Linac Commissioning
Safety Assessment Document
for the
National Synchrotron Light Source II
Photon Sciences Directorate

Version 2

May 11, 2011

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for the
U.S. Department of Energy
Office of Science
Basic Energy Science
under contract DE-AC02-98CD10886

DISCLAIMER

Photon Sciences Directorate

National Synchrotron Light Source II (NSLS-II)

LINAC COMMISSIONING

SAFETY ASSESSMENT DOCUMENT

Version 2

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

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VERSION CONTROL SHEET

VERSION	DESCRIPTION OF ANY CHANGES	DATE	PREPARER	APPROVED BY
1	For presentation to the BNL Laboratory ESH Committee	March 3, 2011	Nicholas F. Gmür	See signature page above
2	Incorporates the changes requested by the BNL Laboratory ESH Committee on April 12, 2011. For presentation to the BNL Deputy Director of Operations and DOE/BHSO.	May 11, 2011	Nicholas F. Gmür	See signature page above

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Acronyms

A	amps
Å	Angstrom
ACGIH	American Conference of Governmental Hygienists
AFD	Adjustable frequency drives
AGS	Alternate Gradient Synchrotron
AHU	air handling unit
ALARA	as low as reasonably achievable
ANSI	American National Standards Institute
ASE	Accelerator Safety Envelope
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing Materials
AV	ambient vaporizer
BCNYS	Building Code of New York State
BHSO	Brookhaven Site Office
BNL	Brookhaven National Laboratory
BORE	beneficial occupancy readiness evaluation
BPM	beam position monitor
BSL	Biological Safety Level
BTMS	Brook Training Management Database
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
CRAC	computer room air conditioning
CSA	Canadian Standards Association
CSAD	Commissioning Safety Assessment Document
dBA	decibel with A-weighting
DC	direct current
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
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
FE	front end
FHA	Final Hazard Analysis
FOE	first optics enclosure
FONSI	Finding of No Significant Impact
FPA	Fire Protection Assessment
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
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
IGBT	Insulated-gate bipolar transistor
IOT	induction output tube
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
lbs	pounds
LCSAD	Linac Commissioning Safety Assessment Document
LEED	Leadership in Energy and Environmental Design
LESHC	Laboratory Environment, Safety and Health Committee
l/h	liters per hour
LHe	liquid helium
Linac	Linear Accelerator
LN2	liquid nitrogen
LOB	Lab Office Building
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
MPFL	Maximum Potential Fire Loss
mph	miles per hour
mrad	milliradian
mrem	millirem
μS	micro-Sieverts
MV	medium voltage cable – or - megavolt
N2	nitrogen
nC	nanocoulomb
NC	noise criteria
NEC	National Electric Code
NEG	non-evaporatable getter
NESHAP	National Emission Standards 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
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	Personal 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
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
SDL	Source Development Lab
scf	standard cubic feet
SCRF	superconducting radiofrequency
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

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
V	Volts
VAC	Volt Alternating Current
VFD	variable frequency drive
WG	water gauge

1. INTRODUCTION

1.1 Motivation for the Linac Commissioning Safety Assessment Document

The purpose of this Linac Commissioning Safety Assessment Document (LCSAD) 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 electron gun, linear accelerator (Linac and Klystron Assembly) and Linac-to-Booster Transfer Line up to and including the first and second beam stops, the energy slit and the safety shutter located in the Injector Building and herein generally referred to as the Linac; and

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

The Linac area covered by this LCSAD is shown in Figure 3.5. The LCSAD lays the foundation for the Credited Controls described in the Linac Commissioning Accelerator Safety Envelope (LCASE). The requirements for writing the LCSAD and LCASE are set out in:

- DOE Order 420.2B*, 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 first module, which includes this LCSAD and LCASE, covers the Linac commissioning; the second will cover the 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

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 synchrotron. The Storage Ring 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 420.2B, *Safety of Accelerator Facilities,* or its successors. These requirements are promulgated in the Brookhaven National Laboratory SBMS *Accelerator Safety* subject area. The NSLS-II Linac 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 Linac operations (during commissioning and routine operations) is highly unlikely, due to the physical aspects of the NSLS-II Linac. The primary hazard is prompt ionizing radiation, which is produced primarily during Linac 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 Linac, and protecting workers and visitors to the facility, NSLS-II programs incorporate DOE P 450.4 *Safety Management System Policy*, 10 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)*.

An NSLS-II LCASE that defines the Credited Controls and operating limits for the Linac is a companion document to this NSLS-II LCSAD. The LCASE is reviewed and approved by the DOE-Brookhaven Site Office (BHSO). The LCSAD 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). At the completion of all the commissioning modules and prior to the start of routine operations, a final, comprehensive SAD and ASE will be reviewed and approved.

1.4 Commissioning the NSLS-II Linac

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 LCSAD to describe in detail the actual Commissioning Plan for the Linac. That Plan shall be provided in a separate document and included as part of the Linac Commissioning Accelerator Readiness Review (ARR) once the LCSAD and LCASE have been reviewed and approved by DOE/BHSO. The Linac Commissioning Plan will follow the guidance and assumptions provided in the *NSLS-II Start-Up Test Plan* (Ferdinand Willeke) and *NSLS-II Coordination Group Commissioning of the NSLS-II LINAC* (Ferdinand Willeke). A Fault Study Plan will be developed in conjunction with the Linac Commissioning Plan. The ARR process and the constituted ARR committee will provide a structured method for verifying that hardware, personnel, and procedures associated with commissioning operations are ready to permit the activity to be undertaken safely. The ARR committee, when satisfied, makes a recommendation to the Photon Sciences Directorate Associate Laboratory Director that the NSLS-II Linac is ready to commence commissioning. DOE-BHSO must provide approval to begin commissioning.

The Linac/Klystron system has been purchased, built, and installed by a private Contractor as a turn-key system. This same Contractor, as a deliverable in the contract, is responsible for commissioning the Linac; this shall be done in collaboration with Photon Sciences Directorate Injector, Radio Frequency, Accelerator Physics, and Operations Group personnel as well as Radiological Control Division personnel. Those portions of the injection system including the two beam dumps and safety shutter downstream of the Linac shall be commissioned by Photon Sciences Directorate personnel. A single Commissioning Plan shall merge the steps and objectives of the Contractor and the Photon Sciences Directorate.

Linac commissioning shall be controlled from either the Injector Control Room, located in the Injection Service Building just north of the Linac/Klystron area (see Figure 3.4), or from the Control Room in Building 725 (changes to the RF system may also be made from the RF Building). Both Control Rooms shall follow the safety requirements and hazard controls specified in this LCSAD and in the Linac 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 assure it is clear which room is the lead Control Room for Linac operations and to prevent conflicting signals. Conditions needed or found during commissioning that are not covered in this LCSAD shall undergo an Unreviewed Safety Issue (USI) determination. The Photon Sciences Directorate Accelerator Division has overall responsibility for the Linac 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 Linac Control Room shall be established per the Linac Commissioning Conduct of Operations Manual. This manual is based on the BNL SBMS subject area Conduct of Operations (and DOE Order 422.1, *Conduct of Operations*).

1.4.2 Linac Commissioning Linac Operator - Credited Control

At least one qualified, trained Control Room Linac Operator shall be on duty when commissioning the Linac and downstream components with electron beam. This is established as a Credited Control. 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 Completion of Linac Commissioning

The Linac Commissioning Plan, which as stated above includes both the Linac itself and the listed components downstream of the Linac, shall specify in detail the conditions that must be met in the commissioning process. These conditions will also assure that the Linac is fully operational for injection into the Booster during the subsequent Booster commissioning (not discussed in this LCSAD). The Linac Commissioning ARR Committee will review the completion of these requirements and provide to the BNL DDO their confirmation that the requirements have been met.

Therefore, this LCSAD will not list all the detailed requirements that must be met for completion of commissioning; however, these requirements will involve the optimized performance parameters in accordance with the Linac specification to the Contractor, a portion of which is repeated here for convenience (repeated from Table 3.2):

Nominal energy	200 MeV
Minimum Energy with single klystron failure	170 MeV
Repetition rate f_{rep}	from single shot to 10 Hz
Short pulse mode	
Time structure	1 single bunch to bunch train with separation between consecutive bunches of 2 to 10 ns.
Charge per bunch Q_b	> 0.5 nC
Long pulse mode	
Pulse train length	160 – 300 ns
Corresponding number of bunches at 500MHz repetition rate	80 – 150
Charge per pulse train	15 nC

The parameters listed in the table above and the further details listed in the Commissioning Plan are those contractual specifications that must be met in order for BNL to accept the Linac from that Contractor and allow final payment. Commissioning of the Linac will then continue to further refine the operation of the Linac and to prepare for the commissioning of the Booster. Both phases of this commissioning adhere to the operating requirements stated in the Linac Commissioning Plan.

2 SUMMARY / CONCLUSIONS

2.1 Overview of Results and Conclusions of the Analysis Provided in the LCSAD

The NSLS-II LCSAD provides a safety assessment of the Electron Gun, Linear Accelerator, and Linac-to-Booster Transfer Line installed for Linac commissioning, as shown in Figure 3.5. The LCSAD meets the requirements set out in the SBMS subject area Accelerator Safety, which in turn meets the requirements of DOE Order 420.2B, *Safety of Accelerator Facilities*, and DOE G 420.2-1, *Accelerator Facility Safety Implementation Guide*.

The NSLS-II LCASE has been developed in accordance with the requirements set forth in the SBMS subject area Accelerator Safety, DOE Order 420.2B, and DOE Guide 420.2-1. The LCASE establishes Safety Envelope Limits, Operational Limits, and Credited Controls within which the NSLS-II Linac and its personnel shall safely operate based on the hazards, controls, and risks described in Chapter 4 of the NSLS-II LCSAD. The LCASE controls are elaborated on further in Chapter 5 of this LCSAD.

This LCSAD identifies a number of hazards and their controls as well as the Maximum Credible Incident (MCI) based on the safety analyses in Sections 4 and 5. The following summarizes the hazards and controls, including those associated with the MCI.

1. The NSLS-II Linac 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 Linac 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 Linac 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 anticipated Linac commissioning 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 1000 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 Linac, 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 Linac 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. Linac electrical systems and work are designed and planned to minimize hazards by adhering to BNL SBMS subject areas as well as to 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 Linac 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 Linac Control Room staff to take appropriate action.

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

8. Bunches of electrons are generated by an electron gun and accelerated by a linear accelerator (Linac) This process results in scattered gamma and neutron ionizing radiation. Commissioning of the Linac is managed through the Injection Control Room near the Linac in the Injection Building or through the Building 725 Control Room (or RF may be adjusted from the RF Building) following the limits, envelopes, and Credited Controls set by the Linac Commissioning Accelerator Safety Envelope; the

Control Room procedures, and the training of the qualified Linac Operators. Interlocks and area radiation monitors are used for radiation protection of personnel.

- Planning for the commissioning phase of the Linac is through an Accelerator Readiness Review (ARR) and a Commissioning Plan, both of which must be approved by DOE-BHSO prior to the beginning of the Linac 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 develop 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 Linac Commissioning Accelerator Safety Envelope.

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

Specific administrative and equipment controls prevent or mitigate beam loss events in order to maintain ALARA doses to personnel, 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 (Safety Envelope Limits, Operational Limits, 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	Routine
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 *Finding of No Significant Impact* (2006) is available in Appendix 1b.

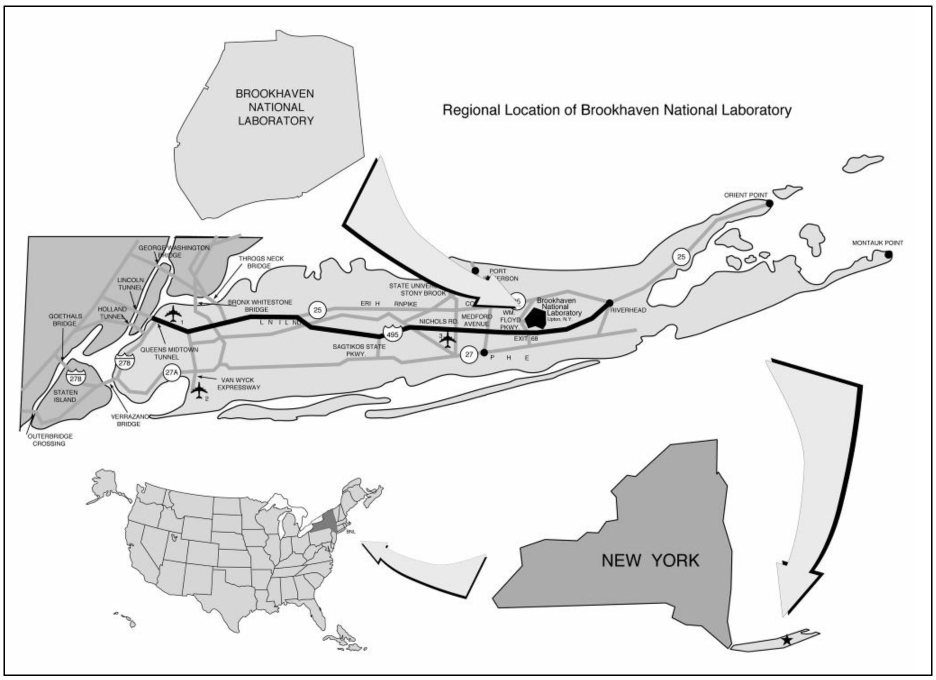

Figure 3.1: Regional view of the location of Brookhaven National Laboratory

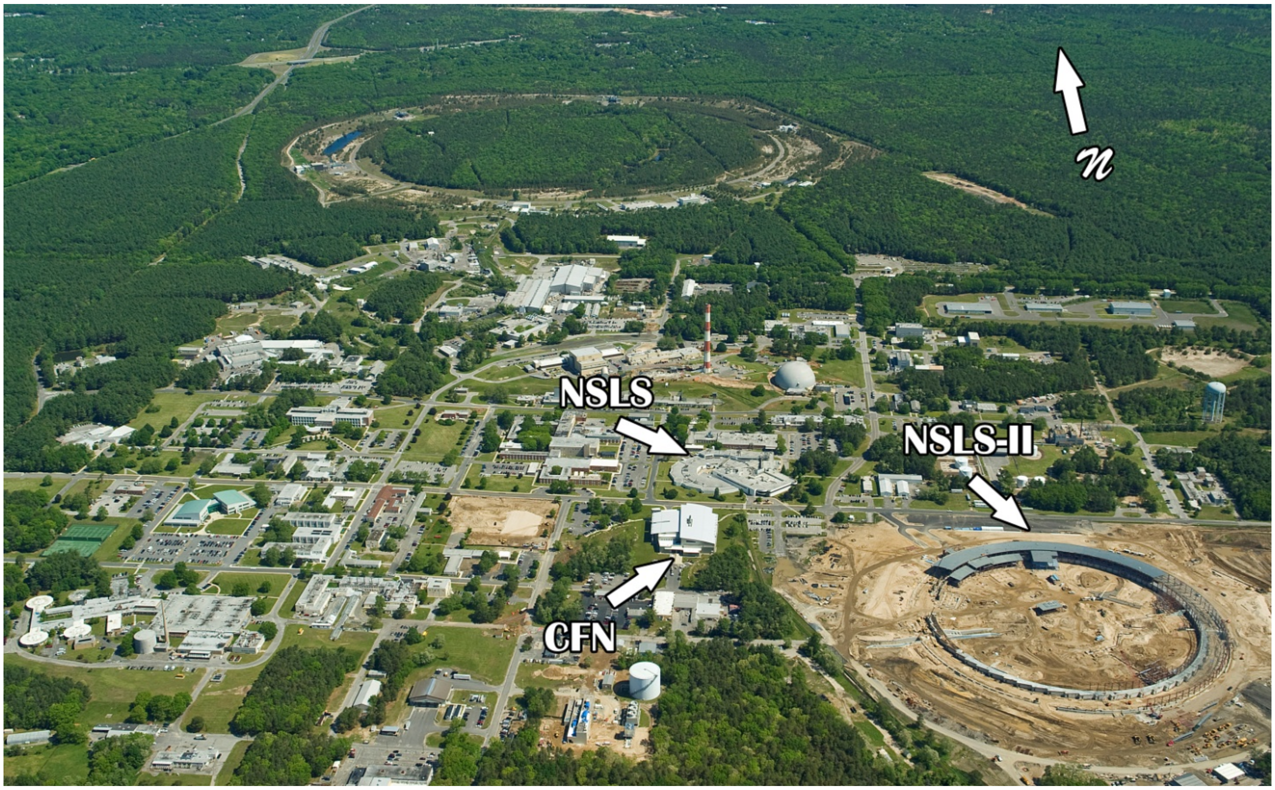

Figure 3.2: Aerial photograph of BNL (June 2010) showing the existing National Synchrotron Light Source (NSLS), the Center for Functional Nanomaterials (CFN), and the NSLS-II construction site.

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, if required; b) the CFN is close by, directly across Grove Street to the west; the c) existing NSLS building is diagonally across the intersection; and d) the Physics, Chemistry, Materials Science, Biology and Medical Departments, and Instrumentation Division are nearby. The NSLS-II Ring Building property itself is bounded on the north by Brookhaven Avenue, on the west by the existing swale, on the south by the 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 building 725 (Control Room, offices, technical and laboratory spaces), buildings 726-727 (mechanical, utility and magnet technical spaces), building 728 (offices) and building 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, Injection Building, RF Building and its associated Compressor Building, and 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 LCSAD focuses on the section of the Injection Building that contains the Linac.

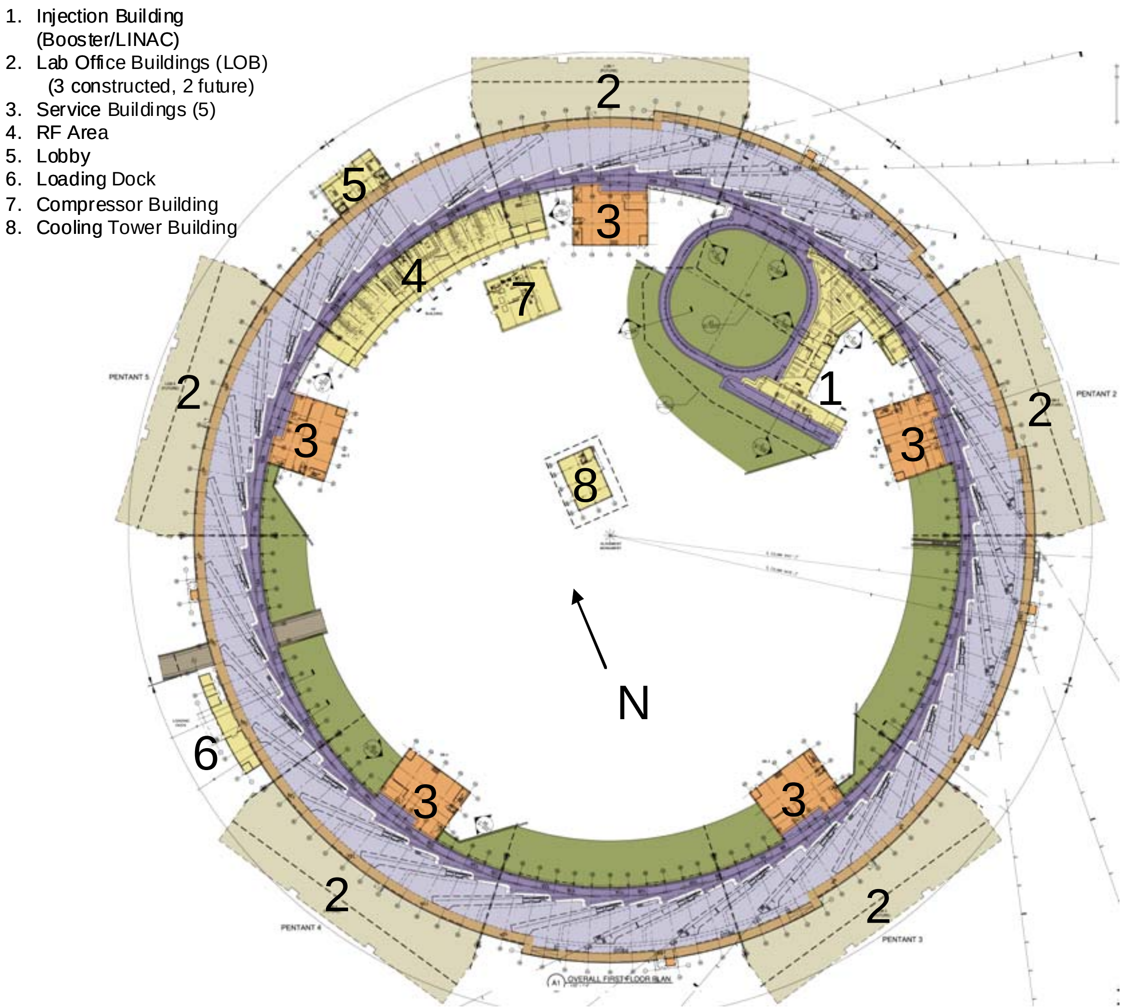

Figure 3.3: Site plan of NSLS-II building with projected locations for long beamlines; 1) Injection Building (Linac/Booster), 2) Lab Office Buildings (three constructed, two future), 3) Service Buildings (5), 4) RF Area, 5) Lobby, 6) Loading Dock, 7) Compressor Building, 8) Cooling Tower Building.

3.2.2 Injection Building

The Injection Building is attached to the inner circumference of the Storage Ring Building in the pentant I area (see Figure 3.4 below). The Injection Building consists of the following spaces: Linac tunnel, Klystron Gallery, Injection Service area, Booster tunnel, and Mechanical Mezzanine (see Table 3.1). 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 a structural steel framing with composite steel deck with concrete topping on the mezzanine floor. The roof consists of steel roof deck with 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 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.

The Linac is housed inside radiological shielding which is provided by a combination of concrete, lead, polyethylene, and berms of soil, the latter external to the Linac tunnel and outside the Injection Building. The Linac Tunnel contains the Electron Gun, Linear Accelerator, two beam dumps, the Linac-to-Booster Transport Line, and other safety systems including a safety shutter and local supplementary shielding around high radiation scatter components. The Linac Klystron Gallery houses three klystrons with their power supplies. A klystron test stand may be situated in the same area. Each of the penetrations into the Linac enclosure bulk shielding for RF wave guides, cable trays and mekometer ports, etc. has been accounted for, shielding requirements have been calculated on a case by case basis, and the penetration walked down. These shielding components have been designed by the NSLS-II Mechanical Engineering group. Design/fabrication drawings have also been prepared.

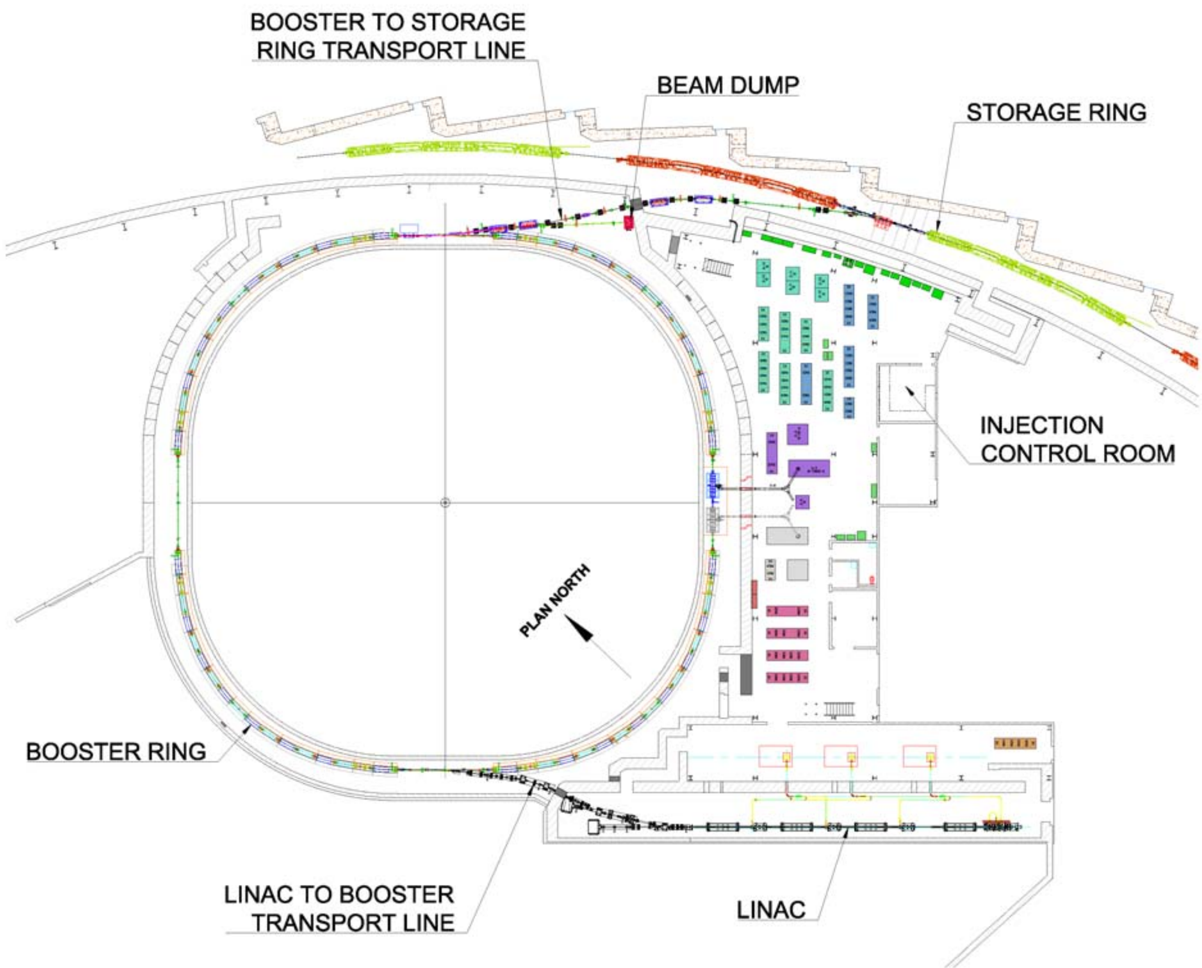

Figure 3.4: Injection Building.

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

*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.

3.2.3 Service Buildings

There are five two-story Service Buildings located inboard of the Storage Ring Building (see Figure 3.4). 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. The first floor provides personnel and equipment access to the Storage Ring tunnel through shielded labyrinths. The inner road access connects to the Service Buildings through their first floors. The Service Building second floor houses air handlers for the experimental floor area. The second floor is serviced by an equipment hoist and double exterior doors located on the second floor and fire stairs from the first floor. The Service Building is a steel frame structure 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 rest of the exterior walls are 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 to 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 Building 50 and managed by the BNL Laboratory Protection Division.

3.3 Accelerator Systems

3.3.1 Accelerator Overview

When complete, NSLS-II is designed to deliver photons with average spectral brightness in the energy range 2 keV to 10 keV, exceeding 10^{21} ph/mm^2/mrad^2/s/0.1%BW. The spectral flux density should exceed 10^{15} ph/s/0.1%BW in all spectral ranges, with a peak value approaching 10^{16} ph/s/0.1%BW for photon energies around 2 keV. This cutting-edge performance requires the Storage Ring (SR) to support a very high-current electron beam (I = 500 mA) with sub-nm-rad horizontal emittance (down to 0.5 nm-rad) and diffraction-limited vertical emittance at a wavelength of 1 Å (vertical emittance <8 pm-rad). The electron beam needs to be actively stabilized in its position to less than 10% of its size, in its angle to less than 10% of its divergence, in its dimensions to less than 10%, and in its intensity to less than ±0.5% variation. The latter requirement provides for constant thermal load on the beamline front ends.

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. The accelerated electrons are periodically added to the electron beam circulating in the Storage Ring to keep the stored current nearly constant in time, a process known as top-off injection.

3.3.2 Physics Design and Parameters of NSLS-II

3.3.2.1 Injection System – General

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. The NSLS-II Injector will support two basic bunch pattern formats in the Storage Ring: uniform fill with an ion-clearing gap and few groups of bunch trains separated by short gaps. 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. Layout of the injection system is shown in Figure 3.5. 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 Linac system are given in Table 3.2.

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

Nominal energy	200 MeV
Minimum Energy with single klystron failure	170 MeV
Repetition rate f_{rep}	from single shot to 10 Hz
Geometric Emittance, $4\sigma x \sigma x'$	150 nm-rad at 200 MeV
Energy spread $\Delta E/E$	< 0.5% rms
Pulse to pulse energy jitter	< 0.2% rms
Pulse to pulse time jitter	< 50 ps rms
Short pulse mode	
Length of a single bunch at 500 MHz repetition rate	< 330 ps
Time structure	1 single bunch to bunch trains with separation between consecutive bunches of 2 to 10 ns.
Charge per bunch Q_b	> 0.5 nC
Relative bunch purity before and after pulse	< 1%
Long pulse mode	
Pulse train length	160 – 300 ns
Corresponding number of bunches at 500MHz repetition rate	80 – 150
Charge per pulse train	15 nC
Relative charge difference between bunches in the pulse	< 10%

3.3.2.2 Linac Layout and Location

The Linac is located in its dedicated Injection Building tunnel shown in Figure 3.5. Auxiliary equipment is located in the adjacent Klystron Gallery. Radiofrequency (RF) waveguides pass through the tunnel walls via a high-level (above head height) labyrinth to prevent the escape of x-radiation down the waveguide paths. The connections between the Linac tunnel, the Klystron area, and electronic cabinets for the auxiliary equipment are accomplished using cable trays and labyrinths.

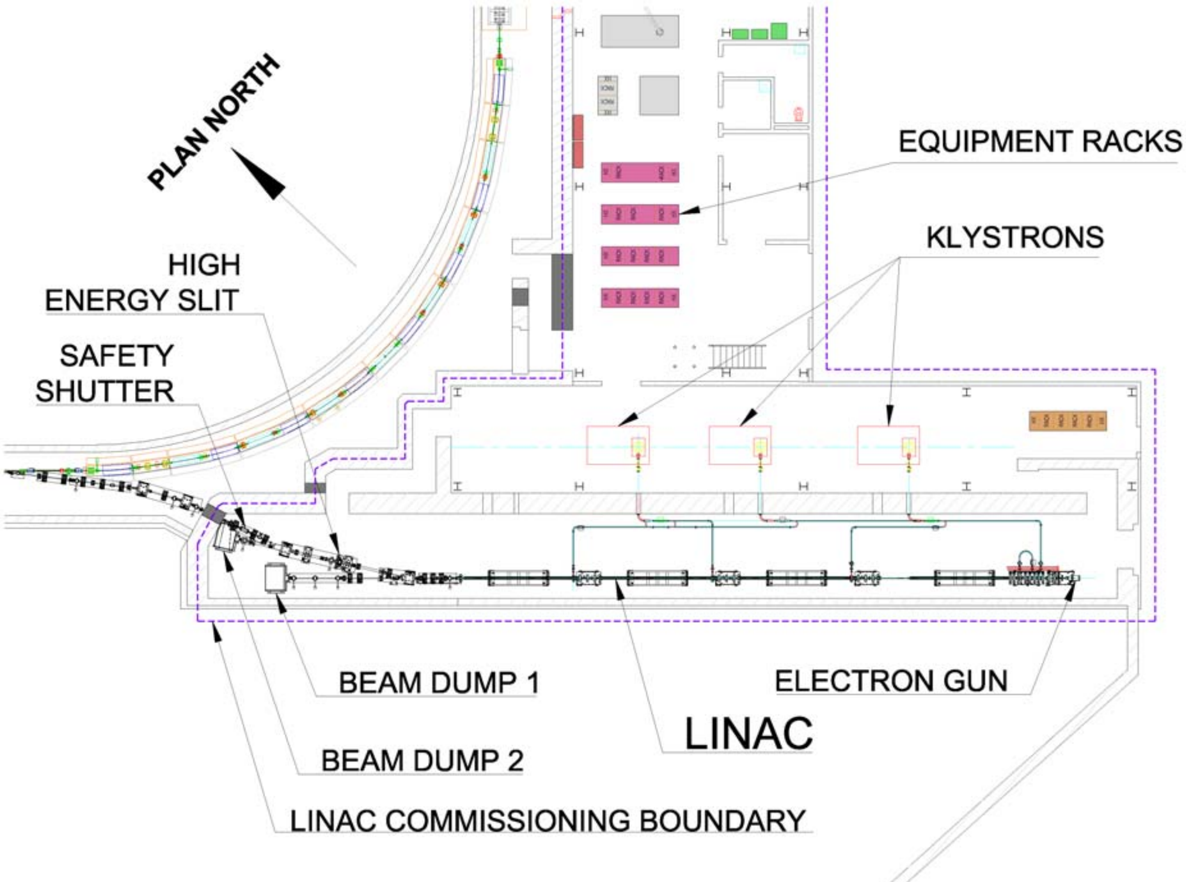

Figure 3.5: Plan view of the Linac, Klystron Gallery and Linac Commissioning area (The Injection Control Room is outside this view and is seen in Figure 3.4.)

3.3.2.3 Linac Performance Specification Overview

The Linac consists of the following equipment located inside the Linac enclosure with the beam height centered at 1.200 m:

- 100 kV triode electron gun with a 500 MHz modulation at the gun grid and a high-voltage deck
- A 500 MHz sub-harmonic pre-bunching cavity
- A 3 GHz pre-bunching cavity
- A 3 GHz traveling wave buncher
- Four traveling wave-accelerating structures at 3 GHz
- Steering and focusing magnets, and beam diagnostics

The following equipment is located downstream of the Linac:

- A beam pipe straight section terminating in the first beam stop with a Faraday cup.
- A dipole magnet bending the electron beam from the above straight into another straight section beam pipe, the start of the Linac-to-Booster Transfer Line, ending in the second beam stop and Faraday cup. This straight also incorporates an energy slit.
- A further dipole magnet bending the electron beam from the above straight into another straight section. This section of beam pipe includes the Linac-to-Booster Safety Shutter and penetrates through the Linac shield wall delivering Linac electrons to the Booster.
- Steering and focusing magnets, beam diagnostics and supplementary shielding.

The following equipment is located in the Klystron Gallery adjacent to the Linac enclosure:

- Three klystrons (42 MW each) and their solid state switched modulators (located in the Klystron Gallery)

Five Linac traveling wave-accelerating structures may be powered by up to three high-power klystrons; the third klystron may act as a hot spare or may be in use. The klystrons are supported by solid state switched pulsed modulators. The Klystrons will be tested prior to Linac commissioning and will be subject to the requirements established in SBMS Subject Area for Radiation Generating Devices. The Klystrons generate x-ray fields during operation and will be shielded with lead sheets to reduce radiation levels to < 0.5 mR/h at contact.

Solenoid and quadrupole focusing is applied to focus the electron beam. Beam diagnostic elements such as current transformers, fluorescent screens, Faraday cups, wall current monitors, and beam position monitors are used to keep the beam under control. The essential parameters of the Linac are specified in Table 3.2.

The Linac will be able to operate continuously at a 10 Hz repetition rate (but typically operates 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 Linac has an availability of greater than 99%. Experience with pulsed, high-voltage systems (such as klystron modulators with vacuum tubes that have finite lifetimes) has shown the need for redundant systems to meet these requirements. In the case of a single klystron failure, the Linac meets the minimum energy of 200 MeV with an energy spread of <0.5% by being able to switch to the third hot spare klystron to replace the failed klystron to continue operations until repairs can be made.

3.3.2.4 Linac Beam Parameter Specifications

To provide high flexibility for the filling structures of the Storage Ring and to allow for new operational modes, the Linac 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 in Table 3.2 above. Significant flexibility is built into the design of the electron gun with the capability of generating flexible bunch patterns; specifically, bunch trains with different numbers of bunches and with the bunches separated by variable time intervals (time intervals of Nx2 ns, where N = 1 to 10).

The charge in the short pulse mode and in the long pulse mode may be varied between the maximum values indicated in Table 3.2 and lower values of 10 pC per bunch or less.

The Linac is capable of performing continuous top-off injection in the short pulse mode and in the long pulse mode. The relevant beam parameters are the same as in Table 3.2, apart from the charge and repetition frequency. These parameters are the design basis for the Booster 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.

3.3.2.5 Linac Beam Diagnostics

The diagnostic systems available for commissioning include:

- Fluorescent screens (FS) and optical transition radiation (OTR) monitors
- Wall current monitors (WCM)
- Faraday cup (F-cup)
- Fast Current Transformer (FCT)
- Integrating Current Transformer (ICT)

Wall current monitors with a minimum of a 3 GHz bandwidth are used. 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 (BPMs are installed, but not in use during commissioning; flags are used instead to determine electron beam position), 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 and may be controlled through a local control.

3.3.2.6 Linac RF System

The klystron driver amplifiers are linear solid state amplifiers. The klystron modulator 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.

3.3.2.6.1 Modulator

The insulated-gate bipolar transistor (IGBT)-based ScandiNova solid state amplifier modulator is built and tested in accordance with NFPA regulations and is NRTL-certified. A solid-state modulator has less down time than a traditional modulator based on a pulse-forming-network (PFN). Also, compared to a traditional modulator, a solid-state modulator has much less DC voltage (1400V vs. 40kV), therefore making it much less prone to arcing and thus safer to operate.

The modulator has four well-defined states: Off, STANDBY, HV, and TRIG; each has a 4-bit state code. Off has the lowest-value code and TRIG has the highest-value code. Any higher state can be tripped to a lower state under certain interlock conditions. To clear interlock faults, a reset is needed.

All cabling is covered by doors and covers, and thus cannot be accessed without keys and/or tools; even when the doors or covers are removed, it is not possible to touch live parts directly. Whenever the modulator is switched from the HV state to a lower state, the DC voltage (1400 Volt) is discharged with a bleeder circuit to below 25 V DC within 5 seconds. The only components that have high voltage (~300 KV) are placed in an oil tank with an oil level interlock which turns off the high voltage if the oil level is either too low or too high; this is a local machine protection interlock.

The cooling oil used in the modulator is free of PCBs. The modulator has a secondary containment for 110% of oil volume specified.

The modulator has a number of interlocks (sensor readings that prevent the modulator from entering/ remaining at a certain operational state), including FGPA-based hardwire interlocks and microprocessor-based software interlocks. All electrical components within the modulator as well as cooling water flow are monitored and controlled. If one component fails or shows unspecified values, the modulator's state will fall back to a safe state. The modulator interlock system monitors all critical temperatures (transformer, rectifier, water, oil, etc.). If over-temperature is detected, the corresponding module is tripped and the modulator is switched to STANDBY mode. For example, transformer and water over-temperature trip the core-bias power supply and the 1400 V DC power supply; thus only the filament supply, the switching circuit, and the water-cooling are kept on.

The BNL Personnel Protection System (PPS) makes sure that when any personal safety interlock is tripped, the klystron is not able to generate RF power for the accelerating structures. Signals from the PPS are used to disable RF power generation in the Klystron by removing the high voltage supply to the modulator. To achieve this, the 480 Volt input to the DC power supplies of the modulators are opened by two independent Safety Integrity Level rated (safety–rated) contactors. These contactors are part of the PPS system, and are mounted in a separate box which is labeled and subject to configuration control.

3.3.2.6.2 Feeder Waveguide

The feeder waveguide is thick wall WR 284 and is constructed using standard waveguide components. The waveguide is evacuated to avoid arcing at high power. There is monitoring of forward and reverse power in each klystron's output waveguide line. Arc detectors are included at each RF vacuum window.

3.3.2.7 Linac Magnets and Power Supplies

To keep the beam in a given area, the fields of solenoid magnets and quadrupoles are used. The solenoid magnets ensure that the majority of the particles are kept in a radius below 0.5 cm from the beam axis. The solenoids are used in the low energy region, below 10 MeV, to insure radial symmetry and to avoid big amplitude oscillations in the transverse plane of the bunching section. At higher energy, quadrupole magnets between the accelerating sections are used to focus the beam. To compensate the misalignment and steering effects of these magnets, small dipole steering magnets of both Helmholtz and window frame type are used.

3.3.2.8 Linac Control System, Interface and Interlocks

All parameters essential for the operation of the Linac are monitored and controlled by the Linac control system. The Linac control system is integrated into the NSLS-II control system based on the 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 monitored by the Linac control system. Several subsystems (magnet power supplies, RF system, cooling system, gun high voltage, driver amplifier, etc.) shall have additional interlocks. 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. 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.

Signals are provided from the Personnel Protective System (PPS) to disable the production of an electron beam from the gun and disable the RF power generation in the klystron to achieve a redundant shutdown mechanism of the Linac. This signal is applied directly to the respective hardware without digital signal conditioning or processing. The status of the AC power feeding the gun and the klystron high voltage power supplies is fed back to the PPS by separate, potential-free status contacts for verification. This is a radiation safety interlock system protecting personnel and is treated as a Credited Control.

A trigger signal is provided to synchronize operation of the Linac 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 2500 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 3000 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 Linac and Klystron Gallery Power Distribution

A three-phase (480 ± 10%) V 60 Hz electrical supply for the Linac is provided with a motorized circuit breaker load panel located in the Klystron Gallery. This 480 VAC panel board is fed from the electrical equipment room of the Linac/Booster Service Building. This panel board also supplies two 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 Linac and the Linac-to-Booster transport line. The UPS supplies power to a circuit breaker load panel board located in the Klystron Gallery and provides power for controls, vacuum equipment, and critical loads associated with the Linac and Linac-to-Booster transport line. For normal power distribution, a 75 kVA transformer supplies power to another circuit breaker panel board. This normal power circuit breaker panel board supplies power for the individual racks, subsystems, and other Linac equipment. Each electrical rack within the Linac 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 Linac tunnel and the Klystron Gallery are used only for maintenance and repair, not for electrical supply to the Linac.

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 Linac shutting down. The emergency generators will not provide power directly to the Linac. Critical controls for the Linac 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 Linac 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 Linac Electrical Equipment Racks

Linac 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 standard 19-inch equipment chassis are mounted in sealed NEMA 12 electronics racks with water-to-air heat exchangers cooling a set of four 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)

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 cooling 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 Linac and Linac Klystron Gallery

The Linac and Klystron Gallery are served by a constant-volume packaged AHU in the mezzanine mechanical equipment room of the Injection Building. This AHU 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 unit includes pre-filter, preheat coil, cooling coil, supply and return fans, hot water reheat coil, 95% final filter, and steam humidifier. Supply air is cooled up to 50°F as needed for dehumidification. Constant-volume air terminal units are used for individual space temperature control.

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 Linac/Klystron area for Linac 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 Linac Deionized Cooling Water System

The total designed power consumption in the Linac is 180 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 Linac. Supply and return DI water temperatures are set at 85°F and 95°F, respectively. The total designed DI water flow rate for the Linac loop is 123 gpm.

3.6.2.3 Process Water Quality Control

Copper corrosion in the copper components cooled by deionized water remains a major 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 Linac 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 Linac 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 *Pressure Safety* subject area section entitled Vacuum Systems Consensus Guideline for Department of Energy Accelerator Laboratories. The vacuum system is designed such that the pressure throughout the Linac and Linac-to-Booster beam transport line (LBT) is less than 5.0×10^{-8} mbar. The electron gun is capable of being isolated from the remainder of the Linac by means of a pneumatically operated all-metal vacuum gate valve. The five Linac vacuum sections and four Linac-to-Booster 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 Linac. Inverted magnetron gauges are used as primary vacuum gauges. For venting the Linac system, dry nitrogen with cleanliness, purity, pressure, and dew point according to UHV specifications for accelerators is used inside the tunnel. Helium is used for leak checking. The rough pumping cart and bleed-up valve shall have overpressure protection and will relieve at <15 psi.

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 LCSAD limits itself to describing the salient design features of that system and focuses, where possible, on the Injection Building which contains the Linac and Klystron Gallery 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 Linac and Klystron Gallery are served by a 22,000 CFM constant volume AHU located in the Booster RF Service 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 Linac 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 adjacent to the door leading into the Injection Building.
- 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.
- Adequate water source 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 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, at all exit stairs, and at 300-foot intervals in egress corridors.
- High Sensitivity Smoke Detection (HSSD) systems are installed in the Linac enclosure/Klystron Gallery area, the Injection Building main floor and in the Booster enclosure.
- Fire extinguishers are installed throughout the NSLS-II facility.

3.9 Cryogenic Systems

No cryogenics at the system level are in use for the Linac and the Klystron Gallery. 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 420.2B, *Safety of Accelerator Facilities*. All radiation protection policies and guidelines at NSLS-II 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 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 NSLS-II facilities on site, and for visitors and minors within NSLS-II 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 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 occupiable areas. The primary means for accomplishing this control for the NSLS-II facility is through an area radiation monitoring network.

The Shielding Policy requires that the area monitoring network be interlocked to the radiation source when monitors detect radiation levels ≥ 100 mrem/h. Studies of the area monitors that are potential candidates for the NSLS-II 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 >2000 mrem/h, a second independent system is required to mitigate or prevent the abnormal condition. See Table 3.3 for a summary of these requirements.

Table 3.3: Interlocking 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 Linac commissioning will be kept well below federal limits and within BNL administrative levels through shielding, operational procedures, and administrative controls. Shielding of the Linac has been provided to reduce radiation levels during normal operation to less than 0.5 mrem/h at contact with the shield wall in occupiable 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 Linac 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 Linac commissioning by area radiation monitors located in the Klystron Gallery and in the Booster enclosure immediately adjacent to the LTB transfer line. In addition, during commissioning, radiation surveys shall be performed by the Health Physics personnel at frequent intervals to confirm adequacy of shielding and controls.

It should be noted that the shielding calculations for the NSLS-II Linac 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 shield material 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."

[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.

Shielding calculations for the Linac 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 3.4).

Table 3.4: Equivalent Dose Comparison between NSLS-II, SHIELD11* and FLUKA** Simulations

	Dose Equivalent at 90^0 (µrem/J				
	Dose Component	**NSLS-II (Swanson methodology)**	**SHIELD11**	**FLUKA Ambient Dose Equivalent**	**FLUKA Effective Dose Equivalent**
Unshielded Dose Equivalent at 1 m in the transverse direction	Total Dose	1693	754	1668	1350
	Gamma Dose	1380	420	1011	850
	Neutron Dose	313	334	657	500
Dose Equivalent at 2 meters in the transverse direction with concrete shielding of 1 meter (ρ=2.35 g/cm^3)	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

Iron cylinder of length 30 cm and of radius 5 cm is used as target for 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 Klystron Gallery adjacent to the Linac enclosure is posted as a radiologically Controlled Area during commissioning. The Booster area near the Linac-to-Booster transport line may also be posted based on the results of radiological surveys. The earthen berms adjacent to the Linac and Booster are fenced, with access through the locked gate only allowed during times when the Linac is interlocked off via the PPS or for the purpose of radiological surveys under Radiological Control Division administrative procedure. Access to all radiological Controlled Areas will require proper BNL radiation training, NSLS-II facility-specific training, and 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 Linac 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 Linac (e.g., the open area outside the fenced enclosure of the Linac 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.

Two fixed, active area radiation monitors providing visual and audible alarms both locally and in the Control Room will be mounted at the downstream end of the Klystron Gallery to monitor elevated radiation levels produced by electron losses at the high energy end of the Linac and along the transport line to the beam stop. These ASE credited control devices are interlocked with the Linac through the Personal Protection System (PPS) and prevent continued Linac pulses when radiation levels are detected at the alarm level. One or more active area monitors will be located within the Booster enclosure to monitor for elevated levels in this region during commissioning. The purpose of these monitors is ALARA-based and intended to alert occupants to increased radiation levels in the Booster enclosure during Linac Commissioning; these monitors are not interlocked through the PPS and are not credited controls. Linac radiation penetrating into the Booster 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 Linac instruments provide information relating to characteristics of the electron beam produced and transported in the Linac enclosure. Although these systems are not installed for safety purposes and are not credited controls, they do provide information that can help Linac Operators detect non-optimal operating conditions and permit diagnosis and correction of conditions which could result in beam losses creating elevated radiation levels. One such device is the integrating current transformer (ICT1), which monitors the average charge per second at the beginning of the LTB transport line. The rate of charge delivered by the Linac is a parameter of interest to Linac Operators, since beam losses at high charge rates can result in elevated radiation levels. This device will have a visual display in the Linac 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 Linac. Personnel and area dosimetry provide an important means for evaluating the adequacy of the radiation protection program and are 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 LCSAD focuses on the Linac PPS interlocks (LPPS) 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.

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. 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.

Once the PPS systems have been installed and certified, a rigorous configuration management program is established 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 is expected to last about 30 to 60 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; when pressed, these instantly remove or prevent the radiation hazard.

3.10.4.1 Linac Personnel Protection System (LPPS)

The LPPS 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 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 Linac to the Booster: a bending magnet (LB-B2) and a safety shutter located downstream of the bending magnet. The Linac to Booster Ring transport safety shutter 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 Booster 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 Booster area when the Linac is producing beam. Such operation requires that the Linac 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 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. .

Access to the Linac enclosure requires that that the power to the Linac gun and the modulators is off. Power to these devices cannot be turned on unless the Linac 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 gun and modulators Off. All Linac doors are monitored with four switches, two each for chains A and B.

The two radiation monitors in the Klystron Gallery are monitored by the A chain logic and inhibit the gun AC power supply which terminates injection.

The LPPS must be fully functional when the Linac klystrons are being tested with RF; in this case the Linac enclosure has been searched and secured. These tests will occur prior to the actual start of Linac commissioning at which time the klystrons and related equipment will be designated as Radiation Generating Devices (RGD) under the requirements of the BNL SBMS *Radiation-Generating Devices* subject area.

All parameters of the LPPS are available for monitoring in the Linac Control Rooms through the EPICS control system. A block diagram of the LPPS is shown in Figure 3.6.

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

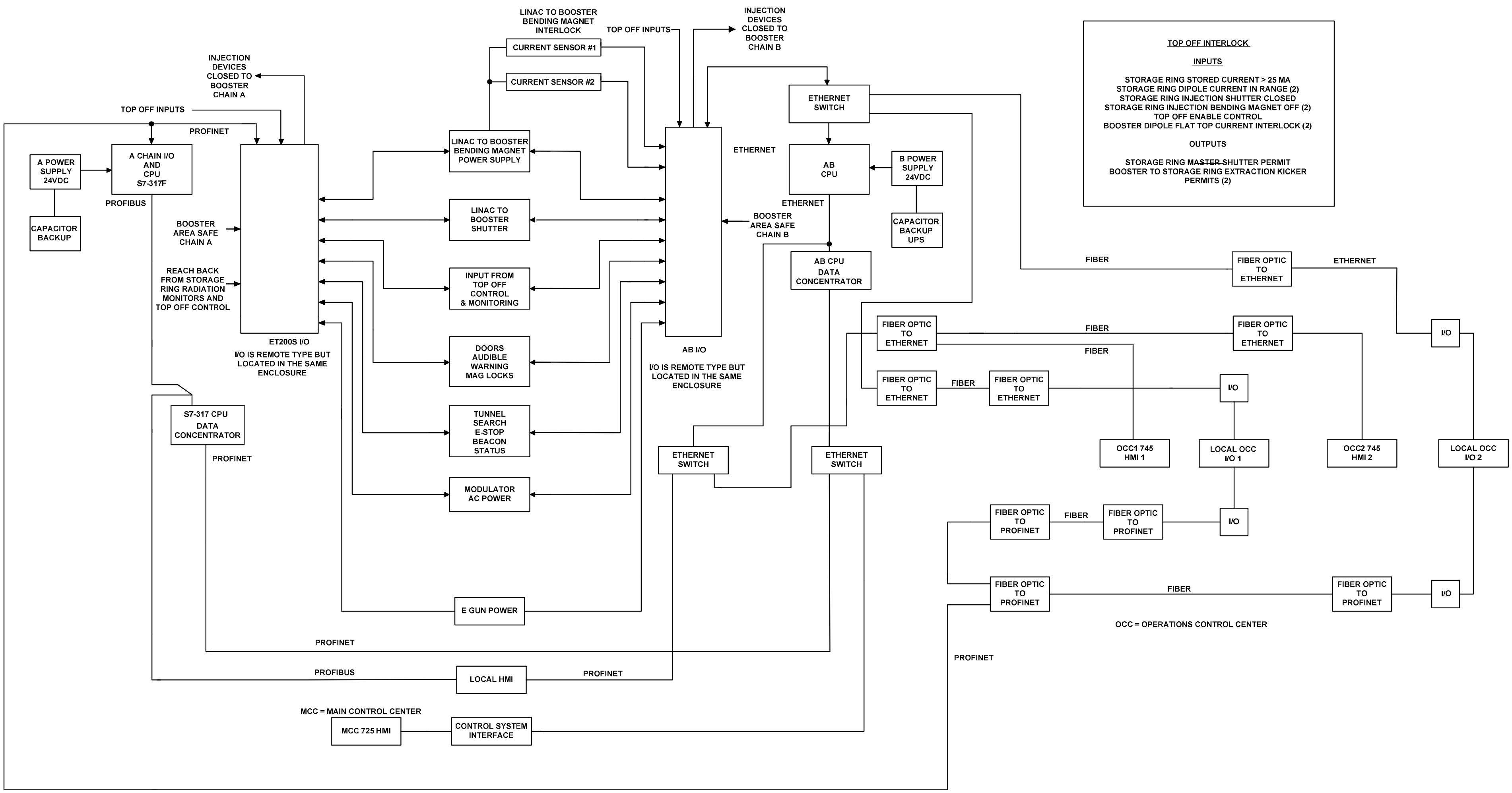

Figure 3.6: Schematic of Linac PPS

3.11 Integrated Safety Management

Integrated Safety Management (ISM) is the basis for performing work safely at BNL. The Photon Sciences Directorate 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
- 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 Facility Support, 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

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 LCSAD and its accompanying LCASE. 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 that are underway include a series of 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), and the Project Safety Reviews that cover research and development (R&D) activities.

Beneficial Occupancy Readiness Evaluations are performed prior to initial occupancy of buildings; Operational Readiness Evaluations are performed once equipment is in place and prior to operations. These are conducted 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 420.2B *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 ESH subject areas and standards in the BNL SBMS. 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

A self-assessment program is being developed as NSLS-II conducts commissioning and proceeds on to the operations phase. 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 Linac 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 subject area Accelerator Safety and is further described in a Photon Sciences Directorate procedure. 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.

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 plus facility- and job-specific training, i.e. Linac commissioning staff, including Contractors. 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 Linac 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 LCSAD documents the residual risk after incorporating the proposed 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, Tier I 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 risks involved and the controls of fifteen hazard types that could be involved with Linac commissioning. In the case of standard industrial hazards (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 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. Where specific industrial hazards are associated with the commissioning, these are discussed in more detail. Other Linac 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 Linac 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 specifically addressed in this assessment: natural phenomena; environmental; waste; fire; electrical; cryogens; confined space; ozone; chemical, and hazardous materials; vacuum system; accelerator cooling water and compressed air; material handling; noise; non-ionizing radiation; ionizing radiation.

The risks of credible accidents involving these hazards are summarized in Appendix 4. These assessments show that the risks following mitigation are low or routine (risk chart based on Risk Screening Matrix provided in the BNL SBMS subject area Hazard Analysis) 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 420.2B, *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, and ice storms. 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 Linac. 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 ring operators would turn off the 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.

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 Linac Commissioning – Natural Phenomena Hazard Considerations

The design and construction of the Injection Building and Linac 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 *Environmental Assessment* for NSLS-II (DOE/EA 1558 – see Appendix 1a), for which a *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 NSLS-II Linac 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 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 subject area Environmental Aspects and Impacts
- BNL SBMS subject area Environmental Assessments and ESH Management Review
- BNL SBMS subject area Liquid Effluents and numerous other subject areas
- BNL SBMS subject area Storage and Transfer of Hazardous and Non-Hazardous Materials

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 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 may be consulted regarding the need to sample waters prior to discharge. Water used in the cooling towers is treated with an ultrasonic treatment 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 used 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 not generate tritiated water or sodium-22 above the BNL-defined Action Levels. Periodic sampling of the cooling water systems and soils will be performed to confirm that tritium and sodium-22 concentrations remain below the respective BNL-defined Action Levels.

The potential for and degree of atmospheric discharges 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. Klystron oil tanks are in secondary containments that meet SCDHS Article 12 requirements.

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 Linac Commissioning – Environmental Hazard Considerations

The commissioning of the Linac 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 Linac Klystron oil tanks (150 gallons each of mineral oil) meet the SCDHS Article 12 secondary containment requirement.

4.3 Waste Hazards

Waste-related hazards from Linac Commissioning include the potential for releasing waste materials (oils and solvents) to the environment and injury of personnel. 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 BNL SBMS subject areas Hazardous Waste Management, and Industrial Waste Management.

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.

The waste oil from mechanical pumps is reduced due to the use of oil-free pumps to back the turbomolecular pumps for roughing down vacuum systems and during system conditioning. 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. 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.

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 any waste. Any need for exposure monitoring of waste operations would be assessed.

4.3.1 Linac Commissioning – Waste Hazard Considerations

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

4.4 Fire Hazards

Extensive design criteria are established through NFPA, BCNYS, and DOE. Typical hazard initiators include equipment failure, accumulation 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. 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*
- 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 subject area *Fire Safety*
- BLN SBMS subject area *Lockout/Tagout*

- 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 I 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 Linac area.

As discussed in Section 3.8, the Linac tunnel/Klystron Gallery is 100% sprinklered with a hydraulically designed wet pipe system, and is equipped with smoke detection (HSSD for the Klystron Gallery) 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 Linac and Klystron electronics are drip tight. The false discharge risks are minimized by the qualified engineers' careful designs, the high quality of installation materials, and pressure testing before placing the system into service. Further protection against leaks is afforded by incorporating any BNL-approved chemicals to control Microbial Induced Corrosion (MIC).

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, 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 for egress requirements; this also satisfies OSHA 1910 requirements. The BCNYS 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. NSLS-II will undergo annual evacuation drill exercises to ensure that building occupants respond adequately to such emergencies. All egress requirements in the BCNYS are met for the NSLS-II design.

4.4.1 Linac Commissioning – Fire Hazard Considerations

The Linac commissioning fire-related hazards have been minimized. The modulator interlock system monitors all critical temperatures (transformer, rectifier, water, oil, etc.). If over-temperature is detected, the corresponding module is tripped and the modulator is switched to STANDBY mode. For example, transformer and water over-temperature trip the core-bias power supply and the 1400V DC power supply, thus only the filament supply, the switching circuit and the water cooling are kept on. The use of a 1400 V DC power supply decreases arcing and therefore decreases the risk of fire.

Linac RF structures, high field magnets and Klystron temperatures are controlled by cooling water systems. If component temperatures exceed pre-established thresholds, temperature sensors on the components alert commissioning staff to take action.

4.5 Electrical Hazards

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. Electrical shock and arc flash, potentially resulting in severe injury or death or damaged equipment 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.

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 subject area Electrical Safety
- BNL SBMS subject area Lockout/Tagout (LOTO)

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 Linac/Klystron area has a large amount of high-power and high-voltage electrical equipment. Power distribution systems are designed in strict compliance with NFPA 70. Systems are grounded (see exception described below) 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.

An exception to the above grounding status of equipment is as follows. The electron gun filament supply, grid bias, pulser electronics and pulse amplifier are floating in a rack at ~90kV. The 90kV is supplied from a HV supply in the Linac power supply racks located in the Klystron Gallery. The HV supply is ground referenced. The electron gun and the floating HV rack are in the Linac enclosure which is an interlocked space. The HV power supply is interlocked in the same way as the modulators for the Klystrons; the area must be swept and gates closed, and PPS interlocks satisfied before the HV power supply and Klystron modulators can be energized. The gun is enclosed in a cage with a door. There is a switch on the door to activate a shorting relay. When the door is opened for service the relay shorts the deck, then the technician will apply a grounding stick to the deck. All this occurs after the power supply is locked out/tagged out (LOTO) and the Linac area unsecured. The PPS controls the AC power to the gun HV power supply redundantly

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 (NRTL). 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 out of a 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 lock-out tag-out (LOTO) capability (in compliance with the BNL SBMS 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 Linac Commissioning – Electrical Hazard Considerations

The Linac and Klystron components follow the above requirements. To further assure the safe operation of the electrical equipment during this Linac commissioning phase, a local commissioning Control Room is situated near the Klystron and Linac areas in the Injection Service Building. This allows more immediate control and response to electrical (and other) conditions in this area by commissioning personnel. The Linac Commissioning Conduct of Operations manual includes the requirements to assure there are no conflicts between the local and building 725 Control Rooms.

4.6 Cryogenic Hazards, Including Oxygen Deficiency Hazards

Cryogenic hazards during Linac 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 subject area Cryogenics Safety

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 Linac Commissioning – Cryogenic Hazard Considerations

The Linac and Klystron Gallery areas themselves 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 Linac, 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. Their 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 Linac cave is 16,757 cubic feet. The SBMS ODH calculation tool determined that for a 50 liter LN2 dewar the “Minimum Oxygen Concentration without Ventilation” is “19.5% - Marginal” and “No ODH Classification Required.”

4.7 Confined Space Hazards

No confined space hazards are associated with Linac commissioning. The risk level is therefore classified as Routine.

4.8 Ozone Hazards

No ozone hazards are associated with Linac commissioning. The electron beam itself is confined within a vacuum enclosure. However, ozone is produced inside the accelerator enclosures 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 Linac energy slit of the NSLS-II Linac enclosure was calculated. The energy selector slit is shielded by 10 cm of lead, where 22 nC/s of charge is dissipated at 230 MeV (~ 5 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 0.6×10^{-4} ppm. The TLV (Threshold Limiting Value) concentration in air is 0.1 ppm. The equilibrium concentration inside the Linac enclosure is therefore at least 10^{-2} smaller than TLV concentration.

The risk level is therefore classified as Routine.

4.9 Chemical and Hazardous Materials

Chemical use during Linac 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 subject area Chemical Safety
- BNL SBMS subject area Work Planning and Control for Experiments and Operations

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 Linac 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. Each Klystron assembly contains 150 gallons of mineral oil; secondary containment is provided to 110% as per requirements of Suffolk County Article 12, *Toxic and Hazardous Materials Storage and Handling Controls*.

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 vacuum failures, 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 subject area Pressure Safety, 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 assures long stored electron beam lifetimes and minimizes the generation of bremsstrahlung radiation. Proper vacuum reduces corrosion to component surfaces. 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 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.

4.10.1 Linac Commissioning – Vacuum System Hazard Considerations

The pump down and conditioning of the Linac 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 Linac 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 and 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 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. Initiators could include cooling water heat exchange and pump failures, compressed air supply failures, improper 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 subject area *Pressure Safety* (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 Linac 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. If water mats for detecting leaks are placed within the accelerator enclosure, alarms will annunciate to the Control Room.

Pressure to all front end valves are supplied from a 100 psi 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 Linac Commissioning – Water and Air System Hazard Considerations

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

4.12 Material Handling Hazards

A single line crane is installed in the Klystron gallery should the need arise during Linac commissioning to move one or more of the Linac Klystrons. The management and control of material handling hazards will follow the requirements in BNL SBMS subject area Lifting Safety (includes ASTM standards).

4.13 Noise Hazards

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

4.14 Non-ionizing Radiation Hazards

Non-ionizing radiation at NSLS-II consists of laser, radiofrequency (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 relevant ANSI, ACGIH and OSHA standards are included in these subject areas):

- BNL SBMS subject area Laser Safety
- BNL SBMS subject area Static Magnetic Fields
- BNL SBMS subject area Non-ionizing Radiation Safety (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

Linac 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 subject area Laser Safety.

4.14.2 Static Magnetic Fields

The Klystrons use electromagnets; these produce static magnetic fields (<5 gauss a few inches from contact) only when the Klystrons are powered. The Linac also utilizes electromagnets to control the path of the electron beam; these magnets are typically powered only when personnel have vacated the area and the Linac 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. Magnet 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 Linac depends on the reliable operation of pulsed Klystrons and continuous wave high-power RF systems for injecting electrons and maintaining the stored beam. Both of these devices generate electromagnetic radiation within the RF and microwave frequency range of 500 MHz to 3 GHz and, in addition, pose significant electrical hazards. They are operated and maintained such that these fields are shielded and, therefore, personnel are not exposed to these fields above relevant standards referenced in the BNL SBMS subject area Non-ionizing Radiation Safety. Trained technicians, surveys, and postings maintain control over these hazards. The Klystron high voltage which is required to provide the RF power is interlocked through the Personal Protection System (PPS). The electron gun high voltage is likewise interlocked to the PPS.

4.14.4 Infrared, Visible, and Ultraviolet Light

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

4.15 Ionizing Radiation Hazards during Commissioning

Potential hazards from ionizing radiation include prompt radiation (x-rays, neutrons, bremsstrahlung) produced during Linac operation and to a much lesser extent, induced activity in Linac components. The primary source of radiation exposure during Linac 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 Linac components. Significant x-ray fields within the Linac enclosure can also be created by electrons released by high electric field gradients within the Linac tanks (dark current) when the tanks are powered by the RF cavities. Commissioning of the RF cavities and tanks will take place prior to the Linac commissioning with beam. These devices will be subject to the requirements of the SBMS *Radiation Generating Devices* subject area. The Klystron tubes located within the Linac Klystron Gallery will also generate x-ray fields requiring shielding. The technical specifications for the Klystrons required that lead shielding be provided to reduce radiation levels to < 0.5 mR/h at contact. These radiation levels will be checked when the Klystrons are commissioned to confirm the adequacy of the shielding.

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. Activities during Linac 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 much more limited from these activities and will be controlled by BNL's sealed source program and work control through Radiation Work Permits.

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

- 10 CFR Part 835, *Occupational Radiation Protection*
- BNL SBMS subject area Radiation Generating Devices
- BNL SBMS subject area Radioactive Airborne Emissions
- BNL SBMS subject area Radiological Dose Limits
- BNL SBMS subject area Radiological Stop Work

- 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 Linac or in the transport lines to the beam dumps. Whenever high-energy electrons strike matter bremsstrahlung radiation fields are produced. The high energy bremsstrahlung can further interact and create additional secondary fields of photons 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 operation of the Linac. In addition, hazards associated with induced radioactivity in accelerator components, air, water, and soil are considered for Linac operations.

4.15.2 Radiological Hazards Associated with the Linac

4.15.2.1 Normal Operation

The Linac serves as the initial accelerator for the facility and is designed to produce 15 nC/pulse at 200 MeV. Although the Linac is capable of operating at a 10 Hz rep rate, it is expected to operate at 1 Hz. The electron source is a 100 keV triode gun. Power for accelerating the electron bunches is provided by 2 Klystrons with a ‘hot” spare Klystron available for back-up. When fully powered and tuned, two Linac Klystrons are capable of producing electrons at energies greater than 200 MeV, but less than 230 MeV. With three Klystrons tuned and fully powered, the maximum beam energy is calculated to be ~ 246 MeV based on Klystron design specifications. However, a conservative value of 250 MeV will be used as the maximum possible energy in subsequent calculations. During normal operations, the Linac will be regulated to operate at 200 MeV 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 Klystron performance and to verify shielding integrity under worst case conditions.

The bulk and supplemental shielding for the Linac is based on the following parameters.

4.15.2.1.1 Linac Radiological Design Parameters for Bulk Concrete Shields

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

Table 4.1: Linac Design Parameters Used in Bulk Shielding Calculations

Beam energy	200 MeV
Beam current	15 nC/s
Pulse frequency	1 Hz
Position of beam from concrete floor	1.2 m
Position of the beam from the Klystron Gallery concrete wall	3 m
Position of electron beam from berm side concrete wall	1 m
Position of the electron beam from the concrete ceiling	1.55 m
Linac average electron beam power	3.0 watts

4.15.2.1.2 Linac Beam Loss Summary

The beam loss assumptions used to calculate bulk concrete and supplemental lead shielding requirements were developed in conjunction with NSLS-II accelerator physicists and are conservative for normal operation. To accommodate the need for Linac studies at energies greater than the normal 200 MeV and 15 nC/s current, supplemental shields at high loss points are based on energies up to 230 MeV and 22 nC/s. A summary of these beam loss assumptions for shield design follows:

Table 4.2: Beam Loss Assumptions Used for Linac Calculations*

Accelerator System	Energy (MeV)	Charge Loss (nC/s)
Linac - General	200	1
First bending magnet	230	2.5
Energy slit	230	11
Beam dumps	230	22

*These assumptions were reviewed during the three NSLS-II Radiation Safety Workshops held between 2007 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 (BNL-79774-2008-CP, *Shielding Requirements for NSLS-II,* P.K Job and W.R. Casey, January 2008).

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

Location	Lateral wall concrete equivalent thickness (cm)	Roof concrete equivalent thickness (cm)
Klystron Gallery side*	100	118
Berm side wall*	130	
Linac downstream wall**	235	
Linac/Booster wall***	220	

*Based on 1 nC/s lost at 200 MeV.

**Based on 2.5 nC/s lost at first dipole; as constructed, the wall has 100 cm of concrete and a minimum thickness of sand (berm) of 270 cm.

***Based on 11 nC/s lost at the energy slit; as constructed, the wall has 100 cm of concrete with a 25 cm thick, 2 ft x 2 ft lead collimator centered on the beam pipe through the wall.

Shielding the side wall for 1 nC/s at 200 MeV provides more than enough shielding for the higher losses that will take place at low energy during the initial phases of the acceleration cycle.

4.15.2.1.4 Supplemental Shielding Requirements

The bulk shielding defined above is based on point loss of 1 nC/s at 200 MeV 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. A substantial lead wall collimator is provided around the transport line pipe that passes through the concrete wall into the Booster enclosure.

Supplemental shielding requirements have been analyzed in Appendix 6a (NSLS-II Technical Note 31, *Preliminary Material Requirement for the Supplementary Shielding at NSLS-II*, P.K. Job and W.R. Casey, July 2007). These calculations were updated to higher energy (230 MeV) and higher current (22 nC/s) in notes authored by P.K. Job dated January 27, 2010 (Appendix 6b) and February 3, 2010 (Appendix 6c). The following materials and thicknesses have been established for supplemental shields at the following locations:

Linac

- Downstream wall, 25 cm thick 2-ft x 2-ft lead collimator through Linac-to-Booster wall
- Energy slit downstream of first dipole, lead (15 cm thick in forward direction, 10 cm thick at 90 degrees), polyethylene (10 cm at 90 degrees)
- Beam dumps (2), forward direction, 30 cm Pb, 25 cm poly; and in the transverse direction 20 cm lead and 25 cm poly
- 15 cm thick lead shields centered on the beamline downstream of the first dipole protecting the forward wall against miss-steered beam

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. The radiological consequences of five abnormal operating conditions are evaluated in this section to determine if additional controls are needed to limit the consequences of the abnormal condition. The abnormal condition producing the highest radiation level is identified as the Maximum Credible Incident (MCI). The five abnormal operating conditions include:

1. Full beam loss (100%) at a point assuming 250 MeV and 22 nC/s operation
2. Linac operates at higher energy than its normal 200 MeV design
3. Linac operates at excessively high beam current > 22 nC/s
4. Bending magnet 1 (LB-B1) or bending magnet 2 (LB-B2) are miss-set and the beam is miss-steered from intended path.
5. One of the two critical devices (bending magnet LB-B2 or safety shutter LB-SS) fails to an unsafe condition while Linac is operating and Booster tunnel is unsecured.

4.15.2.2.1 Linac

Evaluation of abnormal conditions

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

1. Full beam loss (100%) at a point assuming 250 MeV and 22 nC/s operation.

   a. At any location in the Linac without supplemental shields, the highest radiation levels (at 90^o) will be:

      (22 nC/s ÷ 1 nC/s) x (250 MeV ÷ 200 MeV) x 0.5 mrem/h = 13.8 mrem/h in the Klystron Gallery and on the earth shielding (i.e., berm) above and adjacent to the Linac enclosure

      Radiation produced at 0^o will strike either one of the beam dumps and will not result in elevated radiation levels in occupied areas.

   b. Beam dumps are shielded for the full beam at 230 MeV and 22 nC/s. Therefore the maximum radiation level when operating at 250 MeV is (22 nC/s ÷ 22 nC/s) x (250 MeV ÷ 200 MeV) x 0.5 mrem/h = 0.54 mrem/h in any location outside the Linac enclosure in the vicinity of the beam dumps.

   c. The energy slit is shielded with supplemental lead shields at 90^o for 230 MeV and 11 nC/s. Therefore the radiation level for full beam loss at 250 MeV and 22 nC/s is ~1.0 mrem/h on the berm above the Linac enclosure and in the Klystron Gallery in the vicinity of the energy slit. A lead collimator is provided along the beam in the wall between the Linac and the Booster enclosure and provides shielding for 11 nC/s at 230 MeV to reduce radiation levels in the Booster enclosure to 0.5 mrem/h. The supplemental shield enclosing the energy slit protects the Booster wall from radiation emitted at wider angles. Loss at 22 nC/s at the energy slit would raise radiation levels in the Booster enclosure to <1 mrem/h.

      Conclusion: The maximum radiation level outside the shielding for electrons at 250 MeV and a full beam loss of 22 nC/s in the Linac is ~14 mrem/h. There are three regions adjacent to the Linac shields where elevated radiations field must be considered during Linac commissioning.

      i. The berm above and adjacent to the Linac enclosure. To prevent exposure during abnormal beam losses, the berm shall be a restricted area that is fenced to prevent access by unauthorized personnel during Linac operation. Access to the area will be controlled via a locked gate. This gate key will be controlled in a key tree by Linac 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. Note that during commissioning, access to the berm top under controlled conditions by Radiological Control Division personnel may be allowed to conduct radiological surveys during normal and fault conditions.

      ii. The Klystron Gallery. This area is within the NSLS-II Injection Building and shall be a radiological Controlled Area with a low occupancy limited to only trained personnel wearing personnel dosimeters. Two radiation monitors that alarm locally and in both Linac commissioning Control Rooms shall be located in the Klystron Gallery to warn of increased radiation levels. The radiation monitors (ASE Credited Controls) in the Klystron Gallery will be interlocked with the Linac electron gun. The thresholds for these alarms will be established following a series of studies evaluating radiation levels during normal and fault conditions. In addition, administrative procedures defining workers and operators response to radiation alarms will be established.

iii. The Booster Enclosure. This area will be occupied for Booster installation during Linac commissioning and can be accessed through the Injection Building. In general, the Booster enclosure will be treated as a non-controlled area during commissioning. It is protected from radiation produced in Linac by the beam dumps, the lead wall collimator, shadow shields and the energy slit shielding. The portions of the Booster enclosure near the Linac wall will be monitored and controlled during commissioning by Radiological Control Division personnel to confirm that radiation levels are low before personnel are allowed access to this area. 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 Booster enclosure as a non-controlled area.

2. Linac operates at higher energy than its normal 200 MeV design
   Although the normal operating energy of the Linac is 200 MeV, the maximum power provided by three operating Klystrons could produce a maximum energy of 250 MeV. It may be necessary during commissioning and future study periods to operate at >200 MeV; this would involve the use of the third Klystron. For this reason, the consequences of abnormal beam losses at 250 MeV have been analyzed in 1 above.

   Conclusion: Elevated radiation levels during operation up to 250 MeV will be controlled via the interlocked radiation monitors located in the Klystron Gallery area and the locked fence restricting access to the berm. The transition from the normal operation of the Linac at 200 MeV to higher energies using the third Klystron will be administratively controlled by procedure. During commissioning, studies will be done to determine or verify the maximum energy achievable by the Linac when operating with 3 Klystrons. These studies will be treated as fault studies and will be rigorously controlled through plans specifically prepared in conjunction with Radiological Control Division personnel.

3. Linac operates at excessively high beam current > 22 nC/s
   The maximum charge per pulse that Linac can produce is 22 nC. When operating at 1 Hz, the maximum current that Linac can produce is therefore 22 nC/s. However, the Linac is capable of operating at 10 Hz and could generate 220 nC/s (22 nC/pulse x 10 pulse/s = 220 nC/s). The increased repetition rate provides capability when the charge per Linac pulse is lower than needed to provide 15 nC/s to the Booster. Therefore, it is conceivable that the Linac could generate 15 nC/pulse at 10 Hz. Under maximum beam current at 10 Hz and normal beam losses, radiation levels outside the shield walls would approach 5 mrem/h. Full beam loss (100%) at a point assuming 250 MeV and 220 nC/s operation would result radiation levels 10 times higher (i.e., 140 mrem/h) than calculated in 1 above.

   Conclusion: The Shielding Policy requiring mitigation of abnormal conditions that produce radiation fields > 100 mrem/h is satisfied by the radiation monitors located in the Klystron Gallery. These monitors will readily detect radiation fields of this magnitude and will interlock the Linac Off via the

PPS system if this event were to occur. **This is the maximum radiation level produced during a Linac abnormal event and constitutes the Maximum Credible Incident for Linac commissioning.** No additional credited engineered controls beyond the area radiation monitoring network are required to satisfy the Shielding Policy. As a matter of good practice, the actual alarm points for the radiation monitors in the Klystron Gallery will be set at much lower levels than 100 mrem/h. The alarm points will be determined during commissioning, but are expected to be < than 10 mrem/h.

It should be noted that operation at > 22 nC/s is highly unlikely because of two additional controls providing further barriers against high current operation. As mentioned previously, the Linac current will be monitored and controlled by the integrating current transformer (ICT #LB-IT1) located just downstream of the end of the Linac. This current transformer is an important diagnostic tool for Linac operation, but also it will be used to limit Linac current. It will be interlocked to inhibit the Linac gun pulse if the average Linac current exceeds 25 nC/s. Removal of the Linac gun pulse by the current transformer would prevent the next pulse from Linac from occurring. In addition, operation of the Linac at pulse rates > 1 Hz will be controlled by procedure, further reducing the possibility of the Maximum Credible Incident.

4. Bending magnet 1 (LB-B1) or bending magnet 2 (LB-B2) are miss-set and the beam is miss-steered from intended path.

   During commissioning of the Linac there are two modes in which the first dipole (LB-B1) can operate (see Table 4.4 below). In mode 1, the Linac beam will be transported to the straight ahead to beam stop #1. In this mode LB-B1 must be full off to prevent miss-steering. In mode 2, the Linac beam will be transported to the second stop. In this mode, LB-B1 must be set to the correct value for the Linac beam energy, and LB-B2 must be full off. Since the Booster can be occupied during Linac commissioning, LB-B2 must be off at all times to prevent beam from being bent into the Linac to Booster transport line. The PPS system will monitor the status of the Booster tunnel and will require that LB-B2 be off and the safety shutter (LB-SS1) be closed (they will also be LoTo'ed off and closed) when the Linac is secure and the Booster is open.

   If LB-B1 is not set to the proper current, the electron beam can be miss-steered into the vacuum pipe downstream of the bend. Ray traces of possible electron trajectories have been performed and lead shadow shields have been positioned to insure that the electron/bremsstrahlung beam generated when the electron path intercepts the vacuum chamber wall is terminated before it can strike the concrete wall between the Linac and the Booster. Based on 22 nC/s losses at 230 MeV, a minimum of 15 cm of lead is specified to reduce radiation levels in the Booster enclosure to < 5 mrem/h under this fault condition.

Table 4.4: Linac-to-Booster modes of operation

Modes of Operation	Bending Magnet #1	Bending Magnet #2
Booster unsecured	--	Off
Electron beam to beam dump #1	Off	--
Electron beam to beam dump #2	ON	Off
Electron beam to secured Booster*	ON	ON

*This mode of operation is not authorized during Linac commissioning.

Conclusion:
No additional engineered controls are necessary to satisfy the Shielding Policy. The lead shields are subject to formal configuration control to ensure proper placement and control. During commissioning an area monitor with local alarms and rate meter display with sensitivity to neutrons shall be installed in the Booster enclosure on the common wall between Booster and Linac to provide additional warning of elevated radiation levels generated by miss-steered beam. Interlocking is not required for this area monitor.

5. One of the two critical devices (bending magnet LB-B2 or safety shutter LB-SS) fails to an unsafe condition while Linac is operating and Booster tunnel is unsecured.

   During Linac commissioning, access to the Booster will be possible. For the Linac to operate with the Booster enclosure open, the interlock logic for the Linac PPS requires that bending magnet LB-BM2 be off and the safety shutter (LB-SS1) in the transport line be closed. The PPS will be functional during this time but as an additional safeguard and ASE Credited Control, the shutter and magnet power supply LB-B2 will be locked and tagged in the required safe position. There is no need to operate these devices during commissioning.

   In evaluating the adequacy of critical devices which provide protection against dangerous radiation levels, it is necessary to confirm that each critical device is truly redundant and provides protection in the event of the failure of the other. In one case, if the safety shutter were to open while the electron beam is transported to beam dump # 2, the beam will strike in its normal location which is well shielded. Even with beam scraping in the transport line near the open safety shutter, radiation levels through the transport line pipe passing through the wall are low. In the second case, if bending magnet 2 were to power up with Booster occupied, the beam will strike the safety shutter. Calculations for both fault conditions have been performed which indicate dose rates in the Booster tunnel during either of these unlikely faults are <100 mRem/h and do not require additional interlocks to meet the NSLS-II Shielding Policy. In both situations the calculated levels directly within the beam pipe are ~60 mrem/h (primarily neutrons). Radiation levels through the wall immediately adjacent to the beam pipe will be ~10 – 15 mrem/h.

   Conclusion: In either failure mode, the functioning of one critical device prevents the introduction of high radiation levels into the Booster enclosure when Booster is not secured. It should be noted that it is highly unlikely that either device would fail in an unsafe manner since the status of both components are monitored and controlled through two independent chains that are part of the Linac PPS. We conclude that no additional safeguards are required to prevent inadvertent introduction of beam into the Booster enclosure during Linac commissioning. However, during commissioning as an additional safeguard, the magnet power supply and the safety shutter will be manually locked and tagged out in the safe position as an ASE Credited Control. It is also noted that during commissioning two area monitors (non-credited control) sensitive to neutrons shall be installed in the Booster enclosure on the common wall between Booster and Linac to provide additional warning of elevated radiation levels. Interlocking is not required for this area monitor.

4.15.3 Control of Radiation Exposure

The previous section primarily discussed the design of NSLS-II shielding and engineered safeguards as the means for controlling radiation exposure to 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 Linac is Commissioning with Electron Beam

Three engineered systems are considered essential to radiation safety and are credited for mitigating the potential risk of significant radiation exposure during Linac operations.

4.15.3.1.1 PPS Control of Radiation Hazard in the Linac, Booster and Berm top Enclosures – Credited Control

The Personnel Protection System (PPS) provides required interlocking to protect personnel working in and around the Linac 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. A failure mode analysis has been performed for the Personnel Protective Systems (PPS) and the probability of an unsafe failure found to be extremely remote.

There are four instances of protective function provided by the PPS for Linac Commissioning that are considered Credited Controls:

1. A person remaining in or entering into the Linac enclosure while the Linac is operating could experience serious radiation exposure. To prevent such inadvertent access, the electron beam can only be generated and accelerated after the Linac enclosure has been properly cleared and secured. Access into the Linac enclosure is possible only when power to the Klystrons and Linac electron gun are off. Forcibly opening a locked door when Linac is operating will result in immediate shut-down of the Linac Klystrons and 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.

2. During Linac commissioning, personnel will have access to the Booster enclosure. To prevent transport of electron beam into the Booster enclosure during commissioning, bending magnet LB-B2 must be off and safety shutter LB-SS1 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.

3. No entry to the berm area adjacent to and above the Linac and Booster enclosures is permitted when the Linac is operating. Access to the berm is controlled via a locked gate with a key that must reside in a Linac Control Room tree key in order for the Linac to operate. Access to the berm top requires that the Linac be shut down and the key be removed in order to open the gate.

4. Abnormally high beam losses in the Linac or transport line 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. Two active area radiation monitors shall be located in the Linac Klystron Gallery and shall interlock through the Personnel Protective System. On alarm the area monitors shall stop Linac operation by dropping voltage to the electron gun. Only one of the two active area monitors is required to alarm to stop Linac 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 a separate Credited Control, only the PPS will be specifically listed as the Credited Control in the ASE.

The details of the NSLS-II interlock systems are described in Section 3.10.5 above.

4.15.3.1.2 Shielding Credited Control

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 Linac; 3) the supplemental shielding protecting against scattered radiation from the LB-B1 magnet, the energy slit, beam dumps 1 and 2; 4) the transport line collimator protecting the opening between the Linac and Booster enclosures; 5) the lead shielding installed in all penetrations between the Linac enclosure and adjacent locations; and 6) the required lead shielding reducing x-ray emissions from the Klystron tubes. 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 Linac supplemental shields subject to verification include the lead collimator positioned downstream of bending magnet LB-B1 and the supplemental lead and polyethylene shields provided for the beam transport line, energy slit and beam dumps. 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 to safe operation of the Linac during commissioning and are credited for mitigating the potential risk of significant radiation exposure during Linac operation.

4.15.3.2.1. Personnel Protective System Certification and Testing

Prior to initial commissioning of the Linac with electron beam and prior to commissioning the Klystron/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 certification must be repeated following any work on the system which might compromise protective function or at time intervals not to exceed 6 months since the previous test. With the consent of the Manager of the BNL Radiological Control Division, the time interval between tests may be extended to 8 months if the Linac operating schedule did not permit testing within the previous 6 month schedule (SBMS *Electrical Safety* subject area, Section 6 *Interlock Safety for Personnel*, sub-section D4). Failure analyses of PPS systems has demonstrated a failure rate of less than 1 in 10^6 for 6 and 12 month testing periods, therefore an extension to 8 months would fall into this low failure rate (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 response of the interlocked radiation detectors must be confirmed by qualified personnel using approved calibration procedures. In addition, these area monitors must be calibrated before initial use and at regular 12 month intervals. 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 it is subject to configuration control and that only authorized work may be conducted. The process for implementing these requirements are formally described in NSLS "Safety System Work Permit" procedure, LS-ESH-PRM-3.4.1b which will be re-written and issued as a Photon Directorate Procedure applicable to the Linac 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. In order to ensure that any inadequacies are detected early and before serious consequence are experienced, Linac 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 Linac energy and current. Radiological surveys on the berm top shall be conducted using approved procedures to confirm adequacy of the earth shielding and 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 Linac commissioning.

4.15.3.2.5. LB-B2 and LS-SS Status

In order to provide maximum protection of the occupied Booster enclosure during the Linac commissioning with electron beam, the LB-B2 magnet and the LB-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.

4.15.3.2.6. Qualified Linac Operator – Credited Control

Operation of the Linac in a manner consistent with the commissioning plan and operational procedures requires a knowledgeable operator. In addition, the proper response by Linac Operators to abnormal conditions and alarms is necessary for control of radiation exposure. Machine operating conditions which created radiation alarms interlocking Linac operation must be evaluated and adjusted prior to resuming operation. All radiation interlocks shall be recorded in the operating log. During commissioning with electron beam, one qualified Linac Operator must be on duty and available to respond[3] to alarms in the functioning Control Room or the building at all times.

The qualification program for Linac 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 ASE.

[3] 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 klystron).

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 potential for production of induced activity, and for 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 7, "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 7b.

4.15.4.1 Induced Activity in Accelerator Components

It also should be noted that the routine power of the electron beam generated in the Linac is low (~3 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. Experience at the NSLS has demonstrated that induced activity has not been a significant source of radiation exposure. Operation of the Linac is intermittent with operating times that are unlikely to build up longer lived radionuclides. Use of the beam dump for a day with a 3 watt beam will produce radiation levels from induced activity ~2 mR/h at 1 meter from the surface of the dump, dominated by ^{52m}Mn (half life = 21.1 min) and ^{53}Fe (half life = 8.51 min). After an hour of shut down, the exposure rate will be ~0.05 mR/h at 1 meter. ^{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 Linac as an injector, the dumps are very unlikely to ever receive continuous injection for a sustained period of time that would lead to substantial build-up of the longer lived ^{54}Mn.

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. BNL SBMS and Radiological Control Manual requirements for control of radioactive material shall be applied to all work conducted within the Linac tunnel during commissioning. The control of radioactive materials during Linac commissioning is not considered further in this LCSAD.

4.15.4.2 Air Activation

During the normal operation of NSLS-II, small quantities of the short-lived radioactive gases (^{11}C (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. 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 7a, the maximum concentrations of radioactive gas were calculated and are shown in Table 4.5 below. The highest air concentration is during deposition of the beam on the Linac stop at 22 nC/s at 230 MeV. The saturation activity for this mode of operation is 0.65 μCi/m^3 (6.5 x 10^{-7} μCi/cc), which can be compared to the occupational Derived Air Concentration (DAC) of 4 x 10^{-6} μCi/cc. Because of the short-lived nature of these gases, occupational exposure to workers entering the enclosure will be insignificant.

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. There is forced ventilation within Linac and Booster enclosures so the only releases would be fugitive losses through the small openings and doorways in the enclosures. 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 that no EPA permit and continuous air monitoring is required (see Appendix 8b).

The source term calculations used in the CAP-88 calculation were based on the saturation activities of the short-lived gases produced in the accelerator enclosure air, which are given in Table 4.5. Using the methodology and assumptions described in Appendix 8b, 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 (m³)**	**Beam energy (MeV)**	**Beam loss (Watts)**	**^{13}N (µCi)**	**^{15}O (µCi)**	**^{11}C (µCi)**	**Total activity (µCi)**	**Concentration (µCi/m³)**
Linac stop	463.4	230	5.0	266.6	28.9	5.6	301.1	0.65
Linac energy selector	463.4	230	2.5	133.3	14.5	2.8	150.6	0.32

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 0.1mrem/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 Linac, the highest beam loss point in a component with water cooling is the first bending magnet downstream of the Linac. We assume a beam loss of 2.5 nC/s at 230 MeV (0.58 watts). This is slightly less than the loss at the Storage Ring septum. The following calculations are based on the higher Storage Ring septum losses. The saturation activity of radionuclides in the cooling water has been estimated at the

Storage Ring septum using the method described in Appendix 7. A closed loop water system with inventory of 100,000 gal (3.785×10^8 cm^3) of water is used to cool the Linac bending magnet as well as the Storage Ring septum. 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, ^3H will attain saturation only after decades of operation. After 5,000 hours of continuous operation, the concentration of ^3H will be only 3% of the saturation value. Other loss points, including the Linac bending magnet will provide additional small increments to the total inventory of tritium within the system. This cooling water system will be tested periodically for tritium once operations have begun.

Table 4.6: Saturation Activities of Radionuclides in the Cooling Water of the Storage Ring Septum

Beam loss (watts)	^{15}O (pCi/cm^3)	^{11}C (pCi/cm^3)	^{13}N (pCi/cm^3)	^3H (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 ^3H (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 subject area Accelerator Safety, analysis has been done to estimate the rate of formation of two radioactive isotopes, ^3H and ^{22}Na, in the soil during the operation of Linac, Booster, and the Storage Ring. In the calculations, the neutron source inside the accelerators is assumed to be at 1.2 m from the floor and 2 m from the inboard wall. The floor is 0.51 m of standard concrete in Linac. A minimum concrete wall of 0.5 m is assumed before soil is encountered beyond the side walls.

Table 4.7 below gives the activity of ^3H and ^{22}Na created in the soil at the two principle Linac beam loss locations using the operating assumptions planned for future normal operations stated below the table. 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 ^3H and ^{22}Na, respectively. A water concentration factor of 1.1 is taken due to the annual rainfall of 55 cm. 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 ^3H 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)	^3H (pCi/L)	^3H Leachable (pCi/L)	^{22}Na (pCi/L)	^{22}Na Leachable (pCi/L)
Linac Dump 230MeV	22	1.37E11	4.4E2	92	0.54	0.60	5.2	0.39
Linac Slit 230MeV	11	6.86E10	2.2E2	46	0.41	0.46	3.9	0.29

Operating Assumptions

- 200 times Linac operates to fill the Booster from scratch, 3 minutes for each fill from scratch. Total operating time is 200 x 3 min= 10 hours
- 500 hours of Linac study (fill and dump) = 500 hours
- 5000 hours of top-off operation, 3 pulses per minute operation, effective hours of operation = 5000 x 180/3600 = 250 hours
- 500 hours of operation for beam dumps and 760 hours of operation for the Linac slit.

As specified in the BNL SBMS subject area Accelerator Safety, we assumed 100% leachability for tritium and 7.5% leachability for sodium. A soil–water concentration factor of 1.1 is also provided in the subject area.

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 Linac commissioning.

As a monitoring tool for soil activation levels near the Linac, ~1 liter soil samples will be positioned within the Linac 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 down gradient of the Linac beam stop and periodically sampled for ^{3}H in the groundwater as a further means of confirming no impact from Linac operation on the ground water.

4.15.5 Linac Commissioning – Ionizing Radiation Hazard Considerations

A detailed Linac Commissioning Plan defining the objectives, tasks, and schedule has been developed for the Linac 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 Linac 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 Linac can produce using three Klystrons. During this study, the maximum allowable energy authorized during the commissioning period will be increased from 230 MeV to the maximum achievable with three Klystrons, currently calculated to be 246 MeV. 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 Linac at maximum energy capability
- Evaluate effectiveness of shielding for the most extreme case of Linac 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 LINAC COMMISSIONING ACCELERATOR SAFETY ENVELOPE

5.1 Development Basis

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

Ionizing radiation, electrical energy, fire, and chemicals represent the more significant pre-mitigation hazards associated with Linac commissioning. Risk assessments for work with these and other hazards are included in Appendix 4 of this LCSAD. 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 department 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** (described above in Section 4.15.2.2) involves potential for personnel exposure from a prompt ionizing radiation field produced by the loss of a 250 MeV beam at 220 nC/s. It is for this reason that ionizing radiation is the only LCSAD hazard whose credited controls are specified in the LCASE. The LCASE establishes required Engineered and Administrative Credited Controls to provide protection to workers and the environment during the commissioning of the Linac with electron beam.

5.2 Operational Hardware Limits

The requirements described in Sections 2, 3, 4, and 5 of the LCASE ensure that the risks described in the LCSAD are maintained and not exceeded during Linac commissioning.

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

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

The **Linac Maximum Electron Beam Energy** allowed shall be 250 MeV. The calculated maximum energy that the Linac can achieve with the installed Klystrons and accelerating structures is 246 MeV. The actual maximum Linac energy will be determined during Linac commissioning, but will not be allowed to exceed 250 MeV.

The **Linac Maximum Current** allowed shall be 220 nC/s. It is conservatively estimated that the maximum charge per pulse that can be produced by the Linac at 250 MeV is 22 nC/s. When operating at 10 Hz, the maximum current is therefore 220 nC/s.

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 occupiable areas during the MCI is estimated at ~ 140 mRem/h in the Klystron Gallery. The Shielding Policy requires a single credited engineered system to mitigate this fault level. The two active interlocked radiation detectors located in the Klystron Gallery 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 Linac and transport line and their associated shielding are designed for operation at lower energy and current than the maximum hardware limits described above. 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. In particular, internal non-credited controls will be established to limit beam current to ≤ 25 nC/s. Written procedures will be established for operation with 3 klystrons, pulse rates > 1 Hz, and beam currents > 25 nC/s. (see LCSAD 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 Linac 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, which includes the area radiation monitoring system, must be operational for all phases of Linac commissioning with beam. This system provides the following protective functions which are vital for the safe operation of the Linac: 1) ensures an effective search and secure of the Linac enclosure and berm top above the Linac prior to initiation of beam 2) prevents access to the Linac enclosure when the beam is enabled; 3) ensures that the LB-B1 magnet and the LB-SS safety shutter are in the safe condition when the Linac is enabled and the Booster 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 LCSAD section 3.3.2.8 and 3.10.4 and 3.10.4.1 and 4.15.3.1.1.)

All Radiological Shielding described in the LCSAD must be in place during Linac 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 to ALARA values. The required shielding includes: 1) the poured concrete walls (bulk shielding); 2) the earthen berm around the Linac; 3) the supplemental shields protecting losses at LB-B1 magnet, the energy slit, , beam dumps 1 and 2; 4) the transport line collimator protecting the opening between the Linac and Booster enclosures collimator, 5) the lead shielding installed in all penetrations into the Linac enclosure and 5) the lead shielding reducing x-ray emissions from the Klystrons. (See LCSAD 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 Linac commissioning with electron beam:

The PPS interlocks must be tested and certified prior to initial operation and re-validated at 6 month intervals (not to exceed 8 months) as required in the SBMS Subject Area Electrical Safety. The functioning of the PPS is required to provide personnel safety during Linac commissioning. Regular testing as specified in the Electrical Safety Subject Area is necessary to confirm that no degradation of protective function has occurred as the result of component failure or human error. With the consent of the Manager of the BNL Radiological Control Division, the time interval between tests may be extended to 8 months if the Linac operating schedule does not permit testing within the previous 6 month schedule (SBMS Electrical Safety subject area, Section 6 Interlock Safety for Personnel, sub-section D4). Records of all tests and certifications must be retained. (See LCSAD sections 3.3.2.8 and 3.10.4)

The active radiation monitors must be calibrated at 12 month intervals as specified in the SBMS. The response of the interlocked radiation detectors must be confirmed by qualified personnel using approved calibration procedures. These area monitors must be calibrated before initial use and at regular 12 month intervals. This program must be documented. The accurate evaluation of radiation fields in the Klystron Gallery and the Booster enclosure is necessary to provide protection against unnecessary radiation exposure. It is important to ensure that these devices are within calibration and are providing an accurate reading of the radiation fields. Instruments must be labeled showing the date of last calibration and records of calibration must be maintained. (See LCSAD sections 3.10.3 and 4.15.3.2)

A radiation protection configuration control program must be in place to protect the functions provided by the PPS and the radiation shields. The analysis in the LCSAD of radiological consequences is based on the functioning of the engineering controls as described in the LCSAD. 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 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 LCSAD section 3.10.1) 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 area monitoring response, and to assure control of radiation exposure. During commissioning of the Linac, 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 atop the Linac enclosure. All radiological areas shall be posted as required by SBMS. 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 and non-controlled areas adjacent to the Linac enclosure. (See LCSAD section 4.15.3.1.2)

The power supply to the LB-B2magnet and the position of the LB-SS shall be locked and tagged in the safe position during linac commissioning. The LB-B2 magnet and the LB-SS safety shutter are the critical devices preventing introduction of beam into the Booster enclosure, which will be an uncontrolled area during Linac commissioning. It is essential to prevent introduction of Linac beam into this area during commissioning. Although the status of LB-B2 and LB-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 Subject Area. (See LCSAD sections 4.15.2.2.1 and 4.15.3.1.2)

At least one qualified, trained linac operator shall be on-duty during Linac commissioning with electron beam. Operation of the Linac in a manner consistent with the commissioning plan and operational procedures requires a knowledgeable operator. In addition, the proper response by Linac Operators to abnormal conditions and alarms is necessary for control of radiation exposure. Machine operating conditions which created radiation alarms interlocking Linac operation must be evaluated and adjusted prior to resuming operation. All radiation interlocks shall be recorded in the operating log. During commissioning with electron beam, one qualified Linac 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 klystron).The qualification program shall be formally developed and approved and shall meet the BNL SBMS program requirements. Training records of all qualified operators will be maintained. The duties of the Linac Operator are defined in the Linac Commissioning Conduct of Operations manual. (See LCSAD section 1.4.2 and 4.15.3.2.1)

6. QUALITY ASSURANCE

6.1 QA Program

The NSLS-II Project has adopted, in its entirety, the BNL Quality Assurance Program. This QA Program 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 and 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 Standards Based Management System (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 Standards Based Management System (SBMS) supports NSLS-II management's efforts to ensure 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 includes 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 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 Klystron Gallery 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 which take place to determine if changes in design or operational practice that are discussed during committee reviews result in any change in the protective function which provide 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 which need further evaluation to determine if the NSLS-II process for evaluating an Unreviewed Safety Issue should be initiated.

6.12 Configuration Control

As described in Sections 4.15.3.2.3 and 6.4, configuration control of shielding and PPS systems are 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 “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 prior to work by knowledgeable individuals and that restoration of protective function is confirmed at the end of such work.

6.13 Software Quality Assurance

The BNL Quality Management System within the SBMS provides processes for identifying and inventorying software, and 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 Linac, but is added to the LCSAD 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*