LT-C-ESH-BCSAD-001

Photon Sciences Directorate

Booster Commissioning Safety Assessment Document

For the

National Synchrotron Light Source II

Version 2
December 8, 2011

Prepared by
Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
managed by
Brookhaven Science Associates
for the
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DISCLAIMER

Photon Sciences Directorate
BOOSTER COMMISSIONING
SAFETY ASSESSMENT DOCUMENT
For the
National Synchrotron Light Source II (NSLS-II)

Submitted as partial fulfillment for Critical Decision-4 (CD-4)

		Date
Submitted:	**Nicholas F. Gmür** Photon Sciences Directorate - Preparer Brookhaven National Laboratory	08 Dec 2011
Submitted:	**Steven Hoey** Photon Sciences Directorate - Environment, Safety & Health Manager Brookhaven National Laboratory	12/8/11
Submitted:	**Ferdinand Willeke** Photon Sciences Directorate – Accelerator Director Brookhaven National Laboratory	2011/12/10
Approval:	**Steven Dierker** Photon Sciences Directorate – Associate Laboratory Director Brookhaven National Laboratory	4/12/12
Approval:	**Michael Bebon** Deputy Director of Operations Brookhaven National Laboratory	4/27/12

VERSION CONTROL SHEET

VERSION	DESCRIPTION OF ANY CHANGES	DATE	PREPARER	APPROVED BY
1	For presentation to the NSLS-II and BNL LESHC review committees	14 Nov 2011	Nicholas F. Gmür	See above
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Acronyms

A	amps
Å	Angstrom
ACGIH	American Conference of Governmental Hygienists
ADC	analog–digital converter
AFD	Adjustable frequency drives
AGS	Alternate Gradient Synchrotron
AHJ	authority having jurisdiction
AHU	air handling unit
ALARA	as low as reasonably achievable
ALD	Associate Laboratory Director
ANSI	American National Standards Institute
ARR	Accelerator Readiness Review
ASE	Accelerator Safety Envelope
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing Materials
AV	ambient vaporizer
BCASE	Booster Commissioning Accelerator Safety Envelope
BCNYS	Building Code of New York State
BCSAD	Booster Commissioning Safety Assessment Document
BD	Bend Defocusing (defocusing Booster dipole)
BES	Basic Energy Sciences (part of DOE)
BF	Bend Focusing (focusing Booster dipole)
BHSO	Brookhaven Site Office
BNL	Brookhaven National Laboratory
BORE	beneficial occupancy readiness evaluation
BPM	beam position monitor
BPPS	Booster Personnel Protection System
BSL	Biological Safety Level
BS-B2	bending magnet to control Booster injection
BS-SS	Booster-to-SR transport line safety shutter
BSR	Booster-to-Storage Ring (transfer line)
BTMS	Brook Training Management Database
cc	cubic centimeters
CCWF	Central Chilled Water Facility
CD	Critical Decision (#1, 2, 3…)
CDC	Centers for Disease Control
CEQ	Council on Environmental Quality
CESR	Cornell Electron-Positron Storage Ring
CFN	Center for Functional Nanomaterials
CFR	Code of Federal Regulations
Ci	Curie
cm	centimeter
CMS	chemical management system
CONOPS	Conduct of Operation
CRAC	computer room air conditioning
CSA	Canadian Standards Association
CSAD	Commissioning Safety Assessment Document
DAC	digital–analog converter
dBA	decibel with A-weighting
DC	direct current
DCCT	DC current transformer
DDO	Deputy Director of Operations
DI	deionized
DOE	Department of Energy
EA	Environmental Assessment
ECR	Environmental Compliance Representative
EDE	Effective Dose Equivalent
EEI	Electrical Equipment Inspection
EIA	Electronic Industries Alliance
EMS	Environmental Management System
EPA	Environmental Protection Agency
EPHA	Emergency Preparedness Hazard Assessment
EPICS	Experimental Physics and Industrial Control System
EPS	equipment protection system
ERC	experimental review coordinator
e/s	electrons per second
ESH	Environment Safety and Health
ESR	Experimental Safety Review
eV	electron volt
EXAFS	Extended X-ray Absorption Fine Structure
FCT	fast current transformer
FE	front end
FHA	Fire Hazard Analysis
FOE	first optics enclosure
FONSI	Finding of No Significant Impact
FPA	Fire Protection Assessment
FPGA	Field Programmable Gate Array
fpm	feet per minute
fps	feet per second
FSAD	Final Safety Assessment Document
ft	foot, feet
gal	gallon, gallons
GA	general assessment
GERT	General Employee Radiological Training
GeV	giga-electron volt
GHe	gaseous helium
gHz	gigahertz
gm	gram
GN2	gaseous nitrogen
g/s	gallons per second
GSF	gross square feet

HDR	Architect/Engineer firm for NSLS-II
He	helium
HEN	high energy neutron
HEPA	high efficiency particulate air filter
HOM	Higher Order Mode
HP	high pressure or horse power
h	hour
HSSD	Highly Sensitive Smoke Detection
HV	high voltage
HVAC	heating, ventilation and air conditioning
Hz	Hertz
ICT	integrating current transformer
IGBT	Insulated-gate bipolar transistor
IOT	Inductive Output Tube
IR	infra-red
ISM	Integrated Safety Management
JPSI	Joint Photon Sciences Institute
JTA	Job Training Analysis
kcmil	thousands of circular mils
keV	kilo-electron Volt
kHz	kilo-Hertz
kV	kilovolt
kVA	kilovolt-amp
kW	kilowatt
LB-B2	Linac-to-Booster transport line magnet
LB-SS	Linac-to-Booster transport line safety shutter
lbs	pounds
LCSAD	Linac Commissioning Safety Assessment Document
LEC	Local Emergency Coordinator
LEED	Leadership in Energy and Environmental Design
LESHC	Laboratory Environment, Safety and Health Cttee.
l/h	liters per hour
LHe	liquid helium
Linac	Linear Accelerator
LN2	liquid nitrogen
LOB	Lab Office Building
LTB	Linac-to-Booster (transfer line)
m	meter
mA	milliamp
μC	microcoulomb
MCI	Maximum Credible Incident
MEBT	Medium-energy beam transport
meV	milli-electron volt
MeV	mega-electron volt
MHz	megaHertz
MIC	Microbial Induced Corrosion
mm	millimeter
MOSFET	metal oxide semiconductor field effect transistor
MPFL	Maximum Potential Fire Loss
mph	miles per hour
mrad	milliradian
mrem	millirem
μS	micro-Sieverts
MTBF	mean time between failures
MV	medium voltage cable – or - megavolt
N2	nitrogen
nC	nanocoulomb
NC	noise criteria
NEC	National Electric Code
NEG	non-evaporatable getter
NESHAP	National Emission Std. for Hazardous Air Pollutants
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
nm	nanometer
NPH	natural phenomena hazard
NRTL	Nationally Recognized Testing Laboratory
NSLS	National Synchrotron Light Source
NSLS-II	National Synchrotron Light Source II
ntorr	nanotorr
NY	New York
NYCRR	New York Codes, Rules and Regulations
NYSDEC	New York State Department of Environmental Conservation
ODH	oxygen deficiency hazard
OHSAS	Occupational Health and Safety Series
OSHA	Occupational Safety and Health Administration
PAF	Process Assessment Forms
Pb	lead (the element)
PC	performance category
pCi	picocurie
PCM	periodic confirmatory measurements
PEL	permissible exposure level
PFN	pulse-forming network
pH	a measure of acidity or alkalinity
ph	photon(s)
PID	piping and instrumentation diagram
PLC	programmable logic controller
Pm	picometer
PPE	personal protective equipment
PPS	Personnel Protection System
PRM	Policies and Requirements Manual
ps	picosecond
psf	pounds per square foot
psi	pounds per square inch
psig	pounds per square inch gauge
PSM	pulse step modulator
PSU	power supply unit
PTS	permanent threshold shift

rad	radian
RCRA	Resource Conservation Recovery Act
REL	recommended exposure level
Rem	Roentgen Equivalent in Man
RF	radiofrequency
RH	relative humidity
Rads/h	rads per hour
RMS	root mean square
RWP	Radiological Work Permit
s	seconds
SAD	Safety Assessment Document
SBMS	Standards Based Management System
SCDHS	Suffolk County Department of Health Services
scf	standard cubic feet
SCRF	superconducting radiofrequency
SDL	Source Development Lab
SF6	sulfur hexafluoride
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
SPDES	State Pollutant Discharge Elimination System
sq ft	square foot
SSC	structure, system, or component
STD	standard
T	Tesla
TBD	to be decided
TIA	Telecommunication Industry Association
TL	transfer line
TLD	thermoluminescent dosimeter
TLV	threshold limit value
UHV	ultrahigh vacuum
UL	Underwriters Laboratory
UPS	uninterruptible power supply
USC	United States Code
USI	Unreviewed Safety Issue
UV	ultraviolet
V	volts
VAC	volt alternating current
VFD	variable frequency drive
WCC	Work Control Coordinator
WG	water gauge

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1 INTRODUCTION

1.1 Motivation for this Document

The purpose of this Booster Commissioning Safety Assessment Document (BCSAD) is to:

a) Provide in Section 3 a general overview of the National Synchrotron Light Source-II (NSLS-II) accelerator facility, which is part of the Photon Sciences Directorate at Brookhaven National Laboratory, Upton, NY;

b) Describe in sufficient detail in Section 4 the significant hazards presented by the commissioning of the NSLS-II Booster which consists of dipole bending magnet LB-B2, the Linac-to-Booster Transfer Line, Booster Ring, Booster-to-Storage Ring transfer line up to dipole bending magnet BS-B2 and safety shutter BS-SS, and the Booster beam stop (includes Booster radiofrequency [RF] system), located in the Injector Building and herein generally referred to as the Booster; and

c) Describe the controls by which these hazards are managed to an acceptable level of risk.

The Booster area covered by this BCSAD is shown in Figure 3.4. The BCSAD lays the foundation for the Credited Controls described in the Booster Commissioning Accelerator Safety Envelope (BCASE). The requirements for writing the BCSAD and BCASE are set out in:

- DOE Order 420.2C, *Safety of Accelerator Facilities*
- DOE Guide 420.2-1, *Accelerator Facility Safety Implementation Guide for DOE O 420.2B, Safety of Accelerator Facilities*
- BNL Standards-based Management System (SBMS), *Accelerator Safety* subject area

The NSLS-II accelerator commissioning program is divided into four separate and sequential modules, each with its own commissioning SAD and ASE. The Linac Commissioning SAD and ASE have been completed, reviewed and approved by DOE/BHSO; the second module covers this Booster synchrotron commissioning; and the third will cover the Storage Ring and project beamline commissioning. These three commissioning SADs and ASEs will then be combined into a single, final NSLS-II SAD and ASE for routine operations. The creation of these documents benefits from the previous years of experience of the National Synchrotron Light Source, in operation since 1983, and from the following earlier NSLS-II safety analyses:

- *Baseline Hazards List* – 2006
- *Environmental Assessment* – 2006
  - *Finding of No Significant Impact* - 2006
- *Preliminary Hazards Analysis* – 2007
- *Final Hazards Analysis* – 2007
- *Preliminary Safety Assessment Document* – 2008
- *Linac Commissioning Safety Assessment Document* – 2011
- *Linac Commissioning Accelerator Safety Envelope* – 2011

NOTE

The Linac Commissioning Safety Assessment Document (LT-C-ESH-LCSAD-001) and the Linac Commissioning Accelerator Safety Envelope (LT-C-ESH-LCASE-001) will continue as active Linac authorization basis documents during the Booster commissioning period.

1.2 Description of the NSLS-II Facility

The Department of Energy Basic Energy Sciences (DOE BES) program requires a synchrotron light source that will enable the study of material properties and functions, particularly materials at the nanoscale, at a level of detail and precision never before possible. NSLS-II will provide photon beams having ultra-high brightness and flux, and exceptional stability. It will also provide advanced insertion devices, optics, detectors, robotics, and a suite of scientific instruments. Together these will provide the capability to characterize materials with a spatial resolution of ~1 nm and an energy resolution of ~0.1 meV, and with sufficient sensitivity to perform spectroscopy on a single atom. These unique characteristics of NSLS-II will enable exploration of the scientific challenges faced in developing new materials with advanced properties and will support the development of electron-based radiation sources and new applications of this radiation in the physical, chemical and life sciences. The resulting scientific advances will support technological and economic development in multiple sectors of the economy.

NSLS-II will be a large user facility dedicated to the production and utilization of synchrotron radiation. It will consist of an electron Storage Ring and an associated injection system composed of an electron gun, Linac, and a Booster Ring. The Storage Ring, 792 meters in circumference, will operate in top-off mode at 3.0 GeV and 500 mA with a lifetime of ~3 hours, and will provide ground-breaking spatial and energy resolution as described above. NSLS-II will operate an extensive user program built around bending magnet and insertion device beamlines on the Storage Ring. NSLS-II is expected to annually support ~3,500 users from ~400 university, government laboratory, and industry institutions conducting ~1,500 experiments. Bending magnet and insertion device beamlines will cover the infrared, vacuum ultraviolet, soft x-ray and hard x-ray energy ranges. Approximately 5,500 hours of beam time will be delivered per year to the users. Equally important will be 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 NSLS-II. Operation of NSLS-II is primarily funded by the U.S. Department of Energy, Basic Energy Sciences.

1.3 Environment, Worker, and Public Safety

NSLS-II is subject to the requirements of the DOE O 420.2C, *Safety of Accelerator Facilities,* or its successors. These requirements are promulgated in the Brookhaven National Laboratory SBMS *Accelerator Safety* subject area. The NSLS-II Booster presents potential for minor on-site and negligible off-site impacts to people and the environment. The possibility of any off-site or on-site radiological impact as the result of NSLS-II Booster operations (during commissioning and routine operations) is highly unlikely, due to the physical aspects of the NSLS-II Booster. The primary hazard is prompt ionizing radiation, which is produced primarily during Booster operations. The radiation fields are well shielded and are reduced to insignificant levels when the machine is turned off.

As the basis for operating the Booster, and protecting workers and visitors to the facility, NSLS-II programs incorporate DOE P 450.4 *Safety Management System Policy*, 10 Code of Federal Regulations (CFR) 835 *Occupational Radiation Protection,* 10 CFR 850 *Chronic Beryllium Disease Prevention Program*, and 10 CFR 851 *Worker Safety and Health Program* and other regulations, rules, DOE Orders as specified in the BNL/DOE Prime Contract. The BNL SBMS subject areas establish the requirements and provide guidance to assure proper implementation of the Integrated Safety Management (ISM) core functions and guiding principles. Identification and control of hazards for work and research activities are defined through the Photon Sciences Directorate *Work Planning and Control Procedure*. Radiological safety requirements are promulgated in the BNL *Radiological Control Manual*.

The Brookhaven National Laboratory *Environmental, Safety, Security and Health Policy* is the foundation on which NSLS-II will manage significant environmental aspects, worker safety, and its relations with stakeholders and the community. The formal management programs are the BNL *Environmental Management System* (EMS) and the BNL *Occupational Health and Safety Assessment Series* (OHSAS). These are collectively covered by the Photon Sciences Directorate EMS/OHSAS program. BNL has been granted Certificates of Registration under ISO 14001 and OHSAS 18001; NSLS-II complies with the respective requirements. In addition, DOE has approved a *Finding of No Significant Impact* (FONSI) for the NSLS-II *Environmental Assessment (DOE/EA-1558).*

The NSLS-II BCASE that defines the Credited Controls and maximum hardware capabilities for the Booster is a companion document to this NSLS-II BCSAD. The BCASE is reviewed and approved by the DOE-Brookhaven Site Office (BHSO). The BCSAD is reviewed and approved by BNL as well as by the DOE-BHSO (the latter approval as per DOE 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, to satisfy Critical Decision-4 requirements).

1.4 Commissioning the NSLS-II Booster

1.4.1 Commissioning Plan

The BNL requirements and guidance for commissioning an accelerator are provided in the BNL SBMS *Accelerator Safety* subject area. It is not the purpose of this BCSAD to describe in detail the contents of the Commissioning Plan for the Booster. That Plan shall be provided in a separate document (based on the template provided in the *Accelerator Safety* subject area) and included as part of the Booster Commissioning Accelerator Readiness Review (ARR) after being reviewed by DOE/BHSO with the BCSAD and BCASE. A Booster Commissioning Sequence and a Booster Commissioning Fault Study Plan will also be developed. The ARR process and the constituted ARR committee will provide a structured method for verifying that hardware, personnel, and procedures associated with Booster commissioning operations are ready to permit the activity to be safely undertaken. The ARR committee, when satisfied, recommends that the DDO request an approval letter from BHSO to proceed with commissioning.

The Booster has been purchased, built, and installed by a Contractor. Personnel of the Photon Sciences Directorate (PSD) will install the Booster system with guidance from the Contractor's team who will stay on-site for the duration of the installation. This same Contractor, as a deliverable in the contract, is responsible for commissioning the Booster. This shall be done in collaboration with PSD Injector, Radio Frequency, Accelerator Physics, and Operations Group personnel as well as BNL Radiological Control Division personnel. The Booster RF system has been developed, installed and will be commissioned by the members of the PSD RF and Injector groups. Those portions of the injection system, including the upstream and downstream transfer lines, the beam dump, and safety shutter downstream of the Booster, shall be commissioned by Photon Sciences Directorate personnel. A single Booster Commissioning Plan shall cover both the Contractor and the Photon Sciences Directorate personnel.

Booster commissioning shall be controlled from either the Injection Control Room, located in the Injection Service Building east of the Booster ring (see Figure 3.4), or from the Control Room in Building 725 (changes to the RF conditions may also be made from the RF Building). Both Control Rooms shall follow the safety requirements and hazard controls specified in this BCSAD, the BCASE and in the Booster Commissioning Plan. Readouts (indicators, alarms) shall be the same in both Control Rooms. The Conduct of Operations manual defines the coordination between Control Rooms to ensure that it is always clear which room is the lead Control Room for Booster operations and to prevent conflicting signals. Conditions needed or found during commissioning that are not covered in this BCSAD shall undergo an Unreviewed Safety Issue (USI) determination. The Photon Sciences Directorate Accelerator Division has overall responsibility for the Booster commissioning program. A detailed commissioning schedule shall be established and electronic commissioning logs, summaries, technical notes, and other data and information shall be developed and maintained, and a final commissioning report shall be completed.

The commissioning schedule, subject to change, is anticipated to run three 8-hour shifts per day, seven days per week for the duration of the commissioning period. The operation of the Injection Control Room shall be established per the Booster Commissioning *Conduct of Operations Manual*. This manual is based on the BNL SBMS *Conduct of Operations* subject area (and DOE Order 422.1, *Conduct of Operations*).

1.4.2 Booster Commissioning Control Room Operator - Credited Control

At least one qualified, trained Control Room Accelerator Operator shall be on duty when commissioning the Booster and downstream components with electron beam (the Operator will also manage Linac operations). This requirement is established as a Credited Control in the BCASE. The *Conduct of Operations Manual* may further elaborate on the type and number of staff in the Control Room, but these will not be Credited Controls. See section 5.4 for further details.

1.4.3 Requirements That Must Be Satisfied for Beginning Booster Commissioning

The Booster Commissioning Plan, which as stated above includes both the Booster itself and the listed components upstream and downstream of the Booster, shall specify the conditions that must be met for the commissioning process to begin:

- Procedures, administrative controls, and personnel training and qualification for operations
- Engineered safety systems for the accelerator facilities
- Specific facilities, sub-systems, and operations modes
- Locations of controls for the beam and major sub-systems
- Schedule of the most current plan
- Authorization basis documents and completed Accelerator Readiness Review

The goal of the Booster commissioning is to assure that the Booster is fully operational for injection into the Storage Ring during the subsequent Storage Ring commissioning (not discussed in this BCSAD). This BCSAD will involve the optimized performance parameters (see Table 3.2) in accordance with the Booster Specification (LT-SPC-SR-BR-001, *Technical Specification for the 3 GeV Booster System*, T. Shaftan, Jan. 25, 2010) which must be met in order for BNL to accept the Booster from the contractor and allow final payment. The Booster Commissioning ARR Committee will review the completion of these requirements and, if satisfied, will recommend that the Photon Sciences ALD and Deputy Director of Operations (DDO) seek DOE/BHSO approval to commence commissioning.

Once the Contractor's performance parameters have been met and satisfied, commissioning of the Booster will then continue to further refine the operation of the Booster and to prepare for the commissioning of the Storage Ring. Both phases of this commissioning adhere to the operating requirements stated in the Booster Commissioning Plan.

2 SUMMARY / CONCLUSIONS

2.1 Overview of Results and Conclusions of the BCSAD Analysis

The NSLS-II BCSAD provides a safety assessment of the Linac-to-Booster Transfer Line, Booster Ring and Booster-to-Storage Ring transfer line installed for Booster commissioning, as shown in Figure 3.4. The BCSAD meets the requirements set out in the SBMS *Accelerator Safety* subject area, which in turn meets the requirements of DOE Order 420.2C, *Safety of Accelerator Facilities*, and DOE G 420.2-1, *Accelerator Facility Safety Implementation Guide*.

The NSLS-II BCASE establishes Booster Equipment Maximum Hardware Capabilities, Engineered Credited Controls and Administrative Credited Controls within which the NSLS-II Booster and its personnel shall safely operate based on the hazards, controls, and mitigated risks described in Chapter 4 of the NSLS-II BCSAD. The NSLS-II BCASE has been developed in accordance with the same requirements described in the above paragraph. The BCASE controls are also elaborated on further in Chapter 5 of this BCSAD.

This BCSAD identifies a number of hazards and their controls as well as the Maximum Credible Incident (MCI) based on the safety analyses in Section 4. The following summarizes the hazards and controls, including those associated with the MCI.

1. The NSLS-II Booster and associated Injection Building design comply with required consensus codes and standards as per DOE 10 CFR 851 *Worker Safety and Health Program* and the *Building Code of New York State* (BCNYS).

2. The commissioning of the NSLS-II Booster as designed does not pose significant risk to the environment:

    - Existing and projected hazards to the environment have been described in the NSLS-II *Environmental Assessment* (DOE/EA-1558). A *Finding of No Significant Impact* was issued in September 2006.
    - Impacts to the environment and occupational hazards to workers due to NSLS-II Booster commissioning activities are managed through the ISO 14001, *Environmental Management System* and the ISO 18001 *Occupational Health and Safety Assessment Series*, respectively, as well as through the BNL *Integrated Safety Management* system. Periodic audits assure that these programs are maintained at a high level.
    - A National Emissions Standards for Hazardous Air Pollutants (NESHAP) evaluation of NSLS-II accelerator operation radiological air emissions has been conducted with BNL Environmental Protection Division personnel. Site boundary doses from air emissions are calculated to be below the 0.1 mrem/year threshold for routine air monitoring.
    - Hazardous and industrial wastes are managed and, where possible, minimized by the facility through a variety of controls such as recycling and pollution prevention.
    - Effluents, with the exception of those from roofs and parking lots and cooling tower blow-down that drain to recharge basins, are disposed of through the sanitary waste stream, and controlled

through work planning so as not to exceed the limits stated in the BNL State Pollutant Discharge Elimination System (SPDES) permit. Tritium and sodium-22 production in soils and cooling waters are calculated to be below the BNL-defined Action Levels of 1,000 pCi/L and 20 pCi/L, respectively.

3. The natural phenomena hazards (NPH) such as high winds, snow/ice, floods, lightning and earthquakes are managed by building designs conforming to the BCNYS, which specifies design criteria for wind loading, snow loading, lightning protection, and seismic events. Should a NPH cause significant damage, the impact would be mission related and would not pose a hazard to the public or the environment. Based on the guidance in DOE Standard 1021-93, *Natural Phenomena Hazards Performance Categorization* - Change 1, the NPH mitigation Performance Category for the NSLS-II facility, including the Booster, is PC-1, based on the identified hazards and potential consequences.

4. The level of fire protection, as designed, is classified as "improved risk," thereby meeting the objectives of DOE Order 420.1B, *Facility Safety*. The NSLS-II Booster area and adjacent areas are protected by a fire suppression sprinkler system and a smoke detection system, all of which are tied in to the BNL site wide fire alarm system. An *NSLS-II Fire Protection Design Strategy* has been developed and its requirements are followed. It was reviewed and approved by DOE-BHSO on March 28, 2008. An NSLS-II *Fire Hazard Analysis* has been developed based on this design strategy.

5. Booster electrical systems and work are designed and planned to minimize hazards by adhering to BNL SBMS subject areas as well as to National Fire Protection Agency (NFPA) 70, *National Electric Code*, and NFPA 70E, *Standard for Electrical Safety in the Workplace*. Programs are in place to assure that electrical equipment is reviewed and approved by either a Nationally Recognized Testing Laboratory (NRTL) or by a BNL Authority Having Jurisdiction (AHJ) Electrical Equipment Inspector. Interlocks and lockout/tagout procedures are used to maintain personnel safety.

6. When Booster vacuum faults are detected, interlock systems automatically close sector 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 gas systems initiates alarms alerting Control Room staff to take appropriate action.

7. The following are considered routine Booster industrial hazards and are covered by BNL SBMS requirements: lasers, radiofrequency non-ionizing radiation, and magnetic fields. Noise and ozone are not hazards associated with Booster commissioning.

8. Bunches of electrons are generated by an electron gun and accelerated by a linear accelerator (Linac) and the Booster to an energy of 3 GeV in preparation for injection into the Storage Ring. This process results in scattered gamma and neutron ionizing radiation. Commissioning of the Booster is managed through the Injection Control Room near the Booster in the Injection Building or through the Building 725 Control Room (or RF may be adjusted from the RF Building); commissioning adheres to the controls described in the BCASE, the Control Room procedures, and the training of the qualified Accelerator Operators. Interlocks and area radiation monitors are used for radiation protection of personnel.

   - Readiness for the commissioning phase of the Booster is demonstrated through a PSD Instrument Readiness Review, an Accelerator Readiness Review (ARR) and a Commissioning Plan; the latter two must be approved by DOE-BHSO prior to the beginning of the Booster commissioning period.

- A Radiation Shielding Policy has been developed. Radiation shielding, primarily in the forms of standard density concrete, lead, and in some instances polyethylene, is positioned to maintain levels of radiation to personnel as low as reasonably achievable (ALARA). Shielding configuration control is maintained through the use of accelerator safety system checklists and work authorizations.
- Radiation is monitored through the use of personal and area thermoluminescent dosimeters (TLDs), as well as real-time radiation monitors and hand-held radiation surveys, to ensure that conditions are ALARA. In-house Radiological Control Division staff assists in the management of radiological conditions and develops Radiation Work Permits when necessary through work planning and controls. In addition, radiation safety interlocks are tested and radiation monitors are calibrated on a scheduled basis to ensure integrity.
- Air, soil, and water activation levels have been calculated, and are below BNL-defined Action Levels. Equipment determined to be activated in volume is precluded from unrestricted release for the purpose of recycling, in accordance with the Secretary of Energy memorandum *Release of Surplus and Scrap Metals* (dated July 13, 2000 memorandum from DOE Secretary Bill Richardson).
- The Maximum Credible Incident (MCI) is due to ionizing radiation. For this reason, ionizing radiation is the only hazard that has specific Credited Controls listed in the Booster Commissioning Accelerator Safety Envelope.

9. The organizational structure of the Photon Sciences Directorate and the documentation of responsibilities and procedures for safety-related actions ensure safe commissioning of the Booster. Control room operations proceed as per the NSLS-II *Conduct of Operation* (CONOPS) as defined in DOE Order 422.1, *Conduct of Operations* and the Booster Commissioning Plan.

10. Specific administrative and equipment controls prevent or mitigate beam loss events in order to maintain doses to personnel ALARA, and in order to protect facility equipment. An additional benefit of these controls is to provide stable, high-quality beam. Procedures and controls that prevent or mitigate beam loss and maintain radiological conditions ALARA include the Accelerator Safety Envelope (Equipment Maximum Hardware Capabilities, Engineered Credited Controls, and Administrative Credited Controls), real-time radiation monitors, area and personal radiation badges, pre-operations sweep procedures, access-control (interlock) devices, control area beam loss procedures, lock-out/tag-out procedures, configuration control, work planning procedures, and radiological training. The post-mitigation risks, as detailed in Appendix 4, are shown in Table 2.1 below.

Table 2.1: Hazard Types vs. Post-mitigation Risk Levels.

Types of Hazards	**Risk Levels**
Chemical and Hazardous Materials	Low
Confined spaces	Low
Cryogenic, Including ODH	Low
Electrical	Low
Environmental	Low
Fire	Low
Loss of vacuum, cooling water, or compressed air	Low
Material handling	Low
Natural phenomena	Routine
Noise	Routine
Ozone	Routine
Radiation (non-ionizing)	Low
Radiation (ionizing) – routinely occupied areas	Routine
Radiation (ionizing) – within shielded enclosures	Low
Wastes	Low

3 DESCRIPTION OF FACILITY, SITE, AND OPERATIONS

3.1 Characterization of the NSLS-II Site Location

3.1.1 Description of the BNL Site

Brookhaven National Laboratory is a multidisciplinary scientific research institute located close to the geographical center of Suffolk County, New York, about 60 miles east of New York City. Figure 3.1 shows a regional view of Long Island, and Figure 3.2 shows an aerial view of BNL. The BNL site occupies 5,265 acres, with most principal facilities located near its center. The developed area is approximately 1,656 acres, of which about 500 acres were originally developed by the U.S. Army as part of Camp Upton. In excess of 200 acres are occupied by various large, specialized research facilities; and 400 acres are of roads, parking lots, and connecting areas. Outlying facilities occupy about 549 acres; these include the Sewage Treatment Plant, agricultural research fields, solar energy farm, housing, and fire breaks. The balance of the site, 3,607 acres, is largely wooded.

The *NSLS-II Environmental Assessment* (DOE/EA-1558; 2006) is available in Appendix 1a. This document provides the details of the NSLS-II site and the environmental consequences of the proposed action. The related *NSLS-II Finding of No Significant Impact* (2006) is available in Appendix 1b.

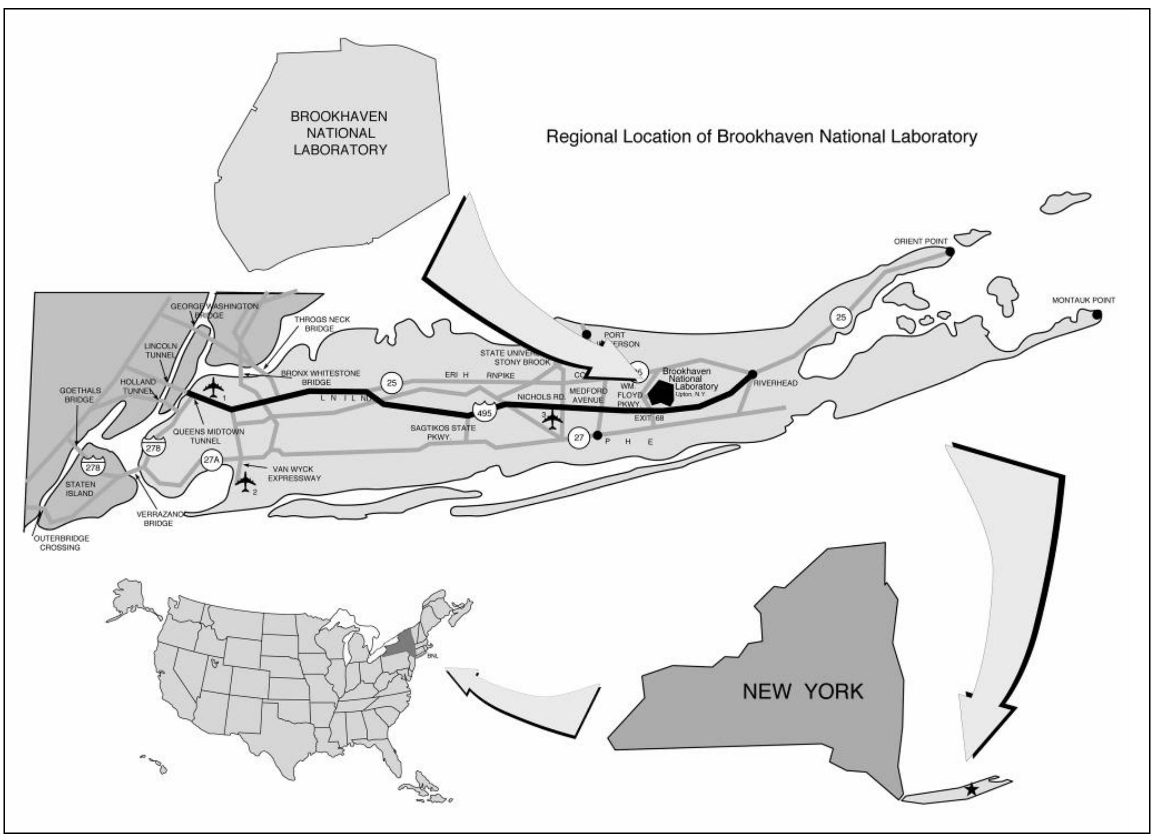

Figure 3.1: Regional view of the location of Brookhaven National Laboratory.

Figure 3.2: Aerial view of BNL (October 2011) showing the existing National Synchrotron Light Source (NSLS), the Center for Functional Nanomaterials (CFN), and the NSLS-II construction site.

3.1.2 Location of NSLS-II Building Site

The approximately 47-acre area immediately south and east of the existing NSLS (Bldg. 725), east of the existing Center for Functional Nanomaterials (CFN; Bldg. 735) and south of Brookhaven Avenue, is the site for NSLS-II (Bldg. 740). This location is desirable because a) the area to the south and east of that site is largely undeveloped and can accommodate long beamlines extending out from the NSLS-II building; b) the CFN is close by; c) the existing NSLS building is diagonally across the intersection; and d) the Physics, Chemistry, Materials Science, Instrumentation Division, and Biology and Medical Departments are nearby. The NSLS-II Ring Building property itself is bounded on the north by Brookhaven Avenue, on the west by an existing swale, on the south by an existing swale and existing landfill, and on the east by Fifth Street. Additional facilities are located north of Brookhaven Avenue on either side of Renaissance Street and include Bldg. 725 (Control Room, offices, technical and laboratory spaces), buildings 726-727 (mechanical, utility and magnet technical spaces), Bldg. 728 (offices) and Bldg. 729 (Source Development Laboratory).

3.2 Conventional Facilities

3.2.1 Building Design

NSLS-II has distinct components that make up the building plan. When fully complete, they consist of the Ring Building, five Laboratory Office Buildings, five Service Buildings, the Injection Building, the RF Building and its associated Compressor Building, and the Cooling Tower Building (Figure 3.3 below). Each of these buildings has separate space and utility requirements. Additional buildings around the BNL campus are used to provide administrative/engineering office, workshop, and technical spaces that support the needs of the NSLS-II Project. This BCSAD focuses on the section of the Injection Building that contains the Booster.

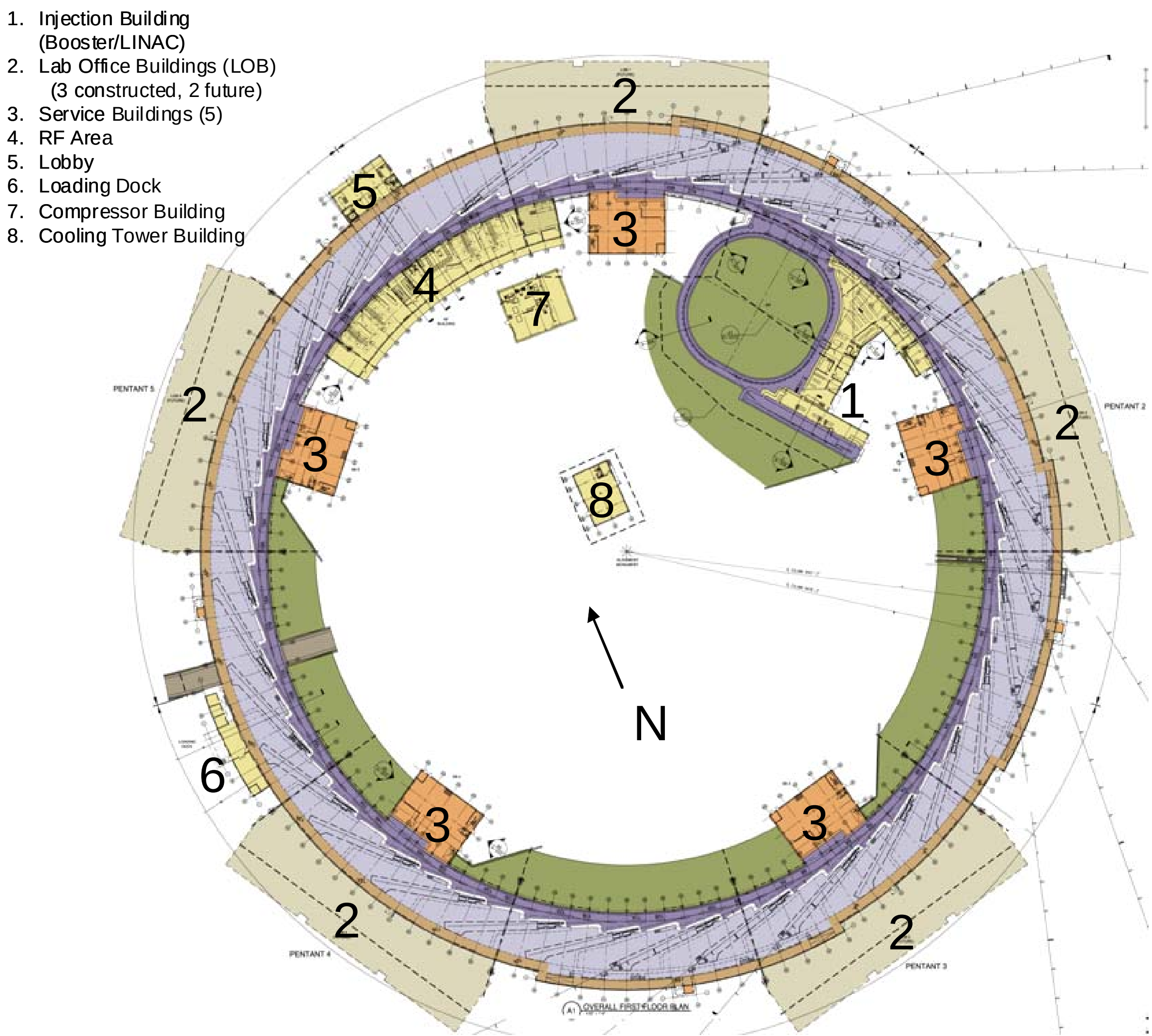

Figure 3.3: Site plan of NSLS-II building with projected locations for long beamlines. 1) Injection Building (Linac/Booster), 2) Lab Office Buildings, 3) Service Buildings (5), 4) RF Area, 5) Lobby, 6) Loading Dock, 7) Compressor Building, 8) Cooling Tower Building.

3.2.2 Injection Building

The Injection Building is attached to the inner circumference of the Storage Ring Building in the pentant 1 and 2 areas (see Figure 3.3 above to see the overall context, and Figure 3.4, below, for details). The Injection Building houses the Linac tunnel, the Linac Klystron Gallery, the Injection Service area, a portion of the Booster tunnel, and Mechanical Mezzanine (see Table 3.1 for the areas in ft^2). The mezzanine (located above the main floor Injection Service area) houses the heating, ventilation and cooling (HVAC) equipment along with water and pumps that supply the Injection Building. The Injection Building is framed in structural steel with a composite steel deck with concrete topping on the mezzanine floor. The roof consists of steel roof decking with a straight-standing-seamed metal roof. The Booster tunnel is constructed of poured-in-place standard weight concrete, which will be covered with a minimum of 2 feet of earth (the berm) for additional shielding. The Linac tunnel is constructed of combined poured-in-place standard weight concrete and a minimum of 4 feet of soil above the roof and an outer soil berm for additional shielding. The exterior walls of the Injection Building, which does not have a concrete exterior wall, have a pre-formed metal siding system with fiberglass insulation, interior vertical metal liner panel and metal girts, and ground face-block at the base.

Table 3.1: Space Summary for Injection Building

Space Description	GSF
Injection Building	27,450
▪ Linac Tunnel	2,443
▪ Linac Klystron Gallery	2,388
▪ Injection Service Area*	8,525
▪ Mechanical Mezzanine**	5,874
▪ Booster Tunnel	8,220

*That part of the Injection Building that contains the Booster power supplies and RF equipment.

**Second story above the Injection Service Area that contains HVAC equipment.

GSF (Gross Square Feet): The total area of all spaces in the building including wall thicknesses. GSF is calculated based on the exterior face of the building spaces and includes non-assignable spaces such as building circulation, mechanical/electrical rooms, restrooms, janitor closets, and the area of interior and exterior walls.

The Booster is housed inside radiological shielding, which is provided by a combination of concrete, lead, polyethylene, and berms of soil, the latter external to the Booster tunnel and outside the Injection Building. The Booster Tunnel contains the Linac-to-Booster Transport Line, the Booster Ring, the Booster-to-Storage Ring transfer line, a beam dump and other safety systems including a safety shutter and local supplementary shielding around high radiation scatter components. The Booster RF area (external and to the east of the Booster tunnel) houses one IOT (inductive output tube) transmitter with power supply. Each of the penetrations into the Booster enclosure bulk shielding for RF wave guides, cable trays, and mekometer ports, etc. has been evaluated. Shielding requirements have been calculated on a case-by-case basis, and the penetrations “walked down” to assure the proper shielding is in place. These shielding components have been designed by the NSLS-II Mechanical Engineering group. Design/fabrication drawings have also been prepared.

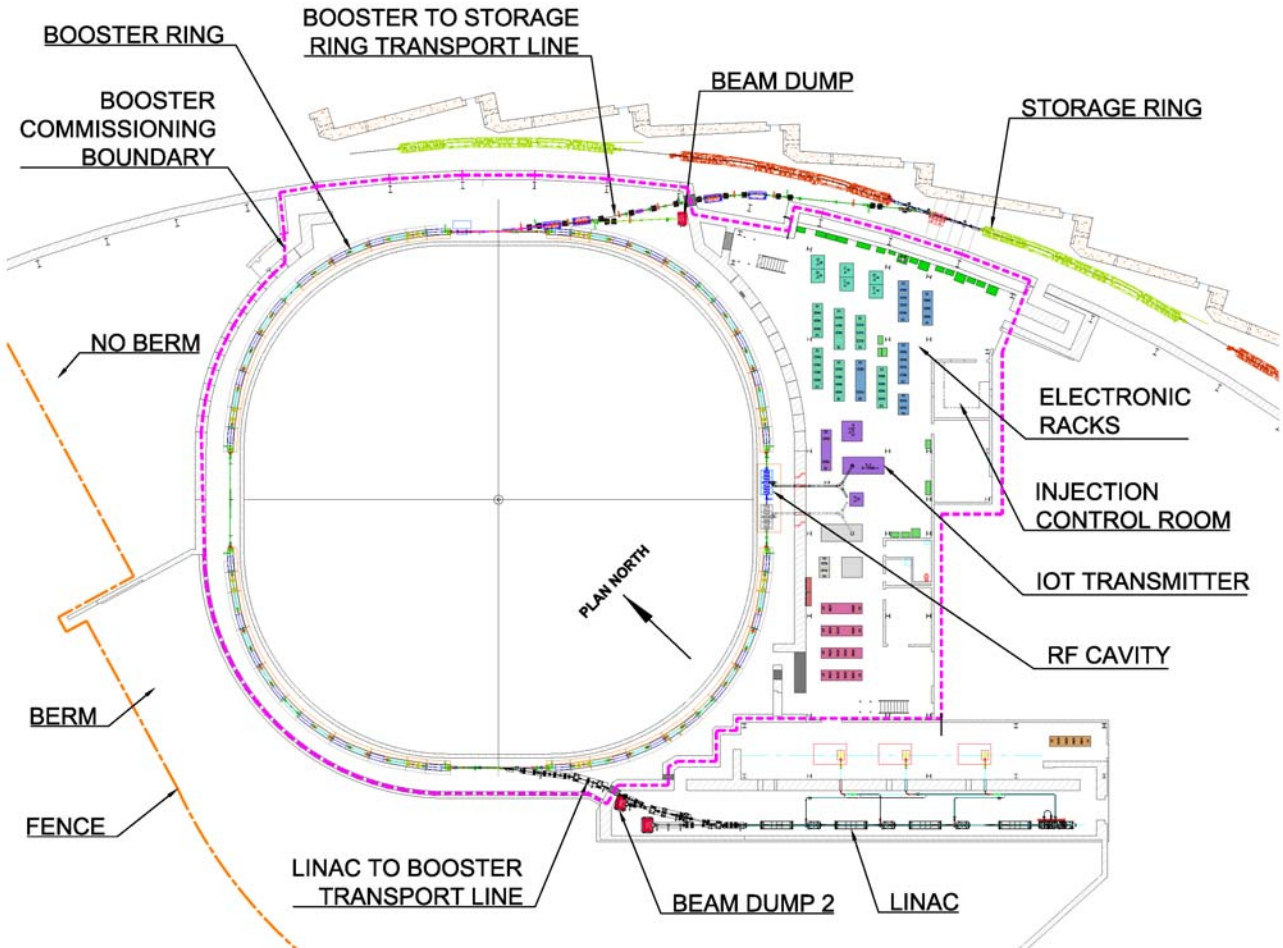

Figure 3.4: Injection Building showing Linac, Booster Ring and partial view of Storage Ring. (Dotted line indicates the Booster commissioning area.)

3.2.3 Service Buildings

There are five two-story Service Buildings located inboard of the Storage Ring Building (see Figure 3.3). Two of these Service Buildings (1 and 2) are located on either side of the Injection Building. The Service Buildings house mechanical and electrical equipment for the Experimental Floor area. The first floors of Service Buildings provide personnel and equipment access to the Storage Ring tunnel through shielded labyrinths, as well as access to the Ring Building's inner road. The second floors of these Service Buildings are serviced by an equipment hoist and double exterior doors located on the second floor, and via fire stairs from the first floor. The Service Buildings are steel frame structures with the lower level constructed of poured-in-place concrete walls with a soil berm to the height of the second level on one wall. The remaining exterior walls are of a pre-formed metal siding system with fiberglass insulation, interior vertical metal liner panel and metal girts, and ground face-block at the base. The roof is a sloped ThermoPlastic Olefin membrane roofing system.

Service Building #2, east of the Injection Building, provides the fire suppression sprinkler system for the Injection Building. Service Building #1, west of the Injection Building, supplies telecommunications and security (door access controls) to the Injection Building.

3.2.4 Facility Access Control

The Injection Building entrances are equipped with encoded card readers to restrict entry only to authorized personnel. The card reader control system is located in BNL Bldg. 50 and is managed by the BNL Laboratory Protection Division.

3.3 Accelerator Systems

3.3.1 Accelerator Overview and Injection System

The layout of the NSLS-II accelerators is shown in Figure 3.4 above. Electrons generated to 200 MeV in the Linac are accelerated to 3 GeV in the Booster. Due to the relatively short 3-h lifetime of the electron beam in the NSLS-II Storage Ring, full-energy (3 GeV) top-off injection at 500 mA is required. Injections will be very brief and occur about once per minute. In contrast with the previous generation of light sources based on high-energy Storage Rings, the short lifetime of NSLS-II means that it cannot perform at its target level if the injector is not readily available. Thus, it is imperative that the injector be a very robust and reliable device. This requirement led to the selection of a full energy Booster for the injector.

The layout of the injection system is shown in Figure 3.4. It consists of an thermionic triode Electron Gun, 200 MeV Linac, Linac-to-Booster beam transport lines, 3 GeV Booster in its own tunnel, Booster-to-Storage Ring beam transport line, and the injection straight that is part of the Storage Ring. All of these components are located inside radiological shielding enclosures. The main parameters of the Booster system are given in Table 3.2.

Table 3.2: Parameters for the NSLS-II Booster during Routine Operations

Energy	200 MeV	3 GeV
Number of periods	4	
Circumference, m	158.4	
Repetition rate, Hz	1 (2 Hz)	
Number of bunches	1; 80-150	
Bunch train length, ns	Up to 300	
Total charge, nC	10	
Revolution time, nsec	528	
RF frequency, MHz	499.68	
RF harmonic number	264	
RF voltage, MeV	0.2	1.2
Synchrotron frequency, kHz	36.4	20.9
RF acceptance, ε_{RF}, %	1.65	0.54
Betatron tunes: ν_x/ν_y	9.6455 / 3.4105	
Horizontal emittance, ε_x, m rad	0.166E-9	37.4E-9
Energy spread, σ_E/E	0.55E-4	8.31E-4
Energy loss per turn, U_0, keV	0.0135	685.8

3.3.2 Booster Design

3.3.2.1 Booster Layout and Location

The Booster Ring is located in its dedicated Injection Building tunnel, shown in Figures 3.4 above and 3.5 below. Auxiliary equipment such as power supplies is located in the Injection Service Area east of the tunnel. Radiofrequency waveguides pass through holes in the tunnel wall above head height; shielding is provided over these holes on the outside of the tunnel wall to prevent the escape of radiation down the waveguide paths. The connections between the Booster tunnel, the RF area, and electronic cabinets for the auxiliary equipment are accomplished using cable trays and shielded labyrinths.

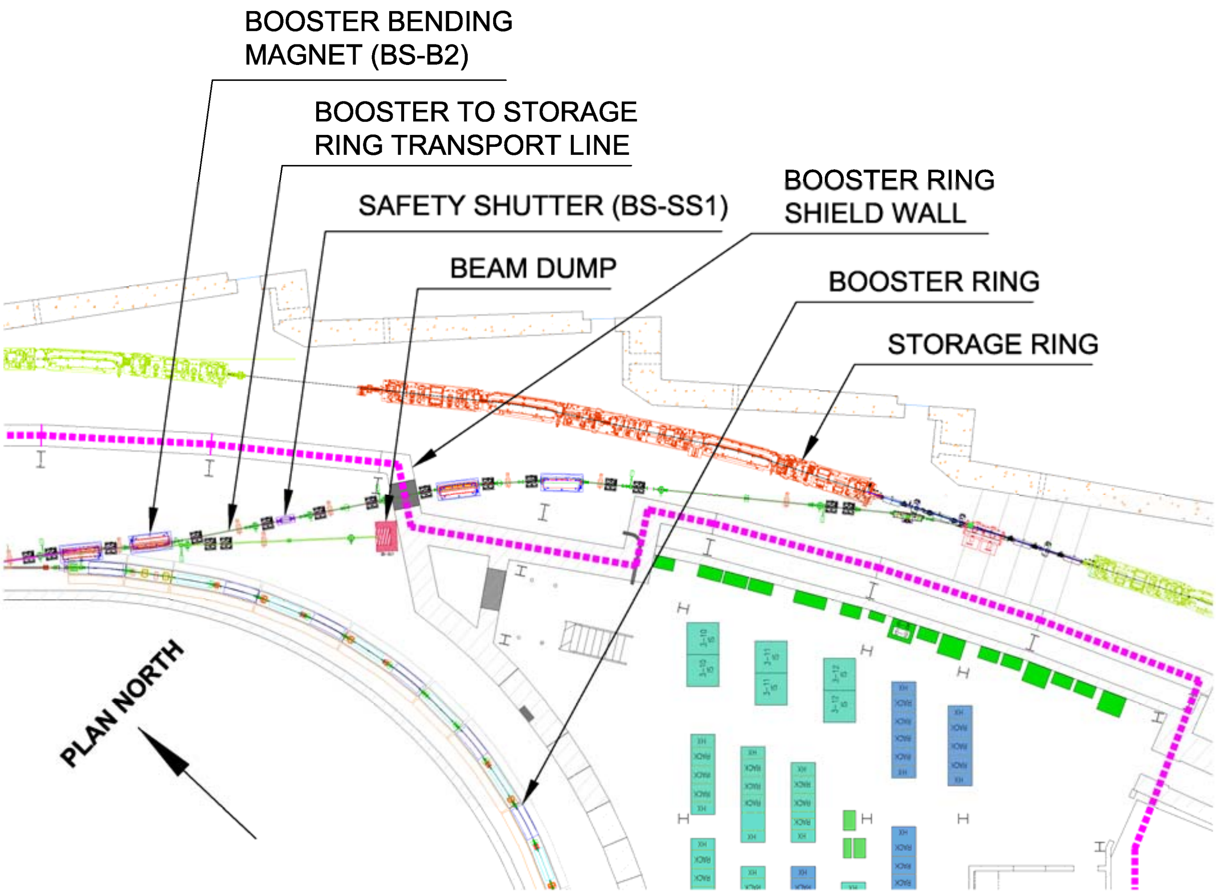

Figure 3.5: Plan view of the Booster Ring and Booster to Storage Ring Transport Line Area. (Dotted line indicates portion of Booster commissioning area; for view of full this area, see Figure 3.4. The Injection Control Room is also shown in Figure 3.4.)

3.3.2.2 Booster Performance Specification Overview

The Booster Ring contains four quadrants and four straight sections located inside the Booster tunnel with the beam height centered at 1.2 m.

Each quadrant contains the following magnetic elements:

- 8 combined function defocusing dipole magnets (BD) with 8.39° bending angle
- 7 combined function focusing dipole magnets (BF) with 3.27° bending angle
- 6 quadrupole magnets to adjust the tune point
- 4 sextupole magnets arranged in two families for correction of chromaticity and optimization of the dynamic aperture

The global orbit correction system of the Booster system consists of 36 beam position monitors (BPM) as well as 20 horizontal and 16 vertical corrector magnets. There are six beam screens, one DC Current Transformer (DCCT) and one Synchrotron Radiation Monitor for machine commissioning and beam tuning.

Four 8 m long straight sections include the injection and extraction straights, an RF straight section and a diagnostics straight section. These sections consist of:

- Injection straight section (from the Linac): one injection septum and 4 injection kickers with associated vacuum chambers and diagnostics
- Extraction straight section (to the Storage Ring): pulsed and DC extraction septa, 1 extraction kicker, 4 slow bumps and associated vacuum chambers and diagnostics
- RF section: 500 MHz RF cavity with vacuum chambers and a BPM
- Diagnostics straight section: two striplines, two BPMs, and their vacuum chambers

The following equipment is located downstream of the Booster:

- A diagnostics transport line terminating in the beam stop with a Faraday cup
- A further part of the Booster-to-Storage Ring Transport Line (BSR TL). This part includes a Safety Shutter and penetrates through the Booster shield wall, delivering the Booster electrons to the Storage Ring.

The following equipment is located in the Injection Service Area adjacent to the Booster tunnel:

- One IOT transmitter (80 kW), modulator, power supply, and waveguide structure
- Booster power supplies (see Tables 3.3 and 3.4), including two 400 V, 900 A BD (defocusing Booster dipole) power supplies and one 200 V, 900 A BF (focusing Booster dipole) power supply; power supplies for the quadrupole, sextupole and corrector magnets; and <25 kV charging power supplies for the pulsed magnets
- Vacuum pump power supplies and electronics
- Diagnostics and instrumentation electronics

- Controls electronics

The IOT transmitter is supported by solid-state switched HV power supply. The transmitter will be tested prior to Booster commissioning and will be subject to the requirements established in Radiological Work Permit. The IOT transmitter generates x-ray fields during operation and will be shielded to reduce radiation levels to < 0.5 mR/h at contact.

The Booster will be able to operate continuously at a 1-2 Hz repetition rate (typically at 1 Hz), with high reliability and stable energy, charge, beam dimensions, and exit position and angle. To meet the specified Storage Ring availability of 98%, the Booster has an availability of greater than 99%. Experience with pulsed, high-voltage systems (such as pulsed magnet modulators with vacuum tubes that have finite lifetimes) has shown the need for redundant systems to meet these requirements. In the case of the component failure there will be a number of the hot spares for all of the systems with low mean time between failures (MTBF), including pulsed magnets, RF components, power supply components, and complex vacuum chambers.

3.3.2.3 Booster Beam Parameter Specifications

To provide high flexibility for the filling structures of the Storage Ring and to allow for new operational modes, the Booster operates in a short pulse mode to generate sequences of single bunches, and in a long pulse mode to generate trains of bunches. The beam parameters for both operational modes are specified below as repeated from Table 3.2.

Repetition rate, Hz	1 (2 Hz)
Number of bunches	1; 80-150
Bunch train length, ns	Up to 300
Total charge, nC	10

The charge in the short pulse mode and in the long pulse mode may be varied between the maximum values indicated in the above table and lower values of 10 pC per bunch or less.

The Booster is capable of performing top-off injection in the short pulse mode and in the long pulse mode. The relevant beam parameters are the same as in the above table, apart from repetition frequency, which is approximately 1 injection cycle per minute. These parameters are the design basis for the Storage Ring injection. In addition, when using the long pulse mode, the macro-pulse length is programmable to be different at each consecutive pulse.

Timing signals are provided for the different time structures in the short pulse mode, as well as the trigger signal to start the injection process.

3.3.2.4 Booster and Diagnostics Transport Line Beam Diagnostics

The diagnostic systems available for commissioning include:

- Fluorescent screens monitors
- Faraday cup (F-cup)
- Fast Current Transformer (FCT)

- Integrating Current Transformer (ICT)
- DC Current Transformer (DCCT)
- BPMs
- Synchrotron Radiation Monitor

The diagnostics system has sufficient dynamic range for measurements from the minimum single-shot bunch charge to the maximum charge per bunch in 150-bunch trains. Where in-vacuum devices such as BPMs, pickups, and devices consisting of ceramic breaks are used, these conform to the vacuum specifications. Diagnostics devices are synchronized via trigger cables with the main injector timing signals. The diagnostic components interface with the NSLS-II control system.

3.3.2.5 Booster RF System

The booster RF system consists of an 80 kW Inductive Output Tube (IOT) transmitter and associated sub-systems. The IOT driver amplifier is a 500 Watt solid state amplifier with in input power of 10 mW. . The IOT transmitter incorporates an interlock and monitoring system based on microprocessor, field-programmable gate arrays (FPGAs), 16-bit analog–digital converters and digital–analogue converters (ADC/DACs) for high speed and accuracy. The maximum charge the Booster RF system is capable of accelerating to 3.2 GeV is 22 nC/pulse; therefore at 2 Hz, the maximum charge rate is 44 nC/s.

3.3.2.5.1 IOT transmitter

The IOT transmitter consists of the IOT amplifier, its HV power supply (HVPS) and the output transmission line and RF circulator and load. The HVPS is a switching power supply providing the DC power to bias the tube. The RF transmission line consists of a mix of 6 1/8 coaxial line and WR1800 rectangular waveguide. The transmission line outer conductor is solid copper throughout providing 100% shielding of the RF power. All energized circuits are covered by doors and covers, and thus cannot be accessed without keys and/or tools.

The BNL Personnel Protection System (PPS) ensures that when any personal safety interlock is tripped, the IOT is not able to generate RF power for the accelerating structures. Signals from the PPS are used to disable the AC power contactor feeding the HVPS eliminating the power source and thus any hazard.

3.3.2.5.2 Feeder Waveguide

The feeder waveguide is a mix of 6 1/8 coax and WR 1800 and is constructed using standard components. There is monitoring of forward and reverse power in the IOT's output waveguide line. Arc detectors are included at the RF vacuum window, at the circulator, and for each of the RF loads.

3.3.2.6 Booster Magnets and Power Supplies

Large dipole bending magnets provide both bending and focusing for the circulating beam. To keep the beam in a given area and focus that beam, the fields of quadrupoles are used. To compensate for the misalignment and steering effects of these magnets, small dipole steering magnets are used.

Three Dipole Power Supplies (DPS), two of them 742A/733V (544 kW) and one 862A/201V (172 kW), are located in the Injector Service Area and connected to the magnet circuits. The maximum currents available from these power supplies limit the maximum energy of the Booster Ring to 3.2 GeV. The ability to cycle these power supplies limits the repetition rate to 2 Hz. Three Quadrupole power supplies 167A/175V (30 kW) feed 3 families of the quadrupole magnets with 8 magnets in each family. Sixteen sextupole power supplies feed 16 sextupole magnets as separate circuits. Thirty-six corrector magnets (20 horizontal and 16 vertical) are fed by 36 power supplies of the same design. Their power supplies are ±6A/±80V (480 W max). The DC extraction septum power supply 500A/12V (6 kW) feeds the magnet located in the extraction straight section. The power supplies are located in the cabinets in the Injector Service Area.

Table 3.3. Booster Extraction (to the Storage Ring) Pulsed Magnets and their Power Supplies.

Pulsed Magnet	Length, m	Peak Current, kA	Peak Voltage, V	Pulse Width, μs
Bumper B1-B4	0.17	2/6turn	4x220	1500
Kicker	0.8	2.2	20000	0.2/0.3
Pulsed septum	0.6	10.2/	662	100

Table 3.4. Booster Injection (from the Linac) Pulsed Magnets and their Power Supplies.

Pulsed Magnet	Length, m	Peak Current, kA	Peak Voltage, V	Pulse Width, μs
Kicker	0.2	1.6	14000	0.1/0.3
Pulsed septum	0.75	1.5	125	100

Power supplies are located inside the cabinets below the extraction magnets. The charging power supplies and control electronics are located in the racks in the Injector Service Area.

3.3.2.7 Booster Control System

All parameters essential for the operation of the Booster are monitored and controlled by the Booster control system. The Booster control system is developed using the same control system tools as all of the other components of the NSLS-II; Experimental Physics and Industrial Control System (EPICS; a set of software tools and applications which provide a software infrastructure for use in building distributed control systems to operate devices such as particle accelerators, large experiments and major telescopes). Systems with water and/or air cooling generate interlocks for system protection in case of failures in the cooling system. These interlocks are implemented in Programmable Logic Controllers (PLC) and are monitored by the Booster control system, also implemented in PLCs. Several subsystems such as magnet power supplies, RF system and cooling systems have additional interlocks implemented in the FPGA based controllers. Interlocks are fail safe. A safe state is indicated by a closed contact sending a DC voltage. An unsafe state is indicated by an open contact that blocks the DC signal. On power failure, the system indicates an unsafe state. In case an interlock has been tripped, the system or subsystem is not operational, even if the cause of the interlock trip has been cleared, until the Operator has reset the interlock, either manually when in local mode or remotely when in remote mode. Control room procedures and the Conduct of Operations manual provide guidance to the Operator for responding to equipment trips. The error conditions must be identified both by the operator and the control system. The interlock system includes “first fault” logic to “catch” the first fault in a cascade for post-mortem. This is an equipment safety interlock system.

A trigger signal is provided to synchronize operation of the Booster with the other accelerator systems.

3.4 Electrical Power

3.4.1 Building 603 Substation Expansion

The existing 69 kV substation yard has been modified to provide the added power required for NSLS-II. A new 20.0/26.7/29.9 MVA, 66.0-13.8 kV main transformer is provided that is capable of supplying all NSLS-II loads along with a new 13.8kV switchgear line-up to feed power to the site and to enable interconnecting to other BNL main transformers as back-up power sources for NSLS-II. The modification also includes the associated equipment of two new 69 kV potential transformers, a new 69 kV SF6 breaker, and a new fire separation wall between the existing Transformer #3 and the new transformer. A fire-rated door and fireproofing have been added to the exterior of Building 603 to protect the building from the new main transformer.

3.4.2 Distribution to Building 740

One 1000 A feeder is provided to serve the NSLS-II facility in Building 740. The primary feeder originates at the Bus #0 switchgear in Building 603. A future back-up feeder will originate at the Bus #2 switchgear.

3.4.3 NSLS-II Site Distribution

The site distribution system has been configured in a primary selective scheme with all unit-substations connected to the primary feeder loop. One unit-substation is located at the Linac/Booster Injection Building; one located at each Service Building; two unit-substations are located at the RF Building. Each unit-substation consists of primary switchgear, a 13,800-480Y V, oil-filled substation-type transformer, and a 480 V section. The primary switchgear consist of two 15 kV outdoor, non-walk-in metal-enclosed switches in series with a 15 kV metal-clad circuit breaker. Each 2,500 kVA transformer is triple-rated 55 OA, 65˚OA, and 65˚FA. 480 V outdoor walk-in switchgear is attached to the transformer secondary. A duct bank and secondary feeders are extended from the secondary switchgear to the 480 V switchgear located in each building's main electrical room.

3.4.4 Interior Power Distribution

3.4.4.1 Service Building Power Distribution

Each Service Building has either a 3,200 or a 4,000 amp, 480Y/277 V, 3-phase, 4-wire switchgear center located in the Service Building's main electrical room. The current capacity depends on the load configuration for each Service Building. The switchgear includes a main breaker section, and two or more distribution sections. 480 Y/277 V distribution panels are located in the mechanical room on both levels to serve lighting and mechanical equipment. Receptacle panels are located adjacent to each mechanical panel to serve receptacles and other 120 V equipment. Service Buildings 1 and 2 are located on either side of the Injection Building.

3.4.4.2 Injection Building Power Distribution

One 3,000 A switchgear line-up is located in the mechanical/service room. This switchgear is dedicated to Linac and Booster equipment within the Injection Building.

3.4.4.3 Booster and Transmitter Power Distribution

A three-phase (480 ± 10%) V 60 Hz electrical supply for all Booster systems is provided with multiple motorized circuit breaker load panels located in the main section of the LINAC/Booster Service Building. These 480 VAC panel boards are fed from the electrical equipment room of the Linac/Booster Service Building. These panel boards also supply multiple 480 to 208 VAC step-down transformers through motorized circuit breakers. A 45 kVA transformer supplies power to a 30 kVA UPS unit. This unit is used for critical equipment on both the Booster and the Booster-to-Storage Ring Transport Line. The UPS supplies power to a circuit breaker load panel board located in the main area of the Linac/Booster Service Building and provides power for controls, vacuum equipment, and critical loads associated with the Booster and Booster-to-Storage Ring Transport Line. For normal power distribution, 115 and 75 kVA transformers are used to supply power to other circuit breaker panel boards. These normal power circuit breaker panel boards supply power for the individual racks, subsystems, and other Booster and Booster-to-Storage Ring Transport Line equipment. Each electrical rack within the Booster and Booster-to-Storage Ring Transport Line system has its own circuit breaker to allow selective switch-off of subsystems during maintenance work. The auxiliary single- and 3-phase power outlets installed in the Booster tunnel and the main section of the Linac/Booster Service Building are used only for maintenance and repair, not for electrical supply to the Booster or the Booster-to-Storage Ring Transport Line.

3.4.5 Emergency Power

Two diesel emergency power generators are provided, one at Service Building #3 and one at the RF Building. The size of each generator is 700 kW. The emergency power requirements are distributed almost equally between the two units which have been located to minimize the cable runs between the emergency generators and the electrical components requiring emergency power. A sub-base fuel tank in compliance with Suffolk County Article 12, *Toxic and Hazardous Materials Storage and Handling Controls,* is provided with a 12-h full load operation capacity. To reduce noise and vibration, a weatherproof, sound attenuated reach-in enclosure is provided. Emergency Generator #1 will be used to support the northern portion of the NSLS-II site and the He Recycling/Cryogenic facility. Emergency Generator #2 will support the southern portion of the site.

The emergency power is provided for key safety systems, including the emergency address system (through the fire alarm panels), egress and exit lighting, the fire alarm system, fire suppression system, smoke exhaust fans; and important utility systems such as selected lab exhaust and make-up systems, sump pumps (sanitary and storm), and select HVAC control systems. The emergency loads will be re-energized within 10 seconds of sensing a power outage.

Loss of electrical power will result in the Booster shutting down. The emergency generators will not provide power directly to the Booster. Critical controls for the Booster will be connected to a UPS (see 3.4.4.3 above) for orderly shutdown in the event of a prolonged power outage. Emergency Generator #1 will feed life safety needs in the Booster area. The emergency generators and transfer switches will be tested monthly as per NFPA.

3.4.6 Grounding

3.4.6.1 Grounding Electrode System

The grounding electrode system consists of underground metal piping, building steel, concrete-encased, 250-kcmil Ufer ground within all exterior wall foundations with direct buried cross-connecting 250 kcmil conductors 100 ft on center, and 10 ft ground rods spaced at approximately 100 ft on center around the perimeter. A main ground bus is located in the main electrical room at each Service Building. The grounding electrode conductors, interior metal pipe grounds, and the telecommunication ground are connected to the main grounding bus.

3.4.6.2 Power System Grounding

All power system grounding is in accordance with the National Electric Code (NEC). The secondary of each 13,800-480Y/277 V substation transformer is grounded at the substation. The grounded neutral is re-bonded at each switchgear main breaker. Ground fault interrupters used to protect personnel are only implemented on circuits that are required by code in locations such as outdoor outlets, restrooms, etc. They are not used on any branch circuits that serve to power accelerator equipment. The proper bonding of the equipment causes the branch circuit breakers to trip if there is a ground fault. The bonding of all the equipment enclosures prevents a shock hazard exposure to personnel. A separate green insulated equipment grounding conductor is provided in all feeders and branch circuits. Branch circuits serving sensitive electronic equipment will be provided with an isolated equipment grounding conductor that is green with yellow stripes, in addition to the green equipment grounding conductor.

The grounding system configuration is arranged to eliminate any low-impedance circuit loops that might generate currents that would interfere with normal operation of the complex's scientific equipment.

3.4.6.3 Lightning Protection

A complete lightning protection system is provided in accordance with NFPA 780 and UL 96A. Surge protection is provided in the power distribution panels.

3.4.7 Cable Tray and Cable Routing

Cable trays are bonded, cables are properly segregated, and tray loading is organized as per NFPA 70. Cables located in cable trays are tray-rated. Power supply cables are arranged to minimize pickup from and to other circuits. Power cables are separated from signal cables.

3.4.8 Electrical Equipment Racks

Booster electronic equipment racks are vender-supplied standard racks modified to be cooled with the BNL-designed custom chilled water-to-air heat exchangers. Linac-to-Booster Transport Line and Booster-to-Storage Ring Transport Line standard 19-inch equipment chassis are mounted in sealed NEMA 12 electronics racks with water-to-air heat exchangers cooling a set of four, three or two racks. Cooled air flows through the power supply racks and circulates back to the heat exchanger. The heat exchanger uses chilled water and has the outlet temperature regulated.

3.5 Heating, Ventilation and Cooling Systems (HVAC)

Temperature and flow alarm points are distributed throughout this system. An alarm signal is sent via the Building Management System to building 600 and to the Site Manager who will determine the appropriate response.

3.5.1 Utility Systems

3.5.1.1 Chilled Water

Twenty-four-inch supply and return chilled water pipes are connected from the existing, underground site chilled water system to the Service Buildings. For the entire NSLS-II complex, an approximate total of 2,500 refrigeration tons of chilled water is supplied by the Central Chilled Water Facility at about 46°F and exits back to the CCWF at about 60°F. Chilled water serves air handling units (AHUs), electrical power supply units, and miscellaneous technical equipment. Since the chilled water pumps at the Central Chilled Water Facility have adequate capacity and head, no additional chilled water pumps are required at each of the Service Buildings. Chilled water is piped directly to the equipment that requires it. Chilled water is also used for temperature control trim and redundancy for process cooling water systems located in the Cooling Tower Building, which feeds each of the Service Buildings. The Cooling Tower Building also provides the primary cooling for the Process Chilled Water system described in section 3.6.2.4.

3.5.1.2 Steam

Steam is available from the BNL Central Utility Plant at 125 psig and is reduced to 50 psig at the NSLS-II main utility vault. The estimated peak steam load for the entire NSLS-II complex is 28,000 lbs/h. The 50 psig steam is routed underground inside the ring and distributed to the individual Service Buildings. It is then reduced to 15 psig for local use. Steam goes to humidifiers and to steam-to-hot-water heat exchangers. Hot water is then distributed to domestic water heaters, reheat coils, and other miscellaneous devices. Condensate is returned to the central plant.

3.5.1.3 Process Cooling Tower Water

Cooling towers, located in the center open space of the NSLS-II footprint above the Cooling Tower Building and operating year round, provide cooling for process systems such as the accelerators and beamlines. The estimated cooling load of 1,200 tons is handled by three cooling towers of 600 tons each, one of which operates as stand-by. This process water will be maintained using anti-fungal, anti-bacterial and anti-freeze chemicals approved for use by BNL Facilities and Operations.

3.5.2 HVAC Systems

3.5.2.1 Booster

The Booster tunnel and Injection Building service area are served by two separate packaged AHUs (nos. 501 and 601) in the mezzanine mechanical equipment room of the Injection Building. AHU #501 is a constant volume, reheat type with 4-inch double wall construction, galvanized steel inner lining, and stainless steel condensate drain pan (sloped and curbed). The #501 unit includes pre-filter, preheat coil, cooling coil, supply and return fans, hot water reheat coil, 95% final filter, and steam humidifier. The #601 is a variable speed unit of the same construction as the #501; however, it has no preheat coil and no hot water reheat coil. Supply air is cooled up to 50°F as needed for dehumidification.

3.5.3 Air Distribution

3.5.3.1 Ductwork

All ductwork is constructed in accordance with Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) standards. Supply air ducts are galvanized steel, insulated on the exterior. Exhaust and return ductwork is non-insulated except in areas where condensation on duct surfaces may occur. No internal duct lining is used. Galvanized steel is used for all lab main exhaust ductwork, and stainless steel is used for all exposed branch ductwork.

3.5.3.2 Air Terminal Units

Temperature control of individual spaces is by constant- and variable-volume terminal units with reheat coils. Heating coils have copper tubes with bonded aluminum fins.

3.5.3.3 Pressurization

The entire building is kept at positive pressure. A negative pressurization of 100 cfm per door is maintained in the laboratories by exhausting more air from the rooms than is supplied. In toilets, janitor closets, and other less critical areas, negative pressurization is maintained at 50 cfm per door.

3.5.3.4 Ventilation

Ventilation is provided as follows:

- The Booster tunnel and Linac are provided with air quantity based on thermal load
- Service Buildings are provided 20 cfm per person and with air quantity based on thermal load

3.6 Process Systems

Process systems are provided to NSLS-II to meet the needs of the accelerators, beamlines, and laboratories. Piping is identified by appropriate color coded labels.

3.6.1 Liquid Nitrogen

A liquid nitrogen supply is not needed for the Booster area for Booster commissioning.

3.6.2 Process Cooling Water

3.6.2.1 Scope

The NSLS-II accelerator and beamline components require a large amount of heat rejection as well as stringent temperature stability. A number of closed-loop water systems exchange heat with the water from cooling towers and chilled water from the BNL Central Chilled Water Facility. The design of the Booster/Linac process water is described in this section.

3.6.2.2 Design of the Deionized Cooling Water System

The total designed power consumption in the Booster is 490 kW, which is released to the Booster/Linac process (de-ionized) water system loop. A pump skid located on the second floor in Injector Building supplies the DI water required by Booster. Supply and return DI water temperatures are set at 85°F and 97.6°F, respectively. The total designed DI water flow rate for the Booster loop is 210 gpm.

3.6.2.3 Process Water Quality Control

Copper corrosion in the copper components cooled by deionized water remains a major programmatic concern. The main factors that affect the copper corrosion process are water resistively, pH, dissolved oxygen, and water temperature. Based on the experience of several accelerator facilities, the following values are selected for the design:

- Resistivity >1 MΩ-cm ±5%
- pH = 7.5 – 8
- Oxygen concentration = 6 – 8 ppb

3.6.2.4 Process Chilled Water

In addition to the DI process water systems, process chilled water is generated in each Service Building for distribution on the tunnel mezzanine for power supply and beamline cooling. It is a closed loop system isolated from the utility chilled water system by plate and frame heat exchangers. Filtration is provided to remove particles larger than 5 microns. Chemical treatment is used to maintain the water quality. Each system discharges into a common pressurized loop extending around the Storage Ring. The pumps for each station are sized to accommodate one-fourth of the process flow, so one station at a time can be taken off line for maintenance without disrupting service to the loads.

Process chilled water is used for cooling of some equipment within the Injection Building, including the Linac electronics racks.

3.6.3 Compressed Air

The compressed air source for the mechanical systems is the Central Chilled Water Facility site wide 100-psig system. The site wide system is oil-free, filtered to 1 micron, clean, and dried to -20°F dew point.

3.7 Vacuum System

The vacuum system is an all-metal system. To guarantee the necessary low out-gassing rate after installation, vacuum-exposed parts of the Booster and transfer lines conform to accepted clean ultrahigh vacuum practice, as specified in NSLS-II specification LT-ENG-RSI-SR-VA-002.

The vacuum system complies with the requirements outlined in the BNL SBMS subject area *Pressure Safety* in the section entitled "Vacuum Systems Consensus Guideline for Department of Energy Accelerator Laboratories." The vacuum system is designed such that the pressure throughout the Booster, the two beam transport lines (Linac-to-Booster and Booster-to-Storage Ring) is less than 5.0×10^{-8} mbar. The eight Booster vacuum sections and the eight transport line vacuum sections are isolatable from each other with pneumatically operated all-metal gate valves.

Diode-type ion pumps are used as high-vacuum pumps in the Booster and the beam transport lines. Inverted magnetron cold cathode gauges are used as primary vacuum gauges. For venting the Booster and the transport line vacuum systems, dry nitrogen from the boil-off outlet valve of a commercial LN2 dewar is used to back fill the vacuum section volumes. The LN2 dewar will have an ASME certified relief valve to provide overpressure protection and will relieve at <15 psig.

3.8 Fire Protection

The NSLS-II fire protection system is described in detail in the *NSLS-II Fire Protection Assessment / Fire Hazard Analysis* (FPA/FHA) – see Appendix 2. This BCSAD limits itself to describing the salient design features of that system and focuses, where possible, on the Injection Building which contains the Booster tunnel and equipment areas.

The Injection Building is classified as "Business" occupancy per the BCNYS and "Industrial, General Purpose" occupancy per NFPA Standard 5000, *Building Construction and Safety Code*.

- The overall building construction classification is IIB (BCNYS) and Type II – 000 (NFPA).
- The Booster area is served by a 12,400 CFM constant volume AHU located in the mezzanine of the Injection Building.
- Two 700 kW emergency generators are provided, one at Service Building #3 and one at the RF Building. The latter (Emergency Generator #1) will provide life safety needs for the Booster area.
- Five Fire Service Rooms are located on the exterior walls in the Service Buildings and another five Fire Service Rooms are located along the exterior walls of the Ring Building. The Fire Service Room in Service Building #2 serves the Injection Building.
- A Fire Department Connection (FDC) is located on the exterior of Service Building #2.
- Hydrants are located between 40 feet and 300 feet from the FDCs.
- A single water service fed wet pipe automatic sprinkler system with flow alarms serves the Booster Ring/Linac Zone.

- An adequate water source is provided to supply sprinkler protection for NSLS-II. The underground mains are provided with sectional control valves and provide a loop around the NSLS-II complex, as well as in the “infield” of the Ring Building.
- The Injection Building has its own dedicated fire alarm panel inside the south east entrance of the Injection Building.
- Automatic audio-visual alarm devices are provided throughout. Manual pull stations for fire alarms are installed at all building exits and at all exit stairs.
- High Sensitivity Smoke Detection (HSSD) systems are installed in the Injection Building main floor and in the Booster tunnel.
- Fire extinguishers are installed throughout the NSLS-II facility.

3.9 Cryogenic Systems

No cryogenics at the system level are in use for the Booster. Nitrogen gas boil-off from portable liquid nitrogen dewars may be used during vacuum chamber bleed-ups.

3.10 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.

3.10.1 Shielding Policy

NSLS-II is subject to DOE radiation protection standards. The primary document that defines the DOE radiation protection standard is 10 CFR 835, *Occupational Radiation Protection*. In addition, the accelerator-specific safety requirements are set by DOE Order 420.2C, *Safety of Accelerator Facilities*. All radiation protection policies and guidelines at Photon Sciences Directorate must be in compliance with these regulations, along with the BNL *Radiological Control Manual* and other pertinent documents in the BNL Standards Based Management System.

For radiation workers and members of the public, maximum annual exposures are limited in 10 CFR Part 835 to 5,000 mrem and 100 mrem, respectively. To keep radiation exposures to workers well below regulatory limits, DOE specifies that annual exposures >2000 mrem be approved by DOE in advance of the exposure. BNL maintains an annual administrative control level of 1,250 mrem for its workers and 5 mrem per year from any single facility to the public off-site. An additional control level of 25 mrem/year from NSLS-II operations is established for personnel working in non-Photon Sciences Directorate facilities on site, and for visitors and minors within Photon Sciences buildings. These latter two control levels are applied as design goals because of the inability to measure accurately these values amidst the natural background of ~60 mrem/yr.

The NSLS-II Shielding Policy is intended to ensure compliance with these requirements. The Policy specifies that facility radiation shielding shall be provided during normal operation to ≤0.5 mrem/h (instantaneous dose rate) at contact with the exterior of the shield wall in normally occupied areas. In addition, an ALARA analysis (see Appendix 3) demonstrated that a criterion for normal operation of ≤0.05 mrem/h at contact is appropriate for the shielding of the beam line experimental enclosures because of higher occupancy by non-radiation workers near the beamline enclosures.

It is typically cost prohibitive to shield a large accelerator using maximum operating parameters (i.e., energy and current) and worst-case accident scenarios. For NSLS-II, as is the case at other accelerator facilities, engineering controls in lieu of thicker shields are provided to detect abnormal operating conditions and to terminate those which create unacceptable radiation conditions in potentially occupied areas. The primary means for accomplishing this control for the Photon Sciences facility is through an area radiation monitoring network.

The Shielding Policy requires that the area monitoring network be interlocked to the radiation source when radiation levels ≥100 mrem/h. Studies of the area monitors that are potential candidates for the Photon Sciences Directorate area monitoring network have demonstrated that the area monitors will measure and alarm within a few pulses from the injection system, thereby limiting the potential radiation exposure to a small fraction of 100 mrem. For abnormal operating conditions creating radiation levels >2,000 mrem/h, a second independent system is required to mitigate or prevent the abnormal condition. See Table 3.5 for a summary of these requirements.

Table 3.5: Requirements to Control Radiation.

Exposure Potential*	**Required Controls**
Less than 100 mrem/h	Administrative procedures[1]
Equal to or Greater than 100 mrem/h	Radiation detectors or other fault sensors interlocked through PPS with accelerator
Equal to or Greater than 2,000 mrem/h	Redundant and independent radiation detectors or fault sensors interlocked through PPS with accelerator

*Instantaneous dose rates

The dose to workers during Booster commissioning will be kept well below federal limits and within BNL administrative levels (see above) through shielding, operational procedures, and administrative controls. Shielding of the Booster has been provided to reduce radiation levels during normal operation to less than 0.5 mrem/h at contact with the shield wall in occupied areas, thereby satisfying the design objective specified in 10 CFR 835.1002, which states that personnel exposure from external sources of radiation in areas of continuous occupational occupancy (2,000 hours per year) shall be limited to exposure levels below an average of 0.5 millirem (5 μSv) per hour and as far below this average as is reasonably achievable. Actual occupancies in occupied areas around the Booster during commissioning and during normal operating periods will be much lower than 2,000 hours with only limited occupancy close to shield walls.

As described below, effectiveness of the shielding shall be actively monitored during Booster commissioning by at least five interlocked area radiation monitors located external to the Booster tunnel at the occupied areas. In addition, during commissioning, radiation surveys shall be performed by the Health Physics personnel at frequent intervals to confirm adequacy of shielding and controls.

[1] Although not required by the Shielding Policy, in many cases when consistent with a good ALARA practice, interlocked radiation detectors will be provided to mitigate radiation levels ‹ 100 mrem/h.

It should be noted that the shielding calculations for the NSLS-II Booster are considered conservative for the following reasons:

- Beam losses are assumed to occur at a single point (rather than scattered and distributed over a more lengthy surface)
- Conservative attenuation lengths in the shield materials are used
- Doses are calculated using thick target dose equivalent factors
- Dose calculations are at the surface of the shield wall rather than at a more reasonable working distance of 30 cm

Note also that independent reviews of shielding methodology and assumptions have been performed on three occasions by experienced radiation physics experts from other light source facilities. At the first review (March 27-28, 2007) the group concluded that the "bulk shielding is well developed and is based on sound principles and reasonable assumptions." At the second review (April 24-25, 2008), the group concluded that the "shielding design is reasonable, comparable to other facilities." At the third review (June 22-23, 2010), the group noted "The committee is highly impressed with the progress that has been made to-date in working and resolving radiation safety issues for design and commissioning of NSLS-II since the last NSLS-II Radiation Safety Workshop in April 2008."

Shielding calculations for the Booster and other NSLS-II accelerators were performed using the analytical methods developed by William Swanson described in the book IAEA Technical Report Series No. 188; *Radiological Safety Aspects of the Operation of Electron Linear Accelerators* (1979); and as further elaborated by A. H. Sullivan in his book *A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators* **(**1992). The source terms and shielding attenuation provided through use of Swanson and Sullivan have been compared to the results of similar calculations using a) SHIELD11, a common shielding program used in many electron synchrotrons, and b) the Monte Carlo program FLUKA, which incorporates the revised neutron radiation weighting factors specified in 10 CFR 835 adopted by BNL in 2010. These comparisons show that the methodology used in the NSLS-II calculations is conservative by at least a factor of 2 (see Table 3.6).

Table 3.6: Equivalent Dose Comparison between NSLS-II, SHIELD11* and FLUKA** Simulations.

	Calculated Dose at 90^0 (μrem·m²/J)				
	Dose Component	**NSLS-II (Swanson methodology)**	**SHIELD11**	**FLUKA Ambient Dose Equivalent**	**FLUKA Effective Dose Equivalent**
Unshielded Dose at 1 meter in the transverse direction	Total Dose	1693	754	1668	1350
	Gamma Dose	1380	420	1011	850
	Neutron Dose	313	334	657	500
Shielded dose at 2 meters in the transverse direction with concrete shielding of 1 meter	Total Dose	4.45	0.87	2.0	1.3
	Gamma Dose	2.87	0.41	1.15	0.3
	Neutron Dose	1.58	0.46	0.85	1.0

3 GeV electrons on iron cylinder of length 30 cm and of radius 5 cm is used as target for Swanson, SHIELD11 and FLUKA simulations.

*W.R. Nelson and T.M. Jenkins. *The SHIELD11 Computer Code*. SLAC-Report-737, February 2005.

**A. Fasso et al. *FLUKA: A Multi-Particle Transport Code*. CERN-2005-10 (2005).

3.10.2 Radiation Controls

The Injection Building service area is posted as a radiologically Controlled Area during commissioning. The Storage Ring area near the Booster-to-Storage Ring transport line may also be posted based on the results of radiological surveys. The earthen berm adjacent to the Booster is fenced, with access through the locked gate only allowed during times when the Booster is interlocked off via the PPS or for the purpose of radiological surveys under Radiological Control Division administrative procedure and in coordination with the Control Room. The fence and gate will be posted as Controlled Areas. The access gate will be further posted with words to the effect of "Entry not allowed during machine operations unless specifically coordinated with and permitted by the Control Room". Access to all radiological Controlled Areas will require proper training and, as posted, a radiation dosimetry badge. Access to the Injection Building is controlled through the use of card readers at access points to the building. Only personnel with appropriate training and authorization shall be allowed access to the Controlled Areas during commissioning unless escorted by qualified, trained personnel. Areas within the Controlled Areas may have additional postings, such as Radioactive Material Areas and Radiation Areas, as required. Access to the Booster enclosure during operation shall be prevented by the PPS interlocks described in Section 3.10.5 below. Radiological Work Permits (RWP) shall be issued by Radiological Control Division personnel as required in accordance with the criteria in the BNL *Radiological Control Manual*.

3.10.3 Radiation Monitoring

A major activity during commissioning is confirmation of the adequacy of the shielding. During commissioning, a radiation monitoring program is established for the Controlled Areas to protect workers and to assure that their doses are kept ALARA. Radiation surveys are also performed in non-controlled areas near the Booster (e.g., the open area outside the fenced enclosure of the Booster berm). Radiation surveys are performed by trained personnel from the Radiological Control Division to ensure that proper shielding is in place for normal operations and to determine radiation levels during abnormal operations, formalized as part of fault studies. A major activity during commissioning is confirmation of the adequacy of the shielding.

At least five fixed, active interlocked area radiation monitors providing visual and audible alarms both locally and in the Control Room are planned (this number may change depending on commissioning results) and will be mounted in the Injection Building service area external to the Booster shield wall to monitor elevated radiation levels produced by electron losses around the circumference of the Booster tunnel and along the transport line to the beam stop. Each monitor has three alarms that annunciate locally and in the Control Room. There is a low level alert radiation alarm which provides an early warning of elevated radiation levels when a pre-set threshold is exceeded; there is a high level radiation alarm which interlocks the Linac gun when a pre-set threshold is exceeded; and there is a fail alarm which provides an alarm whenever the detector does not provide signals to the rate meter within a prescribed time period. These BCASE credited control devices are interlocked with the Booster through the Personal Protection System and prevent continued Linac pulses when radiation levels are detected at the alarm level. Two or more active area monitors will be located within the Storage Ring enclosure to monitor for elevated levels in this region during Booster commissioning. The purpose of these monitors is ALARA-based and intended to alert occupants to increased radiation levels in the Storage Ring enclosure during Booster commissioning; these monitors are not interlocked through the PPS and are not credited controls. Booster radiation penetrating into the Storage Ring enclosure will be carefully monitored to determine if this area needs to be posted as a Controlled Area or not. The final location of these active area radiation monitors may be adjusted based on fault studies performed during commissioning.

Additional Booster instruments provide information relating to charge of the electron beam transported into (injection) and out of (extraction) the Booster. Although these systems are not credited controls, they do provide information that can help Booster Operators detect non-optimal operating conditions, and permit diagnosis and correction of conditions which could result in beam losses creating elevated radiation levels. A DC current transformer (DCCT) measures stored beam within the Booster Ring; this DCCT will be set to allow a maximum Booster current of 20 nC/s. The charge per second measured by an integrating current transformer (ICT) located in the Linac to Booster Transport Line can be compared to the Booster DCCT charge per second for a measure of Linac to Booster injection efficiency. The charge per second measured by another ICT located in the transport line to the Booster beam stop can be compared with the Booster DCCT charge per second for a measure of the Booster extraction efficiency. The rate of charge delivered by the Booster is a parameter of interest to Accelerator Operators, since beam losses at high charge rates can result in elevated radiation levels. These devices will have visual displays in the Control Rooms and will be interlocked with Linac injection through the Linac gun pulse. This interlock is not through the PPS system, since personnel protection against elevated radiation levels comes from the area radiation monitoring network and not from the current transformer.

Personnel dosimetry is provided for workers in Controlled Areas. Passive area dosimetry will be mounted in controlled and non-controlled areas as a further means of monitoring radiation levels in area adjacent to the Booster. Personnel and area dosimetry provide an important means for evaluating the adequacy of the radiation protection program and are BCASE credited controls.

Detailed explanations of radiological credited engineered and administrative controls are provided in Section 4.15.3 and Section 5.

3.10.4 Personnel Protection System (PPS) Interlocks

NSLS-II produces intense radiation fields within accelerator enclosures. A highly reliable interlock system is provided which ensures that personnel cannot inadvertently enter one of these areas during machine operation. This section describes the design for the NSLS-II Personnel Protection System (PPS).

The PPS, described in general below, is segmented into four integrated subsystems designed for the specific functions of the accelerator complex. This BCSAD focuses on the Booster PPS interlocks (BPPS) in Section 3.10.4.1.

ANSI/ISA Standard 84, *Process Safety Standards and User Resources*, is a design guide for the systems. Each system utilizes a dual-chain Programmable Logic Controller (PLC) architecture (both safety rated). PLCs have numerous advantages over the relay logic scheme of interlocks. A PLC can be reprogrammed to reflect changes in configurations and also has numerous diagnostics. The use of PLCs in safety systems is very common and is an accepted practice at accelerator facilities across the United States, including the NSLS, where they have been in use since 1996.

The safety PLCs are write-protected and do not directly interface with the control system. There is an intermediate PLC that is read-only that transfers the safety system data and does not allow any writing to the safety PLCs. In addition to this, the control system has its own cyber security protection plan and does not interface with the campus network directly.

All interlock logic trees have redundant and independent chains. The systems are fail safe for foreseeable failure modes (e.g., loss of power, open circuit, short to ground, and single component failure). All devices attached to the PPS are designed to be fail-safe. In case of failure, the device fails in such a manner to either remove the hazard or remove the permit to generate/maintain the hazard. Redundant circuits do not share cables and are separated physically on circuit boards and terminal strips. All interlock wiring and components are labeled and readily identifiable. Wires are run in dedicated conduit or segregated in cable tray. Safety system wiring is separated from all non-safety wiring. For fiber optics, the overall cable is shared with other use fibers but individual tubes that hold bunches of fibers are only for safety systems. These fibers are configuration controlled for access at the exit of the fiber cable assembly. All PPS equipment is clearly identified and secured in locked cabinets. For operational continuity, each system's power is short-term backed up with a capacitor UPS system. As a means of simplifying maintenance and repair and to reduce potential risk to personnel, voltage to PPS systems is limited to 24 V. Power supplies are powered by plug in line cords.

Design for enclosure search systems includes sequenced and timed inspection stations, warning lights, audible alarms, emergency shutdown switches, and mirrors, where necessary. Test modes are emphasized during design to ensure ease and simplicity for testing. Operation of the test mode disables the opposite redundant chain through wiring and makes the system safe from leaving the test mode asserted. Warnings that the system is in test mode are displayed on the Control Room screens. The system will be brought to the zero state before return to operation following a test.

When PPS systems are installed and certified, a rigorous configuration management program is in place to control unauthorized modifications to interlock system components, including physical access control. In addition, periodic scheduled testing and certification of interlock systems is performed by personnel independent of design and on-going maintenance responsibilities.

A major role for the each PPS is to provide a means of ensuring that no personnel are inside an enclosure when radiation is present. To secure an enclosure prior to introduction of beam, a search of the area is first performed by a qualified staff member. "Search boxes" inside the enclosure must be visited in proper sequence as part of the search. The search boxes are strategically placed to ensure that during the search all parts of the enclosure are either visible or visited by the search personnel and no person is left behind inside the area. The search is completed with the closing of the enclosure door, and the actuation of the Search Complete button.

Once the search process is completed, the PPS subsystem starts a beacon and audio signal inside the secured area, warning all personnel to exit. This signal lasts 30 seconds after the door is closed and the Search Complete button pressed. The function of the beacon and audio signal is to alert any personnel who have been overlooked by the search person and are inside the secured area. Distinct emergency shutdown buttons are placed inside the enclosure to instantly remove or prevent the radiation hazard when pressed. The system utilizes diverse hardware from different manufacturers for the sensors and PLCs to reduce common mode failures.

3.10.4.1 Booster Personnel Protection System (BPPS)

The BPPS system utilizes separate PLCs in chains A and B. The two PLCs provide redundancy and independently monitor all the devices. To immediately stop the production of radiation, AC power to the Linac modulator and gun power supplies will be removed redundantly. This will be accomplished through the use of AC contactors, one for chain A and one for chain B.

Two critical devices[2] control the injection from the Booster to the Storage Ring: a bending magnet (BS-B2) and a safety shutter located downstream of the bending magnet. The Booster-to-Storage Ring transport safety shutter (BS-SS) will have three switches for the A chain to monitor the shutter position. Two switches monitor the closed position and one monitors the open position. The bending magnet upstream of the safety shutter is also redundantly monitored for current by chain B. When the magnet is not powered (i.e. OFF) it prevents electrons from entering the Storage Ring tunnel area and provides the safety function. When OFF, the beam is delivered to a beam dump. During this commissioning period, it is anticipated that personnel will be in the Storage Ring area when the Booster is producing beam. Such operation requires that the Booster safety shutter is in the closed position and that power to the transport line bending magnet is off. The status of these critical devices will be monitored through the PPS. As an additional safeguard during Booster commissioning, the safety shutter will be locked and tagged out in the closed position, and the bending magnet will be locked and tagged in the OFF position. This locking and tagging is an ASE Credited Control. Note: these locks and tags will be removed for Storage Ring commissioning to allow Booster electrons to be injected into the Storage Ring.

Access to the Booster tunnel requires that the power to the RF and dipole power supplies must be off, and the Linac-to-Booster critical devices must be in a safe state. Power to these devices cannot be turned on unless the Booster enclosure has been searched and secured as described above. Once secured, opening the doors to the enclosure requires that the power to these devices be turned off before the Control Room can authorize a release to open the door. If the door was forced open while the enclosure was secured, the PPS would interlock the power to the Booster RF and dipoles power supplies, the power supplies to the Linac klystrons and electron gun, and would place the Linac-to-Booster critical devices in a safe state. All Booster doors are monitored with four switches, two each for chains A and B.

The active interlocked radiation monitors around the Booster tunnel shield wall are monitored by the A chain logic and inhibit the gun AC power supply which terminates injection.

The BPPS must be fully functional when the Booster IOT transmitter is being tested with RF; in this case the Booster enclosure has been searched and secured. These tests will occur prior to the actual start of Booster commissioning at which time the IOT transmitter and related equipment will be commissioned under the requirements set by a Radiation Work Permit as per the Radiological Control Manual, Chapter 3, Part 2, Section 321.

All parameters of the BPPS are available for monitoring in the Accelerator Control Rooms through the EPICS control system. A block diagram of the BPPS is available upon request.

3.11 Integrated Safety Management

Integrated Safety Management (ISM) is the basis for performing work safely at BNL. The Photon Sciences Directorate Environment, Safety and Health (ESH) program described in this section is intended to ensure that work is conducted efficiently and with full protection of the workers, public and environment. Its foundation is set on the core functions and guiding principles of the DOE ISM program. The Photon Sciences Directorate ISM program seeks to ensure that:

- Responsibilities for ESH are clearly understood
- Policies and requirements for ESH are well-defined

[2] Critical device is the term applied to a component or system which prevents unsafe exposure to dangerous radiation fields.

- 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

3.11.1 ESH Roles and Responsibilities

Responsibility for ESH at the Photon Sciences Directorate lies with the Directorate's Associate Laboratory Director. This responsibility flows down to the worker through the various Division Directors and their supervisory chains. The Photon Sciences Directorate ESH Manager assists the Divisions and their staff members through the management of the various safety program elements discussed below.

Each worker within the facility is expected to comply with all safety requirements and to assure that the 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 worker Roles, Responsibilities, Authorities, and Accountabilities. These documents form the basis for training and qualification of each worker.

To provide ESH support to workers and supervisors, and to provide oversight for Directorate activities, an ESH Group exists within the Directorate. Managed by the Photon Sciences Directorate ESH Manager, it is staffed with appropriate personnel to discharge its responsibilities effectively. This staff also includes representatives from BNL Industrial Hygiene, Environmental Compliance, and Radiological Control Division, all matrixed to the Directorate.

The Photon Sciences Directorate manages a number of ESH-related committees, such as:

- Environmental Management System (EMS) and Occupational Health and Safety Management Committee (OHSAS)
- ESH Improvement Committee
- Work Planning Committee
- Interlock Working Group
- Photon Sciences Safety and Operations Council
- Instrument Readiness Review Committee

Additional committees may be constituted for commissioning.

A major role for these committees is to ensure that changes in the facility or work activities do not result in Unreviewed Safety Issues (USI) that are non-compliant with BNL requirements or that could result in a deviation from the approved Authorization Documents such as this BCSAD and its accompanying BCASE. Membership for these committees is drawn from Directorate, BNL-at-large, and also external to BNL when expertise is required.

ESH reviews are conducted to ensure that hazards have been identified, and that codes and standards required have been properly defined and applied. ESH Design Reviews of the accelerator systems were conducted to assure compliance with 10 CFR Part 851.21, *Hazard Identification and Assessment*, and

851.22, *Hazard Prevention and Abatement*; the BNL SBMS subject area Engineering Design; and the Directorate *Quality Assurance Manual* procedures for Engineering Design. Additional examples of reviews are Radiation Safety Workshops; the *Environmental Assessment* (CD-0); the *Preliminary* (CD-1) and *Final* (CD-2) *Hazard Analyses*; the *Preliminary Safety Assessment Document* (CD-3), the Project Safety Reviews that covered research and development (R&D) activities; and the Linac Commissioning Safety Assessment Document/Accelerator Safety Envelope.

Beneficial Occupancy Readiness Evaluations are performed prior to initial occupancy of buildings; Operational Readiness Evaluations are performed once equipment is in place and before operations commence. These are conducted by a Booster Instrument Readiness Review team in accordance with the BNL SBMS subject area Readiness Evaluations. Commissioning activities associated with operation of an accelerator are subject to the Accelerator Readiness Review requirements of DOE 420.2C *Safety of Accelerator Facilities* and the BNL SBMS subject area *Accelerator Safety*.

3.11.2 ESH Policies and Standards

Policies and requirements that apply to work are defined in the Photon Sciences Directorate ESH Policies and Requirements Manual (PRM). The contents of this manual are based on BNL SBMS ESH subject areas and standards. The PRM is maintained and augmented to ensure that ESH requirements that apply to Directorate activities are fully developed at the time of commissioning and initial operation. Reviewed below are a number of key ESH programs that are intended to ensure the proper identification and control of hazards, and ensure compliance with ESH requirements at the operational level.

3.11.2.1 Work Planning and Control

ESH PRM 1.3.6, *Work Planning and Control Procedure*, documents the Work Planning and Control Procedure functions within Photon Sciences Directorate. 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 both to work performed by service organizations and to work performed by staff. 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 Facility Operations Center. The Work Control Manager oversees the WCCs and also chairs a committee that reviews Work Permits.

3.11.2.2 Self-Assessment

Current self-assessment programs include scheduled inspections of program facilities to eliminate the diverse and changing potential for unsafe conditions, and to increase the safety awareness of individual employees. Safety professionals conduct the tours and are accompanied by ESH Coordinators and Research Space Managers. All findings are maintained and tracked to completion. In addition, the Photon Sciences Directorate participates in the ESH Directorate Multi-Topic ESH reviews as well as in the Required Line Self-Assessments detailed in the SBMS *Organizational Self-Assessment* subject area.

3.11.2.3 Environmental Management

The BNL EMS requirements are implemented as defined in the current Photon Sciences Directorate EMS program.

3.11.2.4 Occupational Health and Safety Management

The BNL OHSAS requirements are implemented as defined in the current Photon Sciences Directorate OHSAS program.

3.11.2.5 Emergency Plan

Local Emergency Plans have been prepared and implemented for current facilities. The Photon Sciences Directorate ESH Manager is responsible for the emergency planning program and has appointed a Local Emergency Coordinator (LEC) who has primary responsibility for Pre-Emergency Planning. The LEC ensures that the emergency plans are reviewed and updated as needed or at least annually, particularly after the occurrence of accidents or emergency situations. The LEC also schedules annual drills for those buildings that require them. In addition, the LEC provides this information to the Facility Complex Manager to update the Firehouse Response Cards.

3.11.2.6 Unreviewed Safety Issues (USI)

During Booster commissioning, the USI process determines if there is a significant increase in the probability or consequences of a previously analyzed accident or if a new, previously un-analyzed accident could result in a significant consequence. The USI is a structured process to identify and evaluate whether planned or as-found conditions, equipment, or processes may exceed the bounds of an accelerator's ASE. Activities that exceed the bounds of the ASE must not be performed until restart is approved by the Photon Sciences Directorate management and DOE/BHSO is notified. The USI process is described in the BNL SBMS *Accelerator Safety* subject area and is further described in a Photon Sciences Directorate procedure. Activities that may increase the level of a known hazard or may introduce a new type of hazard not examined in a Safety Assessment Document, and therefore may impact the items below, must be evaluated through the PSD USI determination process:

- The radiation hazard personnel protection system (PPS)
- Radiation shielding for personnel protection
- Radiation monitoring for personnel protection
- Radiological source terms identified in the SAD
- Hazards identified in the SAD

The Directorate also incorporates the use of the "*EMS, FUA and SAD/ASE Checklist for Photon Sciences Directorate Reviews*" form which asks if the review has resulted in changes to the Directorate's Facility Use Agreement, SAD, ASE, Job or Facility Risk Assessments, or the Environmental Assessment.

3.11.3 Safety Training

The Photon Sciences Directorate *Training Requirements for NSLS* and *Training Requirements for NSLS-II* define the training requirements for all personnel working in the Directorate. This program is maintained by the Directorate Training Coordinator, who reports to the Directorate Human Resources Manager. 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 training program consists of training required for BNL employees as well as facility- and job-specific training. Staff members also may receive additional training regarding environmental issues, waste disposal, health issues, hoisting and rigging, lasers, noise, machine shop use, and other issues.

4. SAFETY ANALYSIS

The focus of this Booster Commissioning Safety Assessment Document is to evaluate hazards by identifying the initiator of the hazard and its consequences, establishing a pre-mitigation risk category, recognizing design features to mitigate that risk, and then establishing a post-mitigation risk category. Appendix 4 defines the risk methodology/categories and provides a summary of the analyses. The BCSAD documents the residual risk after incorporating the planned mitigations.

The hazards selected for analysis in this section are based on the past operation of accelerators throughout the DOE complex and, more specifically, on the almost 30 years of operational experience at the BNL NSLS facility. Descriptions and management of hazards have been obtained from facility authorization documents (Safety Assessment Documents, Accelerator Safety Envelopes, and Conduct of Operation Manuals). Additional sources of hazard information have been obtained through engineering design reviews, safety inspections, facility assessments and reviews, as well as through the BNL SBMS subject areas and the experience of personnel working within accelerator facilities. In the case of NSLS-II, hazards were also identified during a series of Design ESH Reviews held in 2008 in which lead personnel were asked to complete hazard identification checklists (based on NSLS and C-AD design review checklists) and then were required to present to an ESH review group descriptions of their projects with emphasis on safety issues. This section discusses the risks and controls of fifteen hazard types that could be involved with Booster commissioning. In the case of standard industrial hazards where there are no circumstances that would exacerbate that hazard, the mitigation and control of that hazard is by following BNL SBMS subject area and PSD requirements, and further elaboration is not warranted in the document. As defined in DOE G 420.2-1, standard industrial hazards are those that are routinely encountered and accepted in general industry and for which national consensus codes and/or standards exist to guide safe design and operation. Where circumstances could exacerbate a hazard, these hazards are discussed in more detail. Other Booster commissioning hazards not covered in SBMS, such as natural phenomena, are also discussed in detail. The Maximum Credible Incident involves ionizing radiation hazards; therefore controls for these hazards are included in the Booster Commissioning Accelerator Safety Envelope.

The hazard analysis described in this section is intended to ensure that work is conducted 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 as described in section 3.11 above. In addition, the hazard analysis establishes controls that follow the requirements set by BNL Standards Based Management System (SBMS) as well as by DOE Order 10 CFR 851, *Worker Health and Safety Program*.

The following hazards are addressed in detail in this assessment: natural phenomena; environmental; waste; fire; electrical; cryogens; chemical and hazardous materials; vacuum system; accelerator cooling water and compressed air; material handling and ionizing radiation. The following are considered routine Booster industrial hazards and are covered by BNL SBMS requirements: lasers, radiofrequency non-ionizing radiation and magnetic fields. Noise and ozone are not hazards associated with Booster commissioning.

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 the BNL SBMS *Hazard Analysis* subject area) for the listed hazards. In addition, the hazards and risks associated with work activities are 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 a low level for personnel working within the NSLS-II facility.

4.1 Natural Phenomena Hazards

Natural Phenomena Hazards (NPH) include high winds, snow/ice, floods due to rain, lightning, and earthquakes. The NSLS-II design is governed by the Building Code of New York State (BCNYS). The BCNYS specifies design criteria for wind loading, snow loading, lightning protection, and seismic events. The NSLS-II facility as a whole will contain small quantities of activated, radioactive, and hazardous chemical materials. Should a NPH cause significant damage, the impact would be mission related (worker injury, equipment or building damage, local release of hazardous materials, or programmatic impact) and would not pose a hazard to the public or the environment. Based on the guidance in DOE Standard 1021-93 (Change 1), *Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems and Components*, the NPH mitigation Performance Category for the NSLS-II facility is PC-1, based on the identified hazards and potential consequences. The Standard defines PC-1 as:

(i) It is a building/structure with potential human occupancy.

(ii) Failure of the structure, system, or component (SSC) may cause a fatality or serious injuries to in-facility workers.

(iii) Failure of the SSC may cause damage that can be prevented or reduced cost-effectively by designing it to withstand NPH effects.

Management and control of NPH follow the requirements in:

- DOE Order 420.2C, *Safety of Accelerator Facilities*
- DOE Guide 420.2-1, *Accelerator Facility Safety Implementation Guide*
- DOE Order 420.1B, *Facility Safety*
- DOE STD 1020-2002, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*
- DOE STD 1021-93, *Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems and Components*
- DOE STD 1022-94, *Natural Phenomena Hazards Site Characterization Criteria*
- DOE STD 1023-95, *Natural Phenomena Hazards Assessment Criteria*
- *Building Code of New York State*
- ANSI/UL-96A, *Installation Requirements for Lightning Protection Systems*
- NFPA-780, *Standard for the Installation of Lightning Protection Systems*

Design criteria and operational controls incorporated to mitigate these risks are given in Table 1 of Appendix 4. The pre-mitigation risk is categorized as Low and the post-mitigation risk is categorized as Routine.

Natural phenomena that could lead to operational emergencies at BNL include hurricanes, tornadoes, thunderstorms, lightning, snowstorms, ice storms and earthquakes. Hurricanes occasionally hit Long

Island and the associated high wind speeds could potentially damage structures. Tornadoes and hailstorms are rare on Long Island. Thunder and rain storms, snowstorms, and ice storms occasionally occur, and potentially could cause significant damage entailing an operational emergency. However, operational emergencies do not involve loss of operational control or significant releases of hazardous or radiological material. In such an emergency, BNL management would decide whether to shut down operating facilities, shelter workers, or evacuate workers from the site.

Typical severe weather-related phenomena, either local or non-local, may affect the stability of electrical power supplied to the NSLS-II facility and so could impact the stability of the accelerator's magnet power supplies, resulting in the loss of stored electron beam in the Booster. Radiological shielding protects personnel from such losses. If BNL were to declare a significant weather-related operational emergency and recommend that staff shelter or evacuate the site, the Operators would turn off the Booster (and Linac). The Photon Sciences Directorate could also take action in advance of any BNL-wide direction. To date, the BNL site has experienced only minimal impacts from extreme weather, typically the incursion of rainwater (leaks in roofs and flooding under doors). Localized flooding could increase the potential for electrical hazards. Depending on the area and height of the floods, there is some possibility for minor chemical and lead (from shielding) contamination of flood water, but no possibility for its radiological contamination. The electrical hazards would be mitigated by 1) having properly grounded and bonded electrical equipment mounted on platforms or held in racks above floor level, 2) maintaining sumps (pumps powered by the emergency generator), 3) having adequate drainage that prevents water from accumulating, 4) installing water vacuum equipment, and 5) installing water mats to detect water leaks and alert operations staff. Chemical hazards would be mitigated by storing chemicals in cabinets and on shelving above the floor.

In recent years, the BNL site has been shut down for upwards of two days following snow storms. The purpose for these shutdowns was to allow for adequate snow removal from roads and walkways.

Earthquakes on Long Island are extremely rare. 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 investigated during planning before construction of the Brookhaven Graphite Research Reactor, High Flux Beam Reactor, and Relativistic Heavy Ion Collider. These investigations remain valid and seismologists expect no significant earthquakes in the foreseeable future. No active earthquake-producing faults are known in the Long Island area.

Further information is available in *Brookhaven National Laboratory Natural Phenomena Hazards Evaluation* (an attachment to the BNL Implementation Plan as per DOE Accelerator Order 5480.25), S. Hoey, April 1994.

4.1.1 Design Loads

To mitigate the effects of natural phenomena hazards, the following design loads have been incorporated into the design of the NSLS-II buildings.

4.1.1.1 Live Loads Design

- Injection Building 250 psf
- Linac tunnel and Klystron gallery 250 psf
- Booster Ring 250 psf
- RF Building 150 psf

    - Office mezzanine 100 psf
    - Equipment mezzanine 150 psf
- Service Buildings 150 psf
- Cooling Tower Building 150 psf

4.1.1.2 Snow Loads

- Ground snow load Pg 30 psf
- Snow importance factor I 1.0 (Category II)
- Snow exposure factor Ce 0.9
- Thermal Factor Ct 1.0
- Design snow load 30 psf (minimum) + drift where applicable

4.1.1.3 Wind Loads

- Basic wind speed (3-second gust) 120 mph
- Wind load importance factor I_W 1.00 (Category II)
- Wind exposure B

4.1.1.4 Earthquake Loads

- Short period acceleration Ss 0.25g
- 1-second period acceleration S1 0.08g
- Site Class D
- Seismic Use Group I
- Seismic Design Category B
- Seismic Importance Factor I_E 1.0 (Category II)

4.1.2 Booster Commissioning – Natural Phenomena Hazard Considerations

The design and construction of the Injection Building and Booster area meet the above requirements. Any impact of an NPH event would be mission related (worker injury, equipment or building damage, local release of hazardous materials, or programmatic impact) and would not pose a hazard to the public or the environment.

4.2 Environmental Hazards

A detailed environmental analysis is contained in the *NSLS-II Environmental Assessment* for NSLS-II (DOE/EA 1558 – see Appendix 1a), for which the *NSLS-II Finding of No Significant Impact* (see Appendix 1b) was issued on September 27, 2006. In June 2008, a comparison was made between the NSLS-II Title II design and the 2006 EA findings. The BNL NEPA Coordinator determined, with DOE concurrence, that no new adverse environmental impacts had been identified and that the Title II design specifications are within the scope of the existing EA.

Environmental hazards associated with the Booster commissioning include the potential discharge of the following materials to soil, surface water, groundwater, air, or the sanitary system: oils, solvents and inert gases (activated air products are described in Section 4.15 below). The principal initiators would be the failure of equipment, impact from a natural phenomenon, fire, or a violation of procedures/ processes.

Management and control of environmental hazards follow the requirements in:

- DOE *National Environmental Policy Act* (10 CFR 1021)
- Suffolk County Department of Health Services (SCDHS) Sanitary Code Article 12, *Toxic and Hazardous Materials Storage and Handling Controls*
- *National Emission Standards for Hazardous Air Pollutants* (NESHAP) (40 CFR 61 - Subpart A)
- NYSDEC *Prevention and Control of Air Contamination and Air Pollution* (6 NYCRR 200 – 234)
- Code of Federal Regulations, *National Pollutant Discharge Elimination System* (40 CFR 122-131, 133)
- NYSDEC *State Pollutant Discharge Elimination System (SPDES) Permits* (6 NYCRR 750)
- Code of Federal Regulations, *Hazardous Waste Management Regulations* (40 CFR 260-262, 264-265)
- NYSDEC *Hazardous Waste Management Regulations* (6 NYCRR 270-374-2)
- International Organization for Standardization - *Environmental Management System* – ISO 14001
- BNL SBMS *Environmental Aspects and Impacts* subject area
- BNL SBMS *Environmental Assessments and ESH Management Revi*ew subject area
- BNL SBMS *Liquid Effluents* and numerous other subject areas
- BNL SBMS *Storage and Transfer of Hazardous and Non-Hazardous Materials* subject area

Design criteria and operational controls incorporated to mitigate these risks are given in Table 2 in Appendix 4. The pre-mitigation risk is categorized as Moderate and the post-mitigation risk is categorized as Low.

NSLS-II Booster uses closed-loop cooling water systems for temperature control (comfort cooling) and equipment cooling. These systems use water supplied from the BNL Central Chilled Water Facility (CCWF) and the NSLS-II Cooling Tower water for heat exchange. The portion of water used for equipment cooling is deionized using ion-exchange columns. Experience at other accelerator installations has shown that on-site regeneration of ion-exchange media creates a waste stream capable of impacting the environment if managed incorrectly. Therefore, ion-exchange columns associated with these deionized water systems are sent back to the manufacturer for regeneration; a Process Knowledge Certification Form will accompany the filters to the manufacturer.

The closed loop cooling waters will not be discharged into the sanitary system on a regular basis; discharges occur when maintenance is performed. These discharges have the potential for environmental impact if heavy metals are present; a situation that is not common, but possible if stagnant water from dead-end lines is drained. The Environmental Compliance Representative participates in the Work Permit process regarding the need to sample waters prior to discharge. Water used in the Cooling Towers is treated with an ultrasonic system, reducing the use of standard water treatment chemicals such as biocides and corrosion inhibitors. Cooling Tower water is routinely discharged to the stormwater recharge basin during tower blow down and during maintenance activities. Any treatment chemicals are pre-approved for use on the BNL SPDES permit.

While some accelerator components will become locally activated as a result of operations, the potential for soil activation is limited and no mitigation is required. Calculations (see Appendices 7a and 7b) have shown that NSLS-II operations will generate tritiated water or sodium-22 below the BNL-defined Action Levels. Periodic sampling of the cooling water systems, soils near high loss points and the groundwater will be performed to confirm that tritium and sodium-22 concentrations remain below the respective BNL-defined Action Levels.

The potential for and the degree of atmospheric discharges of radioactivity have been evaluated by the BNL NESHAP Subject Matter Expert. Please see section 4.15.4.2 for further details.

Oil from the facility is minimized, where possible, by the use of oil-free pumps. Oil-filled pumps are operated within secondary containment, where necessary, to protect against leaks and spills. Aerosolized oil is exhausted through filters to the exterior of the facility. The inductive output transmitter (IOT) high voltage power supply unit (RF system) contains two capacitors containing 1.0-1.5 liters of oil each.

The roof and parking lot stormwater drains into groundwater recharge basin HS that lies southeast of the NSLS-II site and also, to a lesser extent, drains into basin HW (Blues Pond) southwest of the NSLS-II site. If the volume discharged to recharge basin HS is too high, local recharge basins will be evaluated. SPDES-related sampling is conducted at the recharge basins. Work planning, experimental review, Tier I safety inspections, training, and postings are methods for ensuring that hazardous effluents do not enter the sanitary waste stream.

Two emergency diesel generators at 700 kW each supply backup power to the facility. They are designed according to SCDHS Article 12 secondary containment criteria in order to prevent release of the fuel oil to the environment. Each generator is equipped with a 450-gallon fuel oil tank.

Hazardous waste storage areas will also meet SCDHS Article 12 and NYSDEC/RCRA design criteria.

The NSLS-II environmental program is overseen by the Photon Sciences Directorate ISO 14001 Environmental Management System (EMS), as documented in the Photon Sciences Directorate EMS/OHSAS web site.

4.2.1 Booster Commissioning – Environmental Hazard Considerations

The commissioning of the Booster poses minimal risk to the environment. Proper implementation of the Photon Sciences Directorate EMS ensures that the risk is low for releasing, in amounts beyond regulatory limits, of oils, solvents, and radioactive material to the soil, surface water, groundwater, air, or sanitary system. The IOT transmitter high voltage power supply capacitors have secondary containment in the form of a metal trough included in the base frame.

4.3 Waste Hazards

Waste-related hazards from Booster Commissioning include the potential for injury to personnel and for release of waste materials to the environment. Typical initiators would be transportation accidents, incompatible materials, insufficient packaging/labeling, failure of the packaging, a natural phenomenon, or a procedural violation.

The management and control of waste hazards follow the requirements in the BNL SBMS *Hazardous Waste Management* and *Industrial Waste Management* subject areas.

Design criteria and operational controls incorporated to mitigate these risks are given in Table 3 in Appendix 4. The pre-mitigation risk is categorized as Moderate and the post-mitigation risk is categorized as Low.

Waste oil from mechanical pumps is reduced due to the use of oil-free pumps to back the turbomolecular pumps for roughing down accelerator vacuum systems and during system conditioning. Oily rags would be disposed of as industrial waste. Deionizing columns are recharged off site by a vendor, thus column recharge waste waters are not being created on site; follow-up with the vendor to assure proper handling of wastes will also be done. Solvents used for cleaning surfaces would be wiped to dryness resulting in no liquid waste. Cooling tower water and process chilled water systems will be drained at infrequent intervals into the BNL sanitary system. These waters contain anti-fungal and anti-bacterial (and anti-freeze for the cooling tower) chemicals approved for use by BNL Facilities and Operations

Supply, use, waste, and disposal through these and other systems are documented by the Environmental Compliance Representative through the use of Process Assessment Forms (PAF). The Photon Sciences Directorate participates in the BNL pollution prevention program and uses the Environmental Management System to set goals for environmentally friendly design techniques and waste reduction, where practical. Machining waste, for example, would be recycled to the extent possible.

90-day Waste Accumulation Areas and local Satellite Accumulation Areas would be provided dependent on the needs of the staff and to help ensure compliance.

Safety inspections, periodic Chemical Management System (CMS) audits and internal inventory management, chemical limits specified by the NSLS-II Fire Protection Design Strategy, and Emergency Preparedness Hazard Assessments are major factors in maintaining the facility's chemical inventory at minimum levels needed to operate. Many processes do not generate waste. Any need for exposure monitoring of waste operations would be assessed.

4.3.1 Booster Commissioning – Waste Hazard Considerations

The commissioning of the Booster is anticipated to generate limited quantities of waste materials. These could include used solvents, oils and oily rags, and used de-ionizing columns.

4.4 Fire Hazards

Extensive design criteria are established through NFPA, BCNYS, and DOE. Typical hazard initiators include equipment failure, accumulation or use of combustible/flammable materials, the use of pyrophoric or reactive materials, improper chemical storage, inadequate fire detection and suppression, and electrical hazards due to static discharge or lightning. These could result in injury or death to workers, equipment damage or loss, release of hazardous materials to the environment, and programmatic impact.

The management and control of fire hazards follow the requirements in:

- *Building Code of New York State*
- Occupational Safety and Health Administration (OSHA) 1910, *Subpart E, Exit Routes, Emergency Action Plans and Fire Prevention*

- ANSI A-17.1, *Safety Code for Elevators and Escalators*
- DOE Standard 1066-99, *Fire Protection Design Criteria*
- DOE Order 420.1B, *Facility Safety*
- 10 CFR Part 851, Appendix A, Functional Area 2, *Fire Protection*
- BNL SBMS *Fire Safety* subject area
- BLN SBMS *Lockout/Tagout* subject area
- See the *NSLS-II Fire Protection Assessment/Fire Hazard Analysis* (Appendix 2) for a complete list of NFPA standards

Design criteria and operational controls incorporated to mitigate these risks are given in Table 4 in Appendix 4. The pre-mitigation risk is categorized as High and the post-mitigation risk is categorized as Low.

A detailed *NSLS-II Fire Protection Assessment/Fire Hazard Analysis* (FPA/FHA) has been prepared by the BNL Fire Protection Engineer and is included as Appendix 2. The level of fire protection in NSLS-II is classified as "improved risk," thereby meeting the objectives of DOE Order 420.1B. While NSLS-II is considered a high-value property (>$1 billion at full build-out), the noncombustible construction of the building and the accelerator is expected to keep the Maximum Potential Fire Loss (MPFL) of the facility-at-large to $5.5 million. The FPA/FHA outlines the MPFL calculations and assumptions, and provides as well the NSLS-II Fire Protection Design Strategy. Elements of this strategy have been summarized in Section 3.8 above for the Booster area.

As discussed in Section 3.8, the Booster tunnel and Injection Building service area are 100% sprinklered with a hydraulically designed wet pipe system, and are equipped with smoke detection (HSSD for the Booster tunnel and Injection Building service area) and alarm systems. While this action assures excellent protection of the structure and contents, some concerns arise from the potential of water discharging on energized and high-value equipment, either during a fire event or from a false discharge. The racks chosen for the Booster electronics are drip tight. The false discharge risks are minimized by the qualified engineers' careful designs, the high quality of installation materials, pressure testing before placing the system into service and following all NFPA inspection testing and maintenance requirements of the fire protection systems. Further protection against leaks is afforded by incorporating any BNL-approved chemicals to control Microbial Induced Corrosion (MIC); at the time of this writing, BNL has not made a determination.

The combustible loads and the use of flammable and/or reactive materials in the facility are controlled via the BCNYS building occupancy classification. The initial occupancy of the overall Injection Building has been determined to be Business (Group B) occupancy, based on the anticipated amount of hazardous materials and chemicals to be used. This occupancy classification sets the threshold for the maximum amount of hazardous material permitted in the facility. Evaluation of the existing NSLS chemical inventory and operations is a good indicator of the types and amounts of hazardous materials that are anticipated to be present in NSLS-II. The "controlled area" concept, allowed by BCNYS and NFPA, is followed to provide the greatest amount of flexibility and control of materials by allowing inventory thresholds per controlled area ("controlled area" in this sense is a specified area, for instance a laboratory, that has a defined limit on the quantities and types of chemicals allowed to be within that area).

The NSLS-II facility complies with the design requirements in BCNYS and NFPA for egress requirements; this also satisfies OSHA 1910 requirements. The BCNYS and NFPA includes designing egress routes to ensure the safe exit of occupants from fires by imposing limitations on the maximum travel distance, maximum dead-end path lengths, protection of egress paths, emergency lighting of egress paths, and egress signage. Design analysis indicates that travel distances of common paths are not exceeded for the Booster area. NSLS-II will undergo evacuation drill exercises to ensure that building occupants respond adequately to such emergencies. All egress requirements in the BCNYS and NFPA are met for the NSLS-II design.

4.4.1 Booster Commissioning – Fire Hazard Considerations

The Booster commissioning fire-related hazards have been minimized. Booster RF structure, high field magnet and power supply temperatures are controlled by cooling water systems. If component temperatures exceed pre-established thresholds, water flow and temperature sensors on the components alert commissioning staff to take action. Smoke control management systems conforming to Section 909 of BCNYS and NFPA 92B are provided in the Booster Ring in the Injection Building. The sequence of operation of the smoke control management system covering the Booster Ring is to go to 100% exhaust mode in the activated zone. No other smoke control management system zones in the building will go to 100% supply air. The Booster beam dump, injection septum and extraction septum contain polyethylene shielding. The exposed exterior surfaces of the polyethylene are covered by sheet metal. Booster areas containing polyethylene shielding are protected by the HSSD smoke detection and sprinkler systems.

4.5 Electrical Hazards

Electrical shock and arc flash, potentially resulting in severe injury or death, damaged equipment or programmatic impact as a result of unmitigated hazards, can be caused by exposed conductors, defective and substandard equipment, lack of adequate training, or improper procedures. Fire and smoke from defective overheated equipment/components has been experienced at other accelerators. Reflecting operational experience across the DOE complex and at BNL accelerators with electrical-related occurrences and injuries, the post-mitigation risk is deemed to be low due to the design and operational mitigations, especially due to strict adherence to codes.

The management and control of electrical hazards follow the requirements in:

- NFPA 70, *National Electrical Code*
- NFPA 70E, *Standard for Electrical Safety in the Workplace*
- NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance*
- 29 CFR 1910 Subpart S, *Electrical*
- 10 CFR Part 851, Appendix A, Functional Area 10, *Electrical Safety*
- BNL SBMS *Electrical Safety* subject area
- BNL SBMS *Lockout/Tagout (LOTO)* subject area

Design criteria and operational controls incorporated to mitigate these risks are given in Table 5 in Appendix 4. The pre-mitigation risk is categorized as High and the post-mitigation risk is categorized as Low.

The Booster area has a large amount of high-power and high-voltage electrical equipment. These include an RF transmitter, magnet power supplies and pulse power systems. Lower voltage systems include vacuum gauges, beam diagnostics and controls. Power distribution systems are designed in strict compliance with NFPA 70. Systems are grounded and necessary components are bonded to ground. With correct grounding of the input power of systems, the AC circuit breakers will trip if there is a short to ground for all 208 VAC three phase and 120 VAC single phase circuits. The trip of a circuit breaker is remotely monitored and alarmed. The 480 VAC has remote monitoring for ground faults. All AC power systems have local monitoring for ground faults. The DC outputs of all power supplies are remotely monitored and alarmed if there is a ground fault.

Electrical equipment and cables and cable trays are properly rated, and protected against mechanical hazards, both during installation and during use; additional ratings are applied to assure cable insulation properties consist of low smoke, halogen free and high resistance to radiation damage.

Electrical equipment and installations, to the extent possible, bear the seal of a Nationally Recognized Testing Laboratory. Where this is not possible or available, the BNL Authority Having Jurisdiction Electrical Equipment Inspection program provides the review and approval of the equipment.

Arc flash analyses are required prior to operation to ensure the proper labeling of all electrical panels and switch boxes, and to assure that proper PPE has been designated for workers. To reduce arc-flash hazards, the sizes of the transformers have been reduced, their quantity increased, and electrically operated breakers at a 480 volt panel have been provided with push buttons adjacent to the 208-volt panels beyond the potential arc blast zone. The 480 volt breakers de-energize the associated transformer and 208Y/120 volt panel. High voltage switches, breakers, and other equipment provide remote operation, where possible, to eliminate the need for workers having direct contact with the devices while operating them. This includes remote ground fault monitoring and remote alarming. Design of electrical equipment provides LOTO capability (in compliance with the BNL SBMS *Lockout/Tagout (LOTO)* subject area for simple and complex equipment) and prevents the need to service energized components.

Special emphasis is implemented for electrical equipment such as magnet terminals and power supply output terminals, to prevent shock hazards to workers by installing barriers such as polycarbonate material.

Kirk locks are used as part of the electrical safety interlock system to assure that access to high-voltage and/or high-current equipment takes place under controlled circumstances.

Major electrical systems (such as substations and the emergency generators) undergo preventive maintenance as scheduled by BNL Facilities and Operations personnel, and by a Photon Sciences Directorate tracking system.

4.5.1 Booster Commissioning – Electrical Hazard Considerations

The Booster components follow the above requirements. To further assure the safe operation of the electrical equipment during this Booster commissioning phase, a local commissioning Control Room is situated near the Booster tunnel in the Injection Service Building. This allows more immediate control and response to electrical (and other) conditions in this area by commissioning personnel.

4.6 Cryogenic Hazards, Including Oxygen Deficiency Hazards

Cryogenic hazards during Booster commissioning include thermal (cold burn) hazards from cryogenic components, or injury from fragments or missiles. Initiators could include the failure/rupture of systems from overpressure, failure of insulating vacuum jackets, mechanical damage/failure, deficient maintenance, or improper procedures.

Management and control of cryogenic hazards follow the requirements in:

- BNL SBMS *Cryogenics Safety* subject area

Design criteria and operational controls incorporated to mitigate these risks are given in Table 6 in Appendix 4. The pre-mitigation risk is categorized as Moderate and the post-mitigation risk is categorized as Low.

4.6.1 Booster Commissioning – Cryogenic Hazard Considerations

The Booster components do not require large-scale cryogenic systems, nor is there a LN2 fill station in the Injection Building. Should there be a need to bleed up a vacuum section of the Booster, that section would first be valved off and then bled up with nitrogen gas boil-off from a local LN2 dewar brought in from another location, as needed. Cryogen use would be limited to trained personnel using the appropriate personal protective equipment. It is anticipated that the need for a bleed-up will be infrequent. The volume of the Booster tunnel is 60,183 cubic feet. The SBMS Oxygen Deficiency Hazards System Classification/Controls subject area hazard evaluation cryogen calculation tool determined that for a 50 liter LN2 dewar the “Minimum Oxygen Concentration without Ventilation” is “20.6% - Acceptable” and “No ODH Classification Required” (logged in BNL ODH database under bldg 725; NSLS-II bldg 740 is not yet available in this database).

4.7 Confined Space Hazards

Hazards from confined spaces could result in personnel injury due to radiation dose. Initiators would include areas with limited egress or with radiation.

The management and control of confined space hazards will follow the requirements in the:

- BNL SBMS *Confined Space* subject area

Design criteria and operational controls incorporated to mitigate these risks are given in Table 7 in Appendix 4. The pre-mitigation risk is categorized as Moderate and the post-mitigation risk is categorized as Low.

Types of confined spaces in the NSLS-II facility include those associated with the facility’s support/maintenance, and typically includes sump pits**,** elevator pits, and HVAC plenums that would only be accessed by Facility and Operation’s maintenance personnel or vendor personnel. NSLS-II staff and users would not have access to these spaces. These would be reviewed on a case by case basis using guidance in the BNL SBMS *Confined Spaces* subject area.

While BNL’s institutional programs identify and manage confined spaces, the emphasis at NSLS-II will be to ensure the minimum number of confined spaces. This will require that adequate egress is provided, mechanical spaces are adequately sized and, wherever possible, a confined space should not be created. Appropriate labeling of confined spaces, along with adequate work planning and control, will be the operational mechanisms to control these spaces.

4.7.1 Booster Commissioning – Confined Space Considerations

An electrical cable tray labyrinth confined space is located downstream of the Booster beam stop on the outside of the shield wall. The entrance on the Injection Building Service Area side is blocked by a fence and is posted as a Confined Space. This entrance may also be posted as a radiological area as determined by surveys.

4.8 Ozone Hazards

Some ozone hazards are associated with Booster commissioning. While the electron beam itself is confined within a vacuum enclosure, ozone is produced inside the Booster tunnel due to secondary photon irradiation of the air molecules. Electron beam interacting with the accelerator components will produce electromagnetic showers consisting of secondary photons, electrons and a few neutrons. Photo-dissociation of oxygen molecules in air results in free oxygen atoms which further associate with oxygen molecules (O_2) producing ozone (O_3) molecules. Ozone production at the BSR extraction septum was calculated. The extraction septum is shielded by at least 10 cm of lead, where 3 nC/s of charge is dissipated at 3.0 GeV (~9 watts). The methodology adopted for the ozone concentration calculation in air is provided in CERN LEP Report 84-02, Fasso et al., *Radiation Problems in the Design of LEP Collider* (1984). The ozone concentration is calculated to be 0.3 x 10^{-4} ppm (*Ozone Generation Inside Booster Enclosure*, P.K. Job, June 2011). The TLV (Threshold Limiting Value) concentration in air is 0.1 ppm. The equilibrium concentration inside the Booster enclosure is therefore at least 10^{-3} smaller than the TLV concentration.

The risk level is therefore classified as Routine.

4.9 Chemical and Hazardous Materials

Chemical use during Booster commissioning could result in injury or exposures that exceed regulatory limits. Initiators could be the transfer of material, spills, failure of packaging, improper marking/labeling, improper selection of (or lack of) personal protective equipment (PPE), or natural phenomena.

Management and control of chemical hazards will follow the requirements in:

- 49 CFR, *Transportation*
- 29 CFR 1910 Subpart H, *Hazardous Materials*
- 10 CFR Part 851, Appendix A, functional areas 2, *Fire Protection*; 4, *Pressure Safety*; 6, *Industrial Hygiene*; and 8, *Occupational Medicine*
- BNL SBMS *Chemical Safety* subject area
- BNL SBMS *Work Planning and Control for Experiments and Operations* subject area

Design criteria and operational controls incorporated to mitigate these risks are given in Table 9 in Appendix 4. The pre-mitigation risk is categorized as High and the post-mitigation risk is categorized as Low.

4.9.1 Booster Commissioning – Chemical Hazard Considerations

Small quantities of solvents will be properly stored and used to clean surfaces; these surfaces would be wiped to dryness, therefore no solvent or paper wastes would be created. Helium gas may be used for leak checking the vacuum chambers; a local gas cylinder gas rack can be established if there is a need. Liquid nitrogen boil-off gas from a dewar may be used for vacuum chamber bleed-ups. While the Booster IOT transmitter itself does not contain oil, it is water-cooled; the transmitter's high voltage power supply unit contains two capacitors with 1.0–1.5 liters of oil each for heat dissipation. The power supply has secondary containment for the oil, but it does not fall under the registration requirements of Suffolk County Article 12, *Toxic and Hazardous Materials Storage and Handling Controls* due to the small quantity of oil.

4.10 Vacuum System Hazards

Vacuum failure at NSLS-II could result in damage to equipment, programmatic impact, or injury to personnel. Initiators could be equipment or material failure, design error, improper procedure, natural phenomena, fire or operator error.

Management and control of vacuum hazards will follow the requirements in:

- ASME *Pressure Vessel Code*
- ASME B31.3 *Process Piping Design*
- 10 CFR 851, Appendix A, Part 4, *Pressure Safety*, Section C
- BNL SBMS *Pressure Safety* subject area, section "*Vacuum Systems Consensus Guidelines for Department of Energy Accelerator Laboratories*"

Design criteria and operational controls incorporated to mitigate these risks are given in Table 10 in Appendix 4. The pre-mitigation risk is categorized as Moderate and the post-mitigation risk is categorized as Low.

Appropriate design of the vacuum systems and components plays an important role in providing effective machine operation and personnel safety. Proper accelerator vacuum level assures long stored electron beam lifetimes and minimizes the generation of bremsstrahlung radiation. Systems must be designed to prevent personnel injury produced by vacuum system collapse or rupture, or by an over-pressurization of the system from an external pressure source.

The design of synchrotron radiation facilities must address several types of potential vacuum accidents: rupture of vacuum windows/view ports, breakage of the ceramic insulator of a feed-through, damage of a vacuum wall of a cooling channel by miss-steered beam, and failure of pneumatic devices. With the exception of vacuum-to-atmosphere window breakage (waveguide vacuum to accelerator beam pipe vacuum only, both E-8 Torr), most of these failures are slow to develop in the absence of a pressure shock wave, and are handled by the vacuum interlock systems through dedicated vacuum programmable logic controllers. No extensive contamination of the accelerator vacuum which would impact machine performance is expected.

Sudden collapse or failure of the vacuum vessel or windows could result in a loud pressure wave with the potential for hearing injury to personnel close to the point of failure. Such failures are minimized through the application of solid engineering principles and practices in the design and operation of all vacuum systems. All vacuum vessels are designed to ensure that allowable American Society of Mechanical Engineers (ASME) stresses for vacuum systems are not exceeded and to ensure that the vessel is stable (i.e., resistant to buckling). An independent design review has been performed to confirm appropriate design and engineering practice.

In addition, instrumentation is provided to quickly detect and isolate a vacuum failure. If an accelerator vacuum fault is detected, sector valves will close to limit contamination (from air) to as small an area as possible. This automatically dumps the stored electron beam. Rupture of any windows in or adjacent to the Storage Ring will cause significant programmatic down time. Radiological consequences of vacuum failure are discussed in Section 4.15.

The accelerator vacuum systems have the potential for back-fill pressurization under certain failure scenarios associated with the back-fill nitrogen system. The probability of such failure in these systems will be minimized by design in accordance with ASME *Pressure Vessel Code* and B31.3, *Process Piping Code*. However, because of this potential, design of the accelerator vacuum systems must address10 CFR 851, Appendix A requirements for pressure systems. ASME *Pressure Vessel Code* requirements apply to any vacuum system that can be over-pressured to ≥15 psig. A standard has been developed: *Consensus Standard for the Design, Construction, Operation, Inspection, and Maintenance of Vacuum Vessels and Associated Components at DOE Accelerator Laboratories.*” This standard identifies design features that satisfy the requirements of 10 CFR 851 and has been incorporated into the BNL SBMS *Pressure Safety* subject area. A key feature in this standard is the use of pressure relief devices to prevent over-pressurization by back-fill. These devices must keep pressure in the vacuum space from exceeding 15 psig during a failure in the nitrogen gas or cryogenic systems. The design of the NSLS-II accelerator vacuum systems includes pressure relief devices that satisfy the requirements of this consensus standard. Pressure relief devices are reviewed by BNL Safety and Health Services personnel. The vacuum system underwent an ESH Design Review in 2008 by a committee with broad BNL representation (see PSD SharePoint NSLS-II ESH > Shared Documents > ESH Program Documents > ESH Design Reviews – February and March 2008).

4.10.1 Booster Commissioning – Vacuum System Hazard Considerations

The pump down and conditioning of the Booster vacuum system is similar to that of other conventional high vacuum systems, i.e., rough pumped with dry turbopump stations and transferred to sputter ion pumps to reach high vacuum. During Booster RF conditioning and beam commissioning, vacuum gauges and arc monitors are installed at waveguides to detect any abnormal discharges, to automatically turn off the RF power, and thus protect RF windows and vacuum systems.

4.11 Accelerator Cooling Water System & Compressed Air System Hazards

Hazards for the accelerator include the loss of control of the cooling water or compressed air systems. Failure of any of these systems could potentially result in damage to the accelerator due to component overheating or fire, or faulty operation due to lack of pressure, jeopardize the NSLS-II mission to provide a stable beam for its users and staff, or cause injury to personnel due to high temperatures or pressures. Initiators could include cooling water heat exchange and pump failures, compressed air supply failures, improper design, installation or procedure, and operator error.

The management and control of these hazards will follow the requirements in the following:

- 10 CFR Part 851, Appendix A, Functional Area 4, *Pressure Safety*
- BNL SBMS *Pressure Safety* subject area (references ASME codes)

Design criteria and operational controls incorporated to mitigate these risks are given in Table 11 in Appendix 4. The pre-mitigation risk is categorized as Moderate and the post-mitigation risk is categorized as Low.

Temperature regulation, controlled by various closed loops of cooling water, is necessary for the Booster to assure mechanical and beam stability, and to prevent overheating that could result in damage to components, cause injury to personnel or have a programmatic impact. If cooling water flow meters, located throughout the accelerators, sense a drop in flow, interlocks will automatically drop the RF, thus dumping the electron beam. If elevated temperatures are sensed by temperature sensors on the ring pipe, crotches, photon shutters, safety shutters or water-cooled masks, the RF is automatically dropped. Sensors sensing elevated temperature in a magnet automatically turn off the power supply to that magnet; the electron beam would dump as a result. In addition, temperature sensors detecting deviations from preset temperature limits will alarm in the Control Room, initiating an investigation. Water temperature to the ring pipe (Aluminum system) is also sensed in the pump room itself; if measured high, then the RF is automatically dumped. Power supplies on the accelerator tunnel mezzanine have their temperature controlled by air-to-water heat exchangers. Deviations from preset temperature limits are monitored by temperature sensors and will cause an alarm in the Control Room, also resulting in investigation. These temperature sensors are primarily to protect equipment from over-heating, and therefore the interlocking function is through EPICS or the Equipment Protection System, rather than the Personnel Protection System. Calibration and test procedures are determined by the appropriate Group Leader and are based on acceptable industrial practice.

Pressure to all front end valves are supplied from a 100 psig compressed air source originating from the BNL site Central Chilled Water Facility. Compressed air also operates the front end mask, safety shutter, and arms of the fast valve. If the compressed air system fails, alarms will notify Control Room personnel.

4.11.1 Booster Commissioning – Water and Air System Hazard Considerations

The accelerator temperature and compressed air systems controls described above apply to the Booster. No additional hazards are foreseen as a result of Booster commissioning. Controls and their status will be monitored by the Booster commissioning staff.

4.12 Material Handling Hazards

The consequences of hazards encountered in material handling include serious injury or death to equipment operators and bystanders, damage to equipment, and interruption of the program. These hazards could be initiated by a dropped or shifted load, equipment failure, improper procedures, or insufficient training/qualification of operators. Operational experience across the DOE complex and with BNL accelerators with material handling related occurrences and injuries suggests that the post mitigation risk will remain relatively high even though the probability of occurrence will be reduced through strict operational controls.

The management and control of material handling hazards will follow the requirements in:

- BNL SBMS *Lifting Safety* subject area
- ASTM B30 Overhead Cranes
- 10 CFR Part 851, Appendix A, Functional Area 9, Motor Vehicle Safety

Design criteria and operational controls incorporated to mitigate these risks are given in Table 12 in Appendix 4. The pre-mitigation risk is categorized as Moderate and the post-mitigation risk as Low.

The nature of accelerator operations demands a significant amount of manual and mechanical material handling. The material/equipment being moved is typically one of a kind, potentially of high dollar or programmatic value, and may not have dedicated lifting points or an obvious center of gravity. It is planned to conduct material handling operations by employing A-frame cranes, pallet jacks and fork lifts, or simple mechanical hoists serving a particular limited application.

To facilitate material handling throughout the facility, wide aisles will be incorporated to allow the passage of at least a fork truck with palletized equipment. Tight radiuses and blind corners will be kept to a minimum. Aisles will be designated and marked to prevent the storage of materials/equipment and to ensure that gas cylinders, hazardous storage areas, flammable material lockers, electrical equipment, etc, are adequately protected.

Material handling operations throughout the DOE complex have resulted in numerous incidents of injury and equipment damage to which improper equipment, inadequate rigging, or insufficient training/qualification have contributed. BNL instituted extensive training and qualification requirements and significantly limited the number of personnel who have access to mechanical material handling equipment. Personnel requiring authorization to use material handling devices unsupervised must complete laboratory specified training and pass a qualification practical exam conducted by a skilled operator; only then are they deemed "responsible" and given access to the equipment. This program for establishing operation of material handling devices by only trained and authorized personnel will continue for NSLS-II.

4.12.1 Booster Commissioning – Material Handling Hazard Considerations

A review has been made of material handling requirements for NSLS-II and it has been determined that rigging needs can be met without requiring an overhead crane system extending throughout the Ring Building. The NSLS-II design will seek to reduce the amount of manual material handling. For example, a major source of potential injury at research facilities is moving cylinders of compressed gas. NSLS-II will pipe in nitrogen gas, thereby reducing the number of cylinders that must be handled manually. Material receiving and storage will be located close to the facility loading/delivery dock. A staging area will be available to break material down into manageable quantities for distribution throughout the experimental areas.

4.13 Noise Hazards

No noise levels exceeding the ACGIH TLV are anticipated in the Booster commissioning area. Surveys will determine the need for wearing hearing protection in the Service Buildings providing utilities to the Booster area. Management and control of noise hazards will follow the requirements in BNL SBMS *Noise and Hearing* subject area (cites OSHA and ACGIH standards). No noises associated with Intermittent Energy Releases have been identified for the Booster area.

4.14 Non-ionizing Radiation Hazards

Non-ionizing radiation at NSLS-II consists of laser, RF, microwave, static magnetic, visible light, infrared (IR), and ultraviolet (UV) hazards. The consequences of hazards associated with non-ionizing radiation include exposures exceeding regulatory limits, which could result in personal injury. These hazards could be initiated by equipment failure, interlock failure or override, or inadequate or removed shielding.

The management and control of non-ionizing radiation hazards will follow the requirements in the three subject areas listed below (which incorporate the relevant national ANSI, ACGIH, and OSHA standards):

- BNL SBMS *Laser Safety* subject area
- BNL SBMS *Static Magnetic Fields* subject area
- BNL SBMS *Non-ionizing Radiation Safety* subject area (includes radio frequency, microwave, infrared, visible light, ultraviolet)

Design criteria and operational controls incorporated to mitigate these risks are given in Table 14 in Appendix 4. The pre-mitigation risk is categorized as Moderate and the post-mitigation risk is categorized as Low.

4.14.1 Lasers

Booster commissioning may use Class 1, 2, and 3A/R lasers for survey and alignment purposes. Lasers are reviewed and controlled (registration) as required in the BNL SBMS *Laser Safety* subject area.

4.14.2 Static Magnetic Fields

The Booster IOT transmitter magnet cart utilizes four electromagnetic solenoids producing static magnetic fields. The manufacturer of this system has stated that the 5 gauss line was measured at approximately 25 cm from the front of the solenoid assembly and 30.5 cm away on the side of the solenoid; the manufacturer further stated that the steel transmitter cabinet doors provide more than adequate magnetic shielding. These fields will be re-surveyed once the IOT transmitter is in place and operating at NSLS-II. Fields will be posted as required; any additional indicators will be at the discretion of the BNL Industrial Hygienist. The Booster Ring utilizes electromagnets to control the path of the electron beam. These magnets are typically powered only when personnel have vacated the area and the Booster tunnel is secured. Infrequently, personnel may be in the vicinity of these powered electromagnets, during hi-potting, for example; personnel are covered by procedures and work planning in these cases. Magnetic field surveys, postings and medical evaluation requirements are detailed in the BNL SBMS *Static Magnetic Fields* subject area.

4.14.3 Radiofrequency (RF) and Microwaves

The Booster depends on the reliable operation of a high-power IOT transmitter RF system for boosting the energy of the electron beam injected into the Booster Ring from the Linac. The injection electron energy when entering the Booster is 200 MeV and its energy is 3 GeV when extracted into the Storage Ring. The IOT transmitter should supply 6 kW before the electron beam enters the Booster Ring and then ramped up to 60 kW raising the electron energy to 3 GeV. Once the electron beam is extracted the transmitter output is ramped down to 6 kW and the process is repeated once or twice every second when the next electron bunch is injected. This transmitter generates electromagnetic radiation at the RF frequency of 500 MHz and, in addition, poses significant electrical hazards. The transmitter is operated and maintained such that the RF fields are contained by well-secured wave guide mechanical joints and, therefore, personnel are not exposed to RF fields above relevant standards referenced in the BNL SBMS *Non-ionizing Radiation Safety* subject area. Trained technicians and surveys maintain control over RF hazards. The IOT transmitter and its power supply unit contain a number of internal machine protection interlocks related to temperature control, cooling water flow rates, RF power levels, arc detectors, and vacuum.

4.14.4 Infrared, Visible, and Ultraviolet Light

Personnel are not exposed to infrared, visible, or ultraviolet light as a result of Booster commissioning; personnel are not allowed in the Booster tunnel when the electron beam is circulating.

4.15 Ionizing Radiation Hazards during Commissioning

Potential hazards from ionizing radiation include prompt radiation (x-rays, neutrons, bremsstrahlung) produced during Booster operation and to a much lesser extent, induced activity in Booster components. The primary source of radiation exposure during Booster commissioning is created by electron beam losses during the acceleration cycle or by miss-steering during transport to the beam dumps. These radiation sources are the focus of the on-going discussion in the remainder of this section.

It should also be noted that there are two other sources of radiation fields associated with Booster components. Significant x-ray fields within the Booster enclosure can also be created by electrons released by high electric field gradients when the RF cavities are powered. To prevent exposure to these radiation fields, the RF cavity can only be powered when the Booster ring has been secured, i.e. when personnel are inside the ring, the RF cavities are interlocked in the powered off mode. Commissioning of the RF cavities will take place prior to the Booster commissioning with beam. The IOT transmitter located within the Injection Building service area will also generate x-ray fields. Shielding has been placed to either side of the IOT output connect mounting plate. The adequacy of this shielding will be confirmed when the IOT transmitter is turned on. Commissioning the above devices will be subject to the requirements of a *Radiation Work Permit* as per the BNL *Radiological Control Manual.*

Activities during Booster commissioning will also include handling of radioactive check sources by Health Physics personnel and activated materials by NSLS-II staff, but the potential for radiation exposure is limited from these activities and will be controlled by BNL's sealed source program and work control.

Accidental exposure during commissioning with beam could result from failure of an interlock or other protective system, inadequate design or configuration control of shielding, or an inadequate procedure.

Management and control of ionizing radiation hazards will follow the requirements in:

- 10 CFR Part 835, *Occupational Radiation Protection*
- BNL SBMS *Radiation Generating Devices* subject area
- BNL SBMS *Radioactive Airborne Emissions* subject area
- BNL SBMS *Radiological Dose Limits* subject area
- BNL SBMS *Radiological Stop Work* subject area
- BNL SBMS *Interlock Safety for High Risk Hazards* subject area
- BNL Radiological Control Division *Procedures*
- BNL Radiological Control Division *Radiological Control Manual*

Design criteria and operational controls incorporated to mitigate these risks are given in Tables 15a and 15b of Appendix 4. The pre-mitigation risks are categorized as High and the post-mitigation risks are categorized as Low.

4.15.1 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 can be lost during the acceleration cycle within Booster, in the injection or extraction areas, or in the transport lines to the beam dumps. Whenever high-energy electrons strike matter bremsstrahlung is produced. The high energy bremsstrahlung can further interact and create additional secondary radiation of photons, electrons and neutrons. In general, the unshielded secondary radiation fields from such losses are dominated by photons, particularly in the more forward direction, from beam loss points.

The level of radiological hazard and its associated controls are discussed for normal and abnormal operations of the Booster. In addition, hazards associated with induced radioactivity in accelerator components, air, water, and soil are considered for Booster operations.

4.15.2 Radiological Hazards Associated with the Booster

4.15.2.1 Normal Operation

The Booster serves as the intermediate accelerator for the facility, providing electron bunches to the Storage Ring, and is designed to produce 15 nC/s at 3.0 GeV. The Booster is capable of operating at a 1 or 2 Hz rep rate. The Linac is the Booster's source of 200 MeV electron bunches. Power for accelerating the electron bunches is provided by an IOT transmitter. When fully powered and tuned, the transmitter is capable of producing electrons at energies up to 3.2 GeV. During normal operations, the Booster will be regulated to operate at 3.0 GeV and 15nC/s at an assumed pulse rate of 1 Hz. During commissioning and study periods, it is planned to operate for limited periods at increased energies up to the maximum energy and current to test IOT transmitter performance and to verify shielding integrity under worst case conditions. The Booster bulk and supplemental shielding are based on the following parameters.

4.15.2.1.1 Booster Radiological Design Parameters for Bulk Concrete Shields

The shielding specification for the lateral walls and ceiling of the Booster tunnel are based on the design parameters identified in Table 4.1 below.

Table 4.1 – Booster Design Parameters Used in Bulk Shielding Calculations.

Beam energy	3.0 GeV
Repetition rate during top-off	1/min
Maximum ramping frequency	2 Hz
Ring circumference	158.4 meters
Position of beam from concrete floor	1.2 m
Position of the beam from the Service Building wall	2 m
Position of beam from the inner wall (berm)	1 m
Position of the beam from the concrete ceiling	1.55 m
Number of electrons per fill	9.36×10^{10} (15nC)
Total energy in a Booster pulse	45 Joules

4.15.2.1.2 Booster Beam Loss Summary

The beam loss assumptions used to calculate bulk concrete and supplemental shielding requirements were developed in conjunction with NSLS-II accelerator physicists and are conservative for normal operation. Table 4.2 provides the beam loss assumptions used for bulk shielding and supplemental shielding for the Booster enclosure.

Table 4.2: Beam Loss Assumptions Used for Booster Calculations*

Accelerator System	Loss (%)	Energy (MeV)	Power Loss (W)	Charge Loss
Bulk Shielding				
Booster	2	3000	0.015	0.3 nC/min
Bulk + supplementary shielding				
Injection septum	50	200	1.5	7.5 nC/sec
Extraction septum	20	3000	9.0	3 nC/sec
Beam dump	100	3000	45.0	15 nC/sec

*These assumptions were reviewed during the three NSLS-II Radiation Safety Workshops held between 2007, 2008 and 2010.

4.15.2.1.3 Bulk Shielding Requirements

Based on the design parameters and the beam loss assumptions described above, the shielding requirements to satisfy the shielding policy are described in this section. The methodology used for calculating the bulk shielding requirements is described in Appendix 5 (LT-ESHDES-08-002-Rev2, *Bulk Shielding Requirements for Final Design of NSLS-II Accelerator Enclosures,* P.K Job and W.R. Casey, February 2008).

Table 4.3: Concrete Shielding Requirements for the Booster Enclosure to Reduce Radiation Levels to 0.5 mrem/h

Location	Lateral wall concrete equivalent thickness (cm)	Roof concrete equivalent thickness (cm)
Booster outboard side	70	75
Booster inboard side	85	
Booster forward wall	100	

The Booster enclosure has two labyrinths for personnel access. These labyrinths will have access doors to be secured and interlocked during Booster operation. The personnel access labyrinths are designed according to the methodology specified in NCRP51 (pages 62-64). In each case the dose rates at the external door of the labyrinth is <0.5 mrem/h for the assumed beam losses during normal operation of the Booster. No credit has been taken for the additional shielding provided by the access doors.

HVAC supply and return ducting for the Booster enclosure penetrates the ceiling of the personnel access labyrinth (from the second or mezzanine floor of the Injection Building) at the southeast corner of the Booster enclosure; the labyrinth provides a shielded path from the Booster enclosure to the Injection Building Service Area floor. The HVAC penetrations mimic the design to the two-bounce configuration of the personnel labyrinth; therefore, dose at the penetration openings on the mezzanine floor is expected to be the same as the dose at the exterior of the personnel labyrinth, <0.5 mrem/h. This will be confirmed with radiological surveys.

4.15.2.1.4 Supplemental Shielding Requirements

The bulk shielding defined above is based on point loss of 0.3 nC/min at 3.0 GeV operation. Local supplemental shielding to reduce radiation levels to 0.5 mrem/h is provided at the higher loss points identified in Table 4.2.

Supplemental shielding requirements have been analyzed in Appendix 6a (NSLS-II Technical Note 32, *Preliminary Material Requirement for the Supplementary Shielding at NSLS-II*, P.K. Job and W.R. Casey, July 2007); additional information is available in Appendix 6b (*Booster Beam Dump*), Appendix 6c (*Booster Extraction Septum*) and Appendix 6d (*Booster Injection Septum*). The following materials and thicknesses have been established for supplemental shields at the following locations:

- Pb collimator through the Booster to Storage Ring wall, 35 cm thick with 1 m x 1 m transverse dimensions
- Booster injection septum, 10 cm Pb and 15 cm poly on transverse sides; 10 cm Pb and 15 cm poly on roof side.
- Booster extraction septum, 15cm Pb and 15cm poly on roof side; 15cm Pb and 20cm poly on Storage Ring (outboard) side; and 10cm Pb and 15cm poly on the inboard side
- Booster beam dump, 35 cm Pb, 35 cm borated poly in the forward direction; and 20 cm lead and 25 cm borated poly in the transverse direction
- 23 Booster shadow shields of lead, to shield the forward peaking bremsstrahlung component from beam loss at the ramping magnet vacuum chambers (the tangential component of bremsstrahlung radiation due to potential beam loss from every two bending magnets is shielded by a single shadow shield protecting the unfenced berm area, the occupied area in the adjacent Storage Ring and the occupied area of the adjacent Injection Service Area – see Figure 4.1 below for a generic view).

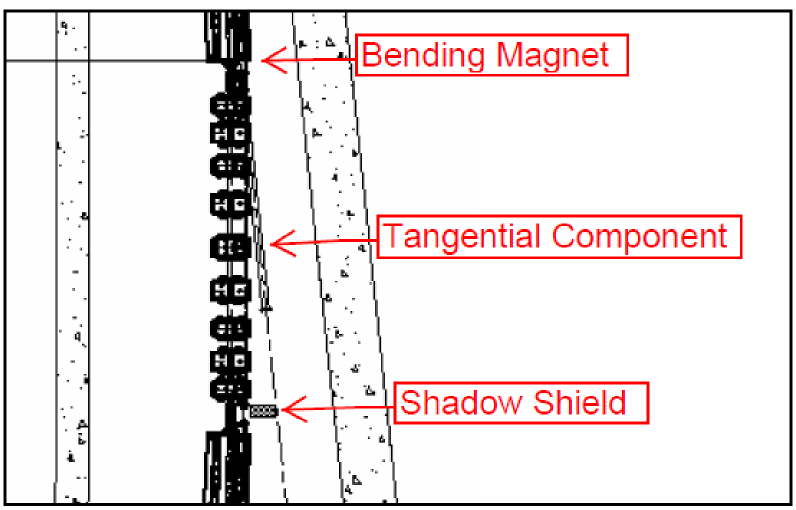

Figure 4.1: View of shadow shield position.

A summary of supplemental shields and shield wall penetration shielding descriptions and calculations is shown in Table 4.4.

Table 4.4: Booster Supplementary Shielding Thickness Specifications

Location	Beam Energy (MeV)	Beam Loss (nC/s)	Forward (cm)	Transverse SR Side (cm)	Transverse Berm Side (cm)	Top/Roof (cm)
Booster to SR Wall Penetration 100 cm x 100 cm transverse	3000	3.0	35 Pb, 65 Conc.	-	-	-
Booster Injection Septum[1]	200	7.5	15 Pb[2]	10 Pb[3] (berm)	10 Pb[3] (berm)	10 Pb[3] (berm)
Booster Extraction Septum[1]	3000	3.0	15 Pb[2]	15 Pb 20 Poly (SR)	10 Pb[3] (berm)	15 Pb 15 Poly
Booster Dump[1]	3000	15	15Fe,35Pb 35 poly	20 Pb 25 Poly	20 Pb 25 Poly	20 Pb 25 Poly
BtSR Transfer Line Dipole[4]	3000	15	TBD	20 Pb 25 Poly	-	TBD
Booster Extraction Kicker	3000	0.3	-	10 Pb	-	-
Booster Dipole Shadow Shields (extremal ray +3.6 cm transverse)[5]	3000	0.3	20 Pb	-	-	-
Cable tray/ wave guide penetrations	3000	0.3	-	10 Pb	10 Pb	-
Mekometer port shielding 26.5 cm dia iron disks	3000	0.3	-	-	-	25 Fe

1. Length is determined by the component dimensions. (Nominal 15 cm overlap for splash back)
2. Dimensions determined by the forward ray tracing from the forward edge of the component
3. Poly shield is not necessary, analysis provided in BNL Technical Note 88.
4. Waiting for mis-steered beam tracking analysis
5. Extremal ray from the upstream of the booster dipole magnets

4.15.2.2 Abnormal Accelerator Operating Conditions, Including Maximum Credible Incident

The shielding described above for normal operation is based on the beam losses defined in Table 4.2. Higher beam losses are possible as the result of miss-set operational parameters or equipment failure. Fault studies may also generate beam losses higher than those experienced during normal operations. The radiological consequences of several abnormal operating conditions have been evaluated to determine if additional controls are needed to limit the consequences of the abnormal conditions. These abnormal Booster conditions and controls have been summarized in section 2.2 of Appendix 7 (LT-C-ESH-DES-009); *Technical Basis for Radiation Safety Interlocks Used in the National Synchrotron Light Source II*, W.R. Casey, October 2010). The abnormal Booster conditions studied in Appendix 7 are the following:

- High beam loss at Booster injection
- High beam loss in locations with supplemental shields
- High beam loss at Booster extraction
- High beam loss in Booster Vault Transport Line (TL)
- Failure of a critical device – TL bending magnets deliver beam to Booster injection shutter
- Injected beam is greater than 15 nC/s
- Accelerated beam is greater than 3 GeV

4.15.2.2.1 Abnormal Condition Resulting in the Maximum Credible Incident

The abnormal condition producing the highest radiation level, identified as the Maximum Credible Incident (MCI), is a combination of the following:

- Injected beam is greater than 15 nC/s
  The maximum number of pulses/s that the Booster can accept and accelerate from the Linac is 2. The maximum output from the Linac is ~22 nC/pulse. Therefore, the maximum charge that can be accelerated by the Booster is ~44 nC/s.
- Accelerator beam is greater than 3 GeV
  The maximum energy that the Booster ring magnets can support is ~3.2 GeV.
- Full beam loss at a point in locations without supplemental shields

Note that radiation levels are calculated in contact with the exterior surface of the shield wall.

Full beam loss (100%) at a point inside the Booster enclosure at beam energy of 3.2 GeV during 44 nC/s (22nC/s from Linac @ 2 Hz) ramping operation:

At any location exterior to the Booster enclosure shield without supplemental shields, the highest radiation levels in the transverse direction during this incident will be:

$$(44\text{nC/s} /(0.3 \text{ nC}/60 \text{ sec})) \times (3.2 \text{ GeV} / 3.0 \text{ GeV}) \times 0.5 \text{ mrem/h} = 4{,}694 \text{ mrem/hr}$$

Conclusion: The maximum radiation level outside the shielding for electrons at 3.2 GeV and a full beam loss of 44 nC/s inside the Booster enclosure is ~4,694 mrem/h. There are four occupiable regions adjacent to the Booster shields where elevated dose rates must be considered due to such an incident during Booster commissioning. These areas are:

a. The berm adjacent to the Booster enclosure: This location can experience radiation levels of ~4,694 mrem/h during the MCI. To prevent exposure during abnormal beam losses, the berm shall be a restricted area that is fenced to prevent access by unauthorized personnel during Booster operation. Access to the area will be controlled via a locked gate. This gate key is controlled in a key tree by Accelerator Control Room personnel and must be in place before the PPS will provide a permit allowing operation of the Linac. The berm (shielding) and access to the berm (Access Control) are part of the ASE Credited Controls. The uncontrolled area at the face of the berm fence is >10 m away from the enclosure, resulting in a calculated dose of <47 mrem/h; no additional controls are necessary. During commissioning, access to the berm top to conduct radiological surveys may be allowed under controlled conditions by Radiological Control Division personnel.

b. Fenced lawn (area without berm): The northwest exterior of the Booster enclosure has no berm. This area is restricted by a fence and is accessed through an interlocked door in a Booster Ring labyrinth. Separate additional gates have interior crash bars to allow egress. These crash bars are not interlocked as the only ways into the interior fenced areas would be to climb over the fence or access these areas through already interlocked pathways. With the fence >10 m away from the shield wall and the shield wall thickness itself increased from 70 to 100 cm, the resulting dose calculated outside the fence is <12 mrem/h; no additional controls are required by the Shielding Policy. This area will be monitored by Radiological Control Division staff during commissioning to verify dose levels.

c. Injection Building Service Area floor: This area is protected from abnormal beam losses by enhancements to the Booster Ring wall from 70 cm to 100 cm of concrete. This results in a factor of 4 reduction in the calculated dose rate to 1,173 mrem/h which, as specified in the Shielding Policy, requires one Credited Control. The Booster electrical cable tray labyrinth was also examined under MCI conditions; a dose of 89 mrem/h was calculated at the Service Area floor opening into the labyrinth. This does not require a radiation monitor based on the Shielding Policy. Personnel occupying the Service Area floor are protected by interlocked radiation monitors which will turn off the Linac gun if predetermined dose rate thresholds are exceeded. The above areas will be also be monitored by Radiological Control Division staff during commissioning to verify dose levels.

d. The Storage Ring Enclosure: This area will be occupied for Storage Ring installation during Booster commissioning and can be accessed through the Injection Building Service Area. In general, the Storage Ring enclosure will be treated as a non-controlled area during commissioning. It is protected from radiation produced inside the Booster enclosure from beam dumps and other scatter sources by a) the lead wall collimator at the transfer line penetration; b) by the shadow shields elsewhere; and c) in the transverse direction, the shield wall between the Booster and the Storage Ring enclosures enhanced thickness of 115 cm. Due to the increased shield wall thickness between the Booster and Storage Ring enclosures (reduction factor of 8), and due to the increased distance between the Booster Ring and the Storage Ring shield wall (reduction factor of 9), the dose at the inner Storage Ring shield wall surface is calculated to be ~65 mrem/h; no additional controls are required by the Shielding Policy. The portions of the Storage Ring enclosure near the Booster wall will be monitored during commissioning by Radiological Control Division personnel to confirm that radiation levels are low before personnel are allowed access to this area (under these conditions, this location is posted as a Controlled Area as long as surveys indicate the necessity). In addition, two non-interlocked (not ASE Credited Controls) radiation monitors will be provided in this area to provide local warning of elevated radiation levels to nearby personnel. Additional shielding or radiological controls will be provided locally, as required, in order to maintain the general Storage Ring enclosure as a non-controlled area.

e. The Credited Controls (section 4.15.3 below) mitigate the hazards defined for the MCI, are adequate to protect personnel health and safety, and are consistent with the Shielding Policy (section 3.10.1 above).

4.15.2.2.2 Additional Abnormal Condition Related to Linac Injection

The Linac Commissioning Safety Assessment Document discusses an MCI for the Linac consisting of a beam at 250 MeV and 220 nC/s. If this beam were to be injected into the Booster and full beam loss were to occur at a point such as the septum, the dose at the exterior surface of the Booster shield wall would be 1,827 mrem/h or 58% of the Booster MCI. If more than two-bunch trains were to be injected into the Booster, the charge from only two of those bunches would survive injection yielding a charge of 44 nC/s, consistent with the Booster MCI.

The Booster DCCT is used as a non-credited control during commissioning to control the upper level of the Booster current to 20nC/s. The Credited Controls providing radiation protection to personnel ALARA continue to be the shielding, the radiation monitors external to the Booster shield wall in the Injection Service Area, and the PPS system.

4.15.3 Control of Radiation Exposure

The previous section discussed the design of NSLS-II shielding and engineered safeguards as the means for controlling radiation exposure to the personnel. This section summarizes the various controls previously discussed and specifically lists those credited for mitigation of radiation hazards.

4.15.3.1 Credited Engineered Systems to Control Radiation Exposure While Booster is Commissioning with Electron Beam. Two engineered systems are credited for mitigating the potential risk of significant radiation exposure during Booster operations.

4.15.3.1.1 Personal Protection System (PPS) Credited Controls

The Personnel Protection System provides required interlocking to protect personnel working in and around the Booster from significant radiation exposure. The PPS provides independent and redundant channels to reduce the possibility of unsafe failure. All interlock systems controlling access to enclosures are designed, installed, maintained, and tested in accordance with BNL SBMS requirements. For all scenarios analyzed, the failure rate is ≤1.1E-06. The system is designed to support this failure rate for 12 months.

There are four instances of protective function provided by the PPS for Booster Commissioning; these are considered Credited Controls:

4.15.3.1.1.1 A person remaining in or entering into the Booster enclosure while the Booster is operating could experience serious radiation exposure. To prevent such inadvertent access, the electron beam can only be generated and accelerated after the Booster enclosure has been properly cleared and secured. Normal access into the Booster enclosure is possible only when power to the IOT transmitter is off, the Booster power supplies are off, the Linac LB-B2 magnet is off, and the Linac LB-SS safety shutter is closed. Forcibly opening a locked door when the Booster is operating will result in immediate shut-down of the IOT transmitter, Booster power supplies, Linac Klystrons, and Linac electron gun, by interlock from the PPS. The status of PPS components is monitored through independent and redundant interlock circuits to prevent an unsafe condition.

4.15.3.1.1.2 During Booster commissioning, personnel will have access to the Storage Ring enclosure. To prevent transport of electron beam into the Storage Ring enclosure during Booster commissioning, bending magnet BS-B2 must be off and safety shutter BS-SS must be closed. The status of these critical devices is monitored through independent and redundant interlock circuits to ensure that unsafe conditions are not encountered. In addition, as described in the next section, each will be locked out-tagged out as an additional Credited Control for these two devices.

4.15.3.1.1.3 Access to the fenced berm is controlled via a locked gate opened with a single active key that must reside in a Control Room key tree in order for the Booster to operate. Access to the berm top requires that the Booster be shut down and the key be removed in order to open either gate. No entry to the fenced berm area adjacent to and above the Booster enclosure is permitted when the Booster is operating unless access is managed under the instructions set by PSD procedure co-written with the BNL Radiological Control Division.

4.15.3.1.1.4 Abnormally high beam losses in the Booster or transport lines can result in increased radiation levels in occupiable areas around the enclosures. The active area radiation monitoring system is provided to detect and mitigate these elevated radiation levels. At least five active area radiation monitors shall be located around the Booster enclosure and shall interlock through the Personnel Protective System. If unacceptable dose levels are detected, the area monitors shall alarm and stop Booster operation by dropping voltage to the Linac electron gun. Only one of the ~5 active area monitors is required to alarm to stop Booster operation.

The PPS system monitors the status of numerous access controls and critical devices. Rather than listing each critical device and access control point operating through the PPS system as separate Credited Controls, only the PPS is specifically listed as the Credited Control in the BCASE. The details of the NSLS-II PPS interlock systems are described in Section 3.10.4 above.

4.15.3.1.2 Shielding Credited Control for the Booster Enclosure

Shielding is essential for personnel radiation safety and has been engineered to reduce radiation fields to acceptable levels. The required shielding consists of 1) the poured concrete walls; 2) the earthen berm above and around the Booster; 3) the supplemental shielding protecting against scattered radiation from the injection and extraction magnets and the beam dump; 4) the transport line collimators protecting the opening between the Booster to Storage Ring enclosures; 5) the lead shielding installed in all penetrations between the Booster enclosure and adjacent locations; 6) lead shadow shields tangential to the ramping magnets to shield forward peaking bremsstrahlung shower from beam loss; 7) the shielding to reduce x-ray emissions from the IOT transmitter (RF cavities are located inside the Booster shield wall and do not require supplemental shielding; a literature search indicates that the maximum x-ray dose rate as a result of RF cavity operation is on the order of 1 Rad/hr, well within the Booster shield wall capabilities). Much of the shielding has been poured in place and does not require on-going confirmation that it is properly located. Some shields have been designed to permit relocation as required for maintenance, or as is the case for the earthen berm, potentially subject to wear or erosion. Therefore, verification prior to machine restart is necessary. Specific examples of required Booster supplemental shields subject to verification include the lead collimator positioned downstream of bending magnet BS-B2, and the supplemental lead and polyethylene shields provided for the beam transport line, the energy slit and beam dump. A formal change control program will be provided to control and verify the required shielding configuration.

4.15.3.2 Credited Administrative Practices to Control Radiation Exposure

Six administrative practices are considered essential for the safe operation of the Booster during commissioning and are credited for mitigating the potential risk of significant radiation exposure during Booster operation.

4.15.3.2.1 Personnel Protective System Certification and Testing

Prior to initial commissioning of the Booster with electron beam and prior to commissioning the IOT transmitter/RF system, the PPS system must be tested to confirm that the system functions as designed. This certification and test program must be accomplished by qualified personnel using approved test procedures. Results of all tests must be documented. The PPS must be tested and maintained in accordance with the requirements specified in the BNL Standards Based Management System and Radiological Control Manual. With the consent of the Manager of the BNL Radiological Control Division, the time interval between tests may be extended.. As stated above, for all scenarios analyzed, the failure rate is ≤1.1E-06. This failure rate is based on the assumption that a complete functional test is performed once per 12 month period (Sys-Tech Solutions, *Evaluation of Safety Interlock Integrity –* National Synchrotron Light Source II, Brookhaven National Laboratory, April 29, 2010, Rev. B).

4.15.3.2.2 Calibration and Control Program for Active Interlocked Radiation Detectors

The calibration of the interlocked radiation detectors must be confirmed by qualified personnel using approved procedures. In addition, these area monitors must be calibrated and maintained in accordance with the requirements specified in the BNL Standards Based Management System and Radiological Control Manual..[3] This program must be documented.

4.15.3.2.3 Radiation Protection Configuration Control Program

It is necessary to maintain the approved configuration of the shielding, PPS, and the interlocked radiation detectors in order to prevent errors that might degrade performance. All work on such systems must be reviewed and approved in advance, and only authorized persons shall be allowed to access these systems. At completion of the work, the authorizing authority shall review and confirm that the system has been restored to its correct configuration. These systems must be labeled noting that they are subject to configuration control and that only authorized work may be conducted. The process for implementing these requirements is formally described in NSLS LS-ESH-PRM-3.4.1b *Safety System Work Permit* procedure, which will be re-written and issued as a Photon Directorate Procedure applicable to the Booster Commissioning. Modification, maintenance, or repair work on required shielding or PPS systems shall be done only under the control of an NSLS *Safety System Work Permit* as described in this procedure.

4.15.3.2.4 Radiation Monitoring and Control Program

It is important to confirm during the initial commissioning process that the shielding and other engineered systems are adequate in their design and performance. To ensure that any inadequacies are detected early and before serious consequence are experienced, Booster commissioning shall proceed in a cautious and considered manner. Radiation surveys shall be conducted and documented by trained and qualified Radiological Division personnel at each increase in Booster energy and current. Radiological surveys on the berm top shall be conducted using approved procedures to confirm adequacy of the earth shielding and shall be documented. A comprehensive fault study at maximum energy and current shall be conducted as defined in an approved Fault Study Plan to confirm adequacy of shielding and to permit corrections as needed. Passive area monitors shall be provided in occupied areas to establish a comprehensive record of radiation levels during the commissioning. Personnel dosimeters shall be required for all workers entering radiological controlled areas established during Booster commissioning.

4.15.3.2.5 BS-B2 and BS-SS Status

To provide maximum protection of the occupied Storage Ring enclosure during the Booster commissioning with electron beam, the BS-B2 magnet and the BS-SS safety shutter shall be locked and tagged out into the safe state. Although the status of these devices is monitored through the PPS system, locking of these devices out of service does not create operational issues, and provides an additional level of safety for the area that will be occupied by non-BNL staff during the commissioning period. Note: this Credited Administrative Control is cancelled once Storage Ring commissioning begins in order to allow injection of the Booster electrons into the Storage Ring.

[3]It is noted that the area monitors are ion chambers which are known for their stability over long periods of time. As a means of confirming response between calibrations, the detectors will be checked with a radiation source at the time of each interlock verification to confirm proper response of the detector and interlock. It is also noted that a history file is maintained for each detector, including the total dose accumulated during every 24 hour period. Significant reduction of the accumulated dose would be noticed and promptly investigated.

4.15.3.2.*6 Qualified Accelerator Operator*

Operation of the Booster in a manner consistent with the commissioning plan and operational procedures requires a cognizant Accelerator Operator. In addition, the proper response by Accelerator Operators to abnormal conditions and alarms is necessary for control of radiation exposure. Machine operating conditions which create radiation alarms interlocking Booster operation must be evaluated and adjusted prior to resuming operation. All radiation interlocks shall be recorded in the operations log. During commissioning with electron beam, one qualified Accelerator Operator must be on duty and available to respond[4] to alarms in the functioning Accelerator Control Room or the building at all times.

The qualification program for Accelerator Operators shall be formally developed and approved, and shall meet the BNL SBMS program requirements. This practice will be credited for control of radiation exposures and will be contained in the BCASE.

4.15.4 Induced Activity and Environmental Radiological Issues

High-energy particle interactions in water, air, and soil can produce radioactivity from spallation reactions or neutron capture in nitrogen, oxygen, or other materials. In high-energy proton accelerators, these interactions can produce significant environmental issues. However, electron accelerators have reduced the potential for production of induced activity, and machines of equal power can produce only about 1 to 5% of the induced activity of a proton accelerator. Historically, light sources throughout the world have not created radiological environmental issues; results of the analyses presented in this section demonstrate that NSLS-II operations will not create environmental issues of concern. Detailed calculations have been performed and are summarized below. (See also Appendix 8a, *Preliminary Activation Analysis of Soil, Air and Water near NSLS-II Accelerator Enclosures*. P.K. Job and W.R. Casey, Technical Note 50, August 15, 2008). These calculations have been updated by P.K. Job and are summarized in Appendix 8b.

4.15.4.1 Induced Activity in Accelerator Components

It should be noted that during routine Booster operation in the future (1 pulse/min), the average power of the electron beam generated in the Booster is low (~0.75 watts). Therefore, even in locations where the entire power of the beam is absorbed (e.g., the beam dumps); the induced radioactivity will be low. Appendix 9 provides preliminary activation analysis of the accelerator components and beam dumps at NSLS-II (*Preliminary Activation Analysis of the Accelerator Components and Beam Stops at NSLS-II,* by P.K. Job and W.R. Casey, NSLS-II Technical Note 15, August 2006). Experience at NSLS has also demonstrated that induced activity has not been a significant source of radiation exposure. Operation of the Booster is intermittent with operating times that are unlikely to build up longer lived radionuclides. Ignoring self-shielding, use of the beam dump for a day with a 0.75 watt beam will produce radiation levels from induced activity 0.48 mR/h at 1 meter from the surface of the dump, dominated by ^{52m}Mn (radioactive half-life = 21.1 min) and ^{53}Fe (half-life = 8.51 min). After an hour of shut down, the exposure rate will be 0.01 mR/h at 1 meter. During commissioning, there will likely be more extended operation of the Booster at or near full power (45 watts) which creates the potential for higher radiation levels at the dump or at other high loss locations. ^{54}Mn, the long living isotope formed in the iron beam stop with a half-life of 303 days, will not attain saturation activity until about three years of continuous operation. Because of the operating nature of the Booster as an injector, the dumps are very unlikely to ever receive continuous injection for a sustained period of time (even during commissioning) that would lead to substantial build-up of the longer lived ^{54}Mn.

[4] The on-duty Operator is expected to be primarily in the Control Room, but it is understood that his/her duties may occasionally require brief absences in order to carry-out the full range of assigned duties (e.g., reset a piece of equipment).

The hazards associated with induced radioactivity are not substantial, but caution and control must be applied to prevent low-level personal exposures and loss of control of radioactive material. Booster enclosure entry control requirements will be evaluated based on surveys conducted by RCD personnel. BNL SBMS and Radiological Control Manual requirements for survey and control of activated material by RCD personnel shall be applied to all work conducted within the Booster tunnel during commissioning. The control of radioactive materials during Booster commissioning is not considered further in this BCSAD.

4.15.4.2 Air Activation

During the normal operation of NSLS-II, small quantities of the short-lived radioactive gases (^{11}C (radioactive half-life = 20.4 min), ^{13}N (half-life = 10 min), and ^{15}O (half-life = 2 min)) will be produced inside the accelerator enclosure by photon–neutron reactions with air. We have evaluated the potential for radiological exposure to workers entering the enclosure following machine operation and to members of the public who may be exposed to environmental releases of these gases.

Using the methodology and assumptions described in Appendix 8a, the maximum concentrations of radioactive gas were calculated and are shown in Table 4.5 below. The highest activated air concentration is during deposition of the Booster beam on the extraction septum at 15 nC/s with energy 3.0 GeV (these calculations were conducted at the routine operating conditions of the ring, not at MCI conditions). The total saturation concentration of the short lived isotopes like N13, O15 and C11 in air for this mode of operation is 0.31 μCi/m^3 (3.1 x 10^{-7} μCi/cc), which can be compared to the occupational Derived Air Concentration (DAC) of 4 x 10^{-6} μCi/cc. The Booster enclosure has a recirculating ventilation system with 12.4 air changes in an hour. The saturation concentration of the air activity has been calculated with the assumption of perfect mixing of the air in the Booster enclosure. Although this is not a conservative assumption, because of the short-lived nature of these gases and the low levels of calculated saturation concentration,, occupational exposure to the workers entering the enclosure is expected to be insignificant. Radiological surveys will be taken during commissioning to confirm these assumptions.

The U.S. Environmental Protection Agency (EPA) promulgated the national emission standards codified in Title 40, Part 61, Subpart H of the CFR “National Emission Standards for Hazardous Air Pollutants (NESHAP)” for Radionuclide Emissions from Department of Energy (DOE) Facilities (EPA 1989).” Specifically, sub-section 61.92 states that “emissions of radionuclides to the ambient air from Department of Energy facilities shall not exceed those amounts that would cause any member of the public to receive in a year an effective dose equivalent of 10 mrem.” The Booster enclosure has a recirculated ventilation system. The releases would be fugitive losses through the small openings and doorways in the enclosure; fresh air is brought in to make up for these fugitive losses. Because there is the potential for release to the environment, however small, the dose standard of 40 CFR Part 61 Subpart H applies. Therefore, a NESHAP evaluation was conducted by the BNL Environmental Protection Division to evaluate the dose to members of the public from operation of the NSLS-II facility. The study concluded that emissions from the NSLS-II facility during operations will be well within exposure limits established in Part 61 and no EPA permit and continuous air monitoring are required (see Appendix 10).

The source term calculations used in the CAP-88 calculation were based on the saturation concentration of activities of the short-lived gases produced in the accelerator enclosure air, which are given in Table 4.4. Using the methodology and assumptions described in Appendix 10, the effective dose equivalent (EDE) was calculated to be 1.67 E-03 mrem. Therefore, the overall dose impact from environmental releases is negligible.

Table 4.5: Saturation Activity in Air at Various Beam Loss Locations.

				Saturation Activity				
Beam loss Location	Enclosure volume (m^3)	Beam energy (MeV)	Beam loss (Watts)	^{13}N (μCi)	^{15}O (μCi)	^{11}C (μCi)	Total activity (μCi)	Concentration (μCi/m^3)
Booster injection septum	1704	200	1.5	79.2	8.6	1.7	89.5	0.05
Booster extraction septum	1704	3000	9.0	475.2	51.4	10.1	536.7	0.31

According to 40 CFR 61.93(b)(4)(i), DOE facilities must also perform periodic confirmatory measurements (PCM) to verify low emissions that could cause an EDE less than 1% of the 10 mrem/yr standard (that is, less than 0.1 mrem/yr). Because the effective dose is much lower than 0.1 mrem; a graded approach will be used to verify that the source term of NSLS-II has not changed over time. The graded approach will use process knowledge during an annual review of the facility operations and practices and, if the potential emissions indicate a significant increase over the previous year and are approaching the 0.1 mrem/yr limit, periodic confirmatory monitoring.

4.15.4.3 Water Activation

Activation of water used to cool the magnets and other accelerator components is estimated by a similar method. The primary reactions leading to the activation of cooling water are the bremsstrahlung interactions with ^{16}O in water. The most abundant of the radionuclides produced by this process is ^{15}O. Other activation products that are formed include ^{11}C (4.4% of ^{15}O), ^{3}H (at saturation, 2.2% of ^{15}O), and ^{13}N (about 1% of ^{15}O). ^{15}O has a radioactive half-life of 2.05 minutes and attains saturation during short periods of operation. Because of the long half-life of ^{3}H (half-life = 12.3 y) this radionuclide will not attain a substantial fraction of its saturation activity.

In the Booster, the highest beam loss point in a component with water cooling is the booster extraction septum. We assume an average beam loss of 3.0 nC/min at 3.0 GeV (0.15 watts). This is less than the loss at the Storage Ring septum. The following calculations are based on the higher Storage Ring septum losses, because of the closed loop cooling water circulation. The saturation activity of radionuclides in the cooling water has been estimated at the Storage Ring septum using the method described in Appendix 8a. A closed loop water system with inventory of 100,000 gal (3.785×10^8 cm^3) of water is used to cool the Booster as well as the Storage Ring septa. Table 4.6 below provides the saturation concentrations of the radionuclides in the cooling water produced by losses at the Storage Ring septum. As mentioned earlier, ^{3}H will attain saturation only after decades of operation. After 5,000 hours of continuous operation, the concentration of ^{3}H will be only 3% of the saturation value. Other loss points will provide additional small increments to the total inventory of tritium within the system. This cooling water system will be tested periodically, using a procedure to be developed, for tritium, once operations have begun.

Table 4.6: Maximum Saturation Activities of Radionuclides in the Cooling Water.

Beam loss (watts)	^{15}O (pCi/cm^3)	^{11}C (pCi/cm^3)	^{13}N (pCi/cm^3)	^{3}H (pCi/cm^3)*
0.63	0.24	0.01	0.002	0.005

*Note that this value is more than two orders of magnitude less than the BNL-defined Action level for tritium of 1000 pCi/L

The computed concentration of radionuclides in cooling water system is orders of magnitude smaller than the derived concentration for environmental discharge limits in DOE Order 458.1. Once the operation is shut down, the concentration of all nuclides, except that of ^{3}H (half-life = 12.32 years), will rapidly decrease due to radioactive decay of the short-lived isotopes.

4.15.4.4 Soil Activation

The mechanism of formation of radionuclides in the soil is due to the interaction of high-energy neutrons with elements in the soil. In the current analysis, only the high-energy neutron component needs to be considered, because only they have the penetrating power to escape the concrete shielding. As required by the BNL SBMS *Accelerator Safety* subject area, analysis has been done to estimate the rate of formation of two radioactive isotopes, ^{3}H and ^{22}Na, in the soil during the operation of the Linac, Booster, and Storage Ring. In the calculations, the neutron source inside the accelerators is assumed to be 1.2 m from the floor and 2 m from the inboard wall. The floor is 0.51 m of standard concrete in the Booster. A minimum concrete wall of 0.5 m is assumed before soil is encountered beyond the side walls. The composition and density (1.6 gm/cc) of the Long Island soil has been provided by the BNL Environmental and Waste Management Services Division.

Table 4.7 below gives the activity of ^{3}H and ^{22}Na created in the soil at a principle Booster beam loss location using the operating assumptions planned for future normal operations stated below the table. The high energy neutron flux is averaged over one mean free path of neutrons. Using the methodology established in the BNL SBMS *Accelerator Safety* subject area, the leachable concentration created in the soil has also been given. Leachability of 100% and 7.5% is assumed for ^{3}H and ^{22}Na, respectively. A water concentration factor of 1.1 and the annual rainfall of 55 cm are taken. Note that the soil beneath the concrete floor is not exposed to rainfall, so the potential leachability of radioactive isotopes from the soil to the water table at these locations will be minimal.

Table 4.7: Activity in the Soil at Various Beam Loss Locations Created by ^{3}H and ^{22}Na.

Soil location	Electron loss (nC/s)	Electron loss(e/s)	Neutron flux (n/cm^{2}.s)	Neutron flux (Av) (n/cm^{2}.s)	^{3}H (pCi/L)	^{3}H Leachable (pCi/L)	^{22}Na (pCi/L)	^{22}Na Leachable (pCi/L)
Booster Dump 3 GeV	15	9.36E10	3.9E3	2.4E3	14.5	15.9	140.1	10.5

Operating Assumptions:

- 200 times per year the Linac and Booster are used to fill the Storage Ring from scratch. Each fill cycle lasts 3 minutes. Total operating time is 200 x 3 min= 10 hours
- 500 hours per year of Linac and Booster study time
- 5,000 hours of top-off operation, 3 pulses per minute operation, effective hours of operation = 5,000 x 180/3,600 = 250 hours
- 500 hours per year of operation for Linac and Booster beam dump and 760 hours of operation for the Linac slit.

These calculated values are well within the BNL-defined Action Levels of 1,000 pCi/L and 20 pCi/L for ^{3}H and ^{22}Na, respectively. Therefore no additional engineered safeguards are required. Electron losses during commissioning are not expected to be as high as estimated for a full operating year, and therefore these calculations represent an upper value for soil activation and ground water contamination associated with Booster commissioning.

As a monitoring tool for soil activation levels near the Booster, ~1 liter soil samples will be positioned within the Booster enclosure near high loss points. These soil samples shall be tested periodically for ^{22}Na and ^{3}H. In addition, groundwater sampling wells shall be established downgradient of the Booster beam stop and periodically sampled for ^{3}H in the groundwater as a further means of confirming no impact from Booster operation on the groundwater.

4.15.5 Booster Commissioning – Ionizing Radiation Hazard Considerations

A Booster Commissioning Plan defining the objectives, tasks, and schedule has been developed for the Booster commissioning period. An important task during the commissioning period is to confirm the adequacy of the shielding and that the area monitoring system functions as intended. The Booster beam currents will be gradually increased in planned intervals so that surveys by radiological control personnel can be conducted during each incremental increase. These studies will eventually culminate in an evaluation of the shielding at the maximum obtainable energy that the Booster can produce. During this study, the maximum allowable energy authorized during the commissioning period will be increased from 3.0 GeV to the maximum achievable currently calculated to be 3.2 GeV. As discussed earlier, the maximum repetition rate for the Booster is 2 Hz and the maximum charge that the Booster could accept and accelerate is limited by the Linac maximum output of 22 nC/pulse. This study period will be scheduled and planned in conjunction with Radiological Control Division personnel and will be subject to rigorous control of potential radiation exposure. The purpose of this study is two-fold:

- Determine performance of Booster at maximum energy capability
- Evaluate effectiveness of shielding for the most extreme case of Booster operation

Commissioning will be conducted over three 8-hour shifts per day, 7 days per week, for the duration of the commissioning period. Radiological safety personnel will be present for all increases in beam intensities and during fault study periods to confirm that all radiological hazards are identified and controlled appropriately. Changes in operating patterns during the commissioning period will be scheduled to ensure that radiological safety personnel are present until it is confirmed that all radiological hazards have been controlled.

5 BASIS FOR BC ACCELERATOR SAFETY ENVELOPE

5.1 Development Basis

The analyses presented in Section 4 of this BCSAD identify the hazards associated with commissioning the NSLS-II Booster. These hazards are controlled through application of BNL SBMS requirements and by development of facility specific programs that define requirement implementation details. Safe Booster commissioning depends on conformance with those requirements.

Ionizing radiation, electrical energy, fire, and chemicals represent the more significant pre-mitigation hazards associated with Booster commissioning. Risk assessments for work with these and other hazards are included in Appendix 4 of this BCSAD. Personnel risks from work with these energy sources are kept to post-mitigation risk categories of Low or Routine through application of the described engineering and administrative controls. All hazards are managed through directorate programs for implementation of BNL SBMS requirements. With the exception of ionizing radiation, the above hazards do not have any direct or indirect influence on the Maximum Credible Incident.

The **Maximum Credible Incident** (see BCSAD Section 4.15.2.2) involves the potential for personnel exposure from a prompt ionizing radiation field produced by the loss of a ~3.2 GeV beam at ~44 nC/s. It is for this reason that ionizing radiation is the only BCSAD hazard whose credited controls are specified in the BCASE. The BCASE establishes required engineered and administrative Credited Controls to provide protection to workers and the environment during the commissioning of the Booster with electron beam.

The Credited Controls mitigate the hazards defined for the MCI, are adequate to protect personnel health and safety, and are consistent with the Shielding Policy (section 3.10.1 above).

5.2 Operational Hardware Capabilities

The requirements described in Sections 1, 2, 3, and 4 of the BCASE ensure that the risk levels described in the BCSAD are maintained and not exceeded during Booster commissioning.

Any proposed changes or modifications to the NSLS-II that impact the operational hardware capabilities must first undergo a USI determination. Any increase in risk as determined by the USI process above that described in the BCSAD must be appropriately approved. Any change to the BCASE requires DOE approval. These approvals must occur prior to making the changes or modifications to the NSLS-II Booster.

The BNL SBMS and Photon Sciences Directorate USI procedures are used to appropriately maintain configuration management and change control consistent with the BCSAD and BCASE risks and credited controls.

The **Booster Maximum Electron Beam Energy** is 3.2 GeV. This is the calculated maximum energy that the Booster can achieve with the installed dipole power supplies. The actual maximum Booster energy will be determined during Booster commissioning. (See BCSAD section 3.3.2.6.)

The **Booster Maximum Current** is ~44 nC/s. The maximum charge per pulse that can be injected into the Booster by the Linac is ~22 nC/pulse. When operating at 2 Hz, the maximum current is therefore ~44 nC/s. (See BCSAD sections 3.3.2.5 and 3.3.2.6.)

Full beam loss at a point while operating at the maximum energy and current create the conditions evaluated in the Maximum Credible Incident (MCI). The highest radiation level produced in an occupiable area during the MCI is calculated at 1,155 mrem/h. The Shielding Policy requires a single credited engineered system to mitigate this fault level. At least five active interlocked radiation detectors located around the Booster enclosure satisfy the Shielding Policy requirement. The evaluation of consequences during the MCI assumes that the configuration established in the design of shielding, PPS, and active radiation monitors is intact, and that all systems have been maintained as required. A series of engineered and administrative requirements are established and described below to ensure this function and to assure the dose to personnel during commissioning is ALARA. The Booster and transport line, and their associated shielding are designed for operation at lower energy and current than the maximum hardware limits described above. During commissioning, any operation at energies and currents above design levels up to the maximum hardware levels will be conducted in a considered manner using approved procedures developed to ensure that the potential for elevated radiation levels is evaluated before personnel can enter potentially impacted areas. (See BCSAD section 4.15.2.2.1.)

5.3 Credited Engineered Controls

There are two Engineered Credited Controls which are required to mitigate the risk of significant radiation exposure to personnel during the Booster commissioning. In addition, there are Administrative Credited Controls described below which are also developed to support the mitigation of the risk of radiation exposure. The Credited Controls are configuration controlled. Changes and/or modifications to the Credited Controls must be appropriately approved by BNL and/or Photon Sciences Directorate personnel. In some cases, additional DOE approval may be needed.

A Personnel Protection Interlock System (PPS) for radiation hazard control must be operational. This system provides the following protective functions, which are vital for the safe operation of the Booster: 1) ensures an effective search and secure of the Booster enclosure and berm top above the Booster prior to initiation of beam; 2) prevents access to the Booster enclosure when the beam is enabled; 3) ensures that the BS-B2 magnet and the BS-SS safety shutter are in the safe condition when the Booster is enabled and the Storage Ring enclosure is open for access; 4) provides the interlocking function to remove production of electron beam when the area monitoring system detects radiation levels above pre-set thresholds. (See BCSAD sections 3.3.2.7, 3.10.4, 3.10.4.1, and 4.15.3.1.1.)

All Radiological Shielding described in the BCSAD must be in place during Booster commissioning with beam. This shielding has been specified and designed to control radiation levels as described in the NSLS-II Shielding Policy and is essential to maintaining radiation exposure to personnel ALARA. The required shielding includes: 1) the poured concrete walls (bulk shielding); 2) the earthen berm around the Booster; 3) the supplemental shields protecting losses at the injection and extraction septa, the BS-B2 magnet and the beam dump; 4) the transport line collimator protecting the opening between the Linac to Booster enclosures and the Booster to Storage Ring enclosures; 5) the lead shielding installed in all penetrations into the Booster enclosure; 6) lead shadow shields tangential to the ramping magnets to shield forward peaking bremsstrahlung shower from beam loss; and 7) the shielding reducing x-ray emissions from the IOT transmitter (RF cavities are located within the shield wall and do not require supplementary shielding). (See BCSAD sections 3.10.1 and 4.15.3.1.2.)

5.4 Credited Administrative Controls

The following administrative controls must be in place for all phases of the Booster commissioning with electron beam:

The PPS interlocks must be tested and maintained in accordance with the requirements specified in the BNL Standards Based Management System and Radiological Control Manual. The functioning of the PPS is required to provide personnel safety during Booster commissioning. Regular testing as specified in the BNL *Radiological Control Manual* is necessary to confirm that no degradation of protective function has occurred as a result of component failure or human error. With the consent of the Manager of the BNL Radiological Control Division, the interval between tests may be extended (BNL *Radiological Control Manual*, Appendix 3A, Section 4.b). Records of all tests and certifications must be retained. (See BCSAD sections 3.3.2.7, 3.10.4, and 4.15.3.2.1.)

The active, interlocked radiation monitors must be calibrated and maintained in accordance with the requirements specified in the BNL Standards Based Management System and Radiological Control Manual. The calibration of the interlocked radiation detectors must be confirmed by qualified personnel using approved calibration procedures. These area monitors must be calibrated and maintained in accordance with the requirements specified in the BNL Standards Based Management System and Radiological Control Manual. The area monitors are ion chambers which are known for their stability over long periods of time. As a means of confirming response between calibrations, the detectors will be checked with a radiation source at the time of each interlock verification to confirm proper response of the detector and interlock. A history file is maintained for each detector including the total dose accumulated during every 24 hour period. Significant reduction of the accumulated dose would be noticed and promptly investigated. Instruments must be labeled showing the date of last calibration, and records of calibration must be maintained. With the consent of the Manager of the BNL Radiological Control Division, the interval between tests may be extended. Records of all tests and certifications must be retained. (See BCSAD sections 3.10.3 and 4.15.3.2.2.)

A radiation protection configuration control program must be in place to protect the functions provided by the PPS and the radiation shields. The BCSAD analysis of radiological consequences is based on functioning engineering controls as described in the BCSAD. PPS devices and radiological shielding must be clearly identified as controlled for radiation protection purposes; a Safety System Work Permit approved by the NSLS-II designated person must authorize all work on these devices. Following all work, the required device or shielding shall be tested or otherwise confirmed to have been restored to its proper protective function. A checklist of all items subject to configuration control must be maintained, as well as records of all verifications. (See BCSAD sections 3.10.1 and 4.15.3.2.3) Prior to commissioning, PPS and shielding systems will be examined and confirmed by the Instrument Readiness Review. The process for implementing these requirements will be based on the existing requirements previously established for configuration control at NSLS and described in Photon Science Directorate procedure *Safety System Work Permit* (LS-ESH-PRM-3.4.1b).

A Radiation Monitoring and Control Program must be in place to verify the adequacy of shielding and operational control of radiation exposure. During commissioning of the Booster, it is necessary to establish a planned and documented approach to verify the adequacy of shielding and the protective function of the area radiation monitoring system. It is essential that comprehensive radiation surveys conducted by Radiological Control Division personnel accompany each planned escalation of energy and current to verify adequacy of shields and control of radiation exposure. These surveys also shall include an evaluation of berm shielding within the fenced area surrounding the Booster enclosure. All radiological areas shall be posted as required by the BNL *Radiological Control Manual*. A comprehensive final evaluation shall be performed at the maximum energy and current attainable under the requirements established in a fault study plan approved by NSLS-II and Radiological Control Division personnel. Radiation exposures shall be carefully documented using personnel dosimeters for all personnel working in Controlled Areas. Passive area dosimeters shall also be used to document radiation levels in Controlled areas adjacent to the Booster enclosure. (See BCSAD sections 3.10.3 and 4.15.3.2.4.)

The power supply to the BS-B2 magnet and the position of the BS-SS safety shutter shall be locked and tagged in the safe position during Booster commissioning. The BS-B2 magnet and the BS-SS safety shutter are the critical devices preventing introduction of beam into the Storage Ring enclosure, which will be an uncontrolled area during Booster commissioning. It is essential to prevent introduction of Booster beam into this area during commissioning. Although the status of BS-B2 and BS-SS are monitored by the PPS, we will provide additional security for the area by manually locking and tagging these components in the safe position. Records of LOTO actions must be maintained in the LOTO log-book as required by the SBMS *Lockout/Tagout* subject area. Note: this Credited Administrative Control is cancelled once Storage Ring commissioning starts in order to allow Booster electrons to be injected into the Storage Ring. (See BCSAD sections 3.10.4.1, 4.15.3.1.1.2, 4.15.3.1.2, and 4.15.3.2.5.)

At least one qualified, trained Accelerator Operator shall be on duty during Booster commissioning with electron beam. Operation of the Booster in a manner consistent with the commissioning plan and operational procedures requires a knowledgeable Accelerator Operator. In addition, the proper response by an Operator to abnormal conditions and alarms is necessary for control of radiation exposure. Machine operating conditions which create radiation alarms interlocking Booster operation must be evaluated and adjusted prior to resuming operation. All radiation interlocks shall be recorded in the operations log. During commissioning with electron beam, one qualified Accelerator Operator must be on duty and available to respond to alarms in the functioning Control Room or the building at all times. The on-duty operator is expected to be primarily in the Control Room, but it is understood that his/her duties may occasionally require brief absences in order to carry-out the full range of assigned duties (e.g., reset an off-line piece of equipment). Supplemental Control Room staff is regulated by the Conduct of Operations. The qualification program shall be formally developed and approved. Training records of all qualified Operators will be maintained. The duties of the Operator are defined in the Booster Commissioning *Conduct of Operations* manual. (See BCSAD sections 1.4.2 and 4.15.3.2.6.)

6 QUALITY ASSURANCE

6.1 QA Program

The NSLS-II Project has adopted, in its entirety, the BNL Quality Assurance (QA) Program, which describes how the various BNL management system processes and functions provide a management approach that conforms to the basic requirements defined in DOE Order 414.1C, *Quality Assurance*.

The quality program embodies the concept of the "graded" approach, i.e., the selection and application of appropriate technical and administrative controls to work activities, equipment, and items commensurate with the associated environment, safety, security, health risks, and programmatic impact. The graded approach does not allow internal or external requirements to be ignored or waived, but does allow the degree of controls, verification, and documentation to be varied in meeting requirements based on risk.

The BNL QA Program is implemented using the NSLS-II QA Plan and its implementing procedures. These procedures supplement the BNL SBMS documents for those QA processes that are unique to the NSLS-II Project.

Quality Representatives serve as focal points to assist NSLS-II management in implementing QA program requirements. Quality Representatives have the authority, unlimited access, both organizational and facility, as personnel safety and training allows, and the organizational freedom to:

- Assist line managers in identifying potential and actual problems that could degrade the quality of a process/item or work performance
- Recommend corrective actions
- Verify implementation of approved solutions

All NSLS-II personnel have access to the Quality Representatives for consultation and guidance in matters related to quality.

6.2. Personnel Training and Qualification

The BNL Training and Qualification Management System within the SBMS supports NSLS-II management's efforts to ensure that personnel are trained and qualified to carry out their assigned responsibilities. The BNL Training and Qualification Management System is implemented via an NSLS-II implementing procedure. NSLS-II provides continuing training to personnel to maintain job proficiency.

6.3 Quality Improvement

The NSLS-II Project has established and implemented processes to detect and prevent quality problems. The Project identifies, controls, and corrects items, services, and processes that do not meet established requirements. NSLS-II staff identifies the causes of problems, and include the prevention of recurrence as a part of corrective action planning. The Project has programs to periodically review item characteristics, process implementation, and other quality-related information to identify items, services, and processes needing improvement.

6.4 Documents and Records

The NSLS-II Project prepares, reviews, approves, issues, uses, and revises documents to prescribe processes, specify requirements, or establish design. Additionally, the Project specifies, prepares, reviews, approves, and maintains records.

NSLS-II documents encompass technical information or instructions that address important work tasks, and describe complex or hazardous operations. They include plans, procedures, instructions, drawings, specifications, standards, and reports. Examples include the 6-month validation testing of the PPS interlocks procedures; safety system work permits (for accelerator changes); EMS, FUA, and SAD/ASE Checklist for Photon Sciences Directorate Reviews form.

Documents and records are retrievable for use in the evaluation of acceptability, and verification of compliance with requirements.

6.5 Work Process

Group leaders and technical supervisors are responsible for ensuring that employees under their supervision have appropriate job knowledge, skills, equipment and resources necessary to accomplish their tasks. Contractors and vendors are held to the same practices.

The BNL Quality Management System, supplemented by NSLS-II procedures, provides processes for identifying and controlling items and materials to ensure their proper use and maintenance to prevent damage, loss or deterioration.

6.6 Design

Specifications, drawings and other design documents are used to represent verifiable engineering delineations, in pictorial and/or descriptive language, of parts, components or assemblies. These documents are prepared, reviewed, approved and released in accordance with NSLS-II procedures. Changes to these documents are processed in accordance with the NSLS-II configuration management procedures.

6.7 Procurement

Personnel responsible for the design or performance of items or services to be purchased ensure that the procurement requirements of a purchase request are clear and complete. Using the graded approach, potential suppliers of critical, complex, or costly items or services are evaluated in accordance with pre-determined criteria to ascertain that they have the capability to provide items or services that conform to the technical and quality requirements of the procurement. The evaluation includes a review of the supplier's history with BNL or other DOE facilities, or a pre-award survey of the supplier's facility. NSLS-II personnel ensure that the goods or services provided by the suppliers are acceptable for intended use.

6.8 Inspection and Acceptance Testing

The BNL *Quality Management System* subject areas within the SBMS, supplemented by NSLS-II procedures, provides processes for the inspection and acceptance testing of an item, service, or process against established criteria and provides a means of determining acceptability. Based on the graded approach, the need and/or degree of inspection and acceptance testing are determined during the activity/item design stage.

The BNL SBMS *Calibration* subject area, supplemented by NSLS-II procedures, describes the calibration process for measuring and testing equipment. NSLS-II management identifies appropriate equipment requiring calibration. Annual calibration of the PPS-interlocked active radiation monitors is overseen by this process.

6.9 Management Assessment

Through the NSLS-II Self-Assessment Program, a regular, systematic evaluation process has been established wherein NSLS-II assesses internal management systems and processes used to make fact-based decisions. The NSLS-II Self-Assessment Program includes such items as: performance measures; compliance checks; effectiveness evaluations; job assessments; surveys; environment, safety and health work observations and facility observations. Strengths and opportunities for improvement are identified. Assessment results are documented and fed back to managers, and provided valuable input into the business-planning process.

6.10 Independent Assessment

Using the graded approach, NSLS-II Management periodically evaluates the implementation of the BNL Management Systems, SBMS subject areas and NSLS-II specific processes. This is done through reviews, assessments, and/or other formal means. The NSLS-II QA Group performs these assessments. They include an evaluation of the safety and quality cultures in terms of the adequacy and effectiveness of the management structure, which includes but is not limited to environment, safety and health, and quality requirements.

6.11 Unreviewed Safety Issue

An important aspect of the QA program are the reviews that are conducted to determine if changes in design or operational practice that are being discussed during committee reviews would result in any change in the protective function which provides a basis for the safety margins described in the SAD. As described in Section 3.11.2.6, the Directorate incorporates the use of the *EMS, FUA and SAD/ASE Checklist for Photon Sciences Directorate Reviews* form, which asks if the review has resulted in changes to the Directorate's Facility Use Agreement, the SAD, the ASE, the Job or Facility Risk Assessments, or the Environmental Assessment These forms are completed by a knowledgeable person and are used to identify issues that need further evaluation to determine whether the PSD process for evaluating an Unreviewed Safety Issue should be initiated.

6.12 Configuration Control

As described in Sections 4.15.3.2 and 6.4, configuration control of shielding and PPS systems is important in order to maintain the safety basis described in this document. As the footing for maintaining the quality and integrity of these systems, all modification, maintenance or repair work on PPS interlock systems or required shielding shall be done only under the control of a Safety System Work Permit as provided in the *Safety System Work Permit* procedure, LS-ESH-PRM-3.4.1b. The purpose of these requirements is to ensure that all work on these credited engineered systems is approved by knowledgeable individuals prior to work and that restoration of protective function is confirmed at the end of such work.

6.13 Software Quality Assurance

The BNL *Quality Management System* subject area within the SBMS provides processes for identifying and inventorying software, and for implementing controls throughout the software development cycle. Using a graded approach, controls are applied based on software classification (i.e., safety or non-safety), risk level, and software type (i.e., custom developed, configurable, acquired, utility calculations, and commercial design and analysis).

7 DECOMMISSIONING PLAN

7.1 Introduction

This plan is not directly connected to the commissioning of the Booster, but is added to the BCSAD for the sake of completeness and to demonstrate that a concept is in place for the eventual decommissioning of the NSLS-II facility. The objectives of the NSLS-II decommissioning plan, to be developed near the end of the NSLS-II operating lifetime, will be 1) to determine the hazards and risks posed by decommissioning the NSLS-II facility at the end of its operating life, and 2) to plan the activities required to complete the decommissioning. Another aspect of the decommissioning plan will be to determine 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. The NSLS-II decommissioning plan shall be managed by the Photon Sciences Directorate.

7.2 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 doses 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.

7.3 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, and 4) Greenfield condition. “Greenfield” means that the NSLS-II 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.

7.4 Decommissioning Methods

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

7.5 Waste Streams

Recyclable materials and wastes anticipated from the decommissioning operation will be identified in the decommissioning plan. Initially, NSLS-II 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, concrete, electrical equipment, or beamline 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 indicate that tritiated water concentrations will be below the BNL-defined Action Level. 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 the decommissioning plan is developed.

Detailed estimates of materials used in the construction of the conventional facilities are available under separate cover:

- LiRo/Gilbane, *NSLS-II Project Title II 100% Submittal Design Estimate*, Revision 1, September 17, 2008
- VJ Associates, *NSLS-II 100% Title II Estimate – Reconciled*, Revision 1, September 25, 2008

7.6 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. Examples currently consist of the following five documents:

- DOE O 430.1B, *Life Cycle Safety Asset Management*
- DOE G 430.1-2, *Implementation Guide For Surveillance and Maintenance During Facility Transition and Disposition*
- DOE G 430.1-3, *Deactivation Implementation Guide*
- DOE G 430.1-4, *Decommissioning Implementation Guide*
- DOE G 430.1-5, *Transition Implementation Guide*