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**X-324: AN UPGRADE TO THE NSLS X-RAY RING
USING B FACTORY TECHNOLOGY**

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X-324:
AN UPGRADE TO THE NSLS X-RAY RING USING
B FACTORY TECHNOLOGY *

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1. INTRODUCTION:

Through much of the last decade, the NSLS has been America's pre-eminent source of synchrotron radiation. In the near future, The NSLS will face formidable competition from the third generation light sources, designed to produce high brightness beams from undulators. Because of the lattice design of the NSLS rings and the limited number of straight sections for new undulators it will be impossible to compete with the new rings in brightness at short wavelengths. It is not clear, however, how many experiments really need brightness (photons per unit time per unit energy bandwidth per unit solid angle) and how many just need flux (photons per unit time per unit energy bandwidth). A good strategy could lie in keeping the NSLS the highest flux synchrotron light source in the country and leaving the brightness frontier to the third generation rings. We are already moving in this direction by raising the X-Ray Ring current to 500 mA but this is only a first step. By using the technology developed for the SLAC B factory we can simultaneously raise the X-Ray Ring energy to 3.0 GeV and the current to 2.4 Amp. From these parameters I am calling the proposed upgrade X-324.

Figs. 1 and 2 compare the flux and brightness from the upgraded X-Ray Ring with the NSLS VUV ring, the ALS, and the APS. Clearly, the flux from the NSLS wigglers exceeds that from any other source over the entire spectral range. The X1 and Prototype Small Gap (PSGU) undulators also produce more flux than the third generation sources in the range from 200 to 2000 eV. In that range, the NSLS undulators are even competitive in brightness, filling in the gap between the ALS U5.0 undulator at low energy and the APS UA undulator at high energy. This may benefit the x-ray microscopy experiments underway at the NSLS as well as other brightness-limited soft x-ray experiments.

After the X-324 upgrade, the X-Ray Ring will produce twenty times more synchrotron radiation power than is produced by today's 250 mA, 2.5 GeV beams. This is a qualitative change from today's conditions and will place great demands on the RF and vacuum systems. The requirements are similar to those for the SLAC PEP-II B factory. PEP-II will have two rings, one

* This work was supported by the United States Department of Energy.

Fig. 1. Flux at different light sources.

Fig. 2. Brightness at different light sources.

at 3.1 GeV and the other at 9 GeV. The maximum design current in both rings is 3 Amp although the operating current will not be as large.¹ The PEP-II design calls for high power, single cell, 476 MHz RF cavities and a copper vacuum chamber to cope with the intense synchrotron radiation emitted. We can adapt these designs for X-324.

The high current and close bunch spacing in X-324 may result in severe multibunch instabilities. The PEP-II design also anticipates multibunch instabilities and handles them with a bunch by bunch feedback system. X-324 can use this system .

Other problems to be solved in X-324 include operation of the X-Ray Ring magnets at 3.0 GeV levels, rapid injection to high current, and most important, upgrading the beamlines for the intense radiation. In this paper I will be describing some estimates that I have made about certain aspects of the upgrade. I will not be presenting a complete design but I hope to show that more detailed planning is warranted.

2. X-RAY RING MODIFICATIONS:

Table 1 lists the major features of the existing X-Ray Ring at 250 mA and 2.5 GeV together with two versions of the upgraded ring. The first version of the upgrade uses eight 476 MHz cavities to support a 3 GeV, 2.42 A beam. A possible problem with this design is a reduction in the Touschek lifetime (as calculated by the program ZAP) from 309 hours to 51 hours. Although this effect will not dominate the lifetime, the reduction may still be a problem. If so, a second version of the upgrade is shown, with a pair of second harmonic cavities used to lengthen the bunch from 0.73 mm to 2.64 mm, increasing the Touschek lifetime to 184 hours. Each of the storage ring systems will be described in the following sections.

Both upgrade designs specify 225 of the 270 buckets filled in order to maintain the same length gap in the beam as is now used. The energy acceptance is also preserved. The horizontal emittance is scaled for the higher energy from the 2.5 GeV value but the vertical incorporates the improved decoupling developed by J. Safranek.

2.1 RF SYSTEM:

The biggest obstacle to raising the X-Ray Ring's energy and current is supplying enough RF power to the beam to replace the synchrotron radiation losses. Only a limited increase in current, to perhaps 1 A, can be accomplished with the existing four, 52.88 MHz RF cavities. There does not seem to be enough space in the ring to add more. We need a way to squeeze more RF into the existing space.

1. *PEP-II An Asymmetric B Factory, Conceptual Design Report*, LBL-PUB-5379, SLAC-418, CALT-68-1869, UCRL-ID-114055, UC-IIRPA-93-01 (June, 1993).

Table 1. Major X-Ray Ring Parameters

	Current Conditions	Upgrade with single RF system	Upgrade with harmonic cavity
Energy [GeV]	2.5	3.0	3.0
Beam Current [A]	0.25	2.42	2.42
Horizontal Emittance [nm-rad]	120	173	173
Vertical Emittance [nm-rad]	1.20	0.29	0.29
Fundamental Cavity RF Frequency [MHz]	52.88	475.92	475.92
Fundamental Cavity RF Peak Voltage [MV]	0.9	4.27	4.26
RF harmonic	30	270	270
Number of Bunches Filled	25	225	225
Harmonic Cavity RF Frequency [MHz]			951.84
Harmonic Cavity RF Peak Voltage [MV]			2.04
Bunch Length [cm]	4.33	0.73	2.64
Synchrotron Radiation Loss [MeV/turn] (bends only)	0.50	1.04	1.04
Transverse Damping Time [msec]	4.56	2.64	2.64
Longitudinal Damping Time [msec]	2.28	1.32	1.32
Energy Acceptance	1.82%	1.82%	1.82%
Synchrotron Frequency [KHz] (fund. RF only)	5.91	35.24	35.22
Touschek lifetime [hours]	309	51	184

Two basic approaches can be considered for the RF problem. One possibility is redesigning the 52.88 MHz RF cavities for a much higher power level. Even if this can be done I suspect it will be very difficult, requiring much research into cavity, window, and transmitter design. A better solution for high current operation, I believe, is to follow the approach taken at other storage rings and switch to a higher frequency RF system. Smaller cavities can then be used and more power can be provided in the available space. The higher frequency will also let us use circulators between the transmitters and cavities, thus simplifying RF system operation.

Having decided to change the RF system, another choice remains — whether to use superconducting or conventional cavities. Superconducting cavities can provide the required power with very few cavities and reduce or eliminate the coupled bunch instabilities that result from the interaction between the beam and the higher order cavity modes. Unfortunately superconducting cavities have not yet been used in many storage rings so I am not be confident that we will meet our goals if we plan an upgrade around them. Laboratories that have used superconducting cavities (including Cornell, CEBAF, DESY, and CERN) have many years of experience with RF superconductivity including the operation of low pressure cryogenic systems and cavity processing using highly corrosive chemicals and remote manipulation. Since we do not have this experience I decided to use conventional cavities.

The best example that I know of a multi-amp electron storage ring is the proposed PEP-II B factory at SLAC. It uses single cell, copper RF cavities operating at a frequency of 476 MHz. The operating frequency was chosen because it is exactly one-sixth of the linac frequency, which

simplifies injection timing and is close to the 500 MHz frequency used in many other electron storage rings, requiring only small modification of existing klystron designs. The upgrade will also benefit from these features so I chose the SLAC system as a model for the upgrade. The RF frequency will be 475.92 MHz which is the 270th harmonic of the revolution frequency.

Details of the 476 MHz RF system are shown in Table 2. Eight cavities were used in the X-324 design to stay within the PEP-II cavity's design limits for gradient, wall losses, and input power, also listed in the table. As in the PEP-II design, one klystron is used for every two cavities. The klystron output is divided between the cavities using a magic tee. A circulator with water load is placed between each cavity and the magic tee to absorb any reflected power. The maximum power from the klystron is within the PEP-II limits.

The peak RF voltage in the ring and the synchronous phase were chosen to maintain the existing 1.82% energy acceptance in the X-Ray ring listed in table 1. The gap voltage listed in table 2 is the peak voltage divided by the number of cavities. The cavity wall losses P_W were then calculated from the gap voltage V_G and the shunt impedance Z_S according to the formula

$$P_W = V_G^2 / 2Z_S. \quad (1)$$

The synchrotron radiation power was calculated directly from the beam energy and current. The higher order mode (HOM) power listed is a very rough estimate obtained by scaling the HOM power calculated in the PEP-II CDR. This will need to be done properly in the future but for now it is reassuring to see that it is small compared to the synchrotron radiation power. The total power is the sum of the cavity wall loss, synchrotron radiation, and HOM power.

The detuning angle was calculated by J.M. Wang to ensure Robinson stability. From this he calculated the reflected power from each cavity. The input power per cavity P_I is

$$P_I = P_R + P_L / N \quad (2)$$

where P_R is the reflected power per cavity, P_L is the total power loss in the ring, and N is the number of cavities.

Four of the 476 MHz cavities will fit very nicely in the space now occupied by two of the 52.88 MHz cavities. Fig. 3 shows the RF cavity straight section in superperiod 2 with the 52.88 MHz cavities and with the PEP-II cavities. Superperiod 7 is similar.

Table 2. 476 MHz RF System Parameters

		PEP-II Design
Frequency [MHz]	475.92	476
Peak Voltage [MV]	4.26	
Harmonic Number	270	
Synchrotron Radiation Loss [MeV/turn] (bends only)	1.04	
Synchronous Phase [Deg.]	19.03	
Number of Cavities	8	
Gap Voltage/Cavity [MV]	0.53	
Cavity Gap [cm]	22.34	
Gradient [MV/m]	2.39	4.5
Shunt Impedance/Cavity [$M\Omega$]	3.50	
Wall Loss/Cavity [KW]	40.6	150
Total Cavity Wall Loss [KW]	325	
Synchrotron Radiation Power [KW]	2525	
Higher Order Mode Power [KW]	417	
Total Power Loss [KW]	3266	
Power Loss/Cavity [KW]	298	
Detuning Angle (Deg)	88.25	
Reflected Power/Cavity [KW]	4.26	
Input Power/Cavity [KW]	413	450
Number of Klystrons	4	
Required Power/Klystron [KW]	825	1200

Table 3. Harmonic Cavity RF Parameters

		Valvo Klystron
Frequency [MHz]	951.84	1000
Peak Voltage [MV]	2.04	
Synchronous Phase [Deg.]	4.89	
Number of Cavities	2	
Gap Voltage/Cavity [MV]	1.02	
Cavity Gap [cm]	11.17	
Gradient [MV/m]	9.15	
Shunt Impedance/Cavity [$M\Omega$]	4.95	
Wall Loss/Cavity [KW]	106	
Total Cavity Wall Loss [KW]	211	
Number of Klystrons	1	
Required Power/Klystron [KW]	211	400

Fig.3a. Existing configuration of a portion of Superperiod 2 showing 52.88 MHz RF cavities.

Fig.3b. Possible configuration of Superperiod 2 with three PEP II 476 MHz RF cavities.

If the second harmonic system is used to lengthen the bunch it will have a frequency of 951.84 MHz. Properties for this system are listed in Table 3. Although the cavities have not been designed, the shunt impedance was scaled from the 476 MHz cavities by the square root of the frequency. The peak voltage and synchronous phase were chosen for optimal bunch lengthening. I have assumed that a 400 KW, 1 GHz Valvo klystron can be modified for the lower frequency. Both cavities will be powered by one klystron. A location for the harmonic cavities has not yet been found.

Table 4 contains an estimate of the cost for the electrical power required to operate the RF system with maximum current in the X-Ray Ring for 80% of the year (an ideal situation that we might approach if we adopt top-off operation using the full energy injector). I assumed the actual efficiency of the 476 MHz klystron for both systems and a reasonable efficiency for the power supply. The electrical cost used was provided by J. Desmond in September, 1993.

Table 4. RF Electrical Cost

Total RF Power (both systems) [MW]	3.51
Klystron Efficiency	60%
Power Supply Efficiency	90%
Power from AC Line [MW]	6.50
Fraction Operating	80%
Annual Operating Time [Hours]	7000
Power Cost [\$ / MW·Hr]	\$63.30
Annual Cost of Electricity for RF Power	\$2.9 M

VACUUM SYSTEM:

The existing aluminum vacuum chamber in the X-Ray Ring can be operated safely at a maximum current of 500 mA at 2.5 GeV. Increasing the current and energy will cause several problems: increased gas pressure, excessive chamber heating, and higher levels of radiation near the chamber. The last problem comes from synchrotron radiation as well as from electrons striking the chamber wall. It may or may not be significant here but it has been a concern in B factory design.

Study may show that the existing chamber can be used at a much higher current, perhaps with new x-ray crotches and additional pumping but I have assumed that the chamber will have to be completely replaced. Two types of chambers can be considered for the ring. The ALS and APS are using extruded aluminum chambers in which the synchrotron radiation strikes the wall of a differentially pumped antechamber, separated from the main beam chamber by a narrow slot as shown in fig. 4. A large amount of non-evaporable getter (NEG) pumping is provided in the antechamber to maintain a good pressure.

SLAC took a different approach to the PEP-II chamber design. Instead of using an aluminum chamber, they plan to use copper. This has three advantages as a chamber material — lower photodesorption, improved thermal conductivity, and higher atomic number for improved radiation shielding. Copper is harder to extrude than aluminum so the PEP-II chamber is welded from three pieces as shown in fig. 5. The lower photodesorption from copper allowed SLAC to use distributed ion pumps instead of NEG pumps.

The maximum beam current permitted by the upgrade, 2.4 A, was determined by the synchrotron radiation heat load on the dipole chamber as follows: The linear density P_L of the synchrotron radiation emitted by the beam is

$$P_L = P_{SR} / 2\pi\rho \quad (3)$$

Fig. 4. Beam pipe with antechamber.

where P_{SR} is the total power of the synchrotron radiation and ρ is the bending radius. The area power density striking the wall is

$$P_A = P_L / h \quad (4)$$

where

$$h = 2d\psi, \quad (5)$$

is the height illuminated, d is the distance from the beam to chamber wall, and

$$\psi = 1 / \gamma \quad (6)$$

is the opening angle of the radiation. The geometry of the radiation striking the chamber is shown in fig. 6. The shortest distance between the beam and the chamber wall is inside the dipole magnet and is

$$d = \sqrt{(\rho + w/2)^2 - \rho^2} \quad (7)$$

where ρ is the bending radius and w is the width of the chamber.

Fig. 5. SLAC design for PEP-II vacuum chamber. [from *PEP-II An Asymmetric B Factory, Conceptual Design Report*, p. 331]

Fig. 6. Geometry of the synchrotron radiation fan striking the wall of the vacuum chamber in the bending magnet.

Table 5 shows the results of the heat load calculation for X-324 and for the PEP-II high energy ring (HER). The copper chamber was designed at SLAC for the maximum heat load in the HER. At 2.4 A, the density of the radiation striking the chamber wall is 2.31 KW/cm², the same as the maximum power density allowed in the PEP-II high energy ring chamber. This determined the maximum current for the upgrade.

Table 5. Synchrotron Radiation Loads on Vacuum Chambers

	Current Conditions	Upgrade	PEP -II HER (Max. Current)
Magnetic Radius [m]	6.88	6.88	165.00
Bending Magnet Field [T]	1.21	1.45	0.182
Energy [GeV]	2.50	3.00	9.00
Current [A]	0.25	2.42	3.00
Synchrotron Radiation Power [KW]	125.71	2524.68	10,557
Linear Power Density [W/cm]	29.10	584.46	101.80
Radiation Half Angle [mrad]	0.20	0.17	0.06
Chamber Width [cm]	8.00	8.00	9.00
Beam to Chamber Distance [cm]	74.27	74.27	385
Minimum Height Illuminated [mm]	0.30	0.25	0.44
Maximum Power Density [KW/cm ²]	0.10	2.31	2.31

The largest contribution to pressure in the vacuum chamber at the maximum current is photodesorption from of gas molecules from the chamber walls by synchrotron radiation. The effective gas load in Torr·L/sec is

$$Q_{\text{gas}} = 8.08 \times 10^{20} E I \eta \quad (7)$$

where E is the beam energy in GeV, I is the current in Amp, and η is the photodesorption coefficient for the chamber material. When S is the total pumping speed, the average pressure in the ring will be

$$P = Q_{\text{gas}} / S. \quad (8)$$

Table 6 compares the average pressure in the X-Ring under current conditions and after the upgrade. The desorption coefficients for copper and aluminum were supplied by C. Foerster and come from measurements on an NSLS VUV Ring beamline, extrapolated to an integrated dose of 10^{26} photons/m incident on the chamber wall. The photodesorption coefficient for copper is consistent with the value of $< 1 \times 10^{-6}$ obtained at the Photon Factory at KEK.² Similar pressures are calculated for both conditions but they are 2-3 times larger than the pressure actually seen in the x-ray ring. This may be because half of the radiation leaves the ring through the beamlines and does not strike the chamber walls. A more detailed calculation of the local desorption should produce more accurate results. For now it is encouraging to see that the estimated pressure with a copper chamber at high energy and current is close to the estimated pressure in the aluminum chamber with 250 mA at 2.5 GeV. It suggests that additional pumping speed will not be needed for the upgrade.

Table 6. Synchrotron Radiation Induced Vacuum Loads

	Current Conditions	Upgrade
Material	Al	Cu
Energy [GeV]	2.5	3.0
Current [A]	0.25	2.42
Photodesorption Coefficient η	4.00E-06	4.00E-07
Photodesorption Gas Load [Torr·L/sec]	6.05E-05	7.03E-05
Total Ion Pump Speed [L/sec]	8880	8880
Average Pressure [Torr]	6.81E-09	7.92E-09

2. Y. Hori, M. Kobayashi, and Y. Takiyama, *Vacuum Characteristics of an OFHC Copper Duct at the KEK-PF Ring*, (in publication) VT-MoA6, AVS 40th National Symposium (Nov. 15-19, 1993).

Recently, a potential problem has emerged with copper vacuum chambers in electron storage rings. Extremely poor electron beam lifetimes have been seen at DESY in the electron rings of the DORIS-III and HERA that both have copper chambers. The effect has been attributed to trapped dust³ and to a plasma formed from copper ions sputtered from the chamber.⁴ It is hard for me to understand this problem because copper has always been an important part of electron storage ring vacuum chambers. The X-Ray Ring, for example, contains many copper masks that could contribute ions or dust to the beam vacuum. They have not caused any problems. The most important difference between the DESY chamber and our masks is that the DESY chambers are inside the bending magnets. The magnetic field may somehow contribute to the phenomenon. Conrad Foerster and SLAC researchers are planning to study this. If the problem is confirmed, SLAC will have to redesign PEP-II and we will not be able to use the copper chamber in the upgrade. Instead we will have to consider using an aluminum chamber with additional pumps. This will significantly raise the cost of the project.

FEEDBACK:

Running a high current in 225 bunches may produce a multi-bunch instability. SLAC has designed a modular feedback system for PEP-II to damp longitudinal multi-bunch instabilities. The system uses broad-band digital feedback, implemented on digital signal processors (DSPs) to individually control the motion of each bunch. The system is designed so that DSP modules can be added to the system as the number of bunches increases. SLAC will require 15-20 modules to control 1658 bunches. We will only need 2-3 modules for 225 bunches. The system will also be used at the ALS.

MAGNETS:

One family of X-Ray Ring quadrupoles (QC) was built from the VUV Ring quadrupole laminations to save money. They are already saturating at 2.5 GeV and will have to be replaced before the energy can be raised to 3.0 GeV. Designing new ones should not be difficult.

INJECTOR:

The existing booster synchrotron can fill the X-Ray Ring at a rate of 0.5 mA/cycle. By the time the upgrade is completed, the booster will have a repetition rate of 2 Hz. It will take 40 minutes to fill the x-ray ring to 2.4 Amp. This is much too long. We will be able to fill in 20 minutes if we can double the booster intensity but I don't know how we can do that. Even if we can, we will still have to ramp the X-Ray Ring from 120 MeV to 3.0 GeV causing large

3. F. Zimmerman, *Trapped Dust in HERA and DORIS*, DESY HERA 93-08 (July 1993).

4. W. Stoeffl, *Notes on Beam Lifetime Limits at DESY*, Informal Report, LLNL (Nov. 9, 1993).

temperature swings in the chambers and x-ray optics. It is also not known if the X-Ray Ring can stably store 2.4 Amp at 120 MeV.

Much better performance will be achieved if we can build a full energy injector for the x-ray ring. The hardest problem is finding a place to build it. Various locations have been proposed in the past. One possibility is building the injector in the X-Ray Ring tunnel. This will require a long shutdown for installation. Another possibility is a new building. This will be expensive and require a long transfer line.

It will also be possible to build a 3 GeV booster synchrotron in the center of the X-Ray ring as shown in fig. 7. The booster will occupy the transformer pad in the courtyard outside the building and the interior space now used for high voltage and RF cavity testing. In order to carry out the X-324 upgrade we will have to install 6 MW of new substations anyway, so moving the old substations off the pad will only be a small complication. The pad is surrounded by a thick retaining wall at the edge of the driveway that can support the roof that will be needed over the booster and the wall will also serve as radiation shielding.

The major features of the 3 GeV booster are listed in Table 7. The booster will be a fast cycling accelerator with a 10 Hz repetition rate. A magnetic field of 1.47 T will be needed to fit the booster into the available space. The field is slightly higher than I like but it is low enough so that saturation will not be a major problem if the magnets are designed carefully. The dipole and quadrupole magnets will be designed with matched saturation characteristics so that the coil inductance can be resonated and the magnets powered with a low power, sinusoidal supply. Two of the PEP-II cavities and one klystron will suffice to replace the synchrotron radiation losses and supply the required acceleration per turn. A ribbed, thin wall, stainless steel vacuum chamber will be needed to allow the 10 Hz fields to penetrate. With a 10 mA current, the high energy booster will fill the X-Ray Ring to 2.4 A in 24 seconds. Although injectors never live up to expectations, there is a large margin for error with this design.

Beams will be injected from a four section, 200 MeV linac located in the center of the booster as shown in fig. 7. The linac sections that the NSLS bought from the People's Republic of China can be used for this. Linac modulators can be built in-house, as we are now doing for the existing 120 MeV linac. The modulators will cost approximately \$100K each. We will consider using a thermionic, RF gun to provide the electrons as at the SSRL injector.

One feature that I have not yet considered is 3 GeV injection into the X-Ray Ring. This may prove to be the crux of the problem of full energy injection. We will have to design pulsed magnets that can deflect the 3 GeV beams in the space now used to inject 120 MeV electrons. There is no room in the X-Ray ring for longer septa and bumps.

Fig. 7. Possible location of 3.0 GeV booster synchrotron.

(Scale: $1/32" = 1'$)

Table 7. High Energy Booster Parameters

Current [mA]	10
Repetition Rate [Hz]	10
Acceleration Time [sec]	0.10
Injection Energy [MeV]	200
Extraction Energy [GeV]	3
Acceleration [KeV/Turn]	10.59
Revolution Frequency [MHz]	5.29
Circumference [m]	56.69
RF Frequency [MHz]	475.92
RF Harmonic	90
Bunches Filled	75
Electrons/Bunch	1.58E+08
Bend Radius [m]	6.80
Dipole Magnetic Field [T]	1.47
Energy Loss/Turn [MeV]	1.05
RF Peak Voltage [MV]	2.00
Overvoltage	1.88
Synchronous Phase [Deg.]	32.17
Number Of Cavities	2
Gap Voltage/Cavity [MV]	1.00
Wall Loss/Cavity [KW]	143
Synchrotron Radiation Power [KW]	10.5
Total Power Loss [KW]	296
Number Of Klystrons	1

BEAMLINE CONSIDERATIONS:

All of the x-ray crotches and beamline components, through the monochromators will have to be replaced to handle the intense radiation from X-324. We may be able to incorporate elements of the beryllium absorbers planned for the APS or the shallow incidence, dihedral absorbers developed at CHESS for the proposed CESR B factory⁵ in our design. The dipole beamline may be able to use the monochromators developed for the X-25 wiggler but new monochromator designs will be needed for the insertion devices. Research into these components must be part of the planning for the upgrade.

X-RAY RING COST ESTIMATE:

Table 8 contains an estimate of the cost of the X-Ray Ring portion of the upgrade. It is based on the WBS for PEP-II. The scaling for each item is described in a note to the table. The estimate includes SLAC's estimates and rates for materials, labor, and ED&I. It does not include contingency or overhead. In the case of the components that have developed at SLAC such as the 476 MHz cavities, I am still including the unit cost of the engineering that has already been performed. I hope to avoid underestimating anything by doing this. The total cost of the X-Ray Ring upgrade is \$13.7M. This does not include the x-ray crotches.

I have not tried to estimate the cost of the high energy booster but it should be similar to the \$14M cost of the SSRL injector. No estimate can be made yet for utilities or beamline upgrades.

SCHEDULE:

With a serious effort, the NSLS can complete a CDR by 1995. Research for this should include the construction of prototype dipole vacuum chamber. If we are to use a copper chamber we may want to test the chamber with beam in the X-Ray ring in a dipole, perhaps in the X30 region where there are no beamlines, in order to rule out the strange effects seen at DESY.

The CDR should be submitted in time for funding in FY 97. The construction schedule must be designed to cause as little disruption as possible to the operating schedule. As soon as construction is approved, we will begin building transformer pads outside the NSLS building. New substations will be installed and cables run into the building to the existing distribution panels. Then, during perhaps a one month shutdown in late 1997 or 1998, we will switch the building power from the old substations in the courtyard to the new ones. The old substations can then be removed and the high energy booster enclosure can be built during ring operation.

5. Q. Shen and D. Bilderback, *Preliminary Design of a Synchrotron Radiation Exit Port Crotch for Cornell B-Factory*, SPIE Vol. 1739 *High Heat Flux Engineering* (1992) p. 191.

Meanwhile the high energy booster components will be built. The booster will be installed in late 1998 or early 1999 and commissioned into a beam dump by late 1999. X-Ray ring component construction will progress and we will shut down in 1999 or 2000 for six months to one year to install the X-Ray ring components. Beamline modification (but not the crotches) can be postponed if necessary. We may want to install some of the components, such as a prototype RF cavity, in advance. With the fully tested booster and a vacuum chamber designed for 2.4 A, we should quickly establish injection and store 500 mA, 2.5 GeV beams (presumably our standard operating current by then). We can then slowly condition the ring and upgrade the x-ray optics for full 2.4 A, 3 GeV operation.

Table 8. X-Ray Ring Upgrade Cost

	System	Component	SLAC cost (K\$)	corrected cost (K\$)	SLAC quantity	units	unit cost (K\$)	quantity	units	total cost (K\$)	note
Upgrade								1	ca.	13714	
	476 MHz RF									7680	1
		system integration	2722		20	ca.	136	8	ca.	1089	
		cavities	4997		20	ca.	250	8	ca.	1999	
		klystrons	2640		10	ca.	264	4	ca.	1056	
		waveguide	2747		10	ca.	275	4	ca.	1099	
		low level & controls	1478		20	ca.	74	8	ca.	591	
		high voltage P.S.	3261	3933	10	ca.	393	4	ca.	1573	2
		cooling	276		10	ca.	28	4	ca.	110	
		cabling	408		10	ca.	41	4	ca.	163	
	952 MHz RF									1894	3
		system integration	2722		20	ca.	136	2	ca.	272	
		cavities	4997		20	ca.	250	2	ca.	500	
		klystrons	2640		10	ca.	264	1	ca.	264	
		waveguide	2747		10	ca.	275	1	ca.	275	
		low level & controls	1478		20	ca.	74	1	ca.	74	
		high voltage P.S.	3261	4413	10	ca.	441	1	ca.	441	2
		cooling	276		10	ca.	28	1	ca.	28	
		cabling	408		10	ca.	41	1	ca.	41	
	vacuum									2669	
		extruded chamber	18356		2199.32	m	8	170	m	1419	4
		insertion chambers					250	5	ca.	1250	5
	feedback		2246		1658	bunches	1.35	225	bunches	305	6
	magnets	C family quads	2779		288	ca.	10	16	ca.	154	7
	injection									1012	8
		pulsed septum	149		2	ca.	75	1	ca.	75	
		fast bump magnet	284		4	ca.	71	3	ca.	213	
		pulsed p.s.	362		2	ca.	181	4	ca.	724	

Notes to Table 8

1. The cost of the 476 MHz RF system includes all of the SLAC development cost. Our actual cost may be somewhat less if we are able to use the SLAC cavities and klystrons.
2. Each SLAC high voltage power supply has its own substation. SLAC was able to save money by reusing old transformer pads and AC switch gear for 8 of the 10 power supplies. I corrected the SLAC cost by adding in the cost of 8 additional substations.
3. I used the cost of the 476 MHz RF system to estimate the cost of the 952 MHz system.
4. The SLAC cost for the extruded chamber includes valves, flanges, and other miscellaneous components. I scaled this by the relative length of the chamber to get our cost. We should be able to save some of the cost by reusing valves and other components.
5. The cost of the insertion device chamber is based on NSLS experience, not SLAC costs.
6. The cost of the feedback system is scaled by the relative number of bunches. This is fairly reasonable because the digital electronics is modular. The number of modules used is proportional to the number of bunches. The cost of the high level amplifier scales with the average power which, in turn, scales with the number of bunches. The pick-up and kicker electrodes are fixed costs but are relatively inexpensive compared to the electronics.
7. I am estimating the cost of the quadrupoles by the cost of the PEP-II Low Energy Ring quadrupoles.
8. Injection components include ceramics, magnets, and pulsed power supplies.

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