National Synchrotron Light Source Operations Policies, Operational Safety Limits and Facility Upgrades

1. Introduction

The National Synchrotron Light Source Safety Analysis Reports (1),(2),(3), BNL reports #51584, #52205 and #52205 (addendum) describe the basic Environmental Safety and Health issues associated with the department's operations. They include the operating envelope for the Storage Rings and also the rest of the facility. These documents contain the operational limits as perceived prior or during construction of the facility, much of which still are appropriate for current operations. However, as the machine has matured, the experimental program has grown in size, requiring more supervision in that area. Also, machine studies have either verified or modified our knowledge of beam loss modes and/or radiation loss patterns around the facility. This document is written to allow for these changes in procedure or standards resulting from their current mode of operation and shall be used in conjunction with the above reports. These changes have been reviewed by NSLS and BNL ES&H committees and approved by BNL management.

2. Description of the Facility

The NSLS synchrotron radiation facility includes two electron storage rings. The first one, with a maximum attainable electron energy of 3.0 GeV, is principally intended for generation of the radiation spectrum of 0.5 Å to 100 Å. The second ring, with a maximum energy of 1.0 GeV, will provide for the wavelength region of about 10 Å and above.

In addition, insertion devices designed to enhance the photon flux in a particular spectral region have been installed in all of the available straight sections of both the VUV and X-ray Storage Rings. Detailed descriptions of these devices, including safety issues associated with their operation, are given in the National Synchrotron Light Source Phase II Safety Analysis Report, BNL 52205. This report also contains a description of the Laser Electron Gamma Source Facility (LEGS) which provides a source of high energy γ-rays (300 to 500 MeV) by back scattering photons in the injection straight.

As there is a considerable interest in utilization of the wavelength domain below 1 Å, a beam wiggler has been incorporated in the X-ray Ring structure, making use of 6 T peak field superconducting multipole magnets: This extends the available spectrum effectively down to 0.1 Å ($h\nu \leq 100$ keV), as is indicated in Figure 1, where the photon flux per mrad of arc and per cent of $(\Delta\lambda/\lambda)$ is given versus wavelength for the NSLS design parameters. There is also interest in operating the X-ray Storage Ring at higher than the 2.5 GeV design energy, since with minimal additional cost, the maximum energy of the X-ray Ring can be increased to 3.0 GeV. Furthermore, the Vacuum Ultra Violet Ring energy may be increased to a maximum of 1GeV.

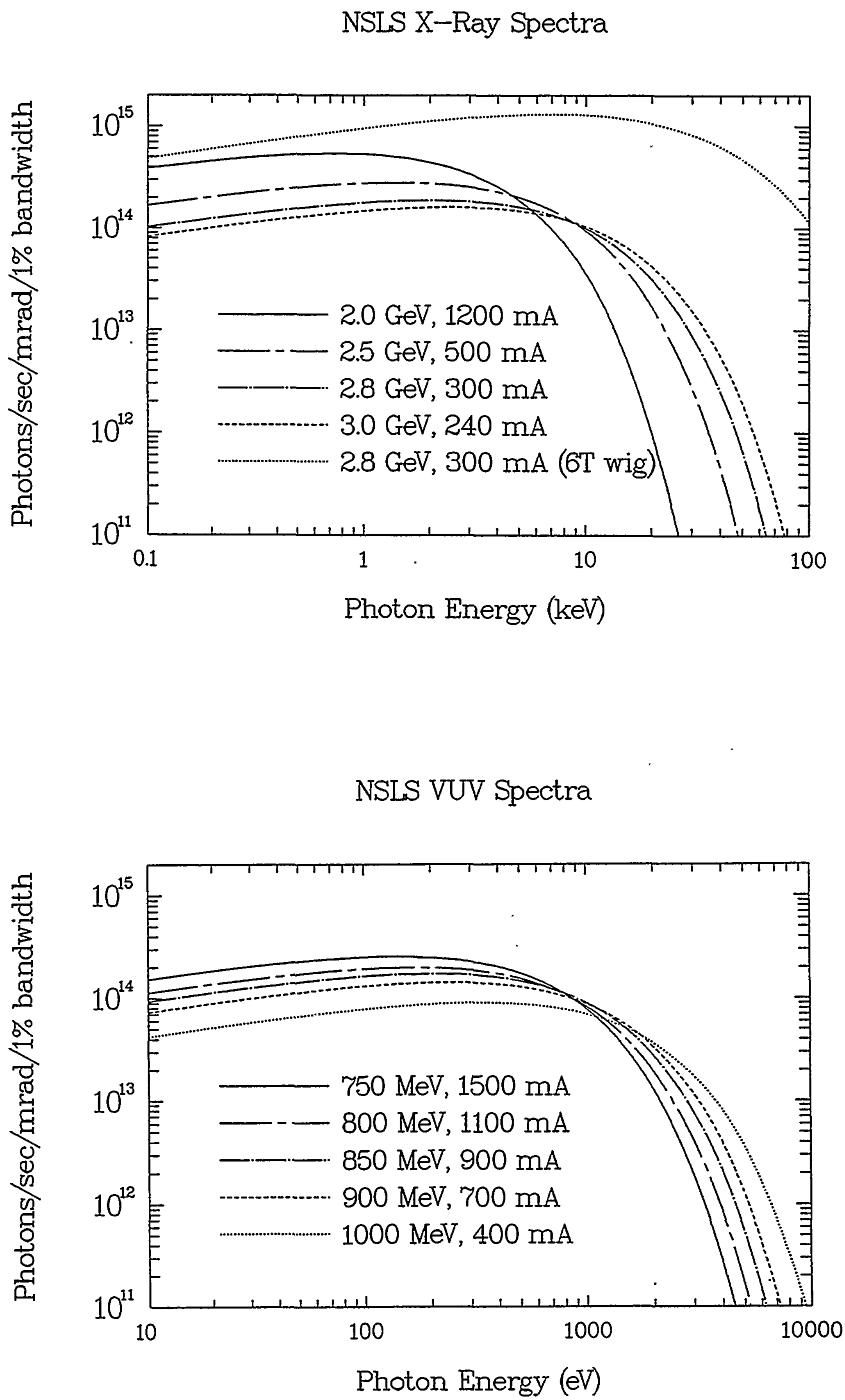


Figure 1. Synchrotron radiation spectra for the NSLS design parameters

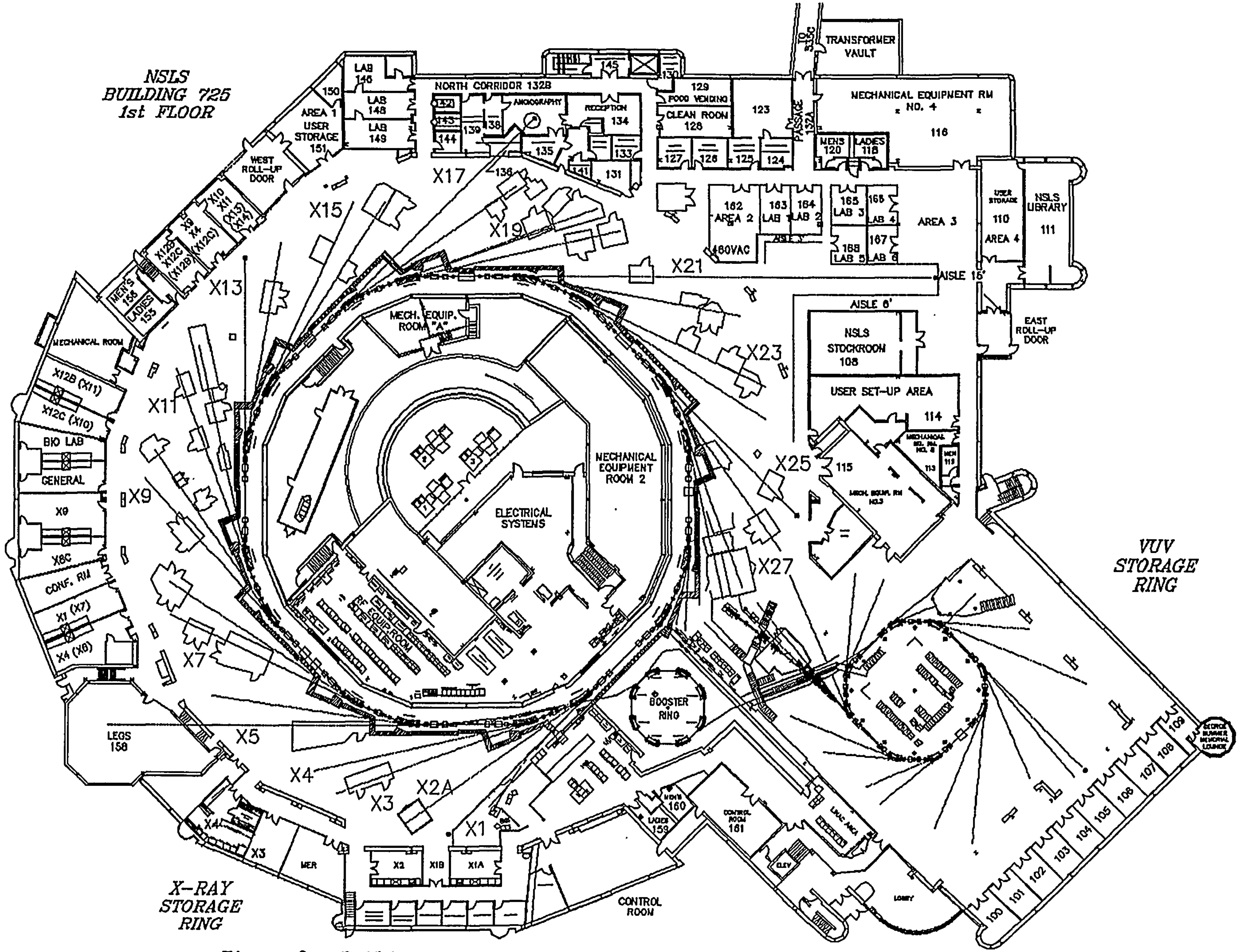


Figure 2. Building layout of the NSLS

For the VUV Ring, beam undulators have been incorporated. However, in this case, there is no particular objective of making available a shorter wavelength domain, which is readily available from the X-ray Ring; rather, in this case, modest field, many pole, coherent undulators are utilized to achieve selected wavelength photon flux enhancements by several orders of magnitude. The VUV Ring provides for 16 primary beam ports (14 arc sources, 2 undulator ports) whereas with the X-ray Ring 28 primary ports are utilized, including 5 wiggler or undulator ports.

The general arrangement of the principal elements of the synchrotron radiation facility is shown in Figure 2. Electrons, originating from a hot cathode triode gun driven by a 110 keV pulsed modulator are accelerated in an S-band linear accelerator to 120 MeV, injected into a booster synchrotron and accelerated to a maximum energy of 1 GeV. The beam is then extracted and transferred either to the VUV or the X-ray Storage Ring. By repeating this process, the charge magnitude is built up in the storage rings to the desired current or charge. Section 4 of this report sets operational limits for the stored current and energy in the storage rings. In the case of the X-ray Ring, the stored charge is then further raised in energy by acceleration to the maximum desired energy. The stored current at a given energy is limited by the ability of the storage ring vacuum chamber to handle the heat load, particularly in the wigglers and undulators.

The experimental beamlines are situated in such a location that they are tangential to the electron orbit in the dipole or insertion device magnetic field regions of the storage rings. Thus, synchrotron radiation, generated when the relativistic electrons are bent by these magnetic fields, emerges down these beam ports and into a series of individual beam lines where the radiation is used for experimental purposes. In the Vacuum Ultra-Violet Storage Ring the photon beam remains in a vacuum all the way to the experimental chamber, whereas in the X-ray Storage Ring the photon beam may, in some experiments, pass through a beryllium window into air before reaching the experiment. Insertion device (undulator and wiggler) beam lines are directly in line with the particular machine straight section in which they are situated and generally pose special bremsstrahlung shielding issues, as well as giving higher X-ray or VUV fluxes.

3. Operations Policy

From a management viewpoint, the NSLS operating policy is to operate the facility within operation limits specified in the various Safety Analysis Reports (1)(2)(3). However, with the development of the experimental program, certain operating policies, procedures or parameters require modification to keep the facility current or state-of-the art. When such changes are required, a full internal review is carried out within the NSLS Department and the changes presented to the appropriate BNL committee for review and recommendation to BNL management. NSLS maintains a "Beam Line Review Committee" to review all experimental beam line designs and an "Environmental Safety and Health Committee" to review all major facility modifications or changes in operational procedures or policies.

Operation of the storage rings and the experimental beam lines has evolved over the past 10 years to the system described in 3.1 below. Detailed operational procedures are contained in the NSLS Conduct of Operations Manual (4).

3.1. Storage Ring Operations

Section 2.4.1.2 of BNL report #51584 shall be amended to the following:

On each shift, except during extended shutdowns, there will be one qualified Machine Operator and one Operations Coordinator on duty. When the LEGS target is in operation a second Operations Coordinator, designated as the target watch shall be on duty. These persons will have the responsibility for the safe operation of the total facility and have the authority to stop or impose restrictions on any activity associated with facility operation. The Control Room is an Emergency Response Center and as such must always be staffed by at least one person except during scheduled shutdowns or when there is an emergency situation or the Emergency Response function is formally transferred to BNL Emergency Forces.

3.1.1 Machine Operator Duties

The machine operator's duties are as follows:

3.1.1.1. Operate the Injection System and Storage Rings.

3.1.1.2. Supervise the searching and securing of the Linac/Booster, X-ray Tunnel and inner VUV Ring Radiation Areas.

3.1.1.3. Maintain a log of machine status and special operating conditions.

3.1.1.4. Read and sign off on the previous shifts operations log.

3.1.1.5. Give a verbal briefing at shift changes.

3.1.1.6. Shut down any part of the facility within their area of control which may present a safety hazard until that hazard has been removed.

3.1.1.7 Act as Local Emergency Coordinators in the event of a Facility Emergency.

3.1.2 Operations Coordinator Duties

3.1.2.1. Monitor the operation of the Experimental Beam Lines and the Laser Electron Gamma Source (LEGS) Target Facility.

3.1.2.2. Maintain a log of Beam Line Status and LEGS Target Facility.

3.1.2.3 Read and sign off on the previous shift's operations log.

3.1.2.4 Give a verbal briefing at shift changes.

3.1.2.5. Conduct regular tours of the Experimental Floors and LEGS Target Facility.

3.1.2.6. Carry out Beam Line checks using the checklists provided and carry out routine radiation checks of the Experimental Beam Lines.

3.1.2.7. Act as back-up to the Machine Operator and assist him/her in securing the machine radiation areas.

3.1.2.8. Check that the beam lines have a current experimental safety approval form.

3.1.2.9. A designated coordinator shall have the responsibility for the safe operation and shut down of the LEGS target system in an emergency situation.

3.1.2.10. Lock out any beam line where a safety hazard is detected and inform the NSLS Safety Office of this action.

3.1.2.11 Perform the assigned duties as given in the Local Emergency Plan.

3.2 NSLS User Training

Section 2.4 of BNL report#52205 shall be amended to the following:

3.2.1 Safety Training

In addition to the training discussed in section 2.4 of the phase I SAR (BNL 51584 for the NSLS Operations Staff, a training program for NSLS users is now in place. This training is a requirement for registration at the NSLS and the issuance of an ID card which provides access to controlled areas at the facility. The training consists of a video tape which covers general safety, radiation protection, emergency signals and responses, and provides an introduction to the NSLS operations and safety staff. This is supplemented by a booklet which covers this material in more detail and emphasizes procedures and rules applying to experimental operations. Finally, the user is required to sign a statement that the training material has been understood and will be followed. Users who plan to be at BNL for more than three months are required to undergo the BNL training for employees.

4. Operational Safety Limits

4.1 Injection System

The primary function of the Injection System is to provide up to 1 GeV electrons for injection into the two Storage Rings. It comprises a 120 MeV linear accelerator followed by a 1 GeV electron synchrotron and two beam transport lines to transport beams to the two storage rings at different times.

4.1.1 Injection System Operation

The basic source of electrons is the electron gun which operates at a maximum peak beam current of 400 mA contained in up to 20 microbunches each 10 nsec long and separated by ~ 100 nsec for a total of 4.8×10^{11} electrons in each macropulse. The electron gun may also be operated at a peak current of 1.5A in a single, 10 nsec, micropulse. The maximum gun energy is 110 KeV and the pulse repetition frequency is 2 Hz maximum. The beam is modulated by a radio frequency buncher to give an injection capture efficiency of between 60% and 70% so that a total of 3.4×10^{11} electrons per second may be accelerated in the linac to its maximum attainable output energy of 120 MeV. All other electrons are lost at low energy and do not contribute to γ-rays which may be produced by electrons striking the walls of the accelerator guide or beam transport lines, for which lead shielding is required. The linac comprises three accelerating sections, each with its own drive klystron providing a maximum peak output power of 20 MW. Thus the maximum achievable electron energy at design beam currents is 120 MeV. Normal beam current losses through the linac sections 2 and 3 are less than 5%, that is, less than 10^{10} electrons per second while the loss in section 1 at energies less then 3.5 MeV may be as high as 1.5×10^{11} electrons per second. Lead and concrete shielding is provided to reduce radiation levels produced by this beam loss to considerably less than 100 mrem per year in non-radiation worker areas adjacent to the machine.

The 120 MeV electron beam is transported to a shielded cave inside the Booster enclosure where up to 50% or 1.7×10^{11} electrons per second may be lost on a momentum defining aperture. The shielding around this region is sufficient to reduce radiation levels in non-radiation worker areas above it to well below 100 mrem per year even if all of the linac beam is lost there. After passing through the momentum selection section, the remaining beam of 1.7×10^{11} electrons/sec is transported to the injection septum of the Booster. The inflection system involves a pulsed septum magnet and pulsed injection magnets to correct the early Booster turns of circulating beam. Each linac microbunch occurs at a time separation of one Booster revolution so that, in principle, each bunch adds current at the proper acceptance time and space, thus increasing the total current in a single bunch or bucket in the Booster. Over 20 linac microbunches this capture process is fairly inefficient and the maximum achievable circulating current in the Booster at injection energy is of the order of 10 mA average, or 8×10^{9} electrons/sec giving a capture efficiency of about 5%. Thus the shielding in the inflector region, where most of this beam loss occurs, is essentially designed to shield against total loss of the electron beam reaching this point.

During the acceleration and radio-frequency capture process, further beam losses occur at energies between 120 MeV and the maximum achievable Booster energy of 1 GeV. Typically 20% of the circulating beam is lost in this way and 50% of the remaining beam at full Booster energy may be lost in the extraction process and transport of the beam to the storage rings. Thus, only about 6.3 mA average Booster current or about $4x10^9$ electrons per second are available at the injection points of either Storage Ring. With this charge and perfect injection efficiency, it would be possible to fill the VUV ring to 1 ampere and the x-ray ring to 0.5A in about 4 minutes. In practice capture losses increase this time by typically a factor of 2 to 3.

The maximum allowable beam operating parameters for the Injection System are summarized in Table I and the maximum beam losses under normal operation are given in Table II.

Table I Injection System Operational Safety Limits

Electron gun energy	110 KeV
Electron gun current (peak)	400 mA or 1.5A
Number of electron gun micropulses	20 or 1
Linac energy	120 MeV
Linac current (peak)	300 mA
Booster energy	1GeV
Booster circulating current	50mA
*Booster repetition rate	1Hz

*Note the Linac repetition rate can be increased to 2Hz without compromising safety or exceeding any design limitations.

Table II Maximum Injection System Electron Beam Losses

Between Electron Gun and Linac capture (<5MeV) ≈ $1.5x10^{11}$ electrons/sec.
Between accelerator guides 1 and the exit of guide #3 (<120MeV) ≈ 10^{10} electrons/sec.
\+ In the Linac cave where momentum selection occurs (120 MeV) ≈ $1.7x10^{11}$ electrons/sec.
During Booster capture, mainly at the injection septum, (120MeV) ≈ $1.67x10^{11}$ electrons/sec.
During Booster acceleration in Booster straights (up to 1GeV) ≈ $1.5x10^{9}$ electrons/sec.
During Booster extraction and transfer at 1 GeV ≈ $7.5x10^{8}$ electrons/sec.
\+ Note that the shielding is sufficient to allow total beam loss at this point without compromising safety limits.

The beam losses in the Booster during acceleration and extraction give rise to radiation levels during the storage ring filling process in certain second floor locations which could lead to total dose for the year of greater than 200 mrem if a person were situated there for every fill of the storage rings. These locations are clearly posted and injection fills are announced prior to their occurrence. Furthermore, injection fills are scheduled out of normal work hours, where possible. Booster studies with beam dumped into a beam stop in the X-ray transfer line are normally carried out during "off" hours. A "chipmunk" radiation monitor situated in room 2-103 on the second floor area above the Booster is utilized to monitor and record radiation levels during Booster operation. This monitor will be used to give an alarm if the integrated dose during Booster operations exceeds 5 mrem in any 12 hour operations shift. Exceeding that value will require clearing of the affected offices of personnel and posting the area before injection can continue.

4.2 Storage Ring Operation

Basically the two storage rings operate in the same way, the only difference being that in the X-ray storage ring the fields in the magnetic bending and focusing elements and the radio frequency power are slowly increased in synchronism in order to achieve acceleration. The injection process after extraction and transfer of a single bunch to the injection septum of the storage ring involves the pulsing of orbit correction bumps to achieve a closed orbit, while still maintaining a stable orbit for beam which has already been stored. Individual Booster micropulses are injected into awaiting buckets in the storage ring in order to achieve a predetermined bunch fill pattern. There are 9 available buckets in the VUV Storage Ring and 30 in the X-ray Storage Ring. Repeated injections will fill the rings to a level determined by the ring vacuum, rf power capability or a beam-related instability. Safe operational limits may be determined by either machine hardware limitations or radiation shielding considerations. The injection and capture process is fairly lossy, with typically between 20% and 40% of the available beam from the Booster being effectively stored. These injection losses are particularly bothersome for the VUV Storage Ring where there are second floor offices overlooking the ring. Radiation levels in certain offices can exceed the yearly 100 mrem limit for non radiation workers, when a reasonable occupancy factor is applied. NSLS policy is 1) to announce prior to, and sound an audible alarm during all VUV injections, allowing personnel to evacuate the area, 2) to limit the total injection time to no greater then 45 minutes in any 2 hour period and 3) to limit the number of injections during "normal" work hours. The affected areas are clearly posted to indicate enhanced radiation levels during VUV injection. Annual radiation doses in these offices resulting from stored beam operation is well below the 100 mrem limit.

Operational current and energy limits for the two storage rings are therefore somewhat inter-related due to the radiation arising from Booster operations.

4.2.1 VUV Storage Ring Operations

For the VUV Ring, both injection losses and stored beam losses tend to occur at the same locations, namely the points in the ring where the "beta function" is largest or, alternatively, the dispersion is greatest. These regions are generally well shielded for γ-radiation and photo neutrons, with lead and concrete. However, certain areas are difficult to shield due to physical conflicts between shielding and machine hardware. Thus certain γ-radiation peaks are present around the facility. In addition, photo neutrons are produced by the γ-rays being stopped in the lead shielding and these give rise to a low level background which could approach the 100 mrem yearly limit at some level of stored beam current (photo neutron production rates are essentially electron beam energy independent in the VUV Ring energy range). Higher energy operation, although it increases the photon energy, also improves the beam lifetime, essentially proportionally. Furthermore, higher electron energy reduces the damping time in the storage ring and this can also lead to better injection efficiency and less beam loss during the fill process. Given all of the above, it is reasonable to set the stored current levels on the basis of electron beam power at a given energy, which gives rise to the values of Table III, for constant beam power. These limiting current are thus set by available r.f. power and not by radiation considerations.

Table III VUV Storage Ring Operational Safety Limits

VUV Beam Energy	750MeV	800MeV	850MeV	900MeV	1GeV
VUV Beam Current	1.5A	1.1A	0.9A	0.7A	0.4A

4.2.2 X-ray Storage Ring Operations

For the X-ray ring, which is inside of a concrete tunnel, the beam loss situation is somewhat different. For the injection process, radiation levels in the occupied areas above the Booster and Linac are somewhat less than those seen during VUV injection, due to different beam loss patterns along the two transport lines.

There are two locations near the Booster-to-X-ray transfer line where beam losses give rise to enhanced radiation levels of up to 5 mrem/hr during a typical 20 to 30 minute injection to the X-ray Storage Ring. Neither of these loss points are normally occupied areas and they are properly posted as required by the RADCON manual. Section 5.4.2.3 of BNL Report #51584 deals with the "Dose Rate During Injection"into the X-ray Storage Ring. The following paragraph shall be added to that section in order to implement changes brought about by the new shielding configuration.

During X-ray injection, the radiation levels resulting from beam losses in the Booster X-ray transport line can create a radiological control area with levels immediately adjacent to the entry door slightly in excess of 5 mrem/hr under certain beam-loss conditions. The area adjacent to the door is clearly marked and posted as a "radiation area during X-ray injection". Audible and visual warnings are provided in this area during X-ray injection. Area monitors record the monthly dose in this area. During stored beam operation, for the energy and current defined by the existing SAR, there is minimal detectable radiation outside of the tunnel due to electron losses in the Storage Ring itself. However, there is a desire to increase the operating energy of the X-ray Storage Ring to 3 GeV which would give rise to a harder photon spectrum than at the original 2.5 GeV design energy. Existing bremsstrahlung shielding around the storage rings and along the Experimental Beam Lines is implemented on data taken at 6 GeV and is therefore appropriate for 3 GeV operation. Furthermore, shielding for photo neutrons is also adequate as long as the electron beam power is maintained constant at the higher energy. This gives the Operational Safety Limits of Table IV for the X-ray Storage Ring, if only bremsstrahlung and neutron radiation is considered. X-ray photons from bending magnet sources inside the tunnel are also not a serious problem for operation at up to 3 GeV electron energy and a beam current of 0.24 Amperes. There may be a need to wrap certain sections of the vacuum chamber with 1/8" lead sheet. This need will be determined during special beam studies carried out with the X-ray Experimental Area secured.

Table IV X-Ray Storage Ring Operational Safety Limits

X-Ray Beam Energy	2.0GeV	2.5GeV	2.8GeV	3.0GeV
X-Ray Beam Current	1.2A	0.5A	0.3A	0.24A

The remaining issue in relation to running at high energy and/or current in the X-ray Storage Ring is that of beam chamber heating by the photon beam. This problem is particularly severe for the insertion devices which give higher photon fluxes than the bending magnet sources. The radiated power from bending magnet sources is proportion to the fourth power of the electron beam energy so that, for a given electron current, increasing the beam energy from 2.584 GeV to 3 GeV will increase the total radiated power by a factor of 2. Currently, the operating current at the 2.584 GeV operational energy is administratively limited to 0.25A or 50% of the value given in Table IV because of potential overheating of the beam chambers associated with operational insertion devices. Studies are underway to determine what extra cooling may be required to attain the stored beam current values given in Table IV.

4.2.3 Experimental Beam Line Operations

4.2.3.1 VUV Beam Line Operations

Lead shielding for bremsstrahlung radiation along the experimental beam lines has been installed with sufficient length and width to shield for electron beam energies of more than 2.5 GeV so there is no increased hazard in operating at 1 GeV rather than 750 MeV in the storage ring and beam lines. The critical wavelength varies inversely as the third power of the electron beam energy and the critical energy (hν) directly as the cube of the electron energy. Thus the critical wavelength, λ_c, is ~10.6Å and critical energy ~1180 eV for 1 GeV electron energy. The photon energies available at 1 GeV are therefore insufficient to penetrate the windows at the ends of VUV beam lines. The beam current operational limits given in Table III are set by maintaining constant beam power over all energies so there is no problem with beam chamber heating at the higher electron energies. Because of redistribution of photon energy with wavelength at the higher electron energy the visible light hazard is less than that given in BNL report 51584.

4.2.3.2 X-ray Beam Line Operations

The situation with regard to bremsstrahlung shielding for the X-ray Storage Ring is similar to that of the VUV Storage Ring, in that the lead shields provided along the beam line in conjunction with exclusion zones constitutes sufficient shielding for electron energies of 3GeV and above. The photo neutron yield, which is essentially independent of electron energy, will remain essentially constant at higher energy, due to the maintenance of constant power in the beam by reducing the allowable beam current as the electron energy is increased. Thus, the concrete enclosure shielding the X-ray Storage Ring will remain appropriate as a neutron shield. Photons produced by higher energy electrons will however have a higher critical energy and there will be a requirement for lead shielding of certain parts of the beam line front ends where the total photon flux is present and where the chamber is not thick enough to attenuate the X-ray photons sufficiently. Table V gives estimates of the thickness of lead sheet required to adequately shield those regions where the X-ray photon beam may be scattered by devices placed or inserted into it for the beam currents and energies listed in Table IV.

Table V NSLS X-Ray Bending Magnet Scatter Calculations

6mrad horizontal and .8mrad full vertical beam size
Compton Scattering at 90° and 1m from Scatter Point
Estimated Dose values in millirads/hour into tissue (ICRU4)

		Ring Conditions	
Scatterers and Shielding	2.5GeV @ 500mA	2.8GeV @ 300mA	3.0Gev @ 240mA
10mil Be Window Scattering			
thru 20mil Stainless Bellows	480	1170	2610
+ 1/16" Pb Shielding	1.2E-03	1.7E-2	.13
+ 1/8" Pb Shielding	5.7E-06	1.3E-4	1.3E-3
+ 3/16" Pb Shielding	-	2.1E-6	2.4E-5
+ 1/4" Pb Shielding	-	-	5.3E-7
Si Monochromator Scattering			
thru 1/8" Stainless Tank	38	265	1310
+ 1/16" Pb Shielding	1.8E-2	.32	2.9
+ 1/8" Pb Shielding	1.5E-4	3.6E-3	3.9E-2
+ 3/16" Pb Shielding	-	6.9E-5	7.9E-4
+ 1/4" Pb Shielding	-	-	1.8E-5
NSLS Hutch (1/8" Steel) with			
White Beam onto Al Plate	42	290	1440
+ 1/16" Pb Shielding	1.9E-2	.34	3.1
+ 1/8" Pb Shielding	1.6E-4	3.9E-3	4.1E-2
+ 3/16" Pb Shielding	-	7.3E-5	8.3E-4
+ 1/4" Pb Shielding	-	-	1.9E-5

"White Beam Hutches" will also be a significant radiation source at the higher electron energies and will require 1/8" to 3/16" thick lead sheet lining added to the existing steel sheet in order to achieve the desired shielding. Insertion device beam lines will also require special attention from the point of view of scattered X-radiation.

Beam chamber heating, particularly for the X17 "wiggler" beam line, will have to be carefully evaluated before the beam power while operating the X-17 beam line can be increased to the values given in Table IV. In the interim, in order to protect the machine hardware, an administrative control limit of half the Table IV beam current figures has been established. This limit and all other relevant operating limits, are posted in the NSLS Control Room.

4.2.4 Bremsstrahlung Source Size for VUV and X-ray Beam Lines

4.2.4.1 Existing Source Size Evaluation

Section V of Appendix IV of BNL report# 51584 defined the source size to be utilized in determining beam line shielding. The source size has been carefully reevaluated by the NSLS ES&H committee and as a result, a new source size is defined.

4.2.4.2 Derivation of Model Radiation Source Sizes for Bremsstrahlung Radiation

4.2.4.2.1 Methodology

What follows is a description of a proposed method to formulate a model radiation source for bremsstrahlung shielding design. In addition to the procedure used to construct the source, some explanation of the situation and reasoning applied is also given.

At the NSLS, the storage ring accident scenario known as the "maximum credible radiation accident" defines the radiation source used in beamline shielding design. This is because the scenario results in the highest possible dose rate, and the source of maximum physical size.

The accident results when a thin target is formed in the storage ring vacuum chamber, at a location which directs γ radiation down a beamline. A meter length of air at atmospheric pressure, a fragment of a Be window, or a Ti flake, are examples of thin targets. The word *thin* denotes that the target dimension is small relative to the radiation length associated with the material. When high energy electrons interact with thin targets to produce γ-rays, the radiation is directed along the instantaneous trajectory of the electron, with an opening angle of $1/\gamma$ (where here γ is the relativistic gamma factor). In thick targets, by contrast, the emission pattern is broader, and the resultant shower of particles and γ-rays can extend beyond 90° from the initial electron trajectory.

During the accident, electrons are lost from stable orbits in the storage ring at the maximum dispersion points and at limiting apertures, due to energy loss in the target by γ-ray production, and through large-amplitude betatron oscillations from elastic coulomb scattering. These loss locations present thick targets, but as a consequence of the storage ring geometry, may not produce much radiation in beamlines, except perhaps 0° ports. As a result, most beamlines receive little radiation during the accident, except the beamline where the thin target is located.

At this location, the electrons are still in orbit, and in general, are not colliding with the storage ring vacuum chamber. However, due to the interaction of electrons with the target and the action of the RF system (which is still on), electrons will not be focussed into a small beam, but may be found throughout the chamber cross section, all around the ring.

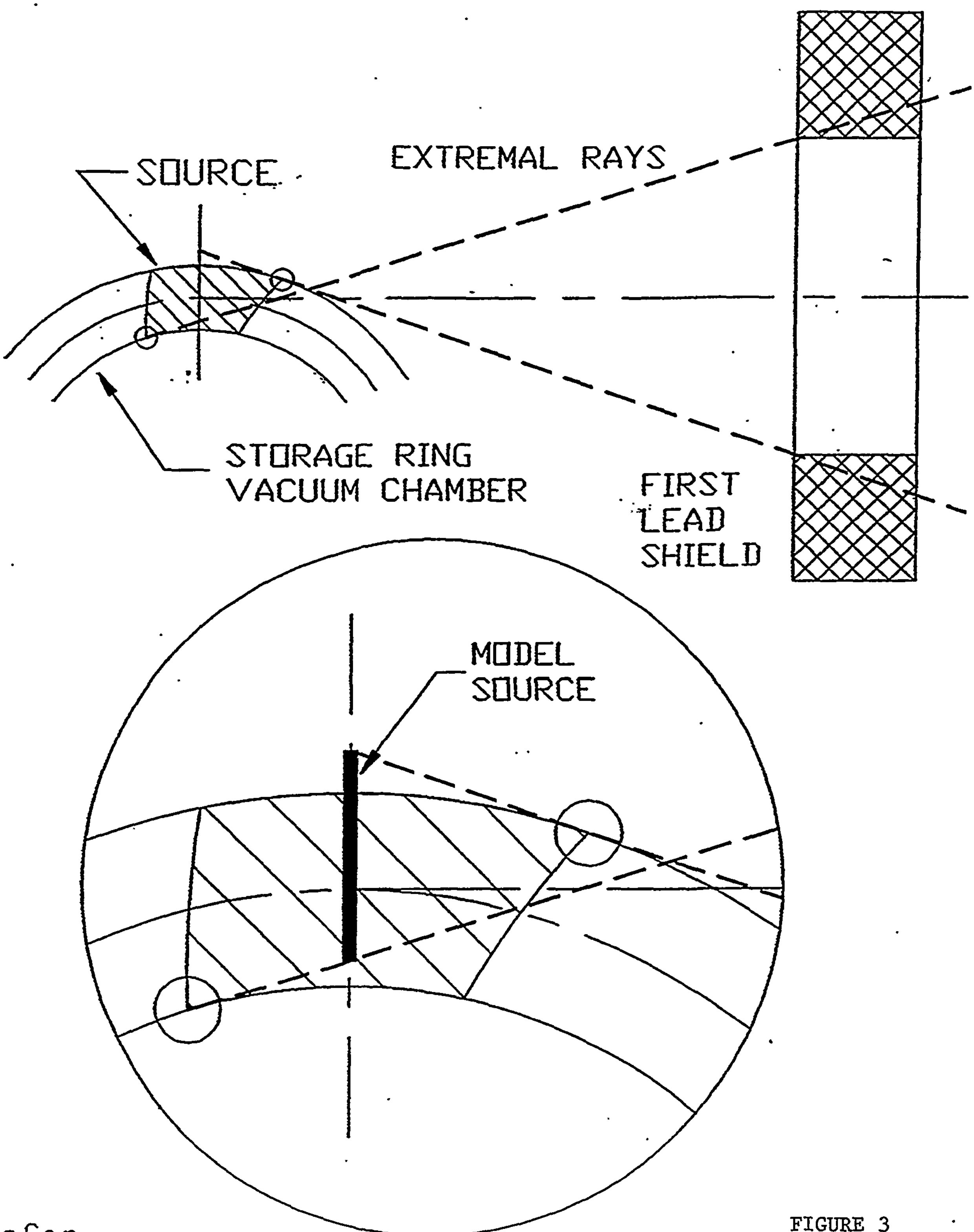
With this ground work, we can describe the source for bremsstrahlung γ-rays which appear in the beamline associated with the thin target. The source is the volume of the storage ring vacuum chamber where paths tangent to the instantaneous electron trajectory are directed through the first bremsstrahlung shield, i.e. the front-end safety shutter shield. (see Fig. 3) This source can be modeled by projection onto a standardized reference plane. The projection is then interpreted as an isotropic radiator through the first shield. This reproduces the original source, aside from a possible small discrepancy in the vertical.

To obtain a model source to be used universally at the NSLS for beamline design, the worst-case geometry should be examined; i.e. the front-end with the worst combination of large synchrotron radiation acceptance, and the first shield close to the source point. Results for four worst beamline cases are summarized below. The standardized reference plane is the source point for the port centerline for bend magnet ports, and the entrance to the downstream bend magnet for the case of 0° ports. The vertical source dimension is ±21mm, in all cases, while the inboard and outboard extents are given below:

Front End Type	Horizontal Model Source Extent (mm)	
	Inboard	Outboard
VUV, 22°	34.6	46.7
VUV U13, 0°	36.2	44.9
X-RAY X28, 10°	34.5	46.4
X-RAY X17, 0°	39.5	41.5

4.2.4.2.2 Bremsstrahlung Source Size for Beamline Shielding Design

The following model source size shall be adopted for beamline shielding design. The source shall have a vertical extent of +/- 21 mm, and a horizontal width of 40mm inboard and 50 mm outboard, measured from the ideal electron orbit. This source is applicable to all bend magnet and insertion device beam ports, on both the NSLS VUV and X-ray Storage Rings. The model source location is at the entrance to the downstream bend magnet, for insertion device ports, and at the source point for the port centerline, for bend magnet ports.



P.M. Stefan
93/2/28

FIGURE 3

This conservatively models the actual source in the maximum credible radiation accident for worst-case beam ports, while not placing unjustified burden on the beamline designer. The horizontal extent of 50 mm is required to correctly reproduce the behavior of the actual 3-dimensional thin-target source in a 2-dimensional model source.

During the maximum credible radiation accident, electrons are lost at the maximum dispersion points and at limiting apertures. None of these locations falls within the appropriate regions downstream of the model source. In contrast, a beam port may receive some radiation from an electron loss point located upstream of the model source location, and these points are generally accounted for in the proposed model source. A beam port will definitely receive bremsstrahlung radiation during the maximum credible accident if the thin target which promoted the event is located at the beam port. This situation is specifically accounted for in the proposal model source. From a thin target, bremsstrahlung radiation is directed along the original electron trajectory. The proposed source accurately models the worst-case, actual, 3-dimensional source region, for which electron orbits interact with the thin target and produce bremsstrahlung directed through the safety shutter shield.

The proposed source is based upon the worst-case geometries presented by existing beam ports. For the evaluation of future ports, which may come to represent a new worst-case, the geometrical factors are summarized below:

Electron beam vacuum chamber dimensions: 80 mm wide, 42 mm high
Ideal orbit location: center of vacuum chamber
Distance from model source to first bremsstrahlung shield:

VUV: 1700.0 mm
X-ray: 2800.0 mm

Maximum horizontal extent covered by opening(s) in the first bremsstrahlung shield (assumed to be centered about the port centerline):

VUV: 244.8 mm
X-ray: 201.3 mm

A new port is adequately represented by the proposal model source as long as the following relations hold:

$$VUV: \quad \frac{\frac{w}{2} + 50mm}{L} - 101.4\ mrad < 0$$

$$X\text{-}ray: \quad \frac{\frac{w}{2} + 50mm}{L} - 53.8\ mrad < 0$$

where:

w = maximum horizontal extent covered by opening(s) in the first bremsstrahlung shield, in mm (assumed to be centered about the port centerline).

L = distance from the model source location to the first bremsstrahlung shield, in mm.

5. Facility Upgrades

During the 10 years since the National Synchrotron Light Source was constructed, there have been numerous upgrades undertaken, in addition to the major work described in the Phase II SAR (2). These include the use of the Booster, operating at reduced energy, to inject into a model of an X-ray Lithography Storage Ring (which was the subject of a separate Safety Analysis Report) and a major upgrade of the fire detection and alarm system. There has been a considerable increase in the available floor space around the X-ray Storage Ring including the addition of sample preparation laboratories for Structural Biology and other X-ray users. A new Control Room adjacent to the old one has also been constructed. The plant equipment is housed in a new Mechanical Equipment Room and all new areas have been provided with climate control, fire detection and protection (sprinklers) and emergency lighting systems to match existing systems and conform with all applicable codes. The new floor plan is included in Figure 2. A radiation monitoring program using TLD's has provided data which has enabled upgrades to γ-ray and neutron shielding to be undertaken around the Linac, Booster, VUV and X-ray Storage Rings. Although operation at higher beam currents has been demonstrated in all parts of the facility over this operating period, the measured radiation levels around the facility have shown a steady decline. This is due to an active ALARA program which is aimed at achieving levels in all occupied areas to substantially below the 100 mrem annual dose allowed for non radiation workers. The work either in progress or planned is described in Section 5.2 below.

5.1 Radiation Monitoring Improvements

In order to understand radiation loss patterns around the facility for different operating conditions, it is necessary to utilize real time measurements of both γ-rays and neutrons. Initially, the data was gathered during special study periods when the areas around the facility could be secured and posted as radiation areas. From these studies, it has been determined that, as a general rule, loss patterns around the two Storage Rings are similar for both injection and stored beam conditions. However, the actual dose rates during the injection process are considerably higher than for stored beam, and the integrated dose over the course of a year is dominated by injection losses. Also the injection loss patterns are consistent with machine theory. The general pattern of radiation does not change a great deal for different operating conditions, although the magnitude of the radiation in a particular area can change by a factor of 5 under some unusual beam operating conditions during the injection process. From this knowledge of loss patterns, it has been possible to install real-time monitors connected to a personal computer which monitors loss patterns (both γ-rays and neutrons) at chosen locations around the facility and develop a more detailed history of dose in those regions over long periods (several months). This data was utilized in developing an upgraded shielding plan for the facility, as specified and prioritized by the NSLS ALARA Committee.

5.2 Shielding Improvements

5.2.1 Linac and Booster Synchrotron Shielding Improvements

The radiation studies described in Section 5.1 indicated that major electron beam losses during injection system operation occur at both points of maximum dispersion and where the Beta Function is largest in both the transport lines and the Booster ring. In addition, high electron losses occur during the beam injection and extraction process. Consequently, lead shielding has been added in specific locations along the transport lines and around the Booster straights. Studies are now under way to determine what shielding method is most appropriate to reduce the photo neutron dose in the second floor office areas adjacent to the Booster. It is estimated that photo neutrons could contribute up to 50% of the annual dose to persons working in that area. Once all of the survey data is available, appropriate neutron and/or gamma ray shielding will be installed around the Booster Ring.

5.2.2 Storage Ring Shielding Improvements

5.2.2.1 VUV Ring Shielding Upgrades

The TLD monitors placed around the VUV Storage Ring as area monitors have given a clear indication of beam loss locations around the facility. The special studies using hand held survey meters and "Chipmunk" radiation monitors has supplemented and corroborated the TLD data. Increased lead and concrete shielding has been introduced in appropriate regions of the Storage Ring to reduce the dose delivered to second floor offices. Loss studies show that a large part of the remaining γ-ray dose to the second floor office region results from losses at the end of the Booster-to-VUV transport line; a region which is difficult to shield. After further studies to determine that this is indeed the major source, a suitable shield will be designed. There are also studies underway to quantify the photo neutron dose and also the neutron spectrum in the second floor office area. Suitable shielding will then be introduced as necessary to achieve our ALARA goal.

5.2.2.2 X-ray Ring Shielding Upgrades

For operation at 2.5 GeV, 0.5A there are no significant radiation levels outside of the X-ray ring tunnel under stored beam conditions. However, during the injection process γ-ray levels of up to 5 mR/hour are present in a few normally-non-occupied areas adjacent to the injection line outside the x-ray ring tunnel. These areas are roped off and posted as radiation areas during x-ray ring injection. Shielding supports have been designed and are in the process of being installed so that extra shielding can be placed in these regions.

In order to accommodate studies of an X-ray lithography source, modification to the X-ray storage ring shield wall, interlock systems and securing procedures were necessary. These changes were reviewed and approved by the NSLS ES and H Committee, the BNL ES and H Committee and the Associate Director for Safety. Figures 2 and 10 of BNL Report #51584 were changed to those given in this document.

Section 5.3.2.3 of BNL Report #51584 deals with the "Dose Rate During Injection" into the X-ray Storage Ring. The following paragraph shall be added to that section in order to implement changes brought about by the new shielding configuration.

During X-ray injection, the radiation levels resulting from beam losses in the Booster X-ray transport line can create a radiation area with levels immediately adjacent to the entry door slightly in excess of 5 mrem/hr, under certain beam-loss conditions. The area adjacent to the door is clearly marked and posted as a radiation area during X-ray injection. Audible and visual warnings are provided in this area during X-ray injection. Area monitors will record the monthly dose in this area.

5.3 Procedure for Securing the X-ray Ring Tunnel Area

Section 5.3.3.2 of BNL Report #51584 shall be replaced by the following:

The x-ray tunnel is the most extensive of the high hazard radiation areas at the NSLS, and the search of this area must be done carefully by properly trained personnel. The control room operator on duty must always be aware of the status of the interlocks and in control of that status. All of this has implications for the search procedure and for the qualifications of those who carry it out.

X-RAY TUNNEL SEARCH PROCEDURE

1. Two people are required for a search. One of these must be either an operator or an operations coordinator, and the other must also be selected from the list of qualified searchers.

2. Permission for securing the x-ray tunnel must be given by the control room operator on duty.

3. The searchers should determine that all work in the tunnel has been completed, and cleanup work done. This often requires that a walk around be done before the search. Anyone in the tunnel should be asked to leave at this time.

4. The Kirk keys for "RF System Test Mode" must be in place in the x-ray security rack.

5. The actual search must be done without interruption, such as waiting for work in the tunnel to be completed, and without extraneous tasks, such as collecting and carrying objects out of the tunnel during the search. If an interruption occurs, the search should be dumped by pressing (and then resetting) an emergency stop button, and then starting the search over when the interruption has been dealt with.

6. Step-by-Step Search Procedure (See figure 4 for security system layout).

The search of the x-ray tunnel is started and completed at the door which separates the x-ray tunnel from the power supply area. The searchers enter the tunnel, closing the door behind them, and press check station CS-5 to start the search. This also illuminates the "DO NOT ENTER" signs over the door and places a guard on the door. If the door is opened before the searchers have completed their circuit and are ready to leave, the search will be dumped and will have to be started over. One searcher turns right and proceeds around the tunnel in a clockwise direction, while the other turns left and goes counterclockwise.

Each searcher presses the search button (CS-1 and CS-2) at the 90° point as they pass. The pilot light on each button remains on, indicating that the search relays are latching properly. The first searcher to reach the 180° point waits for the other searcher to arrive. One guards the tunnel while the other enters the emergency exit area, verifies that no one is there, and presses search button CS-3.

The searchers continue around the tunnel in their original directions, and from this point on they must insist that any person encountered must move ahead of them toward the tunnel entrance. When both searchers arrive back at the entrance door, they compare notes and verify that every person who has been seen in the tunnel is present and ready to leave.

When all are ready to exit, check station CS-5 is pressed providing a ten-second interval during which the exit door may be opened without tripping the interlock. When all are out, the door is closed and CS-4 is pressed and held. This button is not effective until the ten-second time-out is over, so the searchers must remain at the tunnel exit doors until the door guard is active again. At the conclusion of the ten-second exit interval, the interlock latches into the "Secure" state, and the warning interval starts.

The door key is removed and placed in the key switch at the security rack. This, in combination with the redundant interlocks on the x-ray tunnel allows permits to be sent to the x-ray magnet and RF power systems and to the injector.

5.4 Procedure for Controlled Access to the VUV Ring

5.4.1 Any Controlled Access to the VUV ring must be controlled by the person who is acting as Control Room Operator (CRO) at that time. Persons qualified for this position include the NSLS Machine Operators, and the NSLS Operations Coordinators.

5.4.2 Every entry and exit under a controlled access must be logged in the Control Room Operator's log in the following format:

VUV Ring Controlled Access

Time Start ____________ Ring Status ____________________ Time End ___________

Name	Time In	CRO	Time Out	CRO

Note: It is important that this format be used since it permits easy verification that everyone who has entered the ring has come out. The blank for "Time Out" should not be left empty; for example, if the interlock is dumped when people are on access, write "intl dumped" in the "Time Out" slot rather than leaving it blank. Names may be abbreviated so long as there is no ambiguity. The operator who controls the entry or exit should initial in the "CRO" column.

5.4.3 The maximum number of people inside on access at one time is five. In other words, there should never be more than five empty blanks in the "Time Out" column.

5.4.4 The people who enter the VUV ring area on controlled access must have had "VUV Ring Access Safety Orientation" and have signed off on it. A list of personnel qualified for access will be maintained in the control room. A person may become qualified for access by reading the safety orientation in Section 2 and signing it. If there is reason to take a visitor into the ring, this may be done by an escort who is qualified for access. The escort is responsible for the visitor's safety during the access.

5.4.5 The access process consists of the following steps:

5.4.5.1 The person(s) desiring access to the VUV ring make the request and give the name(s) to the Control Room Operator (CRO). This may be done ahead of time or when the party is ready to enter at the gate.

5.4.5.2 The CRO verifies that the proposed access is consistent with machine operation, then stamps the header in the logbook and enters the names.

5.4.5.3 The access party calls the control room using the gate intercom and informs that they are ready for access, and repeats the names.

5.4.5.4 The CRO switches the mode key to "Access" and verifies that there is satisfactory surveillance by TV and that the named people are at the gate.

5.4.5.5 The CRO holds down the "Gate Bypass" switch and informs the access party that they have permission to enter. The switch must be held until the gate is closed again as confirmed by the "gate closed" pilot light on the control panel, otherwise the interlock will be dumped.

5.4.5.6 The CRO enters the entry time for each person in the logbook and initials each entry. There must be an entry for each person since they may exit at different times.

5.4.5.7 When any person wishes to exit, they call the CRO on the intercom at the gate and request to exit. The CRO verifies on the TV, then holds the gate bypass and gives permission to exit, releasing the switch when the gate shows closed. The CRO puts the exit time in the log and initials it, thus closing out that person's entry/exit cycle. If that person goes in again, there must be a new line in the log record.

5.4.5.8 When all people are out, the CRO confirms that the log record of the access has been reconciled, then turns the key switch to "Normal" mode. The warning alarm will sound in the VUV area for 10 seconds.

5.4.6 Control Room Priorities

Servicing requests for entry or exit from the VUV area may be delayed if there is something more important going on in the control room, although requests for exit should be accommodated as soon as possible. However, once an entry or exit process has been initiated, that action must be completed, including the record in the logbook. The logbook entries are particularly important since decisions affecting personnel safety may be made based only on that record.

5.5 VUV Ring Access Safety Orientation

5.5.1 There are three primary considerations involved in ring access to the VUV when there is stored beam: radiation safety, electrical safety, and avoiding disturbance to the stored beam. These risks can be controlled at acceptable levels, but careful attention to procedures, and knowledge of storage ring systems is necessary.

5.5.1.2 Radiation

When there is stored beam in the ring, the radiation level in contact with the ring vacuum chamber in some locations can be higher than 100 mR per hour. Shielding inside the ring reduces the level to below 5 mR/hr in places where a person can stand, and in most places the radiation is much lower than that. The restrictions on work locations noted below will keep possible radiation exposures well below the 5 mRem/hour level. The total radiation caused by an accidental beam dump will also be below 5 mrem in the areas where access is allowed.

During injection into the ring the radiation levels can be as much as 10 times higher, and the hot spots may move around as adjustments are made on injection. For this reason, occupation of the VUV ring area is not permitted during injection, and the interlock system and procedures are designed to prevent this.

5.5.1.3 Electrical Safety

A notable electrical hazard in the ring is from the high current and high energy associated with the ring magnets. The bus work and connections for these magnets are covered to prevent contact, but these covers could be penetrated by plumbing tools used nearby, cables being pulled, or metal measuring tapes. The work rules listed below are designed to avoid these hazards.

5.5.1.4 Stored Beam Stability

Workers in the VUV ring must be aware that seemingly innocuous actions could dump or disturb the stored beam. These include changing the range on a vacuum or other gauge, creating electrical noise, or loading circuits. .

5.5.2 Rules and Restrictions on Activities in the VUV Ring During Controlled Access

5.5.2.1 Anyone inside the VUV ring on controlled access shall remain at least two feet away from the beam vacuum chamber. As a reference, the backs of the shielding buckets are between one and one-half and two feet from the chamber.

5.5.2.2 No task may be undertaken which requires work outside the boundary consisting of the ring of pipes and conduit which is below and inside of the magnet ring. This includes work in cable trays above and below the magnets.

Note: There may be tasks which violate these restrictions but can be done safely if proper precautions are taken. Such proposed tasks shall be approved by the NSLS Safety Officer or Safety Engineer. Technical review and/or written procedure may also be required.

5.5.2.3 Any person working in the VUV ring on controlled access is responsible for getting information about the effect of the proposed work on stored beam stability.

5.5.3 Certification:

I certify that I have read and understand the document "Procedure for Controlled Access to the VUV Ring." This includes section 1 on procedure, and section 2 on VUV Ring Access Safety Orientation. I agree to abide by the procedures, rules, and restrictions therein.

Name ____

Signature ______________________________ Date ______________

Recorded by ______________

5.6 Procedure for Bypassing the Booster, VUV and X-ray Rings Security Systems for Power Supply Testing

5.6.1 Only trained qualified individuals may carry out these procedures.

5.6.2 The magnet power supplies for the booster, VUV and X-ray rings are interlocked to the ring security systems, and normally the respective rings must be searched and served in order for the supplies to be turned on. There are occasions when a supply must be turned on for test or trouble shooting while the ring interlock is not secured. Therefore a Kirk key interlock has been provided which will bypass *only* that circuitry in the security system which provides the power supply interlock thus allowing entry to the normally secured area while the power supplies are energized. In order to operate in this mode the following procedure shall be followed:

5.6.3 The testing team shall contact the control room operator to gain permission to execute an interlock by-pass and an entry shall be made in the control room log book.

5.6.4 All work on power supplies shall be in accordance with electrical safety rules in the BNL ES and H Standard 1.5.0, the NSLS SEAPPM Section 1.5.0 and the procedures defined in the NSLS Maintenance Management Program. This includes personnel qualification, working hot permits, and approvals.

5.6.5 A minimum of three persons shall be involved in the tests one of whom shall guard the entry door to prevent unauthorized entry into the area, a second shall act as an observer to ensure that the third person, carrrying out the tests, does not come into contact with a live bus.

5.6.6 At the conclusion of the test the kirk key shall be returned to its home position on the security rack and an entry made in the control room log book verifying that the test is complete and the system has been returned to normal.

6. Summary

This document represents the current operational status and facility condition of the National Synchrotron Light Source Facility. Future operations may require an update to this document which is expressly designed to ease that process. It and any future changes made require review by Laboratory and NSLS Environmental Safety and Health Committees and approval by BNL and NSLS Management. Operational Policies, Safety Limits and Facility Upgrades given herein supersede those presented in earlier documents.

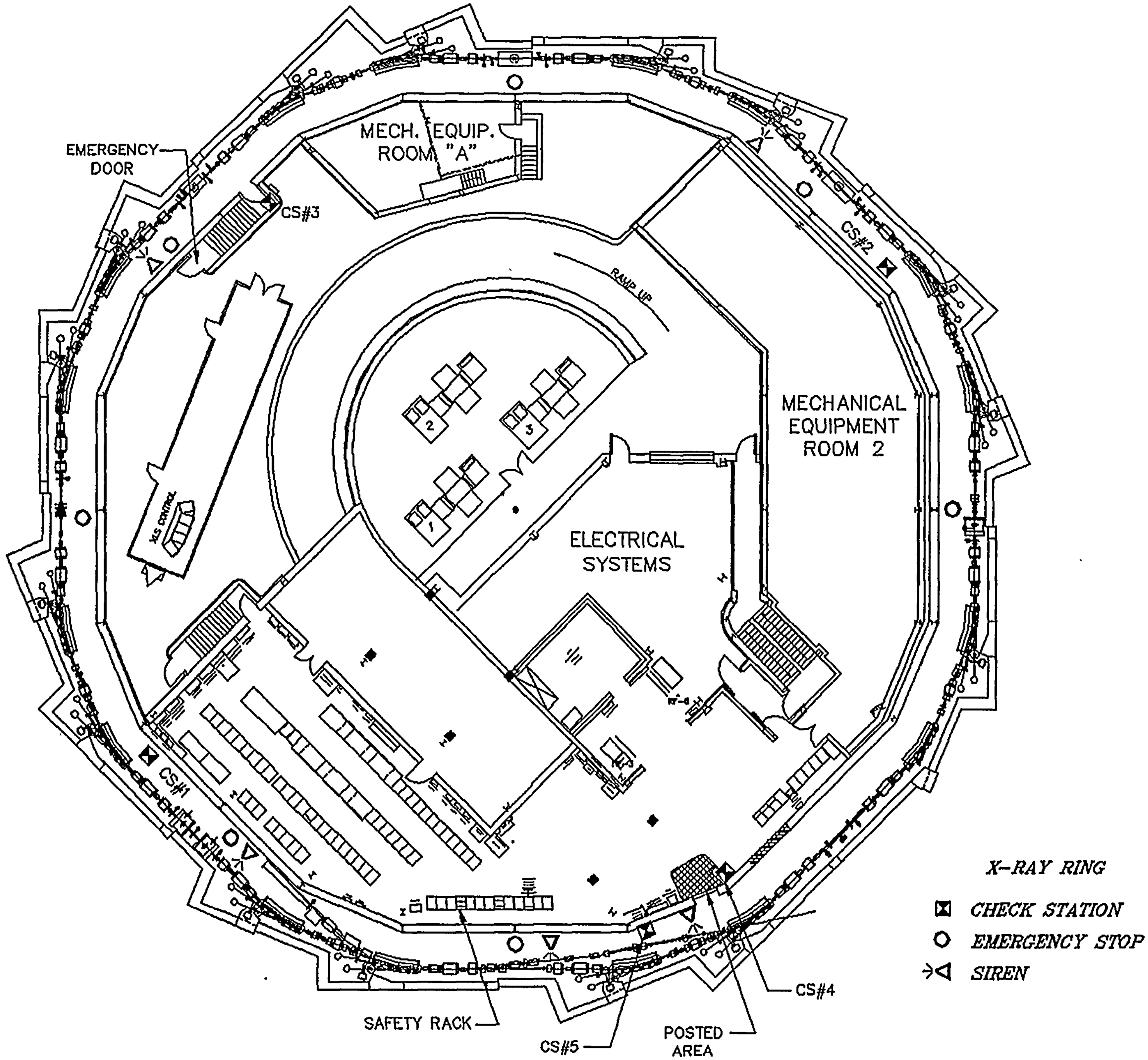


Figure 4. X-ray security system

References

(1) National Synchrotron Light Source Safety Analysis Report, by K. Batchelor, BNL Report #51584, July 1982
(2) Phase II Safety Analysis Report National Synchrotron Light Source by P. Stefan, BNL Report #52205, June 1989
(3) Safety Analysis Report X17B2 Beamline, Synchrotron Medical Research Facility by N. Gmur and W. Thomlinson, BNL Report #52205 (Addendum), February 1990.
(4) Conduct of Operation, National Synchrotron Light Source by N. Fewell, BNL Report #44403, December 1992