SAFETY ASSESSMENT DOCUMENT

National Synchrotron Light Source
Building 725

Date: August 14, 2006

This SAD replaces:

(1) NSLS Upgraded Safety Analysis Document Including Operations Policies, Operational Safety Limits and Policy Changes, March 1996, BNL 49214-Rev. 2
(2) Phase II NSLS Safety Analysis Report, June 1989, BNL 52205
(3) NSLS Safety Analysis Report, July 1982, BNL 51584
(4) Change in Dosimetry Policy for Access to the Controlled Areas of Bldg. 725 (NSLS Experimental Floor) – Elimination of Regulatory Requirement to Wear TLD When in the Controlled Area. September 2003

8/18/2006

W. Robert Casey, NSLS Associate Chair for ESH&Q — **Date**

Aug. 18, 2006

Nicholas F. Gmür, for NSLS ES&H Committee — **Date**

Aug. 18, 2006

Chi-Chang Kao, NSLS Interim Chairman — **Date**

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Revision Log

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1. INTRODUCTION

1.1 Motivation

Since 1982, the National Synchrotron Light Source has served as a resource for the production of synchrotron radiation and as a focus for the multidisciplinary scientific community that utilizes its capabilities for their research. Existing facility authorization documents include two Safety Analysis Reports (1982 and 1989) and an Upgraded Safety Analysis Document (1996). Since then, DOE has updated its requirements for writing a Safety Assessment Document (see DOE Order 420.2), as reflected in the BNL SBMS Accelerator Safety Subject Area. This current NSLS Safety Assessment Document has been written to reflect those new requirements. The 2001 NSLS Accelerator Safety Envelope already meets these requirements.

1.2 Description of the Facility

The National Synchrotron Light Source (NSLS) is a large user facility dedicated to the production and utilization of synchrotron radiation. It supports the development of electron-based radiation sources and new applications of this radiation in the physical and biological sciences. The NSLS began operation in 1982. It consists of two electron storage rings and the associated injection system composed of a linear accelerator and a booster synchrotron. The X-ray ring currently operates at 2.8 GeV and 300 mA with lifetimes of ~20 hours. The vacuum ultraviolet (VUV) ring currently operates at 800 MeV, 1000 mA, and lifetimes of ~4 hours. The NSLS operates an extensive user program built around facility and Participating Research Team (PRT) photon beamlines on the VUV and X-ray storage rings. Typically, the NSLS annually supports 2300 users from ~400 university, government laboratory, and industry institutions conducting over 1100 experiments. Users may conduct research at the NSLS free of charge providing their results are published in the peer review literature. Proprietary research is also allowed in which case the user pays a per-shift fee. As of April 2005 there were 49 operational beamlines on the X-ray ring covering the hard and soft X-ray energy regions, and 16 operational beamlines on the VUV ring covering the ultraviolet and infrared energy regions. There are extensive development programs to improve the stability, reliability, and lifetime of electron beams, and to develop new insertion devices modulating polarization state and producing even brighter photon beams. Approximately 5500 hours of beam are delivered per year to the users on the X-ray ring and to the users on the VUV ring. Equally important are programs to develop new beamline instrumentation including beamline optics, monochromators, and detectors that will permit users to take full advantage of the unique research capabilities offered by the NSLS. Operation of the NSLS is funded by the U.S. Department of Energy, Basic Energy Sciences, with additional support for its structural molecular biology program from the National Institutes of Health.

1.3 Environment, Worker and Public Safety

The NSLS is subject to the requirements of the DOE Accelerator Safety Order, DOE O 420.2 or its successors. These requirements are promulgated in BNL's Accelerator Safety Subject Area. The NSLS presents potential for minor on-site and negligible off-site impacts to people and the environment. The possibility of any off-site impacts or major on-site impacts is highly unlikely due to the physical aspects of the NSLS whereby the primary hazard is prompt ionizing radiation that is limited to regions where the beam is maintained and is in existence only when a beam is present.

The NSLS programs incorporate the DOE's Integrated Safety Management System as the basis for operating the facility and protecting workers, users and visitors to the facility. The NSLS ESH Policies and Requirements Manual together with the BNL Subject Areas establish the requirements and provide the guidance to assure proper implementation of the ISM core functions and the guiding principles. Identification and control of hazards for work and research activities is defined through the Work Planning and Control Procedure, and Experiment Safety Review.

Workers and experimenters at the NSLS work in or near radiological areas. The rules in 10CFR835 establish radiation protection standards, limits and program requirements for protecting individuals from ionizing radiation resulting from the conduct of DOE activities. These requirements are promulgated in BNL's Radiological Control Manual.

Brookhaven National Laboratory's Environmental, Safety, Security and Health Policy is the foundation on which the NSLS manages significant environmental aspects, worker safety and its relations with stakeholders and the community. The formal management programs are the BNL Environmental Management System (EMS) for which the NSLS has developed its own internal EMS Manual and the BNL Occupational Health and Safety Assessment Series (OHSAS) for which the NSLS has developed its own internal OHSAS Manual. BNL has been granted a Certificate of Registration under ISO 14001; NSLS is part of that EMS registration. NSLS has obtained registration under the OHSAS 18001 program. In addition, DOE has approved a Finding of No Significant Impact (FONSI) for the Environmental Assessment: Proposed Upgrade and Improvement of the National Synchrotron Light Source Complex at Brookhaven National Laboratory, Upton, NY.

An Accelerator Safety Envelope that defines the operating requirements for the facility has been prepared for the NSLS. It is a separate document from this SAD and has been approved by the Department of Energy, Brookhaven Site Office.

2. SUMMARY/CONCLUSIONS

2.1 Overview of the Results and Conclusions of the Analysis

This updated Safety Assessment Document (SAD) did not identify any new hazards or require additional controls from those previously discussed in the earlier safety assessment documents. The following summary statements can be drawn from this analysis.

1. The operation of the NSLS does not pose significant risk to the environment:

    - Existing and projected hazards to the environment are described in the NSLS Environmental Assessment and a Finding of No Significant Impact has been issued.
    - Environmental impacts due to NSLS operations and activities are reviewed through the ISO 14001 Environmental Management System. Periodic audits assure that this program is maintained at a high level.
    - A National Emissions Standards for Hazardous Air Pollutant evaluation determined that dose/risk to the members of the public was minimal.
    - Regulated industrial, hazardous, radioactive, mixed and regulated medical wastes are managed and where possible minimized by the facility through a variety of controls.
    - Effluents, with the exception of roof drains, cooling-tower blow down, and parking lot drains (which drain to recharge basins), are disposed of through the sanitary waste stream and controlled through work and experimental planning. Tritium production is calculated and analyzed to be well below the BNL action level.
    - Many waste materials are recycled, thus reducing the overall waste stream.

2. The level of fire protection is classified as “improved risk”, thereby meeting the objectives of DOE Order 420.1. The NSLS is protected by a fire sprinkler system and smoke detection which are tied in to the BNL site wide fire alarm system.

3. The NSLS was determined to be built to the appropriate national consensus codes and standards at the time of its construction as per the 1994 DOE Accelerator Order 5480.25 Implementation Plan for BNL Natural Phenomena Hazards Evaluation.

4. Electrical hazards are minimized by adhering to BNL and NSLS procedures as well as NFPA 70E standards. Programs are underway to assure that electrical equipment is reviewed and approved by either a Nationally Recognized Testing Laboratory or by an Authority Having Jurisdiction. Interlocks and lockout/tagout are used to maintain personnel safety.

5. Oxygen deficiency hazards are managed by a system of oxygen sensors, alarms, interlocks and signs to control and minimize risks to personnel.

6. The NSLS has a limited number of confined spaces, some of which are accessed uniquely by Plant Engineering (EP). These areas are well posted and access is controlled either by procedure or work planning.

7. Experimental materials are reviewed through the NSLS Safety Approval Form as well as enhanced reviews by members of the NSLS ESH Committee as warranted. Quantities of chemicals and materials are minimized and less hazardous substitutes required where possible.

8. Production of ozone by the white synchrotron beam is either eliminated or minimized by controls imposed through beamline or experimental reviews.

9. When accelerator and beamline vacuum faults are detected, interlock systems automatically close sector and beamline valves to minimize the spread of the fault, and dump RF as required. Water flow and temperature faults are similarly sensed and interlock systems close valves, dump RF or dump power supplies as appropriate. Loss of compressed air systems will initiate alarms alerting control room staff to take appropriate action.

10. Non-ionizing radiation (RF, microwave, magnetic, laser and visible) hazards are characterized and documented as appropriate based on BNL and NSLS procedures in order to minimize or eliminate their impact on personnel. Interlocks are used for personnel safety for certain applications.

11. The NSLS produces synchrotron radiation for research purposes. Bunches of electrons are generated by an electron gun. The electron bunches are accelerated by a linear accelerator and a booster synchrotron. The electron bunches are injected into the X-ray and Vacuum Ultraviolet (VUV) storage rings where the electrons are further accelerated and synchrotron radiation is produced at infrared, visible, ultraviolet and x-ray energies (gamma ray energies are achieved at the Laser Electron Gamma Source X5 beamline). Management of these systems is through Control Room personnel, the Operations & Engineering Division and the Accelerator Division. Delivery of synchrotron radiation to the researchers is via the beamlines. Management of the beamlines is through a combination of beamline Participating Research Teams, the Beamline Review Committee, Experiment Safety Approval Forms and Control Room personnel. Interlocks are used for radiation protection of personnel.
    - Radiation shielding primarily in the form of concrete or lead and in some instances borated polyethylene is positioned to maintain radiation to personnel as low as reasonably achievable. Configuration control is maintained through the use of Authorization for Work on NSLS Accelerator/Beamline Safety System forms.
    - Radiation is monitored through the use of personal and area TLDs as well as real-time “chipmunk” and hand-held radiation monitors to assure conditions are ALARA. In-house Radiological Control Division staff assists in the management of radiological conditions and develop Radiation Work Permits when necessary as

a result of experimental or work review. In addition, radiation safety interlocks are tested on a regular schedule to insure integrity.

- Air, soil and water activation have been calculated and are well below BNL action levels. Equipment activation levels are low, but would preclude disposal as recycled material unless sufficient decay-in-storage time had been allowed.
- Radiation Generating Devices operate within the NSLS and are managed through the BNL RGD program which includes periodic interlock checks and radiation surveys.

The organizational structure of the National Synchrotron Light Source and the documentation of responsibilities and procedures for safety related actions assure safe operation of the accelerator, experimental and related areas. Controls for routine operations and emergencies are located in the NSLS Control Room. The Control Room is staffed continuously by a Machine Operator and Operations Coordinators during operations. Procedures for routine operations and emergencies are maintained in the Control Room Accelerator Manual and Operations Procedures, and related documents. These procedures are controlled documents.

Specific operations controls prevent or mitigate beam loss events in order to maintain dose to personnel as low as reasonably achievable (ALARA) and in order to protect facility equipment. An additional benefit to these controls is to provide stable, high quality beam to researchers. Procedures and controls that prevent or mitigate beam loss and maintain radiological conditions ALARA include the Accelerator Safety Envelope, real-time "chipmunk" radiation monitors, area and personal TLDs, pre-operations sweep procedures, access-control (interlock) devices, Control Room beam loss procedures, lock-out/tag-out procedures, experimental and radiation safety check-off lists, work planning procedures, and radiological training.

The risk is determined to be low for contamination of the environment, release of wastes, loss of vacuum & cooling water & compressed air. The risk of injuries is determined to be low or routine for fire, natural phenomena, electrical, cryogenic and oxygen deficiency, confined spaces, chemical and other experimental materials, ozone, material handling, noise, non-ionizing radiation and ionizing radiation.

2.2 Comprehensiveness of the Safety Analysis

The NSLS Safety Assessment Document (SAD) covers Building 725 accelerators, beamlines, and associated systems. The SAD meets the requirements set out in the SBMS Accelerator Safety Subject Area which in turn meets the requirements of DOE Order 420.2, Safety of Accelerator Facilities. The departmental and ESH organizational structures for the operation of the NSLS facility are provided.

Occupational health and safety hazards, and environmental aspects of the facility are identified and controls described. A Fire Protection Assessment / Fire Hazard Analysis is presented. Access to the facility is controlled. No previously unreviewed safety issues were identified in the preparation of this updated SAD.

Radiological occupational exposures are maintained ALARA for existing and planned facilities within the NSLS. Shielding configuration and maintenance of that configuration are described. Calculations are provided to present a conservative view of dosimetry for the NSLS accelerator and beamline systems. Personal and area dosimetry (TLD) results are presented.

2.3 Appropriateness of the Accelerator Safety Envelope

An NSLS Accelerator Safety Envelope (ASE) was developed in accordance with the requirements set forth in the SBMS Accelerator Safety Subject Area. The ASE establishes limits and envelopes within which the NSLS and its personnel shall safely operate based on the hazards, controls and risks described in Chapter 4 of the NSLS SAD. No revisions to the current ASE are suggested on the basis of the revised SAD.

3. DESCRIPTION OF SITE, FACILITY AND OPERATIONS

3.1 Characterization of the NSLS Site Location

Sections 3.1.1 through 3.1.10 below are excerpted from Section 4 of the NSLS Environmental Assessment.

3.1.1 Site Description

The BNL site occupies 21.3 sq-kms (5265 acres). Most principal facilities are located near its center. The developed area is approximately 6.7 sq-kms (1,656 acres), of which about 2.02 sq-kms (500 acres) were originally developed by the Army (as part of Camp Upton), and about 0.81 sq-kms (200 acres) are occupied by various large specialized research facilities. Outlying facilities occupy about 2.22 sq-kms (549 acres); these include the Sewage Treatment Plant (STP), agricultural research fields, housing, and fire breaks. The balance of the site (14.6 sq-kms or 3,607 acres) is largely wooded.

3.1.2 Land Use and Demography

Approximately 8,000 persons live within one-half kilometer (0.3 mile) of the Laboratory's boundary. Although much of the land area within a 16-kilometer (9.9 mile) radius is either forested or cultivated, there has been an increase in residential housing in recent years, a trend that is expected to continue.

3.1.3 Geology and Soils

Long Island was formed by two east-west trending glacial moraines, which were deposited during two separate Pleistocene glaciation events. Hence, the general surface geology of the region consists of deposited glacial sands and gravels. These deposits, which range from 20 to 38 meters deep (65 - 125 feet), lie on the Magothy formation, a unit of unconsolidated sands and clays of Late Cretaceous age. The soils at BNL are predominantly coarse, sandy soils derived largely from glacial outwash materials including the Ronkonkoma moraine. The soils show distinct layering. Coarse gravel often is overlain by finer material. Surface deposits, which vary in texture, range from coarse Duke's sand in the north and east, to finer Sassafras sandy loam in the southwest. The soil types on site, in order of increasing coarseness, are Sassafras loam, Sassafras fine sandy loam, Sassafras sandy loam, Plymouth sand loam, Duke's loamy sand, Plymouth sand, and Duke's sand. Babylon sand and meadows soil are associated with wet sites (ERDA 1977).

3.1.4 Surface Water

The BNL site terrain is gently rolling, with elevations varying between 13 and 37 meters (44 - 120 feet) above sea level. The land lies within the headwaters region of the Peconic River watershed. Wetland areas in the north and eastern section of the site formerly were principal tributaries of the Peconic River. The Peconic River both recharges to, and receives water from, the groundwater aquifer depending on the hydrological potential. Thus, the river is classified as having intermittent flow on-site. The Peconic River on-site recharges to groundwater, and in most years, leaves no measurable continuous flow at the site boundary. Liquid effluents from the BNL Sewage Treatment Plant (STP) constitute the only continual source of surface water in the tributary's riverbed. These liquid effluents also recharge to groundwater before leaving the site boundary. Combined industrial and sanitary wastewater discharged from the STP receives tertiary treatment and conforms to the criteria in the STP's approved State Pollutant Discharge Elimination System (SPDES) permit issued by the New York State Department of Environmental Conservation (NYSDEC).

3.1.5 Groundwater

The BNL site was identified by the Long Island Regional Planning Board and Suffolk County as being over a deep-flow recharge zone for Long Island [Koppleman, 1978]. This finding indicates that precipitation and surface water that recharge within this zone have the potential to replenish the lower aquifer systems lying below the Upper Glacial Aquifer. Up to two-fifths of the recharge from rainfall is estimated to move into the deeper aquifers. The extent to which groundwater at the BNL site contributes to deep flow recharge was confirmed using an extensive network of shallow and deep wells installed at BNL and surrounding areas [Geraghty and Miller, 1996]. In coastal areas, these lower aquifers discharge to the Atlantic Ocean and to the Long Island Sound.

3.1.6 Climate

The climate at the laboratory can be characterized as breezy and well ventilated, like most of the eastern seaboard. The prevailing ground-level winds are from the southwest during the summer, from the northwest during the winter, and about equal from these two directions during the spring and fall [Nagle, 1975; 1978]. The total precipitation for 1999 was 131 centimeters (51.7 inches), which is about 8.6 centimeters (3.4 inches) above the 50-year annual average. The monthly mean temperature in 1999 was 11.5^{o} C (52.7^{o} F), ranging from a monthly mean low temperature of 0.11^{o} C (32.2^{o} F) in January, to a monthly mean high temperature of 24.6^{o} C (76.3^{o} F) in July.

3.1.7 Air Quality

The overall regional air quality is a mix of maritime and continental influences from the Atlantic Ocean, Long Island Sound, and the various associated bays; this results in the region, and the BNL site, being very well ventilated by winds from all directions. The local air quality management in the New Jersey-New York-Connecticut Interstate Air Quality Control Region, which includes Suffolk County and BNL, is in attainment with most National Ambient Air Quality Standards (NAAQS) for criteria pollutants, which include sulfur dioxide, nitrogen oxides, particulate matter, lead, and carbon monoxide. The BNL Central Steam Facility is the only facility required to continually monitor non-radiological air emissions.

3.1.8 Terrestrial Biota

The Laboratory is located in a section of the historically classified Oak/Chestnut forest region of the Coastal Plain. The BNL property constitutes five percent of the 404.7 sq-km (100,000 acre) Pine Barrens on Long Island. Because there are few fires and other disturbances, the vegetation in the Pine Barrens tends to follow moisture gradients. Much of the vegetation at BNL is in various stages of succession, reflecting the history of disturbances associated with the Laboratory and its predecessor Camp Upton that included land clearing, fires, localized flooding, and drainage projects. Fifteen mammalian species are endemic to the site, including those common to mixed hardwood forest and open grassland habitats. At least 85 species of birds are common to BNL and 216 species have been identified on-site since 1948. Nine amphibian and ten reptilian species have been identified. Permanently flooded retention basins and other waters support amphibians and aquatic reptiles.

3.1.9 Wetlands

Because of the topography and porous soil, there is little surface run-off and little open water at BNL. Upland soils tend to be very well drained, while seasonally, depressions form small pocket wetlands with standing water. There are six major regulated wetlands providing a mosaic of wet and dry areas correlated to topography and depth to the water table. Nine species of fish inhabit wetland areas, including the banded sunfish (*Enneacanthus obesus*) and the swamp darter (*Etheostoma fusiforme*), both New York State threatened species.

3.1.10 Natural Hazards

Natural phenomena, which could lead to operational emergencies at BNL, include hurricanes, tornadoes, lightning, rain storms and associated flooding, snowstorms, and ice storms [BNL Site Emergency Plan]. Hurricanes occasionally hit Long Island and the high wind speeds associated with them are most likely to damage structures. Record high winds for BNL were recorded during Hurricane Carol in September 1954 [Hoey, 1994]. Tornadoes and hailstorms are extremely rare on Long Island. Thunder, rain, snow, and ice storms do occasionally occur, and have the potential to cause significant damage. Flooding at the NSLS could increase the potential for electrical hazards. Depending on the extent of the flooding, in area and in height, there is some potential for chemical and lead contamination of the water. There would be no potential for radiological contamination of that flood water. The probable occurrence of an earthquake sufficiently intense (>5.6 on the Richter scale) to damage buildings, accelerators, and reactor structures in the BNL area was thoroughly investigated during planning constructing the Brookhaven Graphite Research Reactor (BGRR), High Flux Beam Reactor (HFBR), and Relativistic Heavy Ion Collider (RHIC) [Pepper, 1992]. Seismologists expect no significant earthquakes in the foreseeable future. No active earthquake-producing faults are known in the Long Island area [Hoey, 1994].

3.2 Conventional Facilities

3.2.1 Building 725

The NSLS Facility is located in the eastern region of the BNL site **(Figure 1)**. Ground was broken in 1979 for construction and first beam was delivered in 1982. The configuration of the building today **(Figures 2, 3 and 4)** is the result of a series of upgrades over the years. The NSLS Facility currently has two stories. The first floor

(123,644 sq. ft.) consists largely of the experimental floor and support equipment, and is constructed below grade. This includes the Linac, Booster synchrotron, VUV ring, X-Ray ring, beamlines, operational control and power systems,

Figure 1. Aerial view of Brookhaven National Laboratory

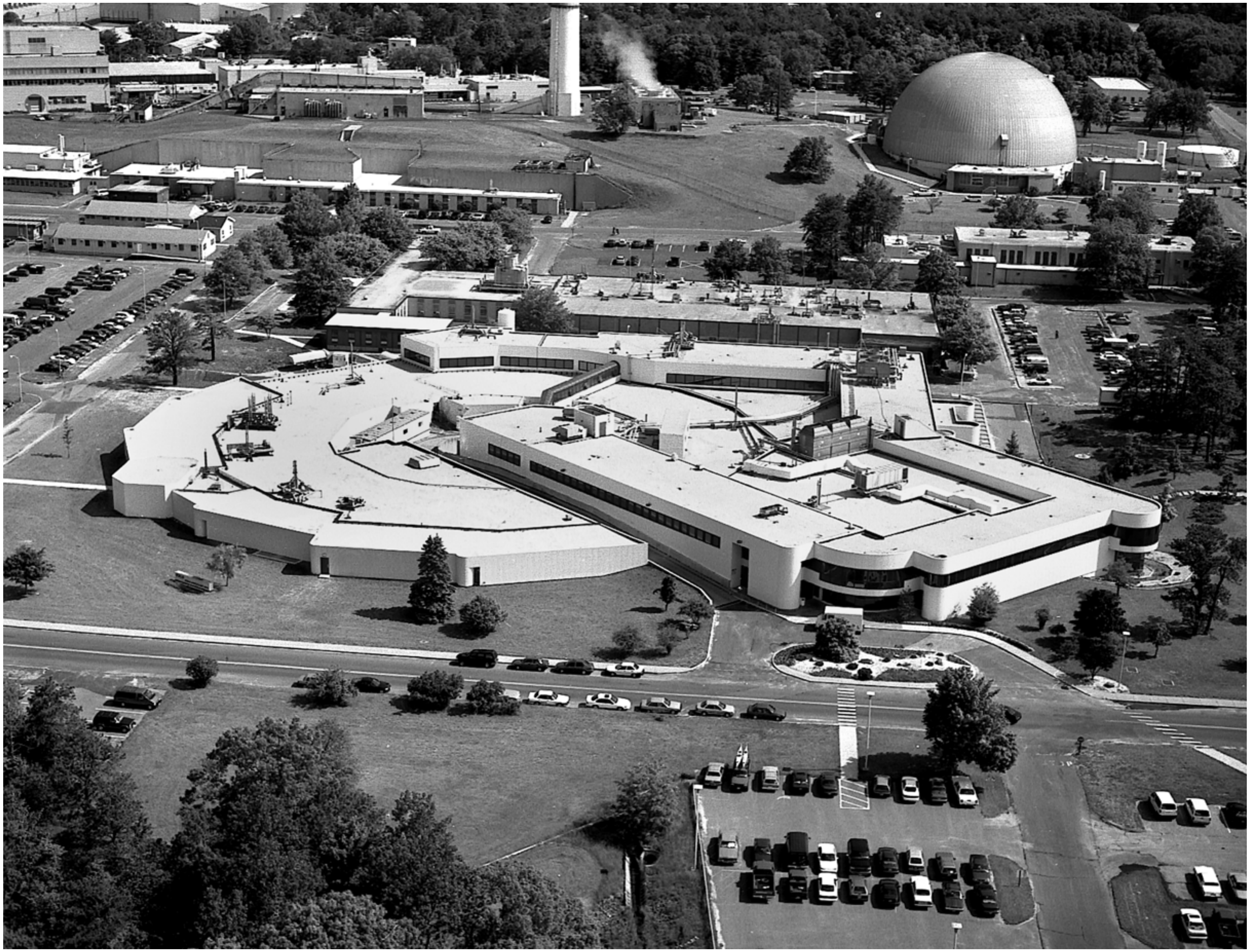

Figure 2. Aerial view of the National Synchrotron Light Source, Building 725.

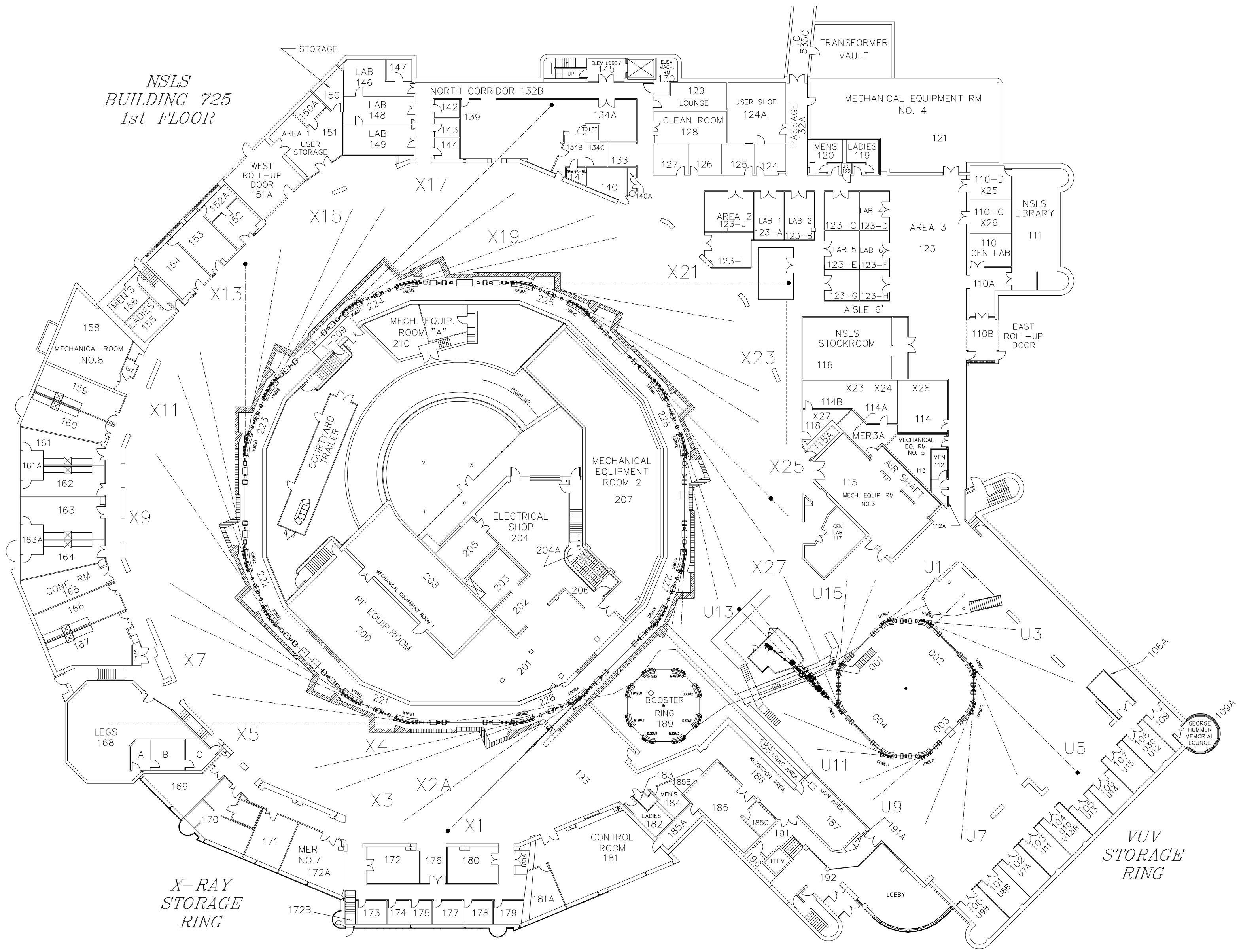

Figure 3. National Synchrotron Light Source experimental floor, Building 725.

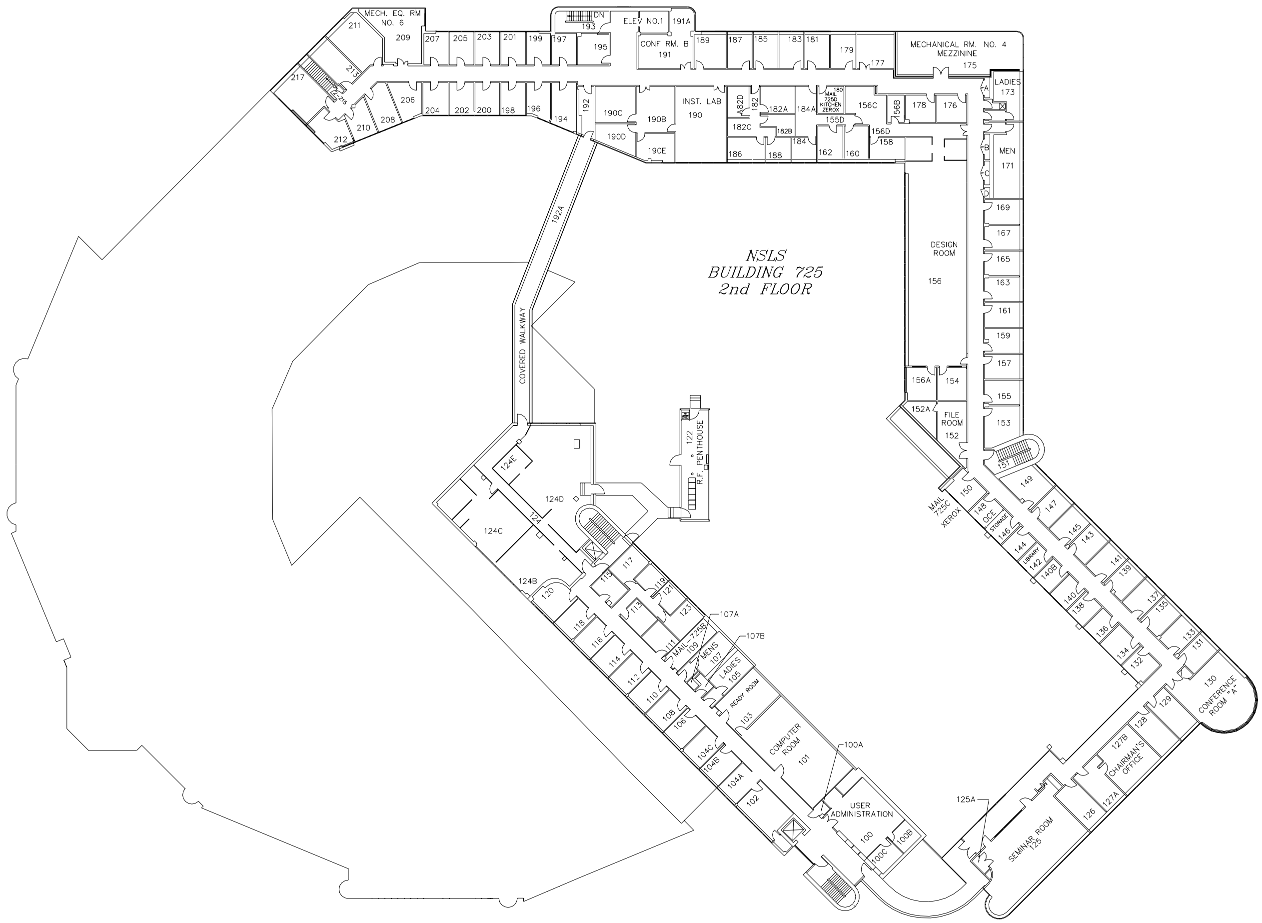

Figure 4. National Synchrotron Light Source second floor offices, Building 725.

laboratories, offices, machine shops, storage and setup areas, stockroom and delivery areas, and library. The stockroom and VUV floor are serviced by a total of three 4,000 lb. capacity overhead bridge & trolley cranes, and the Booster ring is serviced by a 2,000 lb. capacity jib crane. The second floor (38,512 sq. ft.) consists largely of office space and conference rooms as well as machine shops. Both floors have a number of mechanical equipment rooms.

Similar construction has been used in each upgrade. The floor is poured concrete. Exterior walls are insulated metal panels. The panels are UL listed under the large-scale room corner test and do not require sprinkler protection (considered non-combustible). The roof is an insulated metal deck, originally a Factory Mutual Class I built-up tar roof system. Recent roof replacements have been fully nailed to the deck (also considered non-combustible). Exposed metal frames support the structure, except in the perimeter. The perimeter of the facility has a two-story office mezzanine constructed of poured concrete on metal deck. With the anticipation of a third floor in the original design, the office area's steel work has a 2-hour fire rating.

The building is designed to be in compliance with the Life Safety Code, NFPA 101 and with BNL ES&H Standard 4.1.2, "Means-Of-Egress (Exits)", for fully sprinklered, industrial occupancy. The occupancy load within the building is >100 sq. ft./person. Building exterior access and egress doors are indicated in **Figure 5**. Three roll-up door areas are available for large equipment. Standard outdoor lighting and concrete walkways are provided for exterior doors. BNL ID card readers enable experimental floor doors 24 hours/day and also enable exterior doors during off-hours. Exits are marked with appropriate signs. Emergency lighting is provided throughout the building through an emergency power generator (see Section 3.2.2 below). The building is protected with a combination of automatic sprinklers, automatic heat and smoke detectors, and manual fire alarm pull stations. Smoke detectors are provided in the air handling system in compliance with NFPA 90A. Alarms and supervisory points are connected to the BNL Fire Rescue Group annunciators.

Combustible loading within the building is light. Equipment within the building contains combustible wire insulation as well as interconnecting power and signal cables. This is an acceptable risk given the presence of automatic sprinkler protection in the facility and the open configuration of the cable trays. Klystron insulating oil (typically 30-40 gallons per klystron, monitored for PCBs as needed, no Suffolk County Article 12 registration required) and capacitor oil are within metal containers, and protected by ceiling level sprinkler systems. Quantities of combustible gases or fluids and hazardous materials or samples are kept to a minimum and controlled through work planning and experiment review (the X5 beamline maintains a quantity of hydrogen gas). In some locations, borated polyethylene is used for shielding. Although the borated polyethylene is not "fire retardant", the quantities are limited to small shielding areas away from ignition sources. The risk is minimal and acceptable for sprinklered occupancies. A detailed Fire Protection Assessment/Fire Hazard Analysis report, generated by the BNL Fire Protection personnel, is available.

3.2.2 Electrical Power

Electrical Power

The electrical power for the National Synchrotron Light Source (NSLS) originates from a 13.8kV incoming service and is distributed to four substations located on the premises of the NSLS. The four substations reduce the incoming voltage to a 480 volt, 3-phase system with a grounded wye at the substation. The power is then distributed at 480 volts, 3-phase via substation breakers to numerous 480V distribution panels. The 120/208 volt system is derived by way of transformers and distributed to electrical panels and loads. Examples of loads on this system include; building lighting, heat & A.C. equipment, water system pumps, computer& telecommunication equipment, alarm, interlock systems, fire safety monitors, and X-ray, VUV, Booster, and Linac equipment. The installation and operation of the electrical distribution equipment is according to standard industrial practice and conforms to applicable ANSI National Safety Codes, the National Electric Code, and applicable BNL ESH Standards and Subject Areas. Systems operating at exposed voltages above 24 volts rms are contained inside secured enclosures with locked or interlock protection, or bolted access according to the serviceability of the equipment and the potential hazard. In equipment where stored electrical energy may be present a system of discharge bleeders, automatic shorting bars, and/or manual grounding sticks are provided. The power distribution system uses conventional design practices and provides for lockout and tagging of necessary equipment in accordance with the NFPA 70E Standard for Electrical Safety Requirements for Employee Workplaces.

Emergency Power and Lighting

The power for emergency use is derived from one 125kw diesel generator located on the north side of building 725. The generator distributes 480V, 3-phase power via two “Auto Transfer Switches” which are normally fed from breakers on Substation #4 and Substation #3. The emergency generator supplies power for emergency lights, sump pumps, sewage ejectors, sprinkler air compressors, computer equipment, and several electrical panels with various loads. Upon failure of normal service, the emergency load will automatically be transferred to the emergency generator supply. When the normal supply is restored the load will automatically transfer back to its normal service. The electrical service is considered failed when any phase leg drops below 75-85 % of nominal voltage and remains there for one second or longer. Any power dip in voltage of less than one second will not result in a transfer to the emergency circuit. Service is considered returning to normal when voltage on each phase leg reaches 90-95 % of nominal voltage. A delay of up to ~20-25 seconds may elapse before the generator picks up the full emergency load. When normal power is restored the transfer back goes virtually unnoticed. The emergency generator is supplied by a 250 gallon diesel fuel tank with secondary containment. This tank is registered under Suffolk County Article 12.

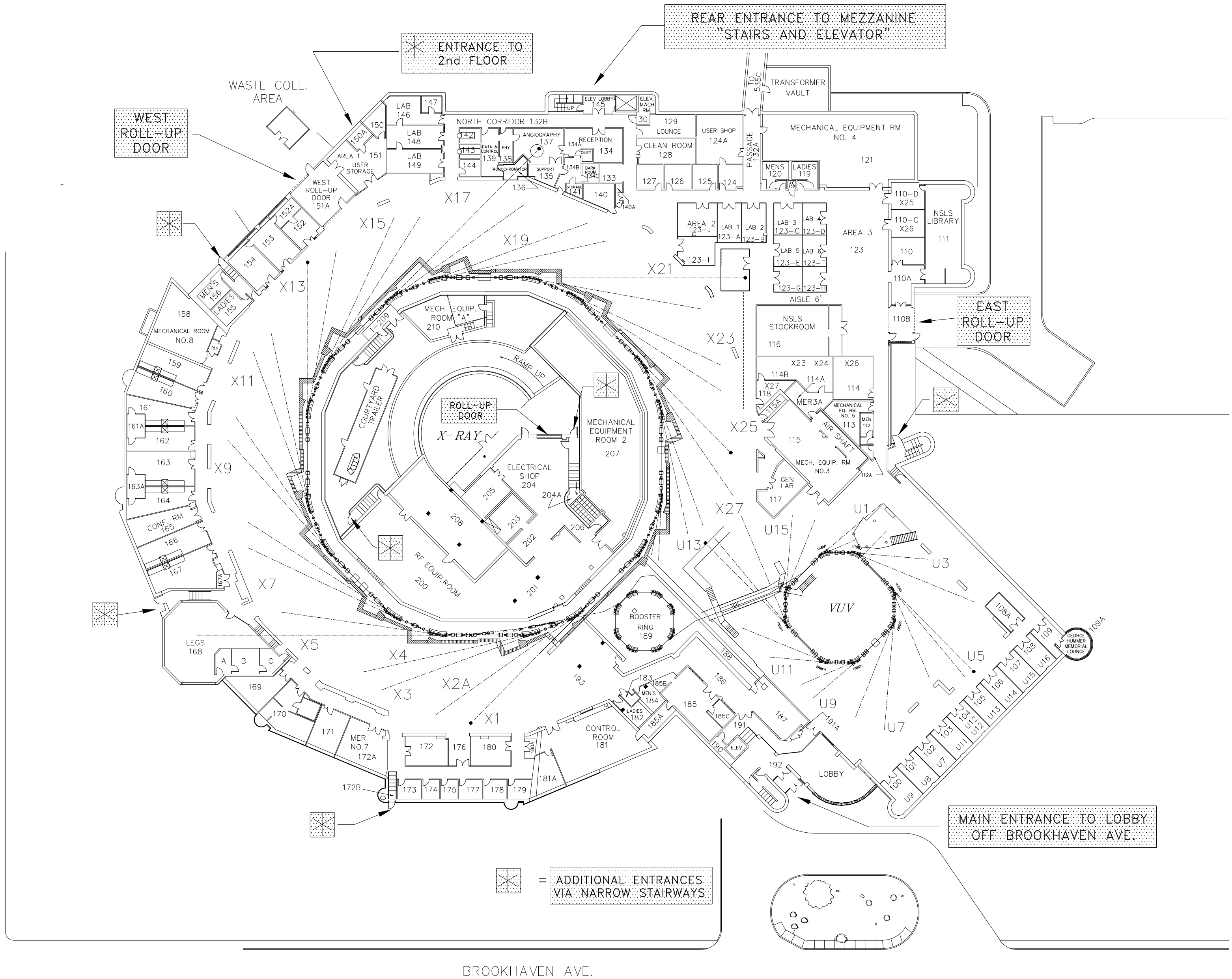

Figure 5. National Synchrotron Light Source access and egress doorways, Building 725.

3.2.3 Cooling Systems

Accelerators and beamlines consist of a multitude of components that require cooling. These components are either water or air-cooled. The water-cooling is performed through a circulating process water system, while the air-cooling is performed through an air conditioning system.

3.2.3.1 Component Cooling Systems

The process water system consists of four independent systems: the High Pressure Copper (HPC) System, the Low Pressure Copper (LPC) System, the Aluminum (Alum) System, and the Experimental (Exp) System. Below is a list of the most important components cooled by each of these systems:

HPC	Accelerator magnets and radio frequency cavities
LPC	Accelerator power supplies and some RF components
Alum	Electron beam aluminum chambers
Exp	Beamline components and user experimental equipment

Each one of these systems circulates deionized water, at various pressures and resistivity levels, through the individual ring/user components. These components are piped in a parallel configuration off a common supply header. From the supply header, cool water flows through the individual components, extracts heat, and then returns to a common header. This water then enters the suction side of a centrifugal pump and is discharged through a heat exchanger, in which the heated water is cooled. The cooled water then proceeds to the common supply header and the process is repeated. The process water supply temperatures are maintained at 74˚F, and each process system experiences a ~10˚F rise in water temperature. These process systems are closed-loop with domestic water acting as make-up. The make-up water is only added as the individual system pressure demands.

The heat extracted from equipment is passed through a heat exchanger (water from this system is discharged into the sanitary system) to one of two chilled water systems, either the BNL Central Chilled Water Facility (CCWF) or the NSLS chillers. The chilled water supply temperature is approximately 45˚F and experiences a 10-15˚F temperature rise as it extracts heat from the individual process systems. The warmed water then enters the chiller(s) and has its heat removed. The chilled water systems use centrifugal pumps and are closed-loop, with domestic water make-up as system pressure demands. The chiller(s) reject heat to a condenser water system that deposits the heat into the environment through a cooling tower (either located at the NSLS or CCWF). The condenser systems use centrifugal pumps and utilize domestic water to make up for "blow down" from the towers. Make-up is cooling tower water level dependent. The condenser water is chemically treated by the BNL Chemical Treatment Group from Plant Engineering with the appropriate safeguards. Blow-down from the cooling towers is discharged to the storm water system. Greater detail concerning the chemicals used in treating the cooling tower water and the monitoring of the discharge is provided in Section 4.2.

The air conditioning system consists of a series of air handlers located throughout the NSLS. The only difference between the process water-cooling and air conditioning cooling is the medium in which the heat is transported from the individual component to the chilled water heat exchanger. For the process systems this heat exchanger is just that, a heat exchanger located within the process loop. While for the air-conditioned system the heat exchanger is an air handler located within the NSLS. Once the heat enters the chilled water system, either via a process water heat exchanger or an air handler, the heat transfer process to the environment is exactly the same.

3.2.3.2 Comfort Cooling
Comfort cooling at the NSLS is provided by the same type of system that cools the air-cooled components throughout the NSLS. In some cases the same air handler supplies both component air-cooling and comfort cooling.

3.2.3.3 Total Heat Load
The NSLS has a total heat (design) load, of approximately 1500 tons A.C. This load includes process water-cooling, air-cooling, and comfort cooling loads. The NSLS agreement with Plant Engineering specifies that the site must supply the NSLS with a minimum of 600 tons A.C. The balance of which (900 tons A.C.) must be supplied by the internal NSLS capacity. These values may change as building additions are made.

3.2.3.4 Compressed Air Systems
The compressed air system (125 psi @ 100EF design pressure) at the NSLS has two independent air pressure supplies; one from the Central Chilled Water Facility and the other from internal NSLS compressors. The site compressed air system is under the responsibility of Plant Engineering. The NSLS system consists of four 10 horse power air compressors in "HOT" standby mode. That is, if the site compressed air system fails, then the NSLS system takes over. Air dryers and water traps are located within the compressed air systems at various locations to assure the compressed air supplied is adequately dry.

3.2.4 Vacuum Systems
High Vacuum (HV) in the mid 10^{-8} Torr or less is required for the NSLS injector system, which consists of an electron gun, linac, booster ring, and transport lines. The linac is pumped using 220 liter/second Differential Ion Pumps (IP) at the ends of the tanks and 60 or 20 liter/second Ion Pumps on the copper, RF wave-guides. Gate valves separate the gun, linac, booster, and transport lines. The transport lines; linac to booster, booster to X-Ray, and booster to VUV, are similar in design. Varian 60 liter/second Triode Ion Pumps are used on transport lines. Six 220 liter/second Differential Ion Pumps are located around the booster ring. Cold cathode gauges and thermistor gauges are located throughout the injector system to monitor and control the system vacuum. Pump currents are converted to vacuum readings to also monitor system operation. Aluminum windows are used to separate injection system vacuum from the storage ring vacuums.
Ultra High Vacuum (UHV) is required for successful operation of the NSLS storage rings. Pressures less than mid 10^{-9} Torr are required for acceptable stored beam life times. There is a Distributed Ion Pump (DIP) incorporated into every dipole-bending magnet in

both storage rings. The VUV DIP speed is approximately 220 liters/second and the X-ray DIP speed is approximately 390 liters/second. 220 liter/second DI pumps are installed between dipole magnets in both storage rings. A 5000 liter/second titanium sublimation pump is also installed between the dipole magnets and there is one in every storage ring DIP. Non-Evaporable Getter (NEG) pumps are used at several insertion device locations. All-metal gate valves are located around both rings so that sectors, insertion devices and RF cavities can be isolated when necessary. 220 liter/second DI pumps, a valve mask, all-metal valves, a fast valve, a Residual Gas Analyzer (RGA) and a safety shutter are located in all front ends for experimental beamline access and control. RGA's are also located around the storage rings to measure vacuum quality. Storage ring pressures are monitored using the Ion Pump currents and hot filament Nude Ion Gauges (NIG) that are distributed around the rings. If any two NIG controllers sense pressures higher than 10^{-7} Torr, the stored beam is dumped, and the ring valves plus the front-end valves are closed. There is also a sensor in every beamline that will close the line's fast valve and front-end valve, if a pressure greater than 10^{-6} Torr is detected.

Beamlines sharing common vacuum with the storage ring have the same UHV requirements and guidelines as the storage ring. Beamlines isolated from ring vacuum with a window may have different requirements and guidelines. All beamlines must be reviewed and approved by the NSLS Beamline Review and the NSLS Vacuum Review Committees.

3.3 Accelerator Systems

The Gun, Linac, Booster Synchrotron, Vacuum Ultraviolet Ring and X-ray Ring are operated and maintained by the NSLS with the goal of providing stable synchrotron radiation to the experimental teams operating the bending magnet and insertion device beamlines.

3.3.1 Gun, Linac and Booster Synchrotron

Electrons are injected into the NSLS storage rings from a booster synchrotron (see Booster Ring Assembly Drawing) fed by a 150 MeV Linac (see Linac and Booster Parameters**).** The electrons are first produced in a 100 keV triode electron gun. The gun is pulsed at the booster revolution period, 94.6 nsec, seven times per booster cycle. Each pulse is 4 nsec long and corresponds to about 11 micro bunches in the linac. After acceleration in the linac, the beam is injected into the booster on seven successive turns. Multi-turn injection in the booster is accomplished in the following way. A pulsed injection kicker magnet is turned on which distorts the closed orbit in the booster, pushing it very close to the injection septum magnet. The beam is deflected into the booster by a septum magnet. The first linac pulse goes around the booster and returns to the injection point just as the second pulse is coming out of the septum. The two pulses continue to circulate. This process is repeated until all seven linac pulses are injected. During the injection process, the strength of the injection kicker is reduced, pulling the closed orbit away from the septum so the circulating bunches do not strike it. After injection, the magnetic field of the booster main magnets increases to maintain a constant orbit radius as the radio frequency accelerating cavity boosts the electron energy to 750 MeV. At maximum energy, a kicker magnet is pulsed to send the beam into the extraction channel for either the X-Ray or VUV storage ring. After extraction, the booster magnets ramp down to their injection settings. The booster cycle takes 0.8 seconds from one injection to the next. In the future, the injection cycle may be decreased to 0.5 seconds and the maximum energy may be raised to 800 MeV for improved storage ring injection. The gun, linac and booster energies and currents could change based on the needs of the facility, but would still adhere to the Accelerator Safety Envelope requirements.

3.3.2 Vacuum Ultraviolet Storage Ring

Vacuum Ultraviolet (VUV) Ring (see VUV Ring Assembly Drawing) routine operations commenced in early FY 1983. There are 19 beam ports that provide synchrotron beam to 16 operational beamlines (as of April 2005; these numbers may change over time) distributed around the ~51 meter circumference of the ring. Six beamlines are dedicated to infrared light. In addition, there are undulator magnetic insertion devices in the U5 and U13 straight sections (see VUV Ring Parameters). Of note is that eleven front end shutter and shield assemblies consist of depleted uranium (DU) shielding material. The quantity of DU and locations by beamline number are tagged and logged in the Material Balance Inventory maintained by the BNL Isotopes & Special Materials group.

Normal operation of the VUV ring consists of providing the beam to users 24 hrs/day and 7 days/week with 2 days per month of scheduled maintenance and 3 machine study days per month. The ring is typically filled to 1000 mA. The fills are at fixed times to allow the users to schedule their experiments around the injection periods. Daytime fills are at 8:00, 12:30 and 17:30 hrs, in order to minimize radiation exposure to staff in the upstairs offices. In addition, there are at least 3 nighttime fills dependent on user needs. The fill pattern has been a 7-bunch train of equal current bunches filled out of the possible 9 RF buckets. This fill pattern provides freedom from ion trapping and coupled bunch instabilities. The operating energy of the ring is 800 MeV. Injection into the ring is at the booster energy of 750 MeV and requires the VUV ring energy to be ramped down for injection, and once again ramped up for stored beam operation. Top-off injection of 500 to 600mA takes place in less than 4 minutes, resulting in beam available to the users within less than 6 minutes after the start of the refill process. Users can request special operating conditions (e.g. single bunch, short bunch, energy or current, etc.). The ring energy and current could change based on the needs of the facility, but would still adhere to the Accelerator Safety Envelope requirements.

The VUV ring configuration is a four super-period double bend achromatic Chasman-Green lattice (June 1975). The two undulators in the two free long straight sections (the other two are used for injection and RF) break the symmetry of the ring. Breaking the 3 quadrupole families into 7, each energized by separate power supplies, restores the ring symmetry. The horizontal emittance at 800 MeV is 162 nm. The natural vertical emittance is 0.35 nm, but is increased to 2.8 nm for normal operations using skew quadrupoles, in order to provide increased beam lifetime.

3.3.3 X-Ray Storage Ring

The X-ray Ring (see X-ray Ring Assembly Drawing) currently operates at 2.8 GeV. The X-ray ring has 30 beam ports that provide synchrotron radiation to 49 operational beamlines (as of April 2005; these numbers may change over time). Six straight sections (X1, X13, X17, X21, X25 and X29) currently incorporate wiggler and undulator magnetic insertion devices (see X-ray Ring Parameters).

The lattice design for the X-ray ring is an eight super-period Chasman-Green double bend achromatic lattice with a circumference of ~ 170 meters. Quadrupole triplets bound the dispersion-free insertion straight sections. The beta functions at the insertion center are quite small, $\beta_x = 1.60$ m and $\beta_y = 0.35$ m, resulting in very small transverse beam dimensions, but somewhat larger angular spread. Some advantages of low beta insertions are: the effects of the wiggler magnetic fields on the lattice are minimized, the brightness is optimized for short high-field wigglers, and the low vertical beta function allows the development of very small gap devices situated at the insertion center. An important disadvantage of low beta insertions is that orbit variations can result in large vertical angular deviations that could illuminate un-cooled portions of the vacuum chamber with high power wiggler radiation. For this reason it has been necessary to develop special active interlock systems, which use dedicated pick-up electrodes on either end of the straight section to detect orbit motion and to dump the electron beam if orbit movements are too large.

Currently, normal operation of the X-ray ring consists of providing the beam to users 24 hours/day and 7 days/week. There are 2 days per month of scheduled maintenance and 5 machine study days per month. Following a fixed schedule developed together with the users, the ring is filled to a current of 300 mA, scheduled twice per day. The normal fill pattern is a train of 25 consecutive equal current bunches filled out of a possible 30 buckets. This fill pattern provides freedom from ion trapping and coupled bunch instabilities. The energy of the ring is 2.8 GeV. Injection of the ring typically takes less than 10 min. The ring energy and current could change based on the needs of the facility, but would still adhere to the Accelerator Safety Envelope requirements.

Special operations may be scheduled in each four month operating period for single bunch or five bunch operations for timing experiments. The five-bunch pattern consists of filling five out of six equally spaced buckets. Because of higher mode heating constraints, the ring is filled to 100 mA in a single bunch and 200 mA in five bunches.

3.3.4 Insertion Devices

As noted in the above sections, a number of magnetic insertion devices are located in straight sections of both the VUV and X-ray rings. The purpose of these devices is to enhance the flux and/or spectra of synchrotron radiation emitted at these locations. A number of 0 degree beamlines are dedicated to these devices.

Two basic types of insertion devices are in use: undulators and wigglers. Both types of devices consist of long arrays of magnets of alternating polarity, usually produced by permanent magnets. In the case of an undulator, when the electron beam threads the field, it gently “undulates” and produces synchrotron radiation. The ratio of the maximum deflection angle (K/γ) to the synchrotron radiation opening angle (1/γ) is the magnetic deflection parameter K. For values of K~1, the spectrum produced has sharp peaks at selected wavelengths referred to as the fundamental and its higher harmonics (multiples of the fundamental). The spectral peaks can be tuned over a wide range of wavelengths (photon energies) by varying the gap between the magnet arrays. The second important feature of undulators is that the flux is collimated both horizontally and vertically resulting in much higher brightness (flux/solid angle/source area) at these harmonic wavelengths, than can be obtained from a bending magnet.

As K is increased, the peaks begin to disappear and the spectrum approaches that of a bending magnet with a field equal to the undulator peak field. At large values of K, the device is called a wiggler. One type of wiggler approximates the magnetic field of a dipole bend magnet (thus matching the broad energy spectrum of the bend magnet), but increases the flux by some multiple related to the number of magnetic periods on the device. Another version of a wiggler uses a higher magnetic field, thus shifting the synchrotron spectrum to higher energies (as well as higher flux). It should be noted that the development of insertion devices is an ongoing effort; as they are developed, newer generations replace older versions, thus the population is not static. It is not the intent of this SAD to provide a detailed description and review of each device. New insertion devices will undergo departmental review, approval and commissioning, and will not impact the status of this SAD. Rather, this SAD provides a brief description of the insertion devices currently in use.

The VUV ring currently has two insertion devices. The undulator supplying synchrotron radiation to the U5U beamline is a standard planar undulator. It is used primarily for spin-polarized photoemission of magnetic materials in the VUV photon energy range (10-100 eV). The U5U device can also operate as a soft X-ray wiggler (K value up to ~7.5). The U13U beamline undulator is also a standard planar type and is used primarily for high-resolution angle-resolved photoemission from high-correlated material surfaces in the VUV photon energy range (5-30 eV). Both devices use neodymium-iron-boron (NdFeB) hybrid magnets.

The X-ray ring currently supports seven insertion devices. The X1 Soft X-ray Undulator (SXU) is a planar hybrid device with samarium-cobalt (SmCo) magnets that produces a very bright, soft X-ray beam in the 200-1500 eV energy range. The beam is near-diffraction-limited in the vertical direction, while in the horizontal direction the emittance of the NSLS X-ray ring leads to a larger beam divergence. This allows three endstations to simultaneously use the undulator beam: one endstation for spectroscopy, diffraction, and scattering experiments, and two for spectromicroscopy with zone plate optics. These endstations must trade off on control of the undulator gap. The presence of strong second harmonic on-axis due to horizontal emittance, and the frequent use of K values greater than 2, means that there is often substantial flux at three energies simultaneously (for example, 290, 435, and 570 eV) and that the undulator peaks are broad enough to acquire XANES spectra without gap tuning.

The X13 beamline insertion devices are used for R&D and instrumentation studies. Currently, two devices are being used. The first is an Elliptically Polarized Wiggler (EPW). The EPW produces variable polarized X-rays (energy range is similar to that produced by an X-ray Ring bend magnet) with right/left-handedness of polarization switchable at up to 100 Hz. The magnetic design of the EPW employs a vertically oriented, permanent-magnet (PM) "hybrid" structure, together with a horizontally oriented electromagnet (EM) wiggler. The poles of the EM are interleaved axially with the poles of the PM structure. This wiggler is used for experimental programs for which circularly polarized X-rays are required, such as magnetic circular dichroism and reflectivity.

An in-vacuum, Mini-Gap Undulator (MGU) is also located on the X13 straight section. Due to its short magnetic period (1.25 cm) and very small gap (down to 3.3 mm), the MGU has a high fundamental energy (3.5 keV), and a tuning range of about 50% (3.5 – 5.5 keV). The corresponding tuning range of the 3rd harmonic is 11 –15 keV. Due to finite emittance, there is also a significant 2nd harmonic on-axis, which covers broadly 5–10 keV. The MGU magnetic structure is a state-of-the-art, planar "hybrid" type with vanadium permendur poles and high-field, high-intrinsic-coercivity NdFeB magnets. This undulator is used for experimental programs requiring a high-brilliance X-ray beam such as microprobe and microdiffraction characterization of materials. A second MGU has been installed in the space between the two accelerating cavities in the X29 straight section. In conjunction with this MGU, a beamline has been constructed to exploit the high-energy photon beam for macromolecular crystallography. A similar device is planned for the X9 straight section.

The X17 beamline is served by a Superconducting Wiggler (SCW). It is the only NSLS device to thus far operate at liquid helium temperatures (to reduce electrical resistance in the coils to 0). The SCW operates at higher magnetic fields than the dipole bending magnets or the other permanent-magnet wigglers, resulting in a shift of the synchrotron radiation spectrum to higher energies, i.e. a higher critical energy. This device is also characterized by a large horizontal divergence of the high power radiation fan. The total power radiated from this source at 2.8 GeV at 300 mA is 10.3 kW for the central 15 milliradian width of the beam (unfiltered by graphite or beryllium). As a result of this harder photon spectrum, the entire beamline downstream of the wiggler is shielded in a steel/lead/steel enclosure. Operation of the X17 superconducting wiggler is administratively limited to a critical energy of 22.2 keV (4.2T @ 2.8 GeV) at this time. The NSLS Accelerator Safety Envelope (ASE) specifies that any proposal to raise the critical energy of the superconducting wiggler will be treated as an NSLS Unreviewed Safety Issue requiring analysis and radiological surveys (by Radiological Control Technicians) at the higher critical energy during X-ray ring studies (or other controlled mode) and additional shielding as necessary. This wiggler is used for high energy material science, medical research, high pressure research, as well as research in X-ray optics and X-ray diffraction techniques.

The devices on X21 and X25 are identical permanent magnet hybrid wigglers and provide their beamlines with a spectrum of 5.7 keV Critical Energy @ 1.1T and 2.8 GeV (slightly different from the X-ray ring dipole bending magnets) but amplified by a factor of 27 due to the number of poles in the wigglers. The total radiated power is 3.5 kW at 2.8 GeV in which 90% of the total power emanates within the central 80% of the horizontal angular opening. X25 emphasizes macromolecular crystallography while X21 emphasizes scattering studies of materials growth, small angle X-ray scattering and X-ray scattering studies of materials in the presence of high magnetic fields. The X25 wiggler is scheduled to be replaced by an undulator device.

3.3.5 Laser Electron Gamma Source (LEGS)
The X5 LEGS beamline is sufficiently unique that it is covered separately within this SAD. A description of standard NSLS X-ray and VUV beamlines is given in Section 3.3.6 below.

3.3.5.1 Introduction and Description of LEGS (X5)
The photon source on the 0° port of X-ray Ring dipole X1BM1, designated as user port X5, is referred to as the Laser-Electron-Gamma-Source, or simply LEGS. This line is operated by the Physics Department at BNL. Many safety considerations for this line are identical to those of a standard X-ray beamline. This section will address principally those areas in which the operating characteristics of LEGS differ from a standard dipole-source or insertion-device beamline.

At LEGS, laser light is reflected into the injection straight section of the X-ray Ring where it can collide head on with electrons traveling in the opposite direction. Almost all of the photons that interact scatter back through nearly 180° and are boosted up in energy to become gamma-rays. Apart from some small kinematic corrections, the maximum backscattered energy is just $4\varepsilon(E_e /mc^2)^2$, where ε is the energy of the primary laser photons, E_e is the electron ring energy, and mc^2 is the electron's rest mass. Two Class-IV laser systems are used at LEGS, an Ar-Ion laser operating between 300 – 515 nm, and a frequency-quadrupled Nd-YLF ring-laser that delivers light at 263 nm. The maximum backscattered gamma energy is obtained using the latter. At 263 nm with the X-ray Ring running at 2.8 GeV, the maximum backscattered photon energy is 4.71×10^8 eV or 471 MeV. The laboratory cross-section for this process is very highly peaked with the result that this γ-ray beam is inherently well confined. Essentially all the beam is contained within a 1-mrad cone centered about the electron beam direction in the straight section. A collimator, located in the X5 hutch, limits the tails of the beam. The central core is then transported in vacuum to a target located in the room 1-168 where a variety of nuclear and/or elementary particle experiments can take place.

The energy of a particular γ-ray within the LEGS beam is determined by detecting the scattered electron that gave up energy to boost up the photon energy. This provides an electronic tag for each γ-ray. To accomplish this, a "tagging spectrometer" has been installed in the X-ray Ring tunnel in the region of the short straight between the ring dipoles X1BM1 and X1BM2. This system transports scattered electrons to a shielded focal plane area.

There are several distinct interlocked zones associated with LEGS, namely the tagging cave, the laser hutch, the target room (rm. 1-168), the vacuum pipe used to transport the γ-ray beam from the laser hutch into the target room, and a mezzanine for air conditioning units located above the computer area.

Finally, LEGS also has a second port, designated X5B, that looks at X-rays from synchrotron radiation emitted at a point 1.25° into the bend of dipole X1BM1. This is used (infrequently) as a diagnostic to monitor the position of the electron beam in the ring. X-rays from this port are entirely contained within a pipe that terminates in a lead stop, and all of this is entirely contained within the laser hutch.

3.3.5.2 Description of LEGS Operation
See Section 4.12.6.

3.3.5.3 LEGS Cryogenic Hydrogen Targets
For most LEGS experiments, cryogenic targets of hydrogen (H_2, D_2, or HD) or helium are used. In past years, liquid targets of ~20 moles were operated and monitored by a separate *Target Watch*, drawn from members of the NSLS Operations Coordinator staff. However, since 1999 all LEGS experiments have focused on a new type of cryogenic target consisting of ~1 mole of HD in the solid phase. The HD samples are condensed and polarized in a Dilution Refrigerator located in X5 CryoLab (room 1-169). The solid targets may be stored either in the Dilution Refrigerator or in a separate Storage Cryostat in the X5 Target Room (room 1-168). A Transfer Cryostat is used to extract these solid HD targets and load them into an In-Beam-Cryostat in the Target Room for use during experiments. The operation of these cryostats and the target watches are now carried out and monitored by trained LEGS personnel. In addition, the X5 LEGS Cryogenic Target Interlock Panel (LEGS Alarm Panel) is located and monitored in the NSLS Control Room. The cryostats described above have been reviewed and approved by the BNL Cryogenic Safety Committee.

In a worst case accident with a solid HD target, equipment could be damaged by expanding gas, but the hydrogen concentrations would remain well below explosive and flammability thresholds. For the foreseeable future, most LEGS experiments will utilize solid HD targets. A 350 cfm fan exhausting out the roof of the building vents air surrounding the window of the In-Beam Cryostat when that cryostat contains the HD target. Should X5 return to the use of large liquid or gas hydrogen targets, this would be examined through experiment review and the BNL Cryo Safety Committee (in the case of liquid targets).

Large quantities of liquid helium are used in the LEGS Target Room (1-168) and the adjacent CryoLab (1-169), and are housed in 250 L or 500 L dewars. An Oxygen Deficiency Hazard (ODH) protection system covers this area. Upon sensing a depleted O_2 level, fans (8300 cfm) are powered to draw fresh air from the NSLS experimental floor and exhaust O_2-depleted air out the roof of the building. This system has also been reviewed and approved by the BNL Cryogenic Safety Committee.

3.3.6 Beamlines
There are 19 beam ports in the VUV Ring and 30 in the X-ray Ring. Each port may direct synchrotron radiation to several beamlines, resulting in approximately 100

beamlines. Figure 6 shows the status of these beamlines as of 2005. Dipole bending magnets supply synchrotron radiation to the majority of the beamlines. Magnetic insertion devices provide synchrotron beam to the remaining beamlines (see Section 3.3.4 above) from their respective straight sections. Participating Research Teams administer certain beamlines, conducting their own research programs and scheduling ≥25% of their available beam time for General Users who are allotted time at the NSLS under a proposal review system. The Teams' affiliations are any combination of BNL departments/divisions, national laboratories, universities and industrial concerns. Other beamlines are Facility Beamlines, administered by NSLS staff members.

All beamlines consist of pipe sections under vacuum and have front end components directly downstream of the beam ports. Front ends consist of a photon mask, an ultrahigh vacuum valve, a fast-acting valve and a safety shutter (see Section 4.12.4).

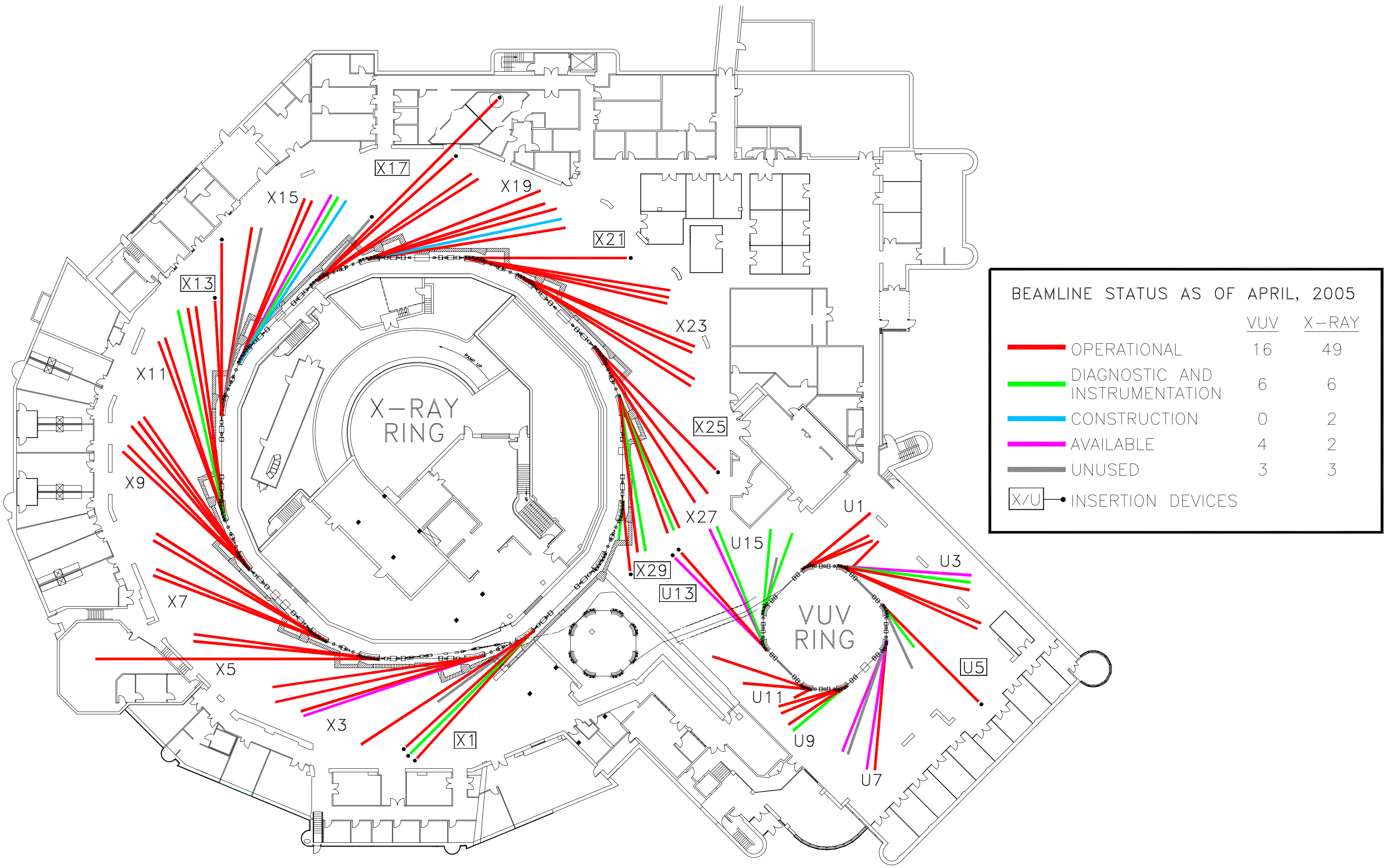

Figure 6. NSLS Beamline status as of April 2005.

3.3.6.1 X-ray Ring Beamlines

The X-ray ring front ends are located within the X-ray ring shield wall. Additional X-ray beam shutters and beam-defining slits may also be located just downstream of the front ends. The water-cooled photon mask is used to protect the ultrahigh vacuum valve from overheating when the valve is closed and therefore is electrically interlocked so that the mask closes whenever the valve is closed. The safety shutter is provided to stop the bremsstrahlung radiation that is produced when electrons strike parts of the storage ring vacuum chamber from reaching the experimental enclosures or hutches. A few of the NSLS beamlines have water-cooled shutters that serve as the valve mask (instead of a dedicated mask). Once outside of the shield wall, X-ray beam typically enters chambers containing monochromators and/or mirrors; the former selects the part of the synchrotron spectrum required for the experiment and the latter adjusts the horizontal and/or vertical dimensions and divergence of the beam. A beamline without a monochromator is termed a “white” beamline. For monochromatic beamlines, a photon shutter may follow, after which the beam may enter a steel hutch. Hutches are radiation-interlocked rooms that contain the actual experiment at the end of the beamline, i.e. that location where the synchrotron beam interacts with the sample under study. In the case of white beamlines, the interior hutch walls are typically covered in lead sheet and a lead brick beamstop is located at the far end of the hutch. Bremsstrahlung shielding is provided along the length of the beamline by a combination of lead stops and exclusion zones. The lead stops absorb the primary bremsstrahlung radiation, while the exclusion zones block access to any regions in the bremsstrahlung cone that extend outside the vacuum piping. In addition, the insertion device straight sections create enough bremsstrahlung radiation to make secondary scattering significant; in these cases, secondary lead shielding is required, as determined by measurement during beamline commissioning. The entire beamline is typically under vacuum (some chambers may be filled with Helium gas instead) and is separated from the ring vacuum by a beryllium window (this is not the case for beamlines using low energy X-ray synchrotron radiation where the beamline vacuum is continuous with the X-ray ring vacuum). More beryllium windows or valves may further subdivide the beamline vacuum to allow bleed-up of certain components without having to bleed-up the entire beamline. The energy of a typical X-ray ring beamline ranges from 4 to 20 keV, but a few beamlines extend down to soft X-ray (0.5-4 keV) and even lower (down to 10eV) and a few extend to higher energy, up to 100 keV.

3.3.6.2 VUV Ring Beamlines

VUV beamline vacuum is contiguous with VUV ring vacuum and can only be separated from the ring vacuum by closing an ultra-high vacuum valve. Further vacuum protection is provided by acoustic delay lines and fast valves. These function together with vacuum interlocking of the beamline valves to provide a complete automated response to changes in beamline vacuum, thus protecting the VUV ring vacuum. Once outside the VUV shield wall, mirrors and monochromators as well as slits adjust the synchrotron beam. VUV beamlines do not have hutches; rather the experiment station is attached to the end of the beamline and consists of a stainless steel chamber that cannot be penetrated by the low energy beam. Bremsstrahlung shielding is handled in the same fashion as for X-ray beamlines. The energy ranges of the VUV ring beamlines are grouped into two categories: above visible and below visible (i.e. infrared). The former typically range from 20 to 1000 eV, but a few extend down to the low UV (~4 eV) or above 1 keV (~5 keV). The energy of the infrared beamlines typically ranges from 2 to 1000 meV, but one extends down to 0.125 meV and another extends up to 3 eV.

3.4 Integrated Safety Management

The NSLS ESH program described in this section is intended to ensure that work is conducted efficiently and with full protection of workers, the public and the environment. Its foundation is set on the core functions and guiding principles of the DOE Integrated Safety Management (ISM) program. The NSLS ISM program seeks to ensure that:

- Responsibilities for ESH are clearly understood
- Policies and requirements for ESH are well-defined
- All hazards in the work place are identified and controlled through work planning and review processes
- All workers are trained and qualified to do their work safely
- Objectives and measures for the ESH program exist, and there is a self-assessment program to evaluate performance and progress on an on-going basis

3.4.1 ESH Roles and Responsibilities

Responsibility for safety at the NSLS lies with the NSLS Department Chairman and flows down to the worker through the various Associate Chairs and management chains. The NSLS Associate Chairman for Environment, Safety, Health/Quality (ESH/Q) assists the NSLS Chairman in this capacity through the management of the various safety program elements discussed below. The department reports to the BNL Associate Lab Director for Light Sources (see NSLS Organization Chart).

Each worker within the facility is expected to comply with all safety requirements and to assure that hazards associated with their work are properly identified and controlled as defined by BNL policy. Roles and responsibilities for work activities and safety are defined through individual documents known as R2A2s (Roles, Responsibilities, Authorities, and Accountabilities). These documents form the basis for training and qualification of each worker.

To provide additional ESH support to workers and supervisors, and to provide oversight for department activities, an ESH/Q Section exists within the NSLS Department. Managed by the NSLS Associate Chair for ESH/Q, the staff consists of the ESH Coordinator, Safety Officer, Deputy Safety Officer, Safety Engineer and Training Coordinator as well as the Quality Assurance Representative. Radiological Control Division staff as well as an Environmental Compliance Representative (ECR) are assigned to the NSLS. In addition, a number of safety-related committees report to the NSLS Chairman through the Associate Chair (see NSLS ESH Organization Chart). Each committee serves in an advisory capacity and reviews program or facility changes as described in each committee's charter:

- ALARA Committee
- Beamline Review Committee

- ES&H Committee
- Environmental Management System & Occupational Health and Safety Management Committee
- Interlock Working Group
- ESH Improvement Committee

A major role for these committees is to ensure that changes in the facility or work activities do not result in unreviewed safety issues that would result in a deviation from the approved Accelerator Safety Envelope. Membership for these committees is drawn from the NSLS, BNL-at-large, and also external to BNL when expertise is required. It should be noted that a number of other committees are constituted as needed and ESH representation is included; examples would be Design Review committees and Installation Readiness Reviews.

ES&H Area Representatives, individuals familiar with their area of work, are selected from the NSLS staff to assist in Tier I safety inspections and to report to the ES&H Coordinator when safety issues arise. NSLS Control Room Operations Coordinators (OpCo's) are a vital component to the NSLS safety program. Managed by the Associate Chair for Operations and Engineering, the OpCo's serve as the interface between the NSLS and the researchers at the beamlines.

3.4.2 ESH Policies and Standards

Policies and requirements that apply to work at the NSLS are defined in the NSLS ESH Policies and Requirements Manual (PRM). The PRMs are based on ESH Standards and Subject Areas in the BNL Standards-Based Management System (SBMS). A number of key programs within the department which are intended to ensure proper identification and control of hazards, and ensure compliance with ESH requirements are reviewed below.

3.4.2.1 Work Planning and Control

NSLS ESH PRM 1.3.6, NSLS Work Planning and Control Procedure, documents the Work Planning and Control Procedure functions within the NSLS. This procedure defines a consistent method for identifying and analyzing job hazards, planning the work, and coordinating job activities. A graded approach is used to determine the level of rigor required that is commensurate with the level of hazard, programmatic impact, and quality assurance. Work Planning and Control applies to both external work performed at the NSLS by service organizations and to internal work performed by NSLS staff and beamline staff members. The procedure provides guidance for filling out, reviewing and implementing a Work Permit. Based on experience and job knowledge, Work Control Coordinators (WCC) are designated, trained and assigned to screen work requests, while having the authority to place Work Orders through the BNL Maintenance Management Center. The NSLS Work Control Manager oversees the WCC's and also chairs a committee that reviews Work Permits.

3.4.2.2 Experimental Safety Review

NSLS ESH PRM 1.3.5a, Experiment Safety Review, details the NSLS procedures for ESH review of experiments at the NSLS. All science at the NSLS is subject to ESH review and must be approved by the NSLS ESH staff before proceeding. The NSLS is committed to minimizing the risks to employees, visitors, the public, and the environment associated with experimental operations.

The vehicle for presenting an experiment for review is the Experiment Safety Approval Form (SAF). An SAF is submitted by a researcher and reviewed by the NSLS Experiment Review Coordinator (ERC) who reports to the NSLS Associate Chair for ESH/Q. Approval or rejection of the SAF is the decision of the ERC. For experiments with unusual hazards such as those that present biosafety concerns, or work with research gasses or transuranics, a committee may be formed from members of the NSLS ESH Committee and other BNL staff with appropriate expertise to assist in evaluating the risks and determining required controls. When researchers are ready to begin experiments at the beamlines, they contact an Operations Coordinator (OpCo) who checks to assure that the experiment is approved and verifies that NSLS requirements are met before enabling the line for operation. The OpCo has Stop Work Authority for beamline operations.

3.4.2.3 Beamline Review

NSLS ESH PRM 1.3.5b, Beamline Safety Review provides guidance to review the design of new beamlines or beamlines that have undergone significant changes, prior to commencement of operation. It provides guidance to the NSLS Beamline Review Committee for review purposes and to the beamline personnel for documentation purposes. Approval for beamline operation is through the NSLS Chairman or a designee (the Review Committee Chair). Reviews require the presentation and discussion of assembly and anamorphic drawings as well as a written beamline description document from the beamline management. This document includes detailed drawings pertaining to the entire new beamline and/or to those components that have been upgraded in an existing beamline. The committee makes recommendations based on their review. A formal Readiness Review Walk-Through takes place once the recommendations have been fulfilled. The beamline may then be approved for restricted operation for radiation surveys, conditioning, and commissioning of research apparatus, which will lead to unrestricted operation. A commissioning plan may be required.

3.4.2.4 Self-Assessment

Each year the department conducts reviews of activities and programs to determine the strengths and weakness in performance or non-compliances with BNL policy. These self-assessment activities are defined annually in the department self-assessment plan. Results of the self-assessments are reviewed by NSLS management in an annual review.

On-going “Tier I” inspections of department facilities are an important element of the self-assessment program. NSLS ESH PRM 1.2.0, Environmental Safety and Health Inspections provides detailed guidance for conducting Tier I Environmental, Safety & Health inspections; an endeavor to eliminate the diverse and changing potential for unsafe conditions, and to increase the safety awareness of individual employees. The NSLS Safety Engineer manages this program and reports directly to the NSLS Associate Chair for ESH/Q. Offices, public areas and the exterior of the building are inspected annually; all other areas are inspected quarterly. The Safety Engineer conducts the tours and may be accompanied by another NSLS staff member, an ESH Area Representative and/or personnel with specific expertise as needed. All findings are maintained in an NSLS database and tracked to completion.

3.4.2.5 Environmental Management

BNL has been awarded a Certificate of Registration for conformance with ISO 14001. The NSLS has an Environmental Management System (EMS) system specific to its operations that is included in that registration. The NSLS Environmental Management System Manual documents the implementation of the ISO 14001 criteria within the NSLS ESH programs, including the NSLS's Environmental Objectives and Targets, the goals of which are to ensure continuous improvement within the facility. The EMS program elements apply to all activities conducted within the NSLS. This manual is intended primarily as a reference for NSLS managers, the NSLS Environmental Management Committee, and assessors who review EMS implementation at NSLS. Responsibilities for maintaining EMS program elements and achieving the objectives and targets are assigned in this manual. An NSLS EMS & OHSAS Committee is maintained; it monitors performance of the NSLS Environmental Management program at regular meetings.

The NSLS Complex (NSLS and DUV-FEL) has been granted a Finding of No Significant Impact (FONSI) by DOE based on the analyses of the NSLS Complex Environmental Assessment.

3.4.2.6 Occupational, Health and Safety Management

The NSLS has obtained registration in Occupational, Health and Safety Assessment Series (OHSAS) 18001. The NSLS OHSAS Manual documents the implementation of the OHSAS 18001 Standard criteria within NSLS programs, and includes the NSLS ESH Improvement Plan whose goals are meant to ensure continuous improvement within the facility. The OHSAS elements apply to all activities conducted within the National Synchrotron Light Source (NSLS), including the Deep Ultraviolet-Free Electron Laser (DUV-FEL) facility. This manual is intended primarily as an OHS management tool for NSLS managers and the NSLS OHSAS Management Committee to implement and improve the OHS system, and to demonstrate conformance to assessors who review OHSAS implementation at NSLS. The NSLS ESH Policies and Requirements Manual (PRM) is the primary NSLS document for defining specific OHSAS requirements relating to performance in the work place. Job risk assessments, worker qualifications and training for the workers are merged in the NSLS Worker Qualification Matrices. An NSLS EMS & OHSAS Committee is maintained; it monitors performance of the NSLS Occupational, Health and Safety Management program at regular meetings.

3.4.2.7 Emergency Plan

NSLS ESH PRM 9.0.0, Local Emergency Plan, outlines the hazards that may exist at the Light Source and describes the actions that should be taken by building occupants in the event of an emergency. It also assigns specific duties to personnel during the response to an emergency. This plan applies primarily to emergencies that occur inside of Building

725 (the topic of this SAD). Buildings 726, 727, 728M, 729, 535A, and 535C Basement are part of the NSLS and many occupants of those areas spend much of their time in Building 725. Hazards and responses specific to those areas are covered in Appendix A to the PRM. The response to an emergency that originates elsewhere at the Laboratory, and that is the subject of a BNL Alert or Site Emergency, is set forth in the BNL Emergency Plan. The response at the NSLS to such conditions is described in Appendix B of the PRM. The NSLS Associate Chairman for ESH/Q appoints a Local Emergency Coordinator (LEC) who has primary responsibility for Pre-Emergency Planning at the NSLS. The LEC shall ensure that the emergency plan is reviewed and updated as needed or at least annually, and in particular after the occurrence of accidents or emergency situations. During an actual or simulated emergency, the NSLS Control Room Operator-on-Duty is the Acting Local Emergency Coordinator. The responsibilities of NSLS Control Room staff are set out in LS-OPS-0005, Response to Emergencies at the NSLS (Operations Group Response). In addition, the NSLS maintains Firehouse Response Cards and Emergency Preparedness Hazard Assessments for its buildings.

3.4.2.8 Unreviewed Safety Issues

It is important to ensure that all safety related events or changes in the facility, work practices or research do not introduce new hazards that have not been previously analyzed and bounded within this SAD and the related ASE. The Unreviewed Safety Issue (USI) process has been established as a mechanism to address this type of issue and provides a path for review and approval.

The primary responsibility for identifying a USI resides with the NSLS ESH personnel who participate in all reviews of facility modification, analysis of hazards in experimental review and work planning, and investigation of incidents. The NSLS ESH Staff utilizes its EMS, FUA and SAD/ASE Checklist for NSLS Reviews to assure examination of review results to determine the need for developing a USI. Examples of changes that could invoke the USI process are described in the Accelerator Safety Subject Area and include:

- Changing or altering procedures referenced in the SAD
- Reorganization impacting departmental/divisional responsibilities listed in the SAD
- Accelerator modifications that are not replacement-in-kind activities
- Non-editorial changes to operational safety limit related procedures
- Change-out/replacement of safety equipment identified in the ASE that is not identical in form, fit, and function

All potential Unreviewed Safety Issues are reviewed by NSLS management to determine if a USI review will be initiated. The DOE Facility Representative to the NSLS will be advised of all potential USIs. Any issue identified as a USI will be formally analyzed and reviewed by the responsible line managers, NSLS ESH personnel, and the NSLS ESH Committee, prior to final review and approval by NSLS Chair. All USIs must be provided to the Laboratory ESH Committee (LESHC) for review and to the Deputy Director of Operations (DDO) for approval; the approved USI is then appended to the SAD. If the changes do affect the ASE, an analysis and revised ASE are sent to the LESHC for review, and the DDO and DOE/BHSO for approval. All revised documents and USIs are managed as controlled documents. This process is described in detail in the SBMS Accelerator Safety Subject Area.

3.4.3 Safety Training

The NSLS Training Policy defines the training requirements for all personnel working at the NSLS and is maintained by the NSLS Training Coordinator who reports to the NSLS Associate Chair for ESH/Q. Training is documented through the Brookhaven Training Management System (BTMS) database. Personnel are assigned Job Training Assessment (JTA) classifications that define their training requirements. The basic NSLS training program is divided into two parts: staff (including non-BNL employees and employees from other BNL departments who support beamlines) and users. NSLS staff has the same training required for BNL employees plus facility specific and radiological training. Users conduct most of their training through the User Administration Office, obtaining facility specific and radiological training. They also receive Beamline Operations and Safety Awareness (BLOSA) for each beamline at which they work. In addition to the above, staff members and users may receive additional training regarding environmental issues, waste disposal, health issues, crane operations, lasers, noise, machine shop use, etc. On-the-job training is also provided and documented within the specific sections of the NSLS. Independent access to areas controlled for radiological purposes requires facility specific training, General Employee Radiological Training (GERT), and an encoded BNL ID badge. Untrained persons (Visitors) may access Controlled Areas with a fully trained Escort. In this case, the Visitor is read a brief training paragraph, signs a Visitor/Escort Form and is then allowed on the experimental floor in the constant presence of the Escort. This condition is allowed for a maximum of 8 hours only and is for observational purposes only.

3.4.4 Operational Safety

NSLS Control Room personnel control the operation of the electron gun, Linac, booster synchrotron, VUV and X-ray storage rings, and the beamlines. The Control Room is managed by the Head of Operations. A Machine Operator and two Operations Coordinators staff the Control Room 24 hours a day on 12 hour shifts, one daytime and one nighttime, with the exception of long term maintenance shutdowns and some holidays when the staff is on duty only during normal work hours. Following is a summary of responsibilities for these individuals:

Machine Operators

- Operate the injection system and storage rings, and monitor equipment.
- Search and secure the Linac/booster, X-ray tunnel and VUV ring radiation areas.
- Maintain a log of machine status, events, occurrences and special operating conditions.
- Read and sign off previous shift’s operations log and give verbal briefing at shift changes.

- Investigate machine/component failures, initiate/coordinate repairs to minimize downtime.
- Shut down any part of the facility within their area of control that may present a safety hazard until that hazard has been removed
- Acting Local Emergency Coordinator in the event of a facility emergency.
- Assure operation of accelerators according to ALARA principles.
- Act as liaison to ESH, staff and users.

Operations Coordinators

- Monitor the operation of experimental beamlines (safety checklists properly filled, Safety Approval Forms and training are current, enable, disable at end of experiment or if safety hazards are detected).
- Maintain a log of beamline status and other matters that affect facility status.
- Read and sign off previous shift's operations log and give verbal briefing at shift changes.
- Conduct regular tours of experimental floor for facility safety status check.
- Back up Machine Operator
- Perform assigned duties during Emergencies.
- Search and secure the Linac/booster, X-ray tunnel and VUV ring radiation areas.
- Act as liaison to ESH, staff and users.

A corollary to safe operation of the machines is the safe operation of beamlines. While the Operations Coordinator has a significant safety responsibility for beamlines and their experiments, the prime safety responsibility lies with members of the beamline management or Participating Research Team (PRT) Spokespersons and Local Contacts, and secondarily with the users of the beamline. The PRT must operate in accordance with the NSLS Policies and Procedures, the NSLS ESH Policies and Requirements Manual, and the BNL Standards Based Management System Subject Areas and ESH Standards. The PRT must assure that all their users are trained in Beamline Operations and Safety Awareness (BLOSA). Users must operate in accordance with their training and within the limits specified by their Experiment Safety Approval Form (SAF). Additional guidance is provided to PRT members and users through their designated R2A2s (Roles, Responsibilities, Accountabilities and Authorities).

Daily schedules are coordinated so that ring fills are scheduled at times of low worker population in the building, e.g. 7:00 hrs and 19:00 hrs for the X-ray ring; 8:00hrs, 12:30 hrs and 17:30 hrs for the daytime VUV ring fills (at least 3 more at night). Long term schedules for the rings are developed for the upcoming ~6 months and are coordinated among many NSLS groups as well as the users to assure that no conflicts exist. This allows for long term planning by both groups, especially users so that they may time their experiments to the proper ring schedule.

3.5 Radiation Protection Systems

Radiation exposure to staff and users is limited by shielding of radiation sources and through a variety of administrative or engineered controls described in this section.

3.5.1 Shielding Policy

The NSLS has been shielded and additional controls established to ensure that occupational exposures for personnel working within the NSLS Complex do not exceed 1250 mrem per year. In addition, the dose equivalent to guests and staff members working in other BNL facilities adjacent to NSLS Building 725 shall not exceed 25 mrem in one year as the result of NSLS operations.

Shielding at the NSLS is provided in the form of lead bricks and sheets, regular and high density concrete and borated polyethylene. Guidance for handling lead is provided to staff members and users through PRM 1.6.0, "Lead Working Guidelines". Staff and users are trained to respect and maintain shielding configuration. If there is any need to alter or remove shielding, a Safety System Work Authorization must be in place before the work is begun. This authorization describes the job, the system affected, the workers doing the job, the lockouts put in place to protect the workers, and what is required once the shielding is replaced, e.g. a radiation survey, before the system reverts to normal operation. Lead and concrete shielding and radiation interlocks protect the workers from the machine electrons and from the synchrotron and bremsstrahlung radiation created by these electrons. In addition, the concrete and borated polyethylene shielding absorb the neutrons created by the high energy bremsstrahlung. Guidance for handling lead is provided to staff members and users

The Linac and Booster Synchrotron are shielded in a similar fashion. The entire assembly is shielded by concrete block walls on the sides and by the second story concrete floor on top. The Linac and the transfer lines are shielded with lead and concrete bricks. The ring is shielded with lead bricks, and the injection and extraction points are covered with additional layers of lead and concrete. These areas are fully interlocked and not accessible during operations.

The VUV ring is shielded by walls of high density (3.76 g/cc) concrete (mixed with hematite and ilmenite; this material does not perturb the electron orbit). The walls are high enough to block line of sight radiation 6' above the second floor level. The ring does not have a roof. In addition, high density concrete brick walls were erected below a number of beam ports, over the injection area and the transfer line, and over the RF cavities to enhance shielding. The interior of the ring is further shielded by lead bricks along the mid-plane of the ring pipe, at the injection point, and by lead and concrete on top of the RF cavity straight section. A number of second floor office walls above the VUV ring are shielded with borated polyethylene sheets to reduce direct and scattered radiation in those offices and eliminate the need for radiological posting. The interior of the VUV ring is accessible during operations through an interlock pass procedure requiring training.

The X-ray ring is shielded on all sides by concrete. Each beamline penetrates the shielding walls at a location known as a sawtooth; the shielding at these penetration areas is enhanced with lead bricks. Worker access to the front ends is through concrete shielded plug doors (movable on air pads) whose closed position is confirmed by the interlock system. Additional local shielding is added to the interior of the ring at locations where beam loss occurs, such as the mid-planes of the dipole bending magnets, downstream of straight sections, along the transfer line and at the injection point. This ring is fully interlocked and not accessible during operations.

Beamlines are shielded in a number of different fashions. Anamorphic drawings of each beamline define the extremal rays of the bremsstrahlung radiation and lead shielding is put in place to absorb that radiation: 8" thick along the direction of the bremsstrahlung and 2" beyond the extremal rays, horizontally and vertically. Where the bremsstrahlung cone exceeds the dimensions of the beampipes, exclusion zones of metal or lead sheet are put into place to prevent contact with the radiation. The original calculations for these dimensions were given in the 1982 NSLS SAR and are reproduced in **Appendix 2**. Beamline bremsstrahlung anamorphic drawings, plan and elevation views, must conform with "Preparation of NSLS Beamline Bremsstrahlung Shielding Anamorphic Drawings" (**Appendix 3**). A lead beamstop, using the dimensions described above, is placed at the last point in the beamline reached by the bremsstrahlung radiation; this could be downstream of a monochromator or at the end wall of a hutch. Areas of synchrotron beam scatter (e.g. monochromator, safety shutter, slits, thin-walled bellows, white beam hutch walls) are shielded with lead bricks or lead sheet as needed, based on surveys conducted by members of the Radiological Control Division. Windows on beamlines are shielded with leaded glass.

The requirements for shielding beamline experimental stations vary with the type of synchrotron radiation used on that beamline. In the case of VUV beamlines and those X-ray beamlines in the UV/soft X-ray energy regime, the end-station is typically a stainless steel chamber that is more than adequate for absorbing these beam energies. All X-ray ring beamlines that use synchrotron radiation consisting of hard X-rays are required to have a steel walled hutch (1/8" thickness steel) with leaded glass windows. This is adequate for beamlines that supply monochromatic beam to the experimental station. For white beam beamlines and for certain insertion device beamlines, there may be an additional requirement of 1/16" lead sheet or more to coat the interior surface of the hutch walls. The Beamline Review Committee examines shielding as part of the review process for new and upgraded beamlines (see Section 3.4.2.3).

3.5.2 Radiation Controls

Proper radiation and facility specific training is required for access to NSLS Controlled Areas. Once completed, a radiation dosimetry badge (TLD) may be issued and the person's BNL ID badge is coded for unescorted access. Access into the Controlled Areas is only through the use of card readers at each door. Areas within the Controlled Areas may have additional postings such a Radioactive Material Areas and Radiation Areas, as needed. Direct access to either the electron or synchrotron beams is prevented by the use of radiation safety interlocks (see Section 3.4.2.5 above). Radiological Work Permits (RWP) are issued as per the criteria in the BNL RadCon Manual and in some circumstances deemed necessary due to the use of benchtop quantities of dispersible radioactive material in experiment samples. This is done in collaboration with the Radiological Control Division Facility Support Representative. Chipmunk radiation monitors form part of the radiation safety system and are discussed below in Section

3.5.3. Public address system announcements are also made to provide guidance during radiological events, e.g. VUV ring fills, ring conditioning.

3.5.3 Radiation Monitoring

The prime purpose for monitoring radiation is for the protection of the workers and to assure that their doses are kept ALARA. Radiation surveys are performed to assure that proper shielding is in place, to monitor machine operations and to assure the containment of sealed sources or experiment samples. Different types of monitoring occur at the NSLS, e.g. TLD personal dosimetry, TLD area dosimetry, chipmunk area monitors and hand-held survey instruments.

Areas posted as Controlled Areas, e.g. the experimental floor, require that all personnel who work within these areas must be properly trained. TLD dosimetry is required by the NSLS for Resident Beamline staff, Scientific/Technical/Professional NSLS staff, minors conducting research, women with a declared pregnancy, persons working with radioactive materials and others based on ESH/RCD assessments. In any month, 0 to 10 TLDs may have reportable doses, the majority of these reporting low shallow doses. Please see **Appendix 12, Figure 6** for the Distribution of Annual Total Effective Dose Equivalent for Monitored Individuals. Starting in 2003, because of the low potential for radiation exposure, personnel who are not routinely working on the experimental floor in building 725 are not required to wear personnel dosimetry. The basis for this policy change is described in section 4.14.7.5 and in **Appendix 13**.

NSLS Collective Dose Goals and Administrative Control Levels are described in the NSLS ESH Policies and Procedures Manual.

Area monitors using TLD dosimeters are arrayed in ~70 locations on the experimental floor and in second floor office spaces, and are read out on a quarterly basis. These integrating dosimeters monitor the long-term radiation doses for the various locations. The doses are a function of machine operating conditions and local shielding. The results are used to determine the ambient equivalent dose recorded in occupied areas (with occupancy factors applied) and where radiological postings should be put up or removed. Please see **Appendix 12, Figures 1-5** for locations of area monitors and area monitoring results for the second floor offices, VUV ring and X-ray ring locations.

Chipmunks are real-time area radiation monitors. They measure gamma and neutron radiation fields and the data are logged in computer history files. Approximately 20 devices are in fixed locations where levels of elevated radiation are anticipated. In some cases, the timing and expected levels are well known and characterized, such as during VUV ring fills. In other cases, the timing and amounts are unknown, such as during out-gassing events when bremsstrahlung is produced. These devices alarm locally and in the Control Room above certain preset levels. As such, they also act in the capacity of radiation security devices (see 3.5.2 above). Locally, personnel are trained to move away from the area and inform the Control Room that they were in the vicinity of an alarming chipmunk. Control Room personnel are trained by procedure to react to the alarms according to the location and duration/amount of radiation produced.

Hand held radiological surveys are conducted throughout the NSLS facility. The bulk of these are conducted and documented by the Radiological Control Division personnel assigned to the NSLS, but the Control Room Operations Coordinators are also trained to check levels around beamlines. The Control Room has been provided with Geiger-Muller based instruments to measure ambient levels when RCD personnel are not available, typically during off-hours. Instances requiring these surveys would include:

- Examination of shielding integrity after lead/concrete had been removed and replaced in the original configuration,
- Verification of shielding integrity on a new or rebuilt beamline after RCD had performed the initial survey during commissioning.

3.5.4 Safety Interlocks

NSLS ESH PRM 1.5.3, Interlock Safety describes the NSLS interlock responsibilities, documentation, and configuration control. Guidance is provided for interlock systems that protect personnel from hazards such as radiation, lasers, RF/microwave energy, radiation generating devices and electrical equipment. These NSLS interlock systems follow the basic principles below and are implemented using a graded approach dependent on the level of hazard. Staff and users are trained to respect and maintain interlock configurations. If there is any need to alter them, a Safety System Work Authorization must be in place before the work has begun. This authorization describes the job, the system affected, the workers doing the job, the safeguards put in place to protect the workers, and what is required once the job has been completed, before the system reverts to normal operation, e.g. test of the system.

The function of the NSLS radiation safety interlock systems described in Radiation Safety Interlocks at the NSLS **(Appendix 1)** is to insure that no one is in an area where there is hazardous radiation, and to turn off the radiation source if a person improperly gains access to such an area. Each system provides signs and/or other indicators of the status of controls on the radiation source, and visual and audible warnings of imminent radiation.

The interlock systems for radiation protection at the NSLS must meet the following general requirements:

1. The design must be fail-safe, i.e. the most likely failure modes leave the system in a safe condition. For example, the following failures must be safe:
    a) loss of power in any part of the system,
    b) any shorts to ground, and
    c) any open circuits.
2. The interlock system must be designed to be testable, with redundant protections tested independently. Credit may not be taken for protective features that cannot be tested. Test procedures should be non-invasive, without requiring actions such as installing clip lead jumpers or disconnecting electrical wires.
3. Critical protective features of the interlock systems for High Radiation Areas >50 rem/hour must be redundant, so that no single failure can render the system unsafe.

This is implemented by providing two independent chains of protection with no common elements. In so far as possible, the two chains should be physically different and act in different manners to minimize the possibility of related coincident failures. Critical protective features include:

a) perimeter control of the area,
b) emergency crash system,
c) beam stops, and
d) radiation source shutdown.

4. Personnel access doors to High Radiation Areas >50 rem/hour must be locked when radiation is present in the area, with the locks incorporated in the interlock system.

5. Before engaging the interlocks for large areas, personnel sweeps are combined with timed check stations, light and audio alerts to assure that areas are clear of personnel.

The NSLS interlock program and designs are overseen by the NSLS Interlock Working Group. Each interlock is tested every six months (unless permission to extend that period is obtained from the Radiological Control Division). This program is managed by the NSLS Interlock Engineer and the Interlock Test Manager.

4. SAFETY ANALYSIS

The hazards, assessment of unmitigated risks, identification of controls and assessment of mitigated risks associated with the various systems identified in Section 3 are reviewed in this section. The identification of the NSLS hazards was conducted by examining work activities and operational experience, the NSLS ESH Policies & Requirements Manual and the BNL Subject Areas, and discussions with pertinent staff members. The following hazards are specifically addressed: environmental, waste, fire, natural phenomena, electrical, cryogenic and oxygen deficiency, confined spaces, chemical and other experimental materials, ozone, accelerator vacuum/cooling water/compressed air, noise, material handling, non-ionizing radiation and ionizing radiation.

The risks of credible accidents involving these hazards are summarized in **Appendix 4** . These assessments show that the risks following mitigation are low or routine (risk chart based on Risk Screening Matrix provided in BNL Hazard Analysis Subject Area). In addition, the hazards and risks associated with NSLS work activities were evaluated through OHSAS 18001 Job/Facility Risk Assessments. These analyses support the conclusions drawn in this document that adequate controls are in place to reduce the risk of injury to personnel working within the NSLS facility.

4.1 Environmental Hazards

As stated in Section 3.4.2.6 above, the NSLS maintains an Environmental Management System and follows ISO 14001 requirements. The NSLS reviews all operations and activities, and identifies their Significant Environmental Aspects (see matrix). These aspects are communicated to employees and are included in job specific training. These aspects are reviewed at least annually and updated as needed. Responsibility for review of these policy documents has been assigned to the NSLS Associate Chair for ESH/Q, in conjunction with the NSLS EMS and OHSAS Management Committee. Any changes in the significant environmental aspects will be identified through the Process Assessment Forms (PAF) and EMS and OHSAS Management Committee participation in various NSLS review activities (e.g. ESH Committee, beam line review, and formal design reviews) as well as in routine work planning, experimental safety reviews and Tier I inspections. Any potential changes in the environmental aspects will be brought to the attention of the NSLS Associate Chair for ESH/Q or the NSLS ESH Coordinator for resolution. An EMS Checklist has been developed to assist in the review process.

The NSLS Environmental Assessment examines environmental concerns associated with NSLS operations. DOE has reviewed this document and has issued a Finding Of No Significant Impact (FONSI) in which it determined that the continued operation, construction and upgrades of the NSLS Complex at BNL do not constitute a major federal action significantly affecting the quality of the human environment within the meaning of the National Environmental Policy Act of 1969. Therefore, the preparation of an Environmental Impact Statement is not required.

A National Emissions Standards for Hazardous Air Pollutants evaluation (NESHAPs; based on guidance in the Radioactive Airborne Emissions Subject Area) for the NSLS has been conducted by the BNL Environmental & Waste Management Services Division and is included in **Appendix 5**. The total dose to the Maximally Exposed Individual (MEI) resulting from the activation of air due to bremsstrahlung /neutron from the NSLS operation was estimated to be 1.12E-08 mrem/year. The calculated dose is well below the 0.1mrem/ yr annual limit as specified in the 40 CFR 61, subpart H, which requires continuous monitoring under NESHAPs. Therefore, the dose/risk to the members of the public is minimal, and an annual administrative review of the facility is sufficient to evaluate any changes in operations, process, beam intensity, or any other factors that may increase emissions to the environment.

4.2 Waste Hazards

LS-ESH-PRM-7.0.0, Hazardous Waste Management, provides guidance in handling and disposal of NSLS wastes. Improper management of wastes can result in injury or illness to workers and the public, or damage to the environment. The Significant Environmental Aspects Matrix discussed in Section 4.1 above cites a number of NSLS significant aspects in the areas of:

- Regulated Industrial Waste
- Hazardous Waste
- Radioactive Waste
- Mixed Waste, and
- Regulated Medical Waste

During a typical year of operations, the NSLS generates a few thousand pounds of hazardous or industrial wastes. Most of this waste results from used machine or cutting oils, but other types of chemical wastes (e.g., solvents, acids, caustics, and wastewaters with high concentrations of metals) also are produced. In a typical year, the NSLS generates less than 10 ft^3 of radioactive waste, and little mixed or medical wastes. Considering both the 2300 scientific users in the NSLS and the 1100 experiments that are run, the amount of waste generated is low. Many experiments generate no waste at all.

A number of controls are in place to assure proper management of wastes and to minimize hazards associated with these wastes.

- The NSLS Waste Manager oversees the satellite waste accumulation area (SAA) and manager program, and manages a 90-day area. SAA managers are required to read and sign NSLS Satellite Area Manager Job Specific Environmental Awareness Training.
- Experimental Safety reviews examine incoming chemicals and materials. Less toxic or less hazardous substitutes are recommended where possible. Reductions in volume are required as needed. Both of these combine to minimize wastes. NSLS ESH PRM 1.3.5a, Experiment Safety Review, provides guidance.
- Work at the NSLS is screened to ensure proper control of hazards and wastes. NSLS ESH PRM 1.3.6, NSLS Work Planning and Control Procedure, provides guidance.
- NSLS Safety Module informs users of the requirements for management of wastes at the NSLS.
- All persons generating and needing to dispose of hazardous wastes must take Hazardous Waste Generator Training.

- Quarterly Tier I safety inspections are a major factor in minimizing the volumes of chemicals brought to and stored within the NSLS, as well as the wastes generated. NSLS ESH PRM 1.2.0, Environmental, Safety and Health Inspections provides guidance.
- When needed, the NSLS Waste Manager may obtain additional assistance from the BNL Waste Management Division for laboratory clean outs.

Roof and parking lot drains as well as cooling tower blow-down empty into BNL's Outfall 005, located ~4827 feet southeast of the NSLS. There are no current requirements to monitor the quantity or chemistry of this outflow at the NSLS, however BNL monitors discharges for compliance with New York State SPDES permit discharge limitations assuring that cooling tower reagents are within permitted levels and examines levels of pH, oil and grease typically associated with parking lot runoff. Work planning, experimental review, Process Assessment Forms, Tier I safety inspections and spill response are methods for ensuring that hazardous effluents do not make their way into the sanitary waste stream.

Maintenance on the heat exchangers is conducted by personnel from BNL's Plant Engineering Division (EPD). The water in the heat exchangers is periodically discharged to the sanitary system. Since this is a discharge of potable water, it is acceptable to go to the sanitary system. Heat exchangers to which propylene glycol has been added are also drained to the sanitary system when put back into service. Discharge of a propylene glycol/water mix is within standard operating procedures for the Plant Engineering Department, and has been approved by BNL's Environmental & Waste Management Services Division (EWMSD).

The water that circulates through the cooling towers is treated with cooling tower reagents. According to the Chemical Management System (CMS), 100 gallons of each reagent type is stored in the Mechanical Equipment Rooms. These quantities are registered under Suffolk County Article 12. Blow-down from the cooling towers is discharged to the storm water system, and collects in BNL's SPDES permitted Outfall 005. This outfall also collects storm water runoff from the NSLS's parking lots, as well as from a number of other sources in the general area. The EWMSD monitors this outfall according to the parameters delineated in the SPDES permit, to assure that no adverse effects from the blow-down are seen at the outfall.

The closed loop cooling water systems include water piped to Building 725 directly from the BNL Central Chilled Water Facility (CCWF), Building 600. An exception to this is the supply of potable water (~10 gallons per minute) to Building 725's cold rooms. This is a single pass system emptying into the sanitary waste stream and operates only when the CCWF is down and not available to those rooms. Some closed loop systems contain deionized water. Rinse water from regenerating resins or descaling activities is segregated into waters that can be pH adjusted and disposed of into the sanitary waste stream, and those that must be disposed of as waste due to their elevated content of heavy metals. While some accelerator components become locally activated as a result of operations, this would not extend to the groundwater. Sampling of the NSLS accelerator closed-loop water systems has been conducted to confirm that tritium is below the minimum detectable level (Gmür 2001). Experiments using radioisotopes are highly controlled by specific facility procedures and the likelihood of these materials entering the sanitary or groundwater systems is remote due to these strict procedures.

As a result of on-going process evaluations and pollution prevention efforts, the NSLS continues to examine its waste streams to reduce them. A recent NSLS example of waste reduction is the installation of pre-deionizers on the make-up water lines to three cooling systems. These vendor-supplied cartridges deionize any water before it is added to process water-cooling systems. This action reduces the frequency with which the main deionizer columns must be regenerated, thus reducing the quantity of wastewater produced as industrial waste. A reduction in P^{32} radioactive waste has also been instituted. All P^{32} wastes are allowed to decay-in-storage for 10 half-lives, i.e. ~5 months, by which time the waste may be discarded as non-radiological waste.

Many NSLS materials are recycled, such as paper products, cardboard, metals, wood, glass, cans, and laser printer cartridges. In a typical year, the NSLS recycles:

- ~90 cubic yards of metals;
- ~400 cubic yards of cardboard; and
- ~100 cubic yards of lumber.

4.3 Fire Hazards

Basic fire protection includes compliance with DOE fire protection orders as well as DOE required National Fire Protection Act's (NFPA) Standards for loss prevention goals. The NSLS is fully protected by a fire sprinkler system (except for the X-ray ring where combustibles are negligible). The accelerator and experimental floors have smoke detection, which is tied into the BNL site wide fire alarm system. Differing occupancies are separated into separate fire zones by fire barriers. Due to the operational nature of the accelerator and the experimental areas, separation of high valued equipment by significant fire barriers to reduce the values below $50 million in each area is not practical and is an accepted risk. Water supplies for automatic and manual fire suppression are provided by the well gridded and highly reliable BNL combination domestic/fire water supply system. The full time, on-site Fire/Rescue Group and mutual aid arrangements with local fire departments provide manual fire fighting capabilities. The means of egress for the NSLS is in significant compliance with NFPA 101. A pre-alarm system has been installed in the NSLS Control Room in order to minimize false alarms. Pre-alarms are enunciated only within the Control Room and at the Fire/Rescue Headquarters. This allows NSLS Operations Coordinators to locate the source of the alarm and determine with Fire/Rescue if an actual evacuation is required. In addition, annual fire evacuation drills are held to assure proper response by staff and users.

A detailed "Fire Protection Assessment/Fire Hazard Analysis" has been prepared by the BNL Fire Protection Engineer and is included as **Appendix 6**. The level of fire protection in the NSLS is classified as "improved risk", thereby meeting the objectives of DOE Order 420.1. While the NSLS is considered a high value property, the noncombustible construction of the building and the accelerator is expected to keep the dollar loss expectancy from any credible fire to below $250,000.

4.4 Natural Phenomena Hazards

Significant Natural Phenomena Events (NPE) including high winds, flooding and seismic were investigated and documented during the Accelerator Implementation Plan submittal in 1994 and documented in that plan entitled "DOE Accelerator Order 5480.25 Implementation Plan for BNL Natural Phenomena Hazards Evaluation". The conclusion was that all the BNL Accelerator facilities including NSLS were built to the appropriate national consensus codes and standards at the time of their construction. Furthermore all accelerator facilities were determined to be low hazard and Performance Category 2 (as per DOE STD-1021-93). The NSLS contains small quantities of activated, radioactive or hazardous chemical materials. Should a Natural Phenomenon Hazard Event cause significant damage, the impact would be mission related and not create a hazard to the public or the environment.

Severe weather events such as thunderstorms, lightning, rainstorms and associated flooding, snowstorms, and ice storms do occasionally occur, and have the potential to cause significant damage resulting in an operational emergency. However, such events at the NSLS would not involve a significant release of or loss of operational control of a hazardous or radiological material. Typical severe weather-related phenomena affect the stability of the electrical power supplied to the NSLS Complex. This impacts the stability of the accelerator magnet power supplies and may result in the loss of the stored electron beam in the accelerators. Shielding protects personnel from such losses. If BNL declares a weather-related operational emergency recommending that staff evacuate the site, ring operators would turn off all accelerators. To date the NSLS Complex has suffered minimal impacts from extreme weather. These include the incursion of rainwater (roof leaks and flooding under doors) and loss of some exterior wall panels. Flooding could increase the potential for electrical hazards. Depending on the extent of the flooding, in area and in height, there is some potential for chemical and lead contamination of the water. There would be no potential for radiological contamination of that flood water. The electrical hazards are mitigated by having electrical equipment mounted on platforms or in racks above the floor level, maintaining sumps (pumps powered by the emergency generator) and providing drainage throughout the facility that prevents water accumulating in depth. Chemical hazards are mitigated by having chemicals stored in cabinets and on shelving above the floor away from the water. In addition, custodians damp mop of the facility's floor surfaces to reduce the build-up of dusts and other materials. Earthquakes on Long Island are extremely rare.

It should be noted that the free-standing walls that constitute the VUV ring shielding (see Section 3.5.1 above) have been designed and braced in accordance with appropriate sections of the 1997 Uniform Building Code to reduce the chance of failure should a seismic event occur.

4.5 Electrical Hazards

Prevention of injuries to personnel through electrical shock and arc flash burns is of paramount importance. Also important to the scientific mission of the NSLS and its user community is the prevention of electrical faults that could damage equipment to the extent of impacting operation. Section 3.2.2 above outlines the NSLS electrical power system. A number of controls are in place to prevent the above conditions and to minimize electrical hazards.

- Proper engineering design is utilized for systems and components over 50V to eliminate any accidental contact with them while they are energized. Where possible, systems are designed to operate at low voltage, e.g. interlock control systems at 24V. NSLS ESH PRM 1.5.2, Standards for Use of Coaxial Cables and Connectors in Signal and High Voltage Systems by NSLS Users and Staff, provides additional guidance.
- Much of the equipment in use at the facility is special purpose and not commonly found in other industrial facilities. In many cases, the equipment has been designed and assembled utilizing NSLS specifications. Although work place experience with this equipment has been very good from a safety and operational perspective, a program has been established to inspect all equipment that is not labeled by a Nationally Recognized Testing Lab (NRTL). These inspections will be performed by designated and approved staff members who will examine all unlabeled equipment to confirm that it is free from reasonably-foreseeable risk due to electrical hazards. This program applies to all electrical equipment built, acquired, or brought to the NSLS by workers, guests and contractors.
- All personnel working with electrical equipment must be qualified by their supervisor to work safely with the equipment. In conjunction with the supervisor, the NSLS Training Coordinator develops Job Training Assessments for staff and users which specifies the training requirements for each electrical worker. . NSLS ESH PRM 1.5.0, Electrical Safety, provides guidance. Each NSLS group, in addition, develops its own set of on-the-job training requirements which are documented as defined in the NSLS work qualification program.

- Work at the NSLS is screened to ensure proper control of hazards and wastes. NSLS ESH PRM 1.3.6, NSLS Work Planning and Control Procedure, provides guidance. Any work requiring access to energized circuits will be subject to the requirements of NSLS ESH PRM 1.5.0, Electrical Safety, BNL Standard 1.5.0, Electrical Safety, and NFPA 70E. NSLS staff is permitted to perform limited energized work. NSLS staff is limited to LOTO zero energy verification and troubleshooting, using appropriate personal protective equipment, up to the following voltages (240 Vac/750 Vdc). LOTO zero energy verification and troubleshooting above (240 Vac/750 Vdc) requires the use of BNL EP Electricians or the use of an approved NSLS procedure. Lockout/Tagout procedure shall be used when maintenance or construction is performed on equipment that has the potential for exposing personnel to electrical shock or to other hazards produced by mechanical or stored energy sources. NSLS ESH PRM 1.5.1, Lockout/Tagout Requirements, provides guidance**.** All personnel conducting LOTO activities or work with exposed energized conductors must be performed in accordance with an electrical work permit. Written procedures are established for more complicated activities to guide personnel to safe operation, maintenance or access for areas with electrical hazards.

- Kirk locks are used as part of an electrical safety interlock system to assure that access to high voltage and/or high current equipment takes place under controlled circumstances. NSLS ESH PRM 1.5.3, Interlock Safety, provides guidance.
- A labeling program is used to identify distribution panels and disconnect switches and their sources of power. This information is maintained in the Master Equipment List database.
- A labeling program is also used to identify hazardous equipment (electrical & mechanical) throughout the facility. The equipment has been labeled with the appropriate hazard label and the equipment has been inventoried in a database.
- Tier I safety inspections incorporate a significant electrical safety component. NSLS ESH PRM 1.2.0, Environmental, Safety and Health Inspections, provides guidance. An NSLS Electrical Safety Officer, assigned by the NSLS Chairman, assists in Tier I inspections and provides interpretation in the requirements of PRM 1.5.0.
- Electrical systems undergo preventive maintenance as scheduled by BNL Plant Engineering (major systems such as substations and the emergency generator) or by the NSLS MARTI (Maintenance and Repair Tracking Information system) database.

4.6 Cryogenic and Oxygen Deficiency Hazards

Typical compressed gases in use at the NSLS include nitrogen, helium and argon. The quantities of inert gases in use present no significant Oxygen Deficiency Hazard (ODH) risk. Liquid nitrogen and liquid helium are routinely used at the beam lines in support of the experimental program. This use of cryogen involves limited quantities of material in large volume, well-ventilated areas and presents little ODH risk. Areas that contain significant volumes of cryogen that can present ODH concerns include the LEGS Cryo-room (1-169), MER A, and the liquid nitrogen fill station (West Roll-Up door area). These locations have been evaluated in accordance with BNL SBMS requirements by the BNL Cryogenic Safety Committee and equipped with oxygen sensors, alarms, interlocks and signs as appropriate to control and minimize risks to personnel.

- NSLS guidance to staff and users on compressed gases, cryogens, oxygen-deficient atmospheres and over-pressurization is given in the NSLS Safety Module.
- Additional training, as determined by the NSLS Training Coordinator and supervisors through Job Training Assessments, is available as Compressed Gas Safety Training, Cryogen Safety Awareness, and Oxygen Deficiency Hazard Training.
- The description of NSLS Oxygen Deficiency Hazard alarm systems and the Operations Group (Control Room) response to alarms from these monitoring systems is described in the procedure entitled, "Oxygen Deficiency Hazard (ODH) Alarms in Bldg. 725", LS-OPS-0049.
- Maintenance of these systems is described in the, "Oxygen Monitoring Systems Preventive Maintenance and Functional Interlock Test Procedure", LS-M-0310.
- Detailed BNL guidance is available through SBMS in ESH Standard 1.4.0 Compressed Gas Cylinder Safety, the Cryogenics Safety Subject Area and the ODH System Classification and Controls Subject Area.

4.7 Confined Spaces Hazards

The NSLS manages a number of Class 2A confined spaces. While it is desirable to keep any confined spaces in this category, this could change in the future with experiment and building developments. A number of confined spaces are managed by Plant Engineering, and not controlled or accessed by NSLS personnel. These include sump pump pits and HVAC interior duct work access ports. The following web links provide additional information.

- LS-ESH-PRM-2.2.4 Confined Spaces provides guidance to managing confined spaces at the NSLS. This PRM also lists, in its attachments, the confined spaces that are documented and managed by the NSLS.
- NSLS Safety Module informs trainees that work involving confined spaces requires additional work permits and/or training.
- Confined Space Entry (HP-OSH-016) classroom training is available for Class 2 confined spaces through the BNL Training and Qualifications Office.

4.8 Chemical and Other Experiment Material Hazards

Researchers conduct some 1100 experiments per year at the NSLS, covering a very broad range of topics. All experiments conducted at the NSLS require prior review and approval by the NSLS Experiment Review Coordinator (ERC) through use of the NSLS Safety Approval Form (SAF). The following information is required to be included in the SAF.

- Materials and their quantities brought to the NSLS are listed. The ERC has the opportunity to require less hazardous substitutes, minimize quantities, and require registration of the chemicals with the BNL Chemical Management System (CMS).
- A description of the experiment equipment and the process task and hazard analysis is provided. This allows the ERC to review and require controls on such variables as pressure, temperature, shielding, exhaust systems, electrical systems, magnetic fields, full-time attended operations, etc, and to specify additional training that will be required by the user
- A listing is required for the presence/use of human bodily materials, biohazards, radioactive materials, lasers, wet chemistry, magnetic equipment or samples, and electrical equipment. The use of these items may invoke additional reviews:
  - review by the BNL Institutional Review Board for the use of human bodily materials and by the Institutional Animal Use and Care Committee for the use of live animals;
  - review by the Institutional Biosafety Committee for the use of biohazards;
  - development of a Radiological Work Permit for the use of radiological samples.
- A list of wastes is provided to determine the hazards involved and training requirements for the disposal of those wastes.
- At any time, if the ERC requires additional expertise and input for an experiment review, assistance may be obtained from NSLS ESH Committee members, BNL staff members and experts from other institutions.

Requirements for use, storage, and disposal of chemicals by NSLS staff member are defined in the NSLS-PRM 2.1.2. Use of chemicals are controlled through work planning requirements and monitored through the NSLS Tier 1 inspection program.

4.9 Ozone Hazards

White synchrotron radiation (raw, broad spectrum) produced by the X-ray ring dipole bending magnets and certain insertion devices can generate significant ozone levels when the unattenuated beam is allowed to pass through air. In some instances, ozone concentrations may approach or exceed the ACGIH Threshold Limit Values for ozone and precautions are needed to control potential exposures.

Transmission of the synchrotron beams from the storage ring to the experimental endstations occurs within either vacuum enclosures or enclosures containing an inert gas. These beam paths present no ozone concern. The experimental endstations are enclosed in metal hutches that act as both an exclusion zone and radiation scatter shielding. For some experiments, the synchrotron beam passes through air within these hutches and that is where the ozone production can occur. The air path length, the energy spectrum, the flux, and the physical size of the beam determine the amount of ozone generated. Several configurations have been implemented to reduce or eliminate the production of ozone inside these hutches. An outline of those controls follows.

- The entire experiment can be contained within an evacuated or inert gas-filled chamber, thus the white beam does not pass through air.
- The white beam path can be contained within a "flight tube", i.e. a tube, sealed at both ends, under vacuum or filled with an inert gas, thus minimizing or eliminating exposure of the white beam to air.
- The beam dimensions can be minimized so that there is very little beam interacting with the air and the interactions are localized.
- If the experiment can tolerate such a change, the beam can be filtered to reduce the flux of the low X-ray energies that are responsible for the highest ozone production rates, i.e. use silicon to filter out the 3-15 keV X-rays, thus reducing the overall ozone production.
- The beam path length through air can be minimized and the air adjacent to the beam path can be scrubbed using an appropriate filter.
- Ozone concentrations generated by an experiment can be measured and a delayed entry time can be determined allowing the ozone concentration within the hutch to diminish; ozone is a reactive gas and will diminish over time.

4.10 Accelerator Hazards - Loss of Vacuum, Cooling Water and Compressed Air

Section 3 above describes the NSLS vacuum (Section 3.2.4), cooling water (Section 3.2.3.1) and compressed air systems (Section 3.2.3.4). All three of these systems have inherent mechanical hazards associated with their operation, maintenance and repair. These hazards are mitigated by assuring that personnel working on these systems have the appropriate levels of training, that procedures, where necessary, are available, and that maintenance schedules are followed.

These systems are integral to the proper operation of the accelerators and beamlines. Failure of any of these systems could potentially result in damage to the accelerators and/or the beamlines, and jeopardize the mission of the NSLS to provide stable beam to its users and staff. Safety systems are in place to protect the accelerators and beamlines, and assure a rapid return to operations.

4.10.1 Vacuum

Proper ring vacuum assures long stored electron bunch lifetimes and minimizes the generation of bremsstrahlung radiation. Proper beamline vacuum minimizes the loss of synchrotron beam intensity and reduces corrosion to beamline component surfaces. If a ring vacuum fault is detected, sector valves around the ring close to limit contamination (from air) to as small an area as possible. Beamline front end valves will also close. This automatically dumps the stored electron beam. A vacuum fault in a beamline front end closes that beamline's front end valve; in addition, the beamline's fast valve may also close if a shock wave is sensed further downstream. When a vacuum fault occurs along an X-ray beamline, user interlocks on that beamline close an upstream beamline valve. For insertion device beamlines, if the fast valve closes, the RF is dumped. Since the vacuum in a VUV beamline is contiguous with that in the VUV ring, a beamline vacuum fault is treated the same as a ring vacuum fault.

4.10.2 Cooling Water

Temperature regulation, controlled by various closed loops of cooling water, is necessary for the rings and beamlines to assure mechanical and beam stability, and to prevent overheating resulting in possible damage to components. If Proteus® units, located throughout the accelerators, sense a drop in flow, interlocks drop the RF, thus dumping the electron beam. On a beamline, a drop in flow would close the safety shutter. If elevated temperatures are sensed by Klixon® units on the ring pipe, crotches, photon shutters, safety shutters or water-cooled masks, the RF is dropped. A Klixon® sensing elevated temperature in a magnet will turn off the power supply to that magnet; the electron beam would dump as a result. Water temperature to the ring pipe (Aluminum system) is also sensed in the pump room itself; if measured high, then the RF and magnet power supplies are dumped.

4.10.3 Compressed Gas/Air

Pressure to all Granville-Phillips® front end valves is supplied from a 500 psi nitrogen gas source; the cylinders are maintained by NSLS staff. Compressed air (125 psi @ 100EF design pressure) is supplied by either the BNL Central Chilled Water Facility or by an in-house NSLS system, each automatically backing the other up if the first should fail. Compressed air operates the front end mask, safety shutter and arms of the fast valve. If compressed air systems fail, alarms will notify Control Room personnel to contact the cognizant technicians.

4.11 Material Handling Hazards

The NSLS facilities have a number of overhead cranes and other manual lifts/hoists. Use of these devices is rigorously controlled to ensure that only qualified and authorized personnel have access to them. The following controls are in place for cranes and hoists at the NSLS.

- Control of all lifting devices is maintained by pad-locks attached to each device.
- Personnel desiring authorization to use a crane unsupervised must complete laboratory specified training and pass a qualification "practical" exam conducted by NSLS crane expert. Personnel who have completed this qualification process are deemed "responsible" and are provided a key to the designated crane(s) and are permitted to use the crane without additional review.
- All "responsible" persons are required to conduct a documented review of the crane and lift conditions on a daily basis or prior to each use if the lifting device is infrequently used.
- Responsible persons are permitted to supervise the use of a crane by a person who has completed all Laboratory training, but has not acquired authorization from the NSLS crane expert to use a crane unsupervised. Such personnel are considered "trainees" and are only permitted use of the lifting device under the direct supervision of a responsible person.
- The NSLS Training Coordinator and the NSLS Crane Expert monitor training qualifications and authorizations.
- All cranes and hoists and associated equipment are reviewed and inspected on an annual basis as required by Lifting Safety Subject Area.

4.12 Noise Hazards

The NSLS supports a wide variety of equipment that produces a range of noise levels. Pumps, fans and machine shop devices, among others, are possible sources of noise levels that could exceed the BNL noise action level. Noise surveys and dosimetry are conducted in areas as well as at individual pieces of equipment. Based on the results, engineering or administrative controls, hearing conservation personal protective equipment, training, postings and additional medical surveillance may be required.

- The BNL SBMS Noise and Hearing Conservation Subject Area provides the basic guidance at the NSLS. Additional information is obtained from the SBMS Personal Protective Equipment Subject Area.
- A Noise and Hearing Conservation Training CBT is provided to those who qualify based on their work in noise areas.
- The NSLS work planning program considers noise hazards in its work permit evaluations and implements hearing protection requirements as needed. Noise levels are also considered as part of beamline and experiment reviews.
- The BNL Safety and Health Services Division industrial hygienists and the Radiological Control Division technicians provide the NSLS with noise level monitoring services.

4.13 Non-ionizing Radiation Hazards

4.13.1 RF and Microwave Hazards

The NSLS accelerators and storage rings depend on the reliable operation of both pulsed klystrons and continuous wave high power radio-frequency (RF) systems for electron injection and maintaining stored beam. Both of these types of devices generate electromagnetic radiation within the RF and microwave energy ranges (30 KHz - 300 GHz) and also have significant electrical hazards. These devices are operated and maintained such that these energies are well shielded and therefore do not thermally or electrically impact personnel working in their vicinity.

- LS-ESH-PRM-2.3.2, RF and Microwaves, provides the basic guidance for the NSLS.
- This guidance is based on the BNL SBMS Radiofrequency/Microwave Radiation Subject Area.
- An inventory of these devices is maintained and baseline sets of RF and microwave measurements have been made and documented. Significant changes to existing equipment or new devices are subject to documented RF measurements.

4.13.2 Magnetic Field Hazards

Devices generating magnetic fields have numerous and diverse uses at the NSLS. Sets of dipole, quadrupole, sextupole and trim electromagnets guide the electrons through the Linac, booster synchrotron and the VUV & X-ray storage rings. Magnetic insertion devices are used on the VUV and X-ray storage rings, and are explained in Section 3.3.4 above. Klystron assemblies employ permanent magnets of 1000 gauss at contact. Ion pumps in use on all evacuated accelerator and beamline pipes and chambers contain magnets of 1800 gauss at contact. Some experiments employ superconducting magnets rated up to 16 Tesla at their cores. The concern with all of these devices is the strength and extent of the fringe fields, and how these may impact persons and equipment in their vicinity. Of particular concern are fringe fields in excess of 5 gauss that could impact medical electronic devices (pacemakers) and fields in excess of 600 gauss that could impact ferromagnetic implants (artificial joints) and other materials (tools).

- The BNL Static Magnetic Fields Subject Area provides the basic guidance for the NSLS.
- A Static Magnetic Fields Training CBT is provided to those who qualify based on their work with magnets.
- The NSLS Safety Module Training CBT provides general guidance on magnetic fields to NSLS users.
- The NSLS Briefing Requirements for Visitors Under Escort forms and the clipboards they are attached to provide a warning that magnetic fields in excess of 5 gauss may be encountered and how to avoid them, if necessary.
- Magnetic field surveys have been conducted for the NSLS. Static Magnetic Fields Exposure Forms document various types of magnets in use.
- Postings alert personnel to local magnetic field hazards and conditions.

4.13.3 Laser Hazards

The NSLS employs Class 1, 2, 3a, 3b and 4 lasers. Many of these lasers occupy relatively permanent locations, while others form part of short-term beamline experiments and are in place for just days to weeks at a time. Lasers, particularly those in Class 3b and 4, have hazards associated with them including electrical, chemical, collateral radiation (including skin and eye damage), fire and explosion. This variety of hazards engenders rigorous oversight of laser operations at the NSLS.

- LS-ESH-PRM-2.3.1, Laser Safety Program Requirements, provides the basic guidelines for the NSLS.

- The above document is based on the guidance provided in the BNL Laser Safety Subject Area.
- A Laser Safety Training CBT is provided for those who qualify based on their work with lasers.
- BNL ESH Standard 1.5.3, Interlock Safety for Protection of Personnel, provides the interlock requirements for various laser classes.
- A General Laser Registration Form and Class 2/3a User Permit must be completed and submitted the BNL Laser Safety Officer.
- A Laser Controlled Area Standard Operating Procedure must be completed for Class 3b and 4 lasers, and submitted to the BNL Laser Safety Officer.
- The BNL Occupational Medicine Clinic requires pre-laser usage eye examinations for Class 3b and 4 lasers.

No Class 3a and Class 4 lasers are permitted to operate at the NSLS until the NSLS Safety Officer and the BNL Laser Safety Officer have reviewed training, procedures, and engineered safeguards and confirmed that all BNL requirements have been adequately addressed.

4.13.4 Visible Light Hazards

VUV and some X-ray beamlines may use the visible light portion of the synchrotron radiation spectrum to align optical components and check their focusing. To do this, light is brought through a glass window (typically Corning type 7056 borosilicate glass) that transmits wavelengths from 280 to 3000 nm, i.e. mostly in the visible spectrum, but including infrared and ultraviolet wavelengths. **Appendix 7** calculates the intensity of that visible, infrared and ultraviolet light. Administrative controls are implemented during normal beamline operation and during alignment. Viewports capable of transmitting the direct or reflected visible portion of the synchrotron beam shall normally be covered and the cover shall bear a caution sign. In the event that the visible beam is required for alignment purposes, the area traversed by the beam is roped off, preventing inadvertent access, and backstopped within the roped off area. Caution signs are placed along the barriers. In addition, all alignments using visible light require the submission of a Safety Approval Form. No unattended operations are allowed during alignment using visible light.

4.14 Ionizing Radiation Hazards

4.14.1 Introduction

Ionizing radiation hazards associated with a high-energy electron beam are significant and must be carefully considered. The electron beam is accelerated and transported within vacuum systems, but significant fractions of the beam are lost in the acceleration cycle and eventually all the beam is permitted to strike the walls of the vacuum chamber or other components in the ring when the stored beam is dumped. Whenever high-energy electrons strike matter, whether on a beam collimator or the side of vacuum pipe, secondary fields of photons and neutrons are produced. Such beam losses occur in the linac, booster, storage rings, and in transport regions. In general, the unshielded secondary radiation fields from such losses are dominated by photons, particularly in the more forward direction from beam loss points. As a consequence, lead shielding is particularly important as the principal mechanism to reduce secondary radiation fields around beam loss points. As a result of lead shielding, neutrons often dominate the secondary fields in occupied areas.

Neutrons produced through electron interactions are principally lower energy (E < 25 MeV) which is rapidly reduced to a few MeV by concrete or other hydrogenous material (e.g. polyethylene). Neutron spectral studies (Presig, 1993, 1994) have been conducted on several occasions to examine the energy spectrum and have shown that the average neutron energy is about 1 MeV, but that the bulk of the dose equivalent is delivered by neutrons in the range from 7 to 15 MeV.

In addition, the NSLS experimental beam lines contain intense photon beams produced by synchrotron radiation and there is potential for exposure from scattered radiation from the photon interactions with collimators, windows, mirrors, monochromators, samples or other objects placed in the beam path. It should be noted that while the photon beams are very intense, they are easily shielded and confined because of low photon energies.

It also should be noted that the total energy of the electron beam stored in either ring is low. Therefore, there is much less potential for exposure from activation of beamline components compared to high-energy proton machines such as the BNL Alternating Gradient Synchrotron (AGS) or high power electron machines such as the SLAC 20 GeV linear accelerator at the Stanford Linear Accelerator Center. The highest levels observed from induced activity at the NSLS are typically in the few tens of micro-R/hr at contact with a few locations at a few millirem/hour.

The level of hazards and their associated controls will be discussed for each of the radiological sources at NSLS. All of these sources must be considered when designing new features or modifying existing components; shielding must be provided to maintain exposures within standards and as low as reasonably achievable. It should be noted that the NSLS rings have operated successfully for more than 20 years with minimal exposure to personnel within the facility and the environment.

Because the overall power associated with the NSLS beams is very small compared to that associated with a high intensity accelerator such as the AGS, other hazards controlled at such machines are insignificant at the NSLS. Hazards included in this category are:

- Exposure to residual radiation induced in machine components and beam dumps.
- Inadvertent release of activated cooling water to the environment.
- Inadvertent release of radioactive contamination to groundwater by allowing rainwater to leach through activated soil.
- Exposure to activated air.

The past history of the NSLS and calculations demonstrate the insignificance of these hazards and the need for only minimal controls will be discussed.

4.14.2 Radiological Hazards Associated with the Linac and Booster

As described in section 3.3, the storage rings are periodically filled using the injection system consisting of the 100 keV electron gun, the 150 MeV linac and the 1 GeV booster. The accelerated electron beams are extracted from the Booster synchrotron and are transported into either the VUV or X-ray ring. The standard operating parameters for the injection system are shown in the table below.

Table 1. Injection System Operating Conditions at 1.2 Hz

Component	Maximum Energy	Pulse Length	Pulses per cycle	Maximum electrons/sec
Electron Gun	100 keV	4 nS	7	8×10^{10}
Linac	150[1] MeV	2.5 μS	1	4×10^{10}
Booster	1000[1] MeV	~ 10 nS	1	1×10^{10}
Transport to Rings	1000 MeV	~ 10 nS	1	5×10^{9}

Because of significant losses during the acceleration and injection process, typically only a few percent of the useful beam initially created by the electron gun is eventually captured in a storage ring orbit. Beam loss points in the injection cycle are well known and primarily occur at the locations identified in the table below. Lead and concrete shielding has been added to these locations over the operating history of the NSLS to reduce radiation levels in near-by work areas, particularly in the second floor offices above the Linac and Booster. Radiation levels shown in Table 2 are based on the identified electron losses and represent conservatively calculated dose rates through the shielding provided at each of the listed locations. As can be noted, radiation levels in occupied areas created during Linac or Booster operations are low and result in few areas requiring posting as a "Radiation Area." However, extensive procedures and practices (described in Section 4.14.7) have been established to maintain radiation exposure to personnel as low as reasonably achievable.

Table 2. Linac and Booster Beam Typical Losses and Conservative Case Radiation Levels[1]

Loss Point	Electron energy	Fraction of Beam lost	Electrons/sec lost	mrem/hr [2] @ 1 m	mrem/hr in 2nd floor office

[1] The normal linac energy is 116 MeV and the normal booster energy is 750 MeV. The calculations in this document have been performed at 150 MeV and 1 GeV respectively to allow for increased energy if desired in the future.

Linac (1st section)	~ 3 MeV	50%	4×10^{10}	2.5	69×10^{-3}
Linac (3rd section)	150 MeV	25%	1×10^{10}	47	0.8
Momentum Slit	150 MeV	50%	1.5×10^{10}	0.05 [3]	0.003
Booster Injection	150 MeV	50%	1×10^{10} [4]	5.8	90×10^{-3}
Booster Extraction	1000 MeV	50%	5×10^{9} [5]	76	1.3

4.14.3 Radiation Hazards Associated with the Storage Rings

The X-ray and VUV storage rings operate in a similar way. Following extraction and transfer of a single bunch from the booster to the injection septum of the storage ring, individual Booster pulses are injected into awaiting RF buckets in the storage ring in order to achieve a predetermined bunch fill pattern and to reach a predetermined circulating beam current. Repeated injection will fill the rings to a level determined by programmatic requirements or machine conditions such as the ring vacuum, or a beam-related instability.

The injection process into either ring is inefficient with typically 50% of the transported beam being lost on the injection magnet septum and other points located around the ring where the dispersion about the central orbit is greatest. In the VUV ring, the injection septum is shielded with at least 4" of lead and 12" of concrete. The X-ray ring is located within a concrete enclosure with 18" of concrete and an additional 2" of lead at injection. The results of the calculations noted below indicate radiation levels of about 10-20 mrem/hr at 1 m at the injection point. Actual radiation levels are less than these calculated values. Calculated and measured radiation levels at other locations during injection are less than these values.

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[1] The normal linac energy is 116 MeV and the normal booster energy is 750 MeV. The calculations in this document have been performed at 150 MeV and 1 GeV respectively to allow for increased energy if desired in the future.

[2] Radiation levels are calculated vertically at 90^{o} to an assumed electron loss at a single point through local shielding installed at each loss point. The calculations are conservative since losses are typically scattered along the beam path after an initial interaction rather than lost at a single point. These loss points are within an interlocked enclosure, but are useful as an upper estimate of source terms for radiation levels in occupied areas. Calculations are performed using the shield code Shield11 (Nelson and Jenkins, 2005). Shield11 is an analytic code developed at SLAC that has been used extensively throughout the accelerator community for shielding electron accelerators in this energy range.

[3] Because of the thickness of the shield, this dose rate is shown at 2 m.

[4] All Booster injection losses are conservatively assumed to occur only on the booster injection septum. In fact, losses will also occur in distributed locations around the booster ring.

[5] All Booster extraction losses are conservatively assumed to occur on the booster extraction septum. In fact, losses will also occur in distributed locations around the booster ring.

Table 3. Calculated Radiation Levels through Lateral Ring Shielding During Injection (All Losses on Injection Septum and Energy of 1 GeV Assumed)

Ring	Shielding Configuration	Assumed Injection Losses	Loss Rate e/s	Radiation Level through Shield (mrem/hr)
X-ray Ring Injection	2" lead 18" concrete	50%	2.5×10^9	11
VUV Ring Injection	4" lead 12" concrete	50%	2.5×10^9	19

Following storage in the rings, the circulating electron current will slowly diminish as the result of various processes which cause an electron to scatter from its central orbit and strike the vacuum pipe or other aperture within the ring. At an energy of 800 MeV, the VUV Ring operates with a maximum current of 1000 mA and typically a 4-hour beam lifetime. The shielding of the VUV ring in non-injection regions is highly variable, consisting of 2" – 4" of lead bricks and/or 8" – 12" of high density concrete in most locations. The X-ray ring operates at a maximum current of 300 mA (@ 2.8 GeV) with lifetimes typically ~ 20 hours. X-ray ring shielding is described above. Calculated radiation levels associated with normal operation and beam dumps are shown below.

Table 4. Calculated Radiation Levels through Lateral Ring Shielding from Normal Operation and from Beam Dump

Ring	Energy[6] (GeV)	Stored Beam Current[6] (mA)	Assumed Beam Life-time (hours)	Average Dose Rate at 1 m during stored beam [7] (mrem/hr)	Dose at 1 m from loss of full beam [8] (mrem)
VUV	0.8	1000	4	0.2 – 1.4	4.9 - 35
X-ray	2.8	300	12	0.03 – 0.07	3.8 – 11.3

Radiation levels created in occupied areas exterior to the shielding during storage ring operations are low and result in few areas requiring posting as a "Radiation Area".

4.14.4 Radiological Hazards Associated with Beam Line Operations

The experimental beam lines are positioned in such a manner that their centerlines are tangential to the electron orbit in the dipole or insertion device magnets within the storage rings. Thus, synchrotron radiation, generated when the high-energy electrons are bent by the magnetic fields of dipole or insertion devices, emerges through the beam port of the storage ring and into one or more individual beam lines where the radiation is used for experimental purposes. Insertion device (undulator and wiggler) beam lines are located in line with the available straight section in the magnet lattice.

The front end of each beam line is very similar in make-up and consists of a water-cooled photon mask, a fast-acting vacuum valve, an ultra-high vacuum valve and a safety shutter (see **Figure 7**). The water-cooled mask is interlocked with the ultrahigh vacuum valve and is used to protect it from overheating when closed. The safety shutter is designed to render the beam line safe for access and must be closed whenever there is access to the downstream portion of the beamline or when injection into the ring is taking place. An exception to this is for monochromatic beamlines in which the closure of a supplementary photon shutter is used to protect downstream beamline access.

Because of the low energy of the photons in the VUV Storage Ring, the photon beam remains in a contiguous vacuum all the way to the experimental chamber. In the X-ray Storage Ring the photon beam may, in some experiments, pass through a beryllium window into air or rough vacuum before reaching the experiment.

The principal radiological hazards during beam line operations are associated with:

[6] Energy and beam current are based on Table 7 in 4.14.8. Dose rates at 0.8 GeV (VUV) and 2.8 GeV (X-ray) are higher because of higher allowed beam currents.
[7] Beam loss assumed to be equally distributed at each high dispersive point. Losses are assumed to be linear throughout beam life-time
[8] Loss of maximum beam at a single thick target is assumed.

1. Electron beam injection into the storage ring,
2. Bremsstrahlung radiation produced from electron interactions with residual gas molecules in the ring vacuum chamber or other materials
3. Synchrotron radiation produced by the bending magnets or the wiggler/undulators.

Each will be considered separately.

4.14.4.1 Injection

It is assumed that beam injected into either of the storage rings could accidentally be directed into a photon beam line as a result of a fault in one of the dipole magnet bending magnets. Therefore, it is required that a safety shutter (see **Figure 7**) be inserted into each beam line whenever injection is taking place into the storage ring. Safety shutters must be a minimum of 8" of lead (see **Appendix 2**) and the position of the safety shutter (in/out) must be sensed by a minimum of two independent and redundant switches interlocked to the injection system. If the switches are not satisfied that the safety shutter is in position to block beam down a beam line during injection, the machine is

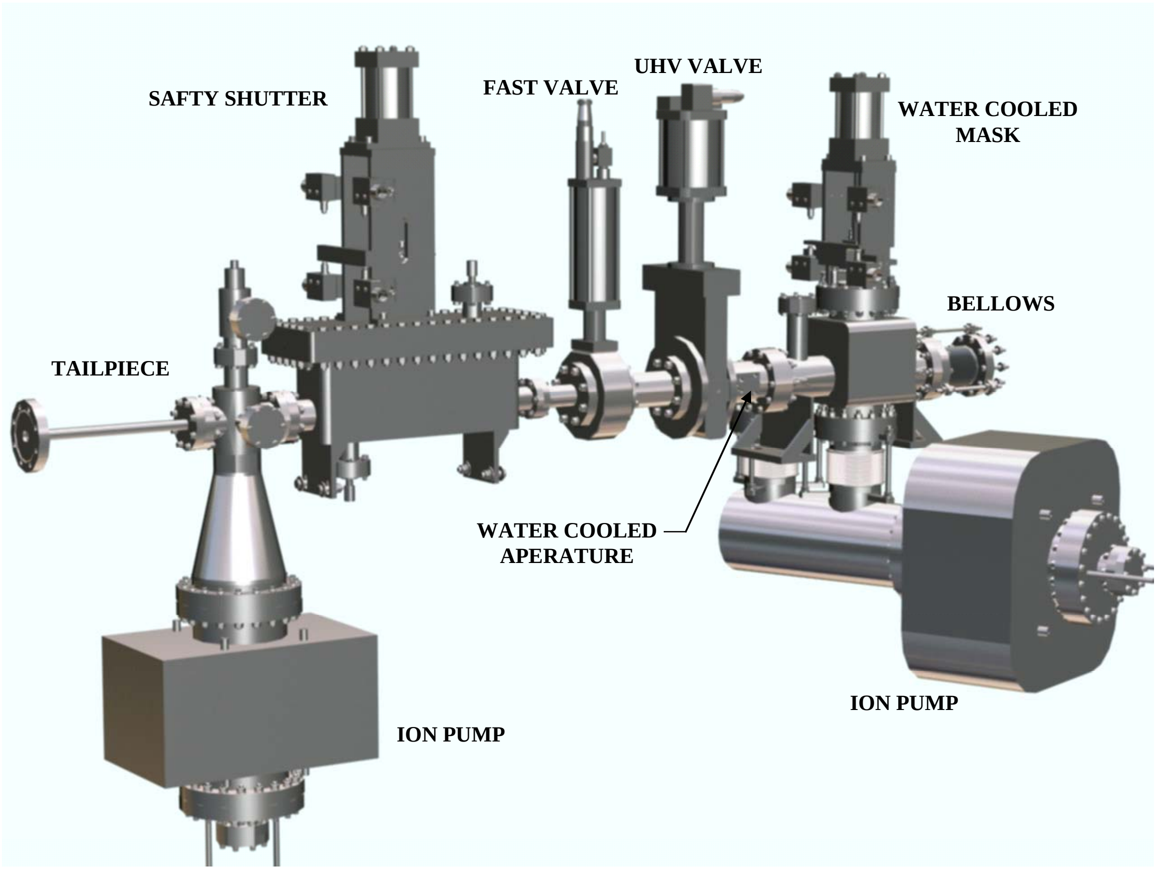

Figure 7: Diagram of X29 beamline front end (direction of synchrotron beam is right to left)

interlocked off. The safety shutters are located near the front end of the each beam line and are always within the shielded enclosure of the X-ray ring. To protect the safety shutter from synchrotron radiation heating, a water-cooled mask is also inserted upstream of the shutter.

4.14.4.2 Bremsstrahlung

Bremsstrahlung represents a potentially significant radiological source term and is produced from the interaction of the circulating electrons with gas molecules in the vacuum pipe or other thin targets that may be introduced into this space. Bremsstrahlung radiation is highly peaked in the forward direction, and for a given electron beam energy is directly proportional to the stored current and the gas pressure in the ring section that electrons pass through. Gas bremsstrahlung is more important for undulator and wiggler beam lines which are tangent to the straight sections in the ring, thereby providing longer flight paths for bremsstrahlung production for the circulating electrons.

Bremsstrahlung in the forward direction must be thickly shielded with lead (or other dense high Z material) to control personnel exposure in occupied areas during normal or abnormal operation. To ensure the adequacy of shielding, each beam line is examined as described in **Appendix 3**. In this analysis, the bremsstrahlung shielding is evaluated by conducting ray traces down the beam line to confirm that adequate lead shielding is provided between any position that a person could occupy on the experimental floor and the bremsstrahlung source. Pb shields for bremsstrahlung γ-rays must provide at least 8 inches along the longitudinal path, and transversely at least 2 inches beyond the outermost rays. The basis for these dimensions is established in **Appendix 2**. Exclusion zones are erected to prevent personnel exposure wherever bremsstrahlung trajectories leave the confines of beam pipes, shields, or other components.

4.14.4.3 Synchrotron Radiation

The synchrotron radiation created in the VUV and X-ray storage rings represents very severe radiological hazards for exposure to a direct beam. The synchrotron radiation is produced by bending magnets or by the wigglers or undulators. Radiation levels in the direct beam from a bending magnet (this synchrotron radiation source is less intense than that from a wiggler or an undulator) exceed 10^9 rad/hr. The beam is small, typically a few centimeters in width and less than a centimeter in height, and has a broad spectrum of photon energy. In the VUV ring, the synchrotron radiation generated by the bending magnets has a useful fluence in the energy range from 10 eV up to a few keV (see **Figure 8**). In the X-ray ring, the useful spectrum ranges from 100 eV up to about 20 keV. The beam in either ring must be securely enclosed to prevent any personnel access to the direct beam. In addition, in the X-ray ring, scattered radiation from beam interactions with windows and beam line components can produce significant radiation fields that must be considered.

The full spectrum of photons emitted from a bending magnet or wiggler is commonly called the “white beam”. White beams constitute the greatest radiological hazards and require the greatest shielding and cooling because they contain the total power of the

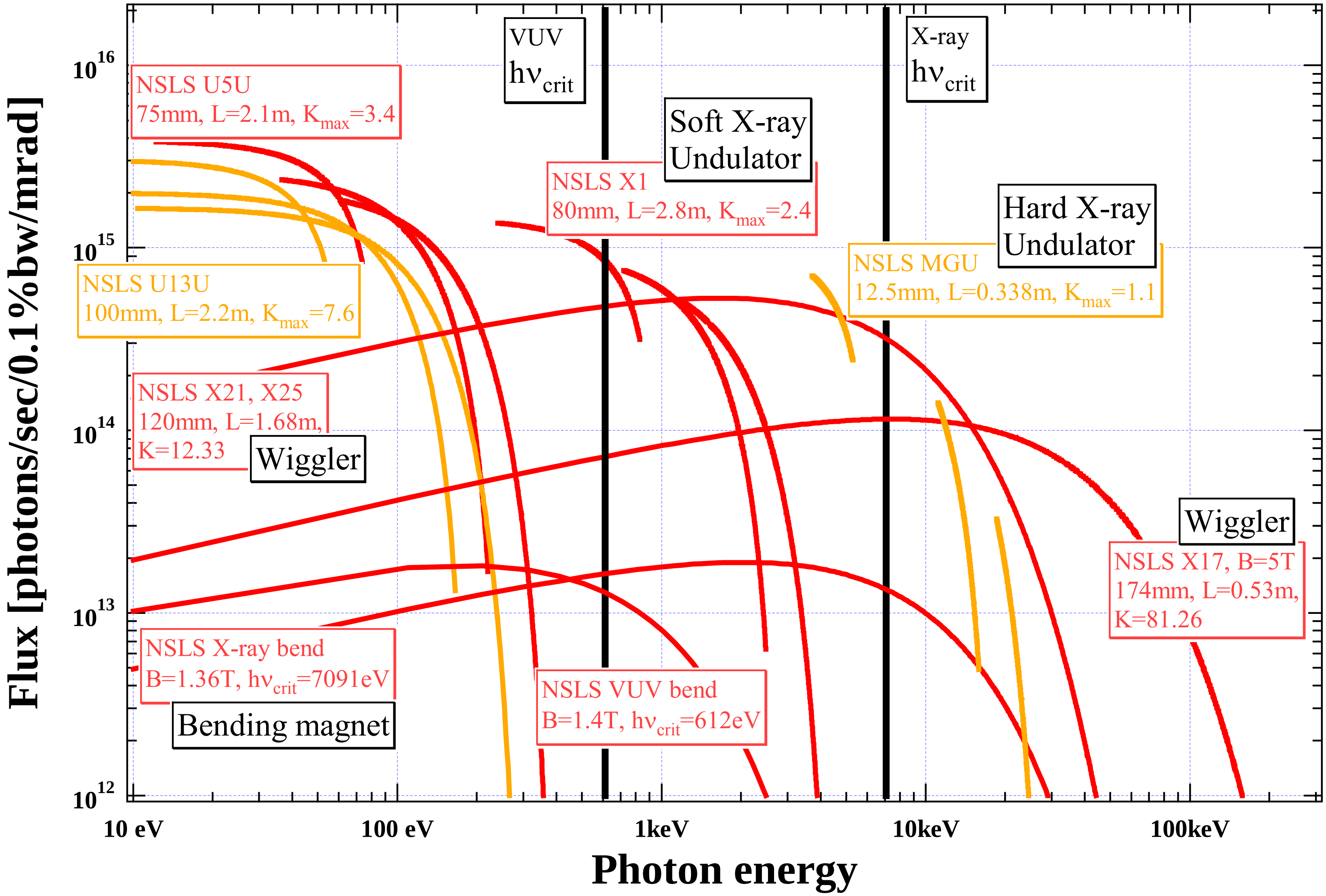

Figure 8: Synchrotron radiation spectra from various NSLS magnets (VUV Ring @ 1000 mA, X-ray Ring @ 300 mA)

emitted synchrotron radiation. In some beam lines, the white beam will be further focused for monochromators through use of mirrors. Such focusing will result in loss of the higher energy components of the white beam. This type of beam is typically called a "pink" beam. Such beams will require additional shielding at beam scatter points, but typically less than that found for "white" beams.

Commonly the research conducted at a beam line requires a monochromatic beam produced by the diffraction of the white or pink beam off a silicon crystal. Monochromators appear in practically all beam lines at the NSLS.

The characteristics and magnitude of hazards for the different synchrotron radiation sources are different and will be discussed separately.

4.14.4.3.1 Synchrotron radiation from bending magnets

Synchrotron radiation from bending magnets has a broad continuous spectrum determined by the strength of the magnetic field and the energy of the electron. The spectrum of synchrotron radiation sources in use at the NSLS is shown in **Figure 8**. Such spectra are characterized by their critical wavelength. The critical wavelength (or energy) has the property that one-half of the power is radiated above this wavelength and one-half below.

In the VUV ring (assuming an upper electron energy of 1 GeV), the critical wavelength (λ_c) is ~10.6 Å and critical energy ~1180 eV. Photons in this energy range are not penetrating and will not penetrate typical thicknesses of vacuum pipe and vacuum windows. Therefore, radiological hazards are confined within the vacuum pipe. In general, all experiments are conducted within the vacuum chamber.

In the X-ray ring (assuming an upper energy of 3 GeV), the critical wavelength from a bend is approximately 1.6 Å (critical energy ~ 7.5 keV). At the critical wavelength, the photon intensity is greater than 10^{14} photons/second. Although much reduced in intensity (e.g. ~ 10^{12} photons/second at ~ 0.1 Å) compared to that near the critical wavelength, there are higher energy photons which are considerably more penetrating. Studies performed by the Radiological Control Division (**Appendix 8**) show that scattered radiation penetrating through vacuum pipe and view ports primarily consists of photons with energy greater than 50 keV. All scattering surfaces that the photons encounter must be evaluated and shielded accordingly. The table below provides examples of calculated scattered radiation levels from several types of surfaces. Calculations are performed using the shielding code "Photon" [9] and represent scattering 1 m from the scatter point at 90°. As would be expected, the scattered radiation is low energy and is readily shielded with small amounts of lead.

[9] "Photon: A Program for Synchrotron Radiation Dose Calculations; Nuclear Instruments and Methods in Physics Research"; A266 (1988)p. 191-194

Table 5. Examples of NSLS X-ray Bending Magnet Scatter Calculations[10] Using Photon
Estimated Dose values in millirads/hour at 1 meter from scattering surface

Scatterers and Shielding	Ring Conditions 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	.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

As can be seen from the table, the scatter from surfaces in a "White Beam Hutch" is a significant radiation source at the higher electron energies and will require 1/8" to 3/16" thick lead sheet lining to control radiation levels in occupied areas.

4.14.4.3.2 Synchrotron Radiation from Insertion Devices

Straight sections available in both the x-ray and VUV ring can be used to accommodate special magnets called "wigglers" or "undulators". These insertion devices are used to increase the photon intensity by subjecting the electron to numerous bends as they traverse the length of the magnet. Depending upon the strength of the magnetic fields and the distance between magnetic poles, the critical wavelength of the synchrotron radiation spectrum can be made harder or softer. **Figure 8** shows the flux and spectrum from the wigglers and undulators in use at the NSLS, as well as that from the bending magnets in the VUV and X-ray rings. As can be seen, the insertion device beam lines have higher flux and therefore greater potential for scattered radiation than bending magnet beam lines. (see **Appendix 9** and the table below)

[10] Beam size is 6 mrad horizontal and 0.8 mrad full vertical beam size

Table 6. Examples of Calculated Radiation Levels Produced by Scatter from an Insertion Device Beam Line assuming 250 mA Stored Beam
Dose Rates in mRads/hr at 4" through a
Vacuum Wall – 1/8" Stainless Steel

Scattering Surface	2.5 GeV Electron Energy	2.8 GeV Electron Energy
10 mil beryllium window	77	910
+ 1/16" lead	0.008	0.32
thick silicon surface	4800	64000
+ 1/16" lead	0.89	36
+ 1/8" lead	0.005	0.32
thick copper surface	810	12000
+ 1/16" lead	0.24	10
+ 1/8" lead	0.002	0.11

4.14.4.3.3 Superconducting Wigglers
Radiation levels associated with the superconducting wiggler used in the X-17 beam lines are a very special case. As can be seen in **Figure 8**, the much higher magnetic field strength (~ 5 tesla) associated with this wiggler produces a synchrotron radiation spectrum with a critical energy greater than 20 keV and with much higher photon fluences. The higher energy and fluence of the scattered radiation creates higher radiation fields around all scattering points (e.g. windows, monochromators, samples) and requires a significantly greater amount of steel and lead shielding. **Appendix 10**, shows the results of radiation calculations performed for scattered radiation produced at the X-17 beam line. As a result of the high scattered levels, shielded and interlocked hutches are provided around all beam line components between the front-end and the experimental area hutch. The shielding of the hutch was specified as ¼" lead and ¼" steel. Additional shielding is provided as needed at strong scatter points. Radiation levels outside the transport hutch were < 0.1 mR/hr following the shielding.

The intense radiation fields also result in a much higher heat load associated with the superconducting wiggler output. The total power radiated at a ring current of 250 mA is greater than 13 kW. A detailed analysis of all surfaces that the beam interacts with was performed to ensure that adequate cooling was provided. More details regarding superconducting wigglers are provided in **Appendix 10**.

4.14.5 Beam Stops for Synchrotron Radiation Beam Lines
As was described in the discussion of bremsstrahlung radiation, a minimum of 8" thick lead stop (or equivalent) is required for all locations on the experimental floor which have a line of sight view back into the storage ring. Therefore, all white beam lines must

terminate with the 8” lead stop. The 8” of lead is more than adequate to handle any of the synchrotron radiation beams. Whenever white beam strikes a mirror or monochromator, a bremsstrahlung stop may be required at the rear of the interaction point if the downstream area does not have a bremsstrahlung stop. Such beam lines may have sufficient deflections that the transmitted photon beam no longer has a line of sight back into the storage ring. These beam lines also require a stop, but shielding requirements are much simpler since the synchrotron radiation is low energy and readily shielded. Stops for these monochromatic beam lines are typically 2” of copper. Beam stops are located on fixed platforms and are surveyed into place. If the beam stop consists of an array of bricks, these are banded into place on the platform. The beam stop’s location is confirmed at the start of each experiment by completing the beamline’s safety checklist.

4.14.6 X5 Beam Line (Laser Electron Gamma Source Experiment)

The LEGS experiment conducted in beam line X5 is discussed in detail in Section 3.3.5. Radiological issues associated with LEGS experiment are different than those described above. We provide a brief summary in this section. More detailed information is available in **Appendix 11**.

Three classes of radiation hazards are encountered in LEGS: synchrotron radiation, high-energy photons, and energetic electrons. The synchrotron radiation hazards originating from the “tail” of upstream dipole bending magnets are minor compared to those associated with a standard NSLS bending magnet beam lines and have been readily addressed using practices common for all beam lines. Estimates of the scattered synchrotron radiation levels inside the X5 hutch, during normal operation and during special alignment operations are discussed in **Appendix 11**. The hazards are easily addressed.

The high energy photon hazard is created by both bremsstrahlung and the LEGS photon beam created by laser photon interactions with the circulating electron beam. The LEGS photon beam is more highly collimated than the gas bremsstrahlung produced in the X5 straight section and is therefore located completely within the bremsstrahlung core. Its energy spectrum extends to an anticipated maximum energy of 530 MeV for 3.0 GeV operation, whereas the bremsstrahlung spectrum extends to the maximum energy of the circulating electron beam. Because of the lower energy and lower fluence of the LEGS photon beam, the bremsstrahlung shield installed in all NSLS beam lines is also adequate for the γ-rays. Bremsstrahlung shields are installed and located along the LEGS beam line to prevent any exposure to the high energy gamma beam in non-exclusion areas. The high energy gamma ray beam interacts with various materials at several locations along the beam line before finally terminating in a beam stop. Shielding has been provided at these locations to control radiation exposure from the scattered radiation. In addition, the laser hutch and the target room hutch are interlocked in the standard NSLS manner to prevent exposure when the LEGS experiment is in operation.

The high energy electron beam hazard is confined to the tagging electron cave located in the inner wall of the X-ray Ring tunnel. The cave is interlocked to prevent personnel entry whenever electrons could be present, and is shielded to prevent scattered radiation from leaving the cave.

4.14.7 Control of Radiation Exposure

The above sections have discussed the potential radiological hazards associated with operation of the NSLS. There are a number of practices at the facility that are in place to ensure that radiation exposures are controlled and monitored in a manner consistent with BNL and DOE requirements.

4.14.7.1 Administrative Practices to Control Radiation Exposure

The highest potential for radiation exposure is associated with beam losses that occur during injection. To reduce the potential for exposure during injection, both rings are normally filled during low occupancy periods. The X-Ray Ring fills are typically scheduled to occur at 0700 and 1900 hours. Injection of the VUV ring is more frequent, typically seven times per day, but is scheduled also for low occupancy periods during the normal work day (i.e. 0800, 1230, 1730 hrs). Other injections occur during the lower occupancy evening and overnight shifts.

Because of the higher exposure potential in the VUV area, additional controls are implemented for all VUV injections. Prior to injection of beam into the VUV, a public address system announcement is made and a klaxon sounds inside the VUV hall. Occupants are instructed to stand clear of designated areas for the duration of the injection cycle (~10 minutes). A similar announcement is made prior to all scheduled VUV beam dumps. The dosimetry data confirm that this practice has been successful in controlling exposure to personnel during beam delivery from the Booster to the VUV.

The X-Ray Ring is more heavily shielded than the VUV Ring and in general there is no need for visual and audible annunciation due to the lower levels of prompt radiation. For most areas, only a building announcement is made prior to the start of an injection cycle. In a few areas around the X-Ray Ring, such as the walk-way over the X-ray injection line and near the X-4 C, visual and audible warning systems have been provided to alert occupants to the potential for increased radiation fields during injections.

4.14.7.2 Engineered Systems to Control Radiation Exposure

Most radiation fields at the NSLS do not exceed a few mrem/hr and there are no “High Radiation Areas” accessible to personnel working at the NSLS. In a number of locations subject to increases in radiation levels during various machine operating conditions (principally injections and vacuum failure), active radiation monitors (Chipmunks) have been installed as a supplement to the visual and audible warning of injections. The Chipmunks provide additional local real-time audible and visual indication of increasing radiation levels at a particular location, and also provide annunciation within the Control Room. Based on written procedures, the operators monitor these radiation levels and will check affected locations and alter operating conditions as needed. In cases when an abnormal radiation field cannot be promptly eliminated, the personnel from the Radiological Control Division will install temporary posting and erect barriers to exclude personnel from exposure, as well as address other related compliance requirements.

As was identified previously, access to a synchrotron radiation beam or to an accelerator enclosures when the machines are operational is typically not allowable and is protected by engineered safety systems meeting all BNL requirements. However, controlled access is allowed into the VUV accelerator during operation. This must be coordinated with the Control Room personnel and involves specific training for those obtaining this access. All experimental work in the VUV beam lines and soft x-ray beam lines in the X-ray ring is conducted within the beam line vacuum system which is common to the main ring vacuum. Any attempt to access one of these beam lines without isolating the synchrotron radiation beam would result in catastrophic vacuum failure and instant shutdown of the ring.

In the hard x-ray beam lines in the x-ray ring, the photons have sufficient energy to penetrate vacuum windows, which may be installed at one or more locations along a beam line. Therefore administrative/engineered controls and interlocks are required for any access point to the synchrotron radiation beam which has a vacuum window between it and the storage ring. Access to beam line components downstream of vacuum windows are rigorously controlled through a system of padlocks and check-lists administered by the NSLS Operations Coordinators. Any access to these areas requires the permission of an Operations Coordinator, who will ensure that the beam line safety shutters are closed and locked before removing the locks controlling access to the beam line.

Access to the beam line is possible in all hard X-ray beam lines in the experimental hutch after a safety shutter has been closed thereby preventing exposure to synchrotron or bremsstrahlung radiation. Users are trained and authorized to access the hutch and to clear and reset the interlock system without intervention from NSLS operations. Because the radiation levels in these hutches with beam on will exceed 50 Rem/hour, the interlock systems are designed to meet the BNL requirements defined in the ESH Standard 1.5.3 for this hazard level.

Access to the accelerator enclosure is possible when the interlock system is satisfied. The status of all critical devices and associated conditions are monitored through independent and redundant interlock circuits to ensure that unsafe conditions are not encountered. All interlock systems controlling access to hutches and accelerator enclosures are designed, installed, maintained and tested in accordance with the BNL requirements.

The details of the NSLS Interlock Systems are available in **Appendix 1**.

4.14.7.3 Other Radiological Control Features

In addition to the administrative practices and engineered systems discussed above, there are a number of other radiological control program elements that provide the radiological safety basis for NSLS operations. These practices are important and ensure that radiological hazards are identified and controlled. A brief description of each practice is provided:

- A Beam Line Safety Review is required for all new beam lines or those which are substantially modified. The purpose of these reviews is to ensure that adequate shielding is included for scatter points, that beam stops are properly specified and located, and that bremsstrahlung shields and exclusion zones are established where needed. The role of the Beam Line Safety Review Committee and its processes are defined in LS-ESH-PRM-1.3.5b.
- The NSLS ALARA Committee meets periodically to review radiation exposure trends and to examine new or modified facilities that may have impact on radiological exposure at the NSLS.
- New or modified beam lines are subject to an initial commissioning period (no unattended operations allowed) at low beam currents to confirm that adequate shielding is provided along the beam line and behind stops. During commissioning, the beam lines are surveyed at all scatter points to evaluate shielding. Additional shielding is provided where possible to maintain contact dose rates at less than 500 c/m (~ 50 μR/hr) when operating at maximum stored current.
- A beam line safety check-list is completed by the research team prior to the beginning of each experiment to confirm that required shielding and other safeguards are in place. Operations staff confirms that the check-list has been completed prior to enabling the beam line.
- Access to any beam line vacuum space downstream of beam window is controlled through a padlock and check-list system to ensure that no access is possible to the primary photon beam. This padlock and check-list system is administered and controlled by Operations personnel.
- All work on shielding or interlock systems is controlled through a work authorization system to ensure review of planned work and restoration of protective function following any modifications.
- All NSLS staff is required to take facility specific training and BNL General Employee Radiological Training (GERT) training. Additional radiological training consistent with BNL requirements will be mandated depending upon individual job duties.
- All users are required to take NSLS specific training and GERT training for unescorted access to the experimental floor. Long term users are required to take additional BNL training depending on their specific duties.

4.14.7.4 Area Monitoring Program

At the NSLS, area monitoring for photon and neutron radiation is provided through an extensive network (~ 70 units) of detectors located around the X-ray and VUV experimental floor. The area monitors are provided to demonstrate compliance with the regulation, to document radiological conditions, to detect changes in the radiological conditions and to verify effectiveness of radiological controls. These monitors use thermoluminescent dosimeters (TLDs) placed on 5-inch diameter polyethylene cylinders. The locations of the area monitors for the VUV and X-Ray Rings are shown in **Appendix 12**. These monitors are exchanged quarterly and utilize the same dosimeters provided to personnel. The monitors provide an excellent method for tracking changes in radiation exposure potential that may occur on the floor and provide an empirical characterization of the upper limit of potential radiation exposures at many locations throughout the building. Most of the area monitors identified in **Appendix 12** are located in typical work areas for researchers and staff working on the floor.

A number of the area monitors are located closer to loss points within the ring or transfer lines and represent areas that have much lower occupancy than those monitors located in typical work areas. Examples of these locations include the units designated as U-7, U-11, U-15ext, VUV injection straight, VUV transfer line, and X-4C hutch. These devices provide a useful tool for tracking changes in radiological patterns on the experimental floor near the machine, but do not represent actual exposure to personnel because of the low occupancy in these areas.

As an example, area monitoring data for the years 1999 through the first 6 months of 2003 are shown in the **Figures 3, 4, 5** in **Appendix 12**. In general, the annual integrated dose equivalent measured on the area monitors in the X-ray region is small. Even uncorrected for occupancy, most of the locations in the X-Ray Ring are less than 100 mrem/yr. Some areas of the X-Ray Ring and a number of areas around the VUV Ring indicate the potential for exposures above 100 mrem/year. As mentioned above, all areas with values greater than 100 mrem/year based on occupancy of 2000 hours per year are located in non-typical work areas which have much lower occupancy factors. The administrative control practices discussed previously assure low occupancy in these locations during operating conditions with potential for increased radiation levels.

The results of the area monitoring indicate that the principal source of radiation exposure is neutron. In most locations reported in **Appendix 12**, the ratio of neutron dose to gamma dose is approximately four. Although photons are the principal secondary radiation produced from high energy electron interactions, the extensive use of lead shielding has reduced the photons substantially and resulted in a higher fraction of neutron exposure.

4.14.7.5 Personnel Monitoring

Until October 2003, the NSLS required that all personnel working in the Controlled Area on the experimental floor wear a TLD even though exposures to individuals were well within the regulatory requirements for this practice. An analysis was conducted during 2003 to determine if it was reasonable to continue this practice (see **Appendix 13**).

This analysis showed that almost 99% of the ~ 2000 people per year who wore monthly TLDs had non-recordable exposures (see **Appendix 13**), and the 1% who did receive a recordable exposure were well within the 100 mrem/year NSLS administrative control level and the DOE regulatory driver for requiring personnel dosimetry. Following this analysis the NSLS personnel dosimetry policy was modified as follows:

An internal NSLS administrative requirement was established for personnel routinely working on the experimental floor throughout the year to wear a TLD dosimeter. The primary purpose of these additional dosimeters is to provide a quality check of the continuing effectiveness of the NSLS radiological controls for personnel with an on-going presence on the floor. Although these dosimeters are not required under DOE Part 835 requirements, their use will provide an additional means to track radiation exposure patterns for people working in all areas of the building throughout the year. In addition, as another internal administrative requirement, dosimetry is required for all women with a declared pregnancy working on the experimental floor, for any minor working on the floor and for anyone handling a sealed source or radiological material.

These changes were reviewed and approved by the BNL Radiological Control Division Manager and were discussed with DOE personnel to ensure correct interpretation of DOE policy.

4.14.8 Storage Ring Current Limits

Although the operation of the storage rings at higher currents or energy could easily be handled without difficulty from radiological control limits[11], heating created in the vacuum chambers from synchrotron radiation is a significant limiting factor. Although operation of the VUV or X-ray rings at higher or lower energies is not likely, it is important to establish acceptable boundaries for such changes in the event such changes become desirable in the future.

Synchrotron radiation production and heating is directly related to the total power of the beam. Therefore, the heating rate would not be expected to change if the power in the circulating beam is maintained constant. Analysis and experience has shown that the heat load in the ring at current storage ring operating parameters can be safely handled. Using this as a point of known safety, heat loads for electron beam currents (I in amps) in the VUV and X-ray rings for a given electron energy (E in GeV) can be defined through the mathematical expression C/E^4 where C=0.46 for the VUV ring and C=19.53 for the X-ray ring (Marion, J.B. 1965; Batchelor, K. 1996). The following tables give maximum values of I for selected ring energies using this formula. Maximum currents for other values of E not listed in the table but limited by the Maximum Electron Beam Energy can be determined using the expression given above.

Table 7. Examples of Allowable Currents in the VUV & X-ray Rings for Selected Ring Energies

VUV Energy (GeV)	0.750	0.800	0.850	0.900	1.000
VUV Current (A)	1.454	1.123	0.881	0.701	0.460
X-ray Energy (GeV)	2.000	2.500	2.584	2.800	3.000
X-Ray Current (A)	1.221	0.500	0.438	0.318	0.241

4.14.9 Environmental Radiological Issues

High-energy particle interactions in water, air and soil can produce radioactivity from spallation reactions or neutron capture in the nitrogen, oxygen or other material. In high-energy proton accelerators, these interactions can produce significant environmental

[11] Higher injection efficiencies and higher beam lifetime would be expected at increased electron energy.

issues. However, electron accelerators have reduced potential for production of induced activity, and for machines of equal power can produce only about 1 - 5% of the induced activity of a proton accelerator.

In addition, the NSLS operates at much lower power levels than the proton facilities at BNL. For example, the X-ray ring at NSLS operates with a circulating beam of ~ 1 x 10^{12} electrons at 2.8 GeV produced once every 12 hours. The AGS operates with a 30 GeV beam of greater than 1 x 10^{13} protons produced every few seconds. Therefore, the AGS has ~10^{6} greater beam power than the X-ray ring averaged over a 12 hour operating period. Combining the two factors, overall, the X-ray ring has ~ 10^{-8} less capability to produce residual radiation during a normal 12 hour operating period than the AGS does. Therefore, from first principles, it should be clear that the NSLS does not create significant environmental issues. However, calculations are presented which demonstrate these conclusions.

4.14.9.1 Air Activation

Short-lived radionuclides such as C-11, N-13, and O-15 are produced from high-energy spallation reactions in air molecules. In **Appendix 5**, production rates for these materials are calculated for two significant loss points:

1. Loss of the booster beam on an injection stopper, and
2. Total loss of the stored beam in the X-ray ring at a thick target.

This analysis confirms that airborne radioactivity in accelerator enclosures during accelerator operation is not a significant issue and that no additional engineered safeguards or administrative controls are required for this potential hazard.

In addition, releases of this radioactivity to the atmosphere were also evaluated to determine permitting applicability in **Appendix 5**. It was determined that no NESHAPS permits are required for this source.

4.14.9.2 Water Activation

Because the power levels of the NSLS injected and stored beams are very low, cooling is not required at the beam loss points discussed in previous sections. In addition, there are no loss points where the beam is terminated in water. The ring vacuum pipe is water cooled to absorb the heat generated by synchrotron radiation, but little if any of the beam power is absorbed within this system from beam losses. Calculations are shown in **Appendix 14** which demonstrate that no additional engineered safeguards or administrative controls are required for induced activity in water. Tritium concentrations within water-cooling systems at the NSLS are periodically monitored and detectable levels of tritium have not been observed.

4.14.9.3 Soil Activation

The potential for soil activation produced by NSLS operations is evaluated in **Appendix 15**. These calculations demonstrate that no additional engineered safeguards or administrative controls are required for induced activity in soil.

4.14.9.4 Ozone

Ozone can be produced from the interaction of ionizing radiation with oxygen in air. The generation of ozone has not been a problem from beam losses in any of the accelerator enclosures, but a "white" photon beam in the synchrotron radiation beam lines, particularly for wiggler and undulator beam lines, can produce ozone in significant quantities if permitted to traverse a hutch in air. Open air traversal of hutches by a "white" beam require evaluation to determine if additional controls (e.g. reduction of air path length; access restrictions, charcoal filtration) are needed to control exposure to ozone and have been discussed in Section 4.9. Environmental releases of ozone are also evaluated in **Appendix 5**.

4.14.10 Radiation Generating Devices

Radiation Generating Devices (RGDs) are used within the facility. They are operated and have been registered with the BNL Radiological Control Division in accordance with the requirements of the Radiation-Generating Devices subject area. One typical example is an x-ray generator for the NSLS Crystal Orientation Facility. The operation of the generator is covered by a procedure and the generator undergoes scheduled interlock checks and radiation surveys. Personnel operating this facility undergo training by the RGD Responsible Person.

5. QUALITY ASSURANCE

The NSLS Quality Assurance Manual applies to the work performed at the NSLS. The NSLS management is responsible for the quality of construction, the operation of the equipment and the work processes in the facility. Responsibility for quality is delegated through the line staff positions and they are responsible for the quality of their own work. NSLS accelerator components are evaluated for Environmental, Safety, Health, & Quality (ESH&Q) Risk Level categories A-1 through A-4 as per the SBMS Subject Area Graded Approach for Quality Requirements. The NSLS will conform to the Brookhaven National Laboratory Quality Assurance Program which in turn implements the requirements of DOE Order 414.1.

6. DECOMMISSIONING PLAN

6.1 Introduction

The objective of the NSLS decommissioning plan, which will be developed near the end of the NSLS operating lifetime, will be to determine the hazards and risks posed by decommissioning of the NSLS facility at the end of its operating life and to plan the activities required to complete the decommissioning. Another aspect of the decommissioning plan will be the determination of the final site configuration, or end-point, in which the facility, or site, will be left. Once baseline conditions are estimated and the alternative end-points are chosen, methods of accomplishing the decommissioning that will meet the end-point goals can be selected. Finally, the waste streams to be managed during decommissioning are to be analyzed in the decommissioning plan, their characteristics and volumes estimated, and treatment and disposal options evaluated.

6.2 Baseline Conditions

Establishing the expected baseline conditions of the facility at the end of its operating life can be accomplished by estimating the radioactivity levels and physical conditions based on calculations, design features, operating procedures and waste management requirements. Records of hazardous or radioactive wastes and personnel radiation dose will be maintained for tracking purposes and will provide additional baseline information. The decommissioning plan will include requirements for characterizing the facility after operations are shut down and before decommissioning begins. This characterization will help establish surveillance and maintenance required to keep the facility in a safe standby mode until decommissioning begins.

6.3 End-Point Goals

Determining the desired end point goals, the final site-configuration and the risks present are essential to planning the decommissioning alternatives for the facility. The decommissioning plan will address the baseline conditions and consider all the alternatives. The decommissioning alternatives that may be evaluated are: (1) reuse for a similar function, (2) safe storage, (3) Brownfield condition, (4) Greenfield condition. Greenfield means that the NSLS site will be returned to its original condition with no remediation or institutional controls required. Brownfield means that some remediation or institutional control will be required such as ground water or soil activation that will be monitored (although we do not anticipate this to be the case). It is assumed that institutional control will remain in effect under Federal oversight for a number of years before decommissioning and a number of years after decommissioning.

6.4 Decommissioning Methods

Decommissioning methods will be chosen based on radiological conditions at the NSLS at the time of decommissioning and on the effectiveness of the methods to achieve the desired end use of the buildings. Additional criteria in choosing the methods are the ability of the methods to keep personnel exposure ALARA and to protect the environment and worker. For example, decay-in-storage methods will be used, where reasonable, to reduce to volume of radioactive waste.

6.5 Waste Streams

Recyclable materials and wastes anticipated from the decommissioning operation will be identified in the decommissioning plan. Initially, NSLS structures and process equipment will be inventoried. Accordingly, the resulting inventory will be comprised largely of process components and structures that are either potentially recyclable, e.g. scrap metal, electrical equipment, or beam line components, or are solid waste. Wastes that will require particular scrutiny include activated metals, suspect metals, sealed radioactive sources, chemicals and gases, and other hazardous materials (e.g. lead and beryllium). Analyses to date indicate that tritiated water has not been produced. Waste treatment facilities and processes in place at the time of decommissioning will be reviewed as part of the decommissioning plan. Cost estimates for waste disposal will be made at the time of decommissioning plan development.

6.6 Regulatory Requirements

The decommissioning plan will delineate the applicable New York State and Federal laws, consensus standards, DOE directives and other requirements applicable to the activities at the time of decommissioning, especially those required to meet the end-point criteria.

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7.2 Acronyms

A.C.	Air Conditioning
ACGIH	American Conference of Governmental Industrial Hygienists
AGS	Alternating Gradient Synchrotron
ALARA	As Low As Reasonably Achievable
Alum	Aluminum
ANSI	American National Standards Institute
ASE	Accelerator Safety Envelope
ATF	Accelerator Test Facility
BGRR	Brookhaven Graphite Research Reactor
BLOSA	Beamline Operator Safety Awareness
BNL	Brookhaven National Laboratory
BTMS	Brookhaven Training Management System
CBT	Computer Based Training
CCWF	Central Chilled Water Facility
CFR	Code of Federal Regulations
CMS	Chemical Management System
DIP	Distributed Ion Pump
DOE	Department of Energy
DUV-FEL	Deep Ultraviolet – Free Electron Laser
ECR	Environmental Compliance Representative
EMS	Environmental Management System
EPA	Environmental Protection Agency
ERC	Experiment Review Coordinator
ESH&Q	Environment, Safety, Health and Quality
Exp	Experimental
FONSI	Finding of No Significant Impact
FWHM	Full Width Half Maximum
GERT	General Employee Radiological Training
HD	Hydrogen Deuteride
HFBR	High Flux Beam Reactor
HPC	High Pressure Copper
HV	High Vacuum
I.D.	Inner Diameter

IP	Ion Pump
ISO	International Organization for Standardization
JTA	Job Training Assessment
LEC	Local Emergency Coordinator
LEGS	Laser Electron Gamma Source
LINAC	Linear Accelerator
LPC	Low Pressure Copper
MARTI	Maintenance and Repair Tracking Information
MEI	Maximally Exposed Individual
MER	Mechanical Equipment Room
MGU	Mini-Gap Undulator
NAAQS	National Ambient Air Quality Standards
Nd-YLF	Neodinium-Yttrium Lithium Fluoride
NEG	Non-Evaporable Getter
NFPA	National Fire Protection Act
NESHAPS	National Emissions Standards for Hazardous Air Pollutants
NIG	Nude Ion Gauge
NSLS	National Synchrotron Light Source
NYSDEC	New York State Department of Environmental Conservation
ODH	Oxygen Deficiency Hazard
OpCo	Operations Coordinator
PAF	Process Assessment Form
PRM	NSLS ES&H Policies and Requirements Manual
RCD	Radiological Control Division
RF	Radio Frequency
RGA	Residual Gas Analyzer
RHIC	Relativistic Heavy Ion Collider
PRT	Participating Research Team
RWP	Radiological Work Permit
SAD	Safety Assessment Document
SAR	Safety Analysis Report
SBMS	Standards Based Management System
SCW	Superconducting Wiggler
SDL	Source Development Laboratory
SmCo	Samarium Cobalt
SPDES	State Pollutant discharge Elimination System
STP	Sewage Treatment Plant
TLD	Thermoluminescent Dosimeter
UHV	Ultrahigh Vacuum
VUV	Vacuum Ultraviolet
WCC	Work Control Coordinator

7.3 Units

eV	electron volt
ft^3	cubic foot
GeV	billion electron volts

GHz	gigahertz
hrs.	hours
Hz	hertz
keV	kilo electron volts
KHz	kilohertz
kV	kilovolt
kw	kilowatt
lb.	pound
m	meter
mA	milliamps
meV	milli-electron volts
MeV	million electron volts
min.	minute
MHz	megahertz
m-rad	meter-radians
mrem	millirem
nm	nanometers
nsec	nanoseconds
R	rad
rms	root mean square
s	second
sq. ft.	square feet
sq. km.	square kilometer
T	Tesla
V	volt
yr	year

7.4 Tables

7.5 Figures

7.6 Appendices

7.7 Acknowledgements (individuals who assisted in the development of this SAD)

Andrew Ackerman
John Aloi
Debbie Bauer
Ron Beauman
Lonny Berman
Al Boerner
Angela Bowden
John Bohenek
Mike Buckley
Scott Buda
W. Robert Casey
Randy Church
Mary Anne Corwin
Mark Davis

Conrad Foerster
Richard Heese
Steve Hoey
Steve Hulbert
Henry Kahnhauser
Robert Kiss
Sam Krinsky
Ed Lessard
Joe Levesque
Kathy Loverro
Marlon McAvoy
Laura Miller
Jim Murphy
Steve Musolino
Sal Pjerov
George Rakowsky
Eva Rothman
Jeff Rothman
Gerry Van Derlaske
Marty Woodle
Nancye Wright
Zhong Zhong