Preliminary Safety Analysis Document for the Linac Coherent Light Source

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Introduction

In accordance with requirements of DOE Program and Project Management Practices, the SLAC Integrated Safety Management Plan (ISM) and the DOE Accelerator Safety Order, this Preliminary Safety Assessment Document (PSAD) has been prepared as part of the Critical Decision 2 (CD-2) process for the Linac Coherent Light Source (LCLS). The LCLS is a Free-Electron-Laser (FEL) R&D facility operating in the wavelength range 1.5–15 Å that utilizes the SLAC Linac and produces sub-picosecond pulses of short wavelength x-rays with very high peak brightness and full transverse coherence.

As of this time, the LCLS organization at the system level has been identified, the proposed building layouts have been determined and the required configuration of the accelerator has been established. Hazard identification and assessment is provided to the degree possible in these early stages of design. Ultimately it will fold into a larger program that will address all sources of risk, ensure that they are understood, and subsequently controlled or mitigated in a manner consistent with the assumptions defined in the Safety Assessment Document (SAD). These assumptions and limits define the Safety Envelope.

The PSAD does not encompass closure or decommissioning. These would be addressed under a closure and decommissioning plan.

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Summary and Conclusions

The LCLS project has been analyzed for hazard potential. A preliminary analysis at the conceptual design stage of the project, helped identify potentially hazardous conditions, equipment or operations. While ongoing reviews assure that new hazards are identified and that control measures are established if required.

Mitigation measures are incorporated into the design and planning of the project, ensuring that during the construction and proposed operation of the LCLS, potential hazards pose only minor on-site and negligible off-site impact to people and the environment. As such, the LCLS is a low hazard facility as defined in DOE Order 5480.1B.

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[i], 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 approach throughout all levels of the LCLS project. Core Functions and Guiding Principals are viewed as the best way of doing business, consistent with the LCLS approach to hazards identification and mitigation.

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Description of Site, Facilities and Operation Requirements

3.1. Facilities

3.1.1. Sector 20 (S20) – The Sector 20 modifications will include Alcove Improvements and an 18.6 square meter [200 square feet] RF Hut. The Alcove Improvements shall include a Laser Room, Load Lock and Control Room. This total gross square footage consists of 158 square meters [1,700 square feet] of space at grade level adjacent to the Klystron Gallery. The existing space requires modifications, including structural supports for seismic retrofit, replacement and repair of existing roofing, siding, lighting, power, utilities, HVAC and other interior modifications. The Laser Room will be environmentally controlled equivalent to a class 100,000 clean room.

The RF Hut will be a temperature stabilized enclosure with a ceiling approximately 2.75 meters high [9 feet]. 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 Sector 20 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 260 square meters [2800 square feet] in size 24.5 meters x

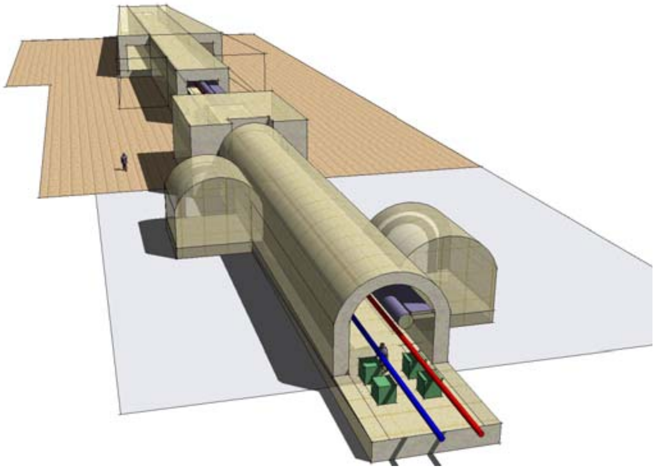
10.5 meters [80 feet long x 35 feet wide] located within existing SLAC Building 81. The primary conventional facilities requirements are for the enclosure structure (walls and ceiling), foundation, HVAC, electric power, cable trays and supports, equipment cooling water and compressed air.

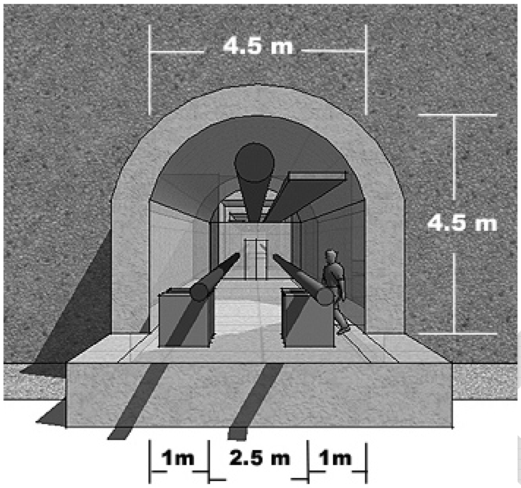
The existing building is a steel frame structure with an average ceiling height of 7.6 meters [25 feet]. In the vicinity of the future MMF, the bay is 40 feet wide with columns spaced at 25 feet. The floor is a 6-inch thick reinforced concrete slab. The vicinity of the future MMF is currently used for 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. **<u>Research Yard Modifications</u>** - 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, #104, #113 and #211. 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. **<u>Beam Transport Hall (BTH)</u>** – 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 4.5 meters wide x 4.5 meters 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 heating, cooling, ventilation and smoke purge systems. A fire sprinkler system shall be provided throughout the BTH. The floor elevation shall be maintained at 247.25’ and will remain constant throughout the entire LCLS facilities.

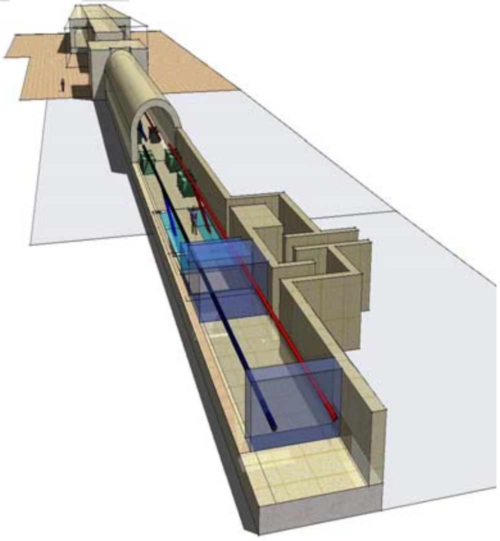
3.1.5. **Undulator Hall (UH) -** The UH shall be a tunnel commencing from the downstream end of the BTH thermal barrier. The UH shall extend 175 meters in the direction of the beam to the downstream end of the UH where it shall be enclosed by another physical thermal barrier separating the UH from the 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’ and will remain constant throughout the entire LCLS facilities.

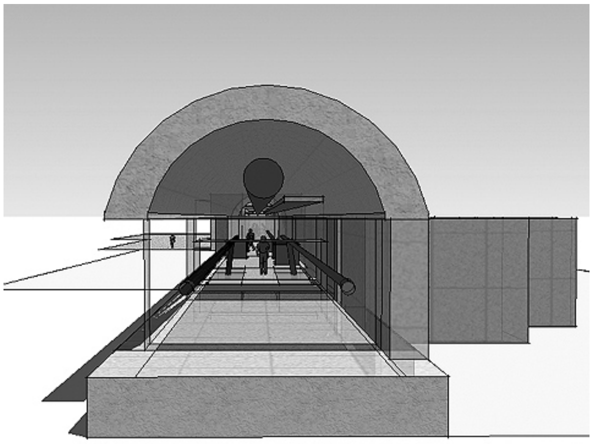




175 Meter Undulator with Alcoves - Cross Section

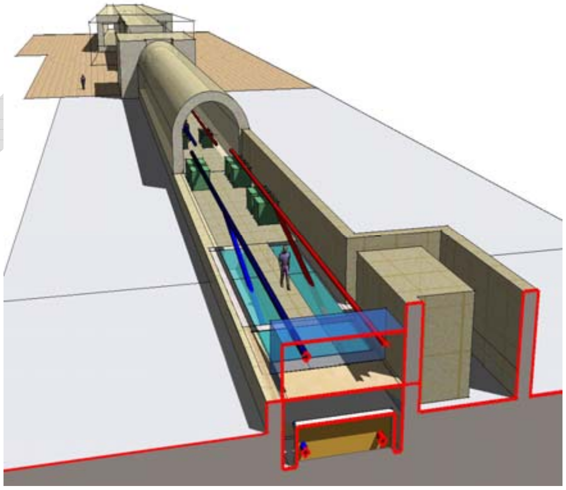
3.1.6. **Front End Enclosure (FEE)** – The FEE structure shall be similar in configuration to the UH and in its appearance shall be continuous. The purpose of the FEE shall be to separate the electron and x-ray beams. The electron beam shall curve downward into the Beam Dump and the x-ray beam shall continue into the Near Experimental Hall and other facility components further downstream. 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’ and will remain constant throughout the entire LCLS facilities.





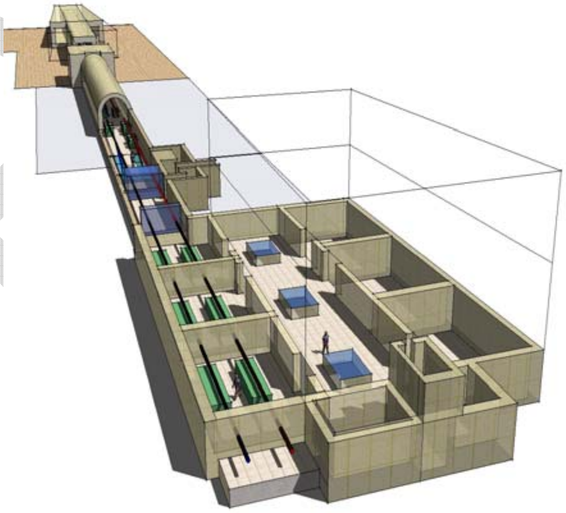
Front End Enclosure & Beam Dump - Cross Section

3.1.7. Beam Dump (BD) – The function of the BD is to act as a terminal point for the high-energy electron beam. The electron beam separated from the x-ray beam bends downward within the FEE and terminates into the Electron Beam Dump. The actual dump is located directly below the FEE and will have provisions for occasional access for maintenance. Within the BD shall be two massive metal/steel blocks which act as radiation shields. The first block is 13’ thick and the second block is 4’ thick. The BD shall be provided with ventilation and smoke purge systems. A fire sprinkler system shall be provided throughout the BD. The floor elevation shall be maintained at 247.25’ and will remain constant throughout the entire LCLS facilities.

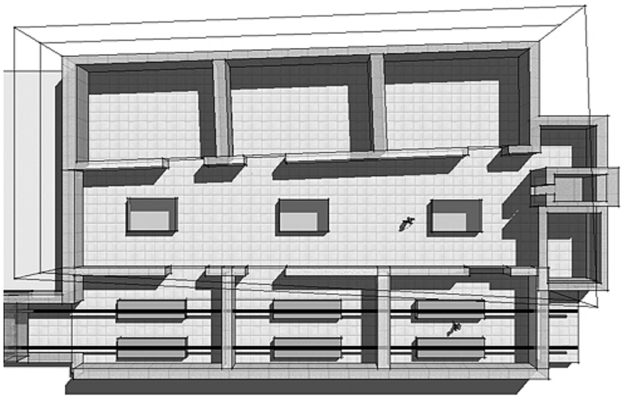


Beam Dump

3.1.8. **Near Experimental Hall (NEH)** – The NEH is a two-story structure (below grade) that will begin downstream of the BD and will extend approximately 33 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 second floor shall house a Laser Bay at approximately 6 meters by 32 meters. A conference room shall also be provided on the second floor for collaboration of the experimental personnel. 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’ and will remain constant throughout the entire LCLS facilities.

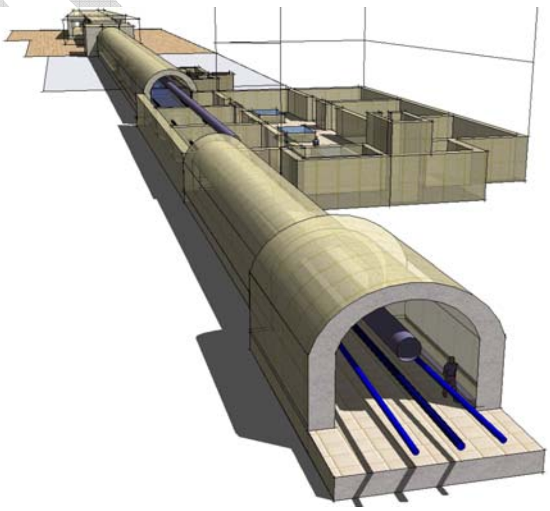


NEH (below grade)



NEH Floor Plan

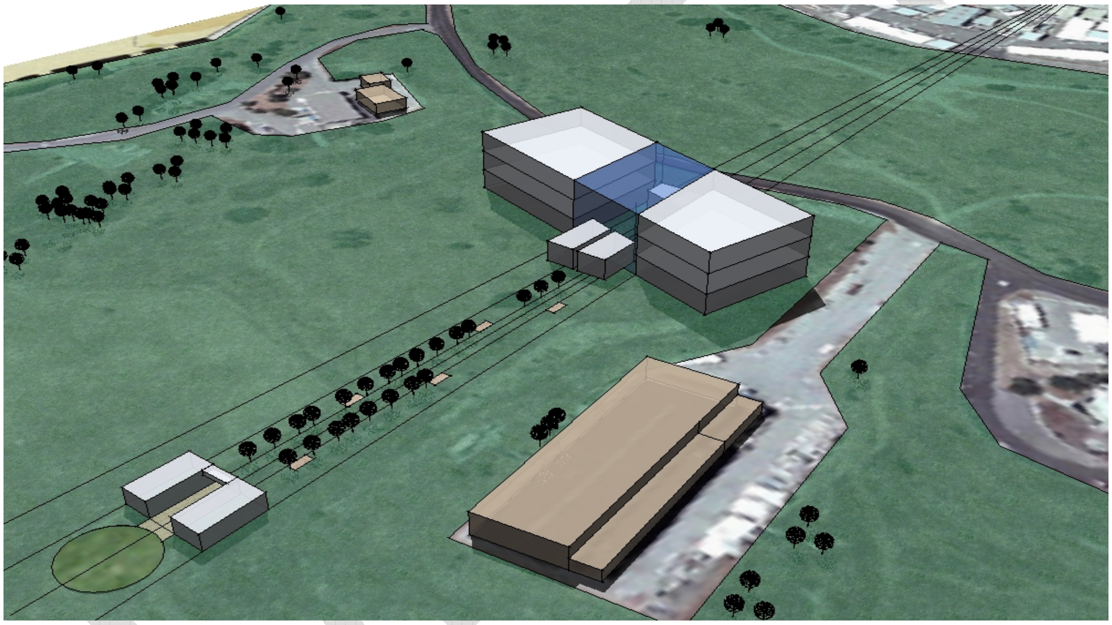
3.1.9. <u>X-Ray Transport, Optics and Diagnostic Tunnel (XRTOD)</u> - The XRTOD tunnel shall extend 290 meters downstream of the NEH and shall span to the FEH. The tunnel width configuration shall grow as it accommodates the main beam (0 degree) and the splitting of said beam to a plus and minus ¾ degree beam. As a result of this splitting of the beam the tunnel shall have a telescope configuration. The XROD 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 XROD. The floor elevation shall be maintained at 247.25’ and will remain constant throughout the entire LCLS facilities.



Telescoping Tunnel

3.1.10. Far Experimental Hall (FEH) – The FEH shall be located 290 meters downstream of the NEH. It shall be located approximately 30 meters 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’ and will remain constant throughout the entire LCLS facilities.

3.1.11. Central Lab Office Complex (CLOC) - A Central Lab Office Complex 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 325 persons with approximately 68,000 square feet of office and lab space. This facility can be located on grade and adjacent to the east edge of PEP Ring Road. Provisions shall be made for a ground floor directly under the office facility at the 246.85’ elevation (approximately 8 meters below existing grade). 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 (non-certified clean room class 10,000). Provide a small machine shop, electronics lab and model shop. Additional space shall include a computational center, storage rooms, mail room, reproduction room and other general amenities (i.e. kitchen, lounge, etc). Conference room space shall include collaboration areas: (3) three small (5-8 capacity), (2) two medium (14-18) capacity, and (1) one large (40-50) capacity [the large room shall be designed to accommodate an acoustical divider]. A lecture style facility shall be provided to accommodate an audience of 100. Parking shall be provided adjacent to or in the immediate surrounding area. Provisions for moderate landscaping shall be provided.



Architectural Rendering

3.2. LCLS Injector

Modifications to the conventional facilities at Sector 20 are needed both upstairs in the alcove area and downstairs in the off axis linac housing. The principal elements downstairs are the dismantling of the existing wall and the construction of a new shield wall with the required penetrations. In addition to the shield wall, Figure 1 shows the injector beam line components with their facilities requirements. Also noted are the proposed locations of the electrical, water and air utilities in the off axis housing. The magnet water is an estimate, based upon previous experience, since the magnets are not yet designed.

Figure 2 shows the general layout of the upstairs area at Sector 20 and gives the locations of the various RF systems used to power the injector. The major conventional facilities effort for the RF will be the construction of the RF Hut with its power and water requirements given in Figure 3. The RF Hut should be located over Penetration 20-17.

A more detailed view of the klystron gallery and alcove at Sector 20 is shown in Figure 3. Here are the power and water needs for power conversion and RF. Also shown are the cable tray runs from the power conversion and RF racks over the top of the Laser Room and down the stairwell access to the injector below. A second set of cable trays are located inside the Laser room, Load Lock room and Control Room areas. A possible layout of racks in the Control Room is given.

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. The location is shown in Figure 1. 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, 100ft 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 up as seen in Figure 2.

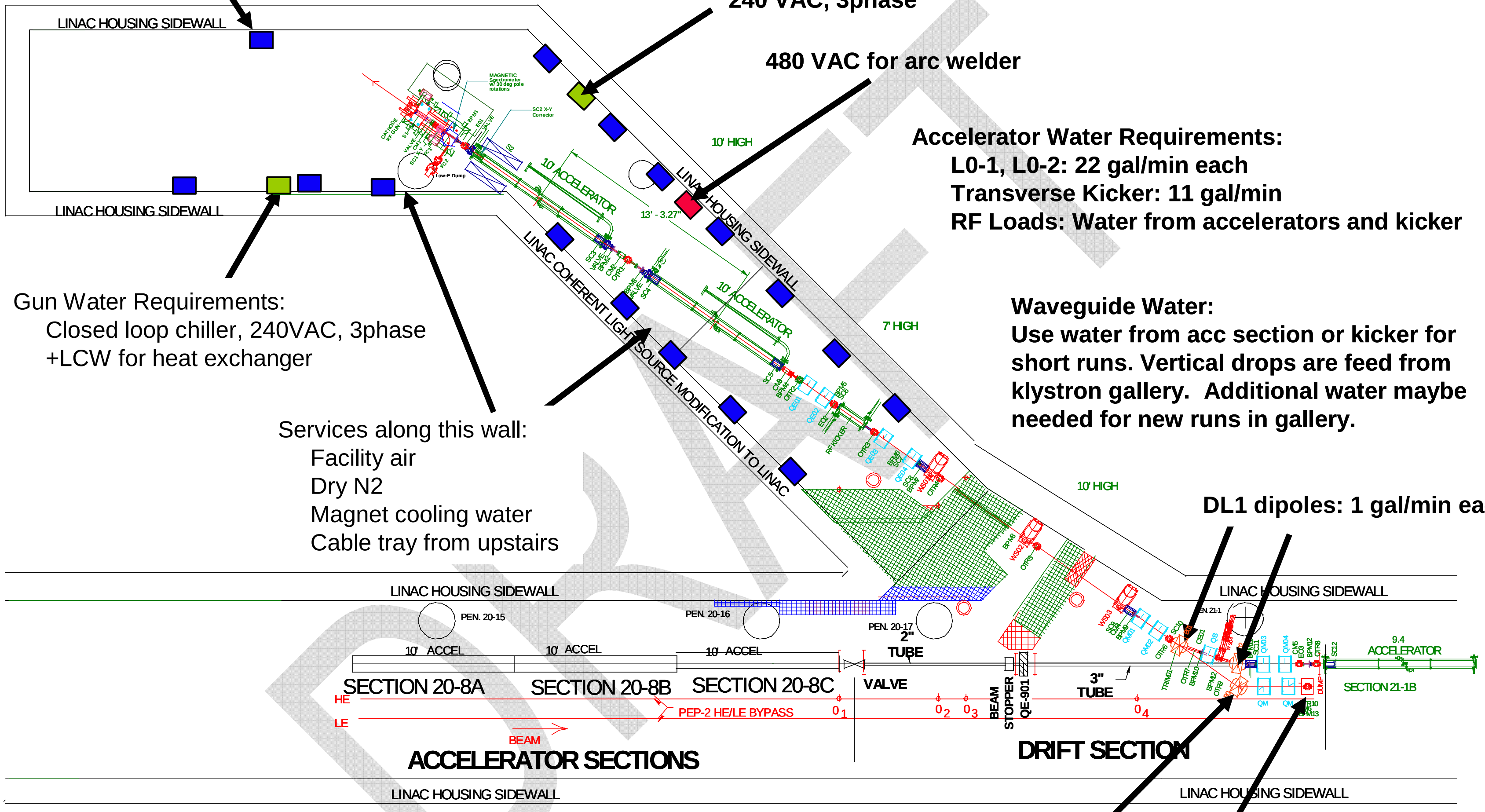
120VAC, 4plex outlets, typ.

Gun Solenoid: 3.6 gal/min
Linac Solenoid: 13.7 gal/min
Gun Spectrometer: 1.7 gal/min

240 VAC, 3phase

480 VAC for arc welder

Accelerator Water Requirements:
- **L0-1, L0-2: 22 gal/min each**
- **Transverse Kicker: 11 gal/min**
- **RF Loads: Water from accelerators and kicker**



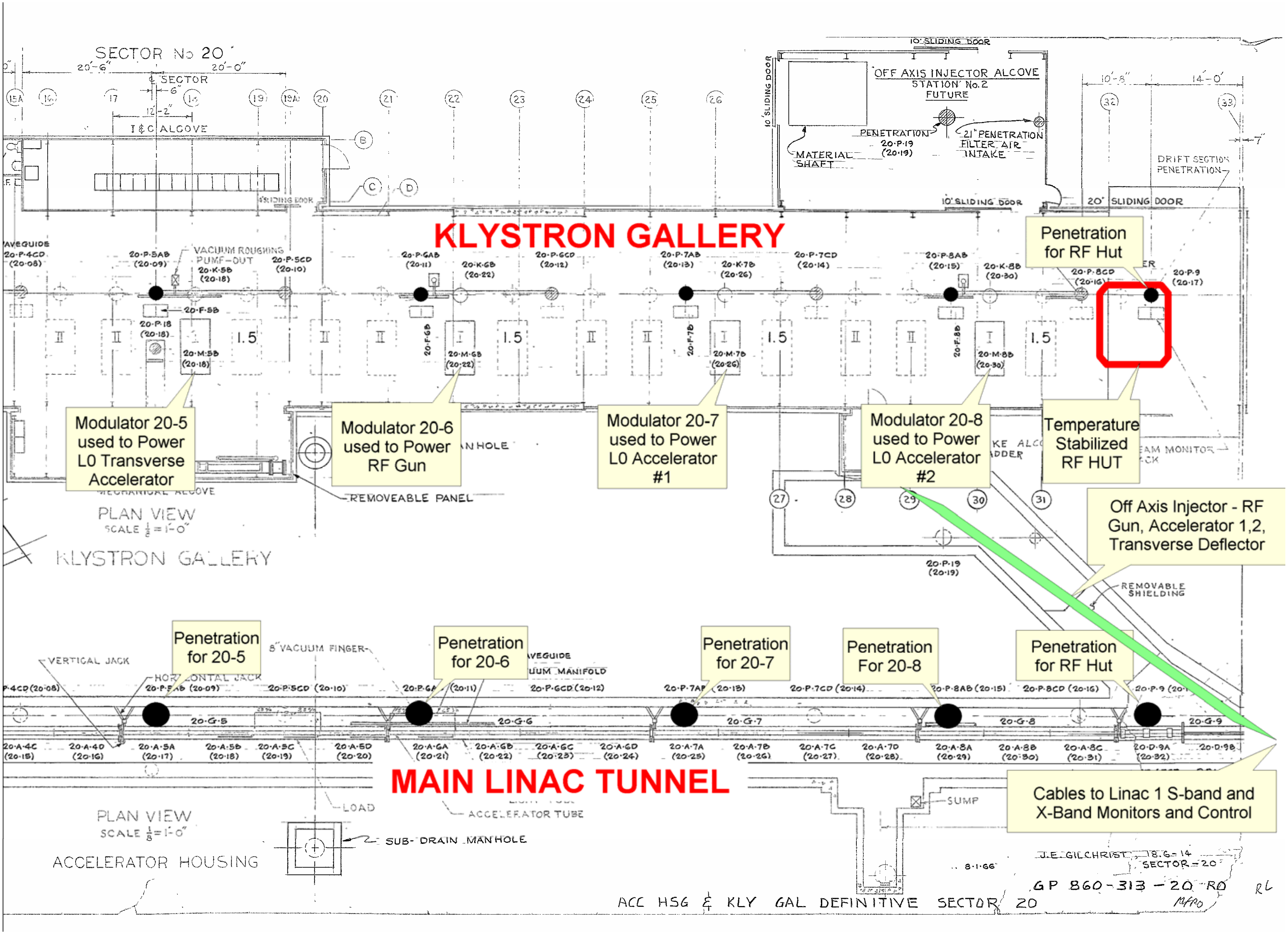
Waveguide Water:
Use water from acc section or kicker for short runs. Vertical drops are feed from klystron gallery. Additional water maybe needed for new runs in gallery.

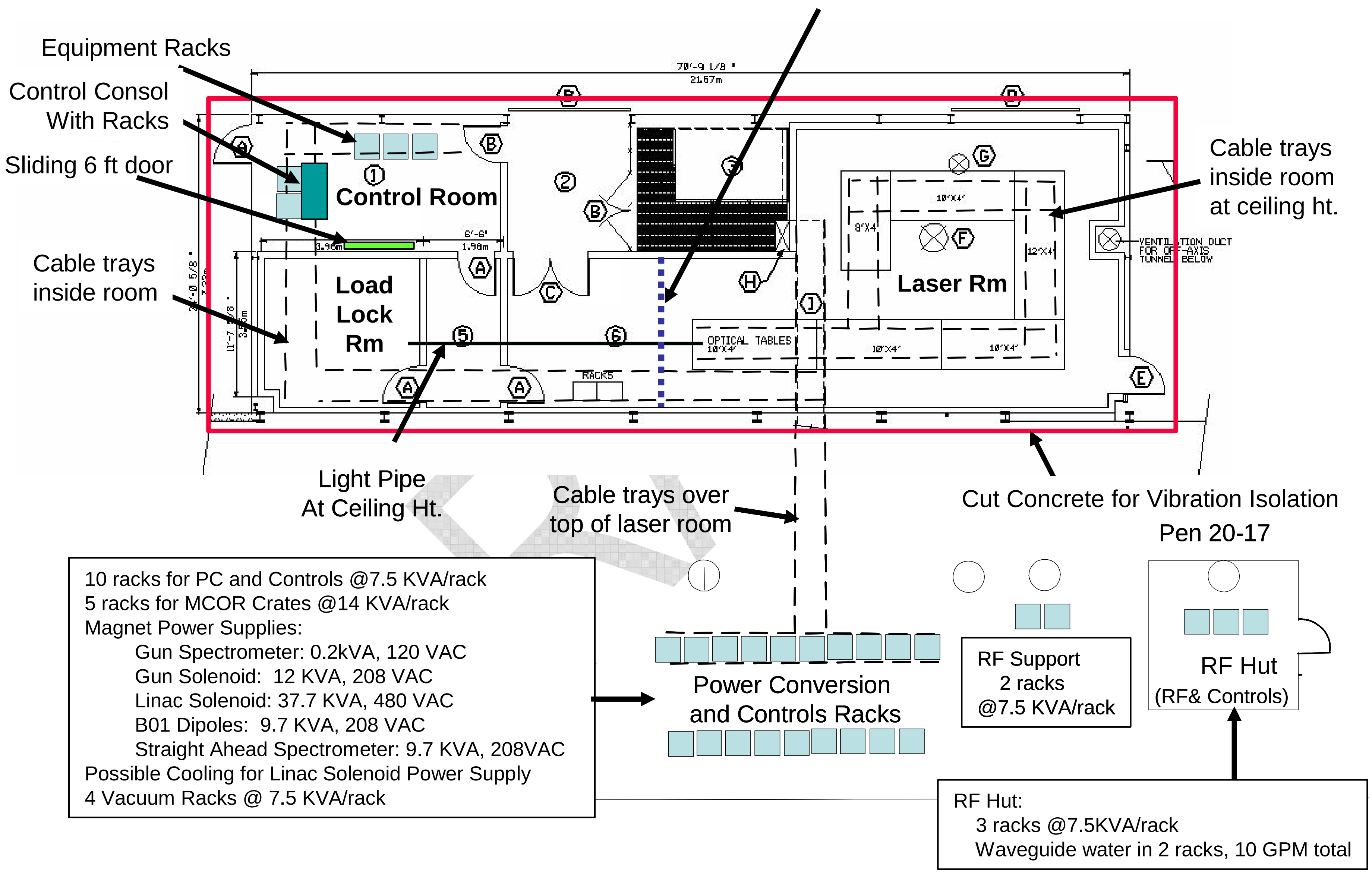
Gun Water Requirements:
- Closed loop chiller, 240VAC, 3phase
- +LCW for heat exchanger

Services along this wall:
- Facility air
- Dry N2
- Magnet cooling water
- Cable tray from upstairs

DL1 dipoles: 1 gal/min each

Straight Ahead Spectrometer: 1.7 gal/min
Possible water for beam dump


KLYSTRON GALLERY
MAIN LINAC TUNNEL
SECTOR No 20
I & C ALCOVE
OFF AXIS INJECTOR ALCOVE
STATION No. 2
FUTURE
10' SLIDING DOOR
PENETRATION 20-P-19 (20-19)
21" PENETRATION FILTER AIR INTAKE
MATERIAL SHAFT
DRIFT SECTION PENETRATION
20' SLIDING DOOR
VACUUM ROUGHING PUMP-OUT
Penetration for RF Hut
Modulator 20-5 used to Power L0 Transverse Accelerator
Modulator 20-6 used to Power RF Gun
Modulator 20-7 used to Power L0 Accelerator #1
Modulator 20-8 used to Power L0 Accelerator #2
Temperature Stabilized RF HUT
Off Axis Injector - RF Gun, Accelerator 1,2, Transverse Deflector
REMOVEABLE PANEL
REMOVABLE SHIELDING
PLAN VIEW
SCALE 1/8 = 1'-0"
KLYSTRON GALLERY
Penetration for 20-5
Penetration for 20-6
Penetration for 20-7
Penetration For 20-8
Penetration for RF Hut
VERTICAL JACK
HORIZONTAL JACK
8" VACUUM FINGER
WAVEGUIDE
VACUUM MANIFOLD
20-G-5
20-G-6
20-G-7
20-G-8
20-G-9
Cables to Linac 1 S-band and X-Band Monitors and Control
LOAD
ACCELERATOR TUBE
SUMP
SUB-DRAIN MAN HOLE
PLAN VIEW
SCALE 1/8 = 1'-0"
ACCELERATOR HOUSING
J.E. GILCHRIST 8-6-14
SECTOR 20
GP 860-313-20 RO
ACC HSG & KLY GAL DEFINITIVE SECTOR 20



10 racks for PC and Controls @7.5 KVA/rack
5 racks for MCOR Crates @14 KVA/rack
Magnet Power Supplies:
  Gun Spectrometer: 0.2kVA, 120 VAC
  Gun Solenoid: 12 KVA, 208 VAC
  Linac Solenoid: 37.7 KVA, 480 VAC
  B01 Dipoles: 9.7 KVA, 208 VAC
  Straight Ahead Spectrometer: 9.7 KVA, 208VAC
Possible Cooling for Linac Solenoid Power Supply
4 Vacuum Racks @ 7.5 KVA/rack

RF Hut:
  3 racks @7.5KVA/rack
  Waveguide water in 2 racks, 10 GPM total

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.

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.

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.

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.

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.

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.

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.

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.

3.3 Undulator System

3.3.1 **Magnets** - There are two types of magnets used in the LCLS undulator system, quadrupole magnets and undulator magnets, both of which are powered by NdFeB permanent magnet blocks.

3.3.1.1 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 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 spares. The undulators will be supported on a five point eccentric cam mounting system. This cam mounting system will allow very accurate remote positioning of each of the 33 undulators. This cam mounting system in on top of a locally adjustable positioner used for initial survey alignment, which in turn rests on top of a stable granite base.

3.3.1.2 Quadrupole Magnets and Supports - The permanent magnet quadrupoles are roughly 10 cm by 10 cm by 5 cm long. The aperture is 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 quadrupoles are supported on a fixed support that is rigidly attached to a cradle that also carries the undulator magnet.

3.3.2 **Vacuum System** - General System Description. 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 is passing through the Undulators in a specially designed vacuum chamber that has polished and copper coated walls to reduce the interaction of the beam with the chamber. Likewise in the breaks between the undulators have diagnostic devices and vacuum components that are used to measure properties of the beam, maintain the vacuum, and machine protection instrumentation.

In maintenance operations there will be equipment attached to the beam-line while work is being performed. In that start-up before standard operations, there will be mobile pumping stations that will pump on the beam-line until the pressure is sufficiently low that the ion pumps can take over. SLAC will be responsible for the mobile pumping stations. 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.

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

3.3.2.2 Bellows Assembly - The Bellow performs two tasks: one it has movable ends to adjust to the actual length of component while the walls are a vacuum barrier, and it has a central channel (liner) that the beam projects through. This assembly weighs approximately 10 lbs.

3.3.2.3 Short Diagnostic Break - This has some vacuum spools, a Tee fitting, 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.

3.3.2.4 Long Diagnostic Break - 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 suite of e-beam and x-ray instruments where there will be optical images that will be projected into nearby lens and cameras. For this there will be glass/quartz/sapphire windows for the images to pass-through. It is possible for the motors in the vacuum and the filters directly in the beam path that some water cooling will be needed, this is still to be determined.

3.3.2.5 Entrance Section - The entrance section contains vacuum spools, ion pumps, vacuum gauges, residual gas analyzers (RGA), pump-out valves, and gate valves. The vacuum gauge has on one leg of the connector 4,000 V to set the potential inside of the gauge. The RGA 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.

3.3.2.6 Exit Section - This has a lot 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 not gas purge on this pump and it will be vented from the top to equalize the pressure on 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 it off 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 do not want people in the tunnel.

3.3.2.7 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, and 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 controlled.

3.3.3 <u>Diagnostics</u> - There are four types of diagnostics used within the undulator: fro-based beam position monitors, wire scanners, optical transition radiation detectors, and Cerenkov detectors.

3.3.3.1 RFBPMs - 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 process with a passive local 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.

3.3.3.2 Wire Scanners - Wire scanners are used to provide profile information of the electron beam in the LCLS. In a wire scanner a thin wire is sweeped 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. This current and position information will be sent to the control system for processing into beam distribution and position information. The wire scanners 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. There will be a total of 11 wire scanners along the length of the undulator system.

3.3.3.3 Optical Transition Radiation Detectors - There are 11 identical optical transition radiation detectors located along the length of the undulator system. These consist of simple translation stages used to insert a thin flat surface into the path of the beam. When electrons pass through this surface they set of image currents and these currents in turn generate a short burst of light. The result is an image on the surface of the OTR screen that is representative of the electron bunch transverse distribution. This light is optically transported to a nearby camera system that captures the image. This captured image is sent to the controls system for further processing.

3.3.3.4 Cerenkov Detectors - Thirty three Cerenkov detectors are installed at regular intervals along the length of the undulator system as a means to detect unwanted radiation. 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.

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

3.3.4.1 Motion - The cam movers beneath the undulators will be driven with servo motors including integrated brakes. These motors do not require current to hold their position. Control will be via multi-conductor cable run back to the equipment alcoves. There are five motors per undulator. The scanning wire motion will be done with stepper motors as specified by the SLAC scanning wire design. It is expected that these motors will be small in comparison to the undulator movers and will not require holding current when the scanning wire is not in use.There are 11 total scanning wire diagnostics.

Diagnostic camera control motion will consist of motor driven focus and iris stages. These will be moved via stepper motor controls in the same fashion as that of the scanning wire. There are a total of 11 diagnostic cameras which monitor the OTR stages. Finally, the EBD stage motion will also be done via stepper motors in the same manner as the other stepper based platforms. There are 11 EBD stages.

3.3.4.2 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 Scanning Wires also require this type of analysis.

3.3.4.3 Video - Each of the 11 OTR stages require one high resolution (4M pixel) camera connected to a PC based video capture system for analysis. Communication to the camera will be done with multi-conductor cable run from the camera to the equipment alcoves.
There will be seven general observation video cameras used for visual inspection of the undulator hall and specific parts of the diagnostic line. The video cables will be routed to the nearest equipment alcove.

3.3.4.4 Temperature - Temperature monitoring of the undulators will be done with thermocouple sensors connected to controllers in the equipment alcoves. The thermocouple cable will be home run to each alcove and terminated at the controllers.

3.3.4.5 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 residual gas

3.4 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.

3.4.1 Electron Dump Systems

3.4.1.1 Fast Close Valve - The fast-close-valve is a fast (< 0.1sec) 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.

3.4.1.2 Fixed Mask - The 3 Fixed Masks insure that all radiation allowed downstream is confined to within a very small angular region. The masks are cm thick blocks of hi-z material with a TBD (~4 mm) clear aperture in the center.

3.4.1.3 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. The jaws are x-ray mirrors designed to reflect the FEL beam. This prevents the jaws from being damaged when inadvertently struck by the FEL.

3.4.2 FEE Systems

3.4.2.1 Gas Attenuator - The gas attenuator is a 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, Ar and Xe at pressures up to 150 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. There are 3 schemes under consideration for windowless operation:

- Tilted nozzles and baffles to direct the escaping gas into the mouth of a pump.
- Plasma windows to hold off much of the gas.
- Rotating slots that limit the duty cycle of the gas leak.

In cases 1 and 2, large amounts of gas must be circulated through the gas attenuator.

3.4.2.2 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.

3.4.2.3 Slit B - Slit B is similar in design and purpose to Slit A.

3.4.3 NEH Hutch 1 Systems

3.4.3.1 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.

3.4.3.2 Imaging Diagnostic tank -This tank is a 2 m x 1 m ss tank and vacuum system housing the imaging diagnostics and associated rails and stages for positioning them.

3.4.3.3 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.

3.4.3.4 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. The Be mirror will be damaged by the FEL if it is not at the correct angle and/or possibly at low photon energies.

3.4.3.5 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.

3.4.3.6 **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.

3.4.3.7 **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.

3.4.4 Tunnel Systems

3.4.4.1 Flipper Mirror - The flipper mirrors are a set of two or more mirrors, located in a differentially pumped tank at the beginning of the tunnel. 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.

3.4.4.2 Tunnel Beam Pipes -The beam transport mechanical and vacuum system contains approximately 900 meters of vacuum beam pipe maintained at 10^{-7} Torr by approximately 140 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.

3.4.4.3 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.

3.4.4.4 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

3.5 X-Ray Endstation Systems

X-Ray Endstation 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 the synchronized laser systems in the NEH and FEH. All x-ray PPS/MPS activity for LCLS is included in section 1.6, along with laser PPS and other experiment-related user safeguards.

Technical Systems

3.5.1 **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.

3.5.2 **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, another in the FEH. 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.

3.5.3 **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.

3.5.4 **Cable Plant** - The Endstation 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

Safety Analysis

4.1. **Safety Analysis** - The identification of hazards for LCLS began with a project review by the SLAC Safety Overview Committee, which coordinates and assigns safety reviews for new projects to other citizen committees, who have hazard knowledge or skills in a specific area. Following this was an internal review of the different systems that define the projects infrastructure and an assessment of proposed activities to define what type of hazards may be encountered. This, along with ongoing examination of sub-systems, tasks and activities via meetings, reviews, etc. is used to identify potential hazards, and mitigate them in a timely manner.

4.2. **Ionizing Radiation** - The design and operation of all radiation producing facilities at SLAC are governed by the ALARA (as low as reasonably achievable) policy. SLAC has always maintained radiation dose limits below the maximum allowed by regulation. LCLS project staff, the SSRL Safety Office and SLAC Radiation Protection Department have meet and will continue to work closely together to review the proposed LCLS project. Discussions include review of designs, changes to existing shielding, changes or modifications to the PPS and BCS systems together with the review and approval of future operating parameters.

4.2.1. Radiation Shielding

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). Under normal operation the design criterion will be

(i) 1 rem/yr at 30 cm from the shield surface, assuming a 2000 hr working year and an occupancy factor of 1. In addition as the LCLS will have non-radiological workers (Users), additional shielding may be required to maintain their annual effective dose equivalent below 0.1 rem/yr taking exposure duration and occupancy factors into account. SLAC's internal design criteria also requires that under a system failure (ii) the effective dose equivalent shall 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 of the beam (iii) the maximum dose equivalent shall not exceed 25 rem averaged over a 1 hour period.

Existing shielding will be reviewed to determine its adequacy with respect to the LCLS design and operation parameters. Radiation hazards identified during this process will be mitigated to acceptable values through the addition of localized shielding, the use of engineered controls (ACM's etc.), beam collimators, active electron beam loss monitoring systems (LION's). Defining the type and amount of local shielding is dependent on the final configuration of the LCLS accelerator and beamlines.

4.2.2. Personnel Protection System

The personnel protection system (PPS) consists of electrical interlocks and mechanical barriers whose primary function is to prevent entry of personnel into a radiation enclosure when beam is operating, and to turn the beam off when a security violation is detected. Other functions it must also accomplish are (i) provide interlocks for the orderly searching of an area before beam is turned on, (ii) allow for various access states, such as No Access, Controlled Access or Permitted Access, (iii) have emergency shut-off capabilities, (iv) control the electrical hazards in beam housing areas.

4.2.3. 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. Beam containment is usually accomplished by a combination of passive devices such as collimators that are designed to absorb errant beams and active devices such as electronic monitors that shut off the beam when out of tolerance conditions are detected. A typical BCS consists of passive mechanical devices such as slits, collimators, magnets, electron beam stoppers, dumps, photon beam stoppers, and injection beam stoppers. Active electronic devices include average current monitors, burn through monitors, and beam shut off ion chambers. The LCLS will incorporate all of the above, however while their design and location may change, their functionality will not.

4.2.4. Radiation Safety Training.

In accordance with SLAC's Site Access, ES&H Training, and Radiation Dosimetry Policies and Procedures[ii], all individuals at SLAC who enter the Radiologically Controlled Area (RCA) or the Accelerator Area must be either properly trained or escorted by a properly trained individual. Levels of training depend on the area to be accessed and in some cases the duration of the individuals stay.

4.3. **Electrical Safety -** An accelerator facility has subsystems that either produce high voltage or high current. Either of which can present an electrical hazard to personnel if not managed properly. As the LCLS will operate in a similar mode to the present machine, control and work procedures for electrical subsystems, as well as entry into the accelerator housing are well understood. Primary mitigation of the hazard will be through de-energization of equipment and the effective 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[iii], and SLAC ES&H Manual, (Chapter 8). Entry into the accelerator housing will require the complete lock down of all electrical hazards, the application of group lockout/tagout hardware and personnel locks as appropriate. 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. Various levels of electrical safety training and Lock and Tag training are provide 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.

4.4. **Non-Ionizing Radiation** –

4.4.1. RF Radiation

The LCLS will use radio frequency radiation which when not controlled could have an adverse health effect on personnel working on or near the system. The LCLS will incorporate safety measures based on present operations and enforce the strict adherence to procedures for installation and testing of the RF system. Wave guides will be primarily be under Ultra High Vacuum (10E-7/10E-8 torr) for operations. A leak in the wave guide will cause a pressure rise, actuation of a pressure switch interlock, and shutdown of the RF producing devices. Running the system under vacuum, guards mainly against operation of the system 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 that 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 the completion of RF leak testing after all installations and maintenance activities, and periodically before start up of the system after scheduled shutdowns.

4.4.2. Lasers Radiation

Laser 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, which establishes hazard classifications based on the laser's ability to cause biological damage to the eye or skin. SLAC also requires Laser Operators to be trained in Laser Safety, so that personnel can identify and categorize laser hazards and know how to effectively control them.

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

4.5. Emergency Preparedness - 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.

4.5.1. Seismic Safety

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.

4.5.2. Emergency Planning

The design, review, installation and operation of all experimental equipment at SLAC, is done in a manner that minimizes the risk of accident or injury to personnel and property in the event of either a natural disaster or emergency situation. SLAC's formal emergency planning system as described in the SLAC Emergency Preparedness Plan[iv] will help ensure a logical, organized, and efficient site wide response to any emergency. Facility specific procedures[v] which supplement the SLAC plan, support a timely initial response, further decreasing the probability of personal injury and limiting potential loss or damage to both property and the environment.

4.6. **Construction Safety** - During construction operations, oversight of subcontractor activities and safety compliance remains a line organization responsibility through the University Technical Representative (UTR) or Project Engineer, if a UTR is not assigned to the activity. Experience to date indicates that communication is the key element to maintaining a “safe” workplace during this active period. The SLAC UTR meets with construction sub-contractors on a daily basis to review ongoing activities, which includes safety practices or issues identified on the job site. The LCLS ES&H officer has stop work authority on such projects and has an active presence on the job site. 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 SLAC Quality Assurance and Compliance Design Assurance and Construction Inspection Procedure (SLAC-I-770-0A22C-001). Responsibilities 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 periodic 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.

Enforcement of subcontractor requirements is carried out by the SLAC Purchasing Department and may involve with holding payment(s) if applicable codes and standards are not met.

4.7. **Hazardous Materials** - During the installation and operational phases of the LCLS it is anticipated that a minimum amount of hazardous materials will be used. Examples would be paints, epoxy's, solvents, oils and lead in the form of shielding. There are no current or anticipated activities at the LCLS that would expose workers to levels of 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 Hazardous Materials Management Handbook, and the SLAC ES&H Manual (Chapter 4, Hazard Communication) which describes minimum standards to maintain for compliance with Code of Federal Regulations (CFR), 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.

4.8. **Fire Safety -** 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 to be written for the LCLS Project, with DOE approval.

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.

4.9. **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, air quality as well as to minimize any ground disturbing activities.

4.10. **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.

4.11. **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.

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Operational Safety Requirements

5.1 Operational Safety

Upon completion of the LCLS, the accelerator will become operational and enter a period of commissioning before routine operations commence. At SLAC before any accelerator facility can operate, a Beam Authorization Sheet (BAS) is required to 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 BAS is issued and approved jointly by the cognizant Radiation Physicist for the facility and the applicable Safety Office. It is signed by the accelerator operator on duty at every shift change, thus noting and acknowledging any changes to the BAS.

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.

5.2 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 accident 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/event	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

5.3 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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Approvals

This Preliminary Safety Assessment Document is concurred and approved by:

SLAC LCLS Project Manager

John Galayda

SSRL Division Associate Director

Keith Hodgson

Appendix 1 –

San Francisco Peninsula Area Map

San Francisco Peninsula Area Map

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	None	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
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	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	Unlikely	Marginal

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
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

Item	Hazard	Causes	Prevention/ Mitigation Means	Potential Impact	Consequences	Likelihood	Risk
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
15	High Magnetic Fields Fringe fields	RASK entry Routine or unplanned maintenance of undulator system or electron beam dump.	Training Use of SLAC IH program for monitoring exposed individuals PPE Barriers	Personnel injury or exposure Property loss	Low	Unlikely	Acceptable
16	Oxygen Deficiency	Use of LN2 Leak of inert gas for vacuum system (Helium, Nitrogen)	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. In as much hazards have been identified for the LCLS project and SLAC/SSRL has a system in place that can address and mitigate hazards on a real time basis.

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References