2 PROJECT OVERVIEW

2.1 Introduction

The unique properties of synchrotron radiation, such as wide-energy tunability, high brightness, extreme collimation, polarization, and time structure, have enabled a number of new and important techniques since the early days of their use in the 1960s. Today's synchrotron light sources are the products of several generations of advances in light source technology.

Most recently, medium energy light sources, occupying the ~2.5 to 3.5 GeV middle ground between low energy and high energy storage rings, have rapidly gained popularity. These machines are distinguished by having a combination of high operating current, low beam emittance, and advanced ID technology. Five such facilities are currently operating and twenty-one more are either in design or under construction around the world.

The utility of the medium energy synchrotrons has been extended by technological progress in many areas, including: shimming of undulator magnets to increase high harmonic content; higher harmonic RF-cavities to extend beam lifetime; bunch-by-bunch feedback systems to control instabilities at high beam current; beam orbit control for high beam stability and reproducibility; in-vacuum, small gap, short period undulators to generate hard X-rays at relatively low electron beam energy; superconducting bend magnets to shift the X-ray spectrum to higher energy; and continual full energy top-off to extend the effective beam lifetime and eliminate thermal cycling of storage ring and X-ray beamline components. Among these, progress in undulator technology is especially important, as it boosts the bright radiation output of the medium energy machines into the most heavily used 5 to 20 keV range. Undulators on the three high energy machines are still required to reach up to the 50 keV and above range required for some experiments.

The performance goals of NSLS-II are motivated by the recognition that major advances in many important technology problems will require scientific breakthroughs in developing new materials with advanced properties. Achieving this will require the development of new tools that will enable the characterization of the atomic and electronic structure, the chemical composition, and the magnetic properties of materials with nanoscale resolution. These tools must be nondestructive, to image and characterize buried structures and interfaces, and they must operate in a wide range of temperatures and harsh environments.

In order to meet this need, NSLS-II has been designed to provide world leading brightness and flux and exceptional beam stability. The brightness is defined as the number of photons emitted per second, per photon energy bandwidth, per solid angle, and per unit source size. Brightness is important because it determines how efficiently an intense flux of photons can be refocused to a small spot size and a small divergence. It scales as the ring current and the number of total periods of the undulator field (both of which contribute linearly to the total flux), as well as being inversely proportional to the horizontal and vertical emittances (the product of beam size and divergence) of the electron beam. Raising the current in the storage ring to obtain even brighter beams is ultimately limited by beam-driven, collective instabilities in the accelerator. Thus, to maximize the brightness, the horizontal and vertical emittances must be made as small as possible.

The conventional approach to designing storage rings for low emittance leads to geometries with many magnetic elements. Achieving small emittances in such lattices results in large nonlinearities in the beam dynamics that ultimately place limits on the lifetime and the minimum achievable size of the emittance.

An alternative to achieving very small emittances which avoids the difficult nonlinearities is based on the use of damping wigglers (a specialized wiggler with a long period and high field). The concept of using damping wigglers for achieving small emittance has previously been employed on storage rings for high energy physics and is incorporated in the designs of all the lepton damping rings required for the various projects of high energy linear colliders. The approach of NSLS-II is to employ a bare lattice with relatively modest nonlinearities and to use damping wigglers to achieve an unprecedented low emittance. This is quite innovative, as no currently operating synchrotron utilizes damping wigglers.

Fully maximizing the effect of damping wigglers in reducing the emittance requires low-field bending magnets and a number of damping wigglers. As a result, NSLS-II has been specifically designed for their incorporation. Because of their lower field, the bending magnets will be excellent sources of radiation in the VUV and soft x-ray range, as well as world leading sources of infra-red radiation. In addition to damping the beam, the damping wigglers will also produce high energy x-rays with much higher brightness and flux than conventional bending magnets and will be used in place of the bending magnets for experiments requiring hard x-rays. As such, the design of NSLS-II is quite innovative and distinct from other synchrotrons in that most of the synchrotron radiation is produced by insertion devices in the non-dispersive straight sections, rather than by the bending magnets, as is the case in all other synchrotrons. As a result, the emittance growth due to synchrotron radiation is minimized.

The performance of NSLS-II will be nearly at the ultimate limit of storage ring light sources set by the intrinsic properties of the synchrotron radiation process. The facility will produce x-rays more than 10,000 times brighter than those produced at NSLS today. The superlative character and combination of capabilities will have broad impact on a wide range of disciplines and scientific initiatives in the coming decades, including new studies of small crystals in structural biology, a wide range of nanometer-resolution probes for nanoscience, coherent imaging of the structure and dynamics of disordered materials, greatly increased applicability of inelastic x-ray scattering, and properties of materials under extreme conditions.

Commissioned in 1982, the existing National Synchrotron Light Source (NSLS) provides essential scientific tools for 2,300 scientists per year from more than 400 academic, industrial, and government institutions. Their myriad research programs produce about 800 publications per year, with more than 130 appearing in premier journals. It was designed in the 1970s and is now in its third decade of service. It has been continually upgraded over the years, with the brightness increasing fully five orders of magnitude. However, it has reached the theoretical limits of performance given its small circumference and small periodicity, and only a small number of insertion devices are possible. For the productivity of the large NSLS user community to continue and even increase, and in order to tackle the “grand challenge” problems of tomorrow, it is essential that NSLS be upgraded to provide much higher average brightness and higher flux.

The National Synchrotron Light Source II (NSLS-II) facility will be constructed as a replacement for the present NSLS. NSLS-II will fill the gap in the nation’s capabilities by enabling the study of material properties and functions, particularly materials at the nanoscale, at a level of detail and precision never before possible. To achieve this, NSLS-II will provide photon beams having ultra high brightness and flux and exceptional stability. NSLS-II will also provide advanced insertion devices, optics, detectors, robotics, and a suite of scientific instruments.

The combination of brightness, flux, and stability of NSLS-II will provide the world’s finest capabilities for x-ray imaging. NSLS-II will enable the study of materials with ~1 nanometer (nm) spatial resolution and with ~0.1 milli-electron volt (meV) energy resolution. It will be possible to focus both soft and hard x-rays to a spatial resolution of ~1 nm and to perform spectroscopy on a single atom. With the development of novel “lens-less” imaging, it will be possible to capture x-ray images with a spatial resolution of ~1 nm. This resolution and sensitivity is unprecedented in x-ray imaging. If there is any doubt that this is needed for our future energy security, one only need remember that all the elementary steps of energy conversion (charge transfer, molecular rearrangement, and chemical reactions), both for fossil fuels and for critical renewable energy sources, take place on the nanoscale, and many of these steps involve a combination of complex physical, chemical, and often biological, transformations.

The unique characteristics of NSLS-II will enable exploration of the scientific challenges faced in developing new materials with advanced properties, including: the correlation between nanoscale structure and function, including the profound effects of confinement, finite size, and proximity; the mechanisms of molecular self-assembly, which produces exquisite molecular structures in both the living and nonliving worlds; and the science of emergent behavior, one of the grand scientific challenges.

2.2 Work Breakdown Structure

The NSLS-II project has been organized into a Work Breakdown Structure (WBS). The WBS contains a complete definition of the project's scope and forms the basis for planning, executing, and controlling project activities. The Project WBS is shown in Figure 2.1. Elements are defined as specific systems/deliverables (WBS 1.3–1.7), project management (WBS 1.1), research and development (WBS 1.2) or pre-operations (WBS 1.8) consistent with discrete increments of project work and the planned method of accomplishment

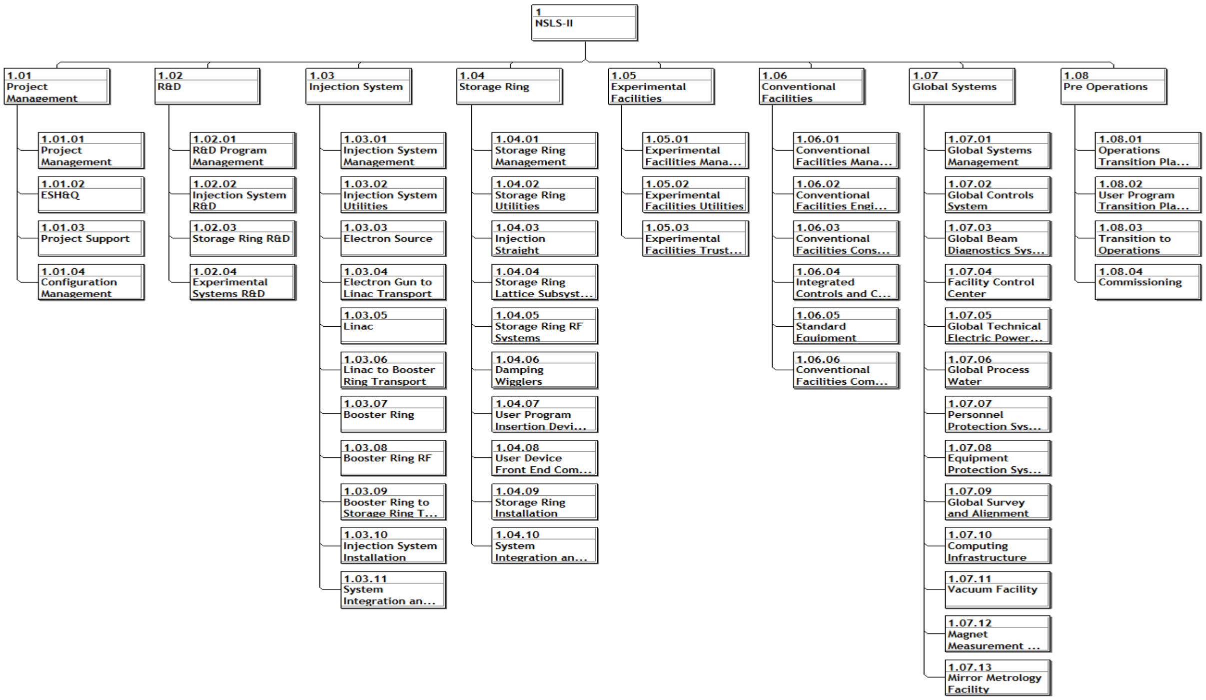

Figure 2.1 Work breakdown structure for the NSLS-II project:

1.01 Project Management – Project Office administrative and management activities that integrate across the entire project (management, regulatory compliance, quality assurance, safety, project controls, etc.)

1.02 Research and Development – R&D activities as necessary to support the delivery of project objectives

1.03 Injection System – All phases of design, procurement, installation, and commissioning of the injection system

1.04 Storage Ring – All phases of design, procurement, installation, and commissioning of the storage ring

1.05 Experimental Facilities – All phases of design, procurement, installation, and commissioning of the suite of beamlines and instruments included in the project scope

1.06 Conventional Facilities – All phases of design, procurement, installation, and commissioning of the conventional facilities including preparation of the site and provision of all utility systems

1.07 Global Systems – All phases of global systems that integrate across subsystems including management of interfaces

1.08 Pre-Operations – Materials, equipment, services, etc. for integrated testing and commissioning

2.3 Cost and Schedule

A preliminary high-level summary of the cost of the NSLS-II project, at the second level of the work breakdown structure, is given in Table 2.1

Table 2.1 Level 2 Cost Breakout for the NSLS-II Project.

NSLS-II Level 2 Cost Element	Cost (AY $M)
1.1 Project Management and Support	53.5
1.3 Injection System	34.1
1.4 Storage Ring System	138.0
1.6 Conventional Facilities	200.1
1.7 Global Systems	22.9
Contingency (35% of TEC cost elements excl. Exp. Facilities)	157.0
1.5 Experimental Facilities (includes contingency)	72.6
NSLS-II Total Estimate Cost (TEC)	678.2
1.2 R&D	35.9
1.8 Pre-operations	61.1
Total Other Project Costs	97.0
NSLS-II Total Project Costs (TPC)	775.2

A preliminary Level 0 milestone schedule to construct NSLS-II is shown in Table 2.2.

Table 2.2 Preliminary Level 0 Milestone Schedule.

Major Milestone Events	Preliminary Schedule
CD-0 (Approve Mission Need)	4th Qtr, FY2005
CD-1 (Approve Alternative Selection and Cost Range)	2nd Qtr, FY2007
CD-2a (Approved Long Lead Procurement Budget)	2nd Qtr, FY2007
CD-2b (Approve Performance Baseline)	1st Qtr, FY2008
CD-3a (Approve Start of Long-lead Procurement)	1st Qtr, FY2008
CD-3b (Approve Start of Construction)	1st Qtr, FY2009
CD-4a (Approve Initial Operations)	2nd Qtr, FY2013
CD-4b (Approve Start of Operations)	3rd Qtr, FY2014