SOURCE DEVELOPMENT LABORATORY

Safety Assessment Document

Building 729, Site of the BNL
Deep Ultra-Violet Free Electron Laser
(DUV-FEL)

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Source Development Laboratory
Safety Assessment Document

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INTRODUCTION 1

1.1 Motivation and Scope

By 2010 or sooner, it is believed that the next major Department of Energy (DOE) light source facility will be operational, and that it will likely be based on some type of single-pass free electron laser (FEL) technology. Since the early 1990's (Brookhaven National Laboratory) BNL has been a key laboratory in the development of technology and theory that will support such a machine. The Source Development Laboratory (SDL) was established as a dedicated experimental platform to pursue research for this type of 'Fourth Generation' synchrotron radiation source.

A major element of the program includes development of a high peak power FEL operating in the vacuum ultraviolet (UV). Known as the Deep Ultra-Violet Free Electron Laser (DUV-FEL), the objective of the program is to develop the source and experimental technology together to provide the greatest impact on UV science, and the broadest possible insight into the virtues and limitations of the technology at yet shorter (x-ray) wavelengths. The concept for the DUV-FEL is an extension of the High Gain Harmonic Generation (HGHG) FEL recently demonstrated in the infra-red at the BNL Accelerator Test Facility (ATF).

The basic configuration of the FEL requires a high peak current, low emittance electron beam that can be made to interact with light from a seed laser in a periodic magnetic structure (wiggler or undulator). The resulting energy modulation in the electron beam can be converted to a spatial modulation which then radiates and is amplified in a longer undulator. The radiation produced can be either at the fundamental of the seed laser (same wavelength output) or can be arranged for a higher harmonic. From the experimentalists' standpoint, the essence of the approach is to capture the properties of the high quality seed laser (stability, bandwidth, pulse duration, chirp) and express them at shorter wavelengths than can be obtained from laser itself.

In the case of the DUV-FEL a Titanium:Sapphire system (*ca* 800 nm) provides the seed, and operation at wavelengths well below 200 nm are anticipated.

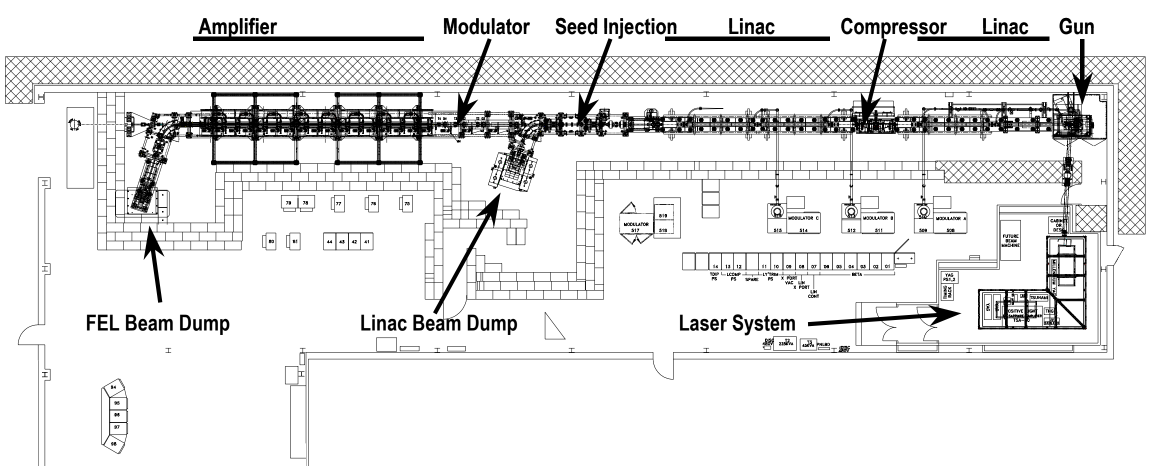
The SDL builds on technological developments pioneered at the ATF in creating the DUV-FEL and experiments involving coherent synchrotron radiation. Therefore, in the creation of this Safety Assessment Document (SAD), much use was made of the previous operational experience at the ATF which shares much of the hardware complement to be installed at the SDL. The SAD analysis also takes advantage of the fact that the linac was originally procured as part of the superconducting x-ray lithography source (SXLS) program. The linac was assembled and tested as part of the procurement process, so experience from the earlier electron linac facility (ELF) installation was factored into the design of the SDL and the creation of this SAD.

The Source Development Laboratory is being assembled in stages, which is reflected in the scope of the SAD through each revision. The initial phase of the program was covered in revision B of the SAD, and was centered on the creation and characterization of the bright electron beam required by the DUV-FEL. Revision C of the SAD expanded the scope of the document to include the DUV-FEL experiment and its equipment. The structure of the SAD is meant to provide an understanding of the project so that the efficacy of the design to ensure the protection of the environment, workers and the public can be fully evaluated. Revision D provided additional backup information to support the methodology used in the safety analysis of the facility.

Section 1 describes the basis for the project and provides a brief description of the facility. Section 2 provides a high level summary of the conclusions of the Safety Assessment Document. Section 3 involves a more detailed description of the facility, its components, and the operating procedures in place. Section 4 concerns itself with an analysis of the safety issues, with particular emphasis on radiological safety. The remaining sections are concerned with Quality Assurance (5), Decommissioning (6), and a listing of References and Supporting Documentation used to establish design criteria (7). As outlined in the SMBS subject area, the Accelerator Safety Envelope (ASE) has been removed and is now a stand alone document (LS-SDL- 0019) that defines the boundaries established for safe operation of the facility described in the SAD.

1.2 Description of the Facility

The goal for the SDL Linear Accelerator is to provide intense electron pulses for subsequent experiments. The average beam power as presently configured is actually comparatively low; 6 W at full machine capability. These characteristics have influenced many aspects of the design of the SDL including the machine, shielding, and distribution of equipment throughout the building. This thumbnail sketch emphasizes the major features of the facility, and the location of the accelerator within building 729.



The electronic characteristics of the SDL linac are shown schematically in Figure 1 (in the figure section of the SAD). It consists of a high brightness RF photocathode electron gun followed by a 230 MeV pulsed linac (~1.5 μsec radiofrequency pulse length) operating at a pulse repetition frequency of up to 10 Hz. The linac incorporates a magnet chicane for bunch compression of the short (~7psec), high peak current (~130A) electron bunches, produced by the electron gun.

The gun cathode is illuminated by the beam from a wide bandwidth Ti: Sapphire regenerative amplifier capable of pulse shaping and lengthening. The pulse length is adjustable from 0.3 ps to 20 ps. With pulse compression, peak bunch currents of up to 10kA are feasible with a corresponding bunch length of ~50 μm.

Following the linear accelerator is a transport line that has a dipole magnet to direct the electron beam to a shielded beam dump. This line constitutes an energy spectrometer that can be used to characterize the beam. The field in the dipole magnet can be reduced to zero so the electron beam is not deflected and it can pass directly to the DUV-FEL experiment. There the beam passes through a transport line that includes an energy modulation wiggler, a dispersive magnet chicane, and the amplifier wiggler where the FEL light is produced and amplified. To separate the optical beam from the electron beam, a second dipole magnet and beam dump are provided. The optical beam is deviated down with mirrors to pass through a penetration in the concrete shielding wall that is below the nominal electron beam height, to minimize the potential for radiation leakage from the accelerator enclosure.

The components of the DUV-FEL are installed and were commissioned in stages starting with an initial configuration that included only the amplifier wiggler and beam dump. The modulator and dispersion section have been added. All components are described in this SAD. In addition, this safety analysis anticipates an upgrade of the linac energy from the presently installed 230 MeV to 300 MeV. The equipment configuration for the analysis and utilization of the FEL light will be reviewed by the NSLS Beamline Review Committee. Individual experiments will be reviewed through the NSLS experimental approval process.

1.3 Environment, Worker and Public Safety

Although the SDL will incorporate and explore very advanced technology in the accelerator physics field, the operations, energies and beam currents associated with this facility are well within those commonly in use at the NSLS and other accelerators at BNL and elsewhere. As a result, the potential hazards associated with the operation of this facility have been successfully addressed at NSLS for a number of years.

The ESH requirements and practices in place at the NSLS will be incorporated into those implemented at the SDL. The ESH design and operational program requirements are described in this document and are subject to the review and approval of the NSLS Department, as well that of the BNL ESH/Q Directorate and the Laboratory ESH Committee.

An Accelerator Safety Envelope which defines the operating requirements for the facility has been prepared for the SDL based on this analysis and will require approval from the Department of Energy (DOE) prior to operation. Prior to initial operation of the facility, an accelerator readiness review will be conducted to ensure that the necessary ESH program elements are in place and are functional.

SUMMARY/CONCLUSIONS 2

This SAD describes all significant environmental, safety and health hazards created by the facility and its operations. Section 4 reviews the risk associated with environmental and hazardous waste issues, ionizing and non-ionizing radiation, electrical, fire, and hazards associated with natural phenomena. Appropriate design and controls have been put into place to mitigate and control these hazards, and it is demonstrated that the facility can operate with a minimum level of risk to the environment, workers, and the public.

The shielding design together with the radiation security interlocks and search and secure procedures ensure that no personnel are exposed to any significant levels of radiation. NSLS workers will receive < 100 mrem/year and the general public will receive less than 25 mrem/year by the measures outlined in this document. This includes normal operation of the Source Development Laboratory at the maximum operational levels given in Accelerator Safety Envelope (LS-SDL-0019), as well as for accident scenarios. This also conforms to or is less than the criteria in 10CFR835.

Design and construction of electrical equipment ensures that no exposed high voltages are present anywhere in the facility. High voltage enclosures are either locked or fully interlocked. Normal NSLS policy prohibits "working hot" on electrical equipment; any deviation from this requires a permit and a working hot procedure. Staff members are trained in these policies and in Lockout/Tagout (LOTO) procedures.

Non-hazardous fluids are used for cleaning purposes where possible and all chemical inventories are kept to a minimum. Generation of hazardous wastes at the facility will be quite low (< 5 gallons/year). Generation of radioactivity in air, water, and soil are minimal, and no permits or monitoring for environmental releases are needed. Generation of radiological waste materials will also be limited.

Small quantities of activated copper, aluminum or stainless steel will need to be disposed of as part of a decommissioning plan. The total volume is estimated to be < 10 cubic feet over the life of the project.

The building has been designed to conform with the National Fire Protection Association "Life Safety Code" No. 101 and DOE Order 420.1 "Facility Safety" dated 11/22/2000. Automatic sprinklers and smoke detectors are installed in the facility. The facility is compliant with the DOE "Improved Risk" criteria for fire protection purposes.

The high power, pulsed, laser beams are contained in interlocked enclosures and are transported inside opaque beam tubes. Entry into or occupancy of laser areas while the lasers are operational shall be only by trained or properly escorted personnel who are required to use suitable protective eyewear.

An Accelerator Safety Envelope (ASE) has been established to ensure the facility operates as defined in this document. This facility, as described in this document, is compliant with the NSLS, BNL and DOE ESH requirements. This Safety Analysis Document (SAD) has been developed to meet the requirements of DOE Order 420.2A "Safety of Accelerator Facilities", as well as the guidance contained in 10CFR835, the Brookhaven National Laboratory Radiological Control Manual, and the Accelerator Safety Subject Area.

FACILITY AND OPERATIONS DESCRIPTION 3

3.1 Introduction

The SDL is housed in Building 729, which was built in 1993. The structure consists of a steel exterior and frame on a slab and a single high bay story. The building was extended in 1996 to allow for more experimental space and for a new injection and laser system. The building extension is of a similar construction to the original building. The structure was built to all applicable Uniform and State Building Codes in force at the time of its construction. The facility is located northeast of the intersection of Brookhaven Avenue and Railroad Street and east of the existing NSLS Building 725 as shown in the site plan (Figure 2). The Mechanical Equipment Room is situated in an area connected to existing Building 726 at the west end of the Building 729 and is separated from both buildings by one low rated fire wall. A cleanroom to house the class IV laser systems used in SDL operations is located at the east end of the building. The detailed description of the conventional facilities is provided in section 3.2.

The 230 MeV linac utilized as the electron source for the SDL was fabricated, installed and tested by an outside vendor, Beta Development Corporation, as part of an earlier project (ELF) in 1993. It has been modified and is housed in Building 729 as shown in Figure 3. The accelerator, a conventional S-Band (2856 MHz) RF electron linac of overall length ~ 60 ft. is located along the north wall of Building 729. The electron gun is located at the east end of the building. The laser system used to produce electrons from the gun is just south of the gun. The DUV-FEL optical systems are located at the west end of the building. These accelerator systems are detailed in section 3.3.

To provide radiological shielding, lead, concrete and borated polyethylene are used to enclose the accelerator. The principal enclosure for the accelerator is comprised of 8 ft. high concrete walls. Inside the building the wall is 32" thick along the south side of the linac, and 48" thick in all other interior locations. The exterior wall is 48" thick running the length of the building on the north side and lapping the corners of both the west and east ends of the building. The accelerator and other critical accelerator components are covered on top and sides by lead shields at least 2" thick. Access to the machine is controlled by interlock systems that prohibit entry to the enclosure when the machine can operate. Details of the radiological protection systems are provided in section 3.4.

Environmental, Worker and Public Safety is an integral part of the design process for SDL equipment. Electrical, radiation (ionizing and non-ionizing) and general safety issues were reviewed and preventative measures such as interlocked enclosures with controlled entry or adequate shielding have been provided based on both normal and unusual or accidental modes of operation anticipated. Various organizational, training and program review policies have been put in place that form the basis of the SDL Safety Program described in section 3.5.

3.2 Conventional Facilities

3.2.1 Building 729

Building 729 is a one story high, butler type building. The concrete slab construction is used for the floor and the walls are insulated metal panels on steel beams. All building materials are considered non-combustible. The plan view of Figure 3 shows an L-shaped structure of approximately 160 feet in length and 40 feet wide with the west end extended an additional 40 feet to join the existing Building 726. The elevation view of Figure 4 shows a minimum inside building height of about 14.7 feet on the north side of the linac enclosure, sloping up to a maximum inside height of about 22.4 feet at the building center. There is a 2 ton bridge crane which covers the buialding area between the laser room and the west end of the building.

The facility is designed to be in compliance with NFPA 101, Life Safety Code, and with BNL Environmental Safety and Health Standard 4.1.2. for an ordinary hazard, fully sprinklered, industrial occupancy. The occupancy is a standard accelerator, with metal beam line transport piping, concrete shielding, electrical power supplies, and cable trays. The occupancy load within the building is low (>100 sq. ft./person). The access and egress doors and gates are indicated on building plan view Figure 5. The primary access and egress for personnel will be through doors located on the west and south side of the building. A roll-up door (door 4) intended only for equipment access will otherwise be closed. Additional egress can be made through a set of double doors into Building 726. The mechanical equipment room is provided with one emergency exit door.

Standard outdoor lighting and concrete walkways for personnel are provided for doors 1 and 2. Doors 1, 2 and 3 are provided with the standard controlled access entry system in effect throughout the NSLS, with entry enabled by a BNL ID card reader. These standard industrial security measures do not conflict with egress from the facility. Emergency lighting is provided within the building by battery-operated units. All exits are marked with appropriate signs. The building is protected with a combination of automatic sprinklers, automatic heat and smoke detectors and manual fire alarm pull stations. Smoke detectors are provided in the air handling system in compliance with NFPA 90A. Alarms and supervisory points are connected to the BNL Fire Rescue Group annunciators.

Combustible loading within the building is light. As previously stated the building is constructed of non-combustible materials. Equipment within the building contains combustible wire insulation as well as interconnecting power and signal cables. This is an acceptable risk given the presence of automatic sprinkler protection in the facility and the open configuration of the cable trays.

Apart from the klystron insulating oil (~450 gallons in well controlled tanks), no significant quantities of combustible gases or fluids are anticipated. Klystron oils are combustible mineral oil types. However, they are within metal containers, within secondary containment, and protected by ceiling level sprinkler systems. For neutron shielding, polyethylene containing 5% boron is used. Both green and white colored borated polyethylene are used at SDL.

This type of shielding is considered non-combustible and acceptable for sprinklered occupancies. No high hazard operations are associated with the operation of the SDL systems. A detailed "Life Safety Code Analysis" and a Fire Assessment/Fire Analysis Report generated by BNL Fire Protection personnel is available (Appendix 1).

3.2.2 Electrical Power

The electrical power for the Source Development Laboratory is distributed at 480 volts, 3 phase with a grounded wye system. Some equipment requires the 480 line voltage such as the overhead crane, linac modulators, klystron magnets, and transport magnet power supplies. The 120/208 volt system is derived from the 480 feed for smaller equipment. Examples of loads on this system include building lighting, heating and ventilation pumps, water system pumps and other small equipment needs such as control console components, fire safety monitors, alarms and communications equipment. The installation and operation of this power distribution system is according to standard industrial practice for this type of equipment. The safety codes used for guidance included ANSI spec #39.5 ("Electrical and Electrical Measurement and Controlling Instrument Safety Requirements"), the National Electric Code, Department of Energy Order 440.1A "Worker Protection Management for DOE Federal and Contractor Employees", DOE/EV-0051-1 "electrical Safety Criteria for Research and Development Activities", and BNL Environmental, Health and Safety Standards 1.5.0 and 1.5.2.

All equipment is enclosed in grounded dead front cabinets. All systems operating at exposed voltages above 24 volts are contained inside secured enclosures with locked or interlock protection, or bolted access according to the serviceability of the equipment and the potential hazard. In equipment where stored electrical energy may be present a system of discharge bleeders, automatic shorting bars and manual grounding sticks are provided.

The A.C. Power Distribution System uses conventional design practice and provides for lockout and tagging of all equipment for which these rules are applicable. The electrical system contains no unusual features when compared to similar Laboratory facilities such as the NSLS and ATF linacs and, as such, hazards are judged to be marginal in terms of occurrence probability and potential consequences as defined in the Brookhaven National Laboratory Environmental Safety and Health

(BNL ES&H) Standards Manual. Electrical hazards are discussed in Section 4.4.

3.2.3 Water Cooling Systems

An air-cooled chiller is located outside the northeast corner of Building 729, and provides the capacity for the water system which circulates up to 435 GPM of glycol/water at a temperature of 45°F. The chilled water system contains approximately 400 gallons of 40% propylene glycol (Eastman Chill Guard 35) with a fresh water make-up line to an expansion tank. The location of the circulation pumps is such that about half of the volume of the glycol/water coolant (200 gallons) could be lost in unlikely event of a catastrophic failure of the piping system. Low flow and temperature excursion alarms immediately enunciate at the Plant Engineering Central Chilled Water facility where the functioning of the cooling system is continuously monitored. Plant engineering personnel are on call 24 hours a day to respond to such alarms.

Approximately 90 GPM of the chilled water is used for the building air handler with the balance available for the other systems. These include the laser room and the linac temperature control systems. The machine systems are both closed loop deionized water systems using ion exchange beds that are removed for regeneration or disposal by a contractor off site. Discharge of contaminants to the ground or to the sanitary system is neither planned nor expected from either the HVAC or accelerator cooling systems.

One system (accelerator components) actually heats the linac sections to keep them operating on frequency. A 75 kW electric heater is used to elevate the temperature of the water for this loop and cooling is used only to damp the temperature against overshoot in the heater. Another system (power supplies) is provided to remove the waste heat from other accelerator components including power supplies, magnets, and auxiliary equipment. The operating parameters for the machine systems are summarized below:

Parameter/System		Power Supplies	Acc. Components
Design Pressure	[psig]	110	150

Design Temperature	[°F]	100	150
Operating Pressure	[psig]	97.5	133.5
Operating Temperature	[°F]	74	113±0.2
Flow rate	[gpm]	135	75
DI Resistivity	[Mohm cm]	<1	~1

3.2.4 HVAC

BNL Plant Engineering and the NSLS utilities group have specified the Heating, Ventilation and Air Conditioning systems. A closed loop propylene glycol/water system provides the cooling for the building air, the laser room, and the accelerator equipment. The building space has one large air handler (AHU1) that provides a minimum fresh air intake of 600 CFM. It is tied into the sitewide Energy Management Control System (EMCS) and provides heating from site steam to a setpoint of 70°F and cooling to a setpoint of 74°F. The laser room is a class 1000 clean room with a class 10,000 ante-room that runs with a separate HVAC system under local control. It is a recirculated air system that takes in 570 CFM of 'fresh air' from inside Building 729. A compressed air system is also located in Building 729 for air operated equipment such as HVAC control valves, valves on the accelerator, or pneumatic flags on the accelerator. It has a 10 hp 43 SCFM compressor operating at 100 psig filling a 120 gallon storage tank located in the mechanical equipment room.

3.2.5 Communication System

The PA system announcements for Building 729 can be made from the control console. Speakers are located throughout the building to keep personnel informed of any occurrence and status within the building. Additional communication through the Building 725 TV/Audio system will keep all personnel advised of the status of Building 725 and also may be used as a back-up for Building 729 communications.

3.3 Accelerator Systems

3.3.1 Linac

All of the accelerator and beam line components as well as the purchased equipment have been designed to conform to applicable guides, codes and standards. There are no deviations from current DOE design criteria outlined in the documents listed in section 7 of this SAD. Specifications for purchased equipment have undergone thorough design reviews prior to issuing of purchase orders and on site acceptance tests have been carried out.

The linac is a commercially built [1] (Beta Development Corp., Dublin, CA) RF electron linear accelerator of nominal installed maximum energy E_0 = 230 MeV, energy range 40-230 MeV, containing four 3 m SLAC, iris-loaded accelerating sections powered by three 45 MW peak pulsed power Thomson-CSF TH-2128 klystrons operating at the Standard S-band frequency of f_{rf}=2856 MHz. A block diagram of the complete system is reproduced in Section 7 for convenience as Figure 1. The overall length, including electron gun, is 60 feet and the diameter of the vacuum enclosure around the drift tubes is about 125 mm and the beam elevation is 1.4 m (55") above the building floor.

The vendor's stated maximum energy performance capability is [1] 222 MeV + electron gun energy. The nominal performance specifications for the machine are listed in the following table:

CHARACTERISTIC	VALUE
Beam Energy:	Variable from 40 to 230 MeV
Beam Pulse Width:	300 fs to 20 ps
Pulse Repetition Rate:	1-10 Hz in 1 Hz Steps
Energy Spread at 230 MeV:	±1%
Maximum Peak Beam Current:	10 kA (1nC; 100fs Compressed Pulse)
Maximum Average Beam Current:	100A at 10 ps, 10 Hz = 10nA/beam pulse
Vacuum Pressure:	≈10^{-8} Torr at vacion pumps
RF Cavity Input Power Pulse Width:	1.2 μsec flat top
Klystron Peak Power:	45 MW x 3 tubes
Klystron Modulator Voltage:	48 kV

Klystron Modulator Peak Current:	13.0 kA
Maximum Gun Peak Current:	1 kA (eg. 1nC; 1ps)
Gun Energy:	Maximum 8 MeV, 5 MeV nominal

The linac is located along the north wall at the eastern end of Building 729. There is a 44" wide aisle between the linac and a 3 ft. thick shielding wall on the south side (see Figure 4). Modulators, magnet power supplies, beam diagnostic and monitoring equipment are located between this shielding wall and the south wall of the building. There is also a control console and a laser equipment room in this area.

The power is transmitted from the klystrons to the accelerating sections and electron gun via vacuum waveguide and therefore presents no hazard. The klystron tanks and the capacitors in the modulators are insulated with oil that has been certified as containing no PCB above the minimum detectable limits. The high voltage end of each klystron tube is immersed in a tank filled with approximately 150 gallons of mineral oil. The three klystron tanks each reside in secondary containment tanks large enough to contain all of the oil if it is accidentally drained from the klystron tank. The tanks have been registered with Suffolk County in compliance with Article 12 of the Suffolk County Sanitary Code.

Various high field magnets are used in the facility including electromagnets for focusing the beam inside the klystrons, and transport elements for the accelerator. Ion pumps are equipped with permanent magnets. These magnets are generally situated in areas not normally accessible to the general public. Their approximate fields have been measured and are posted as warnings for individuals who have pacemakers.

3.3.2 Laser Systems

The gun cathode is illuminated by the beam from a wide bandwidth Ti:Sapphire regenerative amplifier system. A Ti:Sapp oscillator (Spectra Physics Tsunami, 800 nm, 1.25 W cw) is operated at 81.6 MHz pulse repetition rate that is phase locked to the accelerator timing system. The pump energy for the oscillator is provided by a diode pumped Nd:YVO_4 laser (Spectra Physics Millennia, 532 nm, 5W cw). The light from the oscillator is used as the seed for the regenerative amplifier (Positive Light TSA-50, 50 mJ/pulse, ~800 nm, 50 fs). The pump energy for the amplifier is provided by two frequency doubled YAG lasers operating at 10 Hz (Quanta-Ray GCR 170/150, ~0.85J/0.65J per pulse@ 532nm, 6ns). The amplifier is based on chirped pulse technology, hence the pulse length is adjustable from 0.3 ps to 20 ps by adjusting the stretcher/compressor. The IR light from the amplifier is tripled in a Beta-Barium Borate (BBO) harmonic generation system. The resulting 266 nm UV light is used to stimulate the production of photoelectrons from the gun cathode surface.

The gun laser system is classified as a Class IV laser and is housed in an interlocked room. The light is transported to the electron gun in an opaque beam pipe. The electron gun and the final focus optics table are located in a light tight interlocked enclosure. A photon shutter is located in the laser room that intercepts the beam if the gun hutch door has been opened, or if the gun hutch laser interlock has not been satisfied. In addition to the gun laser, alignment laser systems are also used. Typically these are He:Ne lasers with integrated collimating and steering optics. The alignment laser heads may be up to Class IIIb with beam specifications of less than 5mW @ 633 nm cw.

The delivered beam power from the alignment laser systems will be lower than 5 mW due to attenuation in the delivery optics.

The laser and interlock systems have been designed to conform to BNL SBMS 'Laser Safety' subject area. A detailed description of the interlock system is available in Appendix 7 and the hazards associated with the laser are outlined in the Risk Assessments provided in section 4 of the SAD. Appropriate safety goggles are required for those workers who need to enter the interlocked laser areas in order to make adjustments while the lasers are operating. Adjustments to the high power lasers or transport systems can only be made by personnel who have been trained in SDL site specific laser procedures. Only trained and authorized personnel may work in the laser areas while the lasers are in operation.

3.3.3 DUV-FEL Optical System

This section of the accelerator is where energy from the electron beam is converted into light. The properties of the light produced depend upon the mode of operation, and the characteristics of the electron beam and accelerator optics. For the range of parameters anticipated for the SDL, the DUV-FEL should be capable of producing light at wavelengths ranging from 1000 nm down to 200 nm (in the fundamental) with pulse energies of as much as 0.25 mJ in pulses as brief as 0.1 ps. Harmonic output (down to 66 nm) should be available with approximately 1% or less of the power contained in the fundamental. From the standpoint of safety analysis and facility design, the DUV-FEL output light is regarded as class IV laser light. The stringent precautions for class IV systems (as outlined in the BNL Subject Area) are uniformly applied in enclosing the optical path, and utilizing the light produced by the DUV-FEL.

The DUV-FEL is based on sub-harmonic seeding of the electron beam with a laser to provide a controlled energy modulation in the electron beam. To accomplish this, light from the facility laser will be conducted inside an opaque beam tube from the gun hutch to a small optical table just upstream of the linac dipole spectrometer. The light is injected with an optical periscope and passes through the accelerator vacuum system to a focus inside of an energy modulation wiggler. There the electric field of the laser light couples with the electron beam as it passes through the wiggler. This imparts an energy modulation that must be converted to a spatial or density modulation in the electron beam, which is accomplished with a dispersive magnet, which is a small electromagnet chicane.

Once the beam is bunched it passes into the amplifier wiggler that is tuned to be resonant with the bunching, or a harmonic of the bunching. The light generated in the early part of the amplifier reinforces the bunching at the desired wavelength as the beams propagate through the amplifier. As the density modulation is increased, the intensity of light produced is increased. For this process to work correctly the alignment of the magnetic axis of the amplifier with the optical and electron beam trajectories is critical. For this reason extensive intercepting diagnostics have been built into the DUV-FEL which consist of a series of ‘pop-in’ monitors.

The energy modulation wiggler is the ‘mini-undulator’ with a new gap separation mechanism. This device was used in the NSLS X-ray Ring, and was the energy modulation wiggler for the original High Gain Harmonic Generation (HGHG) experiment at the ATF. It uses $SmCo_5$ magnet material and steel poles. The dispersion section is a purpose built electromagnet also recovered from the HGHG experiment. The amplifier wiggler is known as NISUS (Near Infrared Scalable Undulator System) and was originally built for an Army Strategic Defense Initiative program and transferred to BNL for use in the DUV-FEL. It uses $SmCo_5$ magnet material and vanadium Permadur poles. The properties of the undulators are provided in the following table:

PARAMETER	UNITS	MODULATOR	DISPERSION	AMPLIFIER
Period	mm	80	197	38.9
Number of Periods		10	1	256
Peak Magnetic Field	T	0.35	0.55	0.56
K (Max)		2.6	N/A	2.0
Minimum Gap	mm	31	15	14.4
Overall Length	m	0.8	0.3	10
Clear Aperture	mm	25	11.4	11.4

The amplifier wiggler presents the closest integration of machine and safety requirements in the machine. The gap of the device must be small and a large number of diagnostics must be available to monitor the trajectory, which can be corrected by steering coils embedded in the vacuum system chamber. The magnet structure is in 16 segments which can be adjusted to different gaps at each end using stepper motor driven gear boxes. The top and bottom magnet beams can be independently positioned. As a consequence, the NISUS undulator system includes 16 4-wire corrector magnets, 17 pop-in monitors, 34 stepper motors, 34 linear variable differential transformer (LVDT) position sensors, and 134 limit switches. The device is complex with many requirements for stability and survey accessibility in addition to all of the connections and data channels. For this reason the shielding system is closely coupled to the undulator structure to minimize its size and weight. It consists of fitted lead and 5% borated polyethylene segments built around the undulator structure, and is described in more detail in section 3.4.

The light from the FEL will be coupled out of the radiation enclosure by a pair of mirrors that bring the optical beam well below the electron beam height before exiting the enclosure. The objective of this configuration is to contain any possible brehmsstrahlung within the radiation enclosure. Initially a pair of flat mirrors at 45° incidence will be used in a standard periscope configuration, bringing the optical beam from the electron beam height of 1400 mm to 970 mm. As the light produced by the FEL progresses to shorter wavelengths, a grazing incidence system will be installed to improve the efficiency of the beam transport. The same nominal height displacements will be used.

The following table provides parameters for four representative operating configurations of the

DUV-FEL.

PARAMETER	UNIT	I	II	III	IV
FEL Output Wavelength	nm	400	400	200	100
Seed Wavelength	nm	-	800	400	300
Linac Energy	MeV	145	145	205	290
Operation Mode		SASE	HGHG	HGHG	HGHG

Operation at wavelengths shorter than 200 nm will require implementation of the linac energy upgrade by the addition of a new accelerating structure and additional RF power. The space for these devices is anticipated by the current machine configuration.

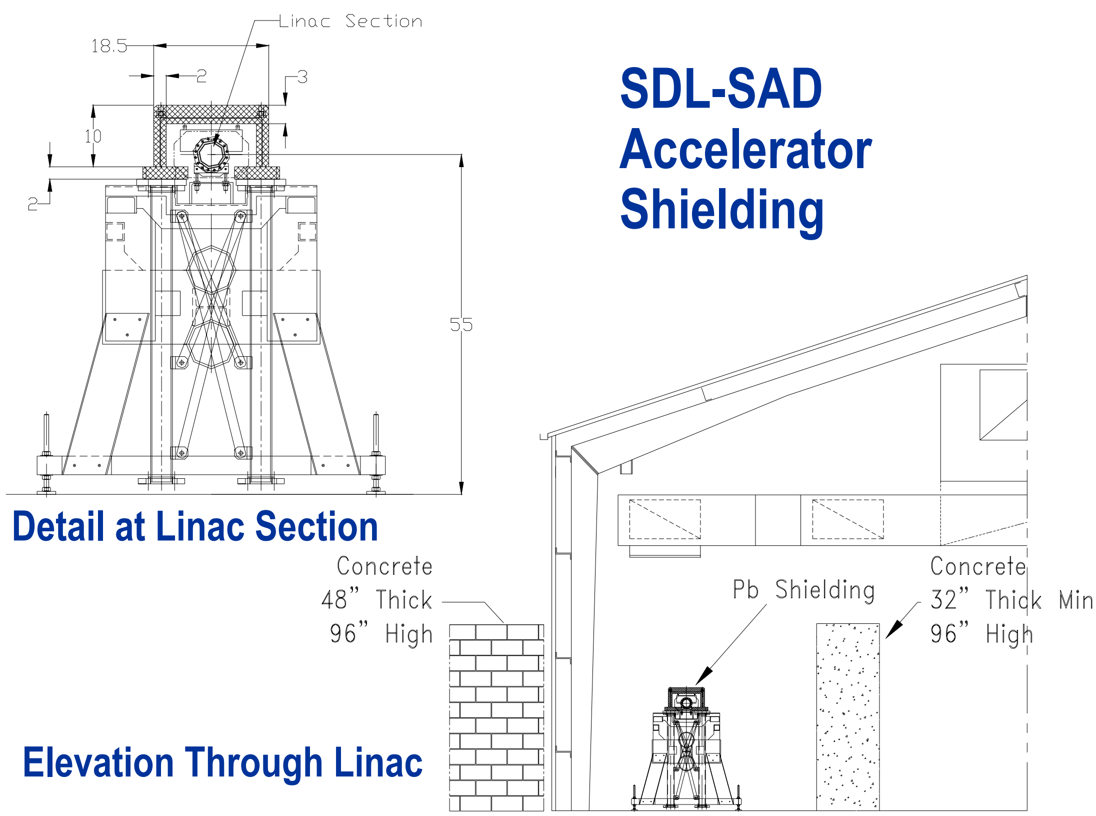
3.4 Radiation Protection Systems

3.4.1 Shielding

Shielding requirements for the facility are based on a maximum average current of 20 nA (1.2×10^{11} electrons/sec) at a maximum energy of 300 MeV. Radiation loss modes are discussed in Section 4.6 of this report and shielding requirements were determined as part of this analysis. This section provides a detailed description of the shielding in place as shown in Figures 4 and 5. For lead shielding standard bricks (2x4x8") are used along with several types of precast lead structures. All of the lead castings were manufactured and painted by Nuclear Lead (Oak Ridge TN). They are also stenciled with the corresponding drawing numbers and their lifting weight. Installation and handling of lead in the SDL will be performed using methods consistent with the ES&H guidance from the NSLS PRM 6.2.0 Lead Working Guidelines.

For long runs of relatively small cross-section, inverted “U” shaped lead covers at least 2" thick on the sides and 3" thick on the top are used. These covers have interlocking ledges on the open ends, so when stacked end to end they form a continuous shielding tunnel.
Threaded sockets were cast into the covers so they can be lifted with the building crane (they weigh approximately 400 pounds each). Stands with aluminum plate shelves were built along side of the

accelerator to hold these covers. Depending on the height of the components they cover, lead bricks were stacked underneath the covers to adjust the elevation as required. In all locations at least one layer of brick is used beneath the covers on each side (2" high) with the bricks placed facing the centerline of the accelerator. This allows only x-rays directed to the floor to escape the lead shielding assembly. The configuration is illustrated in the thumbnail sketch below.



This shielding strategy is used over the full length of the accelerating linac structures and the small cross section transport lines. In locations where the accelerator cross-section is larger, frames were erected to support precast sheets of lead that are at least 3" thick. In several instances the thickness of the lead is more than required for shielding and was determined by structural strength requirements of the cast plates to avoid sagging or deformation when installed.

These larger tunnel structures are built around the bunch compressor and the area downstream of the linac that includes the transport line, beam dump dipole magnet, energy modulator, and dispersion section. Each of the plates or assemblies was sized to be within the load limit of the building crane (2 tons). Special lifting fixtures were used to install the sidewalls of the enclosures that extend north of the linac centerline (past the crane hook limit). Essentially a pair of sidewall panels are lifted simultaneously with their center of gravity at, or south of the linac centerline. Three other areas of the linac have unique shielding configurations; the gun, the Faraday cup beam dumps, and the amplifier undulator.

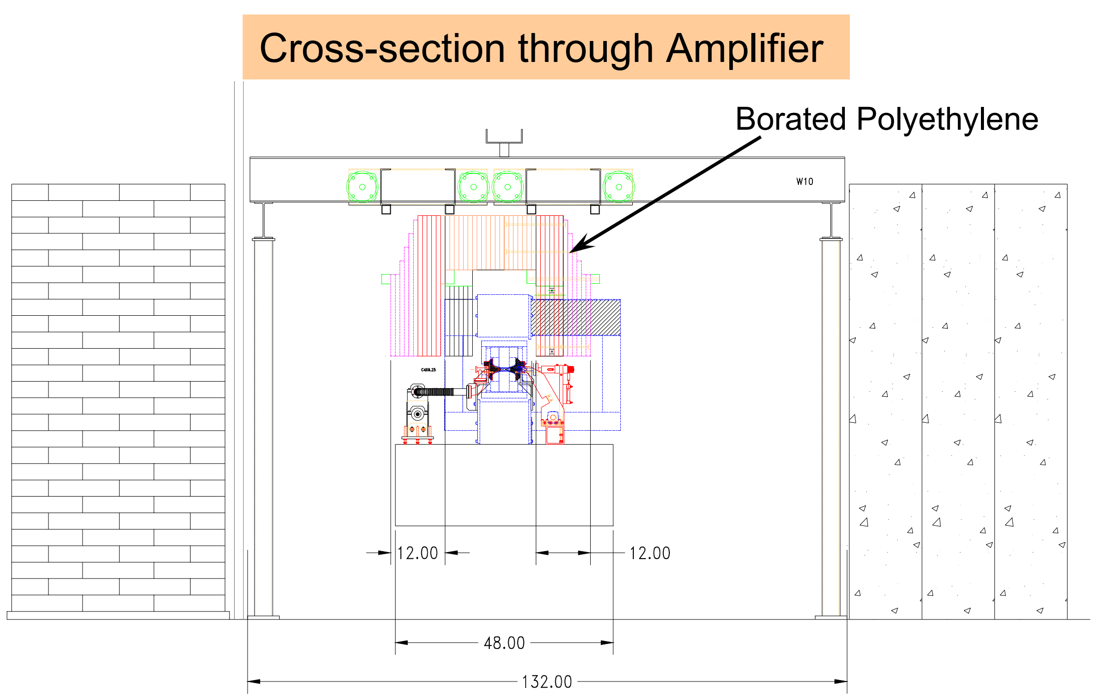
A lead shielding enclosure has been built around the electron gun area. Inside the gun hutch, a separate support structure has been installed that has an aluminum roof with a layer of lead bricks on it over the gun, solenoid, and diagnostic area extending over the start of the first accelerating tank which is shielded with the precast covers. This insures a minimum of 2" of lead shielding above the gun. The north wall of the enclosure is shielded with an assembly of strips of lead 1" thick with overlapped seams to provide a minimum transverse lead thickness of 2" on this wall.

The south wall and east (back) walls of the gun enclosure are actually buckets on rails that can be lowered to ground level to allow servicing of the gun area from two sides. The buckets are filled with lead bricks arranged to provide at least 2" of lead shielding. The lifting is accomplished by permanently installed screwjacks that run through a gear reduction box. To move the shield walls a drill motor is employed. The reduction ratio is sufficiently large that the shielding can not lower itself from its own weight. When the lead curtains are in place, cross pins are installed through the support stand to protect against accidental lowering of the shielding.

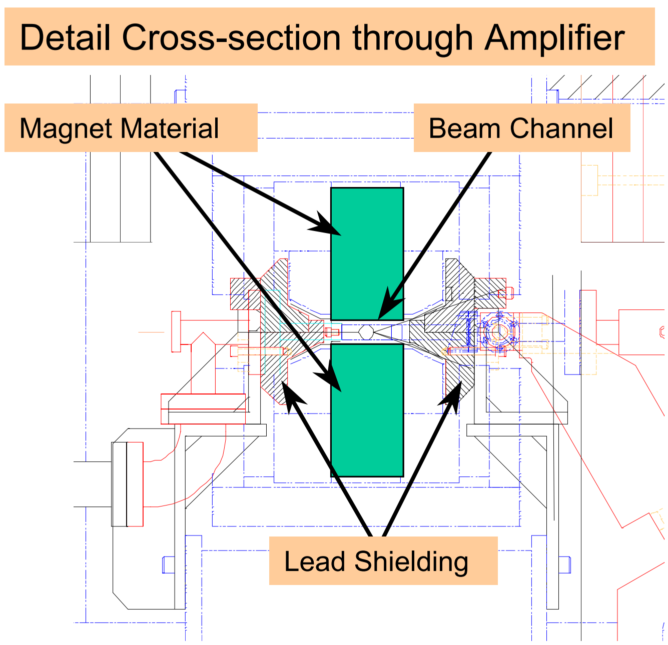
The east gun shield wall also has a shelf with a stack of lead bricks (12" by 12" by 8") centered on the beam to attenuate any high energy x-rays that might be produced in the accelerator and directed back toward the electron gun. The longitudinal lead thickness provide by this arrangement 10".

The beam dumps for normal operations are identical aluminum Faraday cups that are very heavily shielded with lead. At each Faraday cup, an extra layer of lead brick is stacked underneath the transport line covers (inverted U castings) providing an additional shielding thickness of at least 2 inches (transverse and longitudinal). In the forward direction another large stack of lead brick (12" thick, 24" wide, 16" high, centered on beam) is installed to provide a total thickness of 14" longitudinal lead for attenuation of x-rays.

The radiation shielding around the amplifier undulator includes fitted lead castings and large borated polyethylene blocks as shown in the cross section sketches below.



On each side of the undulator, the fitted lead castings are in an upper and lower part supported by the table. The magnetic structure is comprised of Samarium Cobalt magnets and Vanadium Permadur pole pieces. Since these are high Z materials, their value as x-ray attenuators was included in the shielding analysis. To provide neutron shielding above the amplifier, large blocks of borated polyethylene were assembled from sheet stock and supported by an overhead rail system. These blocks can be shifted away from the amplifier for servicing.



The general philosophy of using large structures to accomplish the lead shielding was based on the desire to make servicing less difficult, since large areas of the shielding can be easily removed. Their size and therefore comparatively small number also makes it more readily apparent when a piece is missing or out of place. This helps to ensure that the shielding checklist can be easily and correctly followed.

The design for the concrete enclosure follows a similar design philosophy. Rather than using individual blocks stacked by hand, large precast shielding blocks are used for most of the accelerator vault wall. The shield blocks are 16" by 30" by 96" and made from 'normal' structural concrete. They have internal reinforcing rods and metal edges on the two smallest surfaces. Lifting knobs (attached to the rebar) are cast in sockets in these small surfaces on both ends as are a pair of threaded steel sockets (a total of four holes). A special lifting fixture is used to place the blocks with the building crane. Their odd size was set by the need for an 8 foot high wall and weight restriction set by the 2 ton building crane.

When they are used to form the wall several layers are used, and the joints between them are bond stacked so there are no direct gaps through the entire shield wall. The blocks are secured to each other on top with steel straps that are bolted to the blocks using the cast in place threaded sockets. This significantly improves the resistance of the wall to upset (tipping over). Four of these blocks are also placed around each beam dump to provide attenuation of neutrons from the routine loss of beam at this location.

For the eastern 20 feet of the shielding inside the building, hand stacked concrete block was used to build the wall, since this area is beyond the reach of the crane. Hand stacked block was also used to form the exterior shield wall which has a minimum thickness of four feet, and is stacked to a height of eight feet.

3.4.2 Radiation Security

A number of measures have been taken to ensure that workers are not exposed to radiation fields produced by accelerator operations. The concrete shield wall is fitted with a system of interlocks and warning indications that, when coupled with personnel training, will prohibit access to the accelerator when it is possible to operate the machine and potentially produce radiation. Entry to the linac/experimental region is through one of two doors, each of which gives entry via a labyrinth. One door is near the electron gun at the east end of the building and the other near the beam analysis system near the middle of the building. Two separate interlock chains are provided that turn off the power to the electron gun and linac modulators if either of the doors are opened. This radiation security system is consistent with the requirements of BNL ES&H standard 1.5.3 "Interlock Safety for Protection of Personnel" and the BNL Radiological Control Manual Appendix 3A.

The doors are also provided with a Kirk key system. In order to gain access to the area, the door key(s) must be rotated and removed from the Solenoid Release Unit. This key can only be removed if the linac high voltage power supply is turned off. The key is then used to unlock the area door and is held captive in the lock until the door is again closed and locked. The interlock system is tested and certified at 6-month intervals.

Prior to operation the operators will be required to secure the linac and experimental area utilizing a formal search and secure procedure [Appendix 6]. In order to ensure a proper search, reset buttons are provided which require that the person carrying out the search covers all regions of the search area. The buttons must be reset in a prescribed sequence and in a prescribed time. The person carrying out the search will enter and exit through the door situated adjacent to the electron gun. After exiting and locking the door, the Kirk key for the entry door must be returned to the Solenoid Release Unit and rotated which sets off an annunciator in the areas for 15 seconds. If anyone for any reason wishes to stop operation, they may do so by depressing any of a number of emergency stop buttons situated through the facility at convenient and clearly marked locations. Both doors are interlocked and keyed in the same way and both are provided with an emergency panic release system to allow fast exit in an emergency. If either of the entry doors is opened while the search procedure is in progress the search is automatically aborted and has to be restarted. The Radiation Security System is described in detail in Appendix 6.

To make certain that personnel are aware of the status of the accelerator, beacons, strobes, lighted signs and postings are provided. When a search of the accelerator vault is initiated, five strobe lights begin flashing that are positioned next to signs stating: "Warning, Search of Enclosure in Progress when Flashing". Four of these strobes are located inside the accelerator vault enclosure and one is located inside the gun hutch. When the search has been successfully completed the strobes turn off, and nine beacons located at the top of the shield wall inside the enclosure are illuminated. The signs next to the beacons state: "Enclosure Secured when Flashing, Press Emergency Stop".

This notifies any individual inside the enclosure that they should break security by pressing any one of the fourteen emergency stop buttons (including 1 in the gun hutch) to stop potential accelerator operations.

On top of the wall next to each beacon, but not normally visible from the floor outside the enclosure are signs stating: "Warning, Enclosure Secured When Flashing, Access Prohibited". These signs are placed as a last notification to a person trying to go over the enclosure wall when the enclosure is secured. This is unlikely since there are distributed along the outside wall fourteen readily visible security status signs with warnings. Each has a permanent sign stating: "Warning, Do Not Climb on Wall when Sign is On", next to signs that illuminate when the enclosure is secured that state: "Warning, High Radiation Area Above". In addition, at the two entry doors to the enclosure there are signs that illuminate when the area is secured stating: "Interlocked".

This elaborate information and warning system was installed in recognition of the fact that the enclosure has no physical barrier to prevent entry from the top by climbing over the wall. The placement of the signs and beacons was done in a manner that would deter personnel from climbing the wall. If the signs outside the wall were missed or ignored, on climbing to the top of the wall an individual would see flashing beacons that are not normally visible next to signs telling them access is prohibited.

A security system is also in place for the Ti:Sapp laser system which is classified as a Class IV laser as per BNL ES&H Standard 2.3.1. All entry doors to laser equipment rooms are electrically interlocked so that unauthorized entry will cut power to the lasers. There are also manufacturer provided lock-outs for the laser power supplies. The procedure for securing the laser room is similar to that of the radiation security system for the linac. There is a timed prescribed search path and reset button as well as emergency off buttons. However, in order to provide the capability for tuning the laser, it is possible to secure the area with properly trained and protected personnel inside the laser room and gun hutch. An opaque beam pipe encloses the beam path between the laser room and the electron gun. A detailed description of the Laser Security System is provided in Appendix 7.

3.5 SDL Safety Program

3.5.1 Introduction

Responsibility for safety of the SDL lies with the SDL Project Manager. The SDL project is administratively a part of the NSLS Department and, as such, is under the umbrella of the existing NSLS safety organization. The Department has a strong commitment to safety in the operation of its accelerators and beamlines as evidenced by the central position of the safety group in the NSLS organizational chart. The NSLS Environment, Safety and Health (ES&H) Coordinator, and the NSLS Safety Officer report directly to the Associate Department Chairman for ES&H/Q and are assisted by a full time safety engineer and three representatives of the Radiological Control Division. In addition, the Department maintains an Environment, Safety and Health Committee which acts in an advisory capacity to the NSLS Chairman.

The overall organization at the NSLS for safety is defined in Appendix 2. The NSLS safety policies and procedures are detailed in the NSLS ES&H Policies and Requirements Manual (PRM) [2]. The Source Development Laboratory is included as part of the NSLS Emergency Plan. Any unreviewed safety issue (USI) which presents a significant safety consequence will be thoroughly analyzed and processed as described in the Accelerator Safety Subject Area. Operations affected by the USI will not be performed until a review process has been completed.

3.5.2 Internal Safety Review

The project safety committee is the NSLS ES&H Committee and as such, has reviewed this SAD for the Source Development Laboratory. In addition, the Department conducts quarterly Tier I safety inspections of the facility as outlined in the NSLS PRM 1.2.0. In ongoing or future reviews of the SAD, the standards of NSLS PRM 1.2.0 or its successor documents will be applied.

Within the SDL, the Project Manager will bear primary responsibility for the safe conduct of operations of the accelerator and the associated building support facilities. The NSLS ES&H staff will assist him in these duties. In addition to input from the project technical staff and advice from the NSLS ES&H Committee, the Project Manager will be informed and act upon safety concerns conveyed by the NSLS area safety representative for building 729 appointed by the Department ES&H Coordinator. The area representative has direct responsibility for bringing safety concerns to the attention of the Project Manager and the NSLS ES&H Coordinator. The NSLS has a Beam Line Review Committee whose responsibility is to review new beam lines and ensure that NSLS and BNL ES&H standards have been properly applied to each beam line.

3.5.3 External Reviews

The Laboratory Environment, Safety and Health (ES&H) Committee is required by BNL policy to review this SAD and make a recommendation to the Deputy Director for Operations. Prior to commissioning and final operation, an accelerator readiness review (ARR) will be conducted to ensure that all technical, management, and training requirements have been met. The Deputy Director's approval and that of DOE is required before operation can begin.

The Accelerator Safety Subject Area also directs the ESH/Q Directorate to assist the Department in developing the SAD and in conducting an internal review of the document using ESH subject matter experts as appropriate, prior to its submission to the Laboratory ES&H Committee. In addition, ESH/Q personnel assist the Department in implementing the Laboratory safety program and in training NSLS personnel in safety matters.

3.5.4 Safety Training

The ESH/Q Directorate regularly schedules training programs in areas such as the use of respirators, crane operations, materials handling, personal dosimeter usage, etc. as may be requested by personnel to perform their job assignments. However, there are several topics related to the SDL facility which will require specialized training such as electrical, laser, radiation and radio-frequency safety. Written procedures for securing radiation areas are provided (Appendix 6). Written instructions on safe operation of high voltage power supplies are required for modulators, and vacuum pumps as well as potentially hazardous high current power supplies for the DC magnets in the linac. These will be provided to operations and maintenance personnel by line supervisors with the assistance of cognizant project engineers who will also provide training to carry out these procedures.

3.5.5 Experimental Operations Safety

Operation of the Linac will require a minimum of two trained personnel, at least one of whom is a fully qualified operator. The other individual must be qualified, as a minimum, to shut the machine down and respond to emergency conditions within the facility. The training to become an operator is determined by the accelerator manager (or designee) who will qualify operators by on the job training and challenge examinations. The outline of the qualification process is as follows:

At a minimum, qualified operators will
1. Become proficient in the operation of the linac personnel interlock system - become certified to sweep and secure accelerator vault.
2. Learn where the crash buttons are - emergency power shut-down.
3. Learn layout and indicated levels of SDL ionizing radiation monitoring system.
4. Study and train on the operating system.
5. Become familiar with component and indicator layout in the control area.
6. Be trained in laboratory and SDL emergency response procedures.

Before an operator is certified, on the job training will take place to learn:
1. Controlled turn-on and shutdown sequences of accelerator components.
2. Operating ranges of accelerator components and normal operating conditions.
3. Sequence of steps for resetting trips.

Basic SDL Operator Duties are:
1. Search and secure the accelerator vault.

2. Operate the accelerator and laser systems.
3. Maintain a log of machine status, trips, and special or unusual operating conditions.
4. Shut down any part of the facility within their area of control that may present a safety hazard until that hazard has been removed.

As detailed operational procedures are developed they will be added to the SDL Conduct of Operations Manual for reference in training personnel at the SDL.

The experiments to be carried out at the SDL are either located in-line with the accelerator using the electron beam directly, or will extract optical radiation for analysis. Only one experiment may be carried out at any given time and the electron beam, after passing through the experimental apparatus, will be analyzed and/or dumped. The experimental region within the enclosure is secured as part of the linac security system and cannot be occupied while the linac is operating. Some experiments will be performed using light that is transmitted through the shielding enclosure in areas adjacent to the shielding. Every experiment prior to its installation at the SDL will undergo an Experimental Review carried out by the NSLS Experimental Review Coordinator. The review requirements are given in Appendix 5. This assessment is made to assure that the operation of an experiment will not present any safety or environmental hazards that are not properly controlled.

3.5.6 Radiation Monitoring

The SDL is a radiologically controlled area, and all personnel working at the SDL are required to wear thermoluminescent dosimeters (TLDs). Radiological Control personnel assigned to NSLS provide routine radiation monitoring. In addition TLD's are located at appropriate locations around the facility, outside the shielded area.

These are read and recorded periodically and NSLS safety personnel maintain a database that is regularly evaluated by the NSLS ALARA committee. In addition a number of real-time radiation monitors are used where accidental or unusual operations conditions could give rise to some radiation. Although significantly elevated radiation levels are not anticipated during machine operation, real time radiation monitors (Chipmunks) have been provided in several areas to monitor ambient radiation levels in occupiable areas. The alarm levels for these monitors will be adjusted to ensure prompt detection of radiation faults consistent with NSLS procedures.

SAFETY ANALYSIS 4

Risks associated with the various hazards identified in Section 3 are reviewed in this section. The following hazards are specifically addressed: environmental and hazardous waste issues; fire safety, natural phenomena, electrical safety; exposure to magnetic or electromagnetic radiation, and ionizing radiation. Summary risk assessments for the described hazards are given in Appendix 8.

4.1 Environmental and Hazardous Waste Issues

The operation of the SDL will not create significant environmental releases or generate significant quantities of radioactive or hazardous wastes. The activities at the facility will utilize small amounts of chemicals and will generate minimal hazardous waste (<5 gallons/year). There are no routine discharges of liquids to the environment. Maintenance of the cooling systems is not expected to result in the generation of hazardous wastes.

Operations at SDL will also not generate any significant airborne radiological releases. The electron beam will not traverse an air path anywhere in the system under normal operating conditions. Small quantities of airborne radioactivity will be created during operations, but do not result in either significant building or environmental releases (see section 4.6.2) Very small and inconsequential quantities of ozone are produced (see section 4.7).

A NESHAPS (National Emissions Standards for Hazardous Air Pollutants) evaluation for the 230 MeV linac has been conducted by the Environmental Services Division and is included here as part of Appendix 4.

In addition, operations at the SDL will not generate detectable levels of tritium in cooling water nor significant levels of tritium in the soil below the building (see section 4.6.2). A NEPA Environmental Assessment was prepared for the predecessor of the SDL: "*Construction and Operation of a Support Facility (Building 729) for Operation/Testing of a Prototype Accelerator/Storage Ring (XLS) and Machine Shop for the National Synchrotron Light Source at Brookhaven National Laboratory, Upton, NY; June 1992; DOE/EA-0602.*" DOE approved this Environmental Assessment and a Finding of No Significant Impact (FONSI) was issued on July 2, 1992. The BNL NEPA Coordinator reviewed this EA and the current SDL configuration in June 1997. This review concluded that " … the proposed activities have been effectively evaluated in a current NEPA document and no additional documentation is required in accordance with 10 CFR 1021 and DOE Order 451.1." This documentation is found in Appendix 4.

4.2 Fire Safety

A detailed "Life Safety Code Analysis" and a Fire Assessment/Fire Analysis Report have been prepared by the BNL Fire Protection personnel and are included as Appendix 1. The level of fire protection in the SDL is classified as an "improved risk", thereby meeting the objectives of DOE Order 420.1. While the SDL is considered a high value property, the noncombustible construction of the building and the accelerator is expected to keep the dollar loss expectancy from any credible fire to below $250,000.

4.3 Natural Phenomena

The SDL has been evaluated for Natural Phenomena Hazards (NPH), utilizing the criteria of DOE Order 6430.1A "General Design Criteria" for wind, flood, and earthquake design criteria. DOE Order 5470.28 "Natural Phenomena Hazards Mitigation" and its associated standards were used as guidance for this evaluation. Details of the site geography, seismology, meteorology, hydrology and demography are contained in "DOE Accelerator Order 5480.25 Implementation Plan for BNL

Natural Phenomena Hazards Evaluation" April 25, 1994 by Steve Hoey.

The probability of an earthquake sufficiently intense to damage buildings and reactor structures was thoroughly investigated for this site during the construction of the Brookhaven Graphite Research Reactor (BGRR) and revisited in 1999 as part of the Hazard Classification and Auditable Safety Analysis for the BGRR Decommissioning Project. The most recent evaluation shows that BNL falls into an area where the acceleration velocity is slightly less that 0.10 g, and thus has been classified as a "low" seismicity zone. This classification has been agreed to by DOE during the course of the recent project of implementing Executive Order 12941, "Seismic Safety of Existing Federally Owned or Leased Buildings," as documented in a BNL memorandum, DeBobes to Helms dated May 28, 1998, "Phase 2,3, and 4 submittal for Executive Order 12941." As was the case in the original BGRR review and subsequent examinations of the High Flux Beam Reactor, it is the consensus of seismologists that no significant quakes are to be expected in the foreseeable future. No active earthquake-producing faults are known in the Long Island area.

The SDL is designated as an Accelerator Facility. It does not contain significant quantities of radioactive or chemical materials. Should an NPH event cause significant damage to the SDL, the impact would be mission related and not create a hazard to the public or the environment.

4.4 Electrical Hazards

The klystron/modulator system is used to provide the high power pulses of radio frequency energy to the electron gun and accelerating structures. The modulator consists of a high voltage DC power supply used to charge a pulse-forming network (PFN) to about 40 kilovolts. A thyratron tube is used to discharge this PFN into a high voltage step-up transformer to deliver a pulse of power to the klystron. The modulator, step-up transformer, and klystron are bolted together to form a single enclosure. Three identical klystron systems are used. All of the klystron/modulator assemblies are locked and interlocked to allow both administrative control and interlock protection. Only trained and qualified personnel will service these assemblies.

Several electromagnets are powered by low voltage direct current power supplies that are interlocked because of the possible large short circuit currents, and because of the primary power distribution system in the power supply enclosures. Control of plant and accelerator security as well as operation control of the accelerator is performed at low voltage wherever feasible (<24 volts). No exposed voltage or hazards are present in this equipment. These systems all use conventional equipment and do not represent any unusual hazards. All SDL electrical equipment conforms to the existing codes and regulations.

4.5 Non-ionizing radiation

4.5.1 RF

The emission of non-ionizing radiation is controlled to prevent the radio frequency power generated by the klystrons from interfering with low level instrumentation or from providing a source of personnel hazard. Each klystron is capable of producing a peak power of 45 Megawatts at a frequency of 2856 MHz.

Normally the requirements for preventing interference with sensitive monitoring equipment are much more restrictive than those required for personnel protection. The radio frequency output power is confined to the vacuum enclosure of the klystrons, feed waveguides, and accelerator structures which provides a redundant safety protection system. A break in the vacuum integrity of any of these systems would immediately trip the system interlock. Further, the loss of vacuum would also remove the insulation the system requires to continue generating this power. Thus, the high power radio frequency fields are contained within the system's waveguide or accelerating cavities and do not present a significant exposure potential. Surveys as described in ESH Standard 2.3.2 "RF and Mircowaves" have been made which confirm that RF fields are well within the limits defined by the American Conference of Governmental Industrial Hygienists (ACGIH) and OSHA.

4.5.2 Magnetic Fields

The ACGIH recommends that people with cardiac pacemakers or other medical implants not be exposed to magnetic fields exceeding 5 Gauss (0.5 milliTesla). Magnetic fields in excess of that limit are not accessible to personnel in normal work areas. Magnetic fields are surveyed as described in the SBMS Subject Area 'Static Magnetic Fields'.

4.5.3 Lasers

Conventional Helium - Neon laser systems (up to Class IIIb) may be used for alignment purposes. The titanium sapphire (Ti:Sapp) laser system used to excite the electron gun cathode is comprised of three Class IV laser sources. A 5W CW Nd:YVO_4 laser pumps a Ti:Sapp oscillator that feeds a Ti:Sapp regenerative amplifier. The pump energy for the amplifier is provided by two pulsed Nd:YAG lasers operating at 10 Hz and producing 650 and 850 mJ in the green. The regen output is frequency amplified into the UV which is relayed to the gun enclosure.

A second beam for the purpose of seeding the High Gain Harmonic Generation FEL will also be derived from the Ti:Sapp laser and transported to the gun hutch. From there it will be relayed along side of the linac to an optical table just downstream of the linac.

Stability and timing requirements necessitate the laser light be relayed though controlled environments. The transport line between the laser room and gun hutch is a stainless steel vacuum pipe. Similar enclosed beam paths will be utilized for transporting Class IV laser light. In normal operation the laser components are themselves covered on their tables to improve stability. However, there may be times during setup when the light will not be enclosed on the tables, and at these times only trained laser users wearing appropriate protective eyewear may be inside the special interlocked enclosures used to contain the laser light. The integrated system is effectively a Class IV laser as defined in BNL ES&H Standard 2.3.1, and is operated as required by that document and the NSLS PRM 2.3.1. The FEL laser beam created by the NISUS undulator is expected to operate in the Class IV power level and will also be subject to the requirements and controls specified in BNL and NSLS standards.

4.6 Ionizing Radiation Safety Hazards

Ionizing radiation hazards associated with a 300MeV, 20 nA electron beam are significant and must be carefully considered. The electron beam is accelerated and transported within vacuum systems, and is terminated in a specially designed dump. However, during normal operation, a small fraction of the beam may strike the side of vacuum pipe or flanges and produce secondary fields of photons or neutrons. These losses can occur in the electron gun region, in the linac tanks or in transport regions. Analyses are also necessary for higher intensity beam losses that can occur during abnormal operation as the result of miss-steering or other equipment malfunction. The methodology for calculating source terms and shielding effectiveness are described in depth in Appendix 9.

Calculations are also performed for radiation emitted upward that is scattered back into work areas (skyshine). The methodology for skyshine calculations is described in Appendix 10.

Specialized Monte Carlo calculations were also performed by a shielding physicist (P. Degtyarenko) from Thomas Jefferson National Accelerator Laboratory using DINREG (a nuclear fragmentation model) [21] and a Monte Carlo transport code "GEANT" [22]. A summary of the analysis is provided in section 4.6.4.

4.6.1 Prompt Radiation Hazards Under Normal Operating Condition

High energy electron interaction in matter produces x-rays. During normal operation, several sources of electron losses in vacuum pipe or other beam line equipment are present:

- "Dark current" electrons are generated by the high electric fields in the RF gun and linear accelerating sections. The tune and focus of the accelerator is set for electrons generated at the photo cathode, so dark current electrons are primarily lost early in the acceleration cycle, and therefore at lower energy.
- Electrons near or outside the edge of the acceptance region during transport will be accelerated non-synchronously and will be lost either along the accelerator itself or in transport elements after the accelerator or in the magnetic pulse compressor situated after the first two accelerating sections.
- Beam profile monitors are placed at many locations within the accelerator and transport lines to assist in the set-up and monitoring of beam transport parameters. These monitors are "thick" and essentially produce a full beam loss when the monitors are in use. Use of these monitors is limited to beam set-up and is primarily performed at low beam intensities.
- All accelerated beam is terminated in a specially designed dump at one of the two locations described in Section 3.4.

At energies above 10-20 MeV electron losses also give rise to neutrons, generated by the photons produced by electrons stopping in lead shielding, beam pipe or bending magnet yokes. The magnitude of these electron losses and the associated radiation fields are estimated below.

4.6.1.1 Electron Gun Operational Losses

Photon radiation sources can be produced in the electron gun from losses associated with "dark current" or from photo-cathode beam current that strike surfaces within the gun. The electron gun is shielded with a minimum of 2 inches of lead vertically and horizontally as described in section 3.4.1. On the east wall, to guard against electrons accelerated in reverse down the beam line, a 10 inch thick lead stop is positioned. In addition to the lead, there is a minimum of 4 feet of concrete along the north, south, and east portions of the electron gun region. There is a minimum distance of 3 meters from the source to an accessible area in each direction. Each source is evaluated.

a) Operation of the electron gun has shown that up to 10 nA of electrons can be produced as **"dark current".** Some fraction of these electrons can be accelerated axially, in the forward direction up to the maximum energy of the electron gun (~ 6 MeV) for a fraction of each RF cycle during the 1.5 μsec RF pulse. "Dark current" electrons can also be accelerated in the reverse direction during the reverse part of each RF cycle.

   Dose rates produced by this source will be highly dependent on the final energies of the electrons. Assuming that 10 nA is lost, and using the methodology described in Appendix 9, this shielding configuration reduces radiation levels from electron gun operation to 6 μR/hr outside the north and south wall and 0.2 μR/hr outside the east wall.

b) Losses of some or all of the 20 nA beam current generated by the electron gun can occur at the following locations prior to acceleration in the linac:

   - At an intercepting beam monitor situated before the linear accelerator sections can create losses of $\approx 1.25 \times 10^{11}$ electrons per second at energies up to 6 MeV. Using these assumptions and the methodology described in Appendix 9, the dose rate outside the shield from this loss can be shown to be 12 μR/hr.

   - Losses can also occur due to miss-setting of the transport line solenoid magnets or trim dipoles. The latter would give rise to a loss of beam over a line source downstream of the miss-set device which could give rise to a full beam loss of up to 1.25×10^{11} electrons per second over a length of $\approx$50 cm at an energy of up to 6 MeV.

Because this loss is more distributed than a point source, radiation levels from this source will be less than those calculated in (a) above.

- Up to 10% of the photo-cathode beam (1.25×10^{10} e/s) may be lost during normal operation prior to acceleration in the first section due to transport losses in this region. Radiation levels from this source will be about 10% of those calculated in (a) above.

4.6.1.2 Linear Accelerator Area

The linear accelerator normally operates with minimal losses for the beam produced from the photo-cathode following tuning at start-up to ensure proper beam steering and correct phasing and amplitude in each of the accelerating sections. The accelerated beam is small compared to the dimensions of the vacuum pipe and can be easily controlled. However, for the purpose of analyzing the adequacy of the shielding over an extended operating cycle, we make a conservative assumption that the machine routinely operates with beam losses at a thick target averaging 2 % of the accelerated beam. This rate is far in excess of normal routine operating losses for this machine when properly tuned.

Since the electrons are increasing in energy as they proceed through each accelerating section, the electron energy at the point of loss depends upon its location. As configured, the electrons enter the first section at an energy of ~ 6 MeV and increase ~ 32 MeV in each of the first two sections, and 65 MeV in each of the next two sections. At a future time, additional accelerating sections are planned to increase the energy to 300 MeV, which is assumed in these calculations for all portions of the transport line beyond the first dipole bend.

In the accelerator and transport line, there is a minimum of 2 inches of lead shielding horizontal to the beam and three inches of lead shielding vertically. The concrete shielding is four feet thick at all locations along the North Wall of the accelerator. Along the south wall, the concrete is 32 inches thick up to the near the end of the 4^{th} accelerating section, beyond this point the south wall has a minimum thickness of 4 feet of concrete. The distance to the exterior of the outer wall is 3.2 meters and 2.7 meters to the nearest accessible area on the interior. Assuming proper tune of the beam, electron losses can occur due to the dark current, use of beam profile monitors, or from such phenomena as residual gas ionization, arcing within the tanks and secondary emission. We also calculate a 2% chronic loss of the beam at a thick target. The radiological consequences of each source of electron loss are analyzed separately:

a) Dark current electrons will be primarily lost in the first accelerating sections or in the pulse compression chicane at a maximum energy of 70 MeV. Experience has shown that about 50% of the dark current will be lost in the first two accelerating sections with the remainder lost in the chicane. If the machine is operating without the chicane during commissioning, any remaining dark current electrons will be distributed in the remaining accelerating sections and dipole bends.

Using the methodology shown in Appendix 9, we can calculate the dose rate from photons through the north wall to be 140 μR/hr assuming that 5 nA of dark current is lost at 70 MeV at a thick medium Z target. The dose equivalent rate from neutrons produced by this loss is calculated to 0.5 μRem/hr through the north wall.

Using the same methodology and assumptions, we can calculate the dose rate from photons through the interior south wall to be 1.2 mR/hr. The dose equivalent rate from neutrons produced by this loss is 14 μRem/hr through the south wall. In addition, scattered radiation over the concrete shielding (skyshine) was evaluated using the methodology of Appendix 10. Photon dose rates at the console assuming 5 nA lost at a thick target are calculated to be 100 μR/hr. Neutron dose rates within the building from such a loss are estimated at 140 μRem/hr.

These predicted dose rates are of concern and would require additional local shielding to control exposures within the building to maintain exposures ALARA and consistent with the SDL administrative control levels. However, during commissioning of the SDL, dose rates through the wall or from skyshine of this magnitude have not been observed, indicating that the dark current is being lost at energies lower than 70 MeV and that the losses are more distributed in the accelerating section as opposed to loss at a single point assumed in the calculation. Radiation levels associated with dark current losses will continue to be monitored and additional local shielding provided should conditions change.

b) Beam profile monitors are inserted into the beam during tuning to permit observation of beam size and shape. These "pop-in" monitors constitute a thick target and produce a full beam loss at that location. Use of monitors during routine operation is limited to set up and tuning, and normally is performed with greatly reduced beam intensity. Although “pop-in” monitors are utilized to study the beam at different energies, for this analysis we will assume an energy of 230 MeV. Loss of 300 MeV electrons on the “pop-in” monitors is reviewed in the NISUS section of the SAD.

We assume that 20 nA 230 MeV electrons are striking a thick, medium Z target. Using these parameters and the methodology of Appendix 9, we calculate the dose rate from photons to be 0.6

mR/hr through the exterior north wall and 6 mR/hr through the interior south wall. We calculate the dose rate from neutrons to be 0.75 mRem/hr through the north wall and 4.3 mRem/hr through the interior wall. These represent maximum values since the pop-in monitors are primarily used for tuning at much lower beam intensities and are in use for limited periods of time.

In addition, scattered radiation over the concrete shielding (skyshine) was evaluated using the methodology of Appendix 10. Photon dose rates at the console from full beam at 230 MeV on a pop-in monitor were calculated at 290 μR/hr. Neutron dose rates within the building from such a loss are estimated at 1.8 mRem/hr.

We also calculated skyshine dose rates in non-NSLS facilities, particularly since the BNL limit for annual exposures to these personnel is 25 mrem/year. The nearest non-NSLS buildings are Bldg. 535, Bldg 480, and Bldg 356, all of which are at distances > 100 m from Bldg. 729. For simplicity, all skyshine calculations were performed at 100 m beyond the building. The calculated dose equivalent rate at 100 m for photons is 3.5 μR/hr and 160 μRem/hr for neutrons.

For purposes of analyzing potential total dose equivalent from an unshielded pop-in monitor, we assume that pop-in monitors are used for the equivalent of 100 hours per year receiving 10% of the maximum beam during such use. The total dose equivalent within the building would be 21 mRem per year; and at 100 meters it would be 1.6 mrem. It should also be noted that the actual dose equivalent will be lower because of the greater distances and the shielding provided by the buildings that personnel occupy.

Therefore, although use of the pop-in monitors at high beam intensities creates a significant increase in background radiation levels through the wall and from skyshine, anticipated use for these devices does not create a significant challenge to the ACL within the building or to the BNL limit for adjacent facilities. During the commissioning phase of operations when the beam intensities will be considerably lower than design intensities, studies will be conducted to determine actual radiation levels resulting from pop-in monitor use and local shielding will be provided as needed in order to maintain exposures ALARA and consistent with the NSLS ACL.

c) Electrons can be generated within the linac accelerating sections by the primary beam in such processes as secondary emission or residual gas ionization, or by non-beam related phenomena such as arcing. Radiation from these events was observed in the very early days of the NSLS 120 MeV linac, but has not been observed in many years. Radiation fields produced by these processes will be highly variable and dependent on the amount and location of the primary beam loss. In general, electrons produced by these processes will have much lower energies than that of the accelerated beam. It has been the NSLS historical experience that the thickness of lead shielding provided around the SDL beam lines is quite adequate to control x-ray production from this source. It is important to note that the SDL linac uses the same electron gun and accelerating sections as the Accelerator Test Facility where no radiation of this type has been observed, even at the highest accelerating gradients attainable in the accelerating sections. This is consistent with experience for baked copper surfaces operating in high voltages at or above the accelerating gradients anticipated for the SDL under comparable vacuum conditions.

d) Assuming a **continuous 2% operating loss**, 2.5×10^9 e/s will be lost by striking the vacuum pipe, or flange within the vacuum space. We perform this calculation twice, once at 230 MeV where the inner wall thickness is 32" and at 300 MeV where both the inner and outer wall thickness is 4 feet.

Using these parameters and the methodology of Appendix 9, we calculate the dose rate from photons to be 12 μR/hr through the north wall and 119 μR/hr through the 32" thick south wall. We calculate the dose rate from neutrons to be 15 μRem/hr through the north wall and 87 μRem/hr through the interior wall.

For a continuous 2% loss at 300 MeV, we calculate the dose rate from photons to be 18 μR/hr through the north and south wall, and 19.1 μRem/hr through the wall for neutrons.

In addition, scattered radiation over the concrete shielding (skyshine) was evaluated using the methodology of Appendix 10. At the console, photon dose rates are highest for losses at 230 MeV from an on-going 2% loss and were calculated at 5.8 μR/hr. Neutron dose rates within the building from an on-going 2% loss were highest at 300 MeV and were calculated at 47 μRem/hr. Assuming 2000 hours of operation per year and an occupancy factor of 1, skyshine from these sources will total 105 mrem, in excess of the NSLS Administrative Control Level for occupational workers of 100 mrem per year. Chronic loss points will require careful evaluation as beam intensities increase. Additional shielding to maintain exposures ALARA and to ensure that the 100 mrem/year administrative control level is maintained will be provided as needed.

We also calculated the skyshine at 100 m using the methodology of Appendix 10. Neutron skyshine dose equivalent from losses at 300 MeV is calculated to be 4.2 μRem/hr and photon dose rates are calculated to be 0.09 μR/hr. The annual dose equivalent at 100 m from skyshine from a chronic 2% loss would be 8.6 mRem per year, well within the 25 mrem per year Laboratory Administrative Control Level (ACL). As was the case with skyshine doses resulting from the pop-in monitor, the most limiting condition is the 100 mrem ACL within the building.

4.6.1.3 Beam Dumps

As described in Section 1.2, and depicted in Figure 3 (LINK), two beam dumps are installed in two different locations within the accelerator enclosure. During routine FEL operation, the full beam will be targeted on the FEL dump at the end of the amplifier. During linac tuning, the beam will be directed to the linac beam dump. Energy of the electron beam in the linac dump will never exceed 230 MeV.
The FEL dump may eventually increase to 300 MeV and calculations for this dump were performed at 300 MeV. It should be noted that both dumps cannot be used simultaneously.

The dumps themselves are identical and have lead shielding that extends 14 inches in the direction of the beam and are 24 inches wide and 16 inches high centered on the beam. The aluminum faraday cups are 9.8 inches long and are shielded vertically by 5 inches of lead and horizontally by 4 inches of lead. To reduce neutron skyshine, 12 inches of 5% borated polyethylene is provided above the stops. In addition, to reduce the solid angle for neutrons emitted in the vertical direction, four pre-cast concrete shield blocks (16"x30"x96") are placed alongside the upstream dump (two on each side), which provide additional concrete shielding horizontally for the beam dump and reduce the sky-shine solid angle. Because of the proximity of the FEL dump to the shield wall at the west end of the enclosure, the pre-cast shield blocks are not needed on both sides to reduce solid angle.

The shielding thickness and distance to potentially occupied areas for each dump is as follows:

Linac Beam Dump

At 0^o for the linac dump there is a distance of 6.8 meters from the dump to the exterior of the shielding wall. The total thickness of the shield at 0^o is 2.7 meters. At 90^o the distance from the dump to the accessible area is 4.4 meters and the total shield thickness is 1.86 meters of concrete. The distance from the linac dump to the operating console is 14.6 meters.

FEL Beam Dump

At 0° for the FEL dump, there is a distance of 2.9 meters to the exterior of the shielding wall. The total thickness of the concrete shield at 0° is 1.7 meters. At 90° the distance from the dump to the accessible area is 2.44 meters and the total shield thickness is 1.46 meters of concrete. The distance from the FEL dump to the near-by desk area is 9.75 meters.

Penetration through Shielding

Using these parameters and the methodology of Appendix 9, we calculate the dose rate from photons and neutrons at the exterior of the shield wall for the beam dumps as shown in the table below.

Dose Rates in Accessible Areas from Beam Dumps
(μRem/hr)

Beam Stop	Photon	Neutron	Total
Linac Stop (0^o)	2.2×10^{-4}	0.8	0.8
Linac Stop (90^o)	0.9	37.4	38.3
FEL Stop (0^o)	0.14	279	279
FEL Stop (90^o)	19.5	800	820

Activities in the accessible area around the Linac dump are limited, and there should be no issues created by the radiation exposure resulting from this beam dump. The experimental program for the FEL will be conducted in the areas around the FEL dump, and additional shielding may be needed as beam intensities transported to the beam dump increase. Radiation levels around the stop will be monitored and additional shielding provided as needed to maintain all exposures ALARA and to ensure that the ACL is maintained. There is adequate space within the enclosure to provide additional heavy concrete if further shielding is required.

Skyshine

Scattered radiation over the concrete shielding (skyshine) was evaluated using the methodology of Appendix 10.

- The Linac dump is located at a distance of 14.6 meters from the console. Photon dose rates at the console from the linac beam stop were calculated at 3.4 µR/hr. Skyshine neutron dose rates within the building from the linac dump are estimated at 4.3 µRem/hr, producing a total dose rate of 7.7 µRem/hr at the console. Total annual dose equivalent at the console from 2000 hours of operation at maximum intensity on the dump would be 15.4 mRem.
- The FEL dump is located at a distance of 9.8 meters from a work location at the west end of the building. Photon dose rates at this location from the FEL beam stop were calculated at 6.1 µR/hr. Neutron dose rates within the building from the FEL dump are estimated at 5.6 µRem/hr, producing a total dose rate of 11.7 µRem/hr. Total annual dose equivalent at this work location from 2000 hours of operation at maximum intensity on the dump would be 23.4 mRem.
- We can also calculate the skyshine at non-NSLS buildings using the methodology discussed in Appendix 10. The total dose rate at 100 meters for full beam stopped at the FEL dump is 1.05 µRem/hr or 2.1 mRem /year assuming 2000 hours per year at maximum beam intensities, well within the BNL ACL of 25 mRem per year for adjacent facilities.

Labyrinth

The accelerator enclosure is accessed through a labyrinth that is close to the linac beam dump. We have evaluated the adequacy of the labyrinth for scattered radiation.

The formulation for the X-ray dose rate $D_{m,x}$ at the outside aperture of the maze is given in NCRP-51 [Ref. 14, p. 63] as:

$$D_{m,x} = D_0\alpha_1 A_1(\alpha_2 A_2)^{j-1}/(d_i\, d_{i1}\, d_{i2\ldots}\, d_{ij})^2 \qquad (1)$$

where D_0 is the source dose rate at 1 meter (mR/hr) that is incident on the labyrinth, α_1 is the reflection coefficient of the material at the first reflection point, α_2 is the reflection coefficient at the 2nd and subsequent reflections, A_1 is the surface area irradiated by X-rays at the first reflection (m^2), A_2 is the cross-sectional area of the maze (m^2), d_i is the distance from the source to the first reflecting wall (m), d_{r1} the distance from the 1st to 2nd wall (m), etc; and j refers to the jth reflection process. Reflection coefficients are given in NCRP-51, App. E.15, and reproduced in section 7 as Figure 6.

The geometry of the source and the labyrinth can be examined in Figure 3. Using the methodology established in Appendix 9, we estimate the X-ray dose rate at 1 meter at 90° to the beam dump in the horizontal direction to be D_0 = 25.8 mR/hr. The reflecting area A_1 of the east wall of the enclosure facing the stop is approximately 4' wide by the 8' high, therefore $A_1 \sim 3$ m^2. The distance d_1 from the source to the east wall is ~ 3 m. The cross-sectional area of the maze is estimated at 5 m^2. In scattering through the maze, there is a minimum of 2 other reflections that must occur for a photon to escape. The distances between reflection points can be computed from Figure 3 in the SAD and are shown in the table below.

Parameters for Calculating Photon Transmission through Maze

	Distance to reflection (m)	Reflection coefficient
d_i	3.05	2.3×10^{-3}
d_{i1}	3.35	4×10^{-2}
d_{i2}	5.18	4×10^{-2}

The length of the final leg (d_{i3}) of the labyrinth is 2.44 m. The scattering coefficient for the first reflection is computed in Appendix 11. Subsequent reflections are for photons at much lower energy and the most conservative coefficient in Figure 6 was selected for each reflection. Inserting these values into the equation above and solving we get the scattered x-ray dose rate $D_{m,x}$ at the exterior mouth of the labyrinth to be:

$$D_{m,x} = 4.2 \times 10^{-7} \text{ mR/hr} \qquad (2)$$

Neutrons leaking through the maze can also pose a radiation hazard. NCRP-51 [Ref. 14, p. 64] provides a conservative methodology for estimating the scattered neutron dose equivalent rate $H_{m,n}$ in terms of the neutron flux ϕ_m (neutrons/cm^2 sec) incident on the entrance aperture of the maze

$$H_{m,n} = K\, \phi_m\, B_{mn} / 270 \ \ (\text{mRem/hr}) \qquad (3)$$

where K is a safety factor and set equal to 8 for a two-legged maze and equal to 4 for a 3-legged maze. In this calculation all neutrons incident on the mouth of the maze are assumed to become thermalized and the factor of 270 is the neutron fluence rate per unit dose - equivalent index rate for thermal neutrons. B_{mn} is a transmission factor established from the Figure 7.

The neutron flux ϕ_m can be recalculated by estimating the neutron dose equivalent rate at the entrance to the labyrinth and then using the flux to dose conversion coefficient for 2 MeV neutrons. In Appendix 9, we calculated the giant resonance neutron (GRN) fluence at one meter from the beam dump to be 1.8×10^4 n cm^2/s unshielded. This fluence in the horizontal direction toward the labyrinth is shielded by 16" of concrete. (We do not consider the high energy neutron component since multiple scattering will not occur within the labyrinth.) The 16" of concrete and the geometry reduce the GRN flux incident on the entrance to the labyrinth to 25.2 n cm^2/s. The neutron transmission ratio B_{mn} through the maze is evaluated from Figure 7.

For a maze of width W = 6 feet, height H = 8 feet, and centerline distance = 36 feet; the centerline distance through the maze in units of $\sqrt{HW}$ is 5.2 yielding $B_{mn} \sim 8 \times 10^{-3}$. Then, with K = 4, , we have:

$$H_{m,n} = K\,\phi_m\,B_{mn} / 270 = 4 \times 25.2 \times 8 \times 10^{-3} / 270 = 2.9 \times 10^{-3} \text{ mRem/h} \qquad (4)$$

The total dose equivalent $H_{m,T}$ through the labyrinth is $H_{m,n} + D_{m,x}$

$$H_{m,T} = 4.2 \times 10^{-7} + 2.9 \times 10^{-3} = 2.9 \times 10^{-3} \text{ mrem/hr} \qquad (5)$$

4.6.1.4 NISUS Undulator

As can be seen from Figure 3, downstream from the last accelerating sections are a series of components designed to produce the free electron laser beam. This section addresses radiation issues associated with the transport of a 300 MeV electron beam through the NISUS wiggler and on to the final beam stop. Chronic losses at 300 MeV and the FEL stop have been previously analyzed. Because of the nature of the NISUS undulator, the lead shielding of the beam line vertically that is provided in other regions is not possible. Instead, credit was taken for the relatively high Z samarium cobalt magnets and the vanadium permadur pole pieces in the shielding analysis performed for NISUS.

Three new issues will be evaluated in this section: 1.) bremsstralung production from residual gas interactions during the long straight section transport through the accelerator and FEL components, 2.) bremsstrahlung and neutron production associated with beam loss during transport in NISUS, and 3) radiation leakage through the laser penetration in the downstream shield wall.

Gas Bremsstrahlung Production

The generation of bremsstrahlung x-rays produced by the interaction of the accelerated electron beam with residual gas in the beam line is a potential problem associated with long straight sections in high energy electron accelerators. As an example, extra shielding has been provided in certain beam lines at the NSLS X-ray ring for this source of radiation. The long straight transport of the electron beam from the acceleration cavities through the NISUS wiggler suggests that this source of radiation should be evaluated.

Gas bremsstrahlung is produced by the interaction of the primary electron beam with residual gas molecules or ions in the beam transport vacuum chamber. It is produced in a narrow cone, the characteristic emission angle being given by $1/\gamma$, where $\gamma = E/m_0c^2$ (E= energy of the electron beam and m_0c^2 = the rest mass of the electron). The energies of the bremsstrahlung x-rays range up to the energy of the electron beam.

Ferrari et al [23] have developed an analytical expression to estimate the gas bremsstrahlung dose rate D which has been successfully applied at Argonne's Advanced Photon Source (APS) and other synchrotron light sources.

$$D = 2.5x10^{-27} \left(\frac{E_0}{m_0 c^2}\right)^{2.67} \frac{L}{d(L+d)} I \frac{P}{P_0} \quad \text{Gy/hr} \qquad (6)$$

where E_0 is the primary beam energy (MeV), L is the length of straight section (m) in which the beam may interact with residual gas, d is the distance from the end of the straight section to the point of interest (m), I is the beam current (e^-/s); P is the pressure in straight section (Pa); and P_o is 1.33×10^{-6} Pa. The long straight section for the SDL is shielded at the west wall by a 12" thick lead stop and the four foot thick concrete wall. Using this formula and the parameters identified in the table below, we can calculate the unshielded dose rate at the downstream wall during normal operation to be 2.3 μR/hr.

The 12" of lead and four feet of concrete provides an attenuation of 3×10^{-9}. The dose rate increases when vacuum declines and a major vacuum failure during machine operation would produce a maximum dose rate of ~ 0.5 mR/hr at the end of the shielding at the end of the beam line through the lead and concrete walls. A vacuum failure of this magnitude would result in shutdown of the machine in a very short period of time. Therefore, gas bremsstrahlung is not an important issue at the beam current and energies for SDL. The following parameters were used in this calculation:

Gas Bremsstrahlung Calculation Parameters

Parameter	Value Used
L	23 m
d	3
P	1 P_0 ~1.33×10^{-6} Pa
I	1.25×10^{11}
E_0	300

Beam losses in NISUS

An important difference in the NISUS shielding is the inability to place 3" of lead vertically because of the structural configuration of the magnet. Because of this, it was important to take credit for the samarium cobalt magnets and the vanadium permadur pole pieces. This difference in shielding configuration, coupled with more frequent use of the beam profile monitors (i.e. "pop-in" monitor) to ensure proper positioning of the beam led to a more detailed set of calculations for the NISUS magnet for multiple-scattered "skyshine" radiation produced outside the shielded enclosure. The intent of these additional calculations was to optimize shielding of the NISUS to the extent possible.

Skyshine calculations conducted by a shielding physicist (P. Degtiarenko) from Thomas Jefferson National Accelerator Laboratory were performed using DINREG (a nuclear fragmentation model) and a Monte Carlo transport code "GEANT". This code is used at Thomas Jefferson and has been demonstrated to provide a useful tool for determining shielding requirements for electron accelerators operating in this energy range or higher.

Four sets of analyses were performed by Degtiarenko in an effort to evaluate several shielding configurations. Set-up one modeled the NISUS for full beam loss, coupled with no additional close-in horizontal or vertical shielding. The second included shielding by two inches of lead mounted in close proximity to the vacuum pipe. A third configuration evaluated NISUS for full beam loss, shielded by two inches of aluminum in close proximity to the vacuum pipe. And finally, the fourth configuration included shielding by two inches of lead horizontally and 12" of 5% borated polyethylene in the vertical plane as shown in Figure 8.

The results of each analysis are summarized in the following table. In each case a 300 MeV electron beam with 20 nA current was assumed to strike a thick target. The addition of lead shielding was found to be necessary to reduce the level of x-ray radiation, and the borated polyethylene (model 4) was included to attenuate the neutrons produced by the beam loss.

20 nA 300 MeV Electron Beam, Full beam loss in NISUS (mRem/hr)

Model	Dose at Inside wall (floor level)	Dose at Outside wall (floor level)	Dose 5 meters from inside wall (floor level)	Dose 5 meters from outside wall (floor level)
Model 1 No shielding	Peak - 125 General - 75	Peak - 20 General - 15	Not calculated	Not calculated
Model 2 2" lead	Peak - 10 - 12 General - 8	Peak - 9 - 10 General - 6	Not calculated	Not calculated
Model 3 2" Aluminum	Peak - 25 - 30 General - 20	Peak - 20 General - 15	Peak 25 General - 20	Peak - 10 General - 10
Model 4 2" lead + 12" 5% B- polyethylene	Peak - 4 General - 2	Peak 3- 4 General - 2	Peak ~ 2 General ~ 2	Peak ~ 2 General ~ 2

The radiation levels associated with Model 4 are acceptable for limited periods of operation, particularly during commissioning periods for the facility when beam current capability is far below design values. It should be remembered that Pop-in monitors are used to adjust focusing and steering to optimize beam transport through NISUS. Such tuning is performed primarily at low currents, and will not normally require extended periods of operation. However, the use of pop-in monitors will require on-going evaluation as beam currents are increased to design levels in the future, and operating restrictions may be needed to meet the ACL established in the ASE.

Forward Directed Bremsstrahlung Levels Produced by Pop-in Monitor Use

In addition to the multiple scattered "skyshine" radiation, the use of the pop-in monitor or other significant loss on a thick target will produce an intense, forward directed x-ray beam. Using the methodology described in Appendix 9, the dose rate in this beam for a 20 nA 300 MeV electron beam on a thick medium Z target is 3.84×10^4 Rad/hr at one meter from the loss point. The opening angle of the bremsstrahlung beam is about 1.7 milli-radians. The last pop-in monitor at the end of NISUS is about 10 feet from the wall or about 14 feet from the unshielded area in the forward direction. The shielding in this direction is a 12" lead stop and the four feet of concrete, which in examining Figures 9 and 10, provides a total attenuation factor of 3×10^{-9}. Using the methodology described in Appendix 9, the dose rate through the shield at 0^o during pop-in monitor use will be approximately 0.6 mRem/hr as shown below.

Dose Equivalent Rate at 0^o Through Shield from Pop-in Monitor Use

20 nA 300 MeV Electrons on Thick Target

Particle	Dose Equivalent Rate [mRem/hr]
Bremsstrahlung	6.4×10^{-3}
Neutrons < 25 MeV (Giant Resonance GRN)	4.7×10^{-3}
Neutrons > 25 MeV (High Energy HEN)	0.6

As stated earlier, pop-in monitor use will principally be conducted at beam currents much below maximum design intensities.

Radiation Levels through the Laser Penetration

As described in section 3.4, a small penetration of the down-stream shield wall must be provided to permit transport of the FEL beam out of the accelerator vault. This penetration has a dimension of ~ 16 cm^2. This small penetration is located 15" below the height of the beam line to ensure that there is no line of sight between this penetration and the primary electron beam. The only source of radiation potentially incident upon this opening would be multiple scattered radiation occurring during normal or abnormal operating conditions. The very small size of the opening coupled with the orientation relative to the electron beam results in a minimal leakage path for scattered radiation. Monte Carlo calculations indicated maximum dose rates at the outside end of this opening of less than 1 mR/hr, which can be readily addressed during operations. This opening will be monitored during commissioning and routine operation to ensure on-going evaluation and control.

4.6.2 Activation Hazards

Induction of radioactivity in machine components, water, air, and soil is normally not a significant concern for an electron accelerator operating at these beam energies and intensities. The non-elastic cross-sections for the electron-photon cascade are a factor of 100 below those for the cascades produced in a proton accelerator. As a result, the activation capability of an electron machine is reduced by this amount compared to a proton machine of similar power. In addition, proton accelerators with radio-activation issues normally operate at power levels of kilowatts or higher, as compared to the 6 watts maximum power of the SDL. As an example, radiation levels from induced activity have been seldom measurable at the NSLS, and we expect similar experience with the SDL.

However, we can make conservative assumptions and calculate maximum levels of induced radioactivity for this facility.

Activation of Structural Components

Electrons can strike structural components at a number of locations during operation. The maximum beam loss location is the aluminum faraday cup used to stop the beam. Activation of this aluminum beam stop can be calculated from Swanson [Ref 4, p. 109].

Although a variety of other nuclides are produced, the principal radionuclides produced in the stop will be Al-26m, Na-22 and Na-24. For the 300 MeV electron beam with a maximum power of 6 watts, the saturation activities for Al-26m, Na-22 and Na-24 are 52.8, 1.5, and 1.7 mCi, respectively. Assuming a point source and neglecting self-shielding, this will give rise to a radiation field of about 20 mR/hr at 1m from the target immediately on beam turn-off assuming no self-shielding in the target. Because of the short-half life of Al-26m (6.37 s), this level quickly decays to a value of about 5 mR/hr. Actual dose rates will be lower since the source will be distributed along the length of the faraday cup. The lead shielding around the Faraday cup will reduce these levels within the enclosure to non-measurable values. Beam losses in other structural components of the accelerator will be a small fraction of the beam loss in the faraday cup.

Activation of Air, Water, and Soil

The principal source of activation of air, water, and soil in an electron accelerator would come from exposure to the forward directed bremsstrahlung beam. Since during normal operation, the SDL beam is contained within a vacuum pipe, and is terminated in thick lead stops which absorb the remaining energy, there is little opportunity for activation produced directly by the bremsstrahlung beam except for a small air gap between the faraday cup and the lead stop. Bremsstrahlung interaction in thick targets will produce neutrons which can induce activity through capture or inelastic processes; radio-activation through this secondary process is normally much lower than from direct exposure to the bremsstrahlung beam.

Air

The greatest potential for air activation is in the 4" air gap that the bremsstrahlung will traverse between the faraday cup and the lead stop behind it. Using the formulation of Swanson (Ref 4, p. 129), activation in air can be calculated assuming a 20 nA beam loss at 300 MeV on the Faraday Cup, and an unshielded bremsstrahlung flight path in air of 4".

Although a variety of other nuclides are produced, the principal radionuclides produced in air are: ^{13}N ($T_{1/2}$ = 10 min., β^+) and ^{15}O ($T_{1/2}$ = 2 min. β^+). The saturation activities of these nuclides are calculated to 8.5 μCi and 0.9 μCi respectively for the SDL operating at a beam power of 6 watts. This activity will be produced along the path of the bremsstrahlung beam before its strikes the lead shielding, and will drift away from the path as a result of air movement. If we assume that the activity is distributed uniformly in a small volume close to the point of production (a cube 3 meters on a side) with no ventilation, the saturation activity concentration is 3.5×10^{-7} μCi/cc for the ^{13}N and ^{15}O mixture. These values can be compared to the Derived Air Concentration for these radionuclides of 4×10^{-6} μCi/cc. Actual values will be far less considering the size of the building and the mixing and ventilation that will occur.

Some production of ^{13}N and ^{15}O will also occur from spallation reactions in air molecules produced by the high energy neutrons (HEN) generated in the faraday cup. These production rates are small compared to that produced by the bremsstrahlung beam.

Water

The accelerator sections and beam line components are water cooled by closed loop, low conductivity water systems. However, in no case are the water systems directly used to absorb the electron or bremsstrahlung beam energies. Production of radionuclides (primarily tritium) within the water systems can only occur from HEN produced by the bremsstrahlung interactions in accelerator components. No significant production of tritium or other radionuclides will occur from this mechanism.

This is a similar configuration to the 120 MeV electron linac at NSLS which operates at about the same average beam current as the SDL linac. No induced activity has been observed in the cooling water systems at NSLS or SDL.

Soil

There is no interaction of the forward directed bremsstrahlung beam with soil, and therefore the only mechanism for production of soil activation is from the HEN production created in thick targets. This process would not be expected to be a significant source of soil activation for an electron accelerator operating at this energy and power level. Appendix 12 provides the evaluations of H^3 and Na^{22} production in soil.

Using the methodology established in the BNL Accelerator Safety Subject Area, the potential soil water leachout for H^3 can be shown to be 21 P Ci/ℓ and for Na^{22} to be 3.4 P Ci/ℓ. Both values are less than the action levels established in the Subject Area.

These values represent peak values since the neutron fluence will reduce by $1/r^2$ as the neutrons go deeper into the soil, as well as being further attenuated by removal through interactions. These low values of induced activity support the initial conclusion that soil activation is not a significant issue for this facility.

4.6.3 Accidental Beam Losses

This section describes the various fault conditions anticipated, and the dose levels to be expected. Beam loss monitors are provided along the beam lines and radiation area monitors are provided in work areas as indicators of beam loss conditions. Numerous other operational indicators are available to the machine operators which would also alert them to beam loss conditions. These calculations will be checked and the adequacy of the shielding will be confirmed by conducting fault studies during the commissioning of the machine.

Full beam loss in accelerator or transport area

The first scenario that we examine is a loss of the full beam at maximum energy on a thick copper or steel object such as a flange or momentum slits. This is similar to the analysis conducted for the pop-in monitors in section 4.6.1.2. Using the methodology of Appendix 9, the maximum radiation levels from a 230 MeV beam loss (current maximum energy) at the exterior of the building through the wall are 1.9 mRem/hr and 10.3 mRem/hr through the 32" interior wall. The calculations performed by Degtiarenko at 300 MeV for full loss in NISUS provide a maximum through the wall of 4 mRem/hr inside and outside the building. These calculations are in reasonable agreement for shielding effectiveness of the directly penetrating radiation.

Radiation levels are higher atop the shield walls during such a beam loss. The walls of the accelerator enclosure are posted as restricted areas, and work permits are required for occupancy. However, radiation levels created by the beam striking a thick target can also be calculated as an additional fault scenario. The x-ray transmission path from the loss point to the top of the shield wall will encounter considerably more shielding because of the slant angle in traversing the side and vertical lead shielding. The average lead thickness protecting the top of the north shield wall is 4 inches, which provides a $B_x = 1x10^{-2}$. The distance from the beam line to the top of the wall at waist height is 2.4 meters. Therefore, the dose rate on top of the north (exterior) shield wall during a full beam loss in the linac would be about 12 mrem/hr from x-rays. Neutron production from full beam loss in a thick pipe or flange has been calculated to be on the order of several rem/hr at one meter, and ranging up to 12 rem/hr for stopping in lead. Neutron dose rates on top of the north shield wall from this fault would be up to a maximum of 2.1 rem/hr. Dose rates on the top of other shielding surrounding the enclosure will be similar in magnitude.

Losses of this type can be easily detected by normal beam diagnostics and quickly corrected in the control room. Operators are required to take corrective action within five minutes. A person occupying this area would receive 175 mrem during the five minute period. To mitigate this potential exposure, access to these areas is prohibited and posted to this effect.

A second failure mode that we examine is the full 300 MeV energy beam emerging through the vacuum chamber wall at point M, Figure 5 and impinging directly on the lead shielding wall. The resulting photons, after attenuation in the surrounding lead, will produce a forward beam towards point M7 of Figure 5. This situation could occur from a steering error in the external H-type bending magnet B1 and emerging through the 1/16" stainless steel (S.S.) vacuum pipe wall at the downstream end of B1 in the direction labeled "B" in, Figure 5. A similar situation could occur at the downstream end of magnet B2 since B1 and B2 are powered by the same power supply.

The lead shielding provided in these regions is of sufficient thickness to stop the 300 MeV electrons so we need only to concern ourselves with photons generated in the lead shield impinging on the concrete shielding walls and with photo neutrons produced in the lead shield. We will calculate the dose outside the concrete shielding from photon and neutron penetration, as well as for skyshine over the top of the shield.

The beam emerging from the vacuum chamber at B1 would be 13.5 cm outside the normal beam axis of this 72.34° bending magnet, with normal radius of curvature ρ=792 mm, as shown in the magnet cross section view of Figure 11, and would therefore be making an angle of $\theta = 0.135$ rad = 7.735° with respect to the chamber wall. The slant thickness through the 1/16" = 1.5875 mm stainless steel wall is then t_{ss} = 11.795 mm = 9.28 gm/cm^2, using a density ρ_{Fe} = 7.87 gm/cm^3 for iron. The slant thickness through 2 inches of lead at this angle is equal to about 15 inches. If we disregard the steel vacuum wall and assume that the entire beam strikes the lead, the beam emerging through the lead is 3.4 x 10^{-3} R/hr at one meter.

The slant thickness through the concrete is 1.83 m and the distance to the exterior of the concrete is 6.1 m. The photon beam penetrating through the concrete wall will have been attenuated to 2.7 x 10^{-2} μR/hr.

Finally, we can show that the neutron dose rate outside the shield wall due to this accident is also negligibly small. Using the methodology of Appendix 9, and the parameters listed above, we can calculate the neutron dose rate through the shield from this fault condition to be 18.8 μRem/hr.

Using the methodology for skyshine described in Appendix 10, we can also calculate the skyshine radiation produced by this fault. Neutrons will contribute the greatest dose rate and will produce floor radiation levels of about 3.5 mrem/hr within 20 m of the loss point. This condition will be short-lived, not extending for more than five minutes due to operator intervention.

4.6.4 Summary of Ionizing Radiation Calculations

The following table presents the results of calculations for assumed routine losses associated with operation of the SDL accelerator. These calculations are for a 20 nA transported beam and that beam losses on flanges or beam pipe constitute an optimally thick target to maximize radiation production. Electrons losses will more typically be scattered along a length of beam pipe producing a much more diffuse and less intense radiation source.

Radiation Levels in Accessible Area from the following source	**Total Dose Equivalent Rate (mRem/hr)**
2% loss in transport line at 300 MeV through exterior north wall	37 x 10^{-3}
2% loss in transport line through 32" interior concrete wall	206 x 10^{-3}
2% in transport line - total skyshine at console	52.8 x10^{-3}
2% in transport line - total skyshine at 100 m	4.3 x10^{-3}
Linac Beam dump Total at 0^0	0.8 x10^{-3}
Linac Beam dump Total at 90^0	38.3 x10^{-3}
Linac Beam dump Total Skyshine at console	7.3 x10^{-3}
FEL Beam dump Total at 0^0	279 x 10^{-3}

FEL Beam dump Total at 90^0	820×10^{-3}
FEL Beam dump Total Skyshine at desks	11.7×10^{-3}
FEL Beam dump Total Skyshine at 100 m	1.05×10^{-3}
Labyrinth entrance	2.9×10^{-3}
NISUS Pop-in Monitor Total Skyshine at console	2

The SDL is a lightly occupied building with normally only several personnel routinely present in the building during machine operation. The entire building is posted and treated as a Controlled Area and is accessible to only authorized personnel. The location with highest occupancy factor (assumed to be one) is the operating console. Other locations within the building will have only intermittent occupancy, particularly during the commissioning period for the facility. Radiation surveys will be routinely conducted and with area monitoring and fault studies, will permit identification of local shielding needed to maintain radiation exposure to personnel ALARA and within the NSLS 100 mRem per year ACL.

The principal on-going source of exposure to personnel at the operating console will be skyshine radiation from the beam dumps and from the pop-in monitors and any chronic loss points in the accelerator and transport line. Maximum annual exposure to personnel at the console from the beam dumps is conservatively estimated to be 20 mRem per year. Pop-in monitors will be used at reduced beam intensities and for limited time periods. Local shielding will be provided as needed to control exposures associated with any additional chronic loss points that are identified.

Exposures to non-NSLS personnel working in near-by locations will be maintained ALARA and within limits. The distance between Bld. 729 and non-NSLS buildings is greater than 100 meters and the analysis has demonstrated that the radiation exposure to personnel in these buildings will be less than the BNL ACL of 25 mRem per year. Occupancy of areas adjacent to the building where other non-NSLS personnel may periodically be present (e.g. grass cutters, delivery personnel) is a very small fraction of the work year and no significant exposures will result from their intermittent presence.

Exposures to members of the public are easily controlled to within the BNL ACL of 25 mRem per year. Access to Bldg. 729 is limited to authorized personnel only, and other locations near-by 729 where members of the public may have intermittent access (e.g. BNL tours) are limited in duration and do not result in any significant exposure.

4.7 Noxious Gas Creation

Toxic gases such as ozone and nitric oxides can be produced by ionization of air created by intense radiation fields. These gases can be a problem in accelerators where electron beams pass through air or where bremsstrahlung beams have significant path lengths in air. Neither of these cases is present in the SDL because of the following design and operating characteristics:

- The electron beam is contained in vacuum at all times.
- The most intense bremsstrahlung beam is produced by electron beam interactions in the faraday cup at the end of the beam line. The forward directed bremsstrahlung beam is almost immediately intercepted by a 14" lead stop which will capture essentially all of the beam power. The air gap between the faraday cup and the beam stop is 4".
- Bremsstrahlung beams at wider angles are reduced in intensity by a factor greater than 1000 compared to the forward directed beam and are also significantly reduced in intensity by lead shielding around all beam lines.

Swanson (ref. 4, p. 154) provides an expression that can be used to estimate ozone production from a bremsstrahlung beam in air:

$$p \text{ (liters/min.)} = 2 \times 10^{-7} \, DSL \qquad (7)$$

where p is the ozone production rate, L is the path length in air for the bremsstrahlung beam, S is the cross-sectional area of the beam, and D is the dose rate in R/min at 1 meter from the target.

Using this formula, we can calculate the production rate of ozone at the beam stops produced in the 4" air gap to be 2.7×10^{-11} liters/min from the forward directed bremsstrahlung. This production rate produces an insignificant amount of ozone near the stop and elsewhere in the building.

QUALITY ASSURANCE 5

The SDL project is part of the National Synchrotron Light Source (NSLS). The NSLS Quality Assurance Program applies to the work performed on the project. The SDL project management is responsible for the quality of construction, the operation of the equipment and the work processes in the facility. SDL accelerator components are evaluated for ESH&Q Risk Levels A-1 through A-4 as per SBMS Subject Area "Graded Approach for Quality Requirements." The SDL will comply with the QA Elements of the NSLS QA Manual which meets the requirements of the BNL Quality Assurance Program.

DECOMMISSIONING AND DECONTAMINATION PLAN 6

Operation of the Source Development Laboratory does not, in general, generate large quantities of radioactive or other hazardous material. There is no contamination of accelerator components and there is relatively little radioactive activation, the exceptions being the aluminum beam stops and molybdenum pop-in monitor mirrors where the electron beams are absorbed. These would receive the appropriate treatment at the decommissioning time.

At the appropriate time a full decommissioning plan will be developed based on the requirements outlined in the "Checklist for a Decommissioning Plan" contained in NSLS PRM 1.3.0 "Facility Design and New Program Review."

SUPPORTING DOCUMENTATION 7

- BNL Environment Safety & Health Standards Manual.
- BNL Operations Manual
- BNL Quality Assurance Manual
- BNL Implementation Plan for DOE Accelerator Order 5480.25.
- NSLS ESH Procedures and Requirements Manual
- NSLS Quality Assurance Manual
- DOE Order 420.2A "Safety of Accelerator Facilities"
- Guidance document for implementation of DOE Order 420.2A
- BNL Radiological Control Manual
- 10 CFR Part 835 "Occupational Radiation Protection"
- 10CFR PART 1021 "National Environmental Policy Act Implementing Procedures"
- ANSI Spec #39.5 "Electrical and Electrical Measurement and Controlling Instrument Safety Requirements"
- BNL ESH Standard 1.5.0 "Electrical Safety"
- BNL ESH Standard 1.5.1 "Lock-out/Tag-out Requirements"
- BNL ESH Standard 1.5.2 "Design Criteria for Electrical Equipment"
- BNL ESH Standard 1.5.3 "Interlock Standard for Protection of Personnel"
- BNL ESH Standard 2.3.2 "RF and Microwaves"
- BNL ESH Standard 4.1.2 "Means of Egress"
- DOE Order 420.1 "Facility Safety"
- DOE Guide 440.1-1 "Worker Protection Management for DOE Federal and Contractor Employees Guide"
- DOE Order 451.1B "National Environmental Policy Act Compliance Program"
- DOE Order 5470.28 "Natural Phenomena Hazards Mitigation"
- DOE Order 6430.1A "General Design Criteria"
- DOE/EV-0051-1 "Electrical Safety Criteria for Research and Development Activities"
- "DOE Accelerator Order 5480.25 Implementation Plan for BNL Natural Phenomena Hazards Evaluation" April 25, 1994 by Steve Hoey
- Executive Order 12941 "Seismic Safety of Existing Federally Owned or Leased Building"
- LS-SDL-0019 "SDL Accelerator Safety Envelope"
- Memo DeBobes to Helms May 28, 1998 "Phase 2,3, and 4 Submittal for Executive Order 12941"
- NFPA Code 90a "Standard for the Installation of Air-Conditioning and Ventilating Systems"
- NFPA Life Safety Code No. 101
- NSLS PRM 1.2.0 "Environmental Safety & Health Inspections"
- NSLS PRM 1.3.0 "Facility Design and New Program Review"
- NSLS PRM 1.3.5a " Experiment Safety Review"
- NSLS PRM 1.3.5b " Beamline Safety Review"
- NSLS PRM 2.3.1 "Laser Safety"
- NSLS PRM 6.2.0 "Lead Working Guidelines"

- SBMS Subject Area "Accelerator Safety"
- SBMS Subject Area "Graded Approach for Quality Requirements"
- SBMS Subject Area "Laser Safety"
- SBMS Subject Area "Static Magnetic Fields"
- Suffolk County Article 12 "Storage Requirements for Hazardous Materials"

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FIGURES

APPENDICES

These appendices are available at the SDL website. If you are viewing this document electronically, clicking on the appendix should take you to the relevant document. These are living documents, so, like the SAD, the current official version is the one posted on the website.

Appendix 1: Fire Hazard Analysis

Appendix 2: NSLS PRM (LS-ESH-PRM 0.0.0) NSLS Safety Organization

Appendix 3: NSLS PRM (LS-ESH-PRM 1.2.0) Environment, Safety and Health Inspections

Appendix 4: NEPA and NESHAPS

Appendix 5: NSLS PRM (LS-ESH-PRM 1.3.5a) Experimental Review Requirements

Appendix 6: Interlock Description / Search Procedure

Appendix 7: Laser Interlock System

Appendix 8: SAD Risk Assessments

Appendix 9: Methodology for Calculating Radiation Source Terms and Shielding Requirements

Appendix 10: Methodology for Calculating Skyshine Radiation

Appendix 11: Evaluation of Scattering Coefficient for Maze Calculation

Appendix 12: Radionuclide Production in Soil at SDL