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Linac Coherent Light Source
Global Project Requirements

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Change History Log

Rev Number	**Revision Date**	**Sections Affected**	**Description of Change**
000	5-14-2004	All	Initial Version
001	10-5-2007	All Reviewed	Revised to be consistent with Project Execution Plan

Linac Coherent Light Source Project Requirements

1 Scope

1.1 Identification

This document, the Linac Coherent Light Source (LCLS) Requirements Document, specifies the performance requirements for the LCLS x-ray free-electron laser to be constructed at the Stanford Linear Accelerator Center (SLAC).

1.2 Project Overview

The Linac Coherent Light Source (LCLS) Project will be the world's first "hard" x-ray laser, producing x-ray beams of unprecedented brightness in the wavelength range 1.5 – 15 Angstroms (800 – 8,000 eV photon energy). The Project scope includes:

- facilities for production and transport of a bright, high-current electron beam
- an undulator system in which the electron beam will generate the x-ray beam
- facilities for transport, diagnostics and optical manipulation of the x-ray beam
- endstations and related facilities for x-ray experiments
- conventional facilities for the accelerator systems and x-ray experiments
- office space for operations staff.

The LCLS project will build an x-ray FEL facility at SLAC based on their existing linac. The LCLS requires a new 135 MeV injector to be built at Sector 20 of the 30-sector SLAC Linac to create the high brightness electron beam required for the FEL. The last kilometer of the linac will be modified by adding two magnetic bunch compressors. Most of the linac, and its infrastructure, will not be changed. The existing components in the Final Focus Test Beam tunnel will be removed and replaced by an electron beam transport line that crosses the Research Yard at the end of the linac. This "linac-to-undulator" line will enter the berm at the east end of the Research Yard, connecting to an underground tunnel housing a new 120 meter undulator and associated equipment. A shielded electron beam dump will be located approximately 67 meters downstream of the undulator. Two new experimental halls will be constructed. The Near Hall will be built approximately 100 meters downstream of the undulator. It will contain three experiment stations within shielded hutches. An x-ray transport tunnel will connect the lower level of the Near Hall to the Far Hall, an underground cavern located approximately 386 meters downstream of the Undulator Hall. The Far Hall will contain two experiment hutches with adjacent work areas for experimenters and staff.

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

• Filtering
• Monochromatization
• Focused beams
• Synchronization of the LCLS beam to a pump laser
• 120 Hz x-ray pixel array detectors with large area and high angular resolution

The Project scope also includes x-ray endstation systems for five hutches: personnel protection systems, computer infrastructure, laser oscillators synchronized to the LCLS x-ray pulse, and components necessary to begin a research program in atomic, molecular and optical physics.

Conventional facilities for the LCLS include

- modifying existing building at sector 20 to house the injector linac systems
- modifications to the linac utilities to support the new bunch compressors
- modifying existing building for the magnetic measurement facility
- modifications to the Research Yard to accommodate the LCLS
- a new linac-to-undulator (LTU) shielded enclosure crossing the Research Yard
- improvements to the Research Yard roads necessitated by the presence of the LTU, which will prevent vehicles from passing across the yard
- an undulator hall, 175 meters long,
- a shielded beam dump at the end of the undulator hall
- a Near Experiment Hall housing three experiment hutches
- an x-ray transport tunnel connecting the Near Hall to the Far Hall
- a Far Experiment Hall housing two experiment hutches, with space for a third hutch
- utilities support buildings necessary to house infrastructure systems for the LCLS.
- office space for support of LCLS staff and researchers

The Project will be executed by a collaboration of three institutions. Stanford Linear Accelerator Center will provide central management and coordination of collaborating labs' activities. SLAC will manage all modifications to the linac as well as the installation of technical components. SLAC will be responsible for x-ray endstation systems design and construction. SLAC will also oversee conventional construction.

Argonne National Laboratory will design and construct the undulator systems, including the undulators themselves, electron beam diagnostics in the undulator and the vacuum systems for the electron beam. Argonne will have management responsibility for the magnet measurement facility to

be constructed at SLAC; and the measurement of production undulators, however this work will be done by SLAC personnel.
Argonne will have management responsibility for design of electron beam position monitors in the undulator system; it is expected that this work will be carried out by SLAC personnel.

Lawrence Livermore National Laboratory (LLNL) will be responsible for x-ray transport, optics and diagnostics systems. These systems include x-ray collimators and attenuators, monitors for measurement of intensity, spatial and temporal properties of the x-ray pulse, photon-spectral properties of the x-ray pulse. LLNL will have management responsibility for the construction of prototype monochromators for modification and control of temporal characteristics of the x-ray beam; this work will be carried out by SLAC personnel.

Another collaborating institution, University of California – Los Angeles, has supported the Project with theoretical and numerical predictions of x-ray laser performance, necessary to validate design choices and design tolerances for LCLS technical systems.

1.3 Document Overview

This document specifies, for the LCLS as a whole and for subsystems,

- *Performance requirements* for the LCLS: key design parameters that served as the basis for CD-0 Approval of Mission Need and CD-4 Approval of Start of Operations
- *Performance goals*: intended to serve as guidance for the design of the LCLS
- *Functional requirements*: other requirements, such as compatibility with other functions of the SLAC Linac, that must be satisfied by the LCLS
- *Functional goals* intended to serve as guidance for the design

The scope of this document is limited to technical performance requirements related to the research mission of the LCLS. The LCLS Project must satisfy additional requirements related to project management and operations, including management of environment/safety/health. Such requirements are specified in applicable DOE Orders and LCLS documents such as

- DOE O413.3A
- DOE P 413.1
- SLAC/DOE Contract DE-AC02-76-SF00515

The LCLS Project construction is being executed by a collaboration of institutions:

- Argonne National Laboratory
- Lawrence Livermore National Laboratory

Work carried out at collaborating institutions will be executed in accordance with policies and procedures at the collaborating laboratories.

Environment, safety and health requirements and considerations specific to the LCLS Project may be found in the Safety Assessment Document (SAD) for the LCLS. Project ES&H responsibilities and authorities are defined by SLAC ES&H policies.

1.3.1 Relation of System to Subsystem Requirements

This document is limited to global and general requirements for the LCLS. Subsystem designs and specifications shall be consistent with this document. Possible non-compliances or inconsistencies shall be identified and corrected by LCLS Management.

1.3.2 Document Updates

This document will be revised as necessary to best communicate LCLS requirements to the LCLS Integrated Project Management Team

2 Applicable Documents

2.1 Government Documents

- CD-0: Approve Mission Need for the Linac Coherent Light Source
  http://www-ssrl.slac.stanford.edu/lcls/documents/LCLS_CD-0_final.pdf
- CD-1 Approve Preliminary Baseline Range for the Linac Coherent Light Source
  http://www-ssrl.slac.stanford.edu/lcls/documents/Final_LCLS_CD-1_Approval_Document_09-12-02.pdf
- CD-2B Approve Performance Baseline for the Linac Coherent Light Source
  http://www-ssrl.slac.stanford.edu/lcls/Documents/LCLS_CD-2b_appr.pdf
- Project Execution Plan for the Linac Coherent Light Source
  http://www-ssrl.slac.stanford.edu/lcls/reviews/2007_oct9-12_eir/eir_docs/lcls_pep_final_sep07-r3.pdf

2.2 SLAC Documents

Reserved

2.3 LCLS Documents

- Linac Coherent Light Source Conceptual Design, SLAC-R-593
  http://www-ssrl.slac.stanford.edu/lcls/cdr/

2.4 Other Documents

LCLS Project Physics Requirements Documents, Engineering Specification Documents and the LCLS Safety Assessment Document provide more detailed information to guide the design of subsystems and components. The subsystems must be designed to be consistent with the General Requirements Document requirements and goals.

3. Requirements and Goals

3.1 Performance Requirements for Project Completion and CD-4

The Project Execution Plan states

> Key capabilities to be attained at CD-4 are: All capital facilities installed and commissioned necessary to demonstrate detection of Xrays in the Near and Far Experimental Halls (NEH and FEH), and demonstrate a single pulse x-ray with minimum spectral flux density of ~10^6 photons/(mm^2 ·0.1%BW) initially.

3.2 Key Performance Goals in Fulfillment of CD-0

The key performance goals of the LCLS have been listed in the *CD-1 Approval of Preliminary Baseline Range for the Linac Coherent Light Source*. The same parameters are listed in the LCLS Project Execution Plan, as "Key Design Parameters at Full Operation":

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

These key performance goals form the basis for approval of CD-0 and CD-1. The pulse duration specification requires some clarification. The electron bunch length for nominal operations is 230 femtoseconds. The x-ray pulse can be no longer than the electron bunch, so this duration is an upper limit on the x-ray pulse length for nominal LCLS operating parameters.

3.3 Key Functional Requirements

3.3.1 LCLS Operation Integrated with SLAC Operations

Maintenance to the LCLS linac requiring entry to the linac enclosure may only be carried out when the entire linac is shut down for access.

Operation of the LCLS will be completely compatible with simultaneous operation of the linac in support of the PEP-II program.

It will be possible to switch from LCLS operation to acceleration of beam from the damping rings (e.g. to Endstation A) without the need to enter the linac tunnel.

Acceleration of beam from the CID guns may require removal of the x-band accelerating structure in sector 21 of the LCLS Linac. It will be possible to remove this accelerating structure and make the linac ready for beams from CID in 24 hours or less.

Operations control of the LCLS linac and the electron beam will be carried out from the SLAC Main Control Center. Necessary data for monitoring and control of the LCLS will be available to the SLC controls system.

3.3.2 Safety Envelope, Basis of Radiation Shielding Design

The LCLS nominal operating parameters are 120 nanoamperes of 14.1 GeV electrons, a beam power of 1692 watts. For the purposes of radiation shielding design, the following beam parameters are used:

- Maximum beam power for operations: 5. kW
- Maximum credible incident (MCI) beam power: 100. kW

3.4 Functional Goals

The LCLS linac and undulator systems should be designed to operate with bunch charges in the range 0.2 – 1.0 nanocoulomb.

Operational availability should be greater than 90%. The linac is typically operated about 6600 hours per year for all purposes (PEP, FFTB, Endstation A, tuneup/training/studies)

The traditional tolerance for transverse beam stability in a synchrotron source is 10% of beam size. This will be a challenging goal due to the small emittance of the LCLS beam.

EPICS controls should be implemented where practical; it is expected that the injector, undulator systems, x-ray transport/optics/diagnostics and endstation systems will implement EPICS for device control.

3.5 Subsystem Requirements and Goals

The Project performance requirements and goals can be achieved with a range of operating configurations of the injector, linac and undulator. Performance goals and requirements for the subsystems are separately documented. An abridged list of performance goals for the subsystems is found in the following sections of this document.

3.5.1 Work Breakdown Structure

At Level 2, the work breakdown structure names the major components of the LCLS Project:

1.1 Management
1.2 Injector System
1.3 Linac System
1.4 Undulator System
1.5 X-Ray Transport, Optics and Diagnostics
1.6 X-ray Endstation Systems
1.7 (reserved)
1.8 (reserved)
1.9 Conventional Facilities

3.5.2 Injector(WBS 1.2)

3.5.2.1 Injector Performance Goals

- Maximum beam energy 135 MeV
- Nominal charge/pulse 1 nC
- Nominal pulse length 10 ps at end of injector linac
- Projected emittance, normalized <1.2 mm-mrad
- Slice emittance, normalized <1.0 mm-mrad, for 80% of full pulse length

3.5.2.2 Performance Requirements to Support Commissioning

The parameters listed in 3.5.2.1 are operational performance goals. Productive commissioning of Linac Systems, which is scheduled to begin in the second quarter of FY2007, can be satisfactorily supported by the injector if it has met the following performance goals:

- Repetition rate 1 Hz operation capability
- Repetition rate 10 Hz or greater
- Nominal charge/pulse 0.2 nC - 0.5 nC or greater
- Nominal pulse length 3-10 ps

Check the LCLS Project website to verify that this is the correct version prior to use.

- Slice emittance, normalized 2.0 mm-mrad or less

3.5.3 Linac (WBS 1.3)

3.5.3.1 Linac Performance Goals

The linac accelerates the beam from the injector to energies as high as 14.35 GeV. The spectral coverage of the LCLS requires operation up to 14.1 GeV. Performance goals for the output beam from the Linac System, delivered to the input of the Undulator System, are

- Acceleration to 14.3 GeV
- Bunch compression to 3.4 kA or greater
- Projected emittance, normalized <2.4 mm-mrad
- Slice emittance, normalized <1.2 mm-mrad
- Final energy spread <0.02% 'slice', <0.1% 'projected'

3.5.3.2 Linac Functional Requirements

The electron beam is collimated in the linac-to-undulator transport line, so as to avoid irradiation of the undulators by mis-steered or mis-focused electrons. The proper placement and function of these collimators is of great importance to achieving a satisfactory service life for the undulators.

- Properly aligned and functional collimators

3.5.3.3 Linac Performance Requirements to Support Commissioning

- Repetition Rate 1-10 Hz or greater operation capability
- Nominal charge/pulse 0.2 nC - 0.5 nC or more
- Slice emittance, normalized 2.5 mm-mrad or less

3.5.4 Undulator Systems (WBS 1.4)

3.5.4.1 Undulator Systems Performance Goals

The undulator system is an electron beam transport line incorporating the undulator magnets, which induce the electron beam to produce the x-ray beam. The system includes sensitive beam monitoring devices and remotely-controlled positioning stages to maintain the alignment of components to the stringent tolerances required for laser operation. The primary performance requirement is that the undulator produce 0.15 nm radiation from an electron beam of energy 14.1 GeV. SLAC has chosen the additional constraint that the undulator period should be 3 cm. The undulator period, combined with the x-ray wavelength requirement, constrains the peak magnetic field in the undulator to be B=1.298 T. Prototype undulator measurements have shown that this field can be achieved in a magnet with vertical aperture 6.5mm.

- Undulator radiation wavelength 0.15 nm at electron energy 14.1 GeV

Other dimensions of the undulator and related systems have been chosen to allocate space for quadrupole focusing magnets, diagnostic devices, etc. Additional requirements for undulator system design are found in the Undulator Systems Requirements Document.

3.5.4.2 Undulator Systems Functional Requirements

The primary functional requirement for the undulator system is lossless transport of the electron beam to the beam dump. Loss of electrons in the undulator beam line must be minimized. The undulator beam line must have a completely functional machine protection system, including beam loss monitors and current monitors.

- Machine protection system for undulator

3.5.4.3 Performance Requirements to Support Commissioning

The primary performance goal for the undulator system is reliable loss-free transport of electrons to the beam dump.

- Loss-free transport of beam to the beam dump
- 1 Hz linac operation capability

3.5.5 X-Ray Transport, Optics and Diagnostics (WBS 1.5)

3.5.5.1 Performance Requirements and Goals

This WBS element will include a complete set of diagnostic devices for characterization of the x-ray beam. Also included are prototype components for photon energy selection and mirrors for harmonic rejection and beam re-direction. Goals for the x-ray diagnostics measurement capability and limits are listed below:

- Position of centroid 5% of the beam size
- Transverse dimensions 10% of beam size
- Divergence 10% of the beam divergence
- Photon energy 0.02% of the beam energy
- Photon energy spread 20% of the energy spread

3.5.5.2 Functional Requirements and Goals

- Attenuators operating over the complete photon energy range and intensity range
- Beam defining slit systems

X-ray optics will all be first-of-a-kind in terms of ability to withstand the fluence of the LCLS x-ray beam. By other measures, such as operating wavelength range, energy resolution, etc. the optics are within the state-of-the-art. In view of the fact that there is no means of testing the fluence handling capacity of the LCLS optical elements until the start of LCLS commissioning, no CD-0 performance goals are established for the optics.

3.5.5.2 Performance Requirements to Support Commissioning

- Intensity monitor for spontaneous radiation from >0.2 nC electron bunch
- Beam position monitors for spontaneous radiation from >0.2 nC electron bunch
- Beam profile monitors for spontaneous radiation from >0.2nC electron bunch
- Functional gas attenuator
- Functional solid attenuator

3.5.6 X-Ray Endstation Systems (WBS 1.6)

Support infrastructure for five shielded experiment stations will be included in the scope of the LCLS. Basic experiment station infrastructure including hutch personnel protection systems (PPS), prototype x-ray detectors, computer servers, and communications infrastructure will be provided.

3.5.6.1 X-ray Endstation Systems Performance Goals

- Synchronization between gun laser and lasers in experiment halls to be no more than 100 fs jitter

3.5.6.2 X-Ray Endstation Systems Functional Goals

Reserved

3.5.6.3 X-ray Performance Requirements to Support Commissioning

- Functional hutch Personnel Safety System in the first Near Experiment Hall hutch

3.5.7 Conventional Facilities (WBS 1.9)

For the most part, conventional facilities requirements have been determined by the design of technical systems and components. These requirements are listed in separate Requirements Documents. Requirements set by Project Management are:

- Provision for five x-ray experiment stations, three each in the Near and Far Halls
- Radiation shielding design based on 5 kW electron beam power
- Office space for LCLS support staff, in addition to the floor space in the Experiment Halls

3.5.7.1 Performance Goals

Reserved

3.5.7.2 Functional Requirements

Reserved

3.5.7.3 Performance Requirements to Support Start of FEL Commissioning

Reserved