## Revision Record

<table>
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<tr>
<th>Revision</th>
<th>Date Revised</th>
<th>Section(s) Affected</th>
<th>Description of Change</th>
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<td>R000</td>
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<td>R000 not yet released.</td>
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<tr>
<td>INT</td>
<td>June 12, 2009</td>
<td>All</td>
<td>Interim version for ARR only.</td>
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Preface
This document is intended as a reference to individuals training to be Floor Coordinators. It is supplementary to the Floor Coordinator Qualification Workbook.
CHAPTER 1

REQUIRED ES&H CLASSES

All supervisors and employees conduct a SLAC Training Assessment (STA) yearly, or as needed. The role of Floor Coordinator (FC) has training requirements. The following classes are provided by SLAC ES&H and must be completed for qualification. These courses correspond to FC responsibilities.

Work Planning & Control #120
- Overview of the work planning and control process for yellow and red work
- Explains how work is communicated, authorized, and released
- What to do when a scope changes or a new hazard is introduced during execution

Employee Orientation to Environment, Safety, and Health # 219
- Describe the Integrated System Management System.
- State how to get assistance for ES&H questions and concerns.
- Describe actions for alarms, accidents, and emergencies at SLAC.
- Identify radiological postings and identification used at SLAC.
- Identify access requirements for Controlled Areas (CA) and Radiologically Controlled Areas (RCA).
- Identify SLAC radiological training requirements.
- Define a spill.
- Explain the waste minimization measures used at SLAC.
- List the three recognized methods to control hazards in the work place.

General Employee Radiation Training (GERT) # 115
- Identify fundamental radiological terms and concepts.
- Identify the ALARA concept and practices.
- Identify radiological postings and other methods to control radiological hazards.
- Compare risks due to occupational radiation exposure with other common health risks.
- Describe SLAC's Personnel Protection System (PPS) program.
- State the potential health effects of radiation exposure.

Radiological Worker Training I (RWT I) # 116 and # 116a
- Personnel who work on Radioactive Material, including accelerator housing beam lines
- Radiological workers who are likely to enter posted radiation and high radiation areas
- Radiological workers who are expected to receive a total occupational radiation dose exceeding 100 mrem per year.
- Designated Radiation Generating Device Operators

General Electrical Safety # 239
- Identify basic rules of electricity
- Identify common electrical hazards
- Identify methods to reduce or eliminate electrical hazards
- Identify the electrical principles that were ignored causing a given injury scenario
- Identify common electrical related injuries and effects of electricity on the human body.
- Identify actions to take in an electrical emergency.
- Identify factors related to overhead power line safety.
CPR First Aid # 138
- Primary Assessment
- Cardio-pulmonary Resuscitation
- Anti-choking Techniques
- Control of Bleeding
- Care of the Unconscious
- Injury/illness Prevention Basic First Aid

Laser Worker Safety Training # 253
- Identify the primary parts of a laser.
- Define terms associated with lasers.
- Identify different types of lasers.
- Name the types and classes of lasers.
- Identify non-beam laser hazards.
- Classify non-beam laser hazards by type.
- Identify the biological effects of a laser on the eye.
- Recall the biological effects of a laser on skin.
- Identify descriptions of the three categories of controls used in laser environments.
- Identify important factors to consider when choosing protective eyewear.
- Recognize mandatory controls for Class IV lasers.

Lock and Tag -Affected Employee # 136
- Define terms commonly used in a lockout/tagout program.
- Identify the responsibilities of an authorized person.
- Identify standard techniques and procedures commonly used in a lockout/tagout program.

Cryogenic and Oxygen Deficiency Training # 170
- The potential oxygen deficiency hazards associated with use of compressed gases, liquid cryogens, and cold dense gases resulting from use of liquid cryogens.
- The methods of oxygen deficiency hazard detection and controls that will be used in various work situations.
- The potential hazards of working with cryogenic liquids and the contact damage that may occur from improper or unsafe handling.

Fall Protection/Authorized # 200
- Define 100% fall protection.
- Describe options for working safely at elevations.
- Explain the advantages and disadvantages of working on ladders, scaffolds, aerial lifts, and scissors lifts.
- Demonstrate the proper use of ladders.
- Prepare an elevated work plan to include a fall hazard analysis.
- Perform an inspection of equipment
- Demonstrate how to properly don equipment. Explain the advantages and disadvantages of working on ladders, scaffolds, aerial lifts, and scissors lifts.
CHAPTER 2

SLAC AND XFD FOUNDATION DOCUMENTS

Important SLAC and XFD documents can be found on the SLAC and division document control web sites. Permission may be needed to access division web sites.

**XFD Directives**
SLAC-I-030-00100-001; XFD Document Control SharePoint web site
The *XRD Directives* describes the roles and responsibilities and management directives for programs, work, safety, training and documentation within the XFD.

**SLAC ES&H Manual**
All aspects of laboratory safety are presented in the SLAC ES&H Manual. Of particular interest to LCLS Users and staff members are
  - Chapter 1: Work Authorization
  - Chapter 8: Electrical
  - Chapter 9: Radiological Safety
  - Chapter 10: Laser Safety
  - Chapter 13: Traffic and Vehicular Safety
  - Chapter 14: Pressure & Vacuum Vessels
  - Chapter 15: Ladder Safety
  - Chapter 16: Spills
  - Chapter 17: Hazardous Waste
  - Chapter 19: Personnel Protective Equipment
  - Chapter 20: Lead Safety
  - Chapter 22: Waste Minimization & Pollution Prevention
  - Chapter 25: Portable Tools
  - Chapter 36: Cryogenic and Oxygen Deficiency Hazard Safety
  - Chapter 38: Compressed Gas Cylinders
  - Chapter 40: Hazardous Materials
  - Chapter 41: Hoisting and Rigging
  - Chapter 44: Penetration Safety
  - Chapter 45: Fall Protection
  - Chapter 50: Non-ionizing Radiation
  - Chapter 51: Control of Hazardous Energy

**SLAC Guidelines for Operations**
[https://www-internal.slac.stanford.edu/ad/addo/gfo/gfoindex.html](https://www-internal.slac.stanford.edu/ad/addo/gfo/gfoindex.html)
Laboratory staff members involved with the operations are required to be familiar with these guidelines and procedures.

**Radiation Safety Systems Technical Basis Document**
SLAC-I-720-0A05Z-002-R002; RP Document Control SharePoint web site
The requirements for Radiation Safety Systems are specified by the Radiation Physics, the Radiation Safety Officer and the Radiation Safety Committee.

**Radiological Control Manual**
The *Radiological Control Manual* establishes practices for the conduct of radiation activities at SLAC.

**SLAC Emergency Preparedness Plan**
The SLAC Emergency Preparedness Plan ensures actions are taken to mitigate hazards and plans and provisions are in place to mobilize an appropriate response to emergencies of any scale.

**NEH Emergency Plan**: XFD Document Control SharePoint web site
SLAC-I-030-30400-001

**X-Ray Transport Tunnel Emergency Plan**: XFD Document Control SharePoint web site
SLAC-I-030-30400-002

**FEH Emergency Plan**: XFD Document Control SharePoint web site
SLAC-I-030-30400-003

**LCLS Physics Requirement Document (PRD) Control System**
Documents describe scientific requirements for LCLS systems and components.

**LCLS Engineering Specifications Documents (ESD) Control System**
Documents describe engineering specifications for LCLS systems and components.

**LCLS Technical Notes**
Documents describe technical aspects of LCLS instrumentation and operations.

**LCLS Design Review Documents**
(Gathering and archiving documents in process)
CHAPTER 3

FLOOR COORDINATOR ROLE AND RESPONSIBILITIES

The XFD Floor Coordinator implements monitor experiment safety and implements safety procedures. Floor Coordinators are on shift 24 hours a day, 7 days a week during the LCLS run program. The FC has many responsibilities, as defined in the XFD Directives, SLAC-I-030-00100-001-R000 and the Floor Coordinator Shift Responsibilities Procedure.

Program Responsibilities
Central to the Floor Coordinator shift responsibilities is maintaining the XFD Operations Log Book. The log book is the official record of the shift. It includes a shift summary written by the Floor Coordinator at the end of the shift.

The FC acts as an intermediary between the User and the MCC Control Room and works closely with the Program Manager. User problems with beam quality or performance are reported to the Floor Coordinator. This information is transmitted to MCC. Complex or difficult problems are reported to the Program Coordinator for resolution.

XFD Directives, LAC-I-030-00100-001-R000, Chapter 1

Experiment Activities Responsibilities
During the course of the shift the FC monitors safety in the experimental halls. The FC makes periodic shift tours of the facilities every one to two hours. During the tour, the FC confirms that Users are conducting experiments in compliance with the Experiment Safety Check List, or the Setup Safety Check List. The FC also monitors system status.

The Floor Coordinator implements the Setup Safety Check List for each experiment. This process includes posting updated Activity and Training Authorization (ATA) and Safety Operating Procedures (SOP) and work authorizations, if needed. The FC posts the experiment list of Users, completes the check list and releases the User to do setup work.

The Floor Coordinator conducts on-the-job HPS panel operation and search procedures with the User. The FC the reviews the list of Users with the User Supervisor, then implements the Experiment Safety Check List and Online/Offline Procedure.

XFD Directives, SLAC-I-030-00100-001-R000, Chapter 2, Chapter 4 and Chapter 5
FC Shift Responsibilities Procedure
Online/Offline Procedure

Emergency Response
The on-duty Floor Coordinator and the experiment operations staff respond to emergencies as specified in SLAC Guidelines for Operations and the FEE, NEH, X-ray Transport Tunnel or FEH Building Emergency Plan. The Floor Coordinator acts as the Person-in-charge (PIC) during evacuations and emergencies until relieved by the EOIC or management.

XFD Directives, SLAC-I-030-00100-001-R000, Chapter 3
FEE Emergency Response Plan
NEH Emergency Response Plan
X-ray Tunnel Emergency Response Plan
FEH Emergency Response Plan
# Summary of Floor Coordinator Roles, Responsibilities and Management Directives

<table>
<thead>
<tr>
<th>Area</th>
<th>Responsibility</th>
<th>Directive</th>
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<tbody>
<tr>
<td>Work Planning &amp; Control</td>
<td>• Certify safe operating conditions</td>
<td>• Conduct shift responsibilities</td>
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<tr>
<td></td>
<td>• Enable Users to operate the photon beam shutters</td>
<td>• Coordinate operating conditions with the Program Coordinator</td>
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<td></td>
<td>• Responds to facility emergencies.</td>
<td>• Implement the Experiment Safety Check List (ESCL)</td>
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<tr>
<td></td>
<td></td>
<td>• Put Users online or offline</td>
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<tr>
<td></td>
<td></td>
<td>• Release Users to do work</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Respond to facility emergencies</td>
</tr>
<tr>
<td>Work Planning &amp; Control –</td>
<td>• Review SSCL</td>
<td>• Post updated training requirements and procedures</td>
</tr>
<tr>
<td>Setup and Release</td>
<td>• Release approved setup work to the authorized User</td>
<td>• Post SSCL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Post lists of Users approved to do setup work</td>
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<tr>
<td></td>
<td></td>
<td>• Complete SSCL and release work</td>
</tr>
<tr>
<td>Work Planning &amp; Control –</td>
<td>• Review the ESCL</td>
<td>• Post updated training requirements and procedures</td>
</tr>
<tr>
<td>Experiment Work Release</td>
<td>• Releases approved experiment work to the authorized User.</td>
<td>• Post ESCL</td>
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<tr>
<td></td>
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<td>• Confirm list of Users approved to do experiment work with User Supervisor</td>
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<tr>
<td></td>
<td></td>
<td>• Post lists of Users approved to do experiment work</td>
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<td></td>
<td></td>
<td>• Review HPS and search procedure with User</td>
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<td></td>
<td></td>
<td>• Complete ESCL</td>
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<tr>
<td></td>
<td></td>
<td>• Put hutch online and release experiment work to User</td>
</tr>
<tr>
<td>Work Planning &amp; Control –</td>
<td>• Take the hutch offline</td>
<td>• Take hutch offline</td>
</tr>
<tr>
<td>Experiment Closeout</td>
<td>• Return posted experiment documents to the User Administration.</td>
<td>• Collect experiment documents and take them to User Administration including</td>
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<tr>
<td></td>
<td></td>
<td>• User Training Summary</td>
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<tr>
<td></td>
<td></td>
<td>• Work authorizations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• List of Qualified Users</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Setup Safety Check List</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Experiment Safety Check List</td>
</tr>
<tr>
<td>Safety</td>
<td>• Control User access to photon beam</td>
<td>• Conduct safety procedures</td>
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<tr>
<td></td>
<td>• Conduct safety procedures</td>
<td>• Validate <em>BLA</em></td>
</tr>
<tr>
<td></td>
<td>• Assist and responds to XFD emergencies.</td>
<td>• Implement <em>Experiment Safety Check List</em></td>
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<tr>
<td></td>
<td></td>
<td>• Put Users online/offline</td>
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<tr>
<td></td>
<td></td>
<td>• Act as PIC in the event of emergencies</td>
</tr>
<tr>
<td>Training</td>
<td>• Provide hands-on HPS training for Users</td>
<td>• Provide on-the-job training for Users in hutch stopper operation and search procedures</td>
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<tr>
<td>Documentation</td>
<td>• Maintain the official shift record.</td>
<td>• Maintain log book entries following the <em>Floor Coordinator Shift Responsibilities Procedure</em></td>
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CHAPTER 4

RADIATION SAFETY SYSTEMS

Overview

LCLS has two kinds of beams, electron and photon. Both beams are hazardous and can be damaging to people. The SLAC Radiation Physics (RP) Department manages the evaluation and mitigation criteria for radiation as published in the Radiation Safety Systems Technical Basis Document, SLAC-I-720-0A05Z-002-R002. The primary components of the Radiation Safety System include:

- Shielding
- Personnel Protection System (PPS)
- Hutch Protection System (HPS)
- Beam Containment System (BCS)
- Configuration Control

4.1 Shielding: Radiation Hazard Analysis and Shielding Specifications

Radiation hazard analysis is done in conjunction with machine and beam line radiation physicists, scientists and engineers modeling and designing hazard mitigations. As determined by the SLAC Radiation Safety Officer, new or modified systems are formally reviewed by the SLAC Radiation Citizen Safety Committee.

Shielding requirements are specified assuming that beams are confined to prescribed beam paths. The paths are defined by collimators and fixed masks. Ray traces and one of several radiation analysis packages, e.g. FLUKA or STAC8 or EGS, are used to evaluate the consequences of steered and miss-steered beams. RP publishes descriptions of the specific hazard and specifications for shielding and BCS. Publications are posted on the RP Department web site. LCLS photon experiment specific documents include:

RP-08-14  Total dose for interventions at the LCLS main electron beam dump
RP-08-13  Shielding for Soft X-ray Beamlines in the LCLS NEH
RP-08-11  Comparison of FLUKA and STAC8 for shielding calculations of the hard X-ray line of the LCLS
RP-08-07  Radiation Safety Aspects of LCLS Electron Beam Line Operation
RP-08-05  Dose rate the NEW hutchs due to Bremsstrahlung entering the Front End Enclosure of the LCLS
RP-08-04  Summary of the shielding requirement for the LCLS Near Experimental Hall hutchs
RP-07-19  Safety analysis of the safety dump line of the LCLS facility with geometries of engineering specification design for NEH phase 1 operation
RP-07-11  Shielding Design for the LCLS Near Experimental Hall
RP-07-06  Shielding Design for the LCLS Front End Enclosure
RP-07-05  Prompt Dose study in the LCLS Undulator Study of the Dose During Various Loss Scenarios in LCLS Undulator
RO-04-13  Shielding Design for LCLS Huches
RP-02-06  Radiation shielding Design for LCLS Frontend, e-dump and Hutch1
RP-02-03  Calculation of Gas-Bremsstrahlung for the LCLS Undulator
4.2 Beam Containment System
The Beam Containment System ensures that beams remain in their prescribed paths and within the operating safety envelope. Containment is achieved by passively enclosing and actively monitoring the beam. The beam enclosure is comprised of collimators, masks and stoppers. The monitors are ion chambers and average current monitors. The integrity of the enclosure components may be monitored as well with devices that will turn off the beam if they become damaged.

**Beam Shut Off**
The BCS uses a triple redundancy system. If a BCS monitor detects damaged to an element or excess beam intensity, it will turn off the electron beam at the head of the Linac.
1. Shut off laser beam to electron gun
2. Remove permissive to acceleration triggers
3. Turn off acceleration triggers
The electron beam will be terminated by any monitor in the BCS system.

**Beam Shut Off Monitors**
There are active monitoring elements in the Front End Enclosure (FEE) that houses the X-ray Transport Optics and Detectors for the LCLS beam lines. The active monitors are
1. A pair of ion chambers on collimator 1 (C1) used to detect and limit Bremsstrahlung radiation
2. A pair of ion chambers on horizontal collimator 1 (C2H1) used to detect and limit Bremsstrahlung radiation
3. 2 Beam Shut-off Ion Chambers (BSOIC) that measure background levels of photons, neutrons and gamma rays.
   a. One is located on the west wall of NEH hutch 1
   b. One is located in the FEE entry

**Burn Through Monitors**
There are Burn Through Monitors integrated into the stoppers. The stoppers are comprised of several layers that serve as a BTM or absorbers.

**Electron-Photon Stoppers**
The layers in the electron-photon stoppers are as follows.
1. B4C, boron carbide, is a low Z ceramic with a very high melting point and absorbs photons
2. Titanium absorbs electrons.
3. Copper absorbs electrons
4. Tungsten absorbs electrons
The BTM’s are small chambers filled with Argon gas. The chamber pressures are monitored; values outside of predetermined set points will turn off the electron beam.

**Stopper 1 (ST1) Design**

![Figure 1: The LCLS electron-photon stopper.](image-url)
Photon Stoppers
There are 6 sets of hutch photon stoppers, one set of hard x-ray stoppers and one set for the X-ray Transport Tunnel, each with two BTM's. The layers in the photon stoppers area as follows.
1. B4C, boron carbide
2. Tungsten

Figure 2: The LCLS photon stopper.

ESD # 1.1-311, LCLS Beam Containment System; E. Michael Saleski; 2008
ESD # 1.3-108, LCLS Electron Stopper; Eric Bong; 2008
ESD # 1.6-113 LCLS Photon Stopper, Eric Bong, 2008
4.3 Personnel Protection System

The Personnel Protection System is an Access Control System (ACS) and it controls access to electron beam areas. The system is fail-safe and redundant. Areas are divided into PPS zones. There are three PPS zones in the LCLS beam line experiment area.

1. FEE – Electron dump
2. FEE – XTOD
3. X-ray Transport Tunnel (a hybrid system)

It is possible to access one zone when beam is allowed in another zone. There are three access states:

1. No access
2. Controlled access
3. Permitted access

Each area has an access door, a gate (if there is more than one access door), a key bank, an intercom system and a video camera. The MCC Operator uses the video camera and intercom system to identify personnel requesting access and will release a key to each person during a controlled access.

Inside each area are Emergency Off buttons, an audio-visual warning system, an enunciator and yellow/magenta lights. When the area is taken from permitted access to no access, it must be searched by a qualified search team following a search procedure specific for the area. After the search, the area is secured, the audio-visual system will sound and the yellow/magenta lights will flash. Anyone who has inadvertently been missed during the search procedure immediately presses the Emergency Off button to kill the search.

There are two stoppers placed in series in the beam pipe coming into the PPS zone. Each stopper is controlled by a unique circuit, Chain A and Chain B. There are two limit switches on each stopper, closed and open. When closing the stoppers, Stopper A closes first. After the closed limit on Stopper A is actuated, Stopper B will close. The limit switches are wired normally open, that is they indicate open if there is a wiring error. It is an illegal logic condition if a stopper indicates open when it is supposed to be closed and the PPS will turn off the electron beam.

In summary, the PPS

- Controls access to electron beam areas
- PPS is controlled by MCC
- Area is search by qualified MCC operators
- There are three access states: controlled, permitted and no access
LCLS ESD Document # 1.2-116, *LCLS Injector PPS Stopper*; Richard F. Boyce, 2005
4.4 Hutch Protection System

The Hutch Protection system is an ACS and it controls access to photon beam areas, or hutches. The system is fail safe and redundant. Each hutch is a separate zone. There are three hutches in the NEH (Hutch 1, Hutch 2 and Hutch 3) and three hutches in the FEH (Hutch 4, Hutch 5 and Hutch6). There are two HPS access states.

1. Search Set (no access)
2. Permitted access

Inside the hutch are Emergency Off buttons, a search/reset button and an audio-visual warning system.

Hutches are searched by a qualified person, either the Floor Coordinator or a qualified User using the search procedure. During the procedure, each search preset \((Pr)\) is pressed. The search preset buttons are located around the hutch requiring the searcher to inspect all areas of the hutch, looking around and under equipment, walls and racks.

Figure 4: A basic 1 search preset \((Pr)\) Search.

Figure 5: A 2 search preset \((Pr)\) Search.

When the search preset buttons are pressed, the searcher closes the hutch door and uses the search/reset key \((SR)\) to finalize the search. The audio-visual system then warns anyone inadvertently missed in the search that beam will soon be allowed into the hutch. If anyone is inside the hutch, they immediately press the emergency off button \((EO)\) to disallow beam from entering the hutch. After the audio-visual system time out is complete, the User can toggle the stopper switch to open them.
Adding instrumentation, racks, additional shielding and equipment to hutch can decrease visibility. To prevent a coworker from accidentally entering a hutch to work in a location hidden from the searcher, either a second searcher or engineered hardware, such as a gate, can prevent added to the search to prevent accidental entry.
Like the PPS system, the hutches have two stoppers; each controlled by a unique circuit Chain A and Chain B. The limit switches are wired normally open and will fail safe. It is an illegal logic condition if a stopper indicates open when it is supposed to be closed and the HPS will turn off the electron beam.

**Figure 8: Diagram of near Experimental Hall HPS components.**

In summary, the HPS
- Controls access to photon beam areas
- HPS is controlled by qualified Floor Coordinators and Users
- Hutches are searched by qualified Floor Coordinators and Users
- There are two access states: Search Set (no access) and permitted access.

Like the PPS, the HPS inserts stopper ST1 in the injector, blocking the electron beam, in the event of a fault or illegal logic condition.

4.5 Configuration Control
The Radiation Safety Systems development begins with and is managed through configuration control. Configuration Control of Radiation Safety Systems is Guideline 14 of the SLAC Guidelines for Operations, Document # 01-01-14-03.

Control of RSS Components
All RSS components are identified and labeled. The XFD Safety Officer maintains a list of all components. Any work on an RSS component requires the use of a Radiation Safety Work Control Form (RSWCF). The form is divided into sections.

- Header information
  - Area
  - Form number
  - Date of initiating form
- Section 1: Description of work to be done
  - Description
  - Person responsible for work (signature)
  - Area Manager (signature)
- Section 2
  - Section 2a: Requirements before starting work
  - Section 2b: Requirements after completing work
    - XFDSO (signature)
    - Radiation Physicist (signature)
- Section 3: Signoff indicating requirements are complete
- Section 4: Signoff indicating readiness for beam
  - XFDSO (signature)
  - Floor Coordinator (FC)

Beam Line Authorization (BLA)
A Beam Line Authorization is developed jointly by the Radiation Protection Department and LCLS. The XFD Safety Officer (XFDSO), the responsible radiation physicist and the Area Manager approve and validate the BLA. The BLA contains an itemized checklist of system certifications and locking of permanently fixed in place safety components, and includes elements such as:

- Operating safety envelope (LCLS electron beam energy of 3 to 17 GeV)
- Inspection of shielding and radiation safety system labels
- Inspection of radiation safety items not easily visible (and verified by the Area Manager)
- HPS certification
- BCS certification
- Status of RSWCF for beam line
- Removable shielding panels
- Hutch doors and switches
- Beam pipe and component locks
- FO radiation surveys

There must be a valid BLA before a hutch can be put Online by the Floor Coordinator using the Online/Offline Procedure.
CHAPTER 5

NON-IONIZING RADIATION AND OTHER SAFETY SYSTEMS

Laser Safety
Class IV lasers are used to conduct experiments at LCLS in the NEH. The SLAC Laser Safety Officer oversees laser safety. The NEH System Laser Safety Officer manages up to three Class IV lasers in the NEH Laser Hall located on the second floor of the NEH building, using the NEH Laser Hall Standard Operating Procedure for laser operations. Laser light can be distributed to hutch es on the first floor in the NEH for experiments. Hutch 1 uses the Standard Operating Procedure for the Experimental Hutch 1 Laboratory. Like Hutch 2 and Hutch 3, Hutch 1 users have control of the transport shutter in the NEH Laser Hall.

The hutch es are Class I enclosures. To operate a Class IV laser in the hutch es, the laser is completely encased in a sealed, light-tight enclosure. The laser in the hutch is completely contained within a sealed, light-tight enclosure that delivers light directly to the experimental apparatus. There is a second shutter at the entrance to the apparatus enclosures.

Figure 9: NEH Laser Hall

Figure 10: Diagram of the NEH Hutch 1 Laser Safety System.
Instructions, training and personnel protective equipment are explicitly stated in the Standard Operating Procedure for the Experimental Hutch 1 Laboratory. The Floor Coordinator receives Laser Worker Safety Training, enabling the FC to support laser work done in Hutch 1.

Standard Operating Procedure for the NEH Experimental Hutch 1 Laboratory; Greg Hayes; 209
SLAC ES&H Manual, Chapter 10
http://www-group.slac.stanford.edu/esh/hazardous_activities/laser/policies.htm

Chemical Hazards
Hazardous materials are routinely used and stored at SLAC. The hazards associated with chemicals and materials are communicated to personnel and mitigated through the SLAC ES&H Hazard Communication (HazCom) Program and the Chemical Hygiene (CHP) Program. Proper storage provides control over the types and volume of chemicals stored and used in work areas. Flammable materials and chemical storage cabinets are provided throughout the facility. All staff receives hazardous materials training, and as necessary, in specific chemical handling and use cases.

Lead is a heavy metal element well known to be hazardous to both human health and the environment. Workers exposed to lead can suffer anemia, nerve damage resulting losses in hearing, thinking, touching and muscle control.

Beryllium is used for windows in x-ray path devices: it is low Z and lets most x-rays pass unattenuated. No machining of Beryllium is done at LCLS.

Occasionally, Users bring chemical hazards as experiment samples. Chemical hazards are reviewed during the proposal review and scheduling process. The XFDSO includes chemical hazards, MSDS sheet, SOP and training requirements in the Setup or Experiment Safety Check List, if needed.

The FC will receive special training, if needed.

SLAC ES&H Manual, Chapter 40
http://www-group.slac.stanford.edu/esh/hazardous_substances/haz_materials/policies.htm

Cryogenic and Oxygen Deficiency
Cryogens are super-cooled substances, typically stored in liquid form, that are used to cool other materials to extremely low temperatures, such as user samples and sample holders. Liquefied gases have the property that, if they warm to a temperature above their boiling point, they give off dry gas, such as Nitrogen, N₂. The gas volume can increase by a factor of seven to nine hundred times. The resulting large volume of gas can displace part or all of the air in an unventilated enclosure, thereby creating a potential for asphyxiation for persons entering the enclosure. This hazard is particularly serious in enclosed volumes that have no vents or ventilation systems. Individuals could suffer skin burns or injury to the eye if a cryogen were splashed.

The Floor Coordinator receives special training, Cryogenic and Oxygen Deficiency Hazards.

SLAC ES&H Manual, Chapter 36
6.1 Photon Source

**Synchrotron Radiation**

The x-ray light used at LCLS is synchrotron radiation (SR). It was first detected in 1947 at a General Electric synchrotron accelerator. The SR light is generated by electrons traveling near the speed of light passing through a magnetic field. In general, the radiation from a single magnetic pole has a broad spectrum, ranging from radio wave, through infrared light, visible light, ultraviolet light and x-ray bands. The light is also polarized in the horizontal plane. The spectrum has a broad maximum intensity that gently rolls over, as seen in Figure 1. There is an inflexion point past the maximum intensity called the critical energy, $E_{\text{critical}}$.

The hardness of the critical energy is proportional to the strength of the electron beam energy. An increase in magnetic field will reduce the radius of curvature of the electron path, extending the critical energy of the SR beam.

$$E_{\text{critical}} = 0.665 \, E^2 \, (\text{GeV}) \, B \, (\text{T})$$

where $B$ is the strength of the magnetic field and $E$ is the energy of the electron.

An additional characteristic of the SR beam is its natural, tight collimation. The electron source point is traveling at relativistic speeds so that the photons appear to the observer in the laboratory as all being emitted in the general direction of motion of the electron. This frame of references creates radiation concentrated into a very narrow cone with an opening angle between 0.1 to 1 milliradian.
Bremsstrahlung Radiation
Bremsstrahlung Radiation is produced when electrons interact with atoms or molecules. This gamma radiation consists of high energy photons which are very penetrating. Typical Bremsstrahlung beams are very low power. Bremsstrahlung is produced when the electron beam strikes a component in the storage ring. Gas Bremsstrahlung (GB) is produced when the electron beam interacts with residual gas molecules in the storage ring and is coincident with the SR beam.

Primary GB consists of a GB beam, which has not been attenuated owing to interaction with material. Secondary GB consists of the residual forward directed GB after incident primary GB interacts with sufficient material to create a radiation shower maximum. Scattered GB is the large angle scattered gamma radiation which results from interaction of a GB beam with material.

Undulators
The electron beam in the Linac passes through an undulator system. Instead of being a single magnetic pole, an undulator is a string of alternating magnetic field poles that force the electrons into a serpentine path.

The undulator SR spectrum is very different from the classic SR spectrum; it is concentrated into very narrow energy bands at the fundamental energy and repeated at its harmonics. The odd harmonics have a narrow band width of decreasing intensity. The even harmonics are broad. The LCLS beam uses the 3rd harmonic of the undulator spectrum.

Figure 12: LCLS uses the 3rd harmonic from the undulator spectrum for experiments. Beam intensity as well as photon peak energy increase with increasing electron beam energy.
The periodicity of the string of magnetic poles has a characteristic wavelength, $\lambda_u$. The dimensionless parameter $K$, is defined as

$$K = \frac{eB\lambda_u}{2\pi m_e c^2}$$

where $e$ is the particle charge, $B$ is the magnetic filed, $m_e$ is the rest mass of the electron and $c$ is the speed of light. When $K < 1$ the SR spectrum is like an undulator. When $K > 1$ the spectrum is like the classic spectrum. The photon energy of the first harmonic can be tuned by either adjusting the electron beam energy or the strength of the magnetic field.

**Free Electron Laser**

The photon spectrum has a large dynamic range, from radio waves, through visible light to x-rays. In each form, brightness can be increased by increasing the photon density in phase space.

**Radio Waves:** Klystrons amplify RF signals by passing electrons through a cavity. RF energy is fed into the input cavity near its natural frequency to produce a voltage which acts on the electron beam. The electric field causes the electrons to bunch: electrons that pass through during an opposing electric field are accelerated and later electrons are slowed, causing the previously continuous electron beam to form bunches at the input frequency. The bunched electrons beam emits radio waves.

**Visible Light Lasers:** A laser has a mirrored cavity. Light of a specific energy is passed through the cavity where it bounces back and forth. The light is amplified during each pass where it absorbs energy from a source, like an electric current. One mirror is partially transparent and the laser beam is emitted through this mirror.

**X-rays:** In the LCLS undulator system, the undulator is used to create a Free Electron Laser (FEL). Electrons oscillate in the undulator magnetic field. In the undulator electrons feel the forces from the electromagnetic fields from light they have emitted themselves.

![Figure 13: Forces on the electron in an undulator.](image)

Like RF from a klystron or a visible light laser, the FEL beam is coherent and highly collimated. The coherence is a result of the interaction of the electrons with the SR light it creates as it passes through the undulator.

Path in undulator field

Electromagnetic force in phase creates wider oscillations.

Electromagnetic force out of phase creates smaller oscillations.
A neutral phase relationship has no net effect.

When the photon electromagnetic wave advances on the electrons by one wavelength after each undulator period, their phase relationships are maintained.

![Phase relationship](image1.png)

Figure 14: Phase relationship between electrons in an undulator and photons with the same wavelength.

For a given undulator and electron energy, this selects a particular EM wavelength. It also puts restrictions on electron emittance and energy spread. The interaction between the electrons and the electromagnetic radiation it creates instabilities. The small instabilities lead to a bunching of the electrons.

![FEL instability: electron bunching](image2.png)

Figure 15: FEL electron bunching created by instabilities.
There are three FEL modes using an optical bottle, a seed light to stimulate electron instabilities or an LCLS undulator system using its own spontaneous radiation to bunch electrons and amplify x-rays.

### Three FEL modes

**Oscillator**

Emitted light bounces, affects subsequent electron bunches

**Seeded Amplifier**

Seed light affects electron bunch, gets amplified

**Self-Amplified Spontaneous Emission (SASE)**

Spontaneous light affects its own bunch, amplifies

Figure 16: FEL modes.

The LCLS single pass Self-amplified Spontaneous Emission (SASE) FEL is in the undulator hall at the end of the SLAC Linac. The Linac provides

- A high-brightness electron pulse
- Acceleration to 17 GeV
- Electron bunch compressors (BC)
- A log undulator where FEL action occurs

Figure 17: The SLAC Linac and LCLS Undulator System
The LCLS Undulator System
The LCLS undulator system is designed to optimize synchrotron radiation in the LCLS Wavelength Range, 1.5 - 15 Å. These wavelengths correspond to the electron energy range; 4.31 – 13.64 GeV. The conservative design intensity of the photon beam is $10^{12}$ FEL photons per pulse at 1.5 Å.

The undulator is divided into 33 standard segments. Each segment is separated from the next by a break. Break lengths are short or long. Short breaks are 0.470 meters, or $2\lambda_u$, and long breaks are 0.898 meters, or $4\lambda_u$. The undulator sequence is two short breaks and one long, called the 2-2-4 configuration, meaning that the electrons do not oscillate in the breaks and are 2 or 4 wavelengths behind the radiation wave when entering the next undulator.

![Figure 18: LCLS undulator hall](image)

Undulator segments can be moved remotely transversely to the beam. Any combination of segments is allowed, from 1 to 33. There are also 7 non-standard segments: 1 reference segment, 3 validation segments and 3 contingency/spare segments. The entire length of the undulator is 131.5 meters.

6.2 Electron Beam Dump Enclosure
The Dump Enclosure is located upstream of the Front End Enclosure (FEE) that houses the X-ray Transport, Optics and Diagnostics (XTOD). Both the x-ray photon beam and the electron beam exit the undulator system on the same axis. To separate the electron beam (with an energy range between 4 to 17 GeV) from the photon beam, a set of three electromagnetic dipoles, called Vertical Bend, is used to deflect the electron beam downward at a 5° angle. The electron beam is deposited into the electron Main Dump.

![Figure 19: Electron Beam Dump](image)

Downstream of the Vertical Bend are three Horizontal Bend permanent magnet dipoles that serve as backup in the event of a Vertical Bend failure. The Horizontal Bends are protected by collimators. The horizontal bending electron beam is deposited on the Safety-Dump.

![Figure 20: Electron Beam Safety Dump System](image)

Upstream of the Vertical Bend on the electron-photon beam axis is an average current monitor. Downstream of the Vertical Bend is another average current monitor. The two monitors are compared to ensure that the entire electron beam is dumped. A loss greater than 5% will cause a BCS beam dump.
There are ion chambers and Burn through Monitors on the collimators upstream of the Horizontal Bend as well as the Safety-Dump. The ion chambers and BTM are inputted into the BCS.

There is a final BTM located in the FEE downstream of the XTOD mirror systems. The mirrors translate the photon beam horizontally. In an accident scenario where both the Vertical Bend and the Horizontal Bend fail, the final, zero-degree BTM will dump the electron beam quickly prior to burn through.

LCLS ESD #1.3-008; *Electron Dumpline Requirements*; Paul Emma; 2006
LCLS PRD #1.3-117; *Electron Safety Dump Requirements*; Michael Saleski; 2007
6.3 **XTOD Optical Elements and Detectors**
The XTOD instruments are located in the FEE, immediately upstream of the Near Experimental Hall (NEH). There are 30 elements that intercept the beam. Their longitudinal location along the beam line is referenced to the end of the Linac, section-100. The height of the photon beam is 1.4 meters.

![Diagram of XTOD Optical Elements and Detectors](image)

Figure 21: Diagram of XTOD Optical Elements and Detectors.

LCLS PRD #1.5-120; *Location and Description of Beam-Intercepting Components In the Front End Enclosure*; Peter Stefan; 2007

LCLS-TN-03-8; *LCLS Undulator Coordinate System*; E. Bong, P. Emma, C. LeCocq, T. Mantagne, J. Welch; 2004
**Fixed Mask System (z=723 m)**
The fixed mask defines the maximum aperture of the beam. The mask is laminated and made of two plates, one of Heavy Tungsten Alloy mounted in front on one of Lead. The front aperture is 45 mm horizontal and 25 mm vertical. The transition from the smaller front aperture to the back rear aperture of 108 mm x 108 mm forms a bevel. The bevel eliminates a flat surface surrounding the aperture that could acts as a source for specular reflection of photons creating unwanted background radiation.

**X-ray Slits (z=724 m)**
Downstream of the Fixed Mask are the X-ray Slits. There are four adjustable slits, upper, lower, east and west. When fully open the aperture matches the Fixed Mask aperture. The slits are set at oblique angles to the beam, exposing a larger surface area to absorb the beam power. Each slit is adjustable with a step size of 10 μm.

LCLS PRD # 1.5-007; *Physics Requirements for the STOD X-Ray Slits and Fixed Mask System*, Peter Stefan, 2006
Gas Detectors (#1 z=726 m; #2 z=732 m)
There are two Nitrogen Gas Detectors integrated into the differential pumping systems, one upstream of the Attenuator System and one downstream. The detectors measure the photon beam intensity, pulse by pulse. Comparison of the two intensities enables accurate attenuation measurement of the photon beam.

Figure 23: Nitrogen Gas Detector.

At low pressures, < 1 mTorr, photons interact with gas molecules producing primary negative photoelectrons, electrons that absorb a photon and leave an atom, and positive ions. The charged particles travel centimeters before interacting with other gas molecules and can be measured simply and directly with electrodes. At higher pressures, ~ 1 Torr, photoelectrons and ions interact with other gas molecules, creating more photoelectrons and ions, making an accurate measurement complicated.

Although FEL fundamental photons dominate the spectrum of light passing through the detectors, there are many components, such as spontaneous SR, GB and FEL harmonics of the photons. Low energy photons are more quickly absorbed in gas, and Gas Detector #2 may not measure low energy photons that have already been absorbed by Gas Detector #1.

Calibration of the detectors will be necessary using the total energy measurement device, or calorimeter.

PRD #1.5-008; Physics Requirements for the XTOD Gas Detector System; Peter Stefan, 2006
ESD #1.5-103, Gas Detector, Stefan Hau-Riege, 2007
**Attenuator System (Z=729 m)**
The LCLS photon experiments use the 3rd harmonic of the FEL beam in the energy range of 825 eV to 8.265 keV. The primary purpose of the Attenuator System is to knockdown the unused fundamental FEL photon peak by a factor of up to 1000. The 10 m long system has both a Nitrogen gas attenuator nested between two differential pumping sections and a solid attenuator consisting of 6 Beryllium slides in a binary configuration of increasing thicknesses; 0.5, 1, 2, 4, 8 and 16 mm.

![Image of the LCLS Attenuator System](image)

**Figure 24: The LCLS Attenuator System.** The photon beam enters from the left hand side through the first differential pumping system. Upon entering the main Nitrogen gas cell, the beam transits through up to 6 Beryllium slides. Upon leaving the gas cell, the photon beam passes through the second differential pumping section.

Nitrogen gas absorbs low energy photons. Control of the gas pressure provides excellent attenuation control. The differential pumping transition sections each have chambers separated by Beryllium windows with 3 mm holes in the center to allow the FEL beam to pass. The windows are mounted in gate valves. There is a longitudinal pressure gradient (differential) from the central gas cell to each adjacent chamber in both the upstream and downstream directions.

The solid attenuator slides are located in the upstream portion of the main gas cell of the Gas Attenuator. The slides are polished to attain uniform spatial attenuation.

PRD #1.5-003; *Physics Requirements for the XTOD Attenuator System*; Peter Stefan, 2006
ESD #1.5-102; *XTOD Attenuator*; Stewart Shen, 2007
K-spectrometer \( Z=734 \text{ m} \)
The K-spectrometer, or K-mono, is used to match each undulator segment to a reference segment. The spectrometer system is inserted for calibration purposes. There is a photon detector that is part of the system and can be inserted or removed independently.

The K-mono utilizes Bragg’s Law of Diffraction. Bragg diffraction occurs when photons whose is wavelength comparable to atomic lattice spacing in a single crystal. Incoming photons are scattered by the crystal plane and undergo constructive interference and photons with wavelengths matching the lattice spacing are diffracted. The projected lattice spacing is dependent upon the angle of incidence of the photons. The K-mono uses single crystal Silicon. The surface of the crystal is ground and polished parallel to the Si(111) lattice. The angle of incidence is set to match 8.172 … eV photons. There is a fine adjustment to the angle of incidence to correct for beam alignment and systematic errors.

![Figure 25: The K-mono crystal stage. The incident polychromatic beam is diffracted from four crystal faces machined into two single crystals of Silicon. The beam bounces under a beam stop that terminates un-diffracted, high energy photons. The exiting beam is coaxial with the incoming beam. Small adjustments in pitch correct for beam alignment and systematic errors. The system can be fully retracted.](image)

The K-mono is a four crystal system comprised of two channel cut Silicon single crystals. The incoming spontaneous radiation beam diffracts up from the first crystal and is intercepted and diffracted by the second crystal. The doubly diffracted beam is parallel to but vertically displaced down with respect to the incoming beam. Higher energy photons from the incident beam are not diffracted and may pass through the crystal and its mounting. A Tungsten-alloy heavy metal beam stop between the two crystals terminates higher energy photons. After passing under the beam stop, the monochromatic beam strikes the third crystal face that is part of the second channel cut crystal. The beam is diffracted up to the fourth crystal where it is diffracted for the fourth time. The exiting beam is coaxial to the incoming beam.

The K-mono is used during undulator segment calibration. Optimum LCLS photon performance occurs when all undulator segments are matched to the same K value, the primary undulator parameter that varies with electron beam energy \( (m_e c^2) \), magnetic field strength (B) and magnetic pole spacing \( (\lambda_u) \).

\[
K = \frac{eB \lambda_u}{2\pi m_e c^2}
\]
The spacing of the permanent magnet poles is fixed but both beam energy and magnetic field strength can be changed remotely from the MCC control room. During calibration the electron beam energy is fixed while the gap between undulator jaws is adjusted to change the magnetic field strength. One by one, each undulator segment is calibrated with respect to a reference undulator. When calibration is complete, the K values for each undulator are matched.

The K-mono is also used for experiments, such as XES, that require a fixed monochromatic beam at 8.3 keV.

PRD #1.5-016; Physics Requirements for the XTOD/XES K-Measurement Monochromator System; Peter Stefan, 2009
ESD #1.5-117; XTOD/XES K-Measurement Monochromator System; Peter Stefan; 2009

**K-Mono Detector**

*K-mono Data Acquisition System, K-mono Final Design Review; Elden Ables, 2008*

**K-Monochromator**

*Data Acquisition System*
**Total Energy Monitor (Calorimeter) (Z=736 m)**
The total energy monitor, or calorimeter, absorbs the total energy of each FEL pulse in a silicon wafer. The wafer is thick enough to absorb the 8 keV photons, but too thin to absorb higher energy photons. It is destructive measurement, absorbing all of the FEL pulse energy. The thermal detector is expected to suffer least from ultra-fast non-linear effects and to be easy to calibrate. It is used to cross-calibrate non-destructive Gas Detector or the Direct Imager.

The energy in each FEL 10 pps pulse is about 2 mJ. A thermometer measures the increase in temperature of the silicon wafer that absorbs the pulse. After measurement, the absorber and sensor are cooled down through a thermal link to a temperature reservoir. The silicon wafer is coated with Neodymium Strontium Manganese Oxide (NSMO) to protect it from thermal and radiation damage.

The NSMO sensor on the Si absorber is inside a UHV sample chamber. The copper chamber stage attached to the Pulse Tube Cryostat that allows cooling the NSMO sensor to a desired operating temperature. The cryostat is supported by an xyz-stage so that has a vertical travel of 8” so that the monitor can be withdrawn upwards to clear the LCLS beam path. The calibration laser and its optical components that attenuate, characterize and focus onto the wafer are mounted on a small optical table beside the FEL beam path. When the monitor is withdrawn the optical calibration laser can be used for periodic in-situ recalibration.

The optical calibration system attenuates the pulsed output from the calibration laser to the desired energy and focuses it onto the Silicon wafer. The system measures the incident pulse energy and the reflected pulse energy, to monitor potential damage to the TE surface from exposure to the FEL.
The attenuator consists of a polarizer-analyzer and protects subsequent optical components. A telescope focuses the laser beam onto the back side of the TE, with its focal lengths adjusted to produce a spot size of the desirable diameter, around ~1 mm. The telescope initially expands the incident beam to reduce its energy density and thus prevent damage to the subsequent optical components.

A beam splitter deflects a well-defined fraction, in the simplest case 50%, of the beam towards the wafer while letting the remainder pass onto a pulse energy meter to monitor the energy of the incident beam. A defocusing lens is placed in front of the pulse energy meter to keep the intensity of the beam below the damage threshold of the meter. The meter is slightly rotated to prevent the beam from being reflected into the laser or the secondary meter.

The other half of the beam, after the beam splitter, is deflected onto the sensor through a mirror, achieving increased beam path, where the diameter of the calibration beam is larger to reduce damage to the coating during calibration, in minimal space. The rest is reflected, and the intensity of the reflected beam is monitored with a second pulse energy meter. The role of this secondary meter is to monitor the ratio of incident to, reflected beam to assess the quality of the absorbing Si surface remotely, since FEL radiation damage to that surface is likely going to change the reflection properties of the Si surface.

PRD #1.5-009; Physics Requirements for the XTOD Total Energy Measurement System; Peter Stefan; 2006
ESD #1.5-106; Total Energy Monitor; Stephan Friederich; 2008
Direct Imager Systems \((Z=737 \text{ m})\)

XTOD Direct Imager Systems consists of two electronic imaging systems that view a set of 3 YAG:Ce scintillating crystals that can be remotely inserted into the x-ray beam. Increasing thickness of the scintillators biases the fluorescence of higher energy photons. The scintillators are

1. 5 um thick for soft \(< 2\text{keV}\) x-ray FEL radiation in the presence of spontaneous background radiation,
2. 50 um for hard \(> 2\text{keV}\) x-ray FEL radiation in the presence of spontaneous background, or
3. 1 mm thick to view faint spontaneous radiation from single undulator segments.

The electronic imaging systems, mounted outside of the vacuum chamber, have optics providing either

1. 117 \(\mu\text{m}\) resolution over a wide field-of-view (WFOV) for soft x-rays of about 1 mm FWHM
2. 20 \(\mu\text{m}\) resolution over a narrow field-of-view (NFOV), for hard x-rays of about 200 \(\mu\text{m}\) FWHM

The Direct Imager will also be used in conjunction with the K-mono for locating the center of the spontaneous radiation beam.

The imagers view the 3 YAG:Ce scintillator plates, mounted on a moveable shaft inside the vacuum enclosure, which can be remotely positioned into the photon beam at a 45° angle. The image path consists of a vacuum window, a lens, a remotely-controlled wheel of neutral-density filters, a high-speed CCD camera, a camera mount that provides manual control of the tip and tilt of the camera axis, and a remotely-controlled camera focus adjustment mechanism.

When placed in the x-ray beam, the scintillator plates stop a portion of the incident x-ray photons. The YAG:Ce material converts a small fraction of the energy deposited by the x-ray photons into visible and near-UV light which is radiated in all directions. A small amount of this light is intercepted by the lenses and directed onto the CCD focal plane array. A fraction of the UV/visible photons that strike the focal plane array are converted into photoelectrons that are counted, on a pixel-by-pixel basis, by the CCD readout electronics.

The YAG:Ce can, under high levels of x-ray irradiation, emit enough light to saturate the high sensitivity CCD cameras. Therefore both the WFOV and NFOV systems include neutral density (ND), visible light filters, mounted on a remote-controlled wheel. The illuminator system provides visible

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**Figure 28: Direct Imaging System.**
light in the object plane for focusing and alignment. The UV light source excites visible and near-UV photons from the YAG:Ce scintillator, and enables a check on the spatial uniformity and stability of the light output from the YAG:Ce.

PRD #1.5-010; Physics Requirements for the XTOD Direct Imager; Jacek Krzywinski and Peter Stefan; 2007
ESD #1.5-112; XTOD Direct Imager; Richard Bionta; 2008
Offset Mirror Systems (OMS)
The XTOD Offset Mirror Systems are designed to spatially separate the useful FEL radiation from high-energy spontaneous radiation and Gas Bremsstrahlung γ-rays. Lower energy 1st and 2nd harmonic photons are absorbed by the Attenuator System. The 3rd harmonic FEL radiation is specularly reflected by mirrors. The Soft X-ray Offset Mirror System (SOMS) horizontally deflects the FEL beam from the primary beam path. The Hard X-ray Offset Mirror System (HOMS) vertically deflects the FEL beam from the primary beam path. Unreflected, higher energy photons continue down the primary beam path and are absorbed by shielding collimators located in the Front End Enclosure (FEE).

Figure 29: XTOD Offset Mirror System

Combinations of mirrors direct the photon beam into each of 6 LCLS hutches. The mirrors create two kinds of beam lines: large angle of incidence horizontally reflected soft x-rays and low angle of incidence, vertically reflected hard x-rays. The OMS has five mirrors

1. M1-Soft
2. M2-Soft
3. M3-Soft 1 or M3-Soft 2 (NEH Hutch 2 or 3)
4. M1-Hard
5. M2 Hard (NEH Hutch 1 or FEH Hutch 4, 5 or 6)

There are also eleven photon beam and shielding collimators.

Only one mirror system operates at one time. SOMS has two possible configurations and HOMS has only one configuration.

ESD #1.5-125; XTOD Offset Mirror System Alignment; Peter Stefan; 2009
**Soft X-ray Offset Mirror System (SOMS)**

Soft x-rays are defined to be < 2000 eV. The SOMS mirrors are flat Silicon plates with a protective surface coating of Silicon Boride, B$_4$C.

![SOMS Diagram](image)

**Figure 24: LCLS SOMS Mirror**

The mirrors are oriented to the FEL photons with a grazing angle of incidence, $\alpha$, of 15 mrad. The mirror coating and angle of incidence define the mirror cut-off energy. Photons with energies below the mirror cut-off energy are reflected. Photons with energies above the mirror cut-off energy pass through the mirror unreflected. The SOMS photon energy range is 826.5 eV to 2000 eV.

![SOMS System Diagram](image)

**Figure 30: The first two mirrors of the LCLS Soft X-ray Offset Mirror System**

The SOMS mirrors all have an angle of incidence of 15 mrad and act in series on the beam.

1. M1-Soft deflects the beam $2\alpha$, or +30 mradians, horizontal
2. M2-Soft also deflects the beam +30 mradians, leading to a total angular deflection of 60 mradians
3. M3-Soft 1 deflects the beam -30 mradians, leading to a total angular deflection of 30 mradians
4. Alternatively, M3-Soft 2 deflects the beam +30 mradians, leading to a total angular deflection of 90 mradians

Some photons are scattered from the mirror due to small amounts of surface roughness. Collimators absorb scattered photons and ensure that the photons remain on the correct beam path.

ESD #1.5-122; *HOMS & SOMS Opt-Mechanical Design*; Tom McCarville; 2009
PRD # 1.5-004; *Physics Requirements for the XTOD Soft X-Ray Offset Mirror System*; Peter Stefan, 2006
**Hard X-ray Offset Mirror System (HOMS)**

Hard x-rays are defined to be > 2000 eV. Like the SOMS mirrors, HOMS mirrors are flat Silicon plates with a protective surface coating of Silicon Boride, B$_4$C.

![HOMS Mirror Diagram](image)

**Figure 26: LCLS HOMS Mirror**

The mirrors are oriented to the FEL photons with a grazing angle of incidence, $\alpha$, of 1.3 mrad. The mirror coating and angle of incidence define the mirror cut-off energy. Photons with energies below the mirror cut-off energy are reflected. Photons with energies above the mirror cut-off energy pass through the mirror unreflected. The HOMS photon energy range is 2000 to 25000 eV.

![HOMS System Diagram](image)

**Figure 27: LCLS Hard X-ray Offset Mirror System**

The HOMS mirrors have an angle of incidence of 1.3 mrad and act in series on the beam.

1. M1-Hard deflects the beam $2\alpha$, or $\pm 2.6$ mrad.
2. M2-Hard deflects the beam -2.6 mrad, leading to a total angular deflection of 0 mrad

The HOMS generates a displaced beam parallel to the incident beam. Some photons are scattered from the mirror due to small amounts of surface roughness. Collimators absorb scattered photons and ensure that the photons remain on the correct beam path.

ESD #1.5-122; *HOMS & SOMS Opt-Mechanical Design*; Tom McCarville; 2009
PRD # 1.5-005. *Physics Requirements for the XTOD Hard X-Ray Offset Mirror System*; Peter Stefan; 2007
Angle of Incidence and Image Pop-in Monitors

Pop-in monitors are used to measure the angle of incidence of each mirror. Image pop-in monitors can be inserted for a visual beam image. Downstream of each collimator is an image pop-in monitor.

Alpha Pop-In are located downstream of each mirror and can see both the reflected and unreflected beams using a large scintillator crystal and wide field-of-view camera system. These systems are calibrated so that the separation between the incident photon beam and the reflected photon beam can be accurately measured. Knowing the exact distance between the mirror and the monitor, the angle of incidence can be calculated.

\[ \tan(\alpha) = \Delta s/2d \]

**Figure 28: Alpha Pop-in Diagram**

Mirror and alpha pop-in monitors pairs are
1. M1-Soft and P1
2. M2-Soft and P2S
3. M3-Soft1 and P3S1
4. M3-Soft12 and P3S2
5. M1-Hard and P2H
6. M2-Hard and P3H

Collimator and image pop-in monitors in the NEH are
1. C4-Soft 1 and P4S1
2. C4-Soft 2 and P4S2
3. C4-Hard and P4H
4. C5 and P5

The collimator and image pop-in monitor in the X-ray Transport Tunnel is
1. C6 and P6

ESD #1.5-125; XTOD Offset Mirror System Alignment; Peter Stefan; 2009
6.3 XTOD Photon Spectra

PRD # 1.5-127. *Estimation of the XTOD Beam Line Photon Spectra*; Peter Stefan; 2008

6.4 MPS System

ESD #1.1-312; *LCLS Machine Protection System*; Patrick Krejcik; 2006
ESD #1.1-315; *LCLS Machine Protection system Engineering Design Specifications*; Stephen Norum; 2007
CHAPTER 7

FACILITY SYSTEMS

7.1 Vacuum System

ESD #1.1-328; Vacuum Controls Requirements for XTOD and XES Systems

7.2 Experiment Cryogenics

7.3 PCW System