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NSLS II, A PROPOSED FACILITY

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Abstract

NSLS II is a proposed facility that is being submitted for funding to the United States Department of Energy as an upgrade to NSLS I at Brookhaven National Laboratory. It will be an entirely new facility located adjacent to NSLS I. The goals for the new facility are increased brightness (~10^{21} photons/s/mm^2/mrad^2/ 0.1% bw for 1-15 keV), increased flux (~10^{16} photons/s/0.1% bw), and a large number of insertion devices (~20) while keeping construction costs to approximately $400M in 2004 dollars. A medium-energy (3 to 4 GeV), low-emittance (<2 nm-rad) lattice has been proposed with an on-energy injection system running in top-off mode. The present design being proposed is a storage ring approximately 620 meters in circumference using a Triple Bend Achromat (TBA) lattice with a superconducting RF system. The engineering considerations to insure thermal and vibrational stability will be discussed as will the mechanical engineering approaches to achieve the required machine performance.

1 Introduction

The National Synchrotron Light Source (NSLS) was designed in the late 1970's and built in the early 1980's at Brookhaven National Laboratory (BNL). The NSLS was the first light source optimized to enhance brightness with it's ground breaking Chasman-Green Double Bend Achromat (DBA) lattice. The facility provides many different dedicated beamlines to Users from both dipole magnets and insertion devices. The NSLS is actually comprised of two storage rings, the Vacuum Ultra-Violet (VUV) ring and the X-ray ring shown in Figure 1. A 120 MeV linac with a thermionic electgron gun feeds a booster that is used to inject into both rings at 750 MeV. Each ring is ramped up to its working energy, 800 MeV for VUV and 2.8 GeV for X-ray. The NSLS operates at high current with seven fills of 1 Amp into the VUV ring and two fills of 0.3 Amp into the X-ray ring each day. A total of eighty beamlines are presently in operation on both rings.

The present x-ray emittance of approximately 75 nm-radians is a significant improvement over the original specification for the machine, but further improvement on the existing platform is not possible. Newer machines in this energy range are a factor of ten or more better in this important metric. In addition, after more than twenty years of operation the signs of degradation and wear on the facility infrastructure are becoming evident. Utilities systems have been upgraded several times and the water flows in some cases are reaching the limits of the installed headers and piping. As the machine performance was extended well beyond its original design specifications, costs have been incurred in increased maintenance, increased congestion, and decreased component reliability of accelerator systems. Age, cumulative use, a myriad of changes, long-term thermal cyclic loading, and the long-term effects of synchrotron radiation have each contributed to the present state of NSLS. Safety considerations due to overcrowding continue to add significant time to routine and non-routing maintenance tasks causing longer shutdown periods. With the change in energy from 2.5 to 2.8MeV that started in 1998, increased thermal loading and degradation from scatter and synchrotron radiation exceeded original design limits.

To address these problems, the NSLS began considering upgrades to the facility. Initial studies of an in-place upgrade utilizing the footprint of the existing facility showed this approach to be impractical and not cost-effective. The only practical alternative to achieve the desired enhancements in performance is the construction of a new facility that takes full advantage of current technology. By increasing the multiplicity and circumference of the ring and employing a low-emittance lattice, the new facility, dubbed NSLS-II will provide significant enhancements in capability for the User community from both bending magnet and insertion device beamlines.

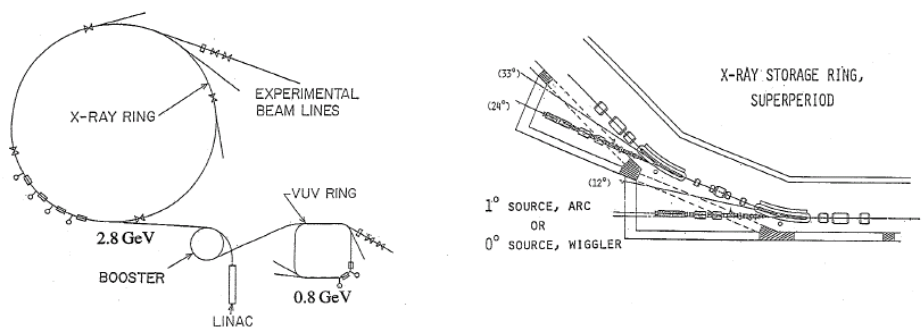
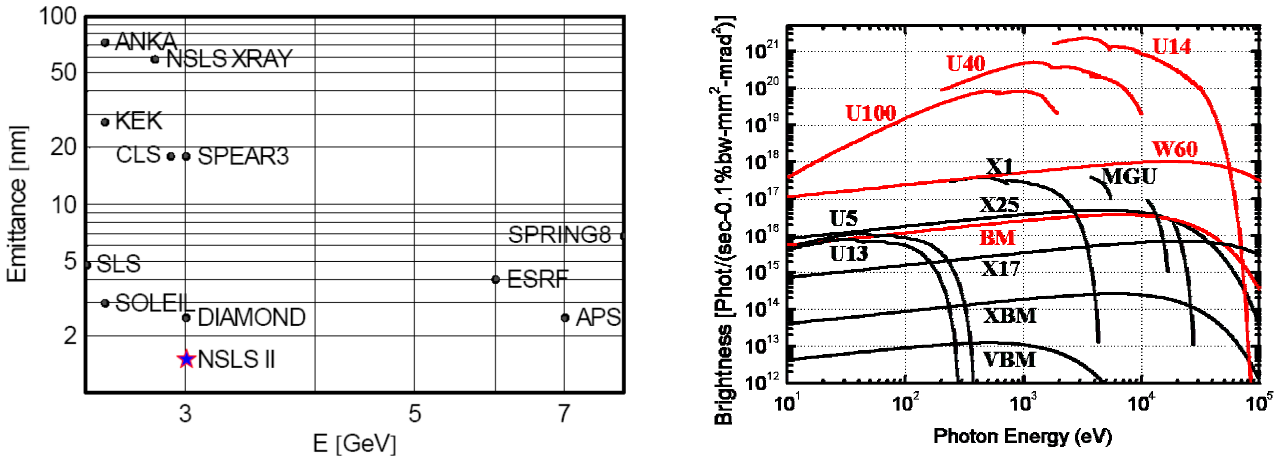


Figure 1: Schematic of the NSLS showing (a) the relative placement of the Linac, booster, and the VUV and X-ray rings; and (b) a one-superperiod section of the X-ray ring showing a straight section with a zero-degree insertion-device and bending magnet front ends.

2 Preliminary Design Parameters

After producing an estimate to revamp the existing NSLS X-ray ring in place that was fiscally impractical, the decision to consider a new facility was made by NSLS management with guidance from the U.S. Department of Energy (DOE). Many different technologies were considered. Preliminary discussions with the U.S. DOE however provided initial guidance as to time frame for producing an operational facility, total project cost, and choice of technology. Energy Recovery Linac and Free Electron Laser sources were initially considered but were rejected due to cost, schedule, and technology risk factors. Preliminary budgetary constraints and discussions between BNL and the U.S. DOE directed efforts toward producing a medium energy (3-4 GeV) low-emittance synchrotron source capable of running in top-off mode for maximum brightness, flux, and thermal stability. Such a facility was considered to most cost-effectively produce a high level of scientific output. Desirable, yet reasonable goals for NSLS II were therefore chosen. Most desirable were ultra-high brightness (~10^{21} photons/s/mm^2/mrad^2/ 0.1% bw for 1-15 keV), high photon flux (10^{15} - 10^{16} photons/s/0.1% bw), and ultra-low emittance (< 2 nm-radians). Relative to other light source facilities, an emittance of <2nm-radians would be at the state-of-the-art and brightness would compare favorably to higher-energy synchrotron light sources (reference figure 2). The use of a large number of insertion devices, including superconducting insertion devices, was also considered to be highly desirable. Since NSLS II will need to operate for many years, it was also desirable to include the capability for future upgrade to an ERL if possible.

Several designs were investigated and various options were costed. Various combinations of injection systems were considered including a booster design, an injector /FEL design, and a full-energy linac injector, and a number of different iterations and combinations of each type. The design presented herein is preliminary, and the result of several different configuration studies.



Courtesy J. Murphy,

Figure 2: (a) Relative emittances for existing and proposed synchrotron light source facilities and (b) brightness comparison of various synchrotron light source devices.

3 Proposed Synchrotron Lattice, Engineering considerations

The current lattice configuration is designated “TBA24 630” for a twenty-four superperiod triple-bend achromat with a circumference of 630 meters. One superperiod, is shown below in figure 3 and a tabularized version of the magnetic elements is shown below in figure 4. It is preliminary and subject to change, but it represents the result of studies that have considered beam loss, emittance, cost, and other design issues. Since the low emittance of the high brightness NSLS-II lattice results in a short beam lifetime, operation in a top-off injection mode is required. This has been a consideration in the choice of injector and is discussed further in the following section, but there are also implications for the design of the ring magnets. Since the ring magnets will not be ramped, only negligible amounts of eddy current losses would be expected in the magnet iron. Therefore, solid-yoke non-laminated magnets will be used to reduce cost. During magnet design, the use of wire electron discharge machining (EDM) to produce the quad, sextupole and corrector flux returns and pole tips will be investigated. Recent advancements in wire-EDM technology allow precision steel parts nearly one meter in length to be fabricated with sufficient accuracy. Segments of the dipole magnets may also be made using this process.

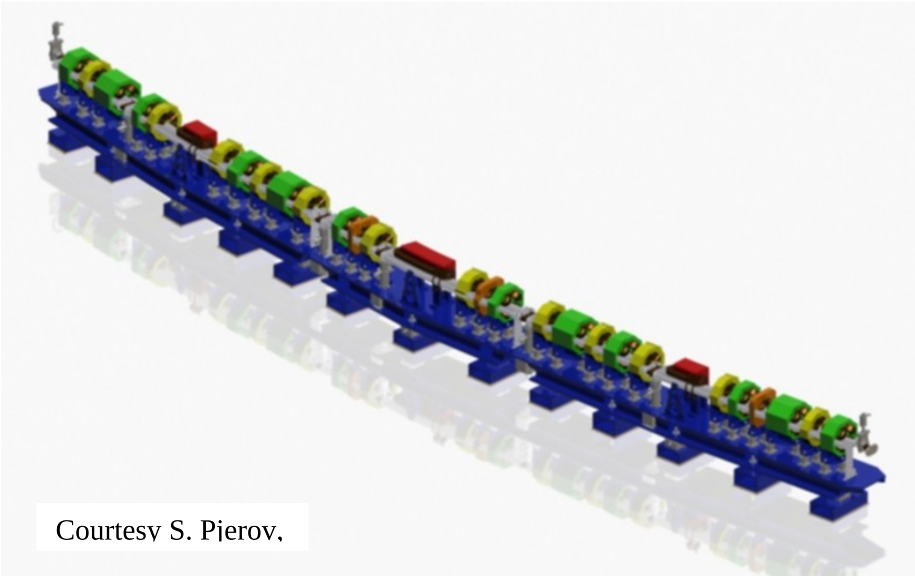


Figure 3: NSLS II typical non-injection superperiod layout (insertion devices not shown).

As noted in figure 4, the TBA24 630 lattice uses seven different types of large magnets in each superperiod; two types of dipole magnets, three different types of quadrupole magnets, and two types of sextupole magnets. Trim magnets are also used but are not listed specifically. A one-meter long 7.5° dipole magnet is located in the center of each superperiod and two half-meter long 3.75° dipoles are symmetrically located on either side. Three quadrupole magnets reside on either end of the dipoles. The quadrupole, sextupole and trim magnets are attached to rigid girders.

Four types of pre-aligned ring girders form the support structure for the bulk of the synchrotron components that include the ring lattice magnets, storage ring vacuum chambers, and beam diagnostic elements. A modularized approach is planned and the girder assemblies will be pre-tested to reduce commissioning time.

Girders A and B support the quadrupole, sextupoles, and correction magnets located between the ring dipole magnets. Girders C and D are essentially single magnet stands that support the 1.0 meter and 0.5 meter long dipoles respectively. Two each of the type A, B, and C and one of the type D girder assemblies comprise a ring super-period. The elements supported by the girders are listed below for convenience:

- Dipole magnets
- Quadrupole magnets
- Magnet to girder adjustment and fixturing
- Survey faducialization system
- Beam-limiting apertures and heat absorbers (“speed bumps”)
- Power and Instrumentation routing systems
- Correction or trim magnets
- Electrical and mechanical safety systems
- Sextupole magnets
- E-beam diagnostics and actuators
- Utility routing systems and safety covers
- Beam diagnostics
- Storage ring vacuum chamber segments
- Vacuum valves, pumps, ports and diagnostics
- Vacuum chamber-to-girder/magnet fixturing

The design of the Girder assembly is determined primarily by alignment and mechanical stability requirements. The following design issues that must be considered.

- Magnet size, weight, adjustability and alignment requirements
- The cross section, length, weight, and vacuum pumping design of the ring vacuum chamber girder segments
- Chamber fixturing and the direction and amount of allowable chamber movement.
- Maximum allowable mechanical modulation of the magnetic elements and e-beam diagnostics
- 3-D magnetic analysis, and estimate of lifetime radiation dosage for the selection of optimum girder materials.
- Tunnel installation, rigging considerations, and plug door accommodations for the girders.
- Geology, Hydrology and Seismic study of storage ring site and how the tunnel will change with time as well as vibration issues involving civil construction and building systems.
- Compliance/Regulatory requirements

The girder system has many design issues that need careful consideration and analysis during the design phase:

- Mechanical linkage to tunnel floor/walls
- Thermal and vibrational stability
- Front End vacuum chamber design, forces, and motions
- Ring straight section design, forces, and motions
- Rigging and safe handling practices and procedures
- Vacuum pump-down procedures, design, forces and motions
- Environmental effects of thermal gradients in tunnel and on girders
- Magnet cooling water, electrical power, and routing
- Vacuum chamber cooling water and routing
- Actuator air and routing
- DC magnet power cabling and routing
- AC instrument power and routing
- Grounding cable attachment and routing
- Integration and routing of power, diagnostics and control lines

The magnets on each girder will be positioned using a pulsed-wire magnetic measurement system. The pulsed-wire system can determine the center of each quad to within a few microns. A removable magnet locator frame will be affixed to the girder around each magnet position. The magnet positions will then be adjusted until the magnetic field center of each magnet is precisely coaxial with the pulsed wire. The locator frame will be designed to be a precision instrument. It will determine each magnets' shim stack size and position the magnet until it can be affixed to the girder. Laser tracker survey targets will be applied to each girder and magnet yokes. Interfaces between the girder and magnets will be composed of shim blocks. Jacking screws between the magnet and the girder and the magnet iron are designed so that the disassembly and replacement of an individual magnet or a group of magnets without breaking vacuum is possible. The magnets will be aligned and pre-surveyed on to the axis of the girder.

TBA24 630 data from Stephen Kramer						24	Super periods			
					3 GeV 630 meter Upgrade Design					
Magnet Parameters			BL	BS	QL	QM	QS	SL	SS	H/V
Bend Angle		deg	7.5	3.75						
Radius		m	7.6394	7.6394						
Length		m	1	0.5	0.5		0.3	0.25	0.2	0.2
Aperture		mm	35	35	80		80	60	60	80
Nominal Field	B_0	T	1.2	1.2						
K1			-0.3	-0.3						
Maximum Field		T			1.2		1.2	0.86	0.86	0.25 / 0.1
Gradient	n/ρ	% /cm	2.29	2.29						
Maximum Gradient		T/m			30		30			
Maximum Gradient		T/m^2						600	600	
# / Superperiod			1	2	4		8	6	4	4
Total for ring			24	48	96		192	144	96	96
Total by Type			72		288			240		

Figure 4: NSLS II Magnets.

A precision Hall probe mapping system will used to map the fields of each dipole. Since the dipole magnets include a focusing gradient, a full field map to allow determination of beam trajectory is essential. Once the entry and exit points are established, laser tracker targets will be affixed to each dipole. A state-of-the-art laser tracker monument system will be installed into the tunnel of NSLS II. The magnet and girder stands will be conventionally located, bolted, and grouted to the floor. A girder transporter will move the girder assemblies from the magnetic survey area to the tunnel floor. The girder will connect to the transporter so that the assembly can be positioned accurately and easily. Once the dipoles and quad girders are mounted on their stands, laser trackers will be used to relate targets that define the magnetic centers of the quads and sextupole girder and beam path of each dipole to laser tracker monument system in the NSLS II tunnel. Methods are being considered to mount laser tracker targets to the beam vacuum chamber and use the pulsed-wire system to relate to the electric center of the pick-up electrodes. This would allow the electron beam-locating instrumentation of the beamtube to be surveyed on the beamline with similar accuracy as the quad and dipole girders.

The main vacuum pumping for the storage ring will be supplied by non-evaporate getters (NEG) and the vacuum electron beam vacuum chamber will have a cross section similar to the Advanced Photon Source (APS). The ring beam vacuum chambers will be probably be constructed from extruded aluminum, utilize TIG welding for construction, and have a cross-section similar to the APS. Explosion bonding will be used to join aluminum to stainless steel and other materials. Water-cooled copper absorbers will be used in vacuum chambers for high heat loads areas. The chambers will be bakeable to 150°C and will utilize all-metal valves, Conflat copper seals, clearing electrodes, pick-up electrodes, metal bellows and UHV hardware. All-metal RF-shielded gate valves will be employed to isolate the girder vacuum when necessary. UHV will be achieved utilizing the NEG pumping supported by differential ion pumps (IP) and titanium sublimation pumping (TSP) systems. The vacuum will be monitored using IP current and additional UHV gauges. A residual gas analyzer will be located in each girder for vacuum diagnostics.

The linac-to-storage ring transport vacuum system will be constructed from stainless steel utilizing TIG-welded construction. The chambers will be bakeable and utilize all metal valves, Conflat seals, bellows, and hardware. Ultra-high vacuum (UHV) will be achieved with 240 liter per second differential ion pumps (IP) and titanium sublimation systems. Vacuum will be monitored using IP current and additional UHV gauges and residual gas analyzers. The transport system will be approximately 90 meters in length.

To deliver the extremely high peak brightness of NSLS II, superconducting undulators must be used. These insertion devices are susceptible to high heat loads from synchrotron radiation and from many other sources. Studies are underway to design a customized dipole pole tip that will minimize the amount of stray synchrotron radiation entering the insertion devices. These changes will impact the lattice and will result in a machine that for the first time the conventional lattice optics will be customized for optimum performance of superconducting insertion devices. In preparing an estimate for the facility, a total of eighteen insertion devices were considered including four MGU's (Mini-Gap Undulators), five SCU's (Superconducting Undulators), four SCW's (Superconducting Wigglers), two SXU's (Soft Xray Undulators), three EPU's (Eliptically Polarized Undulators), and three QPU's (Quasi-Periodic Undulators). The final distribution of devices and their detailed specifications await further development of the facility proposal.

A 500 MHz superconducting RF (SCRF) system similar to Cornell and KEK is currently being considered for the NSLS II storage ring. Among their unique features are: superior voltage gradient, lower RF power requirements, lower operating cost and commercial turn-key availability. SCRF systems have been used successfully in high-energy physics applications such as LEP and KEKB, and have recently been adopted in light sources such as the CLS, DIAMOND and SRRC. Superconducting RF systems can greatly reduce the RF power requirements and the "single mode" design of the large bore cavities can eliminate the need for feedback systems to combat coupled-bunch instabilities. Both the Cornell and KEK designs are commercially available in Europe and Japan. Two or three cavities would be needed depending on the advances in the development of RF power couplers.

The RF system in the storage ring must supply enough voltage to accelerate the electron bunches and to account all of the various energy losses. Because energy losses due to synchrotron radiation increase as the fourth power of the beam energy, the RF systems need to provide a large amount of energy continuously. Other dominant factors are:

1. Physics match of the machine through cavity impedance, Higher Order and Coupled Bunch modes, momentum compaction, etc.
2. Availability of a turn-key system without the need for major in-house development.
3. Overall lower capital and operational cost.
4. High Reliability with minimum maintenance.
5. Reasonable footprint within lattice

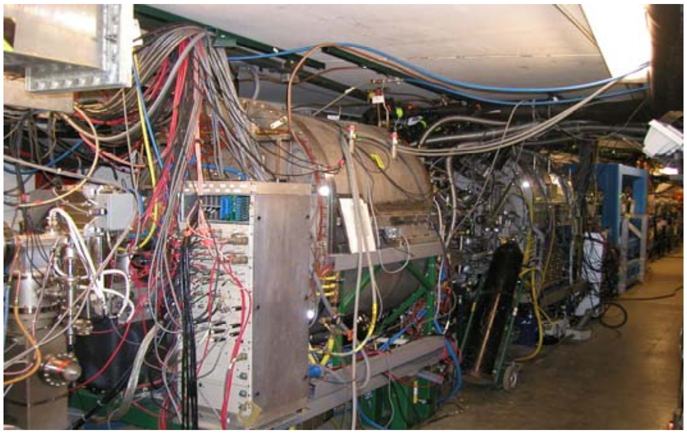


Figure 5: Superconducting RF System at CESR, Cornell University

4 Injector, Engineering considerations

Due to the small dynamic aperture and high beam loss of the low emittance, high brightness NSLS-II lattice, a short beam lifetime is anticipated, making top-off injection highly desirable. The characteristics of the machine also imply that the emittance of the injected beam must not be much larger than that of the stored beam to achieve acceptable injection efficiency. Based on experience at the Swiss Light Source and elsewhere, the emittance of the injected electrons should be no more than a factor of ten larger than the equilibrium emittance in the main ring, i.e., it should be less than 15 nm. The necessary injection charges, rates, and emittances can be achieved with either a low energy linac driving a full energy booster synchrotron or a full energy linac. From an engineering perspective, top-off operation causes more constant heat load on the synchrotron components and beamline optics for increased stability, and constant intensity delivered to experiments.

To keep nearly constant thermal loading and to maintain photon beam stability, it is desirable to maintain the storage ring current constant to within 1%. In order to achieve this, about 1 % of the charge, or about 0.015 nC, must be replenished in each filled bunch about once per minute. If we inject at 10 Hz, we could top-off each bunch with this charge once per minute and maintain the bunch charge constant to within 1%. Alternatively, if bunch-to-bunch charge variations of 10% were acceptable while still maintaining the average current constant to 1 %, 0.15 nC injection at a 1 Hz rate would be feasible. Even at the faster 10 Hz injection rate, 100 ms between injections is still more than ten times greater than the damping time required for the injected charge to reach equilibrium. A full energy linac injector for NSLS-II has the following potential advantages:

- *Higher Rep Rate*: A linac can be operated from a few Hz up to 120 Hz with more or less the same hardware, while a booster becomes increasing difficult for rep rates beyond a few Hz due to eddy currents in the vacuum chamber and the complexity and cost of fast ramping power supplies.
- *Better Beam Quality*: If the linac is coupled to a laser driven photoinjector that produces a 1.5 nC/bunch electron beam with a normalized emittance of 6 μm, the geometric emittance of this electron beam at 3 GeV would be ~1 nm, which is smaller than the horizontal emittance of the storage ring (~1.5 nm) and an order of magnitude smaller than the emittance from the booster presently under consideration.
- *Better Injection Efficiency*: The better beam quality discussed above will result in better injection efficiency. The KEK ATF recently demonstrated nearly 100% injection efficiency with a photoinjector/linac system. Better injection efficiency is especially important for a high current storage ring operating in top-off mode. It can provide a significantly lower radiation background during 'shutters open' top-off injection, resulting in minimized radiation damage to undulators and reduced shielding (and hence reduced cost) requirements.
- *Flexibility in Ring Filling Patterns*: Both single pulse and pulse train injection has been experimentally demonstrated with full energy linac injectors. Furthermore, variable fill patterns and charge/bunch can be easily implemented for the linac with a photoinjector.

Historically, a low energy linac with a full energy booster has been the choice for most light source injection systems because of its perceived advantages in cost and reliability, however, these are much less compelling at the injection rates required for NSLS-II. In addition, developments in normal conducting linac technology, such as SLED, high power klystrons, and solid state modulators, make a full energy linac injector a very attractive alternative. Recent developments in photocathode RF gun technologies, especially in stability and reliability, make it compatible with storage ring operation. Diode-pumped, all solid state lasers and semiconductor, saturable absorber-based passive mode-locked oscillators have improved the laser system stability and reliability tremendously. Both metal cathodes (Mg) and semiconductor cathodes (Cs_2Te) have demonstrated lifetimes of more than several months with a quantum efficiency better than 0.1%. A photocathode RF gun injector is now in routine operation for the damping ring at KEK ATF. A 1.5 cell photocathode gun should adequately deliver a low emittance electron beam into a LINAC at 4.5 MeV. A LINAC assembled from fifty three-meter long SLAC-style accelerating sections should provide adequate acceleration for full-energy injection. For space efficiency, the linac is buried below grade and extends beneath the ring. Between main ring fills, a portion of the linac will be used to fill the NSLS I VUV / IR ring that will be relocated inside the main ring to service the IR/ UV ring. Modulator and klystron galleries will be located on ground level above the linac tunnel.

Detailed trade studies for investment and operating costs as well as reliability and performance need to be completed to finalize the choice of injection system, but work thus far favors the full energy linac for the NSLS-II project.

5 NSLS II Building and Site Location

According to current plans, NSLS II will be built adjacent to NSLS as an additional facility. The building size and configuration was largely determined by the lattice, and the user space requirements for beamlines and laboratories. The ring circumference and amount of space needed inside the ring for services and for a utility corridor determined the inside diameter of the building. An allowable beamline length limit of sixty meters, along with office space and location requirements determined the outside diameter of the building which is approximately 800 feet. The experimental floor alone is expected to require over 110,000 square feet of space while the total floor space for NSLS approaches 344,000 square feet. A breakdown of the floor space planned for each building area is shown in Figure 7.

Approximately sixty beamlines are planned. A domed roof, probably utilizing pre-fabricated sections was chosen to minimize upkeep costs, assure that no leakage problems will occur, and give an aesthetically-pleasing appearance.

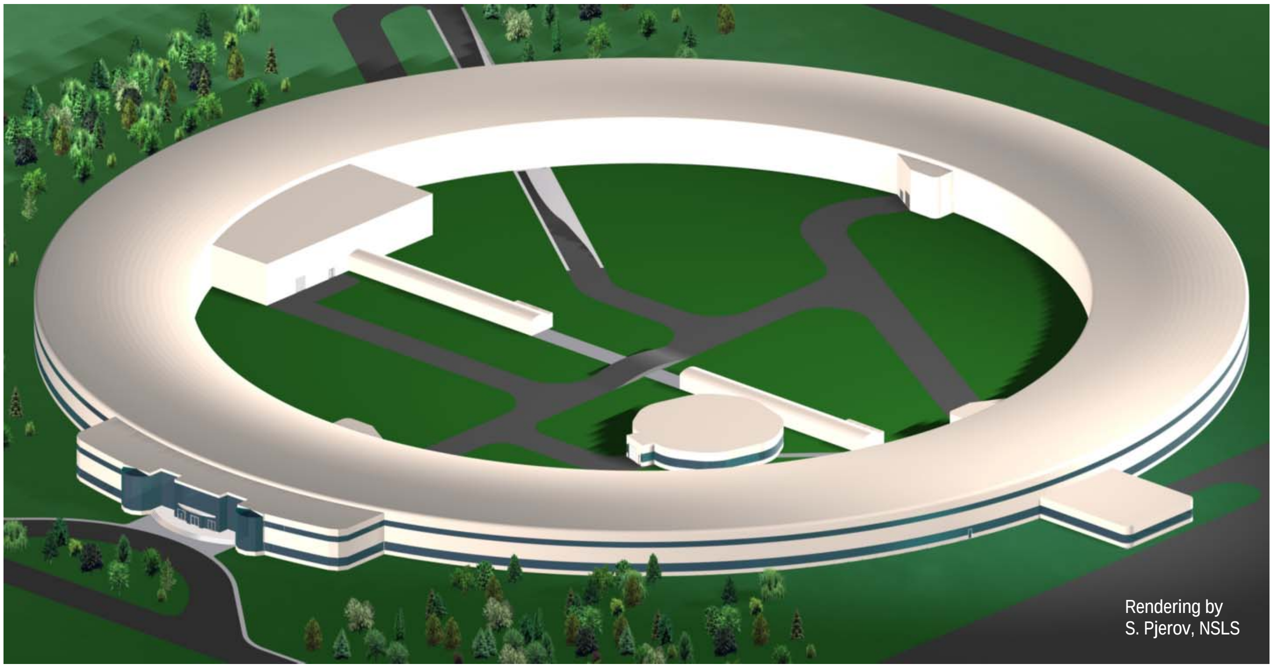
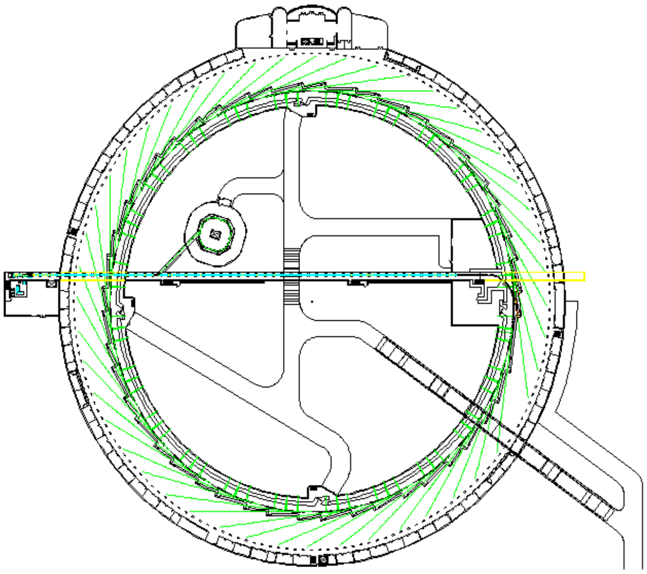


Figure 6: Artistic rendering of NSLS II located adjacent to NSLS at Brookhaven National Laboratory. A VUV / IR ring is shown in the center of the building next to the linac injector.

Although the site location has not yet been finalized, a largely undeveloped location across Brookhaven Avenue adjacent to NSLS is under consideration. The site has approximately a foot four grade overall and is largely composed of glacial sand. Supplementary solar photovoltaic panels are being considered to generate electric power. In the early planning using conventional magnet technologies, it is anticipated that NSLS II will consume more than ten megawatts of electric power when the facility is in full operation.



Building Areas	First Flr	Second	Total
	Area [SF]		
Office Block	11,055	8,945	20,000
Utility Corridor	14,578		14,578
Accelerator Tunnel	51,563		51,563
Experimental Floor	111,230		111,230
Office/Lab	64,173	64,173	128,346
Linac Vault - Kly Gallery	12,493	6,068	18,561
			344,278

Figure 7: NSLS II layout (a) first floor plan view and (b) tabularized building area plan.

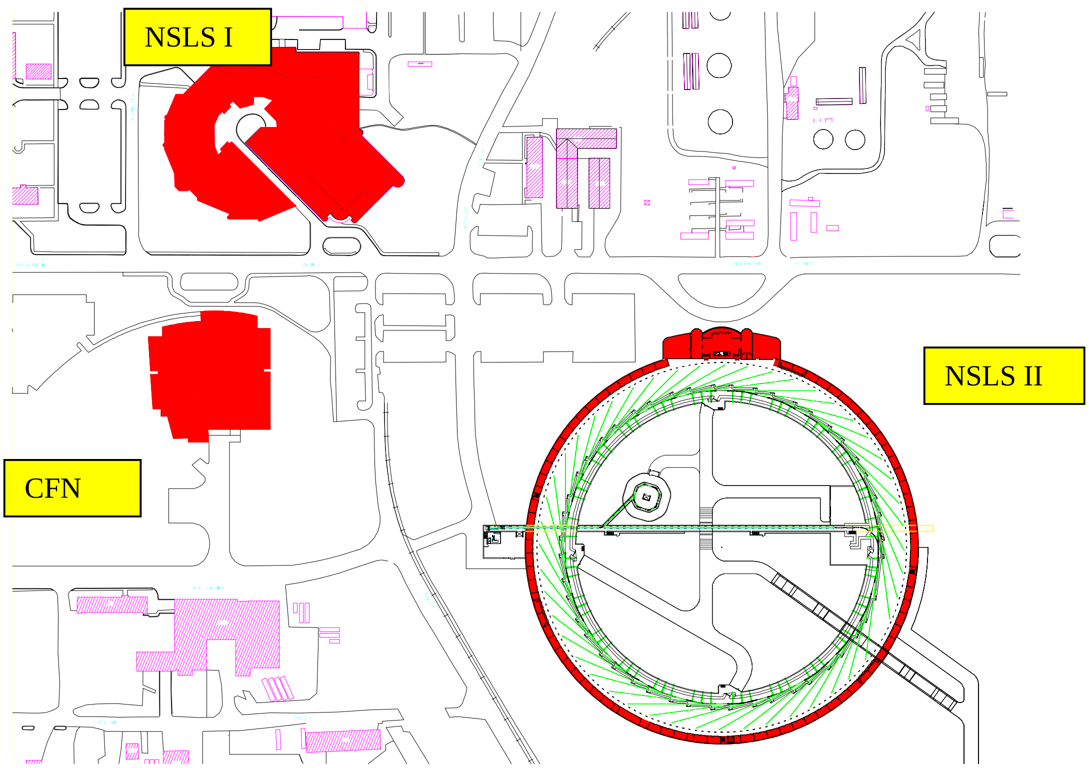


Figure 8: Site map showing NSLS, Center for Functional Nanomaterials and NSLS-II

In order to properly design the building, estimates of required shielding to attenuate energetic neutrons and gamma-rays from a 3 GeV storage ring were considered for NSLS-II [4]. To meet stringent worker exposure requirements, the cumulative dose from electron loss during year-long operation at the defined beam energy and current were critical in determining shielding requirements. The electron loss under normal operational conditions is determined by a) the tunnel configuration, and b) the machine parameters. Assuming that the proposed storage ring is installed at center of a 3.5-m wide, 3-m high, tunnel and that all the ring lattice components are designed to run at 3-GeV and 500-mA of stored beam (along with max. 7-m long ID in 24-TBA, top-off operation), the required shielding thickness of the ring tunnel will be minimally be:

- **1**.0-m reinforced heavy concrete for the ratchet wall (outer wall to beamlines),
- 1.6-m reinforced normal concrete for the tunnel ceiling (floor for ring electrical equipment),
- 1.1-m reinforced heavy concrete for the front-end wall (4"-Pb added to compensate spacing used by electronics and shutters, etc.),
- 1.6-m reinforced normal concrete for the labyrinth wall (inner wall), and
- 0.15-m reinforced normal concrete for the tunnel floor (with 1.22-m wide by 0.30-m high footings).

The shielding of an below ground full-energy Linac (200-m long, 150pC/bunch, 10^4 bunches/s) will be minimally:

- 0.7-m reinforced normal concrete side walls (2 sides),
- 0.7-m reinforced normal concrete roofing, and
- 0.15-m reinforced normal concrete, (with 1.22-m wide 0.30-m high footings).

The preliminary shielding design was based on the scaling of shielding thickness, beam energy, and machine parameters of the present NSLS X-ray ring. When the machine configuration became well enough defined, the tunnel shielding was then simulated by a 3-D model of MCNPX/Fluka code [5], a Fortran-compiled statistical program (Monte Carlo-based) for high-energy physics use to track neutron-photon coupled particle-transport crossing different material regions.

6 Acknowledgements

The NSLS II proposal represents the combined work of many people. The author list of this paper is but a fraction of the staff working on the project and focuses primarily on those involved in the mechanical aspects of the project. Contributions by our colleagues that have influenced our thinking are gratefully acknowledged. The design and status of NSLS II, although preliminary, is being reported at MEDSI 2004 for purposes of stimulating information interchange with the synchrotron engineering community. Although the design is preliminary (actually still in it's inception stage) and funding for this facility has not yet been allocated by the U.S. Department of Energy, many engineering studies and development efforts need to be undertaken to achieve the desired performance goals. It is hoped that ensuing discussions will stimulate and focus information gathering efforts and help direct the needed engineering efforts to produce a world class light source for the overall benefit of mankind.

7 References

[1] National Synchrotron Light Source (NSLS) and proposed NSLS II information extracted from http://www.nsls.bnl.gov for details of the rings and beamlines, 2004.
[2] NSLS-II: A Bright New Light Source reference http://www.nsls2.bnl.gov for details, 2004
[3] NSLS II: Machine Overview presentation by J. B. Murphy for MAC Meeting I, Nov. 14, 2003
[4] Casey, W.R., NSLS Technical Note 9/26/02.
[5] Waters, L.S., MCNPX User Manuals, Accelerator Production of Tritium program, 1999
[6] NSLS-II WBS and Cost Analysis for the Conceptual Design - Phase 0, 2003