Preface

This Conceptual Design Report (CDR) describes the design of the LCLS. It will be updated to stay current with the developing design of the machine. This CDR begins as the baseline conceptual design and will evolve into an "as-built" manual for the completed FEL. The current released version of the CDR can be found on the LCLS web page,

http://www-ssrl.slac.stanford.edu/lcls/.

The Executive Summary, **Chapter 1**, gives an introduction to the LCLS project and describes the salient features of its design.

Chapter 2 is a stand-alone document that gives an overview of the LCLS. It describes the general parameters of the machine and the basic approaches to implementation.

The LCLS project does not include the implementation of specific scientific experiments. Nonetheless, significant work has been done on defining potential initial experiments to aid in assuring that the machine can meet the requirements of the experimental community. **Chapter 3**, Scientific Experiments, describes that work on potential experiments.

The chapter begins with a description of the unique characteristics of the LCLS radiation. Then it describes five experimental areas that can effectively use this radiation, 1) atomic physics, 2) plasma and warm dense matter, 3) structure of single particles and biomolecules, 4) femtochemistry, and 5) nanoscale dynamics in condense matter. In each of these fields, the basic scientific questions that can be addressed by the LCLS are described, the experimental requirements are defined, and appropriate initial experiments are defined.

Chapter 4, FEL Physics, describes the physics that underlies the LCLS design. It begins with a brief history, particularly of work on the Self Amplified Spontaneous Emission (SASE) principles. The SASE mode of operation is central to operation at the LCLS wavelengths and has been demonstrated recently at longer wavelengths.

Then the requirements for the electron beam are described. These are challenging and set the parameters for the generation, acceleration, manipulation, and transport of the electrons.

Finally, the characteristics of both the spontaneous and coherent radiation from the FEL are calculated. This provides important input to the design of the x-ray beam transport and to the design of the experiments.

The basic parameters of the LCLS design are presented in **Chapter 5**, FEL Parameters and Performance. The design of the focusing system is laid-out. Sources of gain reduction and resulting tolerances are discussed and the electron beam tolerance goals are given. Then, the temporal structure of the x-ray pulse is discussed. The start-to-end simulations are presented. The control of x-ray power levels and an overview of the LCLS Commissioning are presented in this chapter.

The LCLS requires a high brightness electron beam with very low timing and intensity jitter. **Chapter 6**, Injector, describes the equipment required to generate this beam; the laser for the photocathode rf electron gun, the accelerator (L0), the matching section into the main linac and the beam diagnostic equipment. It describes beam simulations that have been used to optimize the design and give assurance of meeting the required parameters. These simulations are described along with the results. Experimental results from the Gun Test Facility at SLAC and other laboratories support the results of these simulations.

Chapter 7, Accelerator, describes the acceleration, manipulation, and transport of the electron beam from the Injector to the Undulator. The LCLS uses the last one third of the existing SLAC linac to accelerate the 150 MeV beam from the injector to a final energy between 4.54 GeV and 14.35 GeV. The linac will be modified to include two pulse compression chicanes, an x-band accelerator to linearize the compression, a wiggler for Landau damping, new diagnostics including a pulse length monitor, and the transport line to the undulator.

These systems accelerate and compress the electron beam to produce very short pulses with very high currents while preserving the transverse emittance. This chapter describes the accelerator physics involved and the simulations that have been run. Also, it defines the tolerances required of the microwave and magnet systems required to meet the LCLS requirements.

The basis for the choice of parameters for the undulator line and a tolerance budget are derived in **Chapter 8**, Undulator. The choice of magnetic material and the requirements for measuring individual blocks are presented. Then the overall mechanical design of the undulator segments is described including the precision supports. The vacuum system design is discussed along with how the inner surface roughness requirements will be met. This roughness can be a source of disruptive wakefields. The electron and x-ray diagnostics at each gap between the undulator segments are described.

The tight requirements for keeping the electron beam and the FEL radiation collinear in the Undulator will be met with a beam-based alignment procedure. This procedure and the associated simulations are described.

Chapter 9, X-Ray Beam Transport and Diagnostics, describes the suite of x-ray transport and x-ray diagnostic devices that are included in this construction project. This suite of devices will be used to commission the LCLS, to characterize the generated x-ray beam and to prove the key technologies required for doing experiments at the facility.

Both specular (for the full spectral range) and crystal (for wavelengths shorter than 4.5 Å) optics will be employed. In the initial operation, it is expected that the high peak power and power density will prevent the utilization of the full FEL flux with conventional focusing and transport optics. On the other hand, there will be a unique opportunity to study the effect of high peak power density on materials and optical elements, thereby opening the path to the full exploitation of the radiation in the LCLS. Consequently, a system will be designed that allows intensity of the radiation to be varied from the level of current third-generation facilities up to the maximum LCLS intensity. This will be achieved by introducing a gas attenuation cell into the path of the FEL radiation. Further reduction factors can be obtained on the beam line optics and instrumentation by operating their crystal or specular optical elements at very low grazing-incidence angles. These facilities are described in this chapter.

The LCLS takes advantage of the existing infrastructure at SLAC. **Chapter 10**, Conventional Facilities, describes the modifications required to existing buildings and utilities and the new construction that is required. An extension to the existing FFTB tunnel, two experimental halls and a tunnel connecting the two halls will be constructed.

The LCLS injector will be installed at sector 20 in the existing Off-Axis Injector Tunnel. This tunnel will require some modifications to bring it to current safety standards and to accommodate the specific requirements of the LCLS injector. A clean room will be constructed in the existing surface building for the gun laser.

The undulator is housed in the existing FFTB tunnel after the tunnel has been extended. Two new experimental halls will be built. The Near Hall will begin 40 m downstream of the undulator and the Far Hall will be constructed 322 m downstream the undulator, just outside of the PEP ring road. A tunnel that is 227 m long will connect the two halls. An office and laboratory structure will be constructed at grade on top of the far hall.

Chapter 11, Controls, describes the modification and extension of the existing control system at SLAC to meet the requirements of the LCLS. New systems that are added for the LCLS will be controlled using EPICS-based systems. The LCLS will be controlled from the existing Main Control Room.

The x-ray beam line controls have two major objectives. One objective is to provide control of the x-ray optical elements. The second objective is to provide sufficient data collection capability to allow for thorough testing of different components.

At SLAC the Beam Containment Systems (BCS), Machine Protection Systems (MPS) and Personnel Protection Systems (PPS) are included in the control system and are described in this chapter.

Chapter 12, Alignment, describes the procedures and methods used to position the LCLS components with their required accuracy. Most of the alignment requirements are well within the range of proven traditional alignment techniques. Alignment of the undulator section is the most demanding. The state-of-the-art equipment and procedures that are needed to meet the positioning requirements are described in this chapter.

Chapter 13, Environment, Safety and Health and Quality Assurance, describes the exiting programs at SLAC and their application to the LCLS project. A preliminary analysis of safety hazards is presented along with the planned mitigation.

The radiation concerns related to the LCLS fall into three distinct areas: radiation safety, radiation background in experiments, and machine protection. **Chapter 14**, Radiological Concerns, covers these concerns in the region downstream of the undulator, since the linac operation is within the existing safety envelop. The studies that are described in this chapter indicate that the radiation is quite manageable.

Chapter 15, Work Breakdown Structure, describes the work breakdown structure used of developing the costs and that will be used to manage the project. The chapter defines the scope of work of each element down to level 3.

Appendix A, Parameter Tables, provides and extensive list of the relative parameters and tolerances for the elements of the LCLS.

Appendix B, Control Points, list each piece of equipment along the LCLS beam line and then lists the associated control points.

Appendix C, Glossary, lists the acronyms used in this report and their definition.