LUSI

LCLS Ultrafast Science Instruments

| PROJECT MANAGEMENT DOCUMENT | Doc. No. PM-391-001-34 R0 | LUSI SUB-SYSTEM 1.1 Management |
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# Hazards Analysis Report

Technical Contact: Nadine Kurita
LUSI Chief Engineer

Signature Date

Approved by: Tom Fornek
LUSI Project Manager

Signature Date

Approved by: John Galayda
LCLS Project Director

Signature Date

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# 1. INTRODUCTION

This Hazard Analysis Report (HAR) has been prepared for the Linac Coherent Light Source Ultrafast Science Instruments (LUSI) project as part of the Critical Decision 2 (CD-2) process according with requirements of DOE Order 413.3A, Program and Project Management Practices. The HAR reflects that the project is being developed following SLAC Integrated Safety and Environmental Management System (ISEMS) principles and the DOE Accelerator Safety Order, DOE O 420.2A. The LUSI project will design, build, install and test three instruments to be used in conjunction with the Linac Coherent Light Source (LCLS). The instruments will comply with and operate within the bounds of the approved LCLS Accelerator Safety Envelope (ASE).

## 1.1 PURPOSE AND SCOPE

The purpose of this HAR is to identify hazards associated with the design and operation of the LUSI project; assess risk; and establish controls needed to eliminate or reduce the associated risk to acceptable levels. Hazards capable of causing injury to personnel, damage to the environment, or damage to critical hardware have been considered in this analysis.

This HAR documents the safety analysis of the LUSI instrument design and operation. A separate Operating and Support Hazard Analysis (O&SHA) will be developed for the LCLS experiments. The O&SHA will evaluate activities for hazards introduced into the system by operational and support procedures.

## 1.2 ENVIRONMENT, WORKER AND PUBLIC SAFETY

During the design of the LUSI instruments a concerted effort has been made to eliminate hazards where possible and implement engineering controls in order to protect the public workers and environment. The most significant potential hazard associated with the LUSI instruments is that associated with prompt ionizing radiation. This radiation is limited to regions where the beam is present and radiation will only result when a beam is present. The LUSI instruments will be designed to the standards defined in 10 CFR 835 that defines radiation protection standards for the protection of individuals from ionizing radiation. The SLAC interpretation of these standards is promulgated in SLAC's Radiological Control Manual.

The Environmental Assessment developed for the LCLS resulted in a DOE Finding of No Significant Impact (FONSI) encompassed the physical space occupied by LUSI and its operations.

Integrated Safety and Environmental Management System (ISEMS) principles have been integrated into the management of the LUSI design and will also be applied in the development of its proposed operating procedures. LUSI is also assuring that safety is integrated into the design and construction of project instrumentation consistent with the DOE position taken in the Deputy Secretary of Energy's Memorandum *Integrating Safety* *into Design and Construction*[1] and the requirements of DOE Order 413.3A *Project Management for the Acquisition of Capital Assets.*

Safety parameters of the beam available to the LUSI instrumentation and operating environment have been defined in the Accelerator Safety Envelope (ASE) developed for the LCLS. Details regarding the ASE can be found in the LCLS Safety Assessment Document (SAD).

Environmental protection, worker safety and LUSI relations with stakeholders and the community are based on the direction provided by SLAC's:

- Environmental Management System (EMS),
- Environmental, Safety, Security and Health Policy; and
- Experiment Safety Review Procedures

# 2. SUMMARY

## 2.1 OVERVIEW OF HAZARDS

No previously unidentified safety hazards were found in the development of this HAR beyond the hazards addressed in the LCLS Safety Assessment Document.

The results of this Hazards Analysis Report were consistent with those of the LCLS analysis that resulted in a low hazard facility determination following the criteria defined in DOE-O 420.2B Safety of Accelerator Facilities, based on the following findings:

1. LCLS requirements for SLAC Linac operations are well within existing safety and operating envelopes of the facility. While the peak brightness of the LCLS x-ray beam is unprecedented; it should be understood, that this peak brightness is a measure of the instantaneous power density. The average power of the LCLS x-ray beam, the energy and power of the electron beam, and hence radiation hazard they pose are all well within the range of applicability for SLAC and SSRL shielding and safety systems. Radiation shielding analysis revealed that the LCLS presents some complex geometry questions, however the models used to provide minimum shield wall thickness are well understood.
2. The risk (probability & severity) of all hazards will be similar in nature and magnitude to those already found in the present accelerator storage ring experimental programs. The impact of any hazard will be minor onsite and negligible off-site to people or the environment.
3. Existing and mature programs (citizen safety committees, ES&H division, LCLS ES&H Coordinator) will be engaged to ensure that all aspects of the design, installation, and testing phases of the LUSI project will be properly managed and that they conform to the applicable Work Smart Standards that SLAC has adopted and written into its contract with the DOE.

[1] Integrating Safety into Design and Construction, Clay Sell Memo, Dated December 5, 2005

4. That Integrated Safety and Environmental Management System (ISEMS) has been fully implemented at SLAC via the DEAR clause and incorporated through the contract between Stanford University and DOE in 1998.
5. The LCLS Environmental Assessment did not identify any previously unrecognized hazards or conditions that would adversely affect worker safety and health or the environment during the assembly and installation of the LUSI instruments.
6. DOE's Office of Science classified SLAC as a **"Radiological Facility";** following criteria defined in the DOE Standard "Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports", DOE-ST-1027-92, December 1992.

### 2.2 COMPREHENSIVENESS OF THE SAFETY ANALYSIS

This HAR was developed following the requirements of DOE Order 420.2, Safety of Accelerator Facilities. The Laboratory and project ESH organizational support for the development and assembly of the LUSI components have been addressed. Occupational health and safety hazards, and environmental aspects of the facility have been identified and controls described. A Fire Hazard Analysis developed for the LCLS project includes the area occupied by the LUSI project. No previously unreviewed safety issues were identified in the preparation of the LUSI HAR.

Radiological occupational exposures will be maintained As Low as Reasonably Achievable (ALARA), consistent with SLAC objectives. Shielding configuration and maintenance of that configuration will be developed according to SLAC policies and procedures.

### 2.3 APPROPRIATENESS OF THE ACCELERATOR SAFETY ENVELOPE

The LCLS Accelerator Safety Envelope (ASE) contained in the LCLS Injector Safety Assessment Document (SLAC-I-010-30100-015-R001) will apply to LUSI. This ASE was been established in accordance with the requirements set forth in DOE Order 420.2B. No revisions to the current ASE are suggested on the basis of the LUSI operation.

## 3. PROJECT DESCRIPTION

The Stanford Linear Accelerator Center (SLAC) is a national research facility operated by Stanford University for the U.S. Department of Energy (DOE). Research at SLAC centers around experimental and theoretical particle physics using accelerated electron beams, and a broad program of atomic and solid state physics, biology and chemistry using synchrotron radiation from accelerated electron beams.

The Linac Coherent Light Source (LCLS), funded by DOE’s Office of Basic Energy Sciences (BES) currently under construction at SLAC, will serve as a research and development center for X-ray Free Electron Laser (XFEL) physics in the hard x-ray regime and as a scientific user facility for the application of XFEL radiation to experimental science. It will bring a completely new dimension to the use of x-rays to study matter through its unique properties that have never before been available. Currently synchrotron light sources produce x-rays to study how atomic structures affect the properties of materials, but synchrotron light sources cannot produce ultra-short pulses, so they cannot resolve the ultra-fast motions of atoms during chemical reactions. The LCLS is a revolutionary advance within the synchrotron radiation world, since it produces the x-rays associated with synchrotron light sources, in ultra-short and ultra-intense pulses. The tremendous brightness of the LCLS x-ray pulse will also be invaluable for imaging the atomic structures of small static objects. Individual single molecules or small clusters of molecules may also be able to be imaged.

The LCLS Ultrafast Science Instruments (LUSI) project will augment the LCLS's initial instrument which is directed towards atomic physics, with three x-ray instruments in order to exploit the unique scientific capability of this new facility. LUSI plans to build these devices over a period of six fiscal years (2007 – 2012). One of two instruments will be optimized for hard x-ray studies of ultrafast dynamics at the atomic level, addressing basic problems in chemistry and materials science. The second instrument will concentrate on hard x-ray coherent imaging of nano-particles and large biomolecules. The third instrument will study equilibrium dynamics on the nanometer scale using hard x-rays.

## 3.1 X-RAY PUMP/PROBE DIFFRACTION INSTRUMENT

The X-Ray Pump Probe Diffraction (XPP) instrument will predominantly use a fast optical laser to generate transient states of matter, and the hard x-ray pulses from the LCLS to probe the structural dynamics initiated by the laser excitation. The laser pump will have the ability to conduct precise optical manipulations, in order to create the desired excited states. An ultrafast laser pulse excites a brief change in the positions of the atoms in the sample. This change is studied using diffraction of the LCLS x-ray pulse, which follows the laser pulse after a precise time delay.

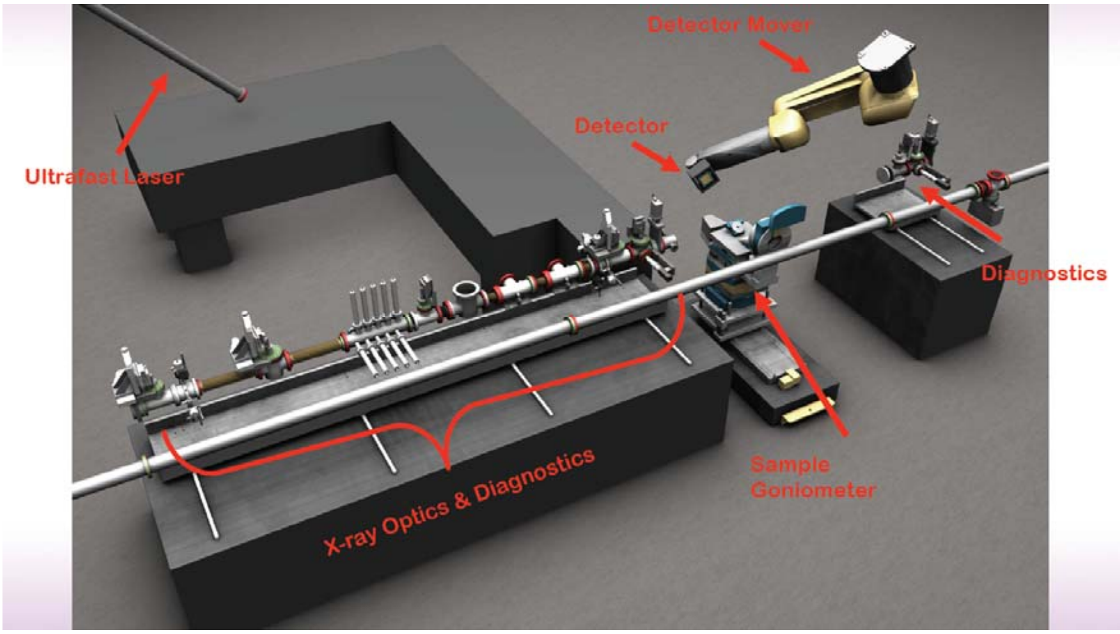

**Figure 3.1.1: Pump Probe Diffraction Instrument**

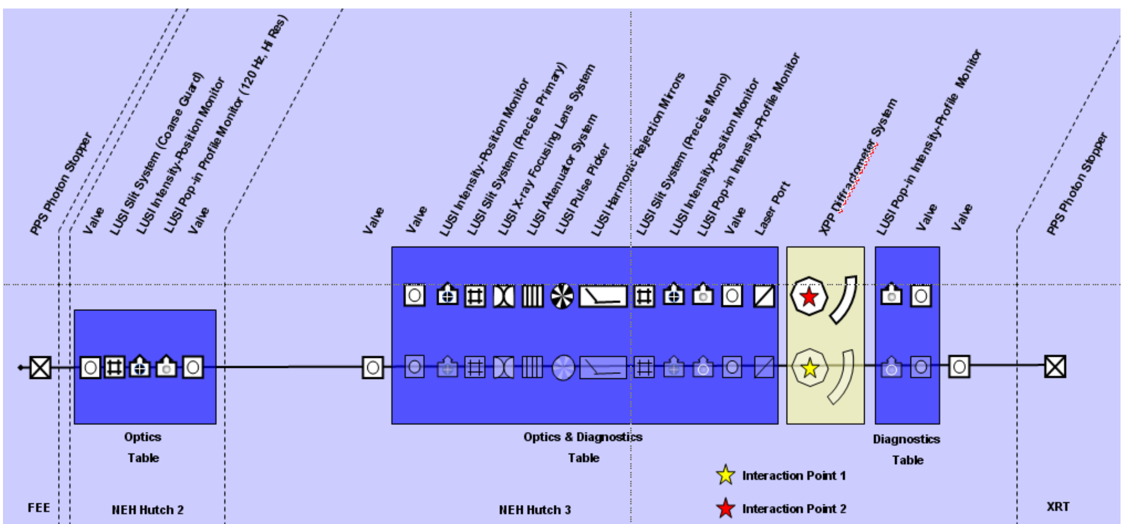

**Figure 3.1.2: Pump Probe Instrument Schematic**

## 3.2 COHERENT X-RAY IMAGING INSTRUMENT

Coherent x-ray imaging can potentially provide a new horizon of imaging nanoscale materials and large single macromolecules at or near atomic resolution in three dimensions. Resolution in these experiments would not depend on sample quality in the same way as in conventional crystallography, but would be a function of radiation intensity, pulse duration, wavelength, and the extent of ionization and sample movement during the exposures. The full peak brightness of the LCLS is fully exploited when imaging biological materials such as viruses and single macromolecules. The penetration depth of hard x-rays in combination with the coherent nature of the radiation will permit detailed 3D study of large, non-periodic structures, and provide capabilities that will go beyond conventional scanning probe microscopy, electron microscopy or x-ray crystallography.

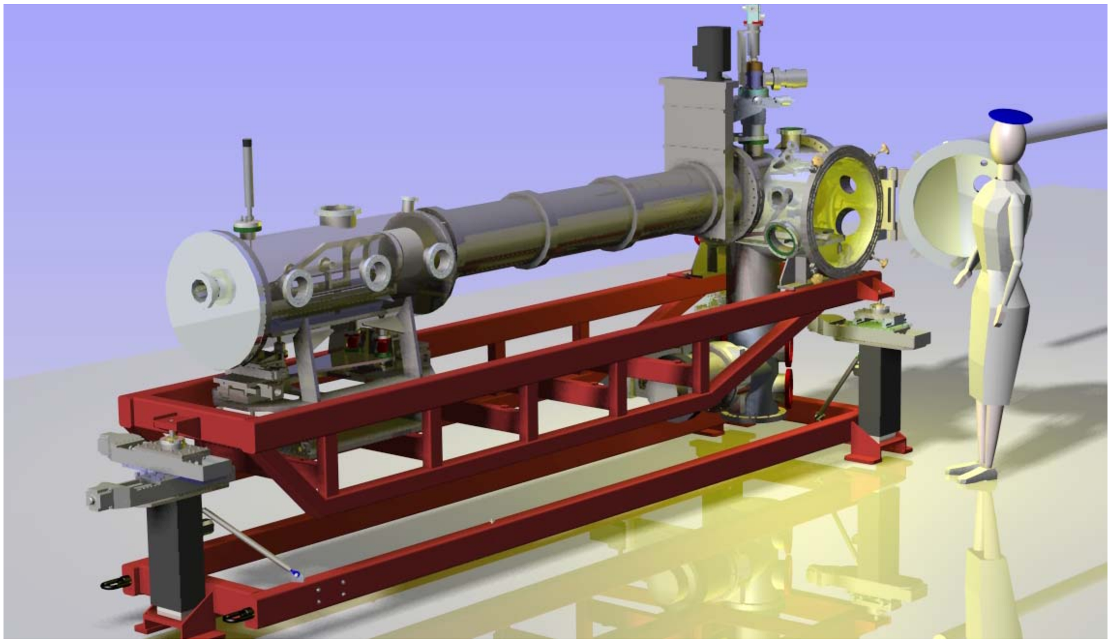

**Figure 3.2.1: Coherent X-Ray Imaging Instrument**

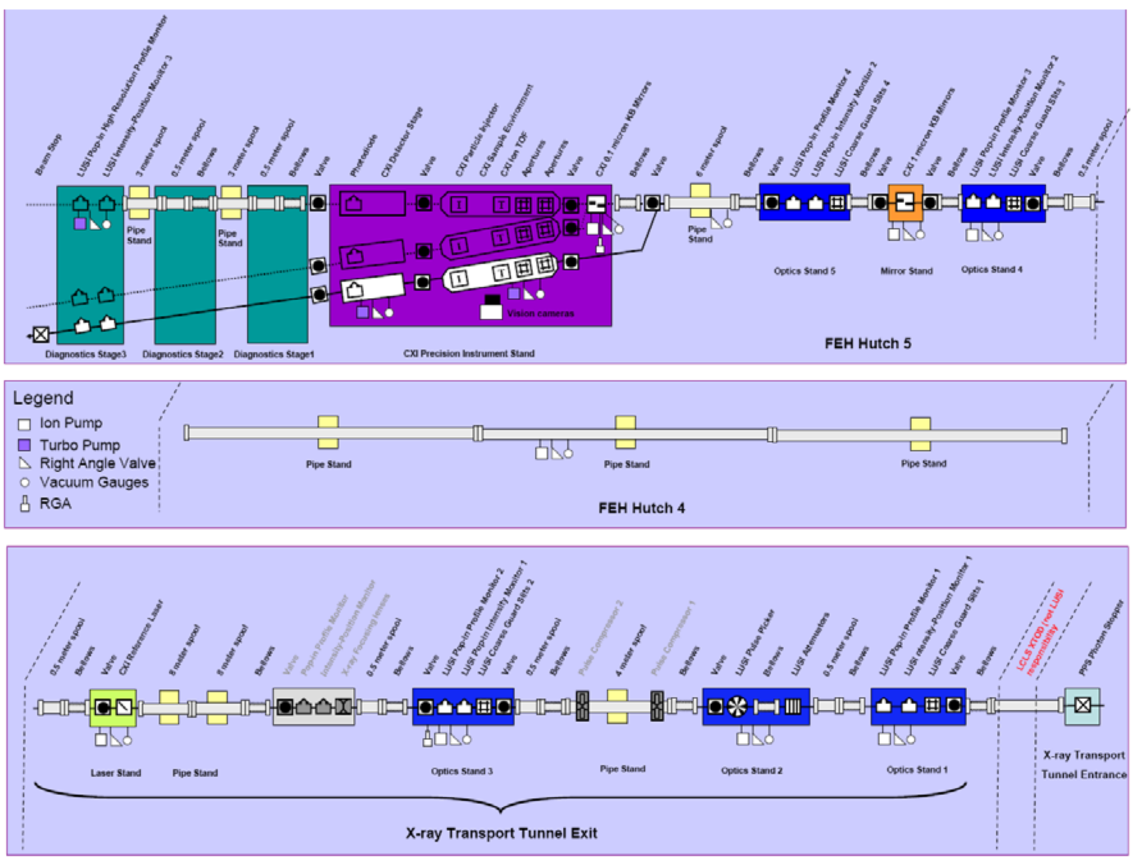


**Figure 3.2.2: Coherent X-Ray Imaging Instrument Schematic**

## 3.3 X-RAY PHOTON CORRELATION SPECTROSCOPY

The unprecedented brilliance and narrow pulse duration of the LCLS provides a unique opportunity to observe dynamical changes of large groups of atoms in condensed matter systems over a wide range of time scales using X-ray Photon Correlation Spectroscopy (XCS). In contrast to the study of stimulated dynamics (pump-probe), the XCS technique studies equilibrium fluctuations excited by the thermal energy of the sample. Images of the speckle scattering pattern are taken with various time delays between images, and the change in the speckle pattern as a function of time delay is used to study the sample dynamics.

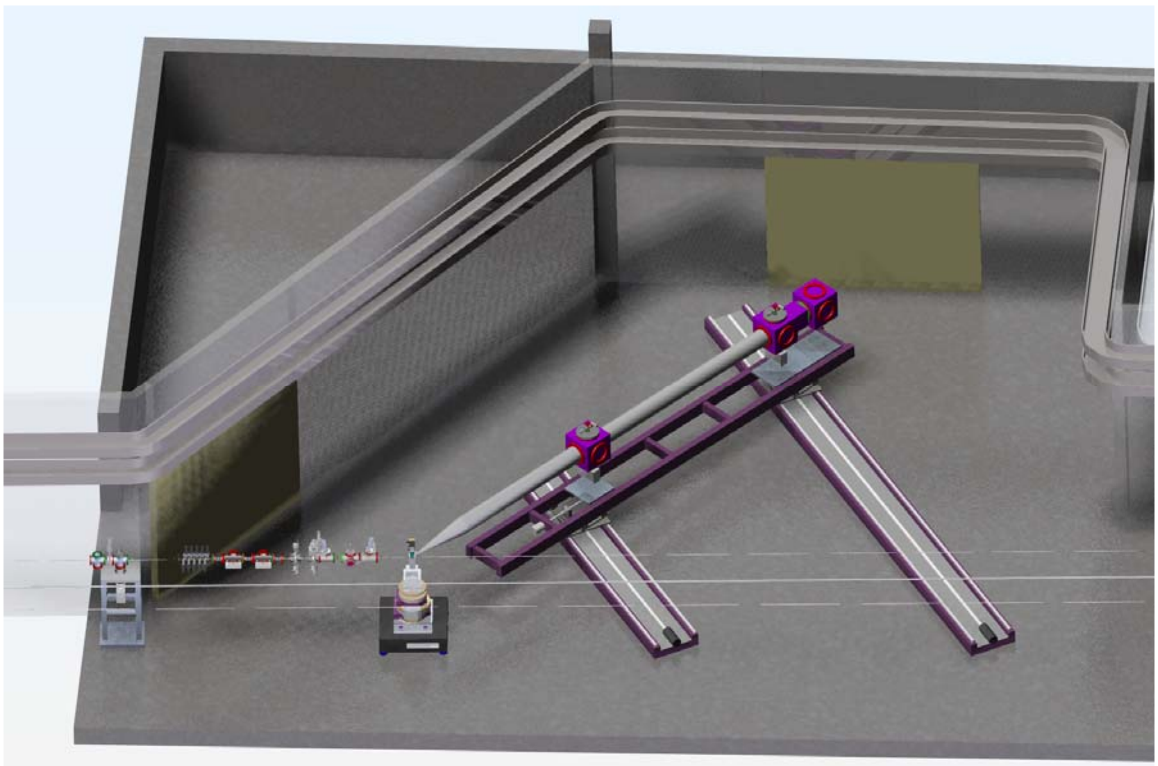

**Figure 3.3.1: X-Ray Photon Correlation Spectroscopy**

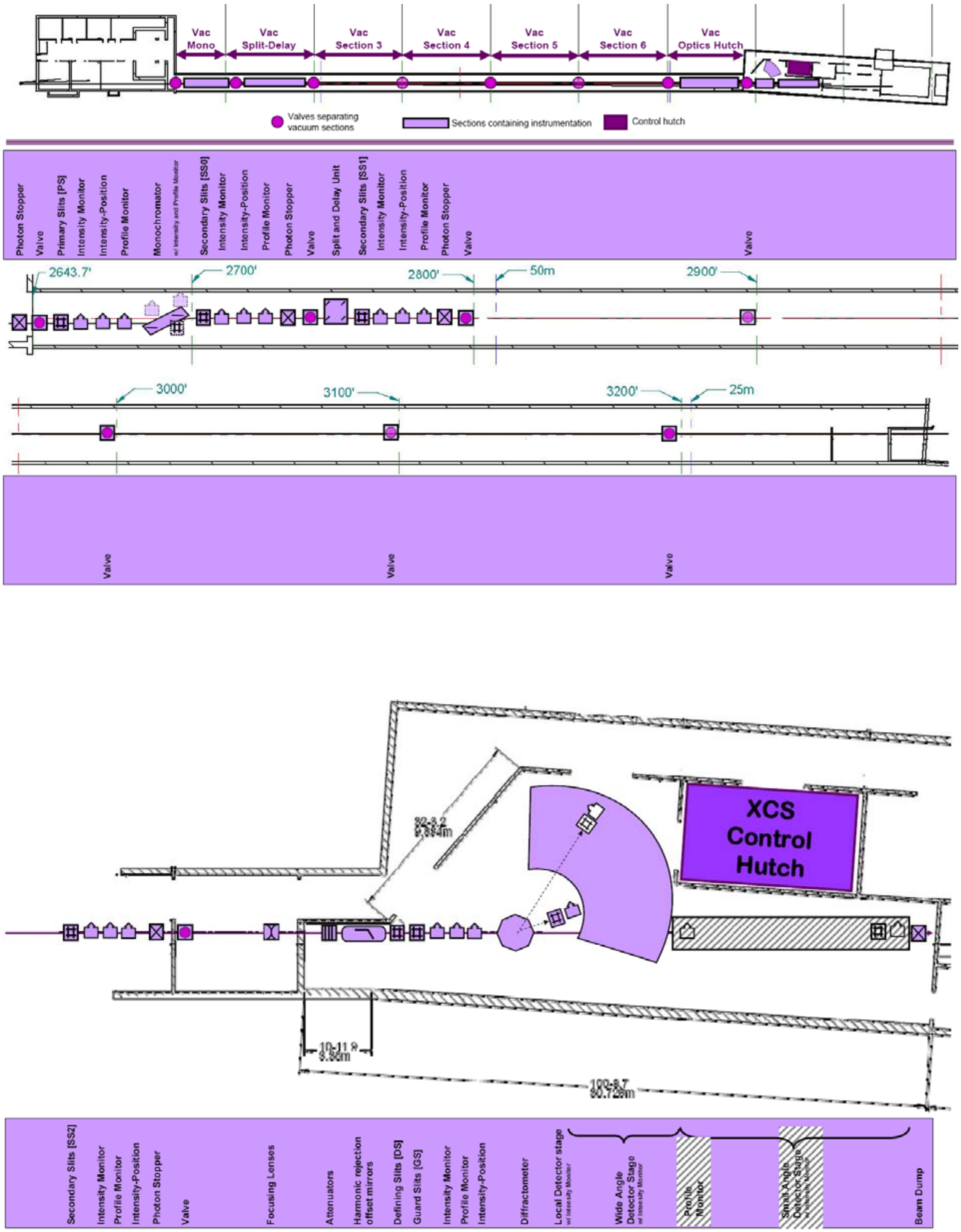


**Figure 3.3.2: X-Ray Photon Correlation Schematic**

# 4. METHODOLOGY

It is SLAC's policy and objective to integrate safety and environmental protection into its management and work practices at all levels, to accomplish its mission while protecting the worker, the public, and the environment. To achieve this objective, SLAC has developed and implemented an Integrated Safety and Environmental Management System (ISEMS), required by DOE P450.4, Safety Management System Policy, which encourages and supports the use of the Work Smart Standards process, development of measurable goals in the form of performance metrics, and uses existing programs and activities that have been deemed successful and which already incorporate the ISEMS elements. ISMES is implemented through the incorporation of a contract clause from the DOE Acquisition Regulations (DEAR), specifically DEAR 970.5204.-2, "Integration of Environment Safety and Health into Planning and Execution". This clause was incorporated into the contract between DOE and Stanford University for operation of SLAC in February 1998.)

Existing and mature programs at SLAC will be used to ensure that all aspects of the design, installation, and testing phases of the project are properly managed. The LUSI project has been presented to the SLAC Safety Overview Committee, which coordinates and assigns safety reviews for new projects or facility modifications to other citizen committees, which have knowledge or skills in a specific area. The hazards for the LUSI may require reviews from committees including but not limited to: Radiation Safety Committee, Electrical Safety Committee, Earthquake Safety Committee, Hazardous Experimental Equipment and the Fire Protection Safety Committee.

Safety requirements are identified through the Work Smart Standard process employed at SLAC and are based on known and identified potential hazards. Appendix A identifies these possible hazards and provides a risk determination summary for the LUSI project. All aspects of the project will conform to the applicable Work Smart Standard that SLAC has adopted and written into its contract with the DOE.

LUSI's ES&H program planning will be standards-oriented. The LUSI project will require its technical managers to address ES&H standards and requirements in their work planning before authorizing work (or purchases) to proceed.

## 4.1 HAZARD ASSESSMENT

The hazard assessment process is a principal factor in the understanding and management of technical risk. Hazards are identified and resultant risks are assessed by considering probability of occurrence and severity of consequence. Risk will be assessed qualitatively. System Safety is an integral part of the overall program risk management decision process.

The hazards have been rated and tabularized in Appendix A, based on the following criteria

#### 4.1.1 Hazard Severity Categories

Severity is an assessment of the worst potential consequence, defined by degree of injury or property damage, which could occur. There are four categories of hazard severity: Class I, Catastrophic; Class II, Critical; Class III, Marginal; and Class IV, Negligible. Figure 4-2 depicts these categories and provides a general description of the characteristics that define the worst-case potential injury or system damage if the identified hazard were to result in an accident. These categories are derived from MIL-STD-882D, Standard Practices for System Safety.

#### 4.1.2 Hazard Probability Categories

Probability is the likelihood that an identified hazard will result in a mishap, based on an assessment of such factors as location, exposure in terms of cycles or hours of operation, and affected population. There are five levels of probability: Level A, Frequent; Level B, Probable; Level C, Occasional; Level D, Remote; and Level E, Improbable. Figure 4-3 depicts these levels and provides a general definition for each probability levels. These levels are derived from MIL-STD-882D, Standard Practices for System Safety.

| CLASS | DESCRIPTION | POTENTIAL CONSEQUENCES |
|---|---|---|
| **I** | CATASTROPHIC | A condition that may cause death or permanently disabling injury, facility destruction on the ground, or loss of crew, major systems, or vehicle during the mission |
| **II** | CRITICAL | A condition that may cause severe injury or occupational illness, or major property damage to facilities, systems, equipment, or flight hardware. |
| **III** | MARGINAL | A condition that may cause minor injury or occupational illness, or minor property damage to facilities, systems, equipment, or flight hardware. |
| **IV** | NEGLIGIBLE | A condition that could cause the need for minor first aid treatment though would not adversely affect personal safety or health. A condition that subjects facilities, equipment, or flight hardware to more than normal wear and tear. |

**Figure 4.1.2.1: Hazard Severity Classification**

| LEVEL | FREQUENCY OF OCCURRENCE | DEFINITION |
|---|---|---|
| **A** | Frequent | Likely to occur frequently. ($X > 10^{-1}$) |
| **B** | Probable | Will occur several times in the life of an item. ($10^{-1} \geq X > 10^{-2}$) |
| **C** | Occasional | Likely to occur some time in the life of an item. ( $10^{-2} \geq X\ 10^{-3}$) |
| **D** | Remote | Unlikely, but possible to occur in the life of an item. ($10^{-3} \geq X > 10^{-6}$) |
| **E** | Improbable | So unlikely, it can be assumed occurrence may not be experienced. |

**Figure 4.1.2.2: Hazard Probability Levels**

### 4.1.3 Mishap Risk Assessment

The Risk Assessment Value is a numerical expression of comparative risk determined by an evaluation of both the potential severity of a mishap and the probability of its occurrence. The Risk Assessment Value is assigned a number from 1 to 20 from the Mishap Risk Assessment Matrix (see figure 4-4). The Risk Assessment Value will be used to prioritize hazards for risk mitigation actions and to group hazards into risk categorizes. The risk categories will be used to establish risk acceptance levels as follows. Risk Assessment Values 1-5 are unacceptable and mitigation actions must be taken immediately or operations terminated. Risk Assessment Values 6-9 are undesirable and require a decision by the LCLS Project Office to accept the risk. Risk Assessment Values 10-17 are acceptable with review by the LCLS Project Manager. Risk Assessment Values 18-20 are acceptable without review.

| SEVERITY<br><br>PROBABILITY | Catastrophic | Critical | Marginal | Negligible |
|---|---|---|---|---|
| **Frequent** | 1 | 3 | 7 | 13 |
| **Probable** | 2 | 5 | 9 | 16 |
| **Occasional** | 4 | 6 | 11 | 18 |
| **Remote** | 8 | 10 | 14 | 19 |
| **Improbable** | 12 | 15 | 17 | 20 |

MIL-STD-882D

**Figure 4.1.3.1: Mishap Risk Assessment Matrix**

| Risk Assesment Value | Description |
|---|---|
| 1-5 | Unacceptable |
| 6-9 | Undesirable requires decision by the LCLS Project Office |
| 10-17 | Acceptable with review by the LUSI Project Manager |
| 18-20 | Acceptable |

**Figure 4.1.3.2: Mishap Risk Assessment Value**

## 4.2 SYSTEM SAFETY PRECEDENCE

Risk management is a decision-making process consisting of evaluation and control of the severity and probability of a potentially hazardous event. By assigning a Risk Assessment Value, a determination can be made as to whether hazards should be eliminated, controlled, or accepted. The process shown in Figure 4-5 helps to determine the extent and nature of preventive controls that can be applied to decrease the risk to an acceptable level within the constraints of time, cost, and system effectiveness. Resolution strategies in descending order of precedence are listed below.

- Design to Eliminate Hazards: This strategy generally applies to any change to equipment. The hazard source or the hazardous operation shall be eliminated by design without degrading the performance of the system.

- Design to Control Hazards: In cases where hazards are inherent and cannot be eliminated completely, they will be controlled through design if possible. The major safety goal during the design process is to include safety features that are fail-safe or have capabilities to handle contingencies through redundancy of critical elements. Complex features that could increase the likelihood of hazard occurrence will be avoided wherever feasible. System safety analysis should identify hazard control, damage control, containment, and isolation procedures.

- Provide Safety Devices: Hazards: that cannot be eliminated through design will be controlled through the use of appropriate safety features or devices if possible. Safety devices (e.g. a pressure relief valve) that are part of the system, subsystem, or equipment, and are an integral part of emergency operations can result in the hazard being reduced to an acceptable risk level.

- Provide Warning Devices: Where it is not possible to preclude the existence or occurrence of an identified hazard, visual or audible warning devices (e.g. a fire alarm bell) should be employed for the timely detection of conditions that precede the actual occurrence of the hazard. Warning signals and their application should be designed to minimize false alarms that could lead to secondary hazardous conditions.

- Provide Special Procedures or Training: Where a hazard cannot be eliminated or controlled using one of the aforementioned methods, special malfunction or emergency procedures should be developed and formally implemented. These special operational procedures should be standardized and used in test, operational, and maintenance activities. For example, the user could be required to wear protective clothing or gear (e.g. face shields, gauntlets, etc.).
- Hazard Acceptance or Terminate System: Where hazards cannot be reduced by any means, a decision process must be established to document the rationale for either accepting the hazard or for disposing of the system.

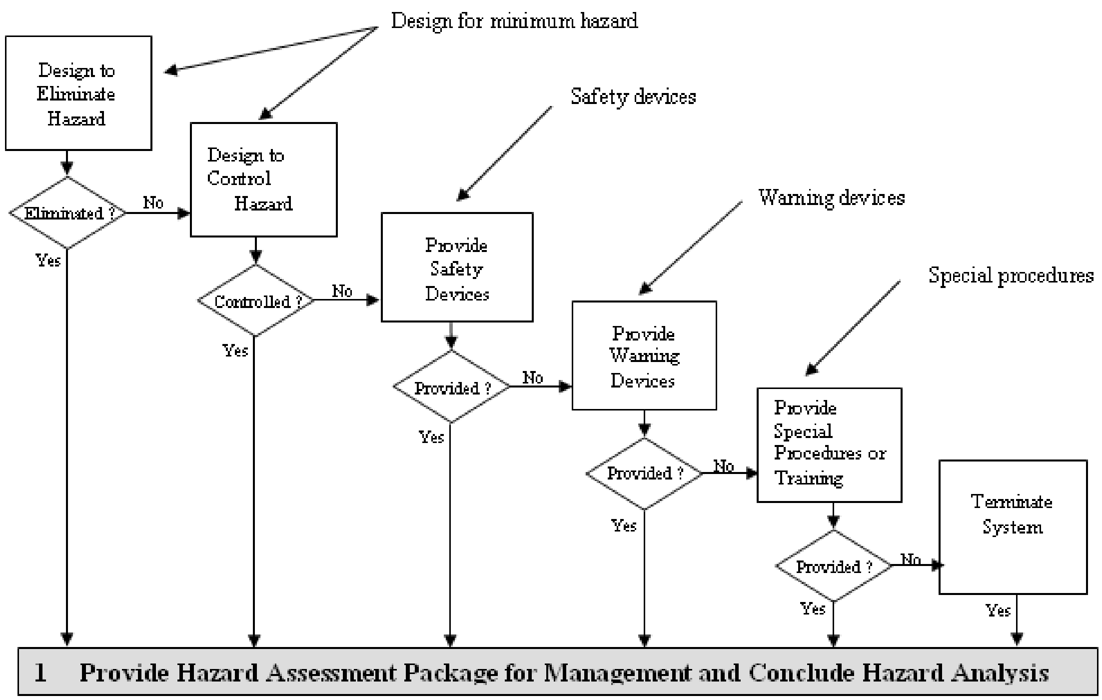


**Figure 4.2.1: Hazard Reduction Precedence**

## 4.3 PROJECT OCCUPATIONAL SAFETY REQUIREMENTS

All LUSI designs shall conform to the requirements of the Occupational Safety and Health Standards 29 CFR 1910. The LUSI equipment shall be designed and constructed in such a manner to protect the safety of workers, the public and the environment. This shall be accomplished following the SLAC Environment Safety and Health program. The safety philosophy and practice to be followed on the LUSI project will include the following elements:

- Safety Management System Policy, DOE Policy, DOE P 450.4 Safety Management System
- Adherence to SLAC Work Smart Standards (WSS)

- Radiation Protection in accordance with 10 CFR 835, "Occupational Radiation Protection"
- Implementation of radiation controls to limit radiation to personnel levels as low as reasonably achievable
- Controlling hazards by eliminating them whenever practical
- Following industry consensus standards, unless a justification to deviate is approved
- Implementing construction safety programs to ensure worker safety during construction and testing
- Performing independent Design Reviews on systems, structures and component designs
- All designs involving the use of lasers shall be compliant with ANSI Z136.1-2000, Safe Use of Lasers, and all laser systems shall be classified by the LSO.

## 4.4 HAZARDS ASSESSMENT

### 4.4.1 Design and Installations Phase Hazards

- ***Radiation* –** There is no source of radiation during the design, fabrication and installation phases of the project.

- ***Fire Protection* –** The Fire Protection system that will be installed in the area to be occupied by the LCLS equipment is classified as an "improved risk" system, meeting the objectives of DOE Order 420.1. The Fire Hazards Analysis of the LCLS Project included recommendations regarding the type of cabling to be used on the LCLS project to minimize the fire hazard and associated risks. These recommendations were followed. The LCLS facility is protected by a conventional fire sprinkler system and a Very Early Smoke Detection Apparatus (VESDA) system. The VESDA air sampling fire detection system continuously samples the air and is tied in to the SLAC site wide fire alarm system. It alarms when it detects by-products of materials as they degrade during the pre-combustion stages of an incipient fire. All facility installations for LCLS instrument designs shall be compliant with the life safety code NFPA 101 and 1910.35 (exit routes, emergency actions plans, and fire prevention plans).

- ***Electrical* –** Electrical distributions systems are conventional systems under 480 volts. Electrical hazards will be controlled by adhering to NFPA 70E standards during design and implementation of SLAC and LCLS safe work procedures for operations. To assure the safety of electrical equipment used in the instruments and supporting equipment must be either approved by a Nationally Recognized Testing Laboratory or by an Authority Having Jurisdiction. LOTO procedures shall be followed pursuant to the SLAC ES&H Manual Chapter 8 on Electrical Safety and NFPA 70E guidelines.

- ***Seismic* -** Installations and experiment equipment will be designed and reinforced to withstand projected seismic activity for this area in compliance with the 2007

California Building Code and SLAC requirements. This process will include stress analyses for seismic forces.

- ***Chemical* –** The only chemicals projected to be used at SLAC in the development of the instrument components or in the installation of the components will be cleaning solvents (isopropyl alcohol and acetone). These containers will be appropriately labeled and stored following manufacturer MSDS recommendations.
- ***Thermal/Cryogenic* –** Some instrument equipment will require an in-situ bake-out at 200°C maximum. Insulation, isolations and identification are the appropriate administrative controls for high heat surfaces.
- It is standard practice at accelerator and photon experimental facilities to use liquid nitrogen during the fabrication and installation of vacuum equipment. Handling of cryogens shall be compliant with SLAC ES&H Manual Chapter 36, Cryogenic Oxygen Deficiency Hazard Safety, which addresses mitigations for cold burns and ODH.
- ***Mechanical* –** During equipment assembly and installation, movement of components presents the risk of equipment falling and pinch hazards. The control for these exposures will be the use of proper material handling equipment, PPE and effective work planning. Equipment designs will include an ergonomic analysis to mitigate the potential for worker injury.
- ***Environmental Insults*** - The construction of instrument components and their assembly will not pose a risk to the environment. During operation the potential for air, soil and water activation have been evaluated and are well below SLAC action levels. Equipment activation levels will be low. A determination of a **Finding of No Significant Impact (FONSI)** was reached in the evaluation of the Environmental Assessment developed for the LCLS project which encompassed LUSI fabrication, installation and experimental activities.
    - ***Air Emissions*** - A National Emissions Standards for Hazardous Air Pollutant evaluation determined that dose/risk to the members of the public was minimal.
    - ***Waste Material Disposal*** - Where practical waste materials will be recycled, thus reducing the overall waste stream.
- ***Magnetic* –** LUSI equipment with magnetic components pose little or no safety and health risk. The type of hardware with magnetic fields includes electric door locks, ion pumps, motors and pulse picker which are standard equipment.
- ***Oxygen Deficiency*** – Oxygen deficiency hazard potential is minimal during the installation phase of the project due to small quantities of gases in liquid state that will be used within the facility. The project is currently analyzing the maximum volume of liquid nitrogen that would be allowed in the experimental areas without an oxygen deficiency monitor. The current plan is to have oxygen deficiency monitors installed in the experimental halls, unless calculations indicate otherwise.

- ***Vacuum / Pressure*** **-** The LCLS instruments consist of numerous vacuum components. The CXI vacuum chamber will be connected to a gas source for the particle injector system. The vacuum chambers shall have burst disk that are compliant with 10CFR851. Also, pressure relief valves are integral to the vacuum system to prevent them from being over-pressurized while venting.

### 4.4.2 Operations Phase Hazards

- ***Radiation*** **–** Potential for exposure to radiation during the conduct of experiments is very low when appropriate radiation shielding and Personnel Protective Systems (PPS) are in place. Area radiation monitors interlocked to the injection systems provide redundancy to the system to disable the beam in the event a failure is identified in either the shielding or the PPS. Appropriate training, the level of which remains to be determined, will be required by individuals conducting experiments. The X-ray Pump Probe (XPP) experiment will have equipment in hutch 2 that will be illuminated for experiments in hutch 3. Appropriate shielding will be required on this equipment to allow occupancy of hutch 2 when experiments are conducted in hutch 3.

- ***Fire*** **-** The Fire Protection system that will be installed in the area to be occupied by the LCLS equipment is classified as an “improved risk” system, meeting the objectives of DOE Order 420.1. The Fire Hazards Analysis of the LCLS Project included recommendations regarding the type of cabling to be used on the LCLS project to minimize the fire hazard and associated risks. These recommendations were followed. LUSI instrumentation will be contained within enclosed hutches. The hall within which the hutches will be located will have a VESDA system in place and sprinklers. The selection of cable used on the project and fire breaks in cable trays were chosen with the view of reducing the fire exposure in the Experiment Hall. The design of the hutches includes features to de-energize the hutches in the event of a fire. Packing material and chemicals will be administratively controlled to minimize their presence in the hutches and the Experiment Hall.

- ***Electrical*** **–** Electrical distributions systems are conventional systems under 480 volts. The presence of electrical hazards will be controlled by adhering to NFPA 70E standards and implementing SLAC and LCLS/LUSI safe work procedures. Electrical equipment used in the instruments and supporting equipment will be approved by either a Nationally Recognized Testing Laboratory or by an Authority Having Jurisdiction. LOTO procedures shall be followed pursuant to the SLAC ES&H Manual Chapter 8 on Electrical Safety and NFPA 70E guidelines.

- ***Seismic*** **-** Installations and experiment equipment will be designed and reinforced to withstand projected seismic activity for this area in compliance with California Building Code/SLAC requirements.

- ***Chemicals*** **–** Chemicals used during the operation of the LCLS instruments will include cleaning solvents and sample gases which will include inert gases and eventually health hazard gases. MSDS will be available for commercially produced chemicals. Chemicals will be labeled and stored in an approved locker. Pump exhausts will be connected to the building exhaust system and appropriate filters and/or absorbers used to limit emissions of sample gases. PPE guidelines will be followed as stipulated in the MSDS when handling chemicals and JHAM's for chemical use will be reviewed by SLAC IH. Chemicals will be purchased and stored in the experimental areas in the minimal quantities required by the experiment to reduce exposure and waste.

- ***Thermal/Cryogenic –***Some instrument equipment will require an in-situ bake-out at 200°C maximum. Insulation, isolations and identification are the appropriate administrative controls for high heat surfaces. Bake-outs will occur in the hutch, limiting access to the high temperature surfaces. It is standard practice at accelerator facilities to use liquid nitrogen to cleanly vent the vacuum system. Some cryogenics may be used to control samples when conducting experiments. Handling of cryogens shall be compliant with SLAC ES&H Manual Chapter 36, Cryogenic Oxygen Deficiency Hazard Safety, which addresses mitigations for cold burns and ODH.
- ***Mechanical –*** During operations equipment will be regularly assembled and components moved. This creates the potential for equipment falling and pinching hazards. The controls for these exposures are the use of proper material handling equipment, PPE and effective work planning. The layout of equipment will be evaluated from an ergonomic perspective to mitigate the potential for worker injury.
- ***Environmental Compliance*** – The SLAC Environmental Management System will periodically monitor LUSI operations as is done for other SLAC activities to ensure environmental compliance is maintained at a high level. Environmental compliance will be reviewed by SLAC EM, and any spills will be handled in accordance with the SLAC ES&H Manual Chapter 16 for spills, which includes reporting and classifying spills.
- ***Control of Effluents -*** Effluents resulting from sample preparation and resulting from the conduct of experiments when the instruments begin operations will be neutralized and disposed of through SLAC approved processes. Regulated industrial, hazardous, radioactive, mixed and regulated medical wastes will be managed applying SLAC procedures and where possible quantities used will be minimized. Effluents will be managed in accordance with SLAC ES&H Manual Chapter 17 for Hazardous Waste and the SLAC Hazardous Materials Management Handbook. A HWMC will be designated to support the LCLS photon hall operations.
- ***Oxygen Deficiency –*** Oxygen deficiency hazards potential is minimal due the small quantities of gases in liquid state that will be used within the facility. The project is currently analyzing the maximum volume of liquid nitrogen that would be allowed in the experimental areas without an oxygen deficiency monitor. The current plan is to have oxygen deficiency monitors installed in the experimental halls, unless calculations indicate otherwise.

- ***Vacuum / Pressure -*** The LCLS instruments will consist of several ultra-high vacuum chambers pumped with turbo pumps and/or ion pumps. Pressurized gas cylinders could be connected to the experimental chambers. Compressed gas systems will be equipped with pressure gages, regulators, and provisions will be in place for emergency shutdown. Gas cylinders will be secured and stored in an upright position. Oxidizers and fuels will not be stored together. All chambers will occasionally be connected to liquid nitrogen boil-off to provide a clean dry environment when venting them. Vacuum chambers will be fit with low positive pressure burst disks that are compliant with 10CFR851 to prevent them from being over pressurized. Gas source cylinders will be fit with flow restrictors to minimize gas flow to the experimental chamber. A continuous vacuum envelope from the accelerator to the experiment is required during operations. Active pressure monitoring will be used for the entire system. An interlock system will isolate the different vacuum volumes if a vacuum fault is detected. When accelerator and beamline vacuum faults are detected, interlock systems will automatically close beamline valves. Loss of compressed air systems associated with PPS will initiate alarms alerting control room staff to take appropriate action. Oxygen and fuel gases will not be stored together.
- ***Remote Controlled Robot Arm –*** The XPP instrument is planning on using an anthropomorphic robot for the detector mover. The robot arm has a maximum one meter radius and is capable of moving the detector around a spherical surface at a prescribed radius. The remote manipulation of the robot arm creates a potential for entrapment, pinching or striking of equipment or personnel. The robot is large and powerful enough to cause physical injury or damage. The robot system will be compliant with OSHA technical manual, section IV, chapter4; "Industrial Robot and Robot System Safety" and ANSI/RIA R15.-06; "American National Standard for Industrial Robots and Robot Systems." The safety measures will include, but are not limited to the following:
  - Personnel protection systems – proximity sensors, light curtains, pressure mats, emergency stops.
  - Hardware systems - docking interlocks to robot power and control systems switching, force sensor interlocks.
  - Software system - training & maintenance modes.
- ***Laser –*** A high powered laser will be used in the XPP experiments. The laser will be located in the laser room, directly above hutch 2 and 3, and in the hutch with an evacuated beam transport tube connecting the two locations. Laser equipment will be located on laser tables with opaque enclosures surrounding them. The beam will be transported to the experimental chambers through tubes and enter the vacuum system through viewports. While exposed beams will be required when aligning the system, the beam path will be entirely enclosed during operations. A laser safety system (LSS) is being designed to manage access, operational modes, etc. A specification for the LSS can be found in the LCLS Requirement, Specification and Interface documents, number 1.6-115. Laser safety procedures will follow the requirements in the ES&H manual, Chapter 10: Laser Safety.

### 4.4.3 Occupational Safety Considerations for Operations

- **Radiation Exposure Control –** Individuals working in and around the Experiment Stations will be required to have the level of training deemed necessary by the laboratory.
    - Configuration control of radiation shielding will be maintained through the use of Authorization for Work on Accelerator/Beamline Safety System forms.
    - Radiation Monitoring will be conducted through the use of personal and area TLDs.
    - Radiation safety interlocks will be tested on a regular schedule to insure integrity. Management of these systems by Control Room and Accelerator Operations Division personnel.

- **Beam Loss Control –**
    - Controls to prevent or mitigate beam loss and maintain radiological conditions ALARA should include real-time radiation monitors with audio alarms, area and personal TLDs, pre-operations sweep procedures, and access-control (interlock) devices.
    - Control Room beam loss procedures should include lock-out/tag-out procedures, experimental and radiation safety check-off lists, work planning procedures, and radiological training.

- **Waste Minimization –**
    - Chemicals brought to SLAC or used in sample preparation at SLAC will be reviewed when the LUSI Experiment Safety Approval review is conducted. Quantities of chemicals and materials will be kept to a minimum and less hazardous substitutes suggested where possible. Effluents will be managed in accordance with SLAC ES&H Manual Chapter 17 for Hazardous Waste.

## 5. QUALITY ASSURANCE

The quality assurance (QA) program is described in the LUSI Quality Implementing Procedure (QIP). This QIP was prepared to meet the SLAC Office of Assurance "Quality Implementing Procedure Requirements", SLAC-I-770-0A17S-001-R000, and the applicable requirements of DOE Order 414.1C, "Quality Assurance".

LUSI's QA program places a high priority on safety as well as on ensuring that equipment procurement, installation, and operations are carried out in an efficient and cost-effective manner.

LUSI's line management is responsible for providing appropriate resources to ensure that the facility meets its long-term performance goals in a safe and effective manner consistent with high standards of quality assurance. At all levels, management communicates high expectations and goals for the attainment of quality, and makes decisions to ensure that performance objectives for both construction and operation are met.

# APPENDIX A – HAZARD IDENTIFICATION & RISK DETERMINATION

| Item | Hazard | Cause | Unmitigated Risk Level | Prevention/ Mitigation | Potential Impact | Mitigated Risk |
|---|---|---|---|---|---|---|
| 1. | Ionizing radiation exposure inside the experimental hutch (greater than 1 rem/h) [10CFR835.502]):1 1. Prompt | PPS failure or inadequate search | Level 1<br>Catastrophic<br>Frequent | Personnel Protection System (PPS). PPS operator training. Periodic testing of PPS. Radiation safety training.<br><br>Search Procedures, Entry and Exit Procedures, PPS Interlock Checklists Instrument operations procedures<br><br>Training – LCLS User orientation will warn of the hazards of being in the experiment enclosure and the personnel protective systems in place.<br><br>Beam Line Authorization, Pre-run Checks, PPS Safety Inspection Checklists<br><br>Shutter open warning lights<br><br>PPS door lock and PPS interlock for beam cutoff if enclosure door is open when shutter is open.<br><br>Ref: *SLAC Guidelines for Operations*, *Radiological Control Manual, SLAC ES&H Manual, Chapter 9 Radiological Safety* | Personnel high radiation exposure | Level 20<br>Negligible<br>Improbable |

| Item | Hazard | Cause | Unmitigated Risk Level | Prevention/ Mitigation | Potential Impact | Mitigated Risk |
|---|---|---|---|---|---|---|
| 2. | Ionizing radiation exposure (greater than 1 rem/hr) outside the hutch enclosure | Failure of shielding, monitoring or interlock systems | Level 1<br>Catastrophic<br>Frequent | Beam Containment System (BCS)<br><br>Beam Line Authorization, Pre-run Checks, PPS Safety Inspection Checklists<br><br>Dosimetry<br><br>Ref: *Radiation Safety Systems*, *Radiation Safety System Technical Basis Document*, *SLAC ES&H Manual, Chapter 9 Radiological Safety* | Personnel radiation exposure. | Level 20<br>Negligible<br>Improbable |
| 3. | Non-ionizing radiation exposure | Laser room connected to experimental hutch<br>Class IV laser in experimental hutch | Level 7<br>Marginal<br>Frequent | Engineered controls including opaque barriers, laser safety system, beam containment during routine operation<br><br>PPS equipment: appropriate laser goggles for wavelengths in use.<br><br>Administrative controls including laser safety training, alignment mode with only trained personnel in hutch<br><br>Ref: *SLAC ES&H Manual, Chapter 10, Laser Safety* | Personnel injury – eye damage or skin burns | Level 20<br>Negligible<br>Improbable |

| Item | Hazard | Cause | Unmitigated Risk Level | Prevention/ Mitigation | Potential Impact | Mitigated Risk |
|---|---|---|---|---|---|---|
| 4. | Fire | Cable Plant<br>Combustible material in experimental areas | Level 8<br>Catastrophic<br>Remote | LCLS Fire Hazards Analysis defined recommended design guidelines to minimize the fire potential on the project.<br>Based on these recommendations the LCLS was classified as an "improved risk" system, meeting the objectives of DOE Order 420.1.<br>Recommendations from this analysis included:<br>VESDA smoke detection system reporting to the Pyrotronics MXL panel.<br>Fire sprinklers.<br>Proper selection of cable plant.<br>Fire breaks in cable trays.<br>Limiting combustible and flammable material in experiment stations.<br>In addition SLAC has an on-site fire department.<br>Ref: *SLAC ES&H Manual, Chapter 12, Fire & Life Safety* | Loss of technical equipment<br>Partial loss of cable plant<br>Shut down of operations<br>Personnel Injury – burns, smoke inhalation<br><br>Death or asphyxiation | Level 14<br>Marginal<br>Remote |

| Item | Hazard | Cause | Unmitigated Risk Level | Prevention/ Mitigation | Potential Impact | Mitigated Risk |
|---|---|---|---|---|---|---|
| 5. | Electrical | Installation of standard industrial distribution (< 210 V) systems.<br><br>Contact with energized cables during installation of instrumentation | Level 4<br>Catastrophic<br>Occasional | Implementation of building and structural codes (UBC)<br><br>Design standards and Safety Committee review and inspections. New equipment complies with all applicable electrical codes and standards.<br><br>All equipment used in LCLS installations must be EEIP certified. Certain conventional equipment will be UL listed.<br><br>Project reviewed by the SLAC electrical safety committee review.<br><br>Installation of standard industrial distribution systems.<br><br>LOTO training for all individuals working on exposed electrical systems.<br><br>Specific LOTO procedure (EEIP) for each power supply.<br><br>Electrical hot work permits, where applicable.<br><br>Ref: *SLAC ES&H Manual, Chapter 8, Electrical Safety* | Shock or arc (flash) | Level 14<br>Marginal<br>Remote |

| Item | Hazard | Cause | Unmitigated Risk Level | Prevention/ Mitigation | Potential Impact | Mitigated Risk |
|---|---|---|---|---|---|---|
| 6. | Seismic | Falling objects during earthquake | Level 8<br>Catastrophic<br>Remote | Design standards and Safety Committee review and inspections.<br>Ensure all equipment is adequately secured during design and readiness reviews.<br>Pre-operational inspections for modifications.<br>Ref: *Specification for Seismic Design of Building, Structures, Equipment, and Systems* | Personnel struck by or pinched between equipment during an earthquake | Level 14<br>Marginal<br>Remote |

| Item | Hazard | Cause | Unmitigated Risk Level | Prevention/ Mitigation | Potential Impact | Mitigated Risk |
|---|---|---|---|---|---|---|
| 7. | Chemical | Cleaning chemical during installation<br><br>Possible exposure to chemicals during sample development and experiment set up<br><br>Health hazard gas leaks | Level 4<br>Catastrophic<br>Occasional | Minimize quantities of chemicals used during experiment.<br><br>Exhaust health hazard gases through building exhaust system<br><br>Secondary containment system for health hazard gases (i.e. exhausted gas cabinet) with verification of integrity of gas lines before use permitted.<br><br>SLAC IH monitoring program will periodically assess chemical handling practices.<br><br>Personnel training<br><br>MSDS will be available for all chemicals used, and all chemicals will be stored in labeled containers and approved storage lockers. Implementation of building and structural codes<br><br>Personnel Protective Equipment (PPE), Secondary chemical containment<br><br>CEF and RPFO procedures<br><br>Ref: *Chemical Process Hazard Analyses*; and *SLAC ES&H Manual Ch. 40, Hazardous Materials & Ch. 16 Spills* | Contact with personnel, spills, injury | Level 20<br>Negligible<br>Improbable |

| Item | Hazard | Cause | Unmitigated Risk Level | Prevention/ Mitigation | Potential Impact | Mitigated Risk |
|---|---|---|---|---|---|---|
| 8. | Thermal / cryogenic | Use of cryogens<br><br>Vacuum bakeout | Level 10<br><br>Critical<br><br>Remote | Cryogens will not be used during the installation of AMO instrumentation.<br><br>Cryogens are likely to be used during the conduct of experiments.<br><br>Use of proper PPE including gloves and face shields when handling cryogenic liquids.<br><br>Analyzing the maximum volume of liquid nitrogen that will be allowed in the experimental areas without an oxygen deficiency monitor. The current plan to have oxygen deficiency monitors installed in the experimental halls, unless calculations indicate otherwise.<br><br>Ref: *SLAC ES&H Manual Ch. 36, Cryogenic and Oxygen Deficiency Hazard Safety & Ch.19, Personnel Protective Equipment* | Personnel cryogenic burn exposures | Level 20<br><br>Negligible<br><br>Improbable |
| 9. | Mechanical | Vacuum chambers<br><br>PCW feed & return lines<br><br>Compressed air and gas lines<br><br>Hoisting and Rigging<br><br>Repositioning of experimental hardware – pinch hazards | Level 8<br><br>Catastrophic<br><br>Remote | Engineered systems designed to conservative standards.<br><br>Training of personnel in hazard recognition and support<br><br>Housekeeping to minimize trip hazards<br><br>Ref: *SLAC ES&H Manual Ch.41, Hoisting and Rigging* | Personnel injury | Level 20<br><br>Negligible<br><br>Improbable |

| Item | Hazard | Cause | Unmitigated Risk Level | Prevention/ Mitigation | Potential Impact | Mitigated Risk |
|---|---|---|---|---|---|---|
| 10. | Environmental | Spills<br><br>Discharges to sanitary or storm drains<br><br>Noise | Level 14<br>Marginal<br>Remote | Training – Stormwater Awareness Course 298<br><br>Hazardous Material Management Core Course 105<br><br>Training<br><br>Secondary containment<br><br>Minimize of chemicals quantities<br><br>Management of waste waters from discreet operations (i.e., purging LCW systems, coolant from concrete-saw cutting)<br><br>IH monitoring<br><br>Dust management during construction<br><br>Ref: *SLAC ES&H Manual Ch. 17, Hazardous Waste and Ch. 43, Industrial Wastewater* | Personnel exposure<br>Release of liquids to drain system | Level 20<br>Negligible<br>Improbable |
| 11. | Magnetic | High magnetic fields will not be present in or at points accessible to individuals assembling or installing LUSI equipment. | Level 10<br>Critical<br>Remote | None required | Personnel injury or damage to medical equipment. | Level 20<br>Negligible<br>Improbable |

| Item | Hazard | Cause | Unmitigated Risk Level | Prevention/ Mitigation | Potential Impact | Mitigated Risk |
|---|---|---|---|---|---|---|
| 12. | Oxygen Deficiency | There will be no oxygen deficient or confined spaces during instrument assembly of installation.<br><br>There could be an oxygen deficient environment in an experiment station if a large dewar of nitrogen spilled or ruptured. | Level 12<br>Catastrophic<br>Improbable | Limit volumes of gasses and liquefied gasses in experimental hall<br><br>Analyzing the maximum volume of liquid nitrogen that would be allowed in the experimental areas without an oxygen deficiency monitor. The current plan is to have oxygen deficiency monitors installed in the experimental halls, unless calculations indicate otherwise.<br><br>Equipment/Process review<br><br>Safe work procedures<br><br>Ref: *SLAC ES&H Manual Ch. 36, Cryogenic and Oxygen Deficiency Hazard Safety* | Asphyxiation | Level 20<br>Negligible<br>Improbable |

| Item | Hazard | Cause | Unmitigated Risk Level | Prevention/ Mitigation | Potential Impact | Mitigated Risk |
|---|---|---|---|---|---|---|
| 13. | Vacuum and Pressure | Vacuum systems are part of the instruments.<br><br>Possible reservoirs of high pressure gasses connected to the vacuum chambers. | Level 10<br>Critical<br>Remote | SLAC safety reviews, acceptance testing of pressure devices<br><br>SLAC safety reviews and training, acceptance testing of pressure devices. Safety reviews will evaluate the need for such devices as barriers for impact debris between workers and equipment if highly pressurized equipment in included in the experimental equipment design.<br><br>The review will also evaluate the of redundant pressure relief devices, like a self-contained burst disk .Limit volumes of gases experimental hall.<br><br>Vacuum chambers with a potential of being pressurized during an experiment will be fit with low positive pressure burst disks that are compliant with 10CFR851 to prevent them from being over pressurized.<br><br>Safe work procedures.<br><br>Ref: *SLAC ES&H Manual Ch. 38 Compressed Gas Cylinders & Ch.14 Pressure and Vacuum Vessels* | Personnel injury | Level 20<br>Negligible<br>Improbable |

| Item | Hazard | Cause | Unmitigated Risk Level | Prevention/ Mitigation | Potential Impact | Mitigated Risk |
|---|---|---|---|---|---|---|
| 14. | Remote Controlled Robot Arm | Software or hardware failure | Level 10<br>Critical<br>Remote | Robot arm will be designed to be compliant with OSHA technical manual, section IV, chapter4; “Industrial Robot and Robot System Safety” and ANSI/RIA R15.-06; “American National Standard for Industrial Robots and Robot Systems.” The safety measures will include, but are not limited to the following:<br>1. Personnel Protection Systems – proximity sensors, light curtains, pressure mats, emergency stops..<br>2. Hardware systems - docking interlocks to robot power and control systems switching, force sensor interlocks.<br>3. Software system - training & maintenance modes.<br>SLAC safety reviews and acceptance testing of device hardware and controls. | Personnel injury | Level 20<br>Negligible<br>Improbable |

## APPENDIX B – ACRONYMS

| | |
|---|---|
| BES | Basic Energy Sciences |
| CD | Critical Decision |
| CF | Core Function |
| CXI | Coherent X-ray Imaging |
| DEAR | DOE Acquisition Regulation |
| DOE | Department of Energy |
| ES&H | Environment, Safety, and Health |
| FEL | Free Electron Laser |
| GP | Guiding Principles |
| ISM | Integrated Safety Management |
| ISEMS | Integrated Safety Management and Environmental System |
| LCLS | Linac Coherent Light Source |
| LUSI | Linac Coherent Light Source Ultrafast Science Instruments |
| XCS | X-ray Correlation Spectroscopy |
| PHA | Preliminary Hazards Analysis |
| HAR | Hazards Analysis Report |
| R&D | Research & Development |
| SAD | Safety Assessment Document |
| SLAC | Stanford Linear Accelerator Center |
| XFEL | X-ray Free Electron Laser |
| XPP | X-ray Pump Probe |