an approved alarm location identification measure in the FEH. Also subject to removal of large air transfer opening for manual smoke purge). (Para. 7.1.3.2.1(6), Para. 7.1.3.2.3.)

3. Acceptance of excessive exit distance through X-Ray tunnel for FEH occupants to exit through secondary exit. (Based on presence of sprinklers and horizontal exits. Also subject to control of combustibles in egress corridors, beam smoke detection in X-Ray tunnel, and fire location notification.) (Table 40.2.6.)

B4. Discussion

CLOC Design Basis

An opportunity for significant construction cost savings could be realized in the CLOC by using NFPA 101 as the basis for life safety design in lieu of, rather than in addition to, UBC life safety code requirements. For sprinklered buildings, the UBC requires more expensive requirements than NFPA 101 for both three-story atriums and fire barrier walls. Adoption of NFPA 101 as the sole design basis for the CLOC, in conjunction with minor egress modifications, could result in ability of LCLS management to delete the entire atrium smoke removal system, most rated fire walls in the building and most fire/smoke dampers and their associated controls. The current design approach is acceptable, but the SLAC Fire Marshal would also accept the revised approach.

Assumptions Requiring Further Confirmation

The following assumptions require confirmation or correction prior to final revision of this report following the 100% design submittal:

Access to tunnel areas will be controlled.

Workers in utility tunnel areas will be in constant radio contact with a central location while in the tunnel areas and will be trained to confirm location of a fire signal prior to determining the appropriate direction for evacuation.

Access to the FEH area will be controlled.

Occupants of the FEH area will receive training regarding response to an evacuation signal.

Temporary storage of materials along the sides of the FEH

Temporary storage of any materials along the sides of the FEH access tunnel will be either prohibited or strictly controlled through a predetermined mechanism such as a permit procedure using predetermined criteria.

Presence and Use of Hazardous Materials

The presence and use of hazardous materials within all structures addressed in this review shall be strictly controlled to avoid the need for either control areas or H occupancy designations. The presence of asphyxiant gases such as nitrogen and possibly argon are anticipated in the tunnel spaces and should be carefully analyzed for safety.

B.5 Reference to Appendices

The following two sections contains a detailed summary of the life safety characteristics of the various fire compartments that make up the LCLS tunnel complex and an analysis of exiting conditions for occupants of the Far Experimental Hall based on various fire scenarios with the sprinklers considered as inoperative. These have been included as the Life Safety Code deviations in exiting from the FEH are considered to be most challenging due to the travel distance to the exterior through both FEH exit paths, and because neither exit path fully complies with NFPA 101 egress requirements.

NFPA 101 Code Compliance Review

The Code Review proceeds through the tunnel from east to west, structure by structure: Beam Transfer Hall, Undulator Hall, NEH, X-Ray Hall, FEH, FEH Utility and Egress Corridor. Conventional features such as width of egress path that are obviously far in excess of requirements are omitted for brevity. For the sake of clarity, the CLOC is addressed last.

Beam Transfer Hall

Applicable Code: NFPA 101-2003

Occupancy: Special Industrial

Description: The BTH is a cut-and-cover concrete tunnel measuring 14 feet in interior width and 10 feet in interior height. Its primary purpose is to serve as a conduit for the electron beam line generated by the Linac. Contents are considered low to ordinary hazard. Combustibles consist primarily of power and communications cables located in two separate cable trays that run the length of the enclosure. Cable jacketing for both power and telecommunications will be rated for low flame spread and smoke production. [*Details to be confirmed for final report*.] Only power wiring directly supporting the LCLS machine will be exposed. All infrastructure wiring (lighting, receptacles, etc.) will be in conduit. No flammable or combustible liquids or gasses will be present in the BTH unless brought in limited quantities for specific maintenance operations during shutdown periods. The BTH is unoccupied while the LCLS machine is in operation, and routine occupancy is not expected during shutdown periods.
Concentration of combustible materials is expected to be low and concentration to be sparse. [*Details to be confirmed for final report*.]

Means of Egress: Egress is limited to two labyrinth exits, one at the BTH head house on the west end of the BTH and the other at the Undulator Hall interface at the east end of the BTH. Both labyrinth exits lead directly to the exterior. The total exit to exit distance, including travel through the labyrinths, is 814 feet. A person in the tunnel mid-way between the exits would thus have the maximum travel distance of 407 feet in either direction. This is considered to meet the total allowable exit distance of 400 feet (NFPA 101-2003, Para. 40.2.6) within an acceptable tolerance. Occupancy loading is considered to be defined as the maximum probable number of workers present in the tunnels during equipment shutdown periods (101, Table 7.3.1.2). During shutdown periods, personnel will be present in the BTH infrequently and solely for purposes of non-routine inspection, repair, maintenance and equipment upgrade. (Charrette I Report, p. A-15) This egress path in this space is considered industrial equipment access. Minimum allowable egress width for this use is 22 inches (101, Table 40.2.5.2.1). This width is greatly exceeded in the design. As initially built, there will be only one beam line on the south side of the tunnel. Since both exits are to the north, this will not pose an egress impediment. The beam line is located approximately 60 inches above floor level and "floats" on metal stands placed no closer than six feet apart. Access to the south side of the beam line will be achieved by ducking under the beam line. Once the second beamline is installed (in perhaps an additional five years), the walkway down the tunnel will be between the beam lines. Workers will duck under the north beam line to go into and out of the tunnel labyrinths. This situation will conflict with NPFA 101 egress requirements for an 80-inch minimum headroom allowance. (101, Table 40.2.5.2.1)

Illumination of Means of Egress: Minimum illumination for floors and walking surfaces shall be at least 10.8 lux (1 ft-candle), measured at the floor (101, 7.8.1.3). Illumination shall be arranged so that failure of any single lighting unit does not result in illumination less than 2.2 lux (0.2 ft-candle) in any specific location (7.8.1.4).

Emergency Lighting: For purposes of emergency lighting requirements, the BTH is considered to be subject a normally unoccupied space. It will be entered only for special purpose (non-routine) repair or maintenance activities. For consistency, LCLS has elected to treat the BTH as an intermittently occupied space for the purposes of life safety egress design. Emergency lighting is required (40.2.9.1, 7.9.1.1(2), 11.7.3.5). It shall be provided for a period of at least 90 minutes. Initial average illumination shall be at least 10.8 lux (1 ft-candle), declining to no less than 6.5 lux (0.6 ft-candle) at 90 minutes. Spot illumination values at any point shall be no less than $1/10^{th}$ of average values (7.9.2.1).

Marking of Means of Egress: Labyrinth exits shall be marked by an approved sign readily visible from either direction of exit access (40.2.10, 7.10.1.2) Requirements for sign placement every 100 feet are deemed to be non-applicable for this occupancy (7.10.1.5.2). Signs shall be mounted within the immediate vicinity of the labyrinth exits and no more than 80 inches above them. The signs shall include directional indicators (7.10.2). Photo luminescent signs are allowed in lieu of LED signs, provided that they are directly illuminated by emergency lighting at a minimum of 54 lux (5 ft-candles) at the illuminated surface (7.10.4, 7.10.5.1, 7.10.6.3, 7.10.8.1.2, AHJ ruling).

Protection from Hazards: Activation of the sprinkler system shall initiate the building fire alarm system (40.3.2.3). This feature is present in the design.

Interior Finish: Interior finish materials must be rated as Class A, B or C (40.3.3.2). This feature is present in the design.

Detection, Alarm and Communications Systems: A fire alarm system shall be provided. All requirements of Section 40.3.4 have been met by this design submittal.

Extinguishment Requirements: Sprinklers shall be provided. This is a DOE requirement as well as an NFPA 101 requirement (DOE-STD-1066-99, Para. 5.3.1; NFPA 101-2003, Para. 11.7.3.4).

Building Services: The BTH has air input of about 5,700 cfm from the east and west ends. A total of 11,350 cfm exhausts through the roof at the center of the Hall. Provide ventilation in compliance with NFPA 90A. Compliance with UMC requirements is deemed to satisfy NFPA 90A for the purposes of this installation, since the applicable requirements are at least as stringent. (Note: Ventilation is provided at over six air changes per hour under manual purge conditions.)

Undulator Hall

Applicable Code: NFPA 101-2003

Occupancy: Special Industrial

Description: The Undulator Hall (UH) is an underground, arched-roof concrete tunnel measuring 18’-9” in interior width and 14 feet in interior height at the peak of the arch. Its primary purpose is to serve as a conduit for the electron beam line generated by the Linac. Combustibles consist primarily of power and communications cables located in two separate cable trays that run the length of the enclosure. Only power wiring directly supporting the LCLS machine and data communications wiring will be exposed. All exposed cable jacketing will be fire and smoke-rated. [*Details to be confirmed for final report*.] All infrastructure wiring (lighting, receptacles, etc.) will be in conduit. No flammable or combustible liquids or gasses will be present in the UH unless brought in limited and controlled quantities for specific maintenance or repair operations during shutdown periods. With the exception of exposed cable in the two cable trays, concentration of combustible materials is expected to be low and continuity to be sparse. [*Details to be confirmed for final report*.]

Means of Egress: Egress is limited to a horizontal exit into the BTH on the west end and a labyrinth exit into the Near Experimental Hall (NEH) on the east end. The entrance into the NEH also constitutes a horizontal exit. The use of two horizontal exits for this space is addressed in an equivalency request.. The total exit to exit distance, including travel through the east labyrinths, is 840 feet. This includes 32 feet of travel within non-rated vestibules leading to the horizontal exits. A person in the tunnel mid-way between the exits would thus have the maximum travel distance of 420 feet in either direction to a horizontal exit door. This is considered to meet the total allowable exit distance of 400 feet (NFPA 101-2003, Para. 40.2.6) within an acceptable tolerance. Occupancy loading is considered to be defined as the maximum probable number of workers present in the tunnels during equipment shutdown periods (101, Table 7.3.1.2). According to Charrette notes (Charrette I Report, A-18), occupancy in this maintenance-intensive area of the LCLS will consist of 10 to 20 people on an intermittent basis. Minimum egress width for this occupancy is 22 inches (101, Table 40.2.5.2.1). The design exceeds this width.

Illumination of Means of Egress: Minimum illumination for floors and walking surfaces shall be at least 10.8 lux (1 ft-candle), measured at the floor (101, 7.8.1.3). Illumination shall be arranged so that failure of any single lighting unit does not result in illumination less than 2.2 lux (0.2 ft-candle) in any specific location (7.8.1.4).

Emergency Lighting: For purposes of emergency lighting requirements, the UH is not subject to routine human habitation and is not required to have emergency lighting. However, by authority having jurisdiction ruling, emergency lighting is required under NFPA 101 guidelines. (40.2.9.1, 7.9.1.1(2), 11.7.3.5). It shall be provided for a period of at least 90 minutes. Initial average illumination shall be at least 10.8 lux (1 ft-candle), declining to no less than 6.5 lux (0.6 ft-candle) at 90 minutes. Spot illumination values at any point shall be no less than $1/10^{th}$ of average values (7.9.2.1).

Marking of Means of Egress: Doors and labyrinth entrances leading directly to exits shall be marked by an approved readily visible sign (40.2.10, 7.10.1.2) Requirements for sign placement every 100 feet are deemed to be non-applicable for this occupancy, since there are only two possible directions of travel in the tunnel and either direction leads to an exit (7.10.1.5.2). Signs shall be mounted within the immediate vicinity of the exit doors and exit access doors and no more than 80 inches above them. For side entrances such as labyrinth exits, the signs shall include directional indicators (7.10.2). Photo luminescent signs are allowed in lieu of LED signs, provided that they are directly illuminated by emergency lighting at a minimum of 54 lux (5 ft-candles) at the illuminated surface (7.10.4, 7.10.5.1, 7.10.6.3, 7.10.8.1.2, AHJ ruling).

Protection from Hazards: Activation of the sprinkler system shall initiate the building fire alarm system (40.3.2.3). This feature is present in the design.

Interior Finish: Interior finish materials must be rated as Class A, B or C (40.3.3.2). This feature is present in the design.

Detection, Alarm and Communications Systems: A fire alarm system shall be provided. All requirements of Section 40.3.4 have been met by this design submittal.

Extinguishment Requirements: Sprinklers shall be provided. This is a DOE requirement as well as an NFPA 101 requirement (DOE-STD-1066-99, Para. 5.3.1; NFPA 101-2003, Para. 11.7.3.4) Sprinklers have been provided. In addition, Class I fire standpipe stations are to be provided per NFPA 14 guidance per AHJ requirement. Distance between stations to not exceed 300 feet.

Building Services: Tight temperature and humidity controls are maintained in the UH. Air in the UH flows from a plenum at the west wall to a plenum at the east wall. Air flow is 20,000 cfm, only 1,000 cfm of which is fresh air on any given pass. Provide ventilation in compliance with NFPA 90A. Compliance with UMC requirements is deemed to satisfy NFPA 90A for the purposes of this installation, since the applicable requirements are at least as stringent.

Beam Dump and Front End Enclosure

Applicable Code: NFPA 101-2003

Occupancy: Special Industrial

Description: The Beam Dump(BD) and Front End Enclosure (FEE) are placed between the Undulator Hall and Near Experimental Hall. They are adjoining, underground, arched-roof concrete chambers, 120 feet long (Beam Dump) and 112 feet long (FEE) and measuring 18'-9" in interior width and 14 feet in interior height at the peak of the arch. The primary purpose of the FEE is to serve as a conduit for the x-ray laser beam line generated in the Undulator Hall, once the accompanying pulses of electrons have been stripped out in the Beam Dump. There is a substantial concrete barrier between the Beam Dump and the FEE. They share a common vestibule from which one can access either space through separate labyrinth entrances or the Near Experimental Hall through a 2-hour horizontal exit. The Beam Dump has remote horizontal exits through both the Undulator Hall and the NEH. Its single egress labyrinth shares a common UH labyrinth that leads through a horizontal exit into the Near Experimental Hall. The labyrinth entrance passes both pits and ramps. *[Details of exiting in vicinity of beam dump pt and floor ramp to be confirmed in final report. Unresolved issue at 60% design stage*.]

Combustibles consist primarily of power and communications cables located in two separate cable trays that run through the enclosure, and beam-bending electromagnets and their associated controls. [*Combustible loading details to be confirmed in final report.*]

An alcove in the FEE labyrinth also contains power distribution equipment, including electric panels and two 45 kVA transformers. Only power wiring directly supporting the LCLS machine and data communications wiring will be exposed. Exposed cable jacketing will be fire and smoke rated. [*Details to be confirmed in final report*.] All infrastructure wiring (lighting, receptacles, etc.) will be in conduit. No flammable or combustible liquids or gasses will be present in the FEE unless brought in limited and controlled quantities for specific maintenance or repair operations during shutdown periods. The FEE is unoccupied while the LCLS machine is in operation. During shutdown periods, personnel will be present in the FEE solely for purposes of repair and maintenance.

Means of Egress: Egress from the chamber itself is limited to a single labyrinth exit from the north side. The labyrinth leads to a common vestibule from which an occupant can exit east through a horizontal exit into the Near Experimental Hall (NEH) or proceed west through a second labyrinth into the Beam Dump area. The common path of travel distance from the FEE is 160 feet. This is 60 feet in excess of the common path of travel allowed by NFPA 101 for a special industrial occupancy (101, Table 40.2.5). This deficiency is to be addressed through compensatory measures (see Recommendations). The occupancy of the FEE is considered to be the same group of people maintaining the Undulator Hall. According to Charrette notes, this will be a group of 10 to 20 people.

Illumination of Means of Egress: Minimum illumination for floors and walking surfaces shall be at least 10.8 lux (1 ft-candle), measured at the floor (101, 7.8.1.3). Illumination shall be arranged so that failure of any single lighting unit does not result in illumination less than 2.2 lux (0.2 ft-candle) in any specific location (7.8.1.4).

Emergency Lighting: For purposes of emergency lighting requirements, the UH is subject to intermittent rather than routine human. Emergency lighting is required under NFPA 101 guidelines. (40.2.9.1, 7.9.1.1(2), 11.7.3.5). It shall be provided for a period of at least 90 minutes. Initial average illumination shall be at least 10.8 lux (1 ft-candle), declining to no less than 6.5 lux (0.6 ft-candle) at 90 minutes. Spot illumination values at any point shall be no less than 1/10th of average values (7.9.2.1).

Marking of Means of Egress: Doors and labyrinth entrances leading directly to exits shall be marked by an approved readily visible sign (40.2.10, 7.10.1.2) Requirements for sign placement every 100 feet are deemed to be non-applicable for this occupancy, since there are only two possible directions of travel in the tunnel and either direction leads to an exit (7.10.1.5.2). Signs shall be mounted within the immediate vicinity of the exit doors and exit access doors and no more than 80 inches above them. For side entrances such as labyrinth exits, the signs shall include directional indicators (7.10.2). Photo luminescent signs are allowed in lieu of LED signs, provided that they are directly illuminated by emergency lighting at a minimum of 54 lux (5 ft-candles) at the illuminated surface (7.10.4, 7.10.5.1, 7.10.6.3, 7.10.8.1.2, AHJ ruling).

Protection from Hazards: Activation of the sprinkler system shall initiate the building fire alarm system (40.3.2.3). This feature is present in the design.

Interior Finish: Interior finish materials must be rated as Class A, B or C (40.3.3.2). This feature is present in the design.

Detection, Alarm and Communications Systems: A fire alarm system shall be provided. All requirements of Section 40.3.4 have been met by this design submittal.

Extinguishment Requirements: Sprinklers shall be provided. This is a DOE requirement as well as an NFPA 101 requirement (DOE-STD-1066-99, Para. 5.3.1; NFPA 101-2003, Para. 11.7.3.4) Sprinklers have been provided. In addition, Class I fire standpipe stations are to be provided per NFPA 14 guidance per AHJ requirement. Distance between stations to not exceed 300 feet.

Building Services: Air for the BD and FEE are provided from a 6,00 cfm air handler located in the NEH. A total of 2,210 cfm of fresh air is provided on each pass. The BD receives 1300 cfm while the FEE receives 5,200 cfm. Provide ventilation in compliance with NFPA 90A. Compliance with UBC and MC requirements is deemed to satisfy NFPA 90A for the purposes of this installation, since the applicable requirements are at least as stringent.

Near Experimental Hall

Applicable Code: NFPA 101-2003

Occupancy: Mixed -- Special Industrial in Sub-Basement and Business in Basement

Description: The Near Experimental Hall sub-basement is an integral part of the LCLS tunnel structure. However, the building as a whole is neither an underground structure nor a windowless structure by NPFA 101 criteria. For building code purposes, the NEH is also part of the same building as the CLOC. However, since the two buildings portions do not overlap vertically, they are treated separately in this report. The CLOC and its horizontal interface to the NEH are addressed in the last portion of this report section. The "sub-basement" (actually the basement) of the NEH is categorized as a special industrial occupancy due to the presence of the beam lines and experimental hutches. The "basement" (actually the first floor) is considered to be a general purpose industrial occupancy. The elevator and stairway access lobby on top of the terrace roof is considered to be business occupancy. The experimental hutches in the sub-basement are not designed to accommodate hazardous materials above amounts that would require an "H" occupancy classification under the UBC.

Means of Egress: According to Charrette, the NEH sub-basement level will be occupied by a staff of 10 to 20 people. Each experimental hutch will have 4 people per shift, present 24/7. In addition, three to five tech support personnel will be present on an intermittent basis. (Charrette Report, p. A-26) Occupancy for the basement level is based on Table 7.3.1.2 occupant load factors. These are quite comparable to the load factors used by the 1997 UBC. Because the NEH sits on a hill, one of the two remote egress stairwells exits at the "basement" level while the second exits at the "terrace" level above the NEH roof. The egress arrangements are satisfactory. Discharge to the roof is approved by the authority having jurisdiction. (101, Para. 7.7.6)

Illumination of Means of Egress: Minimum illumination for floors and walking surfaces shall be at least 10.8 lux (1 ft-candle), measured at the floor (101, 7.8.1.3). Illumination shall be arranged so that failure of any single lighting unit does not result in illumination less than 2.2 lux (0.2 ft-candles) in any specific location (7.8.1.4).

Emergency Lighting: This space is routinely used for egress and ingress for the FEH. Emergency lighting is required (40.2.9.1, 7.9.1.1(2), 11.7.3.5). It shall be provided for a period of at least 90 minutes. Initial average illumination shall be at least 10.8 lux (1 ft-candle), declining to no less than 6.5 lux (0.6 ft-candle) at 90 minutes. Spot illumination values at any point shall be no less than $1/10^{th}$ of average values (7.9.2.1)

Marking of Means of Egress: Exit signage is required above exit doors, and as required in common areas to provide visibility from any point and direction within the common areas. Photo luminescent signs are allowed in lieu of LED signs, provided that they are directly illuminated by emergency lighting at a minimum of 54 lux (5 ft-candles) at the illuminated surface (7.10.4, 7.10.5.1, 7.10.6.3, 7.10.8.1.2, AHJ ruling).

Protection from Hazards: Activation of the sprinkler system shall initiate the building fire alarm system (40.3.2.3). This feature is present in the design.

Interior Finish: Interior wall and ceiling finish shall be Class A or B (101, 7.1.4.1). Interior floor finish shall be no less than Class II (101, 7.1.4.2).

Detection, Alarm and Communications Systems: A fire alarm system shall be provided. All requirements of Section 40.3.4 have been met by this design submittal.

Extinguishment Requirements: Sprinklers shall be provided. This is a DOE requirement as well as an NFPA 101 requirement (DOE-STD-1066-99, Para. 5.3.1; NFPA 101-2003, Para. 11.7.3.4) Sprinklers have been provided. In addition, Class I fire standpipe stations are to be provided per NFPA 14 guidance per AHJ requirement. For the purposes of the NEH, this requires a standpipe station at the entrance to the UH/Beam Dump/FEE vestibule and another at the entrance to the X-Ray tunnel.

Building Services: The NEH air supply provides about 44,000 cfm of air throughout the NEH. About 15,000 cfm is makeup air from the outside. Approximately 6,900 cfm is discharged into the X-Ray Hall after passing through NEH sub-basement spaces. Provide ventilation arrangements in compliance with NFPA 90A. Compliance with UMC requirements is deemed to satisfy NFPA 90A for the purposes of this installation, since the applicable requirements are at least as stringent. Certain HVAC penetrations in the exit enclosure assembly separating this corridor from the FEH are not in compliance with NFPA 101 requirements. These penetrations will be addressed in an equivalency request being prepared in parallel with this preliminary life safety review.

X-Ray Tunnel

Applicable Code: NFPA 101-2003

Occupancy: Special Industrial

Description: The X-Ray Hall is an underground, arched-roof concrete tunnel measuring 18'-9" in interior width and 14 feet in interior height at the peak of the arch. Its primary purpose is to serve as a conduit for communicating the x-ray laser beam line generated by LCLS to the Far Experimental Hall. Exposed combustibles in this space are minimal and sparse and consist primarily of power and for communications cables located in two separate cable trays that run the length of the enclosure. In the absence of materials introduced strictly for maintenance purposes, and with the exception of the two elevated cable trays, I would consider the contents of this occupancy to be low hazard under the definition of 101, Para. 6.2.2.2, "those of such low combustibility that no self-propagating fire therein can occur."

The power tray runs 18 inches above the communications tray. Only power wiring directly supporting the LCLS machine and data communications wiring will be exposed. Exposed cable jacketing will be fire and smoke rated. [*Details to be provided in final report*.] All infrastructure wiring (lighting, receptacles, etc.) will be in conduit. Three electrical panels (two 120 V and one 480 V) and a 45 kVA dry transformer border a 4-foot wide egress path on the north side of the x-ray tunnel. No flammable or combustible liquids or gasses will be present in the X-Ray Hall unless introduced in limited and controlled quantities for specific maintenance or repair operations during shutdown periods. The X-Ray Hall is unoccupied while the LCLS machine is in operation. During shutdown periods, personnel will be present in the X-Ray Hall solely for purposes of repair and maintenance. In the event of a fire in the Far Experimental Hall (FEH), the X-Ray Hall will serve as a second means of egress from the FEH. See the FEH review below for further discussion.

Means of Egress: Egress is limited to two horizontal exits on the east and west ends of the X-Ray Hall. The use of two horizontal exits for this space is comparable to that for the Undulator Hall and is addressed in an equivalency request being written in parallel with this report. The total exit to exit distance is 640 feet. A worker in the tunnel mid-way between the exits would thus have the maximum travel distance of 320 feet in either direction to a horizontal exit door. This is meets the total allowable exit distance of 400 feet (NFPA 101-2003, Para. 40.2.6). Occupancy loading is considered to be defined as the maximum probable number of workers present in the tunnel during equipment shutdown periods (101, Table 7.3.1.2). There will be semi-routine occupancy of the X-Ray Hall during beam shutdown periods for purposes of inspection, maintenance, repair and adjustment.

Illumination of Means of Egress: Minimum illumination for floors and walking surfaces shall be at least 10.8 lux (1 ft-candle), measured at the floor (101, 7.8.1.3). Illumination shall be arranged so that failure of any single lighting unit does not result in illumination less than 2.2 lux (0.2 ft-candles) in any specific location (7.8.1.4).

Emergency Lighting: The X-Ray Hall is subject to periodic occupancy. It also forms an egress path from the FEH and is thus required by the authority having jurisdiction ruling, emergency lighting complying with NFPA 101 guidelines. (40.2.9.1, 7.9.1.1(2), 11.7.3.5). Emergency lighting shall be provided for a period of at least 90 minutes. Initial average illumination shall be at least 10.8 lux (1 ft-candle), declining to no less than 6.5 lux (0.6 ft-candle) at 90 minutes. Spot illumination values at any point shall be no less than $1/10^{th}$ of average values (7.9.2.1).

Marking of Means of Egress: Exit doors shall be marked by an approved readily visible sign (40.2.10, 7.10.1.2) Requirements for sign placement every 100 feet are deemed to be non-applicable for this occupancy, since there are only two possible directions of travel in the tunnel and either direction leads to an exit (7.10.1.5.2). Signs shall be mounted within the immediate vicinity of the exit doors and exit access doors and no more than 80 inches above them. For side entrances such as the east exit, the signs shall include directional indicators (7.10.2). Photo luminescent signs are allowed in lieu of LED signs, provided that they are directly illuminated by emergency lighting at a minimum of 54 lux (5 ft-candles) at the illuminated surface (7.10.4, 7.10.5.1, 7.10.6.3, 7.10.8.1.2, AHJ ruling).

Protection from Hazards: Activation of the sprinkler system by means of heat or smoke detection shall initiate the building fire alarm system (40.3.2.3). This feature is present in the design.

Interior Finish: Interior finish materials must be rated as Class A, B or C (40.3.3.2). This feature is present in the design. All exposed finish materials will be rated Class A.

Detection, Alarm and Communications Systems: A fire alarm system shall be provided. All requirements of Section 40.3.4 have been met by this design submittal.

Extinguishment Requirements: Sprinklers shall be provided. This is a DOE requirement as well as an NFPA 101 requirement (DOE-STD-1066-99, Para. 5.3.1; NFPA 101-2003, Para. 11.7.3.4) Sprinklers have been provided. In addition, Class I fire standpipe stations are to be provided per NFPA 14 guidance per AHJ requirement. Distance between stations to not exceed 300 feet.

Building Services: The X-Ray Tunnel is supplied with about 6,500 cfm makeup air from the NEH. Air is taken into a dedicated exhaust duct at the east end of the X-Ray Hall (about nine feet from the FEH wall). The exhaust air is routed through the FEH and FEH Access Tunnel. It is exhausted from the roof of the exterior FEH service building. Provide ventilation in compliance with NFPA 90A. Compliance with UBC and UMC requirements is deemed to satisfy NFPA 90A for the purposes of this installation, since the applicable requirements are at least as stringent.

Far Experimental Hall (FEH)

Applicable Code: NFPA 101-2003; NFPA 520

Occupancy: Special Industrial

Description: The Far Experimental Hall (FEH) is an underground building with a footprint measuring 213 feet long by 14 feet wide. The building actually consists of a widened section of dome-shaped tunnel, with the concrete walls and floor constructed in a similar manner to the X-Ray and Undulator tunnels. The top of the arch is at 29 feet above finished floor. A mechanical (HVAC) mezzanine is located at 12 feet above floor level. Makeup and exhaust ducts are routed through the access corridor to the outside. The building consists of a single room containing three experimental hutches and three associated preparation areas. Restrooms and a janitor's closet are located on the east side.

Means of Egress: According to Charrette, Far Experimental Hall (FEH) will be occupied by a staff of 10 to 20 people. 4 people per shift per experimental hutch 24/7 plus 3 to 5 tech support people present intermittently. (Charrette Report, p. A-31) The experimental hutches are not designed to accommodate hazardous materials above amounts that would require an "H" occupancy classification under the UBC. The FEH has its main entrance directly from the outside through a 400-foot long access tunnel. The access tunnel is discussed further below. The access tunnel/FEH interface has been located to allow the maximum 100 foot common path of travel distance from the southeast corner of the FEH. The interface will be constructed as a two-hour fire barrier to protect the integrity of the tunnel from a fire originating in the FEH. The access tunnel will be treated as an exit passageway. The manual smoke purge air transfer opening in this wall will be requested to be removed as being incompatible with the intent of NFPA 101 exit passageway wall penetration requirements. A remotely-located secondary exit from the FEH is located on the west side. This 4-foot wide path of egress passes through the X-Ray tunnel and exits through a second two-hour barrier into the X-Ray tunnel.

Illumination of Means of Egress: Minimum illumination for floors and walking surfaces shall be at least 10.8 lux (1 ft-candle), measured at the floor (101, 7.8.1.3). Illumination shall be arranged so that failure of any single lighting unit does not result in illumination less than 2.2 lux (0.2 ft-candles) in any specific location (7.8.1.4).

Illumination of Means of Egress: Minimum illumination for floors and walking surfaces shall be at least 10.8 lux (1 ft-candle), measured at the floor (101, 7.8.1.3). Illumination shall be arranged so that failure of any single lighting unit does not result in illumination less than 2.2 lux (0.2 ft-candles) in any specific location (7.8.1.4).

Emergency Lighting: For purposes of emergency lighting requirements, the FEH is subject to routine (in fact, continuous) human occupancy. Emergency lighting is required under NFPA 101 guidelines. (40.2.9.1, 7.9.1.1(2), 11.7.3.5). It shall be provided for a period of at least 90 minutes. Initial average illumination shall be at least 10.8 lux (1 ft-candle), declining to no less than 6.5 lux (0.6 ft-candle) at 90 minutes. Spot illumination values at any point shall be no less than $1/10^{th}$ of average values (7.9.2.1).

Marking of Means of Egress: Exit doors shall be marked by an approved sign, readily visible from any direction (40.2.10, 7.10.1.2) Requirements for sign placement every 100 feet are applicable for the FEH (7.10.1.5.2). Signs shall be mounted within the immediate vicinity of the exit doors and exit access doors and no more than 80 inches above them. Internally lit LED signs are encouraged, but photo luminescent signs are allowed in lieu of LED signs, provided that they are directly illuminated by emergency lighting at a minimum of 54 lux (5 ft-candles) at the illuminated surface (7.10.4, 7.10.5.1, 7.10.6.3, 7.10.8.1.2, AHJ ruling).

Protection from Hazards: Activation of the sprinkler system shall initiate the building fire alarm system (40.3.2.3). This feature is present in the design.

Interior Finish: Interior finish materials must be rated as Class A, B or C (40.3.3.2). This feature is present in the design.

Detection, Alarm and Communications Systems: A fire alarm system shall be provided. All requirements of Section 40.3.4 have been met by this design submittal.

Extinguishment Requirements: Sprinklers shall be provided. This is a DOE requirement as well as an NFPA 101 requirement (DOE-STD-1066-99, Para. 5.3.1; NFPA 101-2003, Para. 11.7.3.4) Sprinklers have been provided. In addition, Class I fire standpipe stations are to be provided per NFPA 14 guidance at each side of horizontal exits. For the purposes of the FEH, this requires a standpipe station at the entrance to the X-Ray tunnel.

Building Services: Approximately 9,800 cfm of air is brought into the FEH from the exterior through a duct in the FEH Access Tunnel. The air is circulated within the FEH and then exhausted through ducts to the exterior back out through the Access Tunnel. Provide ventilation in compliance with NFPA 90A. Compliance with UBC and UMC requirements is deemed to satisfy NFPA 90A for the purposes of this installation, since the applicable requirements are at least as stringent.

FEH Utility and Egress Corridor

Applicable Code: NFPA 101-2003

Occupancy: Special Industrial. This space is considered to be an exit passageway. Certain HVAC penetrations not typically allowed in exit passageways are addressed as an equivalency.

Description: The FEH utility and access corridor is 18’-9” in width and 16’-6” in interior height to the arched peak. In addition to serving as an egress enclosure, it is used to route the following utilities to the FEH: HVAC makeup and exhaust air ducts; various wall mounted water and waste lines in metal piping; various wall-mounted metallic electrical conduits containing lighting, telecom and power and life safety circuits; one 2-foot wide data cable tray, and one 2-foot wide LCLS electrical power cable tray.

Means of Egress: According to Charrette, Far Experimental Hall (FEH) will be occupied by a staff of 10 to 20 people. 4 people per shift per hutch 24/7 plus 3 to 5 tech support people present intermittently. (Charrette Report, p. A-31)

Illumination of Means of Egress: Minimum illumination for floors and walking surfaces shall be at least 10.8 lux (1 ft-candle), measured at the floor (101, 7.8.1.3).

Illumination shall be arranged so that failure of any single lighting unit does not result in illumination less than 2.2 lux (0.2 ft-candles) in any specific location (7.8.1.4).

Emergency Lighting: This space is routinely used for egress and ingress for the FEH. Emergency lighting is required (40.2.9.1, 7.9.1.1(2), 11.7.3.5). It shall be provided for a period of at least 90 minutes. Initial average illumination shall be at least 10.8 lux (1 ft-candle), declining to no less than 6.5 lux (0.6 ft-candle) at 90 minutes. Spot illumination values at any point shall be no less than 1/10th of average values (7.9.2.1).

Marking of Means of Egress: Exit signage is required above the exterior exit doors, and at 100 foot intervals along the corridor. Photo luminescent signs are allowed in lieu of LED signs, provided that they are directly illuminated by emergency lighting at a minimum of 54 lux (5 ft-candles) at the illuminated surface (7.10.4, 7.10.5.1, 7.10.6.3, 7.10.8.1.2, AHJ ruling).

Protection from Hazards: Activation of the sprinkler system shall initiate the building fire alarm system (40.3.2.3). This feature is present in the design.

Interior Finish: Interior wall and ceiling finish shall be Class A or B (101, 7.1.4.1). Interior floor finish shall be no less than Class II (101, 7.1.4.2).

Detection, Alarm and Communications Systems: A fire alarm system shall be provided. All requirements of Section 40.3.4 have been met by this design submittal.

Extinguishment Requirements: Sprinklers shall be provided. This is a DOE requirement as well as an NFPA 101 requirement (DOE-STD-1066-99, Para. 5.3.1; NFPA 101-2003, Para. 11.7.3.4) Sprinklers have been provided. In addition, Class I fire standpipe stations are to be provided per NFPA 14 guidance per AHJ requirement. Distance between stations to not exceed 300 feet.

Building Services: [*Air flow arrangements to be verified for final report*.] Provide ventilation in compliance with NFPA 90A. Compliance with UMC requirements is deemed to satisfy NFPA 90A for the purposes of this installation, since the applicable requirements are at least as stringent. Certain HVAC penetrations in the exit enclosure assembly separating this corridor from the FEH are not in compliance with NFPA 101 requirements. These penetrations will be addressed in an equivalency request being prepared in parallel with this preliminary life safety review.

Central Laboratory Office Center (CLOC)

Applicable Code: NFPA 101-2003

Occupancy: Business

Description: The Central Lab Office Complex (CLOC) will be the administrative center for the LCLS. It consists of three distinct building areas connected to each other through a central atrium. In addition to the atrium lobby and lounge areas, types uses in this building consist primarily of office and laboratory spaces. As initially constructed, the first two floors of the CLOC will contain laser labs surrounded by office and conference room spaces. The top floor will be a shell that will be used as open office space. The spaces are designed so that they can be built out into office and lab space similar to the lower two floors, except that one lab will be a wet lab rather than a laser lab. (The wet lab design does not incorporate features for what would be considered an "H" occupancy under the Uniform Building Code.)

Means of Egress: Because the CLOC sits at the side of a hill, the primary level of egress is different between the front and the back. The main entrance to the CLOC occurs at what would is called the first floor level. The building code treats this as the second floor. (The first floor level is the NEH "basement," which is physically offset from the CLOC.) At the rear of the building, the primary exits are at what is called the second floor level. Separation and protection of these outside stairs are not required because they serve only two adjacent stories, including the level of exit discharge (101, Exception 7.2.2.6.3.1(2)). Once outside the building, occupants who exit these rear exits must traverse lengthy exterior stairways to reach roadways or parking lots that would be comparable to "public ways." Because the rear exterior stairwells from the third floor to the second floor are exposed to the building interior, they are treated as part of the exit access for purposes of calculating travel distances (101, Para. 7.6.3). Travel distances, egress widths, accessible means of egress, and other required life safety egress components were found to be satisfactory.

Atrium: Under NFPA 101 requirements, the space called an "atrium" meets the requirements for a communicating space (Para. 8.6.6.). Under these requirements, a smoke barrier would have been sufficient in lieu of one-hour walls around the boundary of the communicating space, and no smoke evacuation system would have been required. Atrium arrangements for this space are in compliance with UBC 1997 requirements and would in fact meet the requirements for an atrium under NFPA 101 (Para. 8.6.7).

Illumination of Means of Egress: Minimum illumination for floors and walking surfaces shall be at least 10.8 lux (1 ft-candle), measured at the floor (101, 7.8.1.3). Illumination shall be arranged so that failure of any single lighting unit does not result in illumination less than 2.2 lux (0.2 ft-candles) in any specific location (7.8.1.4).

Emergency Lighting: Emergency lighting is required (40.2.9.1, 7.9.1.1(2), 11.7.3.5). It shall be provided for a period of at least 90 minutes. Initial average illumination shall be at least 10.8 lux (1 ft-candle), declining to no less than 6.5 lux (0.6 ft-candle) at 90 minutes. Spot illumination values at any point shall be no less than $1/10^{th}$ of average values (7.9.2.1)

Marking of Means of Egress: Exit signage is required above exit doors, and as required in common areas to provide visibility from any point and direction within the common areas. I prefer internally illuminated LED exit signs in this building. However, photo luminescent signs are allowed in lieu of LED signs, provided that they are directly illuminated by emergency lighting at a minimum of 54 lux (5 ft-candles) at the illuminated surface (7.10.4, 7.10.5.1, 7.10.6.3, 7.10.8.1.2, AHJ ruling).

Protection from Hazards: Activation of the sprinkler system shall initiate the building fire alarm system (40.3.2.3). This feature is present in the design.

Interior Finish: Interior wall and ceiling finish shall be Class A or B (101, 7.1.4.1). Interior floor finish shall be no less than Class II (101, 7.1.4.2).

Detection, Alarm and Communications Systems: A fire alarm system shall be provided. All requirements of Section 40.3.4 have been met by this design submittal.

Extinguishment Requirements: Sprinklers shall be provided. This is a DOE requirement as well as an NFPA 101 requirement (DOE-STD-1066-99, Para. 5.3.1; NFPA 101-2003, Para. 11.7.3.4) Sprinklers have been provided. In addition, Class I fire standpipe stations are to be provided for at least two of the rear stairwells using NFPA 14 guidance, per AHJ requirement.

Building Services: Spaces within the CLOC are provided through VAV box arrangements. There are seven large AHU's ranging in size from 10,000 to 27,000 cfm. Two smaller AHU's (7,800 and 2,800 cfm) supply laboratory air. Provide ventilation in compliance with NFPA 90A. Compliance with UMC requirements is deemed to satisfy NFPA 90A for the purposes of this installation, since the applicable requirements are at least as stringent. See atrium discussion above.

Exiting Scenarios from the Far Experimental Hall

The most severe deviation from NFPA 101 code requirements were found to involve exiting from the Far Experimental Hall (FEH). The "worst case scenario" for this exiting scheme is a fire occurring either in the NEH, in the FEH itself, or in the FEH access tunnel, with no credit taken for operation of sprinklers, manual notification, or prompt fire department intervention.

Scenario 1 – Effect on FEH Exiting of Fire Originating in NEH

In the event of a fire in the NEH sub-basement, automatic NEH sub-basement smoke detection should alert occupants of the FEH to evacuate through their normal exit route (opposite the direction of the fire). This is an essential point, since someone attempting to exit through the X-Ray Tunnel would travel over 500 feet only to discover they had walked <u>into</u> the fire. In addition, a smoke/fire damper would close, isolating the X-Ray tunnel atmosphere from the NEH sub-basement space. (At this point, system logic should also shut down the X-Ray Tunnel exhaust fan.) The extremely low combustible loading in the X-Ray tunnel would not contribute to combustion in the event the NEH/X-Ray Tunnel wall was breached, and an additional 2-hour wall between the X-Ray Tunnel and FEH would provide ample time for safe exiting through the normal route.

Scenario 2 – Effect on FEH Exiting of Fire Originating in FEH building

In the event of a fire within the FEH itself, exit from the FEH building could be accomplished either of two remote exits. The main exit (which would almost certainly be used by anyone who was not blocked from it by the fire) is separated from the FEH by a 2-hour fire wall and is very close to qualifying as an exit passageway (exception taken for certain utility penetrations). It leads directly to the exterior. In the unlikely event of a fire somehow blocking access from Hutch 1 or 2 areas, the affected occupants would need to “crash” the X-Ray Tunnel door and proceed over 500 feet through the X-Ray tunnel along a 4-foot wide path to the NEH. Favorable features inside the X-Ray tunnel include an extremely low concentration and sparse continuity of combustibles. (This space arguably could be classified as low hazard under NFPA 101 definitions.) In addition, the air movement in the tunnel blows towards the FEH. Once at the NEH, the occupants would cross through a second 2-hour wall and would find themselves only a few feet from an exit stairwell.

Scenario 3 – Effect on FEH Exiting of Fire Originating in FEH Access Tunnel

In the unlikely event of a fire in the FEH Access Tunnel, the Tunnel is assumed to be blocked. Scenario is that someone has transported a combustible load partway into the tunnel and then temporarily stored it against a side wall in the tunnel, at which point it catches fire while unattended. Sprinklers are assumed to not function. Beam detectors in the tunnel provide early warning of the fire situation, and the location is communicated to the FEH occupants, who understand the need to exit through the X-Ray Tunnel egress route. Once through the horizontal exit and in the X-Ray tunnel, the occupants are separated from the Access Tunnel by two 2-hour fire walls. Air flow in the tunnel is towards the FEH (and counter to the direction of potential smoke flow from FEH wall penetration leakage). In addition, the far end of the FEH Access Tunnel borders the outside, so that thermal pressure effects are likely to vent partially through the door opening (even with the door closed). This would lessen the tendency for pressurization effects to breach the interface wall between the FEH and the Access Tunnel. After traveling slightly over 500 feet, the occupants pass through a third 2-hour wall and are then only a few feet from an NEH exit stairwell.

Appendix C - Construction Safety Regulatory Linkage

I. GENERAL				
Issue	Likely	Possible	Not Likely	Regulation
Housekeeping	X			1926.25
Acceptable certification for pressure vessels, boilers, cranes and other equipment.	X			1926.29
Confined spaces	X			1926.21 and 1926.352,3
II. OCCUPATIONAL HEALTH AND ENVIRONMENTAL CONTROLS				
Issue	Likely	Possible	Not Likely	Regulation
Medical services and first-aid	X			1926.50
Sanitation	X			1926.51
Occupational noise exposure – exposure to sounds capable of causing a diminution in hearing acuity.	X			1926.52
Exposure to ionizing radiation (x-rays, Nuclear Density, etc.)	X			1926.53 and 10 CFR Part 20
Exposure to laser radiation (light)	X			1926.54
Exposure to gases, vapors, fumes, dusts and mist	X			1926.55
Illumination – impaired vision due to insufficient light	X			1926.56
Use of ventilation to control hazardous air contaminants	X			1926.57
Exposure to airborne asbestos fibers			X	1926.58
Hazard communication program – exposure to hazardous chemicals (substances)	X			1926.59
III. PERSONAL PROTECTIVE AND LIFE SAVING EQUIPMENT				
Issue/Hazard	Likely	Possible	Not Likely	Regulation
Use of head protection where there is a potential for injury to the head from falling objects or bumping objects	X			1926.100
Use of hearing protection where there is a potential for hearing impairment due to exposure to loud sounds	X			1926.101
Use of eye and face protection to protect against exposure eye or face hazards from flying particles, molten metal, liquid chemicals, acids or caustic liquids, chemical gases or vapors, or potentially injurious light radiation	X			1926.102
Use of foot protection to protect against foot injuries due to falling or rolling objects, or objects piercing the sole, and where such employee's feet are exposed to electrical hazards	X			1926.96

III. PERSONAL PROTECTIVE AND LIFE SAVING EQUIPMENT				
Issue/Hazard	**Likely**	**Possible**	**Not Likely**	**Regulation**
Use of hand protection to protect against exposure to hazards such as those from skin absorption of harmful substances; severe cuts or lacerations; severe abrasions; punctures; chemical burns; thermal burns; and harmful temperature extremes	X			1910.138
Respiratory protection - breathing air contaminated with harmful dusts, fogs, fumes, mists, gases, smokes, sprays, or vapors	X			1926.103
Use of safety belts, lifelines and lanyards as fall protection	X			1926.104
IV. FIRE PROTECTION AND PREVENTION				
Issue	Likely	Possible	Not Likely	Regulation
Fire Protection Program – response to fires	X			1926.150
Fire Prevention – control of ignition sources and storage of combustible materials	X			1926.151
Fire associated with the use of flammable and combustible liquids	X			1926.153
Fire associated with the use of liquefied petroleum gas (LPG)	X			1926.154
Fire associated with the use of temporary heating devices	X			1926.154
Fire extinguishers	X			1926.150
V. SIGNS, SIGNALS, FLAGGING AND BARRICADES				
Issue	Likely	Possible	Not Likely	Regulation
Accident prevention signs and tags	X			1926.200
Signals	X			1926.201
Barricades	X			1926.200
VI. MATERIALS HANDLING, STORAGE, USE AND DISPOSAL				
Issue	Likely	Possible	Not Likely	Regulation
General requirements for storage	X			1926.250
Rigging equipment for material handling	X			1926.251
VII. TOOLS - HAND AND POWER				
Issue	Likely	Possible	Not Likely	Regulation
General requirements	X			1926.300
Hand tools	X			1926.301
Power operated tools – guards	X			1926.302
Abrasive wheels and tools	X			1926.303
Woodworking tools	X			1926.304
Jacks, lever and ratchet, screw and hydraulic		X		1906.305

VIII. WELDING AND CUTTING				
Issue	Likely	Possible	Not Likely	Regulation
Gas welding and cutting	X			1926.350
Arc welding and cutting	X			1926.351
Fire prevention and fire watch	X			1926.352
Ventilation and protection in welding, cutting and heating	X			1926.353
Lead abatement, chemical stripping, HEPA exhaust			X	
Welding, cutting and heating in way of preservative coating		X		1926.354
IX. ELECTRICAL				
Issue	Likely	Possible	Not Likely	Regulation
Wiring design and protection – GFCI Required	X			1926.404
Wiring methods, components and equipment for general use	X			1926.405
Specific purpose equipment and installation	X			1926.406
Hazardous (classified) locations	X			1926.407
Special systems	X			1926.408
Lockout and tagging of circuits and energized sources	X			1926.417
Verifying of circuits and energized sources	X			
Maintenance of equipment	X			1926.431
Environmental deterioration of equipment	X			1926.432
Battery location and battery charging	X			1926.441
Permits	X			
Hot work - CPR trained safety watch	X			
X. LADDERS AND SCAFFOLDS				
Issue	Likely	Possible	Not Likely	Regulation
Ladders (Metal ladders are prohibited)	X			1926.450
Scaffolds - Competent person requirements	X			1926.451
Pickboards	X			
XI. FLOORS AND WALL OPENINGS AND STAIRWAYS				
Issue	Likely	Possible	Not Likely	Regulation
Guardrails, handrails and covers	X			1926.500
Stairways	X			1926.501

XII. CRANES, DERRICKS, HOIST, ELEVATORS AND CONVEYORS				
Issue	Likely	Possible	Not Likely	Regulation
Cranes - Lift plans	X			1926.550
Material hoists, personnel hoists and elevators	X			1926.552
Base-mounted drum hoists			X	1926.553
Overhead hoists		X		1926.554
Conveyors			X	1926.555
Aerial lifts			X	1926.556
Backup alarms	X			
Certifications for annual inspections	X			
Operation certification and physical requirements	X			
XIII. MOTOR VEHICLES, MECHANIZED EQUIPMENT AND MARINE OPERATIONS				
Issue	Likely	Possible	Not Likely	Regulation
Equipment	X			1926.600
Motor vehicles	X			1926.601
Material handling equipment	X			1926.602
Pile driving equipment			X	1926.603
Site clearing	X			1926.604
Marine operations and equipment			X	1926.605
Operation certification and physical requirements	X			
Backup alarms	X			
XIV. EXCAVATIONS, TRENCHING AND SHORING				
Issue	Likely	Possible	Not Likely	Regulation
General protection requirements – Competent person/Qualifications	X			1926.650
Specific excavation requirements	X			1926.651
Specific trenching requirements	X			1926.652
Permits	X			
Confined space provisions	X			1926.21
Fencing	X			
XV. CONCRETE AND MASONRY				
Issue	Likely	Possible	Not Likely	Regulation
General requirements	X			1926.701
Requirements for equipment and tools	X			1926.702
Requirements for cast-in-place concrete	X			1926.703
Requirements for precast concrete			X	1926.704
Requirements for lift-slab operations			X	1926.705
Requirements for masonry construction	X			1926.706
Requirements for saw cutting	X			

XVI. STEEL ERECTION				
Issue	Likely	Possible	Not Likely	Regulation
Flooring requirements	X			1926.750
Structural steel assembly	X			1926.751
Bolting, riveting, fitting-up and plumbing-up	X			1926.752
Fall protection plans	X			1926.104 and 1926.105
Crane use - lift plans	X			
XVII. UNDERGROUND CONSTRUCTIONS, CAISSON, COFFERDAMS, AIR COMPRESSORS				
Issue	Likely	Possible	Not Likely	Regulation
Underground construction	X			1926.800
Caissons			X	1926.801
Cofferdams			X	1926.802
Compressed air	X			1926.803
Confined space provisions	X			1926.21
XVIII. DEMOLITION				
Issue	Likely	Possible	Not Likely	Regulation
Preparatory operations	X			1926.850
Stairs, passageways, and ladders	X			1926.851
Chutes	X			1926.852
Removal of material through floor openings	X			1926.853
Removal of walls, masonry sections and chimneys	X			1926.854
Manual removal of floors			X	1926.855
Removal of walls, floors, and material with equipment	X			1926.856
Storage	X			1926.857
Removal of steel construction	X			1926.858
Mechanical demolition	X			1926.859
Asbestos removal			X	
Lead base painted surfaces			X	
Lockout/tagout procedures	X			
Fencing/signage	X			
XIX BLASTING AND USE OF EXPLOSIVES				
Issue	Likely	Possible	Not Likely	Regulation
Not allowed				

XX. POWER TRANSMISSIONS AND DISTRIBUTION				
Issue	Likely	Possible	Not Likely	Regulation
General requirements	X			1926.950
Tools and protective equipment	X			1926.951
Mechanical equipment	X			1926.953
Material handling	X			1926.953
Grounding for protective equipment	X			1926.954
Overhead lines		X		1926.955
Underground lines	X			1926.956
Construction in energized stations			X	1926.957
External load helicopters			X	1926.958
Lineman’s body belts, safety straps and lanyards			X	1926.959
XXI. ROLLOVER PROTECTIVE STRUCTURES; OVERHEAD PROTECTION				
Issue	Likely	Possible	Not Likely	Regulation
Rollover protective structures (ROPS)	X			1926.1000
Minimum performance criteria for rollover protective structures for designated scrapers, loaders, dozers, grades and crawler tractors	X			1926.1001
Protective frame (ROPS) test procedures and performance requirements for wheel-type agricultures and industrial tractors used in construction	X			1926.1002
XXII. ENERGIZED SYSTEMS (PIPING, HVAC, ELECTRICAL, ETC.)				
Issue	Likely	Possible	Not Likely	Regulation
Lockout and tagout procedures	X			1910.147

Appendix D - Construction Waste Management

Through effective planning it is the project objective to establish a work process that will generate the least amount of waste possible. Of the inevitable waste that is generated, as many of the waste materials as economically feasible shall be reused, salvaged, or recycled. The LCLS shall require contractors to designate an on-site party responsible for instructing workers and subcontractors of appropriate separation, handling, and recycling, salvage, reuse and return methods to be used by all parties at the appropriate stages of the project. The LCLS shall require contractors to lay out and label a specific area to facilitate separation of materials for reuse, salvage, recycling, and return. Recycling and waste bin areas are to be kept neat and clearly marked in order to avoid contamination or mixing of materials. To implement these requirements, a minimum of two dumpsters will be required for the construction site, one for collecting solid waste and the second for collecting recyclables. In addition, the LCLS shall require contractors to be responsible for all waste management, including wastes generated by subcontractors. SLAC will survey waste before it is sent out for recycling.

The LCLS shall require contractors to remove accumulated construction debris as the work progresses and upon completion shall remove from the property of the Laboratory all remaining construction debris, excess material, equipment, tools and temporary construction. Clean scrap metals may be delivered, at the contractor's option and subject to approval by a LCLS representative, to a scrap metal depository located at an SLAC designated area. Unless specified elsewhere, the authorized LCLS representative will decide and instruct the contractor as to whether removed materials and equipment shall be considered salvageable or worthless. Salvageable materials and/or equipment, which are to remain the property of the Laboratory, shall be transported by the Contractor to a location designated by the Laboratory.

The authorized LCLS representative who designates the disposal site shall also arrange for the final disposition of the material. Excess excavated materials, worthless materials, equipment, and/or the contractor shall dispose construction debris removed from the construction site of off-site. Disposal shall be in accordance with all federal, state, and local rules and regulations. A health physics survey of all construction debris and items is required and shall be performed by the Laboratory prior to the contractor's removal of such items from the work site.

The contractor is required to report to the LCLS representative on a monthly basis the number of tons or fractions thereof of any waste materials which are removed from the site for disposal, the types and quantities of materials removed from the site for recycling, and any on-site volume reduction methods employed such as compaction or grinding.

Appendix E – SLAC Work Smart Standards

Description	Primary Standard	Supplementary Standard	Internal Standard
Accelerator Safety	DOE-O-420.2A Contractor Requirements Document	SLAC Guidelines for Operations	
Accessibility, Public Accommodation	28CFR36		
Accidental Release of Regulated Subs.	19CCR Div. 2, Ch. 4.5		
Air Quality	BAAQMD Rules & Regulations	BAAQMD Manual of Procedures	
Air Toxics Inform. & Assessment	CA H&SC Div. 26, Part 6, 44300 et seq.		
Asbestos	29CFR1926.1101; 29CFR1910.1001	40CFR763 (AHERA)	
Backflow Preventers	17CCR7605		
Beryllium Disease Prevention	10CFR850		
Biological Safety	29CFR1910.1030 (Bloodborne Pathogens); Stanford University Biosafety Manual; NIH Guidelines for Research Involving Recombinant DNA Molecules; DOE N 450.7 & 450.11 (as applicable)	Biosafety in Microbiological and Biomedical Laboratories (CDC); Guidelines for the Safe Transport of Infectious Substances and Diagnostic Specimens (WHO/EMC/97.3)	
Calif. Code for Waste Management	22CCR Div. 4.5		
California Contractor's License Law	Business and Professions Code, Div 3, Ch. 9 Contractors Art. 2-5, 11	Contractors State License Board Rules & Regulations Art. 3 Classifications 830-834	
Care of Humans & Animals		NIH Public Health Service Policy on Human Care and Use of Laboratory Animals (appl. portions)	
Chemical Accident Prevention	40CFR68; 19CCR Div. 2		
Chemical Management	Consolidated Chemical User Health and Safety Requirements		DOE Chemical Management Handbook
Chemical Substance Exposures	29CFR1910 (1000-1018)	ACGIH TLV	

Clean Air Act	42USC7401 et seq. (as amended)		
Clean Water	Calif. Water Code, Sections 13000 et seq., Porter Cologne Water Quality Control Act	33USC 1251 et seq.	
Construction Codes		Uniform Building Code (UBC), Uniform Mechanical Code (UMC) & Uniform Plumbing Code (UPC) (Latest versions as adopted by State of California Building Standards Commission)	
Cranes and Hoists	29CFR1910.179-180; 29CFR1926.554; ANSI/ASME B30 (all applicable sections)	DOE STD-1090-01	SLAC ES&H Manual, Ch. 41
Cryogenic Safety		SLAC ES&H Manual, Ch. 36	
Discharge of Pollutants to Streams	CA Fish & Game Code, Sec. 5650-5656		
DOT Hazardous Material Regulations / Hazardous Material & Samples Transportation	49CFR 171-180 (as applicable)		
Electrical Safety	OSHA 1910 and 1926 (Applicable parts of)	NFPA 70E; National Electrical Safety Code (NESC); National Electrical Code (NEC); NFPA 101, Life Safety Code; DOE Handbook, Electrical Safety	SLAC ES&H Manual, Ch. 8; See current Electrical Safety related SLAC ES&H Bulletins
Electroplating Standards	40CFR413		
Emerg. Eyewash and Shower Equip.		ANSI Z358.1-1998	
Emergency Management	NFPA 1600 2000 Edition	29CFR1910; DOE-O-151.1A Ch. IX & Ch. X Sec. 3a & 3b	Campus Emergency Plan (Stanford University)
Emergency Planning	40CFR355 (Except 40CFR355.40)		
Emergency Release Notification	40CFR355.40		
Emission Stds. for Air Pollutants	40CFR61, 63		
Endangered Species / Wildlife & Plants	California Fish & Game Code Section 1603 - Streambed Alteration Agreements / 16USC 1531 et seq. / 7CFR355 / CA Fish & Game Code Section 2050-2089 / 50CFR17		
Environmental Protection	40CFR61, Subpart H		

Environmental Protection	DOE O 450.1, CRD (as applicable)		
Environmental Protection	DOE O 5400.5, Ch. II, para. 1 [except 1.a(3)(c)&1.c], 2, 3, 5, 6, 7, 8a; Ch. III & IV		
EPA Waste Management	40CFR260-279, 302, 761		SLAC ES&H Manual, Ch. 17
Ergonomics; Repetitive Motion Inj.	8CCR5110	ANSI/HFS 100	
Explosives	DOE Explosives Safety Manual (Pantex Version) DOE M 440.1-1		
Fire Safety	Uniform Fire Code (UFC), National Fire Prot. Assoc. Codes and Standards, Uniform Building Code (UBC)	DOE-O-420.1, Sec. 4.2.2 & 440.1A	SLAC ES&H Manual, Ch. 12
Forklifts	29CFR1910.178	29CFR1910.178, Appendix A	
General Duty-Safe Workplace	Occupational Safety & Health Act Sec. 5(a)(1)		
Genetically Altered Organisms	7CFR340		
Hand-arm & Heat Stress		ACGIH TLV hand-arm; heat stress	
Hanford Solid Waste Acceptance Criteria	HNF EP 0063		
Hazard Communication	29CFR1910.1200; Title 8 CCR Section 5194		SLAC ES&H Manual, Ch. 4
Hazard. Materials Release Response	CA H&SC Div. 20, Ch. 6.95, 25531-25543.3		
Hazardous Materials Business Plan/Chemical Reporting	CA H&SC 6.95; 19CCR Div. 2 Ch. 4 / 40CFR355 (Except 355.40) / 40CFR370		
Hazardous Waste Control	CAHSC, Division 20, Ch. 6.5		
Historical & Archeological Sites	40CFR6.301 / 16USC 469 et seq. & 470 et seq.		
Industrial Ventilation		ACGIH, Industrial Ventilation	
Laser Safety	29CFR1910.269(w)(8), 1926.54	ANSI Z136.1 and Z136.2	
Management of Nuclear Materials		DOE Order 474.1A	
Mechanical Refrigeration		ASHRAE-15	

Metal Finishing	40CFR433		
New Stationary Air Sources	40CFR60		
Occupational Injury Record & Report	29CFR1904	DOE O 231.1	
Occupational Radiation Protection	10CFR835; Atomic Energy Act	DOE-N-441.4	
Occurrence Reporting	DOE-O-232.1A Contractor Requirements Document	SLAC Technical Division Document 01-03	
Office & Industrial Illumination		IES RP-1 & RP-7	
Oil Pollution; Hazardous Substance	40CFR110-125		
Oil Spills, prevention & response	California Government Code, Sec. 8670.2(f), .25.5(a)		
Onsite Chemical Transportation	29CFR1910.101; 29CFR1910.253; 29CFR1926.350	CGA Pamphlet P-1 (Compressed Gas Association General Requirements for Compressed Gases); CGA Pamphlet G-1 (Compressed Gas Association Requirements for Acetylene); ANSI Z49.1, Safety in Welding, Cutting, and Allied Processes	
OSHA Construction	California OSHA	29CFR1926 (Applicable parts of)	SLAC ES&H Manual, Ch 42
OSHA General Industry	29CFR1910 (Applicable parts of)		
Package & Transport Radioactive Mat.	10CFR71		
Permits for Dredge Material	33CFR301, 401, 404; 33USC1344		
Petroleum Storage	CA HSC, Div. 20, Ch. 6.67, Sec. 25270-25270.13		
Piping Systems		ASME/ANSI B31.1, .3, .5, .8	
Plant Pests	7CFR330		
Pollution Prevention Act	42USC13101 et seq. (as applicable)		SLAC ES&H Manual, Ch. 22
Polychlorinated Biphenyls (PCB)	40CFR761	15USC 2601-2692	
Pressure & Vacuum Vessels			SLAC Pressure and Vacuum Vessel Safety Comm. Charter
Pressure Vessels		ASME Pressure Vessel Code: I-IX Inclusive	SLAC Mechanical Engineering Safety Inspection

Pretreatment Regulations	40CFR403		
Protection of Human Subjects	10CFR Part 745; 29CFR1910.1030 (Bloodborne Pathogens)	Office of Energy Research "A Human Subjects Handbook;" Stanford University Administrative Panel on Human Subjects in Medical Research	
Protection of Stratospheric Ozone	40CFR82; EO 13148 (Section 505)		
Protection of Water	33CFR320, 322, 323, 328-330		
Radiation Protection, Public & Environment	DOE O 450.1, CRD (as applicable)		
Radioactive Waste Management	DOE-O-435.1(except 4.b.)		
Radioactive Waste Management		DOE-M-435.1-1, Chapters I and IV (except I.1.E, IV.D.4, IV.E, IV.G.(1)(d), IV.M.(1)(c), IV.M.(2)(e), IV.M.(3), IV.N.(2), IV.P, IV.Q, IV.R.(1), and IV.R.(3))	
Release Reporting	40CFR300-302		
Releases to Sanitary Sewer	10CFR20, Subpart K, Sec. 20.2003(a)4		
Resource Conservation & Recovery Act	42USC6901 et seq. (as applicable)		
Rigging and Hooks	29CFR1910.184; 29CFR1926.251; ANSI/ASME B30.9 & B30.10		
Seismic Safety	Executive Order 12699	DOE-O-420.1, Cont. Req. Doc., Sec. 4.4.2	Specification for Seismic Design of Buildings, Structures, Equipment, and Systems at the SLAC
Spider Bites			See current Animal Hazards related SLAC ES&H Bulletins
Storm Water	Industrial Activities, Stormwater General Permit		
Tests for Pollutants	40CFR136		
Toxic Chemical Release Reporting	40CFR372; EO 13148 (Sections 501-503)		
Traffic and Vehicular Safety	California Vehicle Code (Applicable parts of)	SLAC ES&H Manual, Ch. 13	

Training for Animal Research	9CFR2 Subpart C	Animal Welfare Act
UV & RF Radiation; Noise		ACGIH TLV UV & rf radiation; noise
Washington Dangerous Waste Reg.	WAC 173-303	
Waste Water	Regulations of the South Bayside System Authority / Code of General Regs. of the West Bay Sanitary Dist.	
Water Pollution/Flammable Liquids and Hazardous Materials	24CCR Part 9 (CA Fire Code Sections 79 & 80)	
Water Quality Certifications	23CCR Div. 3, Ch. 28, Article 4,3855-3861	
Water Quality Standards	40CFR131	
Well Construction Standards	Calif. Well Std. Bulletin 74-81	Calif. Well Std. Bulletin 74-90

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