Department of Energy
Brookhaven Site Office
P.O. Box 5000
Upton, New York 11973

JAN 1 2 2018

Ms. Gail Mattson
Brookhaven Science Associates, LLC
Brookhaven National Laboratory
Upton, New York 11973

Dear Ms. Mattson:

SUBJECT: APPROVAL OF THE REVISED NATIONAL SYNCHROTRON LIGHT SOURCE-II (NSLS-II) ACCELERATOR SAFETY ENVELOPE (ASE)

Reference: Letter from G. Mattson, BSA to F. Crescenzo, SC-BHSO, Subject: Request BHSO's Approval of Revisions to the NSLS-II Accelerator Safety Envelope, dated January 9, 2018.

The Department of Energy (DOE) Brookhaven Site Office (BHSO) has reviewed your request for approval of the revised NSLS-II ASE. Based on our review of the Unreviewed Safety Issue (USI) analysis for the Oxygen Deficiency Hazard (ODH) authorized alternative change and the Personal Protection System (PPS) Testing schedule change, along with the recommendation of the Brookhaven Science Associates (BSA) Laboratory Environment Safety and Health Committee (LESHC), BHSO approves the revised NSLS-II ASE.

If you have any questions, please contact Patrick Sullivan, of my staff, at extension 4092.

Sincerely,

Frank J. Crescenzo
Site Manager

cc: R. Gordon, SC-BHSO
M. Dikeakos, SC-BHSO
J. Cracco, SC-BHSO
P. Sullivan, SC-BHSO
S. Coleman, BSA
E. Lessard, BSA
R. Lee, BSA
D. Mallon, BSA
C. Schaefer, BSA

Associate Laboratory Director, ES&H

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Managed by Brookhaven Science Associates
for the U.S. Department of Energy

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January 9, 2018

Mr. Frank Crescenzo
Site Manager
Brookhaven Site Office
U.S. Department of Energy
Upton, NY 11973-5000

Dear Mr. Crescenzo:

Subject: Request BHSO's Approval of Revisions to the NSLS-II Accelerator Safety Envelope

Upon review of the attached documentation, I concur with the Laboratory ESH Committee (LESHC) recommendation to approve the revisions to the NSLS-II Accelerator Safety Envelope (ASE). The ASE revisions include a revision to the PPS testing schedule as approved by the Radiological Controls Division Manager, clarification of the ODH Authorized Alternative and revision to the Credited Controls for Oxygen Deficiency Hazards.

I am submitting the revised ASE to the Brookhaven Site Office for review and approval. Attached is relevant documentation to assist you.

Sincerely yours,

Gail Mattson
ALD, ESH

Attachments:

1. NSLS-II Accelerator Safety Envelope (ASE)
2. USI NSLS-II-EVAL-2017-004 "Follow Up on Failed ODH Monitor for 17-IE-B Beamline Enclosure w/BCO"
3. USI NSLS-II-EVAL-2017-006 "Revise Wording of ASE Commitment on PPS Testing Schedule to Include Alternative Listed in BNL Radiological Control Manual, Rev. 8 Date October 31, 2017"
4. Memo, E. Lessard to G. Mattson, dated December 20, 2017, "Request to Approve the changes to the NSLS-II ASE"
5. Memo, E. Lessard to G. Mattson, dated January 8, 2018, "Request to Approve the changes to the NSLS-II ASE"

Copy: P. Sullivan (BHSO)
E. Lessard (w/o att.)
R. Lee (w/o att.)
D. Mallon (w/o att.)

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for the U.S. Department of Energy

Memo

date: *December 20, 2017*

to: *G. Mattson, ALD for ESH*

from: *E. Lessard,* ETL *Chair, Laboratory ESH Committee*

subject: *Request to Approve the changes to the NSLS-II ASE*

The Laboratory ESH Committee (LESHC) recommends your concurrence on the changes to the NSLS-II ASE. Current wording "All PPS must be functionally tested and revalidated every 12 months, not to exceed 15 months to permit variances in the operations schedule" was changed to:

PPS Systems will be tested in accordance with the BNL Radiological Control Manual requirements, specifically, a rigorous functional test of all components and software shall take place within an interval of 24 months; however, in the intervening year a documented test of all critical devices shall be implemented. Testing will be performed within 3 months of the test due date to permit variability in operation schedules.

The LESHC recommends that you forward the revised National Synchrotron Light Source (NSLS-II) Accelerator Safety Envelope (ASE) to the Brookhaven Site Office for its approval.

Copy to: Committee Members, J. Misewich, J. Hill

Attachment: NSLS-II Accelerator Safety Envelope (ASE)

Unreviewed Safety Issue (USI) Evaluation Form

USI Evaluation No.: NSLS-II-EVAL-2017-006

Title of USI Evaluation and Sponsor or Condition Owner:

Revise Wording of ASE Commitment on PPS Testing Schedule to Include Alternative Listed in BNL Radiological Control Manual, Rev. 8 dated October 31, 2017

Steven Moss, NSLS-II Authorization Basis Manager

I. Description of Proposed Activity or Discovered Condition

NSLS-II seeks to implement an alternative schedule for testing of PPS Critical Devices and other PPS components and software, as provided within the current BNL Radiological Controls Manual Appendix 3A (4e) 3rd Bullet down;

An alternative may be employed after the "burn in period" referred to in section D above. A rigorous functional test of all components and software shall take place within an interval of 24 months;, however, in the intervening year a documented test of all critical devices shall be implemented. An implementation plan shall be submitted to the Manager, Radiological Control Division for review and approval prior to implementation.

In order to facilitate this option; it has been determined that revising the ASE wording of the commitment to include the alternative is the simplest way.

See below for specific Credited Controls and applicable ASE/SAD sections. Attachment 'A' contains a detailed listing of Credited Controls to be included, as well as the implementation plan reviewed and approved by RCD Manager [Ref. 8].

REFERENCES

1) *Unreviewed Safety Issue Determination Procedure*, PS-C-ESH-PRC-002, Ver. 4, June 27, 2014.

2) *Safety Assessment Document for the National Synchrotron Light Source II*, PS-C-ESH-RPT-001, Ver. 3, May 2015.

3) *Amendment No. 1 to NSLS-II SAD of May 2015;* dated December 21, 2015 [containing DOE Approval of USI Evaluation No. NSLS-II-EVAL-2015-004, Rev. 1: *Re-Statement of NSLS-II ASE Stored Beam Lower Energy Limit for Storage Ring,* dated December 1, 2015]

4) *Amendment No. 2 to NSLS-II SAD of May 2015;* dated June 3, 2016 [containing DOE Approval of USI Evaluation No. NSLS-II-EVAL-2016-005: *Authorized*

Alternative for Lowering the Minimum NSLS-II Booster Electron Injection Energy Limit, dated May 25, 2016]

5) *Amendment No. 3 to NSLS-II SAD of May 2015,* dated January 30, 2017 [containing DOE Approval of USI Evaluation No. NSLS-II-EVAL-2017-001: *PPS Functional Testing and Recertification / Revalidation Interval Change from Every Six Months to Twelve Months,* January 17, 2017]

6) *Accelerator Safety Envelope (ASE) NSLS-II,* PS-C-ESH-ROASE-001, Ver. 5, January 2017.

7) *Radiological Control Manual (Brookhaven National Laboratory)* Revision 8 dated October 31, 2017.

8) NSLS-II Listing of Credited Controls to be included in the protocol endorsed by RCD Manual Appendix 3A, Section 4e, 3rd Bullet; and, NSLS–II Implementation Plan [as submitted to and approved by, RCD Manager] addressing the details of the methodology for the testing included for those Critical Devices on a yearly basis, as well as the biennial rigorous functional testing of all components and software covered herein; included as Attachment 'A'.

II. Does the proposed activity or discovered condition affect information presented in the Safety Assessment Document (SAD) (e.g., regarding equipment, administrative controls, or safety analyses)?

YES – Within the Safety Assessment Document for the National Synchrotron Light Source II [PS-C-ESH-RPT-001, Ver. 3 dated May 2015, Amendment No. 3], there is specific reference to the intervals at which the PPS must be functionally tested and revalidated (consistent with the BNL Radiological Control Manual). **Section 5.2.8 – Calibration, Testing, Maintenance and Inspection that maintain Credited Controls** states (under the first bullet):

All PPS must be functionally tested and revalidated every 12 months, not to exceed 15 months to permit variances in the operations schedule.

Basis: The continued reliability of the PPS requires that it be tested and re-certified at regular intervals and following any modification of the system to confirm that no protective function degradation has occurred as a result of component failure or human error. Test intervals are every 12 months, not to exceed 15 months to permit variances in the operations schedule). With the consent of the Manager of the BNL Radiological Control Division, the interval between tests may be extended. Records of all tests and certifications must be retained.

Under the proposed revision wording, the commitment becomes:

PPS Systems will be tested in accordance with the BNL Radiological Control Manual requirements, specifically, a rigorous functional test of all components and software shall take place within an interval of 24 months; however, in the intervening year a documented test of all critical devices shall be implemented. Testing will be completed within 3 months of the test due date to permit variability in operation schedules.

Basis: the continued reliability of the PPS requires that it be tested and re-certified at regular intervals and following any modification of the system to confirm that no protective function degradation has occurred as a result of component failure or human error. Test intervals are specified in the BNL Radiological Control Manual (Appendix 3A). With the consent of the Manager of the BNL Radiological Control Division, the interval between tests may be extended. Records of all tests and certifications must be retained.

Additionally, there is passing reference in **Section 6.4 – Documents and Records,** where it states:

Examples include the 12-month validation testing of the PPS interlocks procedures;

...

Authority Having Jurisdiction for establishing Physical Access Controls for High and Very High Radiation Areas in compliance with 10 CFR 835 is BNL's Radiological Control Division and those controls are codified in the current edition of the BNL Radiological Control Manual, Rev. 8 dated October 31, 2017. The requirements established in BNL Radiological Control Manual are included within the NSLS-II SAD (as well as the ASE). In addition to requirements contained within the Radiological Control Manual, there is also guidance on implementation details and options. Use of these already established processes do NOT constitute changes to or violations of requirements, but merely reflect an efficient way of complying with same. Therefore, an RCD Manager-reviewed and approved Implementation Plan for compliance with Appendix 3A, Para. 4e, 3rd Bullet reflects compliance with the BNL Radiological Control Manual as well as concurrence with ASE PPS testing requirements, as found in the SAD.

III. Does the proposed activity or discovered condition affect any of the requirements of the Accelerator Safety Envelope (ASE)?

YES – The DOE-approved NSLS II ASE [PS-C-ESH-ROASE-001], Ver. 5 dated January, 2017; does currently include one Calibration, Testing, Maintenance and Inspection That Maintain Credited Controls criterion that must be revised to reflect the commitment to comply with the guidance provided in the BNL Radiological Control Manual. Specifically, NSLS-II ASE, Rev. 5 criterion 4.1 states:

All PPS must be functionally tested and revalidated every 12 months, not to exceed 15 months to permit variances in the operations schedule.

Under the proposed revised wording, the commitment becomes:

PPS Systems will be tested in accordance with the BNL Radiological Control Manual requirements, specifically, a rigorous functional test of all components and software shall take place within an interval of 24 months; however, in the intervening year a documented test of all critical devices shall be implemented. Testing will be completed within 3 months of the test due date to permit variability in operation schedules.

Basis: the continued reliability of the PPS requires that it be tested and re-certified at regular intervals and following any modification of the system to confirm that no protective function degradation has occurred as a result of component failure or human error. Test intervals are specified in the BNL Radiological Control Manual (Appendix 3A). With the consent of the Manager of the BNL Radiological Control Division, the interval between tests may be extended. Records of all tests and certifications must be retained.

Authority Having Jurisdiction for establishing Physical Access Controls for High and Very High Radiation Areas in compliance with 10 CFR 835 is BNL's Radiological Control Division and those controls are codified in the current edition of the BNL Radiological Control Manual, Rev. 8 dated October 31, 2017. The requirements established in BNL Radiological Control Manual are included within the NSLS-II SAD (as well as the ASE). In addition to requirements contained within the Radiological Control Manual, there is also guidance on implementation details and options. Use of these already established processes do NOT constitute changes to or violations of requirements, but merely reflect an efficient way of complying with same. Therefore, an RCD Manager-reviewed and approved Implementation Plan for compliance with Appendix 3A, Para. 4e, 3rd Bullet reflects compliance and concurrence with the BNL Radiological Control Manual PPS testing requirements, as well as that found in the ASE.

IV. USI Evaluation Criteria

1. Could the change or discovered condition significantly increase the probability of occurrence of an accident previously evaluated in the SAD?

   ☐Y or ☒N

   Justification: The proposed revised wording of the commitment to and use of an RCD Manager-reviewed and approved implementation plan for BNL Radiological Control Manual Appendix 3A; Paragraph 4e; 3rd Bullet, does not constitute a change to the established twelve (12) month interlock certification period and could NOT significantly increase the probability of occurrence of an accident previously evaluated in the SAD. The NSLS-II PPS systems were designed and constructed with an expected testing frequency of 12 months. An independent evaluation of the system was performed that determined the probability of failure for the system is better than a SIL-3 rated system with a test period of 12 months for non-PLC components (10 years for PLC components).

Revising the wording of the commitment in the ASE to utilize guidance provided in the BNL Radiological Control Manual with a RCD Manager-reviewed and approved Implementation Plan does NOT change the 12 month interlock certification period nor does it significantly increase the probability of occurrence of an accident previously evaluated in the SAD.

2. Could the change or discovered condition significantly increase the consequences of an accident previously evaluated in the SAD?

   ☐Y or ☒N

   Justification: The proposed revised wording of the commitment to and use of an RCD Manager-reviewed and approved implementation plan for BNL Radiological Control Manual Appendix 3A; Paragraph 4e; 3rd Bullet, does not constitute a change to the established twelve (12) month interlock certification period and could NOT significantly increase the consequences of an accident previously evaluated in the SAD. The consequences of accidents and events postulated within the SAD have all been determined and cannot be affected by the frequency of certification testing. The only way to increase the consequence of any accident previously evaluated within the SAD would be to change a parameter of the event itself or to add additional concurrent events to an already analyzed event.

   Revising the wording of the commitment in the ASE to utilize guidance provided in the BNL Radiological Control Manual with a RCD Manager-reviewed and approved Implementation Plan could NOT significantly increase the consequences of an accident previously evaluated in the SAD.

3. Could the change or discovered condition significantly increase the probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD?

   ☐Y or ☒N

Justification: The proposed revised wording of the commitment to and use of an RCD Manager-reviewed and approved implementation plan for BNL Radiological Control Manual Appendix 3A; Paragraph 4e; 3rd Bullet, does not constitute a change to the established twelve (12) month interlock certification period and could NOT significantly increase the probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD. The NSLS-II PPS systems were designed and constructed with an expected testing frequency of 12 months. An independent evaluation of the system was performed that determined the probability of failure for the system is better than a SIL-3 rated system with a test period of 12 months for non-PLC components (10 years for PLC components).

Revising the wording of the commitment in the ASE to utilize guidance provided in the BNL Radiological Control Manual with a RCD Manager-reviewed and approved Implementation Plan does NOT change the 12 month interlock certification period nor significantly increase the probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD.

4. Could the change or discovered condition significantly increase the consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD?

   ☐Y or ☒N

   Justification: The proposed revised wording of the commitment to and use of an RCD Manager-reviewed and approved implementation plan for BNL Radiological Control Manual Appendix 3A; Paragraph 4e; 3rd Bullet, does not constitute a change to the established twelve (12) month interlock certification period and could NOT significantly increase the consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD. The consequences of malfunctions of equipment important to safety postulated within the SAD have all been determined and cannot be affected by the frequency of certification testing. The only way to increase the consequence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated within the SAD would be to change a parameter of the event itself or to add additional concurrent events to an already analyzed event.

   Revising the wording of the commitment in the ASE to utilize guidance provided in the BNL Radiological Control Manual with a RCD-Manager-reviewed and approved

Implementation Plan could NOT significantly increase the consequences of a malfunction of equipment important to safety previously evaluated in the SAD.

5. Could the change or discovered condition create the possibility of a different type of accident than any previously evaluated in the SAD that would have potentially significant safety consequences?

   ☐Y or ☒N

   Justification: The proposed revised wording of the commitment to and use of an RCD Manager-reviewed and approved implementation plan for BNL Radiological Control Manual Appendix 3A; Paragraph 4e; 3rd Bullet, does not constitute a change to the established twelve (12) month interlock certification period and could NOT create the possibility of a different type of accident than any previously evaluated in the SAD that would have potentially significant safety consequences. Attachment B [Ref. 9] – NSLS–II Implementation Plan [as submitted to and approved by RCD Manager] addressing the details of the methodology for the testing included for those Critical Devices on a yearly basis as well as the biennial rigorous functional testing of all components and software covered herein; provides the necessary technical assurance to conclude that the proposed revised wording of the commitment in the ASE and use of the RCD Manager-reviewed and approved Implementation Plan creates no new or different type of accident than any previously evaluated in the SAD that would have potentially significant safety consequences.

6. Could the change increase the possibility of a different type of malfunction of equipment important to safety (e.g., engineered credited controls) than any previously evaluated in the SAD?

   ☐Y or ☒N

   Justification: The proposed revised wording of the commitment to and use of an RCD Manager-reviewed and approved implementation plan for BNL Radiological Control Manual Appendix 3A; Paragraph 4e; 3rd Bullet, does not constitute a change to the established twelve (12) month interlock certification period and could NOT increase the possibility of a different type of malfunction of equipment important to safety (e.g., engineered credited controls) than any previously evaluated in the SAD. Attachment A [Ref. 8] – NSLS–II Implementation Plan [as submitted to and approved by RCD Manager] addressing the details of the methodology for the testing included for those Critical Devices on a yearly basis as well as the biennial rigorous functional testing of all components and software covered herein; provides the necessary technical assurance to conclude that the proposed revised wording of the commitment in the ASE to take advantage of the RCD Manager-reviewed and approved Implementation Plan does NOT increase the possibility of a different type of malfunction of equipment important to safety (e.g., engineered credited controls) than any previously evaluated in the SAD.

V. USI Determination

A USI is determined to exist if the answer to any of the 6 questions above (in Section V) is "Yes." If the answers to all 6 questions are "No," then no USI exists.*

Does the proposed activity (or discovered condition) constitute a USI?

☒ Yes – DOE approval required prior to implementing, or discovered condition remedied in accordance with the Section 6.4 of PS-C-ESH-PRC-002, *Unreviewed Safety Issue Determination Procedure.*

☐ No – Proposed activity may be implemented with appropriate internal review, or no further action is required to address the discovered condition's impact on accelerator safety (other actions may be required to meet other PSD or Laboratory requirements).

*According to the SBMS Subject Area, *Accelerator Safety: Section 8 – Unreviewed Safety Issue (USI) Process: Step 6:* **If the USI Process determination is that the discovery or planned change will impact credited controls**, existing MCIs, create new MCIs or cause an increase in the risk classification as per the SAD risk table, **it is a USI.**

STEVE MOSS / [signature] 12/20/17

Prepared by: (Qualified Evaluator) *Date*

[signature] 12/20/17

Approved by: *Date*

ATTACHMENT 'A'

The following pages include not only the Implementation Plan and Schedule for Alternate Testing of NSLS-II PPS Systems, but also, Booster Radiological Interlock Test Procedure, Booster Annual Critical Device Checklist, Beamline Annual Critical Device Checklist, as well as the Tentative 2-Year PPS Testing Schedule for NSLS-II.

approved by the NSLS-II designated person must authorize all work on these components. Following all work, the PPS system shall be tested and certified to have been restored to its proper configuration and function. Barriers such as gates and fencing are subject to a routine inspection procedure to ensure the barriers remain in their approved configuration.

- **The area radiation monitoring system interfaced with the PPS shall be maintained in its approved configuration (Beam requirement only)**

  Basis: The area monitoring system is expected to measure elevated radiation levels and stop further injection if these levels exceed established alarm points. Area monitors have been located on the basis of anticipated loss points. The area monitoring units are labeled as subject to configuration control and any change in location or set point is controlled by procedure. Only designated personnel are authorized to adjust the units. The functionality of the area monitoring system will be tested as a part of the PPS certification program. During the machine operating periods, the radiation monitors will be checked with a radiation source to confirm proper response of the monitor and the interlock. This will occur during interlock checks and b) every time a monitor is exchanged for repair or calibration. The area radiation monitoring system is not required for RF cavity testing since the shielding is adequate for protection of personnel, even for cavity worst case operations

- **The polarity of the Booster ring dipoles, the BTS transport line dipoles and all ring dipole magnets (not including corrector dipoles) must be confirmed to be correct and subject to a formal configuration control program (beam requirement only)**

  Basis: The mis–steering analyses performed the Booster, for electron transport to the Storage Ring and for stored beam within the Storage Ring assumed that all dipole magnets (except corrector dipoles) had the proper power supply polarity. The analyses are not valid and could create an unreviewed safety issue if the polarity of one or more of these magnets were reversed. A formal program has been developed to establish and maintain the correct polarities.

- **All new beamline frontends, and modifications to existing beamline frontends must be approved for Top-Off operation by designated Top-Off Technical Authority, in accordance with procedure, prior to enabling the beamline during Top-Off operation. Top-Off must be disabled prior to enabling any beamline that is not yet approved for Top-Off.**

  Basis: Review and analysis of new or modified beamline frontends by Technical Authority is necessary to assure radiation controls are in place for Top-Off operation of the beamline and that compliance with NSLS-II Shielding Policy is verified and confirmed.

5.2.8 Calibration, Testing, Maintenance and Inspection that maintain Credited Controls

- ~~**All PPS must be functionally tested and revalidated at intervals consistent with the BNL Radiological Control Manual**~~

  PPS systems will be tested in accordance with the BNL Radiological Control Manual requirements. Specifically, a rigorous functional test of all components and software shall take place within an interval of 24 months; however, in the intervening year a documented test of all critical devices shall be implemented. Testing will be performed within 3 months of the test due date to permit variability in operation schedules.

  Basis: The continued reliability of the PPS requires that it be tested and re–certified at regular intervals and following any modification of the system to confirm that no protective function degradation has occurred as a result of component failure or human error. Test intervals are specified in the BNL Radiological Control Manual (Appendix 3A). With the consent of the Manager of the BNL Radiological Control Division, the interval between tests may be extended. Records of all tests and certifications must be retained.

- **Area radiation monitors must undergo annual calibration. The time between annual calibrations shall not exceed 15 months.**

~~**4.1** All PPS must be functionally tested and revalidated every 12 months, not to exceed 15 months to permit variances in the operations schedule.~~

4.2 Area radiation monitors must undergo annual calibration. The time between annual calibrations shall not exceed 15 months.

4.3 Following all major shutdowns (>15 days), radiological shielding and barriers (berms, shield blocks and fencing) must undergo visual inspection prior to operations to ensure that all required elements are in place and functional.

4.4 TOSS Credited Aperture locations must be certified biennially (every two years). The time between certifications shall not exceed 30 months.

4.5 Oxygen monitors must undergo annual testing; the maximum time between testing must not exceed 15 months. Authorized alternative devices will also be routinely tested (e.g., functional check monthly)

– End –

PPS Systems will be tested in accordance with the BNL Radiological Control Manual requirements, specifically, a rigorous functional test of all components and software shall take place within an interval of 24 months; however, in the intervening year a documented test of all critical devices shall be implemented. Testing will be performed within 3 months of the test due date to permit variability in operation schedules.

Radiological Control Division

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Phone 631 344-8705
Coleman@bnl.gov

BROOKHAVEN
NATIONAL LABORATORY

Memo

Date: *December 20, 2017*

To: *R. Lee, NSLS II ESH Manager*

From: *S. Coleman, Manager, Radiological Control Division*

Subject: ***Approval of Implementation Proposal and Schedule for Alternate Testing of the NSLS-II PPS Systems***

RCD Management has reviewed and approved your proposed implementation plan for alternate testing of the NSLS-II PPS systems. Specifically, RCD approves full functional testing of all PPS components and software within an interval of 24 months, with a documented test of all critical devices in the intervening years as described and defined in NSLS-II annual critical device checklists.

This approval does not extend to new PPS systems (e.g., new beamlines) which must initially undergo a full functional test of all components and software. Also, please ensure the full inventory of NSLS-II credited controls is maintained in an auditable fashion, such as within the facility safety assessment document.

SC:bl
RP10QR.17
Attachment:
Memo from R. Lee to S. Coleman dated 12/19/2017

Cc: M. Bebon
H. Kahnhauser
G. Mattson
C. Schaefer

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BROOKHAVEN
NATIONAL LABORATORY

managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

Date: December 19, 2017
To: S. Coleman
From: Robert J. Lee, NSLS-II ESH Manager R. Lee 12/19/17
Subject: Implementation Proposal and Schedule for Alternate Testing of the NSLS-II PPS Systems

In accordance with Revision 8 to the Radiological Controls Manual dated October 31, 2017 NSLS-II is submitting the attached Implementation Proposal and Schedule for Alternate Testing of the NSLS-II PPS Systems. The document is being used in support of a change to the NSLS-II Accelerator Safety Envelope to allow implementation of the two year full-system testing schedule. In accordance with the RCM Appendix 3A, para. 4e, the implementation plan must be approved by you prior to implementation. The following text is being proposed as revised language to the NSLS-II ASE:

> ***PPS Systems will be tested in accordance with the BNL Radiological Control Manual requirements, specifically, a rigorous functional test of all components and software shall take place within an interval of 24 months; however, in the intervening year a documented test of all critical devices shall be implemented. Testing will be performed within 3 months of the test due date to permit variability in operation schedules.***

Please provide this office with your approval of the subject document at your earliest convenience. Once approved, the revised ASE will have to be submitted to the Laboratory ESH Committee then the Brookhaven Site Office for approval.

If there are any questions regarding this request, please do not hesitate to contact me.

Dist.				
	A. Ackerman	M. Bebon	M. Benmerrouche	S. Buda
	R. Chmiel	G. Ganetis	E. Johnson	G. Mattson
	T. McDonald	S. Moss	P. Sullivan, BHSO	T. Shaftan
	L. Stiegler	E. Zitvogel	P. Zschack	

cc: K. Rubino Shoemaker-Skokov

National Synchrotron Light Source - II

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BROOKHAVEN
NATIONAL LABORATORY

managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

Date: December 19, 2017
To: S. Coleman
From: Robert J. Lee, NSLS-II ESH Manager R. Lee 12/19/17
Subject: Implementation Proposal and Schedule for Alternate Testing of the NSLS-II PPS Systems

In accordance with Revision 8 to the Radiological Controls Manual dated October 31, 2017 NSLS-II is submitting the attached Implementation Proposal and Schedule for Alternate Testing of the NSLS-II PPS Systems. The document is being used in support of a change to the NSLS-II Accelerator Safety Envelope to allow implementation of the two year full-system testing schedule. In accordance with the RCM Appendix 3A, para. 4e, the implementation plan must be approved by you prior to implementation. The following text is being proposed as revised language to the NSLS-II ASE:

> ***PPS Systems will be tested in accordance with the BNL Radiological Control Manual requirements, specifically, a rigorous functional test of all components and software shall take place within an interval of 24 months; however, in the intervening year a documented test of all critical devices shall be implemented. Testing will be performed within 3 months of the test due date to permit variability in operation schedules.***

Please provide this office with your approval of the subject document at your earliest convenience. Once approved, the revised ASE will have to be submitted to the Laboratory ESH Committee then the Brookhaven Site Office for approval.

If there are any questions regarding this request, please do not hesitate to contact me.

Dist.				
	A. Ackerman	M. Bebon	M. Benmerrouche	S. Buda
	R. Chmiel	G. Ganetis	E. Johnson	G. Mattson
	T. McDonald	S. Moss	P. Sullivan, BHSO	T. Shaftan
	L. Stiegler	E. Zitvogel	P. Zschack	

cc: K. Rubino Shoemaker-Skokov

Implementation Proposal and Schedule for Alternate Testing of the NSLS-II PPS Systems
December 19, 2017

Purpose

On July 21, 2017 the Radiological Controls Division issued Revision 7 to the BNL Radiological Controls Manual. This revision provided for increasing the frequency for full testing of personal protection interlock system (PPS) from one year to two years providing testing of critical devices is performed annually. The two year testing provision is retained in the current RCM, Revision 8. Specific wording contained in Appendix 3A is excerpted below:

An alternative may be employed after the "burn in period" referred to in section D above. A rigorous functional test of all components and software shall take place within an interval of 24 months; however, in the intervening year a documented test of all critical devices shall be implemented. An implementation plan shall be submitted to the Manager, Radiological Control Division for review and approval prior to implementation.

The PPS at NSLS-II has been in operation since 2013 and annual rigorous testing of the system has been performed as required. The PPS is a dual chain interlock system with several layers of independent redundancy provided.

As provided in Revision 7 to the Radiological Control Manual, the NSLS II facility is proposing to implement the alternative PPS testing schedule. This alternative allows for rigorous functional testing of all components and software on a 24 month interval, with a documented test of all critical devices performed in the intervening year. This outline will serve as a tool to define the specific critical devices that will be tested on the years that a full rigorous functional test is not required.

Critical Device Description:

The NSLS II accelerator complex and experimental beamlines are comprised of PPS systems that were designed and can be tested independently of the other systems. There are currently thirty-three independent PPS systems currently operating at NSLS-II. These include: the Linac, the Booster, each of the five pentants of the Storage Ring, each individual beamline (23 to date), the Top-Off Safety System (TOSS), the Linac to Booster (LTB) Accumulated Charge Monitor Interlock (ACMI), and the Booster to Storage Ring (BTS) Accumulated Charge Monitor Interlock (ACMI). The operation of these systems has been reviewed in order to define the critical devices to ensure that those requiring annual testing are defined. The critical devices for these systems are listed below.

The Linac critical devices are:

- The Electron Gun High Voltage Power Supply
- The Linac RF Modulators AC Contactors (3)
- The Linac to Booster shutter
- The Linac to Booster B2 magnet power supply

As part of the Linac annual check, the Linac to Booster B1 bending magnet power supply energy limits (upper and lower) will also be confirmed. Exceeding these limits will cause the electron gun HVPS to turn off. This ensures that only electrons of acceptable energy are injected into the Booster.

The Booster critical devices are:

- The Booster RF High Voltage Power Supply
- The Booster Dipole "F" Power Supply
- The Booster to Storage Ring shutter
- The Booster to Storage Ring B2 magnet power supply

As part of the Booster annual check, the Booster to Storage Ring B1 and B2 bending magnet power supply energy limits (upper and lower) will be confirmed. Exceeding these limits will cause the electron gun HVPS to turn off. This ensures that only electrons of acceptable energy are injected from the Booster into the Storage Ring.

The Storage Ring (inclusive of 5 individual pentants) Critical Devices are:

- The Storage Ring Dipole Power Supply
- The Storage Ring RF System "C" Power Supply
- The Storage Ring RF System "D" Power Supply

As part of the Storage Ring annual check, the Storage Ring Dipole power supply energy limits (upper and lower) will be confirmed. Exceeding these limits will cause the electron gun HVPS to turn off. This ensures that only electrons within the acceptable energy range of 2.0 GeV and 3.3 GeV are contained in the Storage Ring orbit. Additional RF systems will be added to this list of critical devices when they are installed.

The individual Beamline Critical Devices are:

- The Storage Ring Dipole Power Supply
- The Storage Ring RF System "C" Power Supply
- The Storage Ring RF System "D" Power Supply
- The Beamline Front End Shutters

The Top–Off Safety System (TOSS) Critical Devices are:

- Electron Gun High Voltage Power Supply
- Booster Extraction Septum Power Supply
- Storage Ring Injection Septum Power Supplies

The Linac to Booster Accumulated Charge Monitor Interlock (ACMI) Critical Device is:

- Electron Gun High Voltage Power Supply

The Booster to Storage Ring Accumulated Charge Monitor Interlock (ACMI) Critical Device is:

- Electron Gun High Voltage Power Supply

The methods for testing the listed critical devices will be listed on specific radiological interlock test checklists and the results will be retained in the Key Safety Records section of the NSLS II Document and

Records Center. The testing process will be consistent with currently approved rigorous functional PPS testing techniques.

Proposed Alternative Testing Method:

Testing of PPS systems at NSLS-II is by procedure and the use of area specific checklists that provide the specific testing sequence of PPS system components. The checklists prepared for the complete test of the PPS systems will be used to develop the annual PPS test of critical devices. The Booster full system test is due to be completed during the December 2017 shut-down. In an effort to reduce the time needed to complete the test, an annual test of the critical device checklist has been prepared using the full interlock certification checklist as the guidance document. Attachment 1 is the full Booster Interlock Certification Procedure and Attachment 2, the annual critical device test checklist. The annual device test checklist includes eight specific tests to ensure each of the Booster critical devices respond as expected. These include live testing of the access door switches (both chains are tested at one entrance); tests to ensure the booster to storage ring shutter cannot be opened and the booster to storage ring bending magnet cannot be energized during injection; a test to ensure the front end shutter cannot be opened during injection when top-off injection is disabled; a test of the beamline emergency stop interlock; and tests of the storage ring dipole magnet high and low energy limits. Similarly a Beamline annual critical device checklist has also been prepared that can be used as a template for all beamlines. A copy of that checklist is included as Attachment 3.

Similar annual critical device checklists will be prepared upon acceptance of this alternative testing method for the Linac, for each of the five storage ring pentants and for the ACMIs and TOSS testing procedures.

Implementation of the Alternative Testing Method:

The NSLS-II would like to start implementing this alternative testing method as soon as practicable and will phase in the annual critical device tests as the PPS tests become due. In an effort to spread the 24 month rigorous tests across the two year period, the annual critical device tests will be phased in. In the December/January period the Booster and seven beamlines are due for testing. The Booster and the beamlines at 21-ID, 23-ID, and 2-ID will be tested using the annual critical device checklist; the remaining four beamlines will be tested using the full test checklist. The schedule for testing of the beamlines will be captured in the NSLS-II Safety System Verification Recall System. A tentative two year test schedule has been developed and is included as Attachment 4.

Attachment 1: Booster Radiological Interlock Test Procedure

Department of Energy
Brookhaven Site Office
P.O. Box 5000
Upton, New York 11973

JAN 1 2 2018

Ms. Gail Mattson
Brookhaven Science Associates, LLC
Brookhaven National Laboratory
Upton, New York 11973

Dear Ms. Mattson:

SUBJECT: APPROVAL OF THE REVISED NATIONAL SYNCHROTRON LIGHT SOURCE-II (NSLS-II) ACCELERATOR SAFETY ENVELOPE (ASE)

Reference: Letter from G. Mattson, BSA to F. Crescenzo, SC-BHSO, Subject: Request BHSO's Approval of Revisions to the NSLS-II Accelerator Safety Envelope, dated January 9, 2018.

The Department of Energy (DOE) Brookhaven Site Office (BHSO) has reviewed your request for approval of the revised NSLS-II ASE. Based on our review of the Unreviewed Safety Issue (USI) analysis for the Oxygen Deficiency Hazard (ODH) authorized alternative change and the Personal Protection System (PPS) Testing schedule change, along with the recommendation of the Brookhaven Science Associates (BSA) Laboratory Environment Safety and Health Committee (LESHC), BHSO approves the revised NSLS-II ASE.

If you have any questions, please contact Patrick Sullivan, of my staff, at extension 4092.

Sincerely,

Frank J. Crescenzo
Site Manager

cc: R. Gordon, SC-BHSO
M. Dikeakos, SC-BHSO
J. Cracco, SC-BHSO
P. Sullivan, SC-BHSO
S. Coleman, BSA
E. Lessard, BSA
R. Lee, BSA
D. Mallon, BSA
C. Schaefer, BSA

Associate Laboratory Director, ES&H

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Managed by Brookhaven Science Associates
for the U.S. Department of Energy

www.bnl.gov

January 9, 2018

Mr. Frank Crescenzo
Site Manager
Brookhaven Site Office
U.S. Department of Energy
Upton, NY 11973-5000

Dear Mr. Crescenzo:

Subject: Request BHSO's Approval of Revisions to the NSLS-II Accelerator Safety Envelope

Upon review of the attached documentation, I concur with the Laboratory ESH Committee (LESHC) recommendation to approve the revisions to the NSLS-II Accelerator Safety Envelope (ASE). The ASE revisions include a revision to the PPS testing schedule as approved by the Radiological Controls Division Manager, clarification of the ODH Authorized Alternative and revision to the Credited Controls for Oxygen Deficiency Hazards.

I am submitting the revised ASE to the Brookhaven Site Office for review and approval. Attached is relevant documentation to assist you.

Sincerely yours,

Gail Mattson
ALD, ESH

Attachments:

1. NSLS-II Accelerator Safety Envelope (ASE)
2. USI NSLS-II-EVAL-2017-004 "Follow Up on Failed ODH Monitor for 17-IE-B Beamline Enclosure w/BCO"
3. USI NSLS-II-EVAL-2017-006 "Revise Wording of ASE Commitment on PPS Testing Schedule to Include Alternative Listed in BNL Radiological Control Manual, Rev. 8 Date October 31, 2017"
4. Memo, E. Lessard to G. Mattson, dated December 20, 2017, "Request to Approve the changes to the NSLS-II ASE"
5. Memo, E. Lessard to G. Mattson, dated January 8, 2018, "Request to Approve the changes to the NSLS-II ASE"

Copy: P. Sullivan (BHSO)
E. Lessard (w/o att.)
R. Lee (w/o att.)
D. Mallon (w/o att.)

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managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

date: *January 8, 2018*

to: *G. Mattson, ALD for ESH*

from: *E. Lessard, Chair, Laboratory ESH Committee* ETL

subject: *Request to Approve the changes to the NSLS-II ASE*

The Laboratory ESH Committee (LESHC) recommends your concurrence on the changes to the NSLS-II ASE based on the NSLS-II EVAL-2017-004, "Follow Up on Failed ODH Monitor for 17-IE-B Beamline Enclosure w/BCO".

The LESHC recommends that you forward the revised National Synchrotron Light Source (NSLS-II) Accelerator Safety Envelope (ASE) and the NSLS-II EVAL-2017-004, "Follow Up on Failed ODH Monitor for 17-IE-B Beamline Enclosure w/BCO" to the Brookhaven Site Office for its approval.

Copy to: Committee Members, J. Misewich, J. Hill

Attachment:

USI No. NSLS-II EVAL-2017-004, "Follow Up on Failed ODH Monitor for 17-IE-B Beamline Enclosure w/BCO"
NSLS-II Accelerator Safety Envelope (ASE)

Laboratory Environment, Safety and Health Committee

MINUTES OF MEETING 17-10
November 28, 2017

Committee Members Present
D. Coburn
R. Colichio
M. Cubillo
M. Gaffney
H. Kahnhauser
R. Lee
E. Lessard
D. Mallon [1]
C. Schaefer
G. Shepherd
Y. Than
Q. Wu

Committee Members Absent
L. Hammons
G. McIntyre
J. Tuozzolo

[1] Non-voting

Guests:
A. Ackerman
S. Buda
J. Cracco
B. Heneveld
S. Moss
A. Nunez
P. Sullivan

Agenda: Submission of Positive USID Evaluation No. NSLS-II-EVAL-2017-004 "Follow up on Failed ODH Monitor for 17-ID-B Beamline Enclosure w/BCO"

E. Lessard 12-20-17
E. Lessard — Date
LESHC Chairperson

G. Mattson 12-21-17
G. Mattson — Date
ESH ALD

Unreviewed Safety Issue (USI) Evaluation Form

USI Evaluation No.: NSLS-II-EVAL-2017-004

Title of USI Evaluation and Sponsor or Condition Owner:

Follow-up on Failed ODH Monitor for 17-ID-B Beamline Enclosure w/BCO

Steven Moss, NSLS-II Authorization Basis Manager

I. Description of Proposed Activity or Discovered Condition

The Discovery of Questionable Status of ODH Monitor/Alarm associated with 17-ID-B Experimental Enclosure was initially screened as not a USI. The Authorized Alternative in Section 2.3.1 of the ASE was immediately implemented upon discovery of the questionable status (loss of screen display). The presence of an already established Authorized Alternative within the ASE indicated that the condition was anticipated and not a basis for a positive screening. However, during the investigation of the unit's failure, it was determined that the green light indicator thought to reflect proper ODH Monitor/Alarm operation, only indicated that the supply of AC power to the unit was active. The loss of ODH system function as reflected by a blank screen display caused by a fuse failure within the internal circuitry was confirmed. This then presents as a non-safe failure of a Credited Control component. In acknowledgement of that fact, a Basis for Continued Operation (BCO) was initiated (Reference 6 below, copy attached), in accordance with Reference 1, below. Additionally, an Occurrence Reporting and Processing System (ORPS) Determination classified under Management Concern was also initiated (in accordance with Reference 1).

See below for affected Credited Controls and impacted ASE/SAD sections. See Attachment 'A' for copy of BCO [Ref. 7]. See Attachment 'B' for details of the Hazard Analysis [Ref. 8].

REFERENCES

1) *Unreviewed Safety Issue Determination Procedure*, PS-C-ESH-PRC-002, Ver. 4, June 27, 2014.

2) *Safety Assessment Document for the National Synchrotron Light Source II*, PS-C-ESH-RPT-001, Ver. 3, May 2015.

3) *Amendment No. 1 to NSLS-II SAD of May 2015;* dated December 21, 2015 [containing DOE Approval of USI Evaluation No. NSLS-II-EVAL-2015-004, Rev. 1: *Re-Statement of NSLS-II ASE Stored Beam Lower Energy Limit for Storage Ring,* dated December 1, 2015]

4) *Amendment No. 2 to NSLS-II SAD of May 2015;* dated June 3, 2016 [containing DOE Approval of USI Evaluation No. NSLS-II-EVAL-2016-005: *Authorized Alternative for Lowering the Minimum NSLS-II Booster Electron Injection Energy Limit,* dated May 25, 2016]

5) *Amendment No. 3 to NSLS-II SAD of May 2015,* dated January 30, 2017 [containing DOE Approval of USI Evaluation No. NSLS-II-EVAL-2017-001: *PPS Functional Testing and Recertification / Revalidation Interval Change from Every Six Months to Twelve Months,* January 17, 2017]

6) *Accelerator Safety Envelope (ASE) NSLS-II,* PS-C-ESH-ROASE-001, Ver. 5, January 2017.

7) *Basis for Continued Operation (BCO)*, BCO-NSLS-II-2017-001, November 9, 2017. [Attachment 'A']

8) Hazard Analysis reference material [Attachment 'B']

9) Approved Request for relief or Deviation from a Requirement pertaining to ODH, as per Waiver Number 2017-14.

II. Does the proposed activity or discovered condition affect information presented in the Safety Assessment Document (SAD) (e.g., regarding equipment, administrative controls, or safety analyses)?

YES – Within the Safety Assessment Document for the National Synchrotron Light Source II [PS-C-ESH-RPT-001, Ver. 3 dated May 2015], there is a primary description; **Section 4.6 Cryogenic Hazards, Including Oxygen Deficiency Hazards,** which includes subsections pertaining to Beamline ODH Hazards, Cryogenic Dewar Fill Station ODH Hazards, Experimental Hall ODH Hazards, GN_2 ODH Hazards, and Summary Cryogenic Hazards. **Section 5.2.6 – Credited Controls for Oxygen Deficiency Hazards** states (under the first bullet):

Experimental enclosures equipped with piped in liquid nitrogen from the main LN_2 distribution system or determined to be subject to an ODH condition will have a fixed-area oxygen monitoring and alarm system installed.

Basis: Analysis of the experimental enclosures shows that any enclosure to which liquid nitrogen is supplied via the central distribution system has the potential to have oxygen deficient atmospheres in the event of a nitrogen leak. In accordance with the BNL SBMS subject area for Oxygen Deficiency Hazards, an alarming oxygen monitoring system is required under such conditions. Authorized Alternative: If the fixed oxygen monitoring system is unavailable, personal oxygen monitors shall be *used to monitor staff while working in these areas.* [N.B. Authorized Alternative section of this Basis to be revised to reflect clarification of wording as per ASE Revision]

Additionally, there are analyses in the SAD Appendices particularly referencing Cryogenic Hazards including ODH: Appendix 3 – SC SAD Storage Ring Risk Assessment Tables, Hazard Table 6 – Cryogenic, including ODH; and Appendix 10 – Assessment of Cryogenic Safety and Oxygen Deficiency Hazards for the NSLS-II Experimental Hall, LN_2 Fill Stations, and Beam Lines.

III. **Does the proposed activity or discovered condition affect any of the requirements of the Accelerator Safety Envelope (ASE)?**

YES – The DOE-approved NSLS II ASE [PS-C-ESH-ROASE-001], Ver. 5 dated January, 2017; does currently include a requirement pertaining to the Discovery of a Failed ODH Monitor in Beamline Enclosure 17-ID-B. Specifically, Criterion 2.3 – Credited Controls for Oxygen Deficiency states:

The following credited control for oxygen deficient atmospheres within the experimental enclosures has been identified.

- ***Experimental enclosures equipped with liquid nitrogen supplied directly by the main LN_2 distribution system or if determined by analysis to present an ODH hazard will have an oxygen monitoring and alarm system installed. The alarm system will sound inside and outside the enclosure to warn workers of the potential for oxygen deficiency.***

2.3.1 Authorized Alternative: In the event the oxygen monitoring system becomes inoperable all staff working within the enclosure will be alerted with the use of personal oxygen monitors or other approved oxygen monitoring device (e.g., Multi gas detector).

For the sake of clarification and in accordance with approved Waiver Number 2017-14 [Ref. 9], pertaining to ODH Requirements contained in SBMS subject area, Section 2.3.1 Authorized Alternative is being revised to read:

2.3.1 Authorized Alternative: In the event the oxygen monitoring system becomes inoperable, staff working within the enclosures will be alerted to an ODH environment by wearing personal oxygen monitors for each entrant. Use of the alternative shall be temporary for periods not to exceed 60 days and shall be in accordance with Waiver Number 2017-14).

Associated with the Credited Control is the associated Calibration, Testing, Maintenance and Inspection requirements called out in Criterion 4.5, which states:

Oxygen Monitors must undergo annual testing; the maximum time between testing must not exceed 15 months. Authorized alternative devices will also be routinely tested (e.g., functional check monthly).

IV. USI Evaluation Criteria

1. Could the change or discovered condition significantly increase the probability of occurrence of an accident previously evaluated in the SAD?

   ☐Y or ☒N

   Justification: The mitigated probability of occurrence of the most serious consequence is 'REMOTE' [which translates to "Unlikely to occur in life cycle but possible" in the SBMS Facility Risk Screening Matrix Questions]. The mitigations listed in the SAD Appendix 3, Table 6 Risk Assessment for Cryogenic Hazards, Including Oxygen Deficiency Hazards, include; seven Design-based Mitigations plus six Operations-based Mitigations. The removal of one of the mitigation factors [namely ODH Monitor /Alarm] cannot by itself significantly increase the probability of the highest consequence accident, because it is only part of a defense-in-depth approach to protection and has no impact on the likelihood of those factors pertaining to an uncontrolled release of Liquid Nitrogen or Gaseous Nitrogen, which is a necessary part of the event consequence occurring. Furthermore, even as a credited control (but not the only mitigating factor) the discovery of a previously unanticipated unsafe failure mode for the Oxygen Deficiency Hazard Monitor /Alarm does not, in and of itself, significantly increase the probability of occurrence of an accident previously evaluated in the SAD, it merely represents part of a scenario wherein a remote event could possibly happen.

2. Could the change or discovered condition significantly increase the consequences of an accident previously evaluated in the SAD?

   ☐Y or ☒N

   Justification: The mitigated consequences of the accident previously evaluated in the SAD are entirely the same as the unmitigated consequences, which presupposes no Oxygen Deficiency Hazard Monitor/Alarm. So there is no difference in the consequences assumed whether the ODH Monitor/Alarm is present or not. By that standard, there can be no significant increase in the consequences of an accident previously evaluated in the SAD due to the discovery of a previously unanticipated unsafe failure mode for the Oxygen Deficiency Hazard Monitor /Alarm.

3. Could the change or discovered condition significantly increase the probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD?

   ☒Y or ☐N

   Justification: The discovery of a previously unanticipated failure mode for the Oxygen Deficiency Hazard Monitors / Alarms installed at experimental enclosures could increase the probability of occurrence of a malfunction of equipment important to safety (because the ODH Monitors/Alarms are designated as engineered credited controls). This is especially true as the failure mode discovered was not fail-safe. The unmitigated failure probability is given in the SAD Appendix 3 Table 6 Risk Assessment as 'Occasional' [corresponding to "Likely to occur sometime in life cycle". The mitigated failure probability is given as 'Remote' [corresponding to "Unlikely to occur in life cycle but possible"]. With the discovery of two units (out of 27) failing in a similar mode within 3 years of operation, one must accept that the discovered unanticipated unsafe failure mode constituted a significant increase in probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD.

4. Could the change or discovered condition significantly increase the consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD?

   ☐Y or ☒N

   Justification: The mitigated consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD are entirely the same as the unmitigated consequences, which presupposes no Oxygen Deficiency Hazard Monitor/Alarm. So there is no difference in the consequences assumed whether the ODH Monitor/Alarm is present or not. By that standard, there can be no significant increase in the consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD due to the discovery of a previously unanticipated unsafe failure mode for the Oxygen Deficiency Hazard Monitor /Alarm.

5. Could the change or discovered condition create the possibility of a different type of accident than any previously evaluated in the SAD that would have potentially significant safety consequences?

☐Y or ☒N

Justification: The discovered condition is the appearance of a previously unsuspected unsafe failure mode associated with the ODH Monitors/Alarms installed at experimental beamline enclosures. The mitigated consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD are entirely the same as the unmitigated consequences, which presupposes no Oxygen Deficiency Hazard Monitor/Alarm. So there is no difference in the consequences assumed whether the ODH Monitor/Alarm is present or not. By that standard, there can be no different type of accident associated with ODH than the one already evaluated in the SAD.

6. Could the change increase the possibility of a different type of malfunction of equipment important to safety (e.g., engineered credited controls) than any previously evaluated in the SAD?

☒Y or ☐N

Justification: The apparent engineering design flaw in the ODH monitoring and alarm system was an unrecognized mode of failure indicated by a failed ODH sensor but a functioning indication system used by staff when making entry into an experimental enclosure. For the reasons already discussed in response to Question 3 above, the discovery of a previously unsuspected unsafe failure mode for the ODH Monitors/Alarms installed at the experimental beamline enclosures (where they are designated credited controls) can increase the possibility of a different type of malfunction of equipment important to safety (e.g., engineered credited controls) than any previously evaluated in the SAD.

V. USI Determination

A USI is determined to exist if the answer to any of the 6 questions above (in Section V) is "Yes." If the answers to all 6 questions are "No," then no USI exists.*

Does the proposed activity (or discovered condition) constitute a USI?

☒ Yes – DOE approval required prior to implementing, or discovered condition remedied in accordance with the Section 6.4 of PS-C-ESH-PRC-002, *Unreviewed Safety Issue Determination Procedure.*

☐ No – Proposed activity may be implemented with appropriate internal review, or no further action is required to address the discovered condition's impact on accelerator safety (other actions may be required to meet other PSD or Laboratory requirements).

*According to the SBMS Subject Area, *Accelerator Safety; Section 8 – Unreviewed Safety Issue (USI) Process; Step 6:* **If the USI Process determination is that the discovery or planned change <u>will impact credited controls</u>**, existing MCIs, create new MCIs or cause an increase in the risk classification as per the SAD risk table, **it is a USI.**

STEVE MOSS / Steven H Moss — 12/20/17

Prepared by: (Qualified Evaluator) *Date*

Robert J Lee — 12/20/17

Approved by: *Date*

Photon Sciences Directorate, Brookhaven National Laboratory			
Doc No. **PS-C-ESH-PRC-002**	Author: **L. Hill**	Effective Date: **27Jun2014** Review Frequency: **3 yrs**	Version 4
Title: **Unreviewed Safety Issue Determination Procedure**			**Administrative**

Attachment E

Basis for Continued Operation

BCO-NSLS-II-2017-001 / Prepared By: S. H. Moss 11/09/17

A) **Potential USI:** The Discovery of Questionable Status of ODH Monitor/Alarm associated with 17-ID-B experimental enclosure was initially screened not a USI [copy attached]. The Authorized Alternative in Section 2.3.1 of the ASE was immediately implemented upon discovery of the questionable status [copy attached]. The presence of an already established Authorized Alternative within the ASE indicated that the condition was anticipated and not a basis for shutdown. However, during the investigation of the unit's failure, a second unit (out of a total of 27 units in use and checked) was found in a similar condition. Further, it was eventually determined that the green light indicator was wired in such a way that it reflected only A/C power to the unit and not an absolute indicator of proper ODH Monitor/Alarm operation. This then represents a non-safe failure of a credited control component, regardless of the conservative nature of the Control itself. [The locations of the ODH Monitor/Alarms in question were all previously determined to be ODH '0' and are labeled as such. The SBMS Subject Area on Oxygen Deficiency Hazards (ODH), System Classification and Controls states that for ODH Classification '0' controls must include Postings and Training, plus oxygen monitoring for areas where the analysis shows the oxygen concentration can fall below 10% during an accident scenario] Although the hazard could be managed by administrative controls, the inclusion of ODH monitor/alarms came about as a conservative control during LESHC discussions when it was recognized that a significant number of experimental enclosures would be utilized temporarily by non-BNL personnel, whose familiarity with ODH Training and Postings were not yet known.

Analysis of Existing Condition:

B) Describe potentially impacted sections of SAD:

Section 4.6 - Cryogenic Hazards, Including Oxygen Deficiency Hazards, especially subsections on Beamline ODH Hazards and Summary Cryogenic Hazards

Section 5.2.6 – Credited Controls for Oxygen Deficiency Hazards w/Basis

Appendix 3 – SC SAD Storage Ring Risk Assessment Tables; Hazard Table Number 6 – Cryogenic, Including ODH

Appendix 10 – Assessment of Cryogenic Safety and Oxygen Deficiency Hazards for the NSLS-II Experimental Hall, LN2 Fill Stations, and Beam Lines

C) Describe potential hazards that may be posed by the existing condition:

If the display of the ODH monitor installed in an experimental enclosure cannot be seen before entry and if the unit had failed similarly to the one in question, and in consideration of the misunderstood positive indication of a green light on the ODH Monitor, first entry into a previously closed enclosure could result in exposure to an ODH condition if there had additionally been a rupture or leak of LN2, which was undetected up until that point, and not noticed during the entry process.

D) Provide brief analysis of imposed hazards:

Regardless of the remoteness of the hazard (actual entry into an ODH atmosphere without fore-knowledge - requiring a failure of the ODH Monitor unit combined with an unrecognized LN2 loss into a hutch, and not noticing the problem before entering); it cannot be ruled out as impossible. While an actual Oxygen deficiency is unlikely to overcome an individual upon entry with the enclosure door open and ventilation on, the possibility cannot be ignored, unless additional assurance is provided by either verification of operability of installed ODH monitor by observation of active screen, or by use of a Personal Oxygen Monitor by first entry to the hutch (to verify operability of ODH monitor present).

E) Provide concise description of methods for managing the imposed hazards:

Pending the completion of the wiring change to correct the indication status of the green light at the hutch entrances and on top of all the ODH Monitors installed in Beamline hutches, and effective immediately; entry into an experimental enclosure that has an ODH monitoring system requires that the operability of the ODH monitoring system be verified prior to entering the enclosure. This can be performed in one of two ways. If the ODH monitor display screen is visible from outside the enclosure it must be checked prior to entry. If the display is not visible, a Personal Oxygen Monitoring (POM) Device must be used upon initial entry*. Once the display is verified as functional and the doors remain open and the hutch ventilation system operating the POM can be removed from the enclosure. This must be repeated every time the hutch is entered after being closed for any period of time until changes to the ODH monitoring system can be completed. NSLS-II ESH Group has distributed POMs to each of the lead beamline scientists for this purpose. Note that the ODH system displays at 17-BM, 6-BM and 7-BM are visible from the doorway so POMs have not been provided.

Review of the training system database shows each of the Lead Beamline Scientists has taken training on the use of the POMs (Procedure No. PS-C-ESH-PRC-062). They have been trained on the operation of the POM when ESH group distributed the units. Lead Beamline Scientists shall add this training to all users of the beamline if the Users will make entry into an enclosure with an ODH system.

*It should be noted that this use of a POM as a temporary replacement for the fixed ODH Monitoring and Alarm unit has been recognized as a deviation from a SBMS Subject Area requirement where the potential Oxygen concentration could be below 10%. The issue has been reviewed by the ODH SME and authorized for use on a temporary basis (11/08/17 thru 01/31/18).

F) PS Approval:	**G) BHSO Acceptance:**

TABLE 6 RISK ASSESSMENT FOR CRYOGENIC HAZARDS, INCLUDING OXYGEN DEFICIENCY HAZARDS

NATIONAL SYNCHROTRON LIGHT SOURCE II HAZARD ANALYSIS

HAZARD: Cryogenic

HAZARD INITIATORS: Failure/rupture from overpressure, failure of insulating vacuum jackets, mechanical damage, deficient maintenance, improper procedure

HAZARD CONSEQUENCES: Thermal (cold) burns, overpressure, injury from fragments or missiles, oxygen deficiency, intermittent energy release (startle hazard) from pressure relief

RISK ASSESSMENT PRIOR TO MITIGATION:

CONSEQUENCE ☐ I High ☒ II Moderate ☐ III Low ☐ IV Routine

PROBABILITY
☐ A Frequent ☐ D Remote
☐ B Probable ☐ E Extremely Remote
☒ C Occasional ☐ F Impossible

RISK CATEGORY ☐ I High ☒ II Moderate ☐ III Low ☐ IV Routine

MITIGATING FACTORS (DESIGN)

- Cryogenic system designs as per ASME, ANSI and other applicable codes
- Conduct design and safety reviews of the cryogenic systems, ODH analyses and pressurized components by the BNL LESHC sub-committees as required by SBMS
- Relief/burst disk mechanisms for pressurized systems designed as per 10CFR851 and SBMS guidelines; sited to minimize impact to local workers
- Perform ODH analyses for predictable failure scenarios
- ODH sensors and alarms where required
- Design, provide and conduct reviews of the interlocks/automatic exhaust (quench) systems
- Initial and final pressure testing of all pressurized systems

MITIGATING FACTORS (OPERATIONAL)

- NSLS-II facility specific access training
- Cryogen Safety Awareness training
- Oxygen Deficiency Hazard training
- ODH classifications, postings/alarms/strobes, controls
- System specific training
- Personal protective equipment

RISK ASSESSMENT FOLLOWING MITIGATION:

CONSEQUENCE ☐ I High ☒ II Moderate ☐ III Low ☐ IV Routine

PROBABILITY
☐ A Frequent ☒ D Remote
☐ B Probable ☐ E Extremely Remote
☐ C Occasional ☐ F Impossible

RISK CATEGORY ☐ I High ☐ II Moderate ☒ III Low ☐ IV Routine

Are any controls (design or operational) required to be incorporated into the ASE? ☐Y ☒N

Facility Risk Screening Matrix Questions

CONSEQUENCE / PROBABILITY	FREQUENT Likely to occur repeatedly in life cycle	PROBABLE Likely to occur several times in life cycle	OCCASIONAL Likely to occur some time in life cycle	REMOTE Unlikely to occur in life cycle but possible	EXT. REMOTE Likelihood of occurrence ~ zero	IMPOSSIBLE Physically impossible to occur
Can a radiological or chemical hazard cause multiple deaths or serious injury, off-site evacuation, >100 rem to an individual, > $1,000,000 damage, > 4 mos. facility downtime, total loss of mission data, or have a public impact that closes the Department buildings or a User Facility?	HIGH RISK	HIGH RISK	HIGH RISK	MODERATE RISK	LOW RISK	ROUTINE RISK
Can a radiological or chemical hazard cause a death or serious injury, >25 rem to an individual, > $250,000 damage, 3 weeks to 4 months program downtime, severe loss of experimental data, or have a public impact that closes down an experiment or program?	HIGH RISK	HIGH RISK	MODERATE RISK	LOW RISK	LOW RISK	ROUTINE RISK
Can a radiological or chemical hazard cause multiple moderate injuries, local evacuation, > 5 rem to an individual, > $50,000 damage, 4 days to 3 weeks program downtime, major loss of experimental data, or have a public impact that brings the experiment to the attention of the community and activist groups?	MODERATE RISK	MODERATE RISK	LOW RISK	LOW RISK	ROUTINE RISK	ROUTINE RISK
Can a radiological or chemical hazard cause minor injuries, no on-site or off-site evacuation, < 2 rem to an individual, < than $50,000 damage, < 4 days program downtime, minor loss of experimental data, or have a public impact that is below public perception?	ROUTINE RISK	ROUTINE RISK	ROUTINE RISK	ROUTINE RISK	ROUTINE RISK	ROUTINE RISK

ATTACHMENT B

Key*
High Risk = 3
Moderate Risk = 2
Low Risk = 1
Routine Risk = 0

*Hazard Rating Results from BNL Hazard Validation Tool.

2.3 Credited Controls for Oxygen Deficiency Hazards

The following credited control for oxygen deficient atmospheres within the experimental enclosures has been identified.

- Experimental enclosures equipped with liquid nitrogen supplied directly by the main LN2 distribution system or if determined by analysis to present an ODH hazard will have an oxygen monitoring and alarm system installed. The alarm system will sound inside and outside the enclosure to warn workers of the potential for oxygen deficiency.

2.3.1 Authorized Alternative: In the event the oxygen monitoring system ~~becomes inoperable, all staff working within the enclosures will be~~ to an ODH environment by wearing ~~alerted with the use of~~ personal oxygen monitors for each entrant. ~~or other approved oxygen monitoring device (e.g. Multi gas detector).~~ Use of the alternative shall be temporary for periods not to exceed 60 days and shall be in accordance with Waiver No. 2017-14

SECTION 3 CREDITED CONTROL SUPPORTS

This section identifies the Supports for Credited Controls and their observable parameters that ensure that accelerator operations comply with the Credited Controls in Section 2.

Required Supports for Credited Controls

During RF operations with the accelerating structures or operations with electron and photon beam:

3.1 All required shielding and burn-through devices specified for the start–up of each accelerator or beamline shall be maintained in its approved configuration during operation and properly restored after maintenance periods.

3.2 The accelerators and beamline PPS and associated barriers shall be maintained in its approved configuration.

3.3 The area radiation monitoring system interfaced with the PPS for an area that is operational with beam shall be maintained in its approved configuration (Beam requirement only).

3.4 The polarity of the Booster ring dipoles, the Booster–to–Storage Ring transport line dipoles and all Storage Ring dipole magnets (not including corrector dipoles) must be confirmed to be correct and subject to a formal configuration control program (Beam requirement only).

3.5 All new beamline front ends, and modifications to existing beamline front ends must be approved for Top-Off operation by designated Top-Off Technical Authority, in accordance with procedure, prior to enabling the beamline during Top-Off operation. Top-Off must be disabled prior to enabling any beamline that is not yet approved for Top-Off (Beam requirement only).

SECTION 4 CALIBRATION, TESTING, MAINTENANCE AND INSPECTION THAT MAINTAIN CREDITED CONTROLS

The calibration, testing, maintenance or inspections needed to maintain Credited Controls are:

Primary Management System Evaluation of a Request for Relief or Deviation from a Requirement

The Primary Management System Executive or designee completes the Evaluation form

Instructions – The Primary Management System (MS) Executive or designee of the affected (primary) management system is responsible for performing a technical review and quality check of the **Relief or Deviation from Requirement Request** that concludes with a technical determination. The Primary MS Executive or designee is responsible for consulting with and obtaining concurrence from stakeholders and other MS Executives when a request involves cross-disciplinary review. All stakeholder MS Executives can provide additional documentation, as deemed necessary. The Primary MS Executive or designee submits the completed evaluation to Requirements Management Subject Matter Expert. Additional information is available in the Requirements Management Subject Area.

Request Information (see **REQUEST FOR RELIEF OR DEVIATION FROM A REQUIREMENT** *Form*)			
Title of *Request:*	Deviation from ODH Requirements to Use Alternate Controls		
Date of *Request:*	15DEC2017	*Deviation Request* number:	2017-14
Initiating Organization:	Photon Sciences Department		
Requestor/POC:	Robert J. Lee		

Primary Management System's Evaluation
I. Which category is the *Request* and Primary MS Executive's or designee's acceptance/rejection
☐ **Relief from a DOE Directive or regulatory driver that requires a ****Variance or Exemption*.** Cannot be approved by the Primary MS Executive or designee. [*includes 10 CFR 851 Variance requests]
☐ Primary MS Executive or designee recommends submitting the *Request* to the external regulatory body with jurisdiction [*see the section Requesting Relief or Deviation from a Requirement in the Requirements Management Subject Area*].
☐ Primary MS Executive or designee does not recommend submitting the *Request* to the external regulatory body with jurisdiction.
Name of the regulatory body with jurisdiction:

☐ **Relief from a regulatory driver by BNL Authority Having Jurisdiction (AHJ) (e.g., *Equivalency*)**
- ☐ Approved as submitted.
- ☐ Approved as modified- see Section II.
- ☐ Rejected.

Name of the BNL AHJ that should be consulted:

■ **Relief from an internal requirement (*Waiver*). Primary MS Executive or designee approval only**
- ■ Approved as submitted.
- ☐ Approved as modified- see Section II.
- ☐ Rejected.

☐ **Less than threshold requiring a *Variance* or *Waiver* (e.g., Technical Basis Decision; Acceptable Alternate Approach, complete III). Primary MS Executive or designee approval only**
- ☐ Approved as submitted
- ☐ Approved as modified- see Section II.
- ☐ Rejected.

II. Details of the Requirement and Decision

Relief is recommended to be: ■ Permanent ☐ Temporary

If temporary, what duration is approved?	Start Date:	End Date:

If temporary, is an Implementation Plan provided and is it adequate? ☐ Yes ☐ No

Can the *Relief* be addressed with a revision to the applicable SBMS document? ☐ Yes ■ No ☐ N/A

Will a change to the applicable SBMS document be made? ☐ Yes ■ No

If yes, describe the proposed change to the applicable SBMS document:
NA

If yes, what date will the change be submitted to the SBMS Office:

If yes is selected, then temporary approval to operate under the changes specified, is granted.

Can the *Relief* be globally applied to other organizations, besides the requesting group? ☐ Yes ■ No ☐ N/A
Specific Oxygen Deficiency Hazard (ODH) controls need to be evaluated case by case.

If yes, will this *Relief* be extended to other groups? ☐ Yes ■ No

If yes, what actions do impacted groups need to take:

NA

III. Technical Basis Determination or Justification for Decision (complete when the Evaluation concludes that the Request is Less than Threshold Requiring a *Variance* or *Waiver*)

ODH System Classification and Controls Subject Area requirement for fixed monitors was derived to minimize the risk of only using portable monitors in high risk area (over time). This waiver allows the use of procedure PS-C-ESH-PRC-060 for implementing authorized alternative controls: Using portable monitors if the installed ODH monitors are not functioning for up to 60 days. Limited use of alternate controls does not pose an unacceptable risk.

IV. Follow-up and Additional Items or Actions for Temporary Waivers that Need to be Monitored:		
Action	**Responsible Person and Organization**	**Due Date/ Frequency**

V. Additional Records to be submitted:			
Record	**Submitter**	**Reviewer**	**Due Date/ Frequency**

VI. Communication: List Names and Organizations that Should be Notified of the Evaluation Results

VII. Reviewers and Approvals (include signatures from Parsed Management System[s] Executive[s] if the Request has cross-disciplinary impact[s])			
Print Name	**Signature**	**Org/ Role**	**Date**
Michael Gaffney	MHGAFF/e/	SHSD/ODH SME	28 Dec 2017
		Primary MS Executive	
GAIL MATTSON	[signature]	***Primary MS Steward**	1-2-18

***MS Steward signature/approval is not required for waivers to internal requirements and for below-waiver threshold items**

Approved Evaluation form is transmitted to Requirements Management SME

Department of Energy
Brookhaven Site Office
P.O. Box 5000
Upton, New York 11973

JAN 3 0 2017

Ms. Gail Mattson
Brookhaven Science Associates, LLC
Brookhaven National Laboratory
Upton, New York 11973

Dear Ms. Mattson:

SUBJECT: APPROVAL OF THE REVISED ACCELERATOR SAFETY ENVELOPE (ASE) FOR THE NATIONAL SYNCHROTRON LIGHT SOURCE II (NSLS-II)

Reference: Letter from G. Mattson, BSA to F. Crescenzo, SC-BHSO, Subject: Request BHSO's Approval of the USI No. NSLS-II EVAL-2017-001, "PPS Functional Testing and Recertification/Revalidation Interval Change from Every Six Months to Twelve Months", dated January 23, 2017

The Department of Energy (DOE) Brookhaven Site Office (BHSO) has reviewed your request for approval of the revised NSLS-II ASE. The ASE revision changes the recertification and revalidation time interval of the Personal Protective System from every six months to every twelve months in accordance with the Brookhaven National Laboratory Internal Waiver granted by the Radiological Control Division. Based on the analysis presented in the waiver and the Unreviewed Safety Issue, BHSO approves the ASE revision.

If you have any questions please contact Patrick Sullivan, of my staff, at extension 4092.

Sincerely,

Frank J. Crescenzo
Site Manager

cc: M. Dikeakos, SC-BHSO
R. Gordon, SC-BHSO
P. Sullivan, SC-BHSO
R. Lee, BSA
C. Schaefer, BSA

Associate Laboratory Director, ES&H

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BROOKHAVEN
NATIONAL LABORATORY

Managed by Brookhaven Science Associates
for the U.S. Department of Energy

www.bnl.gov

January 23, 2017

Mr. Frank Crescenzo
Site Manager
Brookhaven Site Office
U.S. Department of Energy
Upton, NY 11973-5000

Dear Mr. Crescenzo:

Subject: Request BHSO's Approval of the USI No. NSLS-II EVAL-2017-001, "PPS Functional Testing and Recertification/Revalidation Interval Change from Every Six Months to Twelve Months"

Upon review of the attached documentation, I concur with the Laboratory ESH Committee (LESHC) recommendation to approve the revisions to the NSLS-II Accelerator Safety Envelope (ASE). The NSLS-II EVAL-2017-001, "PPS Functional Testing and Recertification/ Revalidation Interval Change from Every Six Months to Twelve Months" describes the bases for the ASE change.

I am submitting the USI and revised ASE to the Brookhaven Site Office for review and approval. Attached is relevant documentation to assist you.

Sincerely yours,

for G. Mattson

Gail Mattson
ALD, ESH

Attachments:
USI No. NSLS-II EVAL-2017-001, "PPS Functional Testing and Recertification/ Revalidation Interval Change from Every Six Months to Twelve Months"
NSLS-II Accelerator Safety Envelope (ASE)

Copy: P. Sullivan (BHSO)
E. Lessard (w/o att.)
R. Lee (w/o att.)

Unreviewed Safety Issue (USI) Evaluation Form

USI Evaluation No.: NSLS-II-EVAL-2017-001

Title of USI Evaluation and Sponsor or Condition Owner:

PPS Functional Testing and Recertification / Revalidation Interval Change from Every Six Months to Twelve Months

Steven Moss, NSLS-II Authorization Basis Manager

I. Description of Proposed Activity or Discovered Condition

NSLS-II seeks an exemption to the interlock certification period of six months required under current BNL Radiological Controls Manual Appendix 3A (4e) with a permanent extension to twelve months and the right to receive up to a 3-month allowance (not to exceed 15 months, overall), contingent upon valid operating schedule issues. See below for affected Credited Controls and impacted ASE/SAD sections. See Attachment 'A' for a marked-up copy of the pages to be changed in the ASE and in the SAD. See Attachment 'B' for the detailed Hazard Analysis [Ref. 8, 9].

REFERENCES

1) *Unreviewed Safety Issue Determination Procedure*, PS-C-ESH-PRC-002, Ver. 4, June 27, 2014.

2) *Safety Assessment Document for the National Synchrotron Light Source II*, PS-C-ESH-RPT-001, Ver. 3, May 2015.

3) *Amendment No. 1 to NSLS-II SAD of May 2015;* dated December 21, 2015 [containing DOE Approval of USI Evaluation No. NSLS-II-EVAL-2015-004, Rev. 1: *Re-Statement of NSLS-II ASE Stored Beam Lower Energy Limit for Storage Ring,* dated December 1, 2015]

4) *Amendment No. 2 to NSLS-II SAD of May 2015;* dated June 3, 2016 [containing DOE Approval of USI Evaluation No. NSLS-II-EVAL-2016-005: *Authorized Alternative for Lowering the Minimum NSLS-II Booster Electron Injection Energy Limit,* dated May 25, 2016]

5) *Accelerator Safety Envelope (ASE) NSLS-II,* PS-C-ESH-ROASE-001, Ver. 4, June 2016.

6) *Radiological Control Manual (Brookhaven National Laboratory)* Revision 6 dated August 31, 2016.

7) BNL Memo dated December 8, 2016 from Z. Zhong (Chair – NSLS-II Radiation Safety Committee) to R. Lee (NSLS-II ESH&Q Manager) with subject; *Radiation Safety Committee Endorsement of the Proposal to Test the NSLS-II PPS Annually.*

8) BNL Memo dated December 12, 2016 from R. Lee (NSLS-II ESH&Q Manager) to S. Coleman (BNL Radiological Control Division Manager) with subject; *Request for Exemption to Six Month Testing of the NSLS-II Personnel Protection System.* [copy included within Attachment 'B']

9) BNL E-Mail dated January 13, 2017 from B. Lettier (BNL Radiological Control Division, Sr. Admin. Asst.) to Recipients with attached approved Internal Waiver Request as signed by SME/AHJ (S. Coleman dated 1/10/17) and Management System Steward (G. Mattson dated 1/10/17). [copy included within Attachment 'B']

II. Does the proposed activity or discovered condition affect information presented in the Safety Assessment Document (SAD) (e.g., regarding equipment, administrative controls, or safety analyses)?

YES – Within the Safety Assessment Document for the National Synchrotron Light Source II [PS-C-ESH-RPT-001, Ver. 3 dated May 2015], there is specific reference to the intervals at which the PPS must be functionally tested and revalidated (consistent with the BNL Radiological Control Manual). **Section 5.2.8 – Calibration, Testing, Maintenance and Inspection that maintain Credited Controls** states (under the first bullet):

All PPS must be functionally tested and revalidated at intervals consistent with the BNL Radiological Control Manual

Basis: The continued reliability of the PPS requires that it be tested and re-certified at regular intervals and following any modification of the system to confirm that no protective function degradation has occurred as a result of component failure or human error. Test intervals are specified in the BNL Radiological Control Manual (Appendix 3A). With the consent of the Manager of the BNL Radiological Control Division, the interval between tests may be extended. Records of all tests and certifications must be retained.

Additionally, there is passing reference in **Section 6.4 – Documents and Records**, where it states:

Examples include the 6-month validation testing of the PPS interlocks procedures; ...

III. **Does the proposed activity or discovered condition affect any of the requirements of the Accelerator Safety Envelope (ASE)?**

YES – The DOE-approved NSLS II ASE [PS-C-ESH-ROASE-001], Ver. 4 dated June, 2016; does currently include one Calibration, Testing, Maintenance and Inspection That Maintain Credited Controls criterion that must be revised in order to adjust the frequency of PPS Re-validation /Re-certification. Specifically, criterion 4.1 states:

All PPS must be functionally tested and revalidated at intervals consistent with the BNL Radiological Control Manual (Appendix 3A)

IV. USI Evaluation Criteria

1. Could the change or discovered condition significantly increase the probability of occurrence of an accident previously evaluated in the SAD?

   ☐Y or ☒N

   Justification: The proposed change in the interlock certification period from six (6) months to twelve (12) months could NOT significantly increase the probability of occurrence of an accident previously evaluated in the SAD. The NSLS-II PPS systems were designed and constructed with an expected testing frequency of 12 months. An independent evaluation of the system was performed that determined the probability of failure for the system is better than a SIL-3 rated system with a test period of 12 months for non-PLC components (10 years for PLC components). The time needed to test the PPS system every six months is becoming a daunting challenge due to the continual increase of the number of affected systems installed, with each additional beamline added. Attachment B [Ref. 8] contains details on the independent evaluation and operational experience to date.

   Changing the interlock certification period from 6 to 12 months does NOT significantly increase the probability of occurrence of an accident previously evaluated in the SAD.

2. Could the change or discovered condition significantly increase the consequences of an accident previously evaluated in the SAD?

   ☐Y or ☒N

   Justification: The proposed change in the interlock certification period from six (6) months to twelve (12) months could NOT significantly increase the consequences of an accident previously evaluated in the SAD. The consequences of accidents and events postulated within the SAD have all been determined and cannot be affected by a change in the frequency of certification testing. The only way to increase the consequence of any accident previously evaluated within the SAD would be to change a parameter of the event itself or to add additional concurrent events to an already analyzed event. That cannot happen merely via a change in testing frequency as the original design and failure probability spectrum was based on a certification frequency of 12 months (annual). The proposed change in the interlock certification period from six (6) months to twelve (12) months could NOT significantly increase the consequences of an accident previously evaluated in the SAD.

3. Could the change or discovered condition significantly increase the probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD?

   ☐Y or ☒N

   Justification: The proposed change in the interlock certification period from six (6) months to twelve (12) months could NOT significantly increase the probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD. The NSLS-II PPS systems were designed and constructed with an expected testing frequency of 12 months. An independent evaluation of the system was performed that determined the probability of failure for the system is better than a SIL-3 rated system with a test period of 12 months for non-PLC components (10 years for PLC components). Attachment B [Ref. 8] contains details on the independent evaluation and operational experience to date. Changing the interlock certification period from 6 to 12 months does NOT significantly increase the probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD.

4. Could the change or discovered condition significantly increase the consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD?

   ☐Y or ☒N

   Justification: The proposed change in the interlock certification period from six (6) months to twelve (12) months could NOT significantly increase the consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD. The consequences of malfunctions of equipment important to safety postulated within the SAD have all been determined and cannot be affected by a change in the frequency of certification testing. The only way to increase the consequence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated within the SAD would be to change a parameter of the event itself or to add additional concurrent events to an already analyzed event. That cannot happen merely via a change in testing frequency as the original design and failure probability spectrum was based on a certification frequency of 12 months (annual). The proposed change in the interlock certification period from six (6) months to twelve (12) months could NOT significantly increase the consequences of a malfunction of equipment important to safety previously evaluated in the SAD.

5. Could the change or discovered condition create the possibility of a different type of accident than any previously evaluated in the SAD that would have potentially significant safety consequences?

☐Y or ☒N

Justification: The proposed change in the interlock certification period from six (6) months to twelve (12) months could NOT create the possibility of a different type of accident than any previously evaluated in the SAD that would have potentially significant safety consequences. Attachment B [Ref. 8] – BNL Memo dated December 12, 2016 from R. Lee (NSLS-II ESH&Q Manager) to S. Coleman (BNL Radiological Control Division Manager) with subject; *Request for Exemption to Six Month Testing of the NSLS-II Personnel Protection System*, provides the necessary technical assurance to conclude that the proposed change in the interlock certification period from six (6) months to twelve (12) months creates no new or different type of accident than any previously evaluated in the SAD that would have potentially significant safety consequences.

6. Could the change increase the possibility of a different type of malfunction of equipment important to safety (e.g., engineered credited controls) than any previously evaluated in the SAD?

☐Y or ☒N

Justification: The proposed change in the interlock certification period from six (6) months to twelve (12) months could NOT increase the possibility of a different type of malfunction of equipment important to safety (e.g., engineered credited controls) than any previously evaluated in the SAD. Attachment B [Ref. 8] – BNL Memo dated December 12, 2016 from R. Lee (NSLS-II ESH&Q Manager) to S. Coleman (BNL Radiological Control Division Manager) with subject; *Request for Exemption to Six Month Testing of the NSLS-II Personnel Protection System*, provides the necessary technical assurance to conclude that the proposed change in the interlock certification period from six (6) months to twelve (12) months does NOT increase the possibility of a different type of malfunction of equipment important to safety (e.g., engineered credited controls) than any previously evaluated in the SAD.

V. USI Determination

A USI is determined to exist if the answer to any of the 6 questions above (in Section V) is "Yes." If the answers to all 6 questions are "No," then no USI exists.*

Does the proposed activity (or discovered condition) constitute a USI?

☒ Yes – DOE approval required prior to implementing, or discovered condition remedied in accordance with the Section 6.4 of PS-C-ESH-PRC-002, *Unreviewed Safety Issue Determination Procedure.*

☐ ~~No – Proposed activity may be implemented with appropriate internal review, or no~~ further action is required to address the discovered condition's impact on accelerator safety (other actions may be required to meet other PSD or Laboratory requirements).

*According to the SBMS Subject Area, *Accelerator Safety; Section 8 – Unreviewed Safety Issue (USI) Process; Step 6:* **If the USI Process determination is that the discovery or planned change will impact credited controls**, existing MCIs, create new MCIs or cause an increase in the risk classification as per the SAD risk table, **it is a USI.**

STEVEN H. MOSS / [signature] 01/13/2017
Prepared by: (Qualified Evaluator) *Date*

[signature] 1-17-17
Approved by: *Date*

ATT. A

approved by the NSLS-II designated person must authorize all work on these components. Following all work, the PPS system shall be tested and certified to have been restored to its proper configuration and function. Barriers such as gates and fencing are subject to a routine inspection procedure to ensure the barriers remain in their approved configuration.

- **The area radiation monitoring system interfaced with the PPS shall be maintained in its approved configuration (Beam requirement only)**

  Basis: The area monitoring system is expected to measure elevated radiation levels and stop further injection if these levels exceed established alarm points. Area monitors have been located on the basis of anticipated loss points. The area monitoring units are labeled as subject to configuration control and any change in location or set point is controlled by procedure. Only designated personnel are authorized to adjust the units. The functionality of the area monitoring system will be tested as a part of the PPS certification program. During the machine operating periods, the radiation monitors will be checked with a radiation source to confirm proper response of the monitor and the interlock. This will occur during interlock checks and b) every time a monitor is exchanged for repair or calibration. The area radiation monitoring system is not required for RF cavity testing since the shielding is adequate for protection of personnel, even for cavity worst case operations

- **The polarity of the Booster ring dipoles, the BTS transport line dipoles and all ring dipole magnets (not including corrector dipoles) must be confirmed to be correct and subject to a formal configuration control program (beam requirement only)**

  Basis: The mis–steering analyses performed the Booster, for electron transport to the Storage Ring and for stored beam within the Storage Ring assumed that all dipole magnets (except corrector dipoles) had the proper power supply polarity. The analyses are not valid and could create an unreviewed safety issue if the polarity of one or more of these magnets were reversed. A formal program has been developed to establish and maintain the correct polarities.

- **All new beamline frontends, and modifications to existing beamline frontends must be approved for Top-Off operation by designated Top-Off Technical Authority, in accordance with procedure, prior to enabling the beamline during Top-Off operation. Top-Off must be disabled prior to enabling any beamline that is not yet approved for Top-Off.**

  Basis: Review and analysis of new or modified beamline frontends by Technical Authority is necessary to assure radiation controls are in place for Top-Off operation of the beamline and that compliance with NSLS-II Shielding Policy is verified and confirmed.

5.2.8 Calibration, Testing, Maintenance and Inspection that maintain Credited Controls

- **All PPS must be functionally tested and revalidated ~~at intervals consistent with the BNL Radiological Control Manual~~** [EVERY 12 MONTHS, NOT TO EXCEED 15 MONTHS TO PERMIT VARIANCES IN THE OPERATIONS SCHEDULE]

  Basis: The continued reliability of the PPS requires that it be tested and re–certified at regular intervals and following any modification of the system to confirm that no protective function degradation has occurred as a result of component failure or human error. Test intervals are ~~specified in the BNL Radiological Control Manual (Appendix 3A).~~ [EVERY 12 MONTHS NOT TO EXCEED 15 MONTHS TO PERMIT VARIANCES IN THE OPERATIONS SCHEDULE] With the consent of the Manager of the BNL Radiological Control Division, the interval between tests may be extended. Records of all tests and certifications must be retained.

- **Area radiation monitors must undergo annual calibration. The time between annual calibrations shall not exceed 15 months.**

6 Quality Assurance

6.1 QA Program

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

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

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

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

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

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

6.2 Personnel Training and Qualification

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

6.3 Quality Improvement

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

6.4 Documents and Records

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

NSLS II documents encompass technical information or instructions that address important work tasks, and describe complex or hazardous operations. They include plans, procedures, instructions, drawings, specifications, standards, and reports. Examples include the 3-month validation testing of the PPS interlocks procedures; safety system work permits (for accelerator changes); USI Screening Checklists and Unreviewed Safety Issue (USI) Evaluation forms.

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

4.1 All PPS must be functionally tested and revalidated every 12 months, not to exceed 15 months to permit variances in the operations schedule ~~at intervals consistent with the BNL Radiological Control Manual (Appendix 3A).~~

4.2 Area radiation monitors must undergo annual calibration. The time between annual calibrations shall not exceed 15 months.

4.3 Following all major shutdowns (>15 days), radiological shielding and barriers (berms, shield blocks and fencing) must undergo visual inspection prior to operations to ensure that all required elements are in place and functional.

4.4 TOSS Credited Aperture locations must be certified biennially (every two years). The time between certifications shall not exceed 30 months.

4.5 Oxygen monitors must undergo annual testing; the maximum time between testing must not exceed 15 months. Authorized alternative devices will also be routinely tested (e.g., functional check monthly)

– End –

Att. B

Photon Sciences Directorate

BROOKHAVEN
NATIONAL LABORATORY

Building 745
P.O. Box 5000
Upton, NY 11973-5000
Phone 613-344-7936
Fax: 631-344-5059
blee@bnl.gov

Managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

date: December 12, 2016

to: S. Coleman

from: Robert J. Lee [signature] 12-12-16

subject: Request for Exemption to Six Month Testing of the NSLS-II Personnel Protection System

As you are aware, the NSLS-II has a robust and reliable Personnel Protection Interlock System for the accelerator enclosures and beamlines. The systems have been in operation for up to four years (Linac) and have been tested every six months as required by Appendix 3A(4e) of the Radiological Controls Manual. NSLS-II is seeking an exemption to the six month testing frequency and proposes that testing be done every 12 months with accommodations to extend testing to 15 months should the operations schedule prevent testing at 12 months. As stipulated in Appendix 3A transitioning to an annual testing cycle requires your approval to a formal exemption request.

Attached please find the standard Radiological Control Division Exemption/Variance Request Form and a document to support this petition. In summary the PPS systems at NSLS-II have been designed with an expected testing frequency of twelve months. The system has been independently evaluated by a third-party (SIS TECH LLC). This evaluation supports an annual testing period and estimates the probability of failure at 1.0 E-5.

If there are any questions regarding the attached exemption request, please don't hesitate to contact me at Extension 7936.

cc:

J. Aloi	A. Ackerman	M. Bebon	M. Benmerrouche
S. Buda	R. Chmiel	G. Ganetis	J. Hill
E. Johnson	T. McDonald	S. Moss	T. Shaftan
Q. Shen	L. Stiegler	P. Sullivan (BHSO)	P. Zschack

Att. 'B'

Request for Approval to Perform Annual Personal Protection System Certifications at the NSLS-II

Issue:

Radiation hazards posed by the NSLS-II accelerator and beamlines requires the installation and certification of a Personal Protection System (PPS) that prevents personnel exposures to hazardous radiation conditions, as well as, monitors critical devices to ensure continuous compliance with the NSLS-II Authorization Basis Documents and BNL Radiological Control requirements. A robust PPS system has been designed, and evaluated by an independent third party. The system has a calculated probability of failure of less than 1E-5 with some scenarios less than 1E-6 (i.e., less than once in a million years). Where the probability of failure is defined as the measure in time (years or hours) of the unavailability of a safety function. The system has been installed, maintained and operated for up to four years (Linac). Examination of system events to date show that with the exception of some early malfunctions of mechanical switches due to improper installation, there have been no unsafe events related to the operation of the PPS system. Even in the event concerning two like-switches in one chain failing in the open position which was undetected by PPS, the PPS remained functional through the second chain and a third control (i.e., mag-lock). The PPS systems at NSLS-II have been tested and certified on a semi-annual basis as required by the Radiation Control Manual Appendix 3A, section 4(e)1.

The review by the third party used several assumptions in their evaluation including that all non-PLC based components are tested annually and all PLC components tested every ten years. The analysis, testing performed to date and the PPS events experienced to date all support an annual certification period. The NSLS-II is therefore seeking permission from the Radiological Controls Division to move to an annual certification period for all accelerator and beamline PPS systems. To permit changes in the operations schedule the exemptions should accommodate a test period of up to 15 months.

Background:

The Personal Protection System for the NSLS-II was designed after several years of development and review by NSLS-II managers and the Accelerator Safety Systems Group. In 2010 the final architecture of the PPS was analyzed by SIS TECH Solutions, LLP (ref. 1) to determine the probability of failure for the system. Three modes of failure were analyzed for the five PPS systems (Linac, Booster, Storage Ring, First Optical Enclosure and the Experimental End Station Enclosure). The three modes of failure were:

1. An individual attempts to enter an enclosure without requesting the normal control system to shut down the beam (e.g., breaks a door open to enter the enclosure) while beam or RF is present;

2. Experimenter/staff follows proper procedure to enter an enclosure requesting the control system to shut down the beam but due to equipment failures within the control and safety systems, beam (or RF) is still present after entry;

A11.B

3. An experimenter or staff member has entered an enclosure following proper procedures and the control and safety systems reacted properly. Then while the individual is present malfunction of the control and safety system exposes the individual to beam (or RF).

The failure analysis evaluated two conditions that constitute a complete failure; first failure on-demand of the safety system for a person attempting to make entry and second the failure of the safety subsystem that eliminates beam. Detailed fault tree analyses were performed using ANSI 84 methodologies to determine the probability of failure for each scenario and for each of the enclosure types. Assumptions used in the analysis included no common cause failures since redundant systems are dissimilar, non-PLC systems are tested once per 12 months and PLC systems tested once every ten years.

In summary, the probability of harm per attempt for scenario 1 for the five systems evaluated are better than 3.5×10^{-6}. When one adds the subsystem that prevents beam from being present for scenarios 2 and 3 the rate of a hazardous condition is less than 3×10^{-7}. In terms of Safety Integrity Level (SIL) ratings, the probability of failure on demand and the hazard rate are rated at better than SIL 4. Review of the ANSI-84 SIL Classification process (Ref. 2) indicates that for a location with the potential for serious injury (or one dead), with low probability of occupancy and the ability for someone to escape would be classified to require a system at SIL-2. A typical SIL rating applied to electron accelerators and associated beamline operations is SIL-3. The NSLS-II system design surpasses both recommended and common practice standards.

The PPS also provides protection for equipment (e.g., collimators), protects the authorization basis limiting conditions (e.g., total injected charge per hour), and ensures operability of other devices used to maintain dose rates on the experimental floor ALARA (e.g., area radiation monitors (ARM)). These include: vacuum switches, water flow monitoring devices, injected charge monitoring systems, current monitoring devices and apertures used to ensure the beam remains within the intended trajectory (e.g., PPS apertures). Many of the components used in these devices are SIL rated (3) and independent analyses of the in-house designed circuits (e.g., Accumulated Charge Monitoring system, including the stored beam current monitor, yielded similar probabilities of failure (3). In the case of the ACMI the probability of failure was calculated to be 4.9 E-7 hours. Although the reliability of these devices and systems were not evaluated as part of the SIS TECH analysis, the same level of rigor was applied to the design, installation and testing as was applied to the access control devices. Additionally, many of the components act together to maintain dose on the experimental floor ALARA. For example failure of a PPS aperture could result in damage to a beamline component which could yield a higher than expected dose rate on the experimental floor. The elevated dose rate would be detected by an ARM which would shut down the beamline (close the front end shutter) or if the shutter fails to close in a predetermined time then dump the stored beam. A complete failure would require breach of three levels of protection. To date there have been no unsafe failures of these protective devices and testing at six month intervals performed to date showed all components to react as designed.

Operational Experience:

Ref 1: Failure Analysis of the NSLS-II PPS System, SIS TECH, LLP, May 20 2010
Ref. 2: American National Standard, ANSI/ISA-84.00.01-2004 part 3
Ref. 3: Fault Tree Analysis ACMI-FE Analog Processor, Probabilistic Software, Inc. July 2014

ATT. "B"

A system for personnel to log and track PPS system "events" has been in operation since April 2014. From April 2014 to November 2016 there have been 49 PPS logged events (See Table 1). The following observations can be made from the recorded events:

1. No dangerous failures (both chains failed to shutdown)
2. No dormant failures (switches or equipment that failed without alarm)
3. No safety significant systematic errors (programming or logic errors that impact safety)
4. Frequent B chain trips of the storage ring were due to a safety monitoring configuration time less than the actual communication time. When the monitoring time was configured to be greater than the communication time, tripping was resolved.
5. Frequent (during early operations) events due to misaligned switch positions (door and photon shutter).
6. Other frequent trips of both chains of system were caused by safety system network connections that were physically intermittent. (CAT5 cable connector problems, all connectors replaced.)
7. Trips due to "shutter closed" switch adjustment were resolved with improved installation procedures.

An event that occurred on January 29, 2015 spurred concern for installation of door switches and associated mounting hardware. Two identical switches in the A chain were found stuck in the closed position when the door was open; the B-chain functioned normally so the system remained safe. Analysis of the switch by the manufacturer showed that over-travel of the switches caused internal wear and ultimately failure of the switch auto-return mechanism. Extensive rework of the switch mounting hardware throughout the facility ensued to ensure manufacturer recommended rotation limits are met and mechanical automatic return hardware added in many locations to ensure the arm returns to its "open" position when the door is open. The mechanical arm type switch, while still in use at many locations, is being slowly replaced by plunger-type and magnetic reed switch designs thereby eliminating the mechanical arm failure

Request to move to PPS Certification every 12 months:

Review of the PPS events experienced to date shows that the PPS functioned as designed in all cases and prevented staff exposure to a hazardous radiological condition. The PPS systems of the NSLSII facility were designed to maintain their safety integrity level for a period of one year between certifications. The diagnostic coverage of the system is designed to detect stuck switches, relays and malfunctioning equipment and alarm in the control room. There were no hidden failures discovered during the certifications performed to date.

The independent analyses of the NSLS-II PPS systems indicate that the system is robust and exceeds the recommended SIL classification. Operational experience to date shows no unsafe events. Moving from a certification period of six months to one year is supported by both analysis and operational experience.

Ref 1: Failure Analysis of the NSLS-II PPS System, SIS TECH, LLP, May 20 2010
Ref. 2: American National Standard, ANSI/ISA-84.00.01-2004 part 3
Ref. 3: Fault Tree Analysis ACMI-FE Analog Processor, Probabilistic Software, Inc. July 2014

Table 1: Summary of PPS Events						
Date of failure (Start date: 4/15/14)	Location	Equipment	Symptom	Corrective Action	Present status	Record Crea
Year 2014						
04/16/14		B chain storage ring PPS Dipole permits	B chain dipole permits at the power supply interface off with no apparent fault, all pentants remained secured.	Following examination of the code by D. Dudley it was found to be a read back error of the B chain dipole permit relays. The control room emergency stop was cycled and then reset. A device in the permit chain, mcr estop, ignition key needed to be cycled to allow a reset. Note, the interlocked signal to the power supply control was able to be reset with the I/O box reset before the permits were re-established.	resolved	Buda
04/21/14		B Chain storage ring	B chain Pentant 5 trip on maintenance door 18	Reset I/O box and re searched ring. Will investigate on next maintenance day	resolved	Buda
04/28/14		B Chain Booster	B chain power supply line cord fuse blown	Replaced 3A fuse with 7 A fuse, load on power supply is well below the fuse rating.	resolved	Buda
10/04/14		b chain md13 and 24	insulation for md switches under screw	repositioned wires and tested		Buda
10/26/14		a chain	cell 1 I/O box a chain line cord fuse blown	replaced fuse and system started normally	resolved	Gallagher
11/10/2014		a chain ID 11 FE photon shutter A1-1 switch	switch not making in the closed position	switch re adjusted	resolved	Buda/Gane

Ref 1: Failure Analysis of the NSLS-II PPS System, SIS TECH, LLP, May 20 2010

Ref. 2: American National Standard, ANSI/ISA-84.00.01-2004 part 3

Ref. 3: Fault Tree Analysis ACMI-FE Analog Processor, Probabilistic Software, Inc. July 2014

Table 1: Summary of PPS Events

Date of failure (Start date: 4/15/14)	Location	Equipment	Symptom	Corrective Action	Present status	Record Creato
12/4/2014		ID28 beamline enable switch	B chain would not enable	Corrected improper mounting screw keeping the contact block from engaging	resolved	Santiago
12/4/2014		ID29 maintenance door B chain intermittent trip		Inspected switch wiring and found one terminal with insulation under wire clamp, repositioned wire	resolved	Buda/Sauerwa
12/4/2014		ID10 FE PS	Tripping on conflict B chain when closing	Readjust switches and slow down speed on PS, readjust SS switches.	resolved	Buda/Sauerwa
12/4/2014		ID3A	FOE door switches	Readjusted switches and door stops, doors hitting each other, added bracket to brace switch bracket, readjusted door speed and operator close switch to prevent bouncing.	resolved	Buda/Sauerwa
12/3/2014		ID10 rad monitors	While trouble shooting a shutter problem during maintenance a fuse blew due to a short created while jumping a shutter open command. The fuse was supplying the bussed power of the I/O box.	Replaced fuse and restored normal operation.	resolved	Buda/Stivala

Ref 1: Failure Analysis of the NSLS-II PPS System, SIS TECH, LLP, May 20 2010
Ref. 2: American National Standard, ANSI/ISA-84.00.01-2004 part 3
Ref. 3: Fault Tree Analysis ACMI-FE Analog Processor, Probabilistic Software, Inc. July 2014

Table 1: Summary of PPS Events

Date of failure (Start date: 4/15/14)	Location	Equipment	Symptom	Corrective Action	Present status	Record Cre
12/11/2014		ID 11 FE PS EPS Shutter switch	Following inspection of switch during shutdown by mechanical group the EPS contact was not making with the shutter closed	Opened the photon shutter and removed the cover of the switch, repositioned the switch block and re attached the cover. The switch contact then functioned normally.	resolved	Buda/Gane
12/12/2014		ID5 B L2S4 PS Shutter	The EPS contact in the A chain photon shutter was not making	Opened the photon shutter and removed the cover of the switch, repositioned the switch block and re attached the cover. The switch contact then functioned normally.	resolved	Buda/Saue
12/14/2014		SR P5 PPS	P5 Tripped on B chain mag lock and emergency stop	Pentant was re searched and operations continued, faults were able to be reset	resolved	Buda
Year 2015						
1/20/2015		ID19 maintenance door B chain trip	Door tripped and reset without any apparent cause	Pentant was re searched and operations continued, faults were able to be reset	resolved	Buda
1/23/2015		P1 GATE 1 mag lock would not read back	P1 would not search	During certification the mag lock at gate 1 did not give a read back when turned on. The mag lock plate was too low by about 1/8 " from the solenoid. When the test plate was put in place the mag lock worked normally. The gate was raised until the alignment was corrected. The pentant was secured as a test.	resolved	Buda/Saue Ganetis

Ref 1: Failure Analysis of the NSLS-II PPS System, SIS TECH, LLP, May 20 2010

Ref. 2: American National Standard, ANSI/ISA-84.00.01-2004 part 3

Ref. 3: Fault Tree Analysis ACMI-FE Analog Processor, Probabilistic Software, Inc. July 2014

Table 1: Summary of PPS Events

Date of failure (Start date: 4/15/14)	Location	Equipment	Symptom	Corrective Action	Present status	Record Creato
1/29/2015		P1 SB door switch stuck closed A chain	Noticed during securing of P1	Switch replaced, all switches in facility inspected. All switches on SB1 active door replaced, ISA door B1B, SB2 1A1 replaced. Engineered mechanical device nstalled on all facility doors with PPS switches to force switches open on every operation of doors. Manufacturer analysis states cause of failure was due to over travel on switch operator. Following the report the certification test fixtures were modified to limit travel within factory recommendations. Where possible levers were replaced with plunger actuators and for new designs magnetic switches are used. During surveillance a number of other switches exhibited increased resistance on operating the lever indicating internal binding and were replaced. this comment applies to both the A and B chain switches, both exhibited the same problems.	resolved	Buda/Sauerwa Gallagher, Sar
2/11/2015		ID23 Aux. Box B Chain	Shutter L1B3 Permit went away	Hardware Reset, then system Reset	Resolved	Buda/ Xin
2/11/2015		ID23 Maglock Keypad Release	After an unsuccessful search Maglocks can not be reenergized from Keypad when all shutters are closed	Programming error resolved with changing standard program.	resolved	Buda/Xin
2/12/2015	ID23	L1A3 Photon Shutter Conflict	L1A3 photon shutter conflicted on opening	Edwin Hass adjusted the open switch accordingly and cycled shutter approx. 20 times without conflict.	resolved 2/12/2015	Orr

Ref 1: Failure Analysis of the NSLS-II PPS System, SIS TECH, LLP, May 20 2010

Ref. 2: American National Standard, ANSI/ISA-84.00.01-2004 part 3

Ref. 3: Fault Tree Analysis ACMI-FE Analog Processor, Probabilistic Software, Inc. July 2014

Table 1: Summary of PPS Events

Date of failure (Start date: 4/15/14)	Location	Equipment	Symptom	Corrective Action	Present status	Record Cre
2/13/2015	ID5	ID5_D Door Switch A chain	Doesn't read left door sw. Top switch needs adjustment.	Switches adjusted as per Mark Breitfeller and Certified by Bob Chmiel	resolved 2/17/2015	Orr
2/13/2015	ID3	ID3_C Maglock	Doesn't release ID3_C Maglock when PS 1 is open	Incorrect Shutter contact placed in ID3_C logic DB2.DBX2.6 instead of DB3.DBX2.1.	resolved	Orr
2/18/2015	ID3	ID3_FOE Door Actuator	Not closing completely due to twisted connection point between door and actuator	Need new Interconnect bracket	resolved	Sauerwald
2/20/2015	ID11	Safety Shutter A	Did not indicate CLOSED	Frank Lincoln repositioned Closed Switch A1-1	resolved 2/20/15	JJG/Sauerw
3/10/2015	ID10	Photon Shutter, beamline	a speed difference between A and B shutters was noted.	The speed of the shutters was adjusted to be equal.	resolved 3/10/2015	JJG/Sauerw
3/11/2015	ID5,6	SR I/O box 5, 6	A Chain Network dropped out	replaced faulty CAT 5 cable	resolved 3/11/2015	Santiago
3/14/2015	ID3	id3 foe enclosure	fuse blown	replaced fuse and reset boxes	resolved 3/14/15	Santiago/Xi
3/24/2015	ID3	id3 foe enclosure	lost sigs and fuse blown	replaced fuse and reset boxes investigating on 3/24 maint day	resolved 3/24/2015	Santiago
3/26/2015	ID11	Front End Interlock	A permit dropped on 11ID	Investigated, no problem found, restart normal, shutters closed at the time	resolved	Buda
4/6/2015	ID16	ARM trip	ARM tripped at ID16	Found network switch and safety modules faulted, reset to normal operation.	unresolved	Santiago

Ref 1: Failure Analysis of the NSLS-II PPS System, SIS TECH, LLP, May 20 2010
Ref. 2: American National Standard, ANSI/ISA-84.00.01-2004 part 3
Ref. 3: Fault Tree Analysis ACMI-FE Analog Processor, Probabilistic Software, Inc. July 2014

Table 1: Summary of PPS Events

Date of failure (Start date: 4/15/14)	Location	Equipment	Symptom	Corrective Action	Present status	Record Creat
5/1/2015	Linac PPS	Overheated fuse holder	Fuse holder overheated on A chain and interrupted power to A chain system causing booster security to dump.	Fuse holder replaced with circuit breaker and system restored to normal operation.	resolved	Buda
6/1/2015	RF	RF PPS test mode	Cant reset RF waveguide after test. B chain	Used the MCR E stop and reset to reset waveguide switch and RF test mode.	resolved 12/19/2015	Buda
6/2/2015	SR	SR P5 PPS B chain	Interlock dumped from SB 5 door and E stop	System reset normally, problem resolved with correcting safety watchdog timer timeout.	resolved 12/19/2015	Buda/Xin
6/16/2015	ID23	ID23 FOE downstream door	Door has closing problem causing PPS faults	Door was causing switch 1oo2 faults, replaced door brackets and re adjusted switches.	resolved 6/16/2015	JJG/Sauerwal
8/11/2015	SR FE	SR front end PPS A,B Chain	All A and B chain front ends tripped	The 24V power backup modules dropped out from power dip, config sw set wrong.	resolved 8/11/2015	Xin/ Orr
10/7/2015	SR PPS	SR P2 PPS A chain	Secured status drop out with no faults found.	Due to intermittent CAT5 network connectors, replaced all in system.	resolved 10/7/2015	Buda
10/14/2015	ID11 FE	SR ID11 A chain front end PPS	ID11 PPS dropping out and tripping the ring	Safety shutter A closed position switch re adjusted.	resolved10/14/2015	Buda
10/15/2015	ID3C EESE	ID3 EESE Chain B	Shutter relay read back fault causing shutter interlock	Relay not drawing min. current. Placed resistor in parallel.	resolved 10/15/2015	Buda

Ref 1: Failure Analysis of the NSLS-II PPS System, SIS TECH, LLP, May 20 2010
Ref. 2: American National Standard, ANSI/ISA-84.00.01-2004 part 3
Ref. 3: Fault Tree Analysis ACMI-FE Analog Processor, Probabilistic Software, Inc. July 2014

Table 1: Summary of PPS Events

Date of failure (Start date: 4/15/14)	Location	Equipment	Symptom	Corrective Action	Present status	Record Cre
				YEAR 2016		
1/5/2016	SR P2	SR P2 PPS HMI	HMI stopped displaying data	Reloaded firmware and program, resolved operation.	resolved 1/5/2016	Santiago
1/29/2016	SR P4	SR P4 PPS B Chain	Frequent dumping of the security in P4 over several hours.	Replaced P4 central B Chain communications switch, intermittent from overheating, placed fans in all I/O cabinets that required cooling.	resolved 1/29/2016	Buda
2/18/2016	ID16 A	ID16 EESE A Photon shutter B Chain	Shutter delay on close causing shutter conflict faults.	Re adjusted photon shutter B closed proximity sensor.	resolved 2/18/2016	Xin
2/19/2016	Booster PPS	Booster PPS A Chain	Booster tripping on MCR E stop with no actual E stop being pushed.	Replaced A Chain network switch with faulty fiber optic port.	resolved 2/19/2016	Buda
2/29/2016	BSTR	Booster A chain	A chain critical devices dropping out randomly	Replaced fiber optic Ethernet switch, fiber port bad, other port on module was ok.	resolved	Buda
7/26/2016	Linac PPS	Linac PPS A & B Chain	Safety trip amplifiers fault occasionally requiring a reset.	Placed ferrite beads in analog input lines, reduced trips but did not eliminate them. Installed manufacturer updated trip amplifiers and solved the tripping problem.	resolved	Buda
9/15/2016	BSTR	BSTR BSB2 A CHAIN TRIP AMPLIFIER	Not able to inject into storage ring, gun inhibited.	Found loose sensor wire in the B2 PPS shunt box, tightened terminal	resolved	Buda
10/8/2016	P5 PPS	Storage ring interlock	P5 search dropped out	Blown A chain fuse main power distribution A, replaced with 10A and will replace with circuit breaker in he future in all I/O boxes.	resolved	Buda/Sant

Ref 1: Failure Analysis of the NSLS-II PPS System, SIS TECH, LLP, May 20 2010
Ref. 2: American National Standard, ANSI/ISA-84.00.01-2004 part 3
Ref. 3: Fault Tree Analysis ACMI-FE Analog Processor, Probabilistic Software, Inc. July 2014

Att 6 B.

Table 1: Summary of PPS Events

Date of failure (Start date: 4/15/14)	Location	Equipment	Symptom	Corrective Action	Present status	Record Creat
10/27/2016	BSTR	BSTR BSB2 A CHAIN TRIP AMPLIFIER	Not able to inject into storage ring, gun inhibited.	Reset the trip amplifier and returned to normal operation. Need to upgrade or replace trip amplifiers due to this known problem. The trip amplifier symptom is an ADC fault. Manufacturer has a update for this problem and the malfunction produces a safe failure mode.	resolved	Buda/Santiag
10/27/2016	ID17B	ID17B HMI Display	Display blacked out and could not access hutch	Cycled power to HMI, possible connection issue with power connector, also supplies keypad this would make closing the shutter and gaining access not possible.	resolved	Buda/Santiag
11/28/2016	I/O 17	ID17 A-Chain Power Supply Swap out	ID17C Hutch dropping out due to voltage variations on the A-Cain Power	Swapped out A-Chain Power Supply and Capacitor backup for Beamline	resolved	Buda/Sauerw

Ref 1: Failure Analysis of the NSLS-II PPS System, SIS TECH, LLP, May 20 2010

Ref. 2: American National Standard, ANSI/ISA-84.00.01-2004 part 3

Ref. 3: Fault Tree Analysis ACMI-FE Analog Processor, Probabilistic Software, Inc. July 2014

ATT. 'B'

Moss, Steven H

From:	Lettieri, Beth M
Sent:	Friday, January 13, 2017 8:36 AM
To:	Coleman, Steven A; Schaefer, Charles W; Bebon, Michael J; Moss, Steven H; Lee, Robert J; Todosow, Helen K
Subject:	NSLS II Interlock Waiver
Attachments:	NSLS_II_Interlock_Waiver.pdf

Hi All,
Please see attached from Steve Coleman.

Thanks,
Beth

Beth Lettieri, CAP
Assistant to Dr. Steven A. Coleman
Deputy Associate Laboratory Director for ES&H
Manager of the Radiological Control Division
Brookhaven National Laboratory
81 Cornell Avenue – Bldg. 120
Upton, NY 11973
(631) 344-8035
blettieri@bnl.gov

ATT. 'B'

Waiver #:

Assigned by SBMS

Brookhaven National Laboratory
Internal Waiver Request and Approval

Section 1 – To be completed by Requestor

Page 1 of _3__

Initiating Organization: _National Synchrotron Light Source II
Management System: _Radiological Control_
Management System Steward: _Gail Mattson_

Waiver Type: X Permanent ☐ Temporary Start Date: ________ End Date: ________

1. **Identify the Relevant Requirement:** NSLS-II seeks an exemption to the interlock certification period of six months required under the BNL Radiological Controls Manual Appendix 3A (4e).

2. **Describe Subject/Operation Affected by the Required Procedure:** (*Provide background for waiver request; describe project operation, activity, group, how they are affected by the required procedure, and why the request is being submitted*).

NSLS-II seeks an exemption to the interlock certification period of six months required under the BNL Radiological Controls Manual Appendix 3A (4e). The NSLS-II PPS systems were designed and constructed with an expected testing frequency of 12 months. An independent evaluation of the system was performed that determined the probability of failure for the system is better than a SIL-3 rated system with a test period of 12 months for non-PLC components (10 years for PLC components). The time needed to test the PPS systems every six months is becoming an increasing challenge due to the number of systems being installed.

A supporting document is attached that provides details on the independent evaluation and operational experiences to date.

3. **Describe the Waiver Approach:** (*Analyze the approach and describe how it will satisfy the required procedure).*

The NSLS-II PPS was designed with an expected testing frequency of 12 months. Independent analysis of the PPS systems and operational experience support an annual testing schedule. NSLS-II will continue to test and certify the PPS systems for the accelerators and beamlines every 12 months with accommodations to extend the testing period to 15 months if the operations schedule prevents testing at 12 months. This request is consistent with the Radiological Control Manual requirements, as permitted by the Radiological Controls Division Manager.

4. **List Required Actions:** (*List compensatory actions that provide equivalent protection/assurance to be taken based on the analysis of the approach in step 3*).

Testing will be performed annually (not to exceed 15 months). The system has been designed and evaluated assuming a 12 month testing cycle. The diagnostic coverage of the system is designed to detect stuck switches, relays and malfunctioning equipment and alarm in the control room. There were no hidden failures discovered during the certifications performed to date. The system as designed, installed and tested provides protection equivalent to six month testing.

Signatures:

Waiver Requestor: [signature] Date: 12-14-16
Phone #: 7936 Building: 745
Department Chair/Division Manager: [signature] Date: 12-14-16

ATT.'B'

NO WORK IS TO PROCEED UNDER THIS REQUEST UNTIL OFFICIAL APPROVAL IS RECEIVED FROM THE MANAGEMENT SYSTEM STEWARD

Continued on Next Page

Section 2 – To be completed by SME / AHJ

Determination by Subject Matter Expert / Authority Having Jurisdiction:

☒ Internal Waiver Approved

☐ External Variance/Exemption Required (Waiver request cancelled and Requestor notified that an external variance request must be processed per Requirements Management Subject Area, Section 5 *Requesting a Subject Area or Program Description Variance/Exemption from an External Requirements Document.* Record in Section 3 that MS Steward approval is N/A and continue to Section 4 – Distribution.)

☐ Equivalency – determination by AHJ (for Safety & Health related Waiver request)

☐ Waiver Denied (Waiver request cancelled and Requestor notified. Record in Section 3 that MS Steward approval is N/A and continue to Section 4 – Distribution.)

Requirement Information – Appendix 3A, Physical Access Controls for High
Requirement Title: and Very High Radiation Areas
Citation Text: "Tests of All Components Shall take place within an
Other Related Citations: Interval of Six Months" (p. 80).
"Exemptions from testing requirements may be requested from Manager" (80)

SME / AHJ Signature: [signature] Date: 1/10/17

Check appropriate AHJ or SME:

☐ Laboratory Fire Safety Committee (LFSC)
☐ Electrical Safety Committee (LESC)
☐ Laboratory ESH Committee (Pressure Safety)
☐ Institutional Biosafety Committee
☒ Subject Area SME – Title of Subject Area: Radiological Control Manual - Program Description.

☒ SME / AHJ Analysis Attached

Section 3 – Management System Steward Approval

Signature Approval:

Management System Steward: [signature] Date: 1-10-17

☐ N/A (Steward signature not necessary when waiver cancelled because External Variance/Exemption required or when the waiver is denied)

Section 4 – Distribution

Approved Waiver:

☐ Original approved Waiver sent to the BNL Requirements Coordinator
☐ Copy of approved Waiver sent to Requestor

Cancelled Waiver - External Variance/Exemption Required or Waiver Denied:

☐ Waiver request cancelled and sent to the Requestor
☐ Copy of Waiver sent to BNL Requirements Coordinator

ATT. 'B'

NO WORK IS TO PROCEED UNDER THIS REQUEST UNTIL OFFICIAL APPROVAL IS RECEIVED FROM THE MANAGEMENT SYSTEM STEWARD

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Unreviewed Safety Issue (USI) Evaluation Form

USI Evaluation No.: NSLS-II-EVAL-2016-005

Title of USI Evaluation and Sponsor or Condition Owner:

Authorized Alternative for Lowering the Minimum NSLS-II Booster Electron Injection Energy Limit

Steven Moss, PS Authorization Basis Manager

I. Description of Proposed Activity or Discovered Condition

See Attachment 'A' which includes Description of Proposed Activity and Safety Analysis. See below for affected Credited Controls and affected SAD sections. See Attachment 'B' for a marked-up copy of the pages to be changed in the ASE and in the SAD. See Attachment 'C' for the detailed Hazard Analysis [Ref. 6].

REFERENCES

1) *Unreviewed Safety Issue Determination Procedure*, PS-C-ESH-PRC-002, Ver. 4, June 27, 2014.
2) *Safety Assessment Document for the National Synchrotron Light Source II*, PS-C-ESH-RPT-001, Ver. 3, May 2015.
3) *Amendment No. 1 to NSLS-II SAD of May 2015;* dated December 21, 2015 [containing DOE Approval of USI Evaluation No. NSLS-II-EVAL-2015-004, Rev. 1: *Re-Statement of NSLS-II ASE Stored Beam Lower Energy Limit for Storage Ring,* dated December 1, 2015]
4) *Accelerator Safety Envelope (ASE) NSLS-II,* PS-C-ESH-ROASE-001, Ver. 3, November 2015.
5) LT-C-ASD-RSI-BST-001, *"System Specification and Shielding Design Document (SSDS) for the LBT-P2, Booster, and BSR-P1"*, August, 2013.
6) NSLS-II Technical Note No. 214 - *Hazard Analysis for 90 MeV Booster Injection Energy Limit,* 05/18/2016, as prepared by R. Fliller, S. Kramer and R. Faussete. [copy included as Attachment 'C']
7) *Photon Science Radiation Safety Committee (RSC) Memo,* (from Dr. Z. Zhong – Chairman to Dr. R. Fliller & Dr. F. Willeke), with subject, *Review of the radiation safety analysis of the proposed new 90 MeV Booster injection energy limit",* May 18, 2016.

II. Does the proposed activity or discovered condition affect information presented in the Safety Assessment Document (SAD) (e.g., regarding equipment, administrative controls, or safety analyses)?

YES – Within the Safety Assessment Document for the National Synchrotron Light Source II [PS-C-ESH-RPT-001, Ver. 3 dated May 2015], there is specific reference to minimum injected electron energy sent from the Linac to the Booster. Section 5.2.2 – Booster Credited Controls for the MCI; 3rd Bullet states, "**The minimum injected electron energy shall be 150 MeV.**" However, none of the other bullets pertaining to Linac or Booster Credited Controls for the MCI are affected, at all.

Low energy electron injection to the Booster is specifically controlled by implementation of the applicable ASE Limit, as called out in Chapter 5 of the SAD, as well as the ASE itself. Because of the prior significant safety issues associated with the Mis-steering Event during Linac Commissioning, it is understood that changing any of the ASE limits resulting from the corrective or mitigation actions taken after that event, even temporarily, will represent a positive USID, requiring a formal safety analysis and review process within NSLS-II as well as review by LESHC and ALD for ESH. Based upon the analyses attached, which shows NO increase in Hazard or Risk due to lowering the particular ASE Limit in question as long as the re-analyzed shielding conditions comply with the NSLS-II Shielding Policy and it does, the proposed Authorized Alternative should be approved. This would allow the proposed Authorized Alternative to be implemented once the internal BNL/BSA requirements for review and approval are met; with subsequent DOE-BHSO concurrence.

Additional areas of the SAD reviewed for potential impact by the proposed Authorized Alternative include: Section 4.15.8 – Abnormal Operating Conditions, Including Maximum Credible Incident, with particular attention to Sub-section on Summary of Linac Abnormal Operating Conditions and Fault Studies; which refers to Fault conditions established with 150 MeV electrons at various locations, and Summary of Booster Fault Studies, which refer to Fault conditions established with 200 MeV electrons at various locations. See References 5-7, listed above, for original and updated radiological safety and shielding analyses, which confirms compliance of this Authorized Alternative energy limit lowering for electron injection into the Booster with NSLS-II Shielding Policy; and defines the associated temporary changes to be made to the current credited controls.

III. **Does the proposed activity or discovered condition affect any of the requirements of the Accelerator Safety Envelope (ASE)?**

YES – The DOE-approved NSLS II ASE [PS-C-ESH-ROASE-001], Ver. 3 dated November, 2015; does currently include one credited control that must be revised in order to utilize NSLS-II with a minimum injected electron energy of 90 MeV into the Booster. References 5 through 7 above, analyze the radiological risk associated with Electron Injection Energy Limits for the NSLS-II Booster MCI. They clearly show that revising the lower electron energy limit on injected beam into the Booster to allow for continued operation of NSLS-II with reduced injected electron energy into the Booster does not increase established and accepted levels of risk, as the re-calculated consequences still comply with the NSLS-II Shielding Policy and require no additional mitigation, as suggested by the updated analyses. As this mode of operation is intended only during periods when operational conditions preclude the availability of 150 MeV electrons for injection (and/or associated periods of study to prepare for such operations); it has been decided to establish an Authorized Alternative for the current lower electron injection energy limit of 150 MeV, which would remain in place during normal modes (when operational conditions support electron injection energy of 150 MeV or more).

ASE Section 2.1.2. – Credited Controls for Booster Maximum Credible Incident includes one specific commitment which must be modified to allow for the running NSLS-II with only one Linac Klystron operational. ASE Section 2.1.2.3 currently states,

"The minimum injected electron energy shall be 150 MeV."

This shall be supplemented by the following Authorized Alternative [proposed new ASE Section 2.1.2.4],

"Authorized Alternative: In the event that operational conditions require (e.g., only one available klystron) and for the purposes of associated studies, the minimum injected electron energy shall be 90 MeV."

As no changes are proposed to the normal and established limits on maximum injection energy or electron charge to the Booster from the Linac; ASE Sections 2.1.2.1 and 2.1.2.2 will remain in force throughout any operation of the Booster with the Linac.

IV. USI Evaluation Criteria

1. Could the change or discovered condition significantly increase the probability of occurrence of an accident previously evaluated in the SAD?

☐Y or ☒N

Justification: The establishment of an Authorized Alternative which temporarily lowers the ASE limit on minimum electron injection energy into the Booster could NOT significantly increase the probability of occurrence of an accident previously evaluated in the SAD. These include: the Linac MCI Analysis for electron energy of

250 MeV and current of 100 nC/s; the Booster MCI Analysis for electron energy of 3.0 GeV and current of 15 nC/s (with an increase of <5% for scaling up to 3.2 GeV); the Storage Ring MCI Analysis for electron energy of 3.2 GeV and injection current of 15 nC/s; the Storage Ring MCI Analysis for stored electron beam of energy 3.3 GeV and stored beam current of 1,000 mA and the Beamline MCI Vacuum Surges (with potential overheating).

With the Authorized Alternative in place temporarily lowering the minimum electron injection energy to the Booster, the probability of occurrence is not increased, only the potential location of the striking of any mis-steered beam is potentially impacted, which is the basis for the updated computer analysis. With shielding designed for the current higher minimum electron injection energy; no increase in probability of occurrence of a mis-steering event can be correlated to a reduction in the minimum electron injection energy; especially as all the other Credited Controls remain unaffected as established. Attachment A – Description and Safety Analysis Lowering the Minimum NSLS-II Booster Electron Injection Energy Limit, when combined with Attachment C – NSLS-II Technical Note No. 214 [Ref. 6] provide the necessary technical assurance to conclude that the introduction of the Authorized Alternative for the ASE limit, lowering the value on the minimum injected electron energy in the Booster does NOT significantly increase the probability of occurrence of an accident previously evaluated in the SAD.

2. Could the change or discovered condition significantly increase the consequences of an accident previously evaluated in the SAD?

☐Y or ☒N

Justification: The establishment of an Authorized Alternative which temporarily lowers the ASE limit on minimum electron injection energy into the Booster could NOT significantly increase the consequences of an accident previously evaluated in the SAD. These include: the Linac MCI Analysis for electron energy of 250 MeV and current of 100 nC/s; the Booster MCI Analysis for electron energy of 3.0 GeV and current of 15 nC/s (with an increase of <5% for scaling up to 3.2 GeV); the Storage Ring MCI Analysis for electron energy of 3.2 GeV and injection electron current of 15 nC/s; the Storage Ring MCI Analysis for stored electron beam energy of 3.3 GeV and stored beam current of 1,000 mA and the Beamline MCI Vacuum Surges (with potential overheating). With the injection from the Linac to the Booster lowered from a minimum of 150 MeV to a temporarily reduced minimum of 90 MeV [as per the Authorized Alternative] no more serious consequence can be had for those MCI previously analyzed, which are based on 250 MeV electrons leaving the Linac; the remaining established credited controls protect against the impact of reduced injected electron energy into the Booster from affecting previous accident analyses in the SAD, analyzed for higher initial energies (as long as the NSLS-II Shielding Policy is complied with for any newly located fault collision points as a result of lower injection energy of electrons, and it is). Attachment A – Description and Safety Analysis Lowering the Minimum NSLS-II Booster Electron Injection Energy Limit, when combined with Attachment C – NSLS-II Technical Note No. 214 [Ref 6] provide the necessary technical assurance to conclude that the introduction of the Authorized Alternative for the ASE limit, lowering the value on the minimum injected electron energy in the Booster does NOT significantly increase the consequences of an accident previously evaluated in the SAD.

3. Could the change or discovered condition significantly increase the probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD?

☐Y or ☒N

Justification: The establishment of an Authorized Alternative which temporarily lowers the ASE limit on minimum electron injection energy into the Booster could NOT significantly increase the probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD. The temporary lowering of the limit (setpoint) for the minimum injection electron energy does nothing to affect any Credited Control (other than the PPS link to the low limit trip point on the LtB Dipoles B1 and B2, which are designed to be adjustable). Attachment A – Description and Safety Analysis Lowering the Minimum NSLS-II Booster Electron Injection Energy Limit, when combined with Attachment C – NSLS-II Technical Note No. 214 [Ref. 6] provide the necessary technical assurance to conclude that the introduction of the Authorized Alternative for the ASE limit, lowering the value on the minimum injected electron energy in the Booster does NOT significantly increase the probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD (as long as the NSLS-II Shielding Policy is complied with for any newly located fault collision points as a result of lower injection energy of electrons, and it is).

4. Could the change or discovered condition significantly increase the consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD?

☐Y or ☒N

Justification: The establishment of an Authorized Alternative which temporarily lowers the ASE limit on minimum electron injection energy into the Booster could NOT significantly increase the consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD. The temporary lowering of the limit (setpoint) for the minimum injection electron energy into the Booster does nothing to increase the consequences of any malfunction of equipment important to safety previously evaluated in the SAD. Attachment A – Description and Safety Analysis Lowering the Minimum NSLS-II Booster Electron Injection Energy Limit, when combined with Attachment C – NSLS-II Technical Note No. 214 [Ref. 6] provide the necessary technical assurance to conclude that the introduction of the Authorized Alternative for the ASE limit, lowering the value on the minimum injected electron energy in the Booster does NOT significantly increase the consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD.

5. Could the change or discovered condition create the possibility of a different type of accident than any previously evaluated in the SAD that would have potentially significant safety consequences?

☐Y or ☒N

Justification: The establishment of an Authorized Alternative which temporarily lowers the ASE limit on minimum electron injection energy into the Booster could NOT create the possibility of a different type of accident than any previously evaluated in the SAD that would have potentially significant safety consequences. Attachment A – Description and Safety Analysis Lowering the Minimum NSLS-II Booster Electron Injection Energy Limit, when combined with Attachment C – NSLS-II Technical Note No. 214 [Ref. 6] provide the necessary technical assurance to conclude that the introduction of the Authorized Alternative for the ASE limit, lowering the value on the minimum injected electron energy in the Booster creates no new or different type of accident than any previously evaluated in the SAD that would have potentially significant safety consequences.

6. Could the change increase the possibility of a different type of malfunction of equipment important to safety (e.g., engineered credited controls) than any previously evaluated in the SAD?

☐Y or ☒N

Justification: The establishment of an Authorized Alternative which temporarily lowers the ASE limit on minimum electron injection energy into the Booster could NOT increase the possibility of a different type of malfunction of equipment important to safety (e.g., engineered credited controls) than any previously evaluated in the SAD. The DOE-approved NSLS II ASE [PS-C-ESH-ROASE-001], Ver. 3 dated November, 2015; includes all credited controls that are necessary for operations up to the upper electron energy limits of 3.3 GeV in the Storage Ring. Attachment A – Description and Safety Analysis Lowering the Minimum NSLS-II Booster Electron Injection Energy Limit, when combined with Attachment C – NSLS-II technical Note No. 214 [Ref. 6] provide the necessary technical assurance to conclude that the introduction of the Authorized Alternative for the ASE limit, lowering the value on the minimum injected electron energy in the Booster does NOT increase the possibility of a different type of malfunction of equipment important to safety (e.g., engineered credited controls) than any previously evaluated in the SAD, nor does it represent an overall increase in risk (as long as the NSLS-II Shielding Policy is complied with for any newly located fault collision points as a result of lower injection energy of electrons, and it is). The reduction of injected electron energy from the Linac to the Booster could result in a slightly different shielding location struck or angle of strike, but at a reduced energy level, compared to the MCIs previously analyzed.

V. USI Determination

A USI is determined to exist if the answer to any of the 6 questions above (in Section V) is "Yes." If the answers to all 6 questions are "No," then no USI exists.*

Does the proposed activity (or discovered condition) constitute a USI?

☒ Yes – DOE approval required prior to implementing, or discovered condition remedied in accordance with the Section 6.4 of PS-C-ESH-PRC-002, *Unreviewed Safety Issue Determination Procedure.*

☐ No – Proposed activity may be implemented with appropriate internal review, or no further action is required to address the discovered condition's impact on accelerator safety (other actions may be required to meet other PSD or Laboratory requirements).

*According to the SBMS Subject Area, *Accelerator Safety; Section 8 – Unreviewed Safety Issue (USI) Process; Step 6:* **If the USI Process determination is that the discovery or planned change will impact credited controls**, existing MCIs, create new MCIs or cause an increase in the risk classification as per the SAD risk table, **it is a USI**.

S.H. Moss / S.H. Moss

Prepared by: (Qualified Evaluator)

05/25/16

Date

Approved by:

5/25/16

Date

USI Evaluation No.: NSLS-II-2016-005

Attachment A – Description and Safety Analysis

Authorized Alternative for Lowering the Minimum NSLS-II Booster Electron Injection Energy Limit

Description:

SAD Section 5.2.2 – Booster Credited Controls for the MCI [3rd Bullet] states,

"The analysis of mis–steering events for electrons from the injection into Booster and the eventual extraction into the Storage Ring was over the energy range of 150 MeV to 3.2 GeV. Since the Linac could be operated at energies less than 150 MeV, the current in the last dipole in the Linac to Booster transfer line is monitored as a part of the PPS system. If the current in the magnet drops below the value that would inject a 150 MeV electron into the Booster, the current monitor will interlock the Linac electron gun off using the PPS. This credited control prevents faults that have not been analyzed and could possibility exceed the shielding policy."

The NSLS-II linac requires two klystrons to operate at or above the minimum booster injection energy of 150 MeV. Typical operating energy is 200 MeV. There is nominally also a "hot spare" klystron which can be switched online in a few minutes should one of the operating klystrons fail. Part of the procurement of the linac included a fourth klystron as a "cold spare", to serve as a replacement in case one of the three other klystrons needs to be removed for service.

The present state of the NSLS-II linac is that the "cold spare" is being serviced off site, and is not due to return for several months. Recently, the "hot spare" klystron suffered a failure and is not functional at this time. This leaves the linac with only the two operating klystrons. If one of these klystrons were to fail, the linac would not be able to inject into the booster, as the maximum energy with one klystron is approximately 120 MeV. In this scenario, this would preclude injecting any beam into the storage ring, under any circumstances until one of the failed klystrons is repaired or replaced. As the lead time is several months, this would be a major event for the facility.

Therefore, to mitigate such a scenario, it is proposed to incorporate an ASE Authorized Alternative to lower the minimum energy for injection into the booster accelerator from 150 MeV to 90 MeV. This would allow operations to continue with the use of only one linac klystron should the need arise. The only safety issue associated with lowering the injection energy is the radiological safety in the event of a mis-steered beam during injection or a mis-timed firing of the pulsed magnets when the beam energy is below 150 MeV; the present shielding was designed for beam energies as low as 150 MeV.

To mitigate the new hazard associated with reduced injection energy into the booster, an evaluation was conducted to see if the present supplemental shielding will intercept mis-steered 90 MeV beams and/or if the bulk shielding is sufficient. The results of the analysis are known and confirm the adequacy of the current shielding to satisfy the NSLS-II Shielding Policy even with mis-steered beams at 90 MeV. Additionally, ARMs already present in the vicinity would immediately shutdown the Linac gun and preclude any significant exposure whatsoever, even well below the Shielding Policy requirements.

The following Authorized Alternative for the lower injected electron energy limit from the ASE Section 2.1.2.3 has been proposed:

"2.1.2.4 Authorized Alternative: In the event that operational conditions require (e.g., only one available klystron) and for the purposes of associated studies, the minimum injected electron energy shall be 90 MeV."

This will allow NSLS-II to accomplish the following goals:

- If the anticipated relaxation of the lower energy limit is permitted, the prospect of an unplanned extended outage fails to materialize even if either of the remaining linac klystrons act up / fail, increasing overall efficiency of operations.
- High-impact accelerator physics experiments are possible with the existing NSLS-II hardware even if the Booster injection energy is reduced below 150 MeV.

Safety Analysis:

Booster Injection at 90 MeV

The NSLS-II linac requires 2 operational klystrons in order to successfully inject into the Booster. It normally has a third klystron wired up as a 'Hot' spare to rapidly switch into service if one operating klystron fails.

At present, 2 linac klystrons are operational, the 'Hot' spare is not operational and a 'Cold' spare (4^{th} klystron) is out being repaired/rebuilt, and not expected back for several months yet (est'd. July).

Should one of the two remaining operational klystrons become non-functional, there is not enough power in the remaining klystron to inject into the Booster at the current lower energy limit specified in the NSLS-II ASE (i.e., 150 MeV). With one klystron, the maximum beam energy is limited by klystron power to 120 MeV.

Nominal injection energy into the Booster is typically 200 MeV. It is expected to be able to operate with injection energy of 170 MeV (though this has never been tested). The shielding for the Booster is designed for energies from 150 MeV up to 3.2 GeV. Linac shielding is good for all energies below 250 MeV. The PPS system limits the lowest energy beam from the Linac to 151 MeV.

To assure the radiological safety of Booster operations with 90 MeV injection from the Linac:

- All shielding in the Booster Vault has been reanalyzed to assure it can intercept the beam at 90 MeV.

- Current shielding has been shown to be adequate by computer modeling, and is, well below any personnel dose limits.

- Formal Return-to-Service requirements with verification will assure proper operation of the PPS after the necessary modifications to lower the trip limits on the LtB dipoles B1 and B2 are completed. Re-commissioning activities for the Linac / Booster with 90 MeV electron injection to the Booster will based upon the results of the analysis in Attachment C – NSLS-II Technical Note No. 214 [Ref. 6].

In accordance with LESHC guidance, the following additional commitments will be implemented:

- Placement of a local alarming Area Radiation Monitor (ARM) will be provided on the SR mezzanine which will be monitored by the RCTs during the commissioning of the Booster acceleration ramp.

- The USI with all attachments will be appended to current SAD when revised ASE approved by DOE.

- The non-safety rated integrating current transformer shall be used to shut-off the injection gun if the 3 nC/s rate is exceeded during the low-energy commissioning period.

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2.1.2.3 The minimum injected electron energy shall be 150 MeV

2.1.2.4 AUTHORIZED ALTERNATIVE: IN THE EVENT THAT OPERATIONAL CONDITIONS REQUIRE (e.g., ONLY ONE AVAILABLE KLYSTRON) and FOR THE PURPOSES OF ASSOCIATED STUDIES, THE MINIMUM INJECTED ELECTRON ENERGY SHALL BE 90 MeV.

2.1.3 Credited Controls for Storage Ring Maximum Credible Incident

The following limits establish the operational envelope for Storage Ring operation that may not be exceeded.

2.1.3.1 The maximum electron charge shall not exceed 54 μC integrated over one hour as measured by an ACMI located in the Booster to Storage Ring (BtS) transport line. The maximum electron charge stored within the Storage Ring shall not exceed 2.6 μC (2600 nC) at 3.3 GeV.

2.1.3.2 The maximum stored electron energy shall not exceed 3.3 GeV.

2.1.3.3 The minimum stored electron energy shall not be less than 2.8 GeV.

2.1.3.4 The minimum electron energy transported to the Storage Ring shall be equal to or greater than 2.0 GeV.

2.1.4 Credited Controls for Top-Off Operation MCI

Top-Off Operation shall be defined as the mode of operation when it is desired to inject electrons into the Storage Ring with the photon shutters open.

2.1.4.1 During Top-Off Operation, the maximum electron charge injected into the Storage Ring shall not exceed 2.7 μC integrated over one hour as measured by an ACMI located in the BtS transport line and an ACMI immediately downstream of the fourth accelerating cavity of the Linac.

2.2 Credited Controls for Radiation Hazard

There are a number of credited controls which are required to maintain the radiological consequences within bounds of the MCI. Except as designated, these apply to the operation of all accelerators and beamlines:

2.2.1 Each accelerator and beamline when operational must have its Personnel Protection System (PPS) and associated barriers, including gates, fencing, and berms, and the area radiation monitoring system operational and certified in compliance with the approved procedure. The relevant PPS must be operational during testing of RF cavities.

2.2.2 All required radiological shielding for an area must be in place and certified in compliance with the approved inspection procedure during operation of that area with the radiation hazard.

2.2.3 All required burn-through devices must be in place and certified in compliance with an approved inspection procedure during operation of a front-end with the radiation hazard.

2.2.4 At least one qualified, trained operator shall be on-duty during operation of the accelerators with electron beam.

2.2.5 All required TOSS apertures for approved front ends must be in place and certified in compliance with the approved inspection procedure during Top-Off Operations within that area.

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significantly different and additional controls are not required for a 250 MeV beam energy. Therefore the maximum energy of 250 MeV is used as the limiting case for the ASE so that the Linac cannot physically exceed the ASE energy limit.

5.2.2 Booster Credited Controls for the MCI

- **The maximum electron charge injected in an hour shall not exceed 90 μC**

  Basis: The MCI for Booster was calculated using 25 nC/s (90 μC/h). This injection rate will be limited by the ACMI installed in the LtB transport line. The ACMI is incorporated into the PPS. A different threshold established in the ACMI ensures that the Booster current limits are protected. In the event that the ACMI becomes unavailable the Authorized Alternatives will be used. The Authorized Alternatives are: The LtB IT1 current transformer and at least one of the following diagnostics devices located within the Linac transport line (i.e., faraday cups in the beam dumps or LtB IT2).

- **The maximum electron energy shall not exceed 3.2 GeV**

  Basis: The MCI was calculated using an electron energy of 3 GeV. The maximum electron energy that can be maintained in the vacuum pipe by the Booster ring magnets is 3.2 GeV. The radiological consequences of a 3 GeV electron beam and a 3.2 GeV beam are not significantly different and therefore the maximum energy that can be controlled in the ring is used as the limiting case for the ASE

- **The minimum injected electron energy shall be 150 MeV**

  Basis: The analysis of mis–steering events for electrons from the injection into Booster and the eventual extraction into the Storage Ring was over the energy range of 150 MeV to 3.2 GeV. Since the Linac could be operated at energies less than 150 MeV, the current in the last dipole in the Linac to Booster transfer line is monitored as a part of the PPS system. If the current in the magnet drops below the value that would inject a 150 MeV electron into the Booster, the current monitor will interlock the Linac electron gun off using the PPS. This credited control prevents faults that have not been analyzed and could possibility exceed the shielding policy.

AUTHORIZED ALTERNATIVE: IN THE EVENT THAT OPERATIONAL CONDITIONS REQUIRE (e.g. ONLY ONE AVAILABLE KLYSTRON) AND FOR THE PURPOSES OF ASSOCIATED STUDIES, THE MINIMUM INJECTED ELECTRON ENERGY SHALL BE 90 MeV.

5.2.3 Storage Ring Credited Controls for the MCI

- **The maximum electron charge injected into the Storage Ring shall not exceed 54 μC (54,000 nC) integrated over one hour**

  Basis: The MCI for injection into the Storage Ring is evaluated at an injection rate of 15 nC/s, which if continued for a period of 1 hour would result in 54 μC/hr. The charge injection rate of 15 nC/s allows for rapid fills of the storage ring. This injection rate will be limited by the ACMI installed in the BtS transport line. The maximum integrated injected charge per hour will be limited to 54 μC (54,000 nC). The shielding analysis has shown that the areas adjacent to the storage ring will satisfy the NSLS-II Shielding Policy even at this high hourly injection charge. Operators will be able to monitor the injected rate and hourly charge through Control room display and ensure compliance with this limit.

- **The maximum electron charge stored within the Storage Ring shall not exceed 2.6 μC (2600 nC) at 3.3 GeV**

  Basis: A stored charge of 2.6 μC circulating in the NSLS–II ring is equivalent to a 1000 mA stored beam. This current exceeds the design values for the scientific program. The radiological consequences of a loss of the 1000 mA of stored beam at a point were evaluated. The maximum dose from this event was calculated as 23 mrem which is well within the NSLS–II Shielding Policy. The NSLS-II storage ring (SR) design calls for the maximum (nominal) circulating

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NSLS-II TECHNICAL NOTE BROOKHAVEN NATIONAL LABORATORY	NUMBER: 214
AUTHOR **R. Filler, S. Kramer & R. Faussete**	DATE **5/18/2016**
TITLE **Hazard Analysis for 90 MeV Booster Injection Energy Limit**	

Introduction

The NSLS-II booster is designed to accelerate 200 MeV electrons to an energy of 3 GeV to serve as a full energy injector for the NSLS-II storage ring. Electrons are supplied to the booster from the NSLS-II linac. The NSLS-II booster was specified to accept electrons with an energy as low as 170 MeV. The supplemental shielding is designed to shield all energies from 150 MeV to the booster's maximum energy of 3.2 GeV. Due to the shielding design, the NSLS-II PPS system guarantees that the beam energy must be above 151 MeV upon transport to the booster ring for injection.

Recently, problems with the linac klystrons have come to the point that operating the NSLS-II linac below the 150 MeV may be the only possible way for the linac to deliver electrons to the booster. If the NSLS-II linac were limited to operate on only 1 klystron, at full power only 120 MeV beam energy would be possible. The nominal operating energy would be 100 MeV to leave overhead for beam loading compensation and to not stress the last remaining klystron any more than necessary. Since this is below the design of the booster shielding, the supplemental shielding needs to be analyzed to ensure that it is sufficient for lower energy beams.

In this report, we discuss the impact of lowering the booster injection energy to 90 MeV on the supplemental shielding. Issues relating to how the booster will perform at this lower energy are not discussed.

Beam Miss-steering

The booster shielding is designed for all electron energies from 150 MeV to 3.2 GeV. Shielding becomes more effective at lower energies. Since all shielding can shield 3.2 GeV beam, the supplemental shielding thickness at 90 MeV is sufficient. If the beam strikes existing supplemental shielding at lower energy this does not pose a hazard.

The hazard of lower beam energy is that the maximum possible deflections from the magnetic elements are larger. Therefore the dimensions of the shielding may be such that the lower energy beam may miss the shield completely, or strike some other object so that there is an increase in dose in occupied areas. The physics behind the calculation of the mis-steering angles for the booster is discussed in Reference 1 and the references therein and will not be described here. Our analysis differs from the analysis in Reference 1 in the following ways:

1. The minimum considered beam energy is 90 MeV.
2. The initial angles of the beam entering the magnets is not considered, except for the injection and extraction pulsed magnets.
3. The quadrupole and sextupole component of the field in the combined function dipoles is ignored.

The maximum miss-steering angles are so large in the case of a 90 MeV beam, that the additional angles allowed by the physical aperture upstream of a particular magnet are small, except for the injection and extraction pulsed magnets. In the case of the booster dipoles and the extraction septum, the hazard exists when the beam is not deflected by the magnets, allowing it to escape the design orbit. This case is shielded for, regardless of beam energy. Even at 150 MeV, the maximum deflection strikes the magnet yoke facing the interior of the booster berm. At 90 MeV, this fact is unchanged.

Table 1: Calculated Maximum Bending Angle at 90 MeV

Magnet Type	Maximum Bend Angle (Degrees)
LtB Dipole B2 and B3	52.3
LtB Quads Q7-15	24.6
Booster Injection Septum	17.6
Booster Injection Kickers	11.8,4.1,5.2,3.7
Booster BD dipole	279.5
Booster BF dipole	109.0
Booster Quads	29.7
Booster Sextupole	1.1
Booster extraction bump1	26.2
Booster extraction kicker	12.2
Booster CX Corrector	3.7
Booster CX1 Corrector	2.3

Table 1 lists the maximum steering angles for all magnets in the Linac to Booster Transport Line and the booster at 90 MeV. This table does not account for beam striking the aperture of the magnet. The booster extraction septum is not included in the table, as the aperture is such that miss-steered beam will strike the wall. The LB-B4 dipole is not included as the shielding analysis for this magnet is unaffected. The injection kickers show four angles, as the input angle is different for each one. Only one extraction bump is considered as the others are powered in series, with it. The hazard by this magnet is caused by beam escaping the pipe at this magnet. The analysis for the other extraction bumps is the not affected.

Ray tracing has been performed to show the beam path for these mis-steered beams. The results of the ray tracing show that except for the booster quadrupoles, the beam is found to strike either:

1. The injector tunnel wall shielded by berm (particularly the LtB and injection elements).
2. Existing supplemental shields.
3. Subsequent magnets.
4. The yoke of the magnet causing the miss-steering. (such as the Booster Dipoles, extraction septum).

The ray trace drawings are contained in the Vault with drawing numbers LT-SHLD-6050 and BR-SHLD-6050.

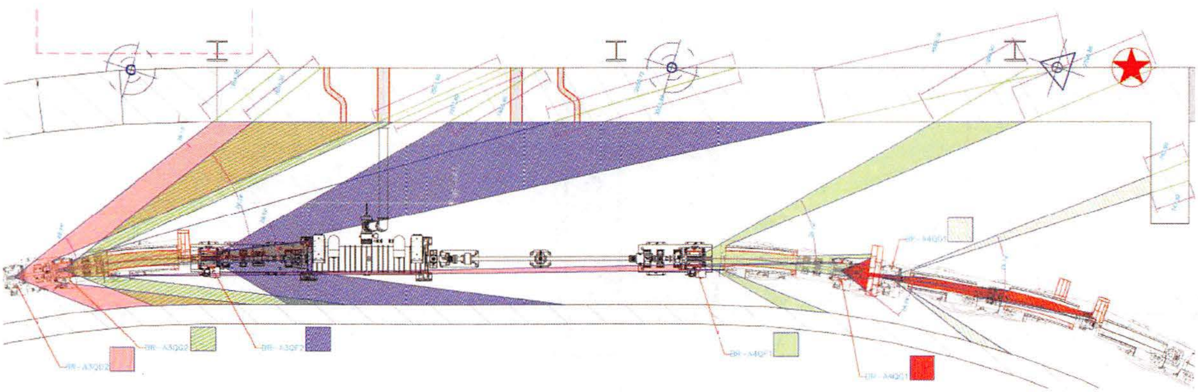

Figure 1: Possible horizontal miss-steering angles, Θ, from the booster quadrupoles. Beam moves from left to right in the image. The bottom shield wall borders the berm. The upper wall is adjacent to the Injector Service Area (ISA).

It was found that the booster quadrupoles, particularly those in the RF straight, which is adjacent to the ISA shield wall have the potential to steer the 90 MeV beam into the ISA wall. We note that the booster quads are broken into three families and each family is on a bus. Therefore, if one booster quad is set wrong, all of the other quads in that family are set incorrectly as well. As there are two quads per family per straight, this would mean that for the any quadrupole in the RF straight, the beam would be required to pass through the booster with at least 5 other quadrupoles of that family set to the same wrong settings as the quad in the RF straight. Stated in another way, if the beam was mis-steered and escaped the existing shielding in the RF straight due to the quadrupole, it is difficult to imagine a scenario where this does not occur in one of the quadrupoles of that family in the previous three arcs. Completely ruling out that there is no possible setting of the booster magnets such that the beam can survive to the RF straight only to escape shielding and strike the ISA wall is computationally intensive and the condition is most likely improbable. Therefore, we note that it would be highly unlikely that such a scenario could occur, even intentionally, we consider it nonetheless.

Figure 1 shows the ray trace drawing for the quadrupoles in the Booster RF straight. There are 6 quadrupoles within this section. Four of them A3QD2, A3QG2, A3QF2, and A4QF1 have the possibility of striking the ISA wall. These are the only possible cases of missing existing shields and striking a potentially occupied area in the ISA. The concrete wall is 1m thick at this location. The effective thickness at the mis-steering angle is 1.6-2.5m depending on the exact location of the quadrupole.

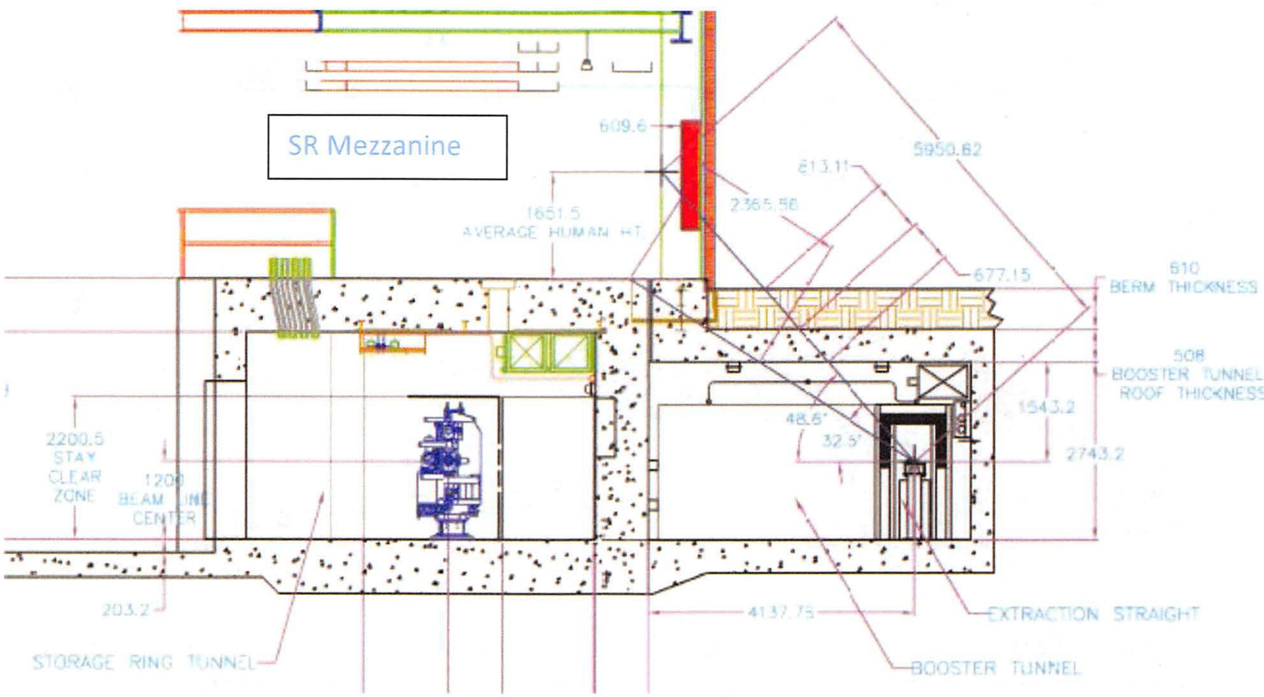

Figure 2: Possible elevation angles, φ, in the plane orthogonal to beam axis, for beam loss from the BA2QF2 quadrupole in the Booster extraction to Storage Ring straight. For the angles of concern on the SR mezzanine, the projected equivalent concrete thicknesses are shown to be > 1m thick.

There is some concern that personnel on the storage ring mezzanine may be exposed to beams miss-steered by a quadrupole in the extraction straight. Figure 2 shows a cross-section of the storage ring tunnel with the adjacent booster tunnel. There are two extreme rays of interest from the booster extraction line going to the mezzanine. These rays are those intercepting an average height person, standing at the SR mezzanine inner wall, feet and head. When calculating the effective shielding for the SR mezzanine, it is noted that the path length, p, of the beam ray through a shield wall, of thickness t, depends on the beam loss angle, ϴ, as $p = t/\sin(\Theta)$ only for beam loss in the vertical plane for the roof shield. For angles to the mezzanine there is an additional scale factor that increases the path length by $1/\sin(\phi)$, for elevation angle, ϕ, in the plane orthogonal to the booster beam axis, as shown in Fig. 2. The maximum elevation angle for a person (ϕ ~ 48°) contributes a factor of 1.33 to the effective thickness of shielding material along the beam loss ray. This factor increases to 1.9 at the floor location. The booster roof thickness is equivalent to 0.8 meter in concrete (actually 50 cm concrete plus 60 cm dirt berm). The floor shield thickness of concrete increases to over 1.3 m of concrete in the overlap between the SR tunnel roof with the booster tunnel roof. The minimum increase of the path length from ϕ contributes to an effective booster roof shield thickness (1.33 *0.8m = 1.1m) which greater than the 1m ISA wall thickness for horizontal beam loss angles shown in Fig. 1. Therefore the estimated penetration doses (along the beam loss path) for the mezzanine locations will be significantly reduced compared to the ISA estimated dose rates, due to this angle ϕ factor. Also to be noted is the distance from the dose location of concern on the mezzanine to the roof shield, which will significantly lower the expected dose compared with the dose calculated at the surface of the roof shield.

Once all these geometric factors are accounted for, a person standing on the mezzanine close to the interior wall would be shielded by an effective thickness ranging from 1.1 m of concrete at their head to 2.4 m of concrete at their feet. For these elevation angle beam loss geometries, the quadrupole yoke, which only have horizontal and vertical gaps, will intercept beam losses at these large miss-steering angles, providing some additional shielding which is not considered here.

Similar arguments of the likelihood of this accident occurring apply. If the beam was miss-steered and escaped the existing shielding in the extraction straight due to the quadrupole, it is difficult to imagine a scenario where this does not occur in one of the quadrupoles of that family in the previous two arcs. Completely ruling out that there is no possible setting of the booster magnets such that the beam can survive to the RF straight only to escape shielding and strike the Storage Ring Mezzanine is computationally intensive and most likely improbable. Therefore, we note that it would be highly unlikely that such a scenario could occur, even intentionally, we consider it nonetheless.

As the effective concrete thickness seen on the mezzanine is larger than those in the ISA, doses on the mezzanine will be lower. FLUKA simulations were not performed for the mezzanine, and we will use the ISA doses as representative of the maximum possible for the mezzanine.

FLUKA Simulations

Figure 3 shows a FLUKA model of beam hitting the ISA wall from A4QF1 where a possible bend angle of 27° would miss the installed shields and magnet yokes. A low emittance electron beam of 100 MeV was assumed to miss both iron yokes and pass only through the stainless steel vacuum chamber, which scatters the emittance somewhat as it passes through the material of the beam pipe.

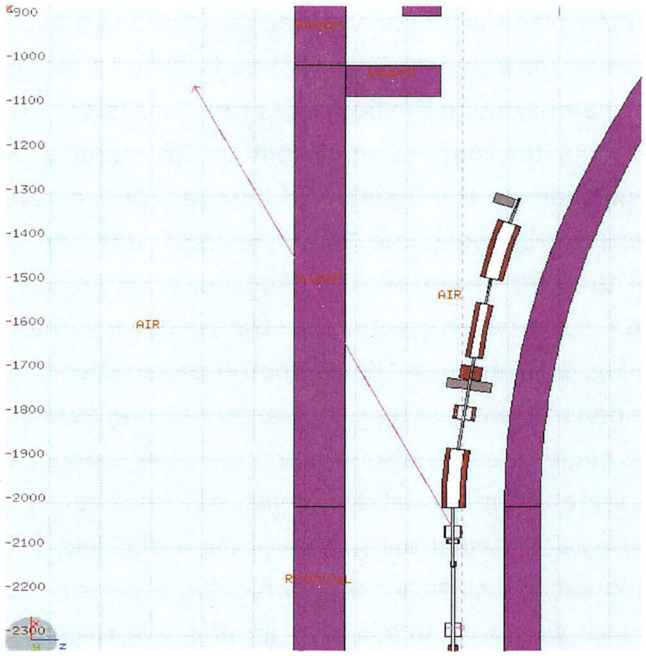

Figure 3: Miss-steered beam direction in the A4QF1 magnet, shown at 27° to beam axis. Arrow shows the assumed beam loss angle from the QF magnet, which misses the yoke of the both magnets, used in the FLUKA model calculated below. Nominal bema direction is up in this image.

The FLUKA model previously used to calculate Labyrinth dose rates was modified to give the dose rate at the ISA wall surface on the beam plane. The total dose rate distribution for a 100 MeV beam loss is shown in Figure 4 and 5. Figure 4 shows the beam spreading due to the vacuum chamber at this small angle and the levels outside the tunnel are shown better in Figure 5. The dose rate at the ISA shieldwall surface inside the ISA and on the beam plane is shown in Figure 6 with the neutron component shown in Figure 7. The peak dose rate is greater than the 100mrem/h (~132 mrem/h/15nA) level that would require coverage with an Area Radiation Monitor (ARM). To keep the peak dose rate below 100 mrem/h would require running below 10nA beam current which should have little impact on commissioning. We will administratively limit the linac current to 3nA for the duration of commissioning this mode of operation. This will reduce all dose rates by 1/5 and keep them below 100 mrem/h.

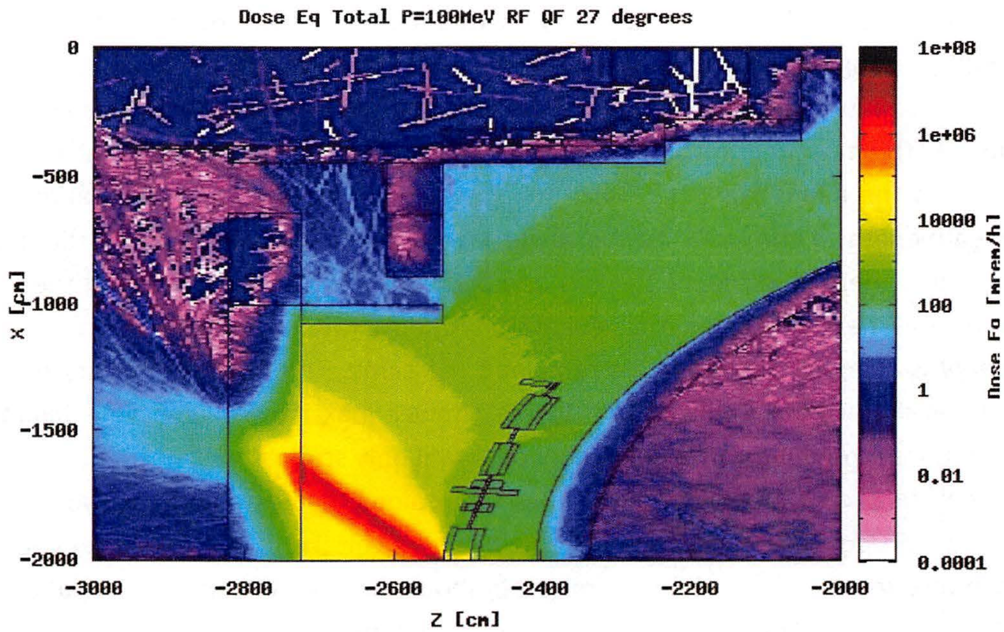

Figure 4: Radiation distribution for 100 MeV beam loss in Booster A4QF1 steered outward by 27° ahead of the first dipole in Arc4.

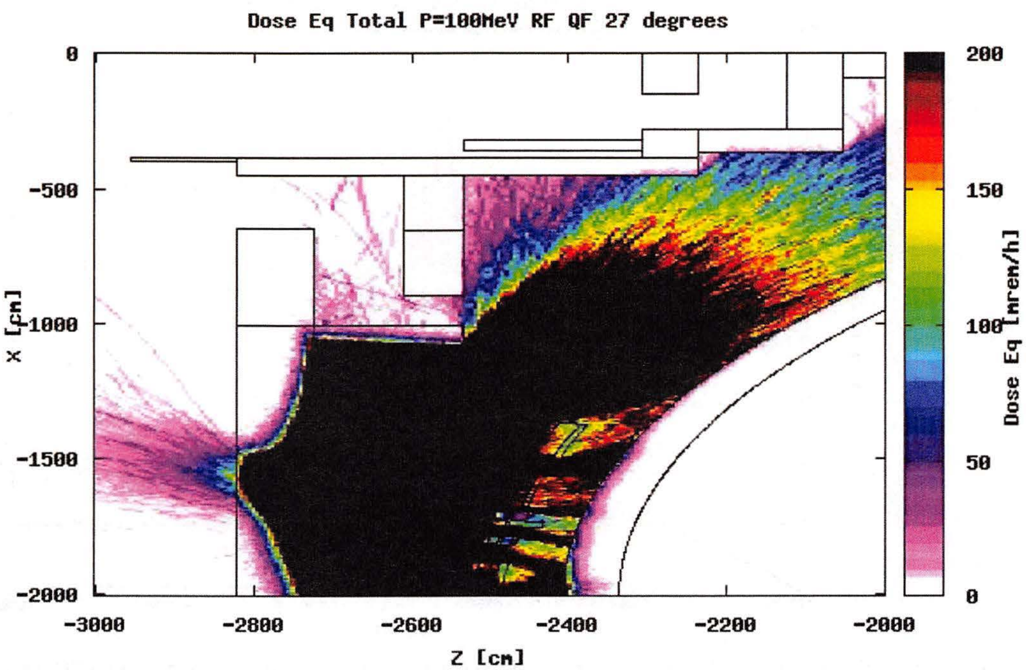

Figure 5: Same beam loss model as Fig. 4 but with linear dose rate scale up to 200 mrem/hr at 15nA loss rate.

The dose distribution shows the two peaks along the wall. The first peak in Fig. 6, is close to the location of the beam axis exit of the ISA shieldwall (x= -1440 cm at the ISA wall surface). The second peak (larger peak) is upstream of this peak and arises from the shortest pathlength (orthogonal to the wall) for the secondary particle (dose) production as the beam enters the shield wall and the shower builds up to the shower maximum value along the beam direction. As the miss-steering angle decreases this second peak increases in relative magnitude compared to the beam axis peak, since the forward peak sees more attenuation due to the longer pathlength in the wall. As the angle increases (toward orthogonal) these peaks will merge, until at normal incidence there is one peak in the beam direction with the attenuation of the wall thickness. The beam axis peak (forward) dose rate will vary between $\propto E^{-1}$ and E^{-2} as the energy is changed but the angle remained the same. The lower secondary peak will also decrease as the angle is reduced due to the shower max moving along the beam direction suffering more attenuation. This secondary peak will only scale as ~E^{-1} since it is transverse and from a thick target (i.e. the distance to shower max along the beam path). However if the angle from the quadrupole decreases too much the beam will hit the dipole yoke attenuating this at a large distance from the wall. Steering magnets should have less bend angle capability but their miss-steering is required to generate the larger miss-steering angle from the quadrupole.

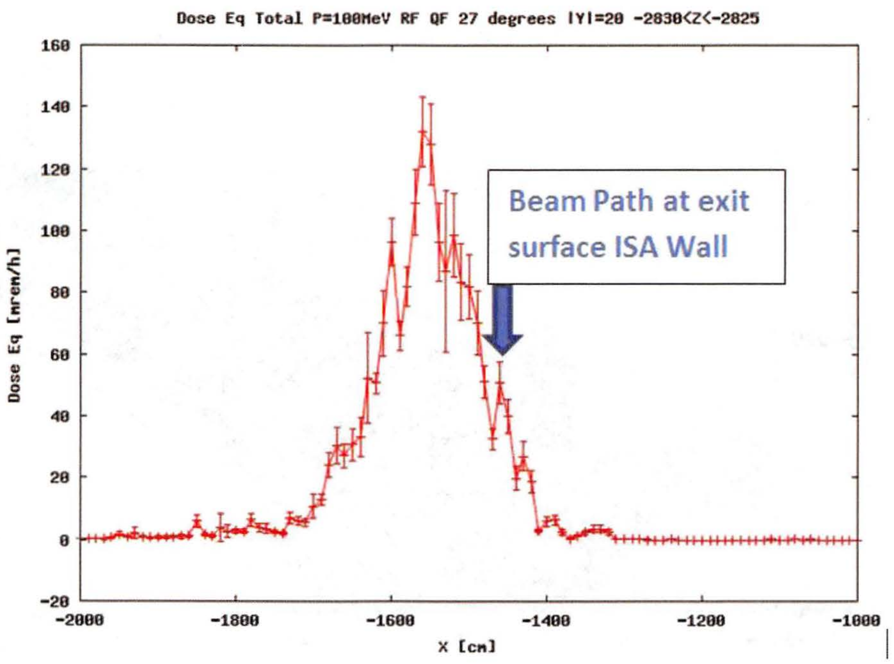

Figure 6: Beam plane total dose rate distribution along the ISA wall for 100 MeV 15nA beam loss rate at Arc4 first QF with 27° to RF straight beam axis. Peak dose rate is <132 $\pm$ 10 mrem/h/15nA.

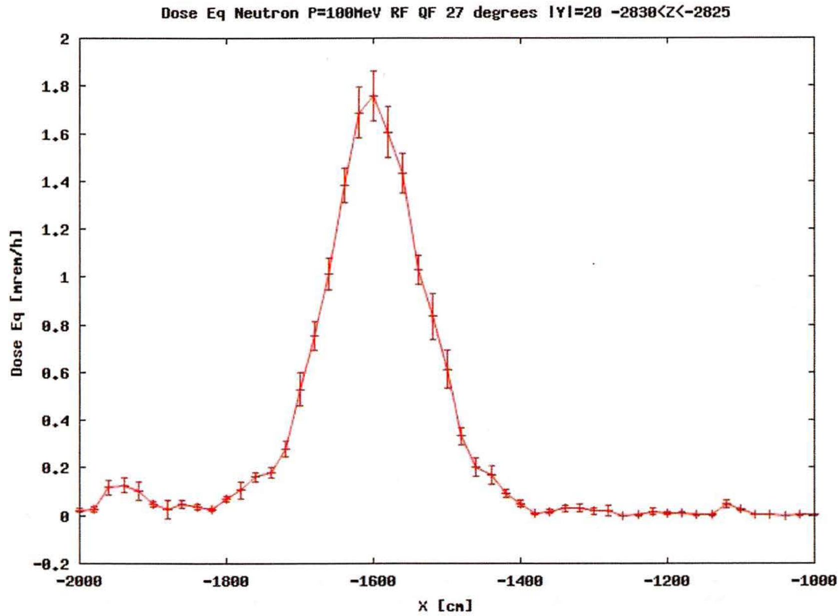

Figure 7: Beam plane neutron dose rate distribution along the ISA wall for 100 MeV 15nA beam loss rate at Arc4 first QF with 27° to RF straight beam axis. Peak neutron dose rate is < 1.8 $\pm$ 0.09 mrem/h/15nA.

In order to allow a safety margin for lower energy injection, the beam energy was lowered to 90 MeV, which would allow the maximum beam angle to increase. However we assumed a somewhat larger bend angle of 35° (compared to the scaled bend angle from the 100 MeV bend angle) for this beam loss. This also accounts for a slightly larger incident angle on the ISA wall which occurs if the errant quad is the A3QG2 or A3QD2. The dose rate distribution is shown in Fig. 8 to be slightly narrower and have less separation between the multiple peaks than the 100 MeV 27° distribution. For this beam loss assumption the peak dose rate is < 400mrem/h/15nA, with a neutron component of < 4.3 mrem/h/15nA, shown in Fig. 9. To meet the 100 mrem/h level this would require injection current to be less than 3.8nA, this is consistent with our administrative limit of 3 nA.

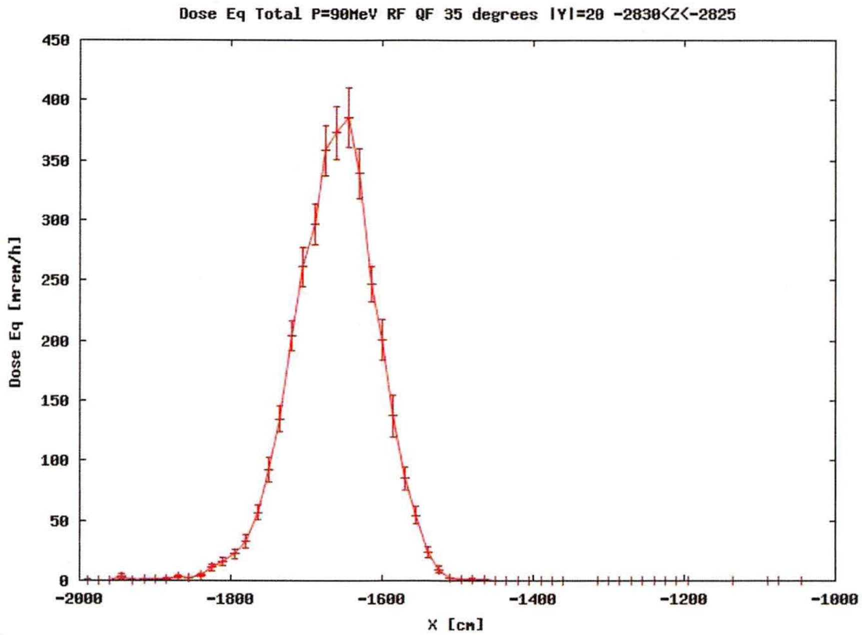

Figure 8 Beam plane total dose rate distribution along the ISA wall for 90 MeV 15nA beam loss rate at Arc4 first QF with 35° to RF straight beam axis. Peak dose rate is < 400 $\pm$ 20 mrem/h/15nA.

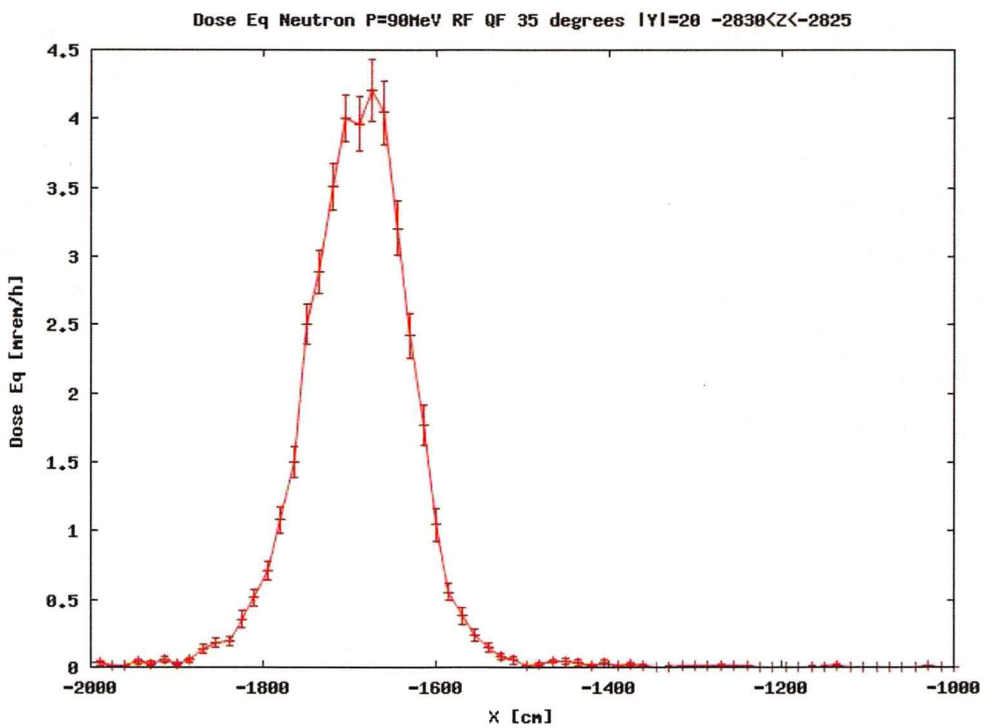

Figure 9 Beam plane neutron dose rate distribution along the ISA wall for 90 MeV 15nA beam loss rate at Arc4 first QF with 35° to RF straight beam axis. Peak neutron dose rate is < 4.2 $\pm$ 0.3 mrem/h/15nA.

Table 2: Summary of FLUKA calculations for beam striking the ISA wallfor 15nA beam current..

Beam Energy [MeV]	Beam loss Angle [°]	Peak Dose [mrem/h]	Neutron Dose [mrem/h]
90	27	93 $\pm$ 13	1.34 $\pm$ 0.15
100	27	132 $\pm$ 13	1.8 $\pm$ 0.15
90	30	158 $\pm$ 14	2.15 $\pm$ 0.15
90	35	400 $\pm$ 20	4.2 $\pm$ 0.3

The storage ring mezzanine dose rates will be in a similar range as the ISA doses, as the effective concrete thickness ranges from 2.1 m to 4.7 m depending upon the exact geometry. There are no interlocked ARMs located on the mezzanine. The administrative limit of 3 nA will reduce and keep all dose rates ALARA during commissioning of this mode of operation.

Conclusion

We have re-analyzed all of the possible mis-steerings that can occur for the booster at 90 MeV beam energy. Based on this analysis:

1. No existing supplemental shields need modification.
2. Only the quadrupoles in the RF straight of the booster have the possibility of steering the beam into the ISA wall when the beam energy is below 150 MeV.
3. Quadrupoles in the extraction straight of the booster may steer the beam onto the storage ring mezzanine when the beam energy is below 150 MeV.
4. The bussing of the quadrupoles makes the mis-steering in either location highly improbable.
5. We will administratively limit the linac current to 3nA while we are commissioning this mode. This limit shall not apply once the new booster ramp has been commissioned.

References

1. S. Kramer. Performance Requirements, Engineering Specifications, and Interface Control Document Shielding Specification Design Document for LBT-P2, Booster and BSR-P1.

Department of Energy
Brookhaven Site Office
P.O. Box 5000
Upton, New York 11973

DEC 21 2015

Ms. Gail Mattson
Brookhaven Science Associates, LLC
Brookhaven National Laboratory
Upton, New York 11973

Dear Ms. Mattson:

SUBJECT: BROOKHAVEN SITE OFFICE AUTHORIZATION TO ELIMINATE THE NATIONAL SYNCHROTRON LIGHT SOURCE-II (NSLS-II) STORED BEAM LOWER ENERGY LIMIT FOR STORAGE RING

Reference: Letter from G. Mattson, BSA, to F. Crescenzo, SC-BHSO, Subject: Request BHSO Approval of the USI Evaluation NSLS-II EVAL 2015-004: Re-Statement of NSLS-II ASE Stored Beam Lower Energy Limit for Storage Ring, dated December 1, 2015

The Brookhaven Site Office (BHSO) has reviewed your request to eliminate the NSLS-II stored beam lower energy limit for the storage ring. BHSO approves the request and the November 2015 NSLS-II Accelerator Safety Envelope (ASE). BHSO authorizes Routine Operations to proceed in accordance with the November 2015 ASE. If you have any questions, please call Maria Dikeakos, of my staff, at extension 5434.

Sincerely,

Frank J. Crescenzo
Site Manager

cc:
R. Gordon, SC-BHSO
R. Caradonna, SC-BHSO
M. Dikeakos, SC-BHSO
J. Eng, SC-BHSO
P. Kelley, SC-BHSO
P. Sullivan, SC-BHSO
A. Ackerman, BSA
M. Bebon, BSA
R. Fliller, BSA
J. Hill, BSA
R. Lee, BSA
E. Lessard, BSA
S. Moss, BSA
B. Podobedov, BSA
C. Schaefer, BSA
F. Willeke, BSA

Unreviewed Safety Issue (USI) Evaluation Form

USI Evaluation No.: NSLS-II-EVAL-2015-004, Rev. 1

Title of USI Evaluation and Sponsor or Condition Owner:

Re-statement of NSLS-II ASE Stored Beam Lower Energy Limit for Storage Ring

Steven Moss, PS Authorization Basis Manager

I. Description of Proposed Activity or Discovered Condition

See Attachment 'A' which includes Description of Proposed Activity and Safety Analysis. See below for affected Credited Controls and affected SAD sections. See Attachment 'B' for a marked-up copy of the page to be changed in the ASE and in the SAD.

REFERENCES

1) *Unreviewed Safety Issue Determination Procedure*, PS-C-ESH-PRC-002, Ver. 4, June 27, 2014.
2) *Safety Assessment Document for the National Synchrotron Light Source II*, PS-C-ESH-RPT-001, Ver. 3, May 2015.
3) *Accelerator Safety Envelope (ASE) NSLS-II,* PS-C-ESH-ROASE-001, Ver. 2, May 2015.
4) *NSLS-II Technical Note No. 178, "Beam Energy Limits for NSLS-II SR"*, June 18, 2015. [copy attached]
5) *NSLS-II Local Shielding Design Coordinating Group Memo,* (from Dr. S. Kramer – Chairman and Dr. Z. Xia to Mr. R. Lee – Manager of ESH&Q for NSLS-II), with subject, *Removal of the NSLS-II ROASE stored beam lower energy limit,* June 22, 2015. [copy attached]
6) *Photon Science Radiation Safety Committee (RSC) Memo,* (from Dr. Z. Zhong – Chairman to Mr. S. Moss – ABD Manager, et. al.), with subject, *Review of the proposed elimination of NSLS-II ASE stored Beam lower energy limit for storage ring",* October 19, 2015.
7) *PS-C-ASD-PRC-095, "Scheduling and Performing NSLS-II Machine Studies"*
8) E-mail dated November 10, 2015 [From Dr. M. Benmerrouche to LESHC Chair, Mr. E. Lessard], with subject: RE: Response to LESHC Comment(s) on Potential for Ozone Production Associated with USI Evaluation No. NSLS-II-EVAL-2015-004, "Elimination of NSLS-II ASE Stored Beam Lower Energy Limit for SR".

II. **Does the proposed activity or discovered condition affect information presented in the Safety Assessment Document (SAD) (e.g., regarding equipment, administrative controls, or safety analyses)?**

YES – Within the Safety Assessment Document for the National Synchrotron Light Source II [PS-C-ESH-RPT-001, Ver. 3 dated May 2015], there is specific reference to minimum stored electron energy circulating in the Storage Ring. Section 5.2.3 – Storage Ring Credited Controls for the MCI; 4^{th} Bullet states, "**The minimum stored electron energy shall not be less than 2.8 GeV.**" However, none of the other bullets pertaining to Storage Ring Credited Controls for the MCI are affected, at all.

Low energy operation of the Storage Ring is specifically barred by implementation of the applicable ASE Limit, as called out in Chapter 5 of the SAD, as well as the ASE itself. Because of the prior significant safety issues associated with the Mis-steering Event during Linac Commissioning, it is understood that changing any of the ASE limits resulting from the corrective / mitigative actions taken after that event, even temporarily, will represent a positive USID, requiring a formal safety analysis and review process within NSLS-II and review by LESHC / ALD for ESH. Based upon the accepted analyses attached, which shows NO increase in Hazard or Risk by re-stating the particular ASE Limit in question to clarify that injection energy will NOT be lowered but that it is acceptable to allow the stored beam energy after injection to be reduced by use of accelerator controls, and the required LESHC / ALD-ESH review and approval; allowing the change proposed with prior DOE concurrence.

Additional areas of the SAD reviewed for potential impact by the proposed clarification include: Section 3.3.3.6 – Storage Ring (no impact); Section 3.3.3.9 – Control System (no impact); Section 3.3.3.10 – Top Off Operation (which has interlocks and controls that would preclude Top Off Operation during low energy operations of the Storage Ring); Section 3.3.4 – Storage Ring RF System (no impact); Section 4.15.3 – Radiological Hazards Associated with the Storage Ring and associated subsections (no impact); 4.15.8 – Abnormal Operating Conditions, including Maximum Credible Incident (no impact); 4.15.10 – Radiological Hazards Associated with Top-Off Operations (conservative impact, as previously noted when in experimental low energy mode within Storage Ring, Top-Off Operations are disabled by internal interlocks and controls); and Chapter 5.0 – Basis for Accelerator Safety Envelope (only affected as already noted above in first paragraph). The documents, "*Beam Energy Limits for the NSLS-II SR*" [NSLS-II Technical Note No. 178, dated June 2015 – Ref. 4, cited above] and "*Removal of the NSLS-II ROASE stored beam lower energy limit*" [NSLS-II Local Shielding Design Coordinating Group Memo, dated June 22, 2015 – Ref. 5 cited above]; confirms compliance of this re-statement of the lower energy limit for injected beam into SR with NSLS-II Shielding Policy; and defines the change to be made to the current credited controls.

III. **Does the proposed activity or discovered condition affect any of the requirements of the Accelerator Safety Envelope (ASE)?**

YES – The DOE-approved NSLS II ASE [PS-C-ESH-ROASE-001], Ver. 2 dated May, 2015; does currently include one credited control that must be re-stated in order to undertake the Experimental Machine Studies requiring lowered stored beam energy in the SR. Ref. 4 above analyzes the radiological risk associated with Beam Energy Limits for the NSLS-II Storage Ring and clearly shows that re-stating the lower energy limit on injected beam into the Storage Ring to conduct valuable scientific studies of the machine at lower stored beam energies represents a reduced risk compared to the risks associated with studies at normal operating energies (3 GeV) for which all required shielding was designed and verified effective through comprehensive fault studies and surveys.

ASE Section 2.1.3 – Credited Controls for Storage Ring Maximum Credible Incident includes one specific commitment which must be restated for the completion of the Experimental Machine Studies contemplated herein. ASE Section 2.1.3.3 currently states,

"The minimum stored electron energy shall not be less than 2.8 GeV."

It shall be re-stated as follows,

"Injection to the Storage Ring shall be prohibited if the storage ring dipole current is outside of the range which corresponds to 2.8 GeV to 3.3 GeV beam energy."

As no changes are proposed to the normal and established limits on injection energy to the Storage Ring from the Booster; ASE Section 2.1.3.4 will remain in force throughout any Experimental Machine Studies conducted, and that states,

"The minimum electron energy transported to the Storage Ring shall be equal to or greater than 2.0 GeV."

IV. USI Evaluation Criteria

1. Could the change or discovered condition significantly increase the probability of occurrence of an accident previously evaluated in the SAD?

☐Y or ☒N

Justification: The re-statement of the ASE limit to eliminate the restriction on minimum stored electron energy in the Storage Ring does NOT significantly increase the probability of occurrence of an accident previously evaluated in the SAD. These include: the Linac MCI Analysis for electron energy of 250 MeV and current of 100 nC/s; the Booster MCI Analysis for electron energy of 3.0 GeV and current of 15 nC/s (with an increase of <5% for scaling up to 3.2 GeV); the Storage Ring MCI Analysis for electron energy of 3.2 GeV and injection current of 15 nC/s; the Storage Ring MCI Analysis for stored electron beam of energy 3.3 GeV and stored beam current of 1,000 mA and the Beamline MCI Vacuum Surges (with potential overheating). With the injection from the Booster to the Storage Ring at nominal 3 GeV energy combined with a ramping down within the Storage Ring by the dipole magnets to lower energy levels for Experimental Machine Studies; the remaining established credited controls protect against the impact of reduced stored beam energy in Storage Ring from affecting previous accident analyses in the SAD, analyzed for higher initial energies. Attachment A – USI Evaluation for Re-statement of Stored Beam Lower Energy ASE Limit, when combined with References 4 and 5 above provide the necessary technical assurance to conclude that the re-statement of the ASE limit to eliminate the restriction on minimum stored electron energy in the Storage Ring does NOT significantly increase the probability of occurrence of an accident previously evaluated in the SAD.

2. Could the change or discovered condition significantly increase the consequences of an accident previously evaluated in the SAD?

☐Y or ☒N

Justification: The re-statement of the ASE limit to eliminate the restriction on minimum stored electron energy in the Storage Ring does NOT significantly increase the consequences of an accident previously evaluated in the SAD. These include: the Linac MCI Analysis for electron energy of 250 MeV and current of 100 nC/s; the Booster MCI Analysis for electron energy of 3.0 GeV and current of 15 nC/s (with an increase of <5% for scaling up to 3.2 GeV); the Storage Ring MCI Analysis for electron energy of 3.2 GeV and injection electron current of 15 nC/s; the Storage Ring MCI Analysis for stored electron beam energy of 3.3 GeV and stored beam current of 1,000 mA and the Beamline MCI Vacuum Surges (with potential overheating). With the injection from the Booster to the Storage Ring at nominal 3 GeV energy combined with a ramping down within the Storage Ring by the dipole magnets to lower energy levels for Experimental Machine Studies; the remaining established credited controls protect against the impact of reduced stored beam energy in Storage Ring from affecting previous accident analyses in the SAD, analyzed for higher initial energies. Attachment A – USI Evaluation for Re-statement of Stored Beam Lower Energy ASE Limit, when combined with References 4 and 5 above provide the necessary technical assurance to conclude that the re-statement of the ASE limit to eliminate the restriction on minimum stored injection electron energy in the Storage Ring does NOT significantly increase the consequences of an accident previously evaluated in the SAD.

3. Could the change or discovered condition significantly increase the probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD?

☐Y or ☒N

Justification: The re-statement of the ASE limit to eliminate the restriction on minimum stored electron energy in the Storage Ring does NOT significantly increase the probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD. The re-statement of the limit (setpoint) for the minimum injection electron energy does nothing to affect any other Credited Control as it only involves the re-setting of the SR dipole magnet current low limit trip point which is designed to be adjustable. Attachment A – USI Evaluation for Re-statement of Stored Beam Lower Energy ASE Limit, when combined with References 4 and 5 above provide the necessary technical assurance to conclude that the re-statement of the ASE limit to eliminate the restriction on minimum stored electron energy in the Storage Ring does NOT significantly increase the probability of occurrence of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD.

4. Could the change or discovered condition significantly increase the consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD?

☐Y or ☒N

Justification: The re-statement of the ASE limit to eliminate the restriction on minimum stored electron energy in the Storage Ring does NOT significantly increase the consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD. The re-statement of the limit (setpoint) for the minimum injection electron energy into the Storage Ring does nothing to increase the consequences of any malfunction of equipment important to safety. It only allows for postulated events to occur at lower stored beam energy, if at all. Attachment A – USI Evaluation for Re-statement of Stored Beam Lower Energy ASE Limit, when combined with References 4 and 5 above provide the necessary technical assurance to conclude that the re-statement of the ASE limit to eliminate the restriction on minimum stored electron energy in the Storage Ring does NOT significantly increase the consequences of a malfunction of equipment important to safety (e.g., engineered credited controls) previously evaluated in the SAD.

5. Could the change or discovered condition create the possibility of a different type of accident than any previously evaluated in the SAD that would have potentially significant safety consequences?

☐Y or ☒N

Justification: The re-statement of the ASE limit to eliminate the restriction on minimum stored electron energy in the Storage Ring could NOT create the possibility of a different type of accident than any previously evaluated in the SAD that would have potentially significant safety consequences. Attachment A – USI Evaluation for Re-statement of Stored Beam Lower Energy ASE Limit, when combined with References 4 and 5 above provide the necessary technical assurance to conclude that the re-statement of the limit for minimum injection electron energy into the Storage Ring creates no new or different type of accident than any previously evaluated in the SAD that would have potentially significant safety consequences.

6. Could the change increase the possibility of a different type of malfunction of equipment important to safety (e.g., engineered credited controls) than any previously evaluated in the SAD?

☐Y or ☒N

Justification: The re-statement of the ASE limit to eliminate the restriction on minimum stored electron energy in the Storage Ring could NOT increase the possibility of a different type of malfunction of equipment important to safety (e.g., engineered credited controls) than any previously evaluated in the SAD. The DOE-approved NSLS II ASE [PS-C-ESH-ROASE-001], Ver. 2 dated May, 2015; includes all credited controls that are necessary for operations up to the upper electron energy limits of 3.3 GeV in the Storage Ring. Attachment A – USI Evaluation for Re-statement of Stored Beam Lower Energy ASE Limit, when combined with References 4 and 5 above provide the necessary technical assurance to conclude that the re-statement of the ASE limit to eliminate the restriction on minimum stored electron energy in the Storage Ring does NOT increase the possibility of a different type of malfunction of equipment important to safety (e.g., engineered credited controls) than any previously evaluated in the SAD, nor does it represent an overall increase in risk.

V. USI Determination

A USI is determined to exist if the answer to any of the 6 questions above (in Section V) is "Yes." If the answers to all 6 questions are "No," then no USI exists.*

Does the proposed activity (or discovered condition) constitute a USI?

☒ Yes – DOE approval required prior to implementing, or discovered condition remedied in accordance with the Section 6.4 of PS-C-ESH-PRC-002, *Unreviewed Safety Issue Determination Procedure.*

☐ No – Proposed activity may be implemented with appropriate internal review, or no further action is required to address the discovered condition's impact on accelerator safety (other actions may be required to meet other PSD or Laboratory requirements).

*According to the SBMS Subject Area, *Accelerator Safety; Section 8 – Unreviewed Safety Issue (USI) Process; Step 6:* **If the USI Process determination is that the discovery or planned change will impact credited controls**, existing MCIs, create new MCIs or cause an increase in the risk classification as per the SAD risk table, **it is a USI**.

Prepared by: (Qualified Evaluator) [signature] 11/16/2015 Date

Approved by: [signature] 11/16/15 Date

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Attachment A – Description and Safety Analysis

Re-statement of NSLS-II ASE Stored Beam Lower Energy Limit for Storage Ring

Description:

SAD Section 5.2.3 – Storage Ring Credited Controls for the MCI [4th Bullet] states, "The radiological consequences of miss-steering electrons in the Storage Ring were evaluated over the energy range between 2.8 GeV and 3.2 GeV. To ensure that electrons with energy less than 2.8 GeV are not accepted into the ring and stored, the Storage Ring magnet-current is monitored. If the magnet current is less than the value corresponding to 2.8 GeV the PPS will turn the RF off and prevent further injection. The scientific program of the machine is operated at 3.0 GeV and at present has no needs for lower beam energy."

The last sentence of the statement above is no longer correct. The following re-statement of the lower stored beam energy limit from the ASE Section 2.1.3.3 has been proposed:

"Injection to the Storage Ring shall be prohibited if the storage ring dipole current is outside of the range which corresponds to 2.8 GeV to 3.3 GeV beam energy."

This will allow NSLS-II to accomplish the following goals:

- High-impact accelerator physics experiments are possible with the existing NSLS-II hardware if the ring energy is reduced below 3.0 GeV.
- If the anticipated experiments are not performed here and soon, they will be done elsewhere without NSLS-II providing the necessary support as a National User Facility.
- Machine studies in the same energy region would also be of great interest for beamline developers and soft x-ray users.
- Most of these studies can be done at very low beam current, < 10 mA [Minimal Risk].
- Lower stored beam energy will be achieved through standard down-ramping, with nominal 3 GeV beam injection.
- Storage Ring is well-shielded for losses of up to 0.5 A beam at 3 GeV. The lower the stored beam energy the more effective the shielding is.
- To allow for the early initiation of Storage Ring RF, before the dipole magnets are brought up to appropriate current range. Delaying the start-up of the RF system hinders reliability as this is the system requiring the most attention and being able to start RF sooner would allow for the early resolution of potential issues and promote more efficient restart after shutdowns. This is a no-beam situation, of course (early restart of RF). Removing the low energy limit on stored beam is the easiest way to alleviate this issue.

Note that the reduction of energy would occur only in the storage ring proper, not the injector. The booster would still operate at 3 GeV, 3 GeV electrons would be injected into the storage ring, and after stored beam is established, the ring energy would be lowered by ramping down all magnets and RF. Radiation physicists and Accelerator physicists who have reviewed this plan see no problem with this mode of operation [see authors of Ref. 4 and Ref. 5 attached].

SAD Section 5.2.3 – Storage Ring Credited Controls for the MCI [5th Bullet] states, "BTS magnets will be monitored by the PPS and interlock the Linac gun off if the magnet currents are outside their allowed current window and the Storage Ring shutter is open. Portions of the beam phase space with energies ranging from 2.0 GeV to 3.2 GeV can be transported into the Storage Ring enclosure. This control reduces the analysis that would need to be conducted to examine potential MCIs at lower energies in the Storage Ring Enclosure" This statement will not be changed.

As presently designed, the TOSS does not allow injection into the Storage Ring unless the energy is within 2% of 3 GeV, if any front end shutter is open. If the front end shutters are all closed the TOSS is by-passed and locking out TOSS has no effect.

There are two energy limiters on the Storage Ring dipole current. One trips the Storage Ring RF and the other trips off the Linac Gun. It is only the one which trips off the Storage Ring RF that will be changed. The energy limit that disables the Linac Gun remains and ensures that it is not possible to inject at lower energies.

The experimental Machine Studies contemplated above, at reduced storage ring beam energies, will be detailed and analyzed separately, in accordance with PS-C-ASD-PRC-095, "*Scheduling and Performing NSLS-II Machine Studies*". The Machine Study write-up(s) will reflect the commitment to administratively limit the number of Storage Ring re-fills to no more than 20 per hour during such Machine Studies, independent of the instrumentation designed to protect against exceeding MCI conditions [which is done by an ACMI in the Booster-to-Storage Ring line which interlocks the Linac gun at 48 uC/hr].

Safety Analysis:

The proposed "Re-statement of the NSLS-II ASE Stored Beam Lower Energy Limit for Storage Ring" [ASE Criterion 2.1.3.3] can be effected by just changing a setting on the Storage Ring Energy Limit Trip Amplifiers that interlock the Storage Ring RF transmitters. This will need to be done for both 'A' and 'B' chains of the Storage Ring Personnel Protection System (PPS). The lower limit will be reduced to 2.0 GeV (or lower, if needed), the upper limit will remain in place. The separate Injection Energy Limiter Trip Amplifiers will not be changed and they will prevent the Linac gun from operating if the Storage Ring energy is below 2.8 GeV and if the BST B2 Dipole is within its energy limits and the BtS Shutter is open. This will prevent injection into the Storage Ring at Storage Ring energies below 2.8 GeV.

Storage Ring is designed and constructed to be well-shielded for losses of up to a 500 mA beam at 3 GeV. All testing and surveys to date at lower currents support the accuracy of that statement. Moreover, the lower the stored beam energy, the more effective the shielding is.

The current interlock topology exists that eliminates the possibility of injecting beam into the Storage Ring, if the dipoles are set at incorrect energy. Presently, whenever the dipole current is outside of plus-or-minus 1.8% of the 3 GeV energy window, the system drops the RF and disables the gun. This precludes the injection of a 3 GeV beam when the magnets are down-ramped to lower energies.

With respect to experimental studies with lowered stored beam energies, limits on associated beam currents can and will be stated in the Machine Study Plan(s), which must be reviewed and approved before implementation. One additional administratively controlled Operational Limit will be included for the Machine Studies planned at lowered energies and that is, No more than 20 Storage Ring Refills per hour. The lead operator has the responsibility for control over the maximum stored beam current in the machine through the controls system by setting an upper limit on the beam current that is only changeable at the lead operator's console, which inhibits the trigger to the gun once reached or exceeded. This is routinely done by an ACMI in the Booster-to-Storage Ring line which interlocks the Linac gun at 48 uC/hr cumulative charge.

Control of the distribution of losses from the Storage Ring is not a current requirement, nor is any acceptable distribution pre-defined. What is defined is the alarm and trip points for the Area Radiation Monitoring System, which reacts at such low levels as to preclude radiation overexposures to personnel, even with intentionally miss-steered beams. Nonetheless, beam scrapers can be used to localize beam losses in the more heavily shielded areas. Efficiency of such plans would be dependent on the specific ramps and the beam motion.

The analyses contained within Ref. 4 and Ref. 5 (attached) show that if the stored beam strikes the shielding at lower energies (below 3 GeV) the shielding will be more than adequate. The analyses have been reviewed and accepted by the NSLS-II Radiation Safety Committee [Ref. 6].

Re-statement of the NSLS-II ASE Stored Beam Lower Energy Limit for Storage Ring [ASE Criterion 2.1.3.3] cannot create a miss-steering event, even at lower energies, similar to the Linac event. The PPS will continue to restrict injection to a narrow window around 3 GeV. Once beam is stored within the Storage Ring, no large miss-steers in the beam exist, nor is it possible to ramp the magnet current fast enough to lose a beam at a focused location. That would require ramping supplies to a current limit on the order of a microsecond, something only the injection kickers can do. The design of the Storage Ring magnet power supplies are such that, tenths-of-seconds to seconds are required to effect a change in magnet current. Therefore, miss-steers such that the beam does not hit a shield are not possible once beam has been stored.

Regarding the injection kickers; they are set up to bump the stored beam toward the injection septum for injections. Once the beam energy is lower, the bump would cause the beam to strike the aperture at the inside of the ring or the injection septum. These areas are analyzed for losses at the ASE maximum.

An extremely conservative calculation was performed to assure that circulation of the lowered energy beam would not create an Ozone production concern. The maximum ozone concentration produced was determined to be 0.007 ppm (where TLV for Ozone 0.1 ppm). This is not expected to be a problem for workers accessing the storage ring tunnel following the Machine Studies of ramped down stored beam energy.

In conclusion, given the fact that injection will be restricted to 3 GeV by the PPS, that the shielding is designed for 3 GeV, and that miss-steers at lower energies resulting in a point loss are not possible once stored beam is established, there can be no deviation created from the existing safety analysis, even at maximum stored beam current or anything less than that which presents an increase in hazard or dose to workers or the environment.

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current of 500 mA. An operational limit for circulating current in the storage ring has been established of 550 mA (providing a 10% margin on top of the nominal value) The operators are charged with not exceeding this limit, and receive specific training focused on the operating limits on the beam energy and intensity (circulating current). In addition, two engineering systems provide additional back-up to the operators for defense in depth.

- **The maximum stored electron energy shall not exceed 3.3 GeV**

  Basis: An upper ring energy PPS interlock monitoring the storage ring magnet current is established for 3.2 GeV which matches the maximum energy permissible for the Booster extraction energy. At energies higher than 3.2 GeV, the interlock will turn off the ring RF and stop further injection into the ring. The ASE upper energy limit for the Storage Ring is set at 3.3 GeV, providing a slight margin to the action of the upper ring energy interlock. Energies higher than the Booster injection energy are unlikely but could occur due to acceleration by the storage RF cavities. The MCI was calculated using an energy of 3 GeV. The radiological consequences of a 3 GeV electron beam and a 3.3 GeV beam are not significantly different.

- ~~**The minimum stored electron energy shall not be less than 2.8 GeV**~~

  Basis: The radiological consequences of mis–steering electrons in the Storage Ring were evaluated over the energy range between 2.8 GeV and 3.2 GeV. To ensure that electrons with energy less than 2.8 GeV are not accepted into the ring and stored, the Storage Ring magnet-current is monitored. If the magnet current is less than the value corresponding to 2.8 GeV the PPS will turn ~~the RF~~ off the Gun High Voltage. ~~and prevent further injection. The scientific program of the machine is operated at 3.0 GeV and at present has no needs for lower beam energy~~.

- **The minimum electron energy transported to the Storage Ring shall be greater than 2.0 GeV**

  Basis: BTS magnets will be monitored by the PPS and interlock the Linac gun off if the magnet currents are outside their allowed current window and the Storage Ring shutter is open. Portions of the beam phase space with energies ranging from 2.0 GeV to 3.2 GeV can be transported into the Storage Ring enclosure. This control reduces the analysis that would need to be conducted to examine potential MCIs at lower energies in the Storage Ring enclosure.

5.2.4 Credited Controls for Top-Off Operations MCI

- **The maximum electron charge injected into the Storage Ring shall not exceed 2.7 uC (2,700 nC) integrated over one hour**

  Basis: The MCI for injection into the Storage Ring is evaluated at an injection rate of 45 nC/min, which if continued for a period of 1 hour would result in 2.7 μC/hr. The charge injection rate of 45 nC/min allows for rapid Top-Off of the storage ring and exceeds other operational limit pre-sets. The maximum integrated injected charge per hour will be limited to 2.7 μC (2,700 nC). Top-Off operations are expected to be regular relatively small injections continuously. The accident analysis has shown that the areas adjacent to the storage ring will satisfy the NSLS-II Shielding Policy during Top Off Operation at this hourly injection charge. Operators will be able to monitor the injected rate and hourly charge through Control room display and ensure compliance with this limit. The injected charge will be monitored and controlled through the PPS system (i.e., ACMI in the BtS transport line and after the fourth accelerating structure in the Linac.

"Injection to the Storage Ring shall be prohibited if the storage ring dipole current is outside of the range which corresponds to 2.8 GeV to 3.3 GeV beam energy."

2.1.2.3 The minimum injected electron energy shall be 150 MeV

2.1.3 Credited Controls for Storage Ring Maximum Credible Incident

The following limits establish the operational envelope for Storage Ring operation that may not be exceeded.

2.1.3.1 The maximum electron charge shall not exceed 54 μC integrated over one hour as measured by an ACMI located in the Booster to Storage Ring (BtS) transport line. The maximum electron charge stored within the Storage Ring shall not exceed 2.6 μC (2600 nC) at 3.3 GeV.

2.1.3.2 The maximum stored electron energy shall not exceed 3.3 GeV.

2.1.3.3 ~~The minimum stored electron energy shall not be less than 2.8 GeV.~~

2.1.3.4 The minimum electron energy transported to the Storage Ring shall be equal to or greater than 2.0 GeV.

2.1.4 Credited Controls for Top-Off Operation MCI

Top-Off Operation shall be defined as the mode of operation when it is desired to inject electrons into the Storage Ring with the photon shutters open.

2.1.4.1 During Top-Off Operation, the maximum electron charge injected into the Storage Ring shall not exceed 2.7 μC integrated over one hour as measured by an ACMI located in the BtS transport line and an ACMI immediately downstream of the fourth accelerating cavity of the Linac.

2.2 Credited Controls for Radiation Hazard

There are a number of credited controls which are required to maintain the radiological consequences within bounds of the MCI. Except as designated, these apply to the operation of all accelerators and beamlines:

2.2.1 Each accelerator and beamline when operational must have its Personnel Protection System (PPS) and associated barriers, including gates, fencing, and berms, and the area radiation monitoring system operational and certified in compliance with the approved procedure. The relevant PPS must be operational during testing of RF cavities.

2.2.2 All required radiological shielding for an area must be in place and certified in compliance with the approved inspection procedure during operation of that area with the radiation hazard.

2.2.3 All required burn-through devices must be in place and certified in compliance with an approved inspection procedure during operation of a front-end with the radiation hazard.

2.2.4 At least one qualified, trained operator shall be on-duty during operation of the accelerators with electron beam.

2.2.5 All required TOSS apertures for approved front ends must be in place and certified in compliance with the approved inspection procedure during Top-Off Operations within that area.

"Injection to the STORAGE RING shall be prohibited if the storage ring dipole current is outside of the range which corresponds to 2.8 GeV to 3.3 GeV beam energy"

REFERENCE 4 – NSLS-II-EVAL-2015-004, Rev. 1

NSLS-II TECHNICAL NOTE BROOKHAVEN NATIONAL LABORATORY	NUMBER 178
AUTHOR **S.L. Kramer, B. Podobedov and Z. Xia (and LSDCG members)**	DATE **June 18,2015**
TITLE **Beam Energy Limits for NSLS-II SR**	

I. Introduction

The bulk shielding for the NSLS-II was specified [1] using the Analytic Model for radiation penetration of thick shields [2-4]. This model assumes that the dose rate of concern is at a total distance **R** from the radiation source to be shielded. This source originates from a total beam power (**J**) hitting a thick target. The source terms for each components of ionizing radiation emitted by the target (i. e. electrons, gamma rays and neutrons of concern here) is expressed as radiation dose equivalent factors (F_i for each component **i**), which are the unshielded equivalent dose rates for that component per unit of incident beam power **J,** at a distance **R** = 1meter from the target. Each radiation component is then shielded by the material of thickness **t**, with attenuation length λ_i for each radiation component, **i**. The shielded total dose rate (**H**) is estimated by the sum of each attenuated radiation component for the incident total beam power **J**, at the total distance **R**, by the equation (1)

$$\mathbf{H} = (\mathbf{J} / \mathbf{R}^2) * \Sigma_i \mathbf{F}_i * \exp[-t/\lambda_i] \qquad (1)$$

This equation is only valid for transverse radiation dose rate at ~90° (transverse walls of tunnel) from the incident beam direction and the target needs to have at least 3 radiation lengths of thickness and 6 Moliere radii in transverse size, in order to generate a significant E-M shower and transfer sufficient energy to the shower particles.

This equation can be used to calculate either dose rate if the beam power loss is **continuous** (injection) or for exposure dose if the beam power is lost in a **single pulse** (dump of stored beam or one injection pulse), for which the beam energy loss (integral of beam power loss over the pulse time duration) is used. The dose equivalent factors, F_i, are usually given in units of (μSv m^2/Joule) or (mrem m^2/Joule) and the time unit for dose rate or exposure dose coming solely from the units for **J** being either beam power loss, P_b (Watts = Joule/second) or beam energy loss, U_b (Joule). In either case the radiation outside the shield only depends on the total beam power or energy lost.

1) For continuous beam loss, the beam power loss P_b (Watts) is the product of the particle kinetic energy E_0 (eV)/e (total energy less rest energy, which is negligible for electron beam):

$P_b = E_0$ (eV)/e × beam current **I** (Amps).

2) For single pulsed beam loss the total beam energy loss $\mathbf{U_b}$ (Joules) is the product of the particle energy $\mathbf{E_0}$ (Joule) x number of beam particles $\mathbf{N_b}$, which is equal to the beam charge divided by e or $\mathbf{Q}$ (C) /e (C/particle) or just:

$\mathbf{U_b} = \mathbf{E_0}$ (eV)/e × $\mathbf{Q}$ (C).

For the dose rate calculated in the forward direction, the E-M shower has a more intense higher energy core that increases faster than linearly with the $\mathbf{E_0}$ due to conservation of momentum. At 0° a good representation is that the dose equivalent factors $\mathbf{F_i}$ increase linearly with particle energy. The constancy of the $\mathbf{F_i}$ can be restored, by scaling the $\mathbf{F_i}$'s by the particle energy $\mathbf{1/E_0}$ in the appropriate units (e.g. eV) and then modifying Eq. 1 for different particle energy beam by including $\mathbf{E_0}$ in the first bracketed term $(\mathbf{J} * \mathbf{E_0} / \mathbf{R^2})$. For angles between 0° and 90° the dose rate or exposure dose scaling with $\mathbf{E_0}$ is more complicated, but will vary from $\mathbf{E_0}^2$ at 0° to $\mathbf{E_0}$ at 90° (transverse direction). A conservative approach would be to use the transverse linear dependence on $\mathbf{E_0}$. This means that dose rates or exposure dose will scale down at least as $\mathbf{E_0}$ for a fixed beam current or stored charge.

The FLUKA [6] calculated dose rates are more accurate since they include: the full target and shield wall geometry, changes in attenuation length λ_i with component particle energy, radiation component generation (changes in flux) in the shielding and the full angular dependence relative to the beam direction. All reported FLUKA estimated dose rates for the SR [5] were calculated for 3 GeV particle energy and 15 nC/sec beam loss rate. These could be scaled as $\mathbf{E_0}^2$ at 0° (forward ratchet wall dose) or $\mathbf{E_0}$ for the transverse shield wall dose. Local dose exposure (mrem) for a beam dump can be calculated from the FLUKA dose rates (mrem/h for 15 nC/s) by scale the beam charge lost and correcting the disparate in time units. The dose exposure D, resulting from a 500 mA 3 GeV beam loss, at the same location used by FLUKA to calculate a dose rate value D' (mrem/h for 15nC/sec loss), can be obtained simply by dividing D' by 41 h^{-1}. Similarly the exposure dose levels for other energies can also be estimated by scaling by $\mathbf{E_0}$ or $\mathbf{E_0}^2$.

The maximum FLUKA calculated surface dose rate for a beam fault (miss-steered 3 GeV beam loss rate at 15nC/s hitting the G6-DSS) condition was ~1300mrem/h total and ~200mrem/h total neutron dose rate at a Long ID doorway Krack for a beam line with components installed only to the photon shutter (i.e. no Bremsstrahlung shields or safety shutters installed)[7]. The measured Cell08ID (beam line completed only to photon shutter) Phase 3 Fault Study maximum dose rates scaled to 15nC/s and total neutron dose rate was 1350mrem/h total and 270mrem/h for neutron component, with a factor of ~4X reduction of these rates at 30cm from the Krack surface [7], in good agreement with the FLUKA estimated dose rate. Although this fault condition would have tripped both high and low ARM interlocks (at the 15nC/s loss rate), a beam loss rate of 1.5nC/s would not have tripped either level of the ARM interlock and the 135mrem/h surface and 34mrem/h at 30cm dose rate would have continued until operator intervention terminated the injected beam. From the scaling mentioned above, a single 500mA 3 GeV stored beam dump hitting one G6-DSS, the exposure dose at the surface of the door Krack would be 33mrem and at 30cm 8.2mrem. Once the stored beam energy is lost the dose rate drops to zero and would require a significant operator effort to restart injection and the radiation risk. Assuming the ARMs handle the instantaneous high dose rate of the dump in a linear response, the high level alarm (> 5mrem/h) would have tripped requiring even more operator and RCT actions to restart injection (radiation risk) into the SR.

II. Radiation Risk of Injected Beam Loss

Injection of beam power $\mathbf{P_b}$ into any synchrotron is always of concern, since without stored beam being present the beam trajectory may not have a closed orbit (a requirement to accumulate stored beam charge) and may even not be within the vacuum chamber and will then be a beam loss point in the tunnel. The beam of particles isn't a beam after it hits the first solid material, but becomes an E-M shower that requires codes like FLUKA in order to propagate. The point at which the beam is miss-steered (lost) outside the vacuum chamber becomes a loss point that needs to be evaluated for the radiation risk it could cause. The radiation risk is directly related to the total $\mathbf{P_b}$ that could be lost at any one or several locations. For the same loss point and beam angle the resulting dose could scale either as $\mathbf{E_0}^2$ or $\mathbf{E_0}$ as described above. However with changes in $\mathbf{E_0}$, the beam will be miss-steered over different angular ranges since the bend angle from a magnet (with magnetic field **B**) will scale as: $\Theta \approx \mathbf{B} / \mathbf{E_0}$. The local shielding was provided [5] for the most likely miss-steered beam locations assuming 3 GeV beam was being transported from the booster, within the limits of the magnetic fields possible from either the power supplies or limited by a credited PPS limit on the magnetic current from the power supply.

Despite this limited range of dose rate estimates, the SR local shielding design, e.g. Dipole Shadow Shields (DSS), (a credited radiation safety system) has several built-in safety features. Most importantly is the requirement that all beam transport and SR dipole magnets have a credited control on their bending polarity. This insures that the risk to the SR experimental floor (SR-EF) is not underestimated for lower energies when electron beam could be bent beyond the installed local shields. With this dipole polarity assurance, the worst case miss-steering risk to the SR-EF from the dipoles is the "dipole off" case. This loss location can only be after the first dipole. This case has been studied with FLUKA for 3 GeV beam, and the results could be scaled for any $\mathbf{E_0}$. This is because zero field corresponds to zero bend angle for all $\mathbf{E_0}$ and the location is fixed, since beam cannot propagate past the first G4-DSS. If the first dipole after injection has enough field to propagate the beam to the 2nd dipole aperture, it and all subsequent dipoles will similarly bend the beam inward, since all dipoles are in series and guaranteed to be powered with the correct polarity by the polarity check procedure. The G4 and G6-DSS shields were designed to shield the SR-EF for the maximum possible miss-steering angles that could exit the dipole vacuum chamber, within the beam parameters allowed by the PPS interlock.

The second feature in the SR local shielding design requirement is a PPS interlocked energy window on the transported beam using the current in the BS-B1&B2 transport line dipoles equivalent to 3GeV $\pm$ 5% and the SR dipole current of 3 GeV $\pm$ 2%. Despite this energy interlock there is an unlikely, but possibility that a 2 to 3.15 GeV beam could be transported with a poor efficiency (low current) into the SR injection region. Therefore the maximum miss-steering angle analysis for injection into the SR included this energy range and the FLUKA analysis looked at these maximum angles, but for $\mathbf{E_0} = 3$ GeV. This will insure that the worst case radiation dose rates have been estimated for the SR-EF and that other beam energies could be estimated by using the appropriate power of $\mathbf{E_0}$. In addition, radiation fault studies have now been run which could similarly be scaled to other energies. The highest dose rate measured has been at the downstream edge of the sliding ID door Kracks (see above). These dose rates have been shown to be in excellent agreement with the FLUKA calculations for beam hitting the G6-DSS shield after the 2nd dipole in the SR cell [7]. This places the beam loss angle to the Krack about 45°, making the dose rate scaling with a power of $\mathbf{E_0}$ between 1 and 2 (conservative would be to use 1 for lower and 2 for higher $\mathbf{E_0}$).

However the risk of lower $\mathbf{E_0}$ injection operations to the inner shield walls (ISA, service and RF building) and the mezzanine would have to be evaluated. These areas haven't been well measured during fault studies, since emphasis has been on getting beam lines operational and these areas could have more restricted access during injections. **The NSLS-II ROASE states in section 2.1.3.5 "The minimum electron energy transported to the storage ring shall be equal to or greater than 2.0 GeV"** [8]. This lower energy limit disagrees with the PPS limits of 3 GeV $\pm$ 5% on the BS-B1&B2 magnets, which would prevent efficient injection below a 2.85 GeV beam energy. Changes to that PPS limit, would require a re-analysis of the transport line and injection component miss-steering for lower particle energy to insure the shields have adequate coverage. **However no suggestion to change either limit is being proposed and all beam injections would continue to be at 3 GeV, within the PPS dipole energy selection window.**

III. Radiation Risk of Stored Beam Loss

The radiation risk analysis for stored beam operations is simpler in two respects: 1) the existence of stored beam insures that the magnets are within tight tolerances of the values which insure a closed orbit is inside the SR vacuum chamber (SR-VC) and 2) the stored beam energy and therefore the energy loss, $\mathbf{U_b}$, is fixed and finite (as opposed to infinite for the case of continuous injection beam loss) . For most synchrotrons having a closed orbit inside the SR-VC requires magnets to be typically set to within several percent of the design values for dipoles and quadrupoles and the sextupoles only impact the lifetime value for the stored beam current. NSLS-II is unique compared to NSLS-I and other accelerators, in that the accelerator is highly non-linear, which means the potential well that allows current to be stored in a bunch has a small stable region not defined by the SR-VC aperture but smaller than that aperture. Therefore in order to have beam current stored long enough to measure on a DCCT, the SR requires quadrupole fields tolerances to be few 0.1% and sextupoles to be a few % of design values. This also means that beam losses from the stable potential well don't directly hit the SR-VC aperture but propagate on non-linear trajectories to the material apertures defined by the SR-VC walls, ID gaps or the photon absorber apertures or the variable scrapers. **The important point is once injection has filled the ring to an allowed beam current and is turned off; the presence of stored beam insures tight tolerances on the magnetic fields and RF parameters of the ring, as well as limiting the stored beam energy that could be lost consequently limiting the resulting radiation dose**

The radiation risk from stored beam current can be divided into two components: (1) stable beam lifetime beam losses and (2) unstable beam dumps or trips (PPS interlock, RF trips, magnetic field changes or instability losses). They both result in stored beam current losses (either total or partial loss) but they differ in the rate of loss typically a few second or less for (2) and lifetime current decay of minutes to hours for (1). In either case a beam current loss will almost never occur at one location but will be distributed over many cells of the ring. This is due to the bunches making 378K revolution per second and undergoing 32-66 transverse oscillation peaks around the ring for each revolution. Even if the PPS induces an RF trip or the RF trips off on its own, the beam particle energy will decrease (due to synchrotron radiation losses) over 10's of milliseconds until the beam starts hitting the dispersion region vacuum chamber aperture in the 30 cells or ID gap apertures, reducing the radiation exposure at any one location by factors > 30X as compared to a total beam loss at that location. Some instabilities could be slightly faster but would still last many turns over which to distribute the beam losses. Similarly, with orbit feedback on, the corrector magnets may attempt to miss-steer beam but they will take several to many milliseconds to move the beam to an aperture while undergoing many oscillations around the ring, dispersing the beam losses. **The important point is that stored beam losses almost always are**

distributed losses over many locations reducing the radiation exposure risk by large factors as compared to injection beam miss-steering losses.

The one beam loss scenario that does not result in the distributed loss location is the scraper-induced beam loss which will be at one or a few locations (i.e. one or more of the 5 scraper in the heavily shielded injection region) when the scrapers are inserted [6]. This is by design and is part of the Loss Control and Monitoring system (LCM) that was proposed to limit the beam loss for high current operations to the more heavily shielded injection region of the SR tunnel, where they are located. The scrapers also have associated beam loss monitors that will verify what fraction of the stored beam current loss actually hit the scraper and therefore beam lost in the injection region. The inner two dispersion region horizontal scrapers Hscraper1 and 2 will control this loss for both components if they are inserted to an aperture limit that is closer to the beam orbit than any other aperture of the ring. These scraper locations also have additional local shielding [6] to allow a higher rate continuous beam loss at these locations. The particles that pass through the scraper (lower energy) are bent inward inside the subsequent dipole inducing the radiation shower in the massive iron yoke of the dipole and at angles away from the SR-EF. The radiation levels outside the tunnel for injection beam hitting the scrapers has been calculated with FLUKA [5] and measured during fault studies. Although FLUKA estimated dose level of < 2 mrem/h at the beam loss rate that the fault studies were run, the measurements showed little dose above background. However these measurements are suspect, since the scrapers may not have been inserted sufficiently to intercept the beam or the measurements were not made downstream of the loss point, missing the peak of the dose distribution (clearly the case for at least one measurement set). Despite these discrepancies the FLUKA calculations showed that the dose exposures are less than 1mrem per 500mA on the SR-EF beam loss hitting a scraper and < 2mrem on the mezzanine.

All these estimated or measured radiation levels will decrease at least as $\mathbf{E_0}$, since the beam current would be limited to the 500mA by the 3 GeV injection energy limit. In fact increasing $\mathbf{E_0}$ should also pose no added radiation risk as long as the total stored beam energy $\mathbf{U_b}$ is reduced as $\mathbf{E_0}$ increases.

The process of reducing $\mathbf{E_0}$ in the SR is quite simple in principle and entails ramping down the dipole field. As the energy is lowered the quadrupoles, sextupoles and correctors must also track this change by lowering their field proportional to $\mathbf{E_0}$. It could take several attempts to track these fields accurately enough with $\mathbf{E_0}$ to not dump the beam. This ramp generation machine study will be done at low beam current reducing the exposure dose of a dump. The ramping down and then restoring magnetic fields of the ring to accept another injection after a beam dump will takes considerable time, lowering the average beam power loss well below the level of a constant 3 GeV injection beam loss. This loss, of course, has already been shielded and verified for normal injection losses. **Therefore lowering the beam energy through down-ramping poses much lower potential radiation risks, then those that are already shielded for at 3 GeV operations.**

IV. Conclusion and Recommendation for ROASE

The NSLS-II ROASE (section 2.1.3.4) states that: "the minimum stored electron energy shall not be less than 2.8 GeV." From the previous discussion of the radiation risk associated with lower energy stored beam , this limit for stored beam particle energy is not warranted since lower stored energy represents lower radiation risk, not increased. The total stored beam energy, $\mathbf{U_b}$, will be limited to the maximum current allowed at the 3 GeV injection energy, while ramping down the particle energy reduces the stored beam energy as $\mathbf{E_0}$. Beam lifetime will decrease at lower particle energies as compared to 3 GeV lifetime, but this will have little impact since the radiation per particle lost will also decrease. Also lower lifetimes have also been generated during 3GeV operations as higher bunch currents and more nonlinear lattices are studied and they have been measured to impose no added radiation risk. The SR is not expected to run at energies below 3 GeV for long periods initially. Once the down ramp is perfected, lower energy runs for studies and users operation could be scheduled as needed with no increase in exposure dose to the SR.

In order to better understand and hence improve the SR operations at 3 GeV operations with high beam currents, important studies are needed at lower energies where these high current effects have greater impact. Since the synchrotron radiation power per electron decreases as $\mathbf{E_0}^4$, the damping rate as $\mathbf{E_0}^3$ and the emittance as $\mathbf{E_0}^2$, this will allow for better understanding of these radiation effects on the high current related issues. For example the beam impedances (source of instabilities) are independent of $\mathbf{E_0}$ and the voltage generated depend only on the charge in the bunch or total current. These voltages will have a bigger impact on the instability of the beam at lower $\mathbf{E_0}$ since the beam is less rigid and the damping reduced. In addition the soft X-ray and VUV users will benefit from the lower emittance beam with less higher energy X-ray power to contend with. These beam properties might actually lead to special user request periods for lower energy operations. **Therefore this ASE lower limit on stored particle energy represents a major limitation to the scientific potential of the NSLS-II SR. From the radiation risks point of view this lower energy is not warranted.**

The recommendation is that no lower limit should be specified in the NSLS-II ROASE for stored beam operations. This is in agreement with the other DOE-funded synchrotron light sources (SSRL, ALS, and APS) which do not have an ASE limit for the minimum stored particle energy.

No change is suggested for the injection energy lower limit in the NSLS-II ROSAE. This will insure that all stored beam running at lower energy will be done by injecting at 3 GeV (subject to current limits at that energy) and then ramped down to the desired energy. When beam has dumped or a refill is necessary, this will require the ring particle energy to be ramped up to 3 GeV for re-injection.

VI. References

[1] LT–C–ESH–SCSAD–001 and Appendix 4 (LT-ESHDES-08-002-Rev002 (2008).

[2] Panakkal K. Job and William R. Casey, Radiological considerations for bulk shielding calculations of national synchrotron light source-I I, Nucl. Instr. And Meth. in Physics Research A 660, 1-6, (2011).

[3] A.H. Sullivan, "A guide to Radiation near High Energy Particle Accelerators", Nuclear Technology Publishing, 1992.

[4] W.P. Swanson, Radiation Safety Aspects of the Operation of Linear Accelerators, IAEA Technical Report 188, 1979.

[5] NSLS-II Technical Note 101 "Local Radiation Shielding Design Methodology"(2013), and LT-C-ASD-RSI-SR-001 "Shielding Specification and Design Document (SSDD) for the BST-P2 and Storage Ring", (2013)

[6] FLUKA: a multi-particle transport code developed at CERN by Alfredo Ferrari, Paola R. Sala, Alberto Fasso and Johannes Ranft.

[7] NSLS-II Technical Notes 155-RevA "SR Phase 3 Radiation Fault Study and FLUKA Estimates" and 170 "SR ID Doorway High Radiation Levels and Proposed Shielding" (2015).

[8] NSLS-II Routine Operations Accelerator Safety Envelope, PS-C-ESH-ROASE-001, (2014).

ReFERENCE 5 - NSLS-II-EVAL-2015-004, Rev. 1

Photon Sciences Directorate

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June 22, 2015

To: Bob Lee, PS-ESHQ Manager
From: Stephen Kramer, Chairman Local Shielding Design Coordinating Group
and Z. Xia, PS- ESHQ

Subject: Removal of the NSLS-II ROASE stored beam lower energy limit

This letter is to inform you that the LSDCG has reviewed the radiation risks of stored beam energy limits for the NSLS-II storage ring and find that the lower stored beam energy limit of the ROASE is not warranted from the radiation risk point of view. The injection energy limit of the PPS, was used as the basis for the radiation risk assessment for the Supplemental Shielding Design Document (SSDD) LT-C-ASD-RSI-SR-001 and limited the injection energy to 3 GeV. The stored current will be limited to the administrative operational value for 3 GeV, relevant at the time ($\leq$ 500mA, 1.32μC). This current limit will always be less than the value specified in Section 2.1.3.1 of the PS-C-ESH-ROASE. After the current is stored the injection system will be turned off, then the SR dipoles and other magnets can be safely ramped down to lower particle energy maintaining the stored beam current at the injection value or small losses during the ramp. Several studies will be required to develop a down ramp with sufficient correlation between the field settings of these magnets to maintain the stored current without losing any significant fraction. These studies will be done at low currents and therefore reduced radiation risk when beam is lost. Once the ramps are developed, the radiation risk at these lower energies will be reduced since the total stored beam energy will be reduced proportional with the particle energy for a constant beam current. The potential radiation exposures outside the SR tunnel, should the beam be lost, will decrease with the decreasing particle energy. The reduction along the transverse tunnel walls and mezzanine will decrease linearly with energy and will decrease as the square of the energy to the ratchet wall hutches. Therefore even if beam is lost at these lower energies less radiation exposure dose will occur as compared to 3 GeV energy beam loss.

Once beam is lost at the lower energy the SR magnets will have to be ramped up to their 3 GeV values in order to inject current into the ring. The PPS will prohibit injection gun turn-on unless both the BST magnets and the ring dipoles are at their 3 GeV values. This down and up ramp will reduces the time during which the injection losses can occur compared to injection losses for 3 GeV operations. Since the injection losses represent the major radiation risk outside the SR tunnel, the net reduction in total exposure dose will be reduced during periods of lower energy stored beam operations.

Therefore the LSDCG can confidently recommend that the lower stored beam energy operations limit should be eliminated altogether, since it represents lower radiation exposure risk outside the SR tunnel. This change is in agreement with the ASE limits on stored beam energy at the other DOE light sources; APS, ALS, SSRL-SPEAR3, which similarly have no lower stored beam energy limit. More details on the LSDCG review are given in Tech Note 178.

CC: F. Willeke, T. Shaftan, V. Smalyuk, E. Blum, B. Podobedov

Ref. 6

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for the U.S. Department of Energy

Memo

Date: October 19, 2015
To: Steven Moss, Robert Lee, Boris Podobedov, and Ferdinand Willeke
From: Zhong Zhong (chair), Photon Science Radiation Safety Committee
Subject: Review of the proposed elimination of NSLS-II ASE stored beam lower energy limit for storage ring

Dear Mr. Moss,

On Tuesday October 13, 2015, the Photon Science Radiation Safety Committee (RSC) reviewed your USI (Un-reviewed Safety Issue) evaluation form NSLS-II_EVAL-2015-004 regarding elimination of the stored beam lower energy limit for storage ring from the NSLS-II ASE.

Written documents

The following documents were submitted to the RSC for review:

1. USI (Un-reviewed Safety Issue) evaluation form NSLS-II_EVAL-2015-004 regarding elimination of the stored beam lower energy limit for storage ring from the NSLS-II ASE.
2. Powerpoint presentation "Why it is Safe (and Useful) to Perform NSLS-II Ramp-down Studies below 2.8 GeV", by Boris Podobedov, dated October 13, 2015.

Presentation

Attendance: Andrew Ackerman, Mo Benmerrouche, Andy Broadbent, Mark Breitfeller, Mary Carlucci-Dayton, Edward Cheswick, Steve Kramer, Robert Lee, Wah-Keat Lee, Steve Moss, Boris Podobedov, Howard Robinson, Chuck Schaefer, Chris Stelmach, Ray Fliller (via e-mail comments), Emil Zitvogel, and Zhong Zhong

Boris Podobedov gave the presentation entitled "Why it is Safe (and Useful) to Perform NSLS-II Ramp-down Studies below 2.8 GeV", dated October 13, 2015. In essence, this proposed change to ASE would allow the storage ring to operate at lower than the designed 2.8 GeV energy.

The reason for operating the storage ring at lower than 2.8 GeV is to experiment with the concept of achieving higher photon beam brightness at lower ring energy – experimental verification of which would allow the NSLS-II to stay at the fore-front of the current world-wide trend towards higher brightness, for example, via MBA lattice.

Results of radiation studied were presented showing no additional risks operating the storage ring at lower than the design energy. Specifically, in case of accidental beam dump, the dose expected outside of the shield-wall is proportional to E and E^2 for transverse and longitudinal directions, respectively. Thus operating at lower energy (E) reduces the radiation exposure risk.

It was also noted that the other DOE-operated light sources do not have lower limit on their storage ring energies.

Notes:
The following are noted here for completeness:

1. The impact of lower storage-ring energy on the beam excursion and photon-beam divergence of wigglers is discussed.

2. We note that lowering the injected beam energy is not in the current scope of change. We further note that lowering the injected beam poses possible additional hazard that may require more radiation shielding to deal with the relatively larger mis-steering at lower energy. Current PPS system limits the lowest possible beam energy that can be injected into the storage ring. Current proposal is to inject at 2.8 GeV and down-ramp in the storage-ring.

3. We note that top-off operation will be precluded by lower beam energy.

Recommendations

Based on our study of the presented material, we believe that there is no additional hazard from lowering the stored beam energy to arbitrarily low values. Therefore we recommend proceeding with the LESHC review and DOE approval of the proposed change to ASE.

Radiation Safety Committee

Name	Expertise	Directorate
Andrew Ackerman	Deputy ESH Manager	PS
Dana Beavis	Experimental Nuclear Particle Physics	NPP
Mohamed Benmerrouche	Nuclear and Radiation Physics	PS
Scott Buda	Personnel Protective Systems	PS
Ray Fliller	Accelerator Physicist	PS
Les Hill	Conduct of Operations Manager	PS
PK Job	Radiation Physicist	PS
Wah-Keat Lee	Beam Line Physicist	PS
Boris Podobedov	Accelerator Physics	PS
Chuck Schaefer	Accelerator SME	ESH
Om Singh	Accelerator Controls	PS
Scott Walker	Health Physics	ESH
Lutz Wiegart	Beam Line Physicist	PS
Zhong Zhong	Beam Line Physicist	PS
Emil Zitvogel	Accelerator Operations	PS
Leighley, Tabatha	Administrative Support	PS

NSLS-II DEPARTMENT

SAFETY ASSESSMENT DOCUMENT

FOR THE

NATIONAL SYNCHROTRON LIGHT SOURCE II

MAY 2015

PS–C–ESH–RPT–001

PREPARED BY
BROOKHAVEN NATIONAL LABORATORY

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MANAGED BY
BROOKHAVEN SCIENCE ASSOCIATES

FOR THE
U.S. DEPARTMENT OF ENERGY
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BASIC ENERGY SCIENCE
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DISCLAIMER

NSLS-II DEPARTMENT

SAFETY ASSESSMENT DOCUMENT

FOR THE

NATIONAL SYNCHROTRON LIGHT SOURCE II (NSLS–II)

MAY 2015

SUBMITTED: ______ 05/22/15

Steven H. Moss — DATE
NSLS-II Department – Preparer
Brookhaven National Laboratory

SUBMITTED: ______ 5/22/15

Robert J. Lee — DATE
NSLS-II Department – Environment, Safety & Health Manager
Brookhaven National Laboratory

SUBMITTED: James Rose for F.W. ______ May 22, 2015

Ferdinand Willeke — DATE
NSLS-II Department – Accelerator Director
Brookhaven National Laboratory

SUBMITTED: ______ May 28th, 2015

Paul Zschack — DATE
NSLS-II Department – Photon Science Director
Brookhaven National Laboratory

APPROVAL: ______ 6-12-15

John Hill — DATE
NSLS-II Department –Director
Brookhaven National Laboratory

APPROVAL: ______ 6-15-15

Gail Mattson — DATE
ES&H Directorate – Assistant Laboratory Director
Brookhaven National Laboratory

BROOKHAVEN NATIONAL LABORATORY

VERSION CONTROL SHEET

VERSION	DESCRIPTION OF ANY CHANGES	DATE	PREPARER	APPROVED BY
1	For presentation to the NSLS–II and BNL LESHC review committee	April ,2014	Steven H. Moss	Steven Dierker / Gail Mattson
2	Resolution of Routine Operation's IRR Findings	July 2014	Steven H. Moss	Steven Dierker / Gail Mattson
3	Incorporation of Top-Off Operations	May 2015	Steve H. Moss	John Hill / Gail Mattson

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https://ps.bnl.gov/esh/Shared%20Documents/Forms/AllItems.aspx?RootFolder=%2Fesh%2FShared%20Documents%2FROSAD%20%2D%20Routine%20Operations%20Safety%20Assessment%20Document&FolderCTID=0x0120000FEC557CC1633049A5A9DD9FEF86F02B&View={A417EA36–0C82–4454–A989–43E84C8AE7E7}&InitialTabId=Ribbon%2EDocument&VisibilityContext=WSSTabPersistence

ACRONYMS

A	amperes
ACGIH	American Conference of Governmental Hygienists
AD	Accelerator Division
AFD	Adjustable frequency drives
AHJ	authority having jurisdiction
AHU	air handling unit
ALARA	as low as reasonably achievable
ALD	Associate Laboratory Director
ANSI	American National Standards Institute
ARM	Area Radiation Monitor
ARR	Accelerator Readiness Review
ASE	Accelerator Safety Envelope
ASME	American Society of Mechanical Engineers
ASSG	Accelerator Safety Systems Group
ATS	Automatic Transfer Switches
AV	ambient vaporizer
BCNYS	Building Code of New York State
BCSAD	Booster Commissioning Safety Assessment Document
BES	Basic Energy Sciences (part of DOE)
BHSO	Brookhaven Site Office
BNL	Brookhaven National Laboratory
BPM	beam position monitor
BSL	Biological Safety Level
BS–B2	bending magnet to control Booster injection
BS–SS	Booster–to–Storage Ring transport line safety shutter
BTS	Booster–to–Storage Ring (transfer line)
cc	cubic centimeters
CCWF	Central Chilled Water Facility
CD	Critical Decision (#1, 2, 3…)
CESR	Cornell Electron–Positron Storage Ring
CFR	Code of Federal Regulations
Ci	Curie
cm	centimeter
CONOPS	Conduct of Operation
CTB	Cooling Tower Building
dBA	decibel with A–weighting filter
DBA	double bend achromat
DC	direct current
DCCT	DC current transformer
DI	deionized
DOE	Department of Energy
DW	Damping Wiggler
ECR	Environmental Compliance Representative
EDE	Effective Dose Equivalent
EESE	Experimental End Station Enclosures
EMS	Environmental Management System
EPA	Environmental Protection Agency
EPICS	Experimental Physics and Industrial Control System
EPS	equipment protection system
ERC	experimental review coordinator
e/s	electrons per second
ESH	Environment Safety and Health
ES&H	Environment Safety and Health
ESR	Experimental Safety Review
eV	electron volt
FCT	fast current transformer
FDC	Fire Department Connections
FE	front end
FHA	Fire Hazard Analysis
FOE	first optics enclosure
FPA	Fire Protection Assessment
fpm	feet per minute
FSR	Fire Service Rooms
ft.	foot, feet
gal	gallon, gallons
GeV	giga–electron volt
GHe	gaseous helium
gHz	giga–hertz
gm	gram
GN_2	gaseous nitrogen
gpm	gallons per minute
g/s	gallons per second
GSF	gross square feet
GU	General User
He	helium
HEPA	high efficiency particulate air filter
HOM	Higher Order Mode
h	hour
HSSD	Highly Sensitive Smoke Detection
HV	high voltage
HVAC	heating, ventilation and air conditioning
HVPS	High Voltage Power Supply
Hz	Hertz
ID	insertion device(s)
IOT	Inductive Output Tube
IPC	integrated power centers
IR	infra–red
IRP	Instrument Readiness Plan
IRR	Instrument Readiness Review
ISA	Injector Service Area

ISM	Integrated Safety Management
ISO	International Standards Organization
JTA	Job Training Analysis
keV	kilo–electron Volt
kHz	kilo–Hertz
KSU	klystron supply unit
kV	kilovolt
kVA	kilovolt–amp
kW	kilowatt
LB–B2	Linac–to–Booster transport line magnet
LB–SS	Linac–to–Booster transport line safety shutter
lbs.	pounds
LCM	loss control and monitoring system
LCSAD	Linac Commissioning Safety Assessment Document
LCSC	Laboratory Cryogenic Safety Committee
LEC	Local Emergency Coordinator
LESHC	Laboratory Environment, Safety and Health Committee
LHe	liquid helium
Linac	Linear Accelerator
LN_2	liquid nitrogen
LOB	Laboratory Office Building
LOTO	Lockout/Tagout
LSDCG	Local Shield Design Coordination Group
LtB	Linac–to–Booster (transfer line)
m	meter
mA	milliamp
µC	microcoulomb
MBSA	Maintenance Bypass Switch Assemblies
meV	milli–electron volt
MeV	mega–electron volt
MHz	mega–Hertz
MIC	Microbial Induced Corrosion
mm	milli–meter
MPFL	Maximum Potential Fire Loss
mph	miles per hour
mrad	milli–radian
mrem	milli–rem
MV	megavolt
MVA	mega volt amps
MW	Mega Watts
mΩ	megohm
nC	nanocoulomb
NC	noise criteria
NEC	National Electric Code
NEG	non–evaporable getter
NEMA	National Electrical Manufacturing Association
NEPA	National Environmental Policy Act
NESHAP	National Emission Std. for Hazardous Air Pollutants
NFPA	National Fire Protection Association
nm	nano–meter
NPH	natural phenomena hazard
NRTL	Nationally Recognized Testing Laboratory
NSLS	National Synchrotron Light Source
NSLS–II	National Synchrotron Light Source II
ntorr	nano–torr
NYCRR	New York Codes, Rules and Regulations
NYSDEC	New York State Department of Environmental Conservation
ODH	oxygen deficiency hazard
OHSAS	Occupational Health and Safety Series
OSHA	Occupational Safety and Health Administration
PAF	Process Assessment Forms
Pb	lead (the element)
PC	performance category
pCi	pico–curie
PCM	periodic confirmatory measurements
PFN	pulse–forming network
pH	a measure of acidity or alkalinity
ph	photon(s)
PLC	programmable logic controller
PPE	personal protective equipment
PPS	Personnel Protection System
PRM	Policies and Requirements Manual
psf	pounds per square foot
psi	pounds per square inch
psig	pounds per square inch gauge
PSM	pulse step modulator
PTS	permanent threshold shift
PU	Partner User
QA	Quality Assurance
rad	radian
RCD	Radiological Control Division
RCRA	Resource Conservation Recovery Act
RCT	Radiological Control Technicians
RF	radiofrequency
RH	relative humidity
RSC	Radiation Safety Committee

s	seconds
SAD	Safety Assessment Document
SBMS	Standards Based Management System
SC	Storage Ring Commissioning
SPDES	State Pollutant Discharge Elimination System
sq ft	square foot
SR	synchrotron radiation
SSC	structure, system or component
STD	standard
SOW	statement of work
SF6	sulfur hexafluoride
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
SCRF	superconducting radiofrequency
T	Tesla
TCR	Technical Change Request
TL	transfer line
TLD	thermoluminescent dosimeter
TLV	threshold limit value
TPO	thermo setting poly–olefin
UHV	ultrahigh vacuum
UL	Underwriters Laboratory
UPA	universal power alerts
UPS	uninterruptible power supply
USI	Unreviewed Safety Issue
UV	ultraviolet
V	volts
VAC	volt alternating current
VUV	vacuum ultra violet
WCC	Work Control Coordinator

1.0 INTRODUCTION

1.1 Purpose of this Document

The purpose of this NSLS–II Routine Operations Safety Assessment Document (SAD) is to:

a) Provide in Section 3 a general overview of the NSLS–II facility located at Brookhaven National Laboratory, Upton, NY;

b) Describe in sufficient detail in Section 4 the significant hazards presented by the routine operations of the NSLS–II facility which consists of the Linear Accelerator (Linac), the Linac to Booster transfer line, the Booster, the Booster–to–Storage Ring Transfer Line, the Storage Ring and the project Beamlines and

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

The NSLS–II complex covered by this SAD is shown in Figure 3.3. This SAD lays the foundation for the Credited Controls described in the NSLS–II Routine Operations Accelerator Safety Envelope (ASE). The requirements for writing the SAD and ASE are set out in:

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

The NSLS–II accelerator commissioning program has been divided into three separate and sequential modules, each with its own commissioning SAD and ASE. The Linac Commissioning SAD/ASE, the Booster Commissioning SAD/ASE and the Storage Ring Commissioning SAD/ASE have been completed, reviewed and approved by DOE/Brookhaven Site Office (BHSO). These three commissioning SADs and ASEs have been combined into a single, final NSLS–II Routine Operations SAD and ASE and the commissioning documents will be retired when Routine Operations are authorized. The creation of these documents benefits from the previous years of experience of the National Synchrotron Light Source, in operation since 1983 and from the following earlier NSLS–II safety analyses:

- *Baseline Hazards List* – 2006
- *Environmental Assessment* – 2006
  - *Finding of No Significant Impact* – 2006
- *Preliminary Hazards Analysis* – 2007
- *Final Hazards Analysis* – 2007
- *Preliminary Safety Assessment Document* – 2008
- *Linac Commissioning Safety Assessment Document, Version 2* – May 2011
- *Addendum to NSLS–II LC SAD Ref.* 1 to NSLS–II Unreviewed Safety Issue (USI) No. 6 , "Mis–steering Event in the NSLS–II Linac during Commissioning"
- Addendum to the NSLS–II LC SAD and BC SAD (USI Evaluation No, NSLS–2–EVAL–2013–002, Review of Soil Shielding Depth vs SAD/ASE Commitments)
- *Linac Commissioning Accelerator Safety Envelope (ASE) Rev. 2 July* 2013
- *Booster Commissioning Safety Assessment Document Version 2 December* 2011
- *Addendum to the NSLA II BC SAD (USI Evaluation No. NSLS–II EVAL–2013–001, Review of Booster Supplemental Shields and Maximum Credible Incident*
- Addendum to the NSLS–II LC SAD and BC SAD (USI Evaluation No, NSLS–2–EVAL–2013–002, Review of Soil Shielding Depth vs SAD/ASE Commitments)

- Addendum to the NSLS–II BC SAD to Address Elimination of Personnel Protection System (PPS) Interlock on the B2 Bending Magnet (USI Evaluation No. NSLS–II–EVAL–2013–003)
- *Booster Commissioning Accelerator Safety Envelope (*ASE*) Rev. 2 September 2013*
- *Storage Ring Commissioning Safety Assessment Document December* 2013
- *Storage Ring Commissioning Accelerator Safety Envelope (ASE) December 2013*

1.2 Description of the NSLS–II Facility

The DOE Basic Energy Sciences (BES) program requires a synchrotron light source that will enable the study of material properties and functions, particularly materials at the nanoscale, at a level of detail and precision never before possible. NSLS–II will provide photon beams having ultra–high brightness and flux and exceptional stability. It will also provide advanced insertion devices, optics, detectors, robotics and a suite of scientific instruments. Together these will provide the capability to Beamlines to characterize materials with a spatial resolution of ~1 nm and an energy resolution of ~0.1 meV and with sufficient sensitivity to perform spectroscopy on a single atom.

NSLS–II will be a large user facility dedicated to the production and utilization of synchrotron radiation. It will consist of an electron Storage Ring and an associated injection system composed of an electron gun, Linac and a Booster Ring. The Storage Ring, 792 meters in circumference, will operate at 3.0 giga–electron volt (GeV) and 500 mA with a lifetime of ~3 hours. NSLS–II will operate an extensive user program built around bending magnet and insertion device Beamlines on the Storage Ring. NSLS–II is expected eventually to support annually ~3,500 users from ~400 university, government laboratory and industry institutions conducting ~1,500 experiments. When fully built out, NSLS–II will accommodate ~58 Beamlines using a) a combination of bending magnet sources, covering the infrared (IR), vacuum ultraviolet (VUV) and soft x–ray range; b) three–pole wigglers, covering the hard x–ray range up to ~20 keV; and c) insertion devices (ID) (undulators, damping wigglers and superconducting wigglers), covering the VUV through the very hard x–ray range. Additional Beamlines are possible through canted IDs (2 IDs sharing a single straight section) and multiple branches. While this SAD focuses primarily on the accelerators, it also includes a description of the general features and hazards of the Beamlines, the safety review processes used to ensure their operational safety and the processes used to design, construct and operate new experimental facilities.

1.3 Environment, Worker and Public Safety

NSLS–II is subject to the requirements of the DOE O 420.2C, Safety of Accelerator Facilities or its successors. These requirements are promulgated in the Brookhaven National Laboratory SBMS Accelerator Safety subject area. Because of the engineered and administrative controls incorporated into the facility design and operation, the NSLS–II facility presents minor potential for on–site and negligible off–site impacts to people and the environment. In addition, the physical characteristics of an accelerator essentially eliminate off–site hazard since the primary hazard is prompt ionizing radiation which exists only when the accelerator operates. These radiation fields are well shielded and are reduced to insignificant levels when the machine is turned off.

NSLS–II programs incorporate DOE P 450.4 *Safety Management System Policy,* 10 CFR 835 *Occupational Radiation Protection,* 10 CFR 850 *Chronic Beryllium Disease Prevention Program* and 10 CFR 851 *Worker Safety and Health Program* and other regulations, rules, DOE Orders as specified in the BNL/DOE Prime Contract. The BNL SBMS subject areas establish the requirements and provide guidance to assure proper implementation of the Integrated Safety Management (ISM) core functions and guiding principles. Identification and control of hazards for work and research activities are defined through the NSLS-II *Work Planning and Control*

Procedure. Radiological safety requirements are promulgated in the BNL *Radiological Control Manual*.

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

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

2.0 SUMMARY / CONCLUSIONS

2.1 Overview of Results and Conclusions of the SAD Analysis

The NSLS–II SAD provides a safety assessment of the routine operations within the NSLS–II Facility, including the Linac, the Linac to Booster transfer line, the Booster, the Booster–to–Storage Ring Transfer Line, the Storage Ring and the experimental Beamlines. The SAD meets the requirements set out in the SBMS *Accelerator Safety* subject area, which in turn meets the requirements of DOE Order 420.2C, *Safety of Accelerator Facilities* and DOE G 420.2–1, *Accelerator Facility Safety Implementation Guide*.

The NSLS–II ASE establishes the limits of facility operation and the Engineered Credited Controls and supporting programs within which the NSLS–II Facility operates. These limits and controls and the resulting mitigated risks are described in Chapter 4 of the NSLS–II SAD. The basis for the ASE controls is also discussed in Chapter 5 of this SAD.

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

2.1.1 The NSLS–II facility buildings comply with required consensus codes and standards as per DOE 10 CFR 851, *Worker Safety and Health Program* and the Building Code of New York State (BCNYS).

2.1.2 The operation of the NSLS–II facility does not pose significant risk to the environment:

- Existing and projected hazards to the environment have been described in the NSLS–II *Environmental Assessment* Appendix 1a (DOE/EA–1558). A *Finding of No Significant Impact* was issued in September 2006 Appendix 1b.
- Impacts to the environment and occupational hazards to workers due to NSLS–II operations are managed through the ISO 14001, *Environmental Management System* and the ISO 18001 *Occupational Health and Safety Assessment Series*, respectively, as well as through the BNL *Integrated Safety Management* system. Periodic audits assure that these programs are maintained at a high level.
- A NESHAP evaluation of NSLS–II accelerator operation radiological air emissions has been conducted with BNL Environmental Protection Division personnel. Site boundary doses from air emissions are calculated to be below the 0.1 mrem/year threshold for routine air monitoring.
- Hazardous and industrial wastes are managed and where possible, minimized by the facility through a variety of controls such as recycling and pollution prevention.
- Effluents, with the exception of those from roofs, parking lots and cooling tower blow–down that drain to recharge basins are disposed of through the sanitary waste stream and controlled through work planning so as not to exceed the limits stated in the BNL SPDES permit. Tritium and sodium–22 production in soil and groundwater are calculated to be below the BNL–defined Action Levels of 1,000 pCi/L and 100 pCi/L, respectively. Tritium production in accelerator cooling waters is calculated to be below the Drinking Water Standard of 20,000 pCi/L.

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

2.1.4 The level of fire protection, as designed, is classified as "improved risk," thereby meeting the objectives of DOE Order 420.1C, *Facility Safety*. The NSLS–II buildings are protected by a fire suppression sprinkler system and a smoke detection system, all of which are tied in to the BNL site wide fire alarm system. An *NSLS–II Fire Protection Design Strategy* has been developed and its requirements are followed. It was reviewed and approved by DOE–BHSO on March 28, 2008. An NSLS–II *Fire Hazard Analysis* Appendix 2 has been developed based on this design strategy.

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

2.1.6 When vacuum faults are detected within accelerator or experimental Beamlines, interlock systems automatically close sector valves to minimize the spread of the fault and to turn off RF, as required. Water flow and temperature faults are similarly sensed and interlock systems close valves, turn–off RF or power supplies, as appropriate. Loss of pressure in compressed air systems initiates alarms alerting Control Room staff to take appropriate action.

2.1.7 The following are considered routine industrial hazards and are covered by BNL SBMS requirements: material handling, lasers, radiofrequency (RF) non–ionizing radiation, noise, confined spaces, ozone and magnetic fields.

2.1.8 The primary source of radiation exposure is created by electron beam losses during operation of the accelerators. These electron–induced radiation sources and the synchrotron radiation created during Beamline operations must be shielded to protect workers from radiation exposure.

- Radiation shielding consistent with the NSLS–II Shielding Policy, is provided around accelerators and Beamlines to protect workers. This shielding in the forms of standard density concrete, high density concrete, lead, steel and in some instances polyethylene, is positioned to limit levels of radiation to personnel to values as low as reasonably achievable (ALARA). Shielding configuration control is maintained through the use of accelerator and Beamline safety system checklists and work authorizations.
- Access to the interior of the accelerator or Beamline enclosures is prevented by interlocked doors. Prior to the turn–on of accelerators and Beamlines, a search and secure procedure is used to ensure that no personnel are present within these enclosures.
- Area radiation monitors are used to detect elevated radiation levels in occupied areas and are interlocked to the radiation source to protect personnel.
- Radiation safety interlocks are tested and radiation monitors are calibrated on a scheduled basis to ensure integrity and are in accordance with the BNL Radiation Control Manual Requirements.
- Radiation exposure to personnel is monitored through the use of personnel and area thermoluminescent dosimeters (TLD), as well as real–time radiation monitors and hand–held radiation detection devices, to ensure that conditions are ALARA. In–house Radiological Control Division staff assists in the management of radiological conditions and develops Radiation Work Permits when necessary through work planning and controls.
- Air, soil and water activation levels produced during accelerator operations have been calculated and are below BNL–defined Action Levels and Drinking Water Standards. Equipment determined to be activated in volume is precluded from unrestricted release for the purpose of recycling, in accordance with the requirements identified in the SBMS

2.1.9 Readiness for the transition from the commissioning phase to routine operations for the accelerators is demonstrated through an Accelerator Readiness Plan, a NSLS-II Instrument Readiness Review (IRR) and Accelerator Readiness Review (ARR). The Accelerator Readiness documents must be approved by DOE–BHSO prior to the beginning of routine operations. Readiness of Beamlines is demonstrated through a different process described below. ARRs will not be performed for beamlines or installation of accelerator components associated with delivery of photons to the beamlines (e.g., insertion devices and front ends). The ARR conducted for Routine Operations will validate the review process conducted for beamlines which will satisfy the need for an independent review of a new beamline ready for operation. This beamline review process includes: 1) the completion of a series of design reviews from initial concept to through design, fabrication, and installation; 2) a USI screening and/or evaluation; 3) the development and execution of a Instrument Readiness Plan; and 4) the implementation of an IRR. Upon the successful completion of these reviews, including closeout of Pre-start findings identified during the IRR and the recommendation of the ESH Manager, the beamline or accelerator component is authorized for commissioning by the NSLS-II Director. Transition to operations follows development and implementation of a commissioning plan. The execution of the commissioning plan and transition to full operations will commence upon authorization from the NSLS-II Director or designee.

2.1.10 The organizational structure of the Energy Sciences Directorate (see the current NSLS-II Department Organization Chart next page) and the documentation of responsibilities and procedures for safety–related actions provide for safe operation of the facility. Control room operations proceed as per the NSLS–II CONOPS matrix as defined in DOE Order 422.1, *Conduct of Operations* and the applicable NSLS–II operations procedures. Operation of the accelerators as described in the ASE is managed through the Main Control Room using Control Room procedures implemented by trained and qualified Accelerator Operators. These procedures address issues such as

- Actions to prevent or mitigate beam loss and maintain radiological conditions ALARA and within ASE limits
- response to radiation alarms
- pre–operations sweep procedures
- lock–out/tag–out procedures
- configuration control
- work planning procedures

Implementation of these controls summarized above and as described in more depth in Chapter 4 reduces the risk of NSLS–II routine operations to personnel and the environment to acceptable levels. The post–mitigation risks, as detailed in Appendix 3, are shown in Table 2.1.

TABLE 2.1
2.1 HAZARD TYPES VS. POST–MITIGATION RISK LEVELS

TYPES OF HAZARDS	RISK LEVELS
Accelerator Cooling and Compressed Air	Low
Chemical and Hazardous Materials	Low
Confined Spaces	Low
Cryogenic, Including oxygen deficiency hazard (ODH)	Low
Electrical	Low
Environmental	Low
Fire	Low
Material Handling	Low
Natural Phenomena	Routine
Noise	Low
Ozone	Low
Radiation (non–ionizing)	Low
Radiation (ionizing) – routinely occupied areas	Routine
Radiation (ionizing) – within shielded enclosures	Low
Waste	Low
Vacuum	Low

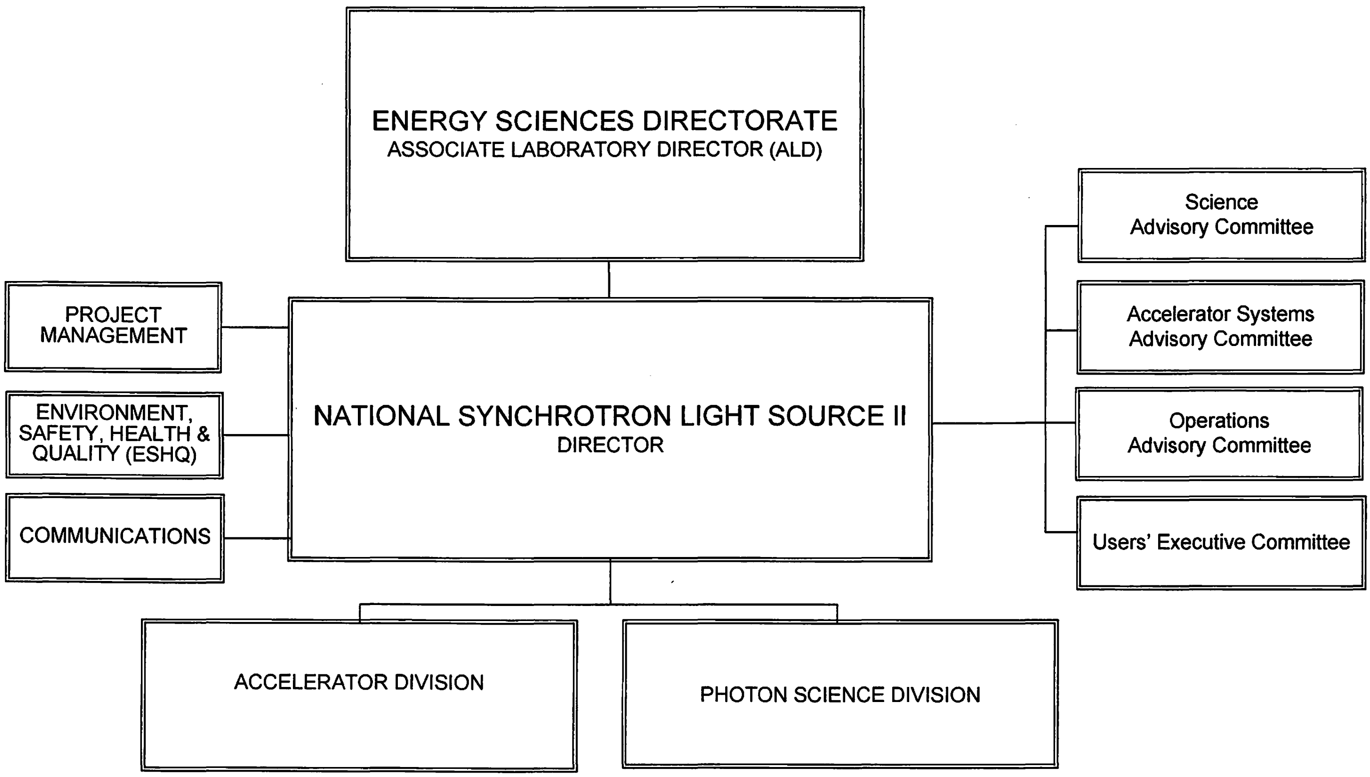


FIGURE 2.1

2.1 NSLS-II DEPARTMENT ORGANIZATION CHART

3.0 Description of Facility, Site and Operations

3.1 Characterization of the NSLS–II Site Location

3.1.1 Description of the BNL Site

Brookhaven National Laboratory is a multidisciplinary scientific research institute located close to the geographical center of Suffolk County, New York, about 60 miles east of New York City. Figure 3.1 shows a regional view of Long Island and Figure 3.2 shows an aerial view of BNL. The BNL site occupies 5,265 acres, with most principal facilities located near its center. The developed area is approximately 1,850 acres, of which about 500 acres were originally developed by the U.S. Army as part of Camp Upton. In excess of 200 acres are occupied by various large, specialized research facilities; and 400 acres are of roads, parking lots and connecting areas. Outlying facilities occupy about 750 acres; these include the Sewage Treatment Plant, agricultural research fields, solar energy farm, housing and fire breaks. The balance of the site, 3,415 acres, is largely wooded.

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

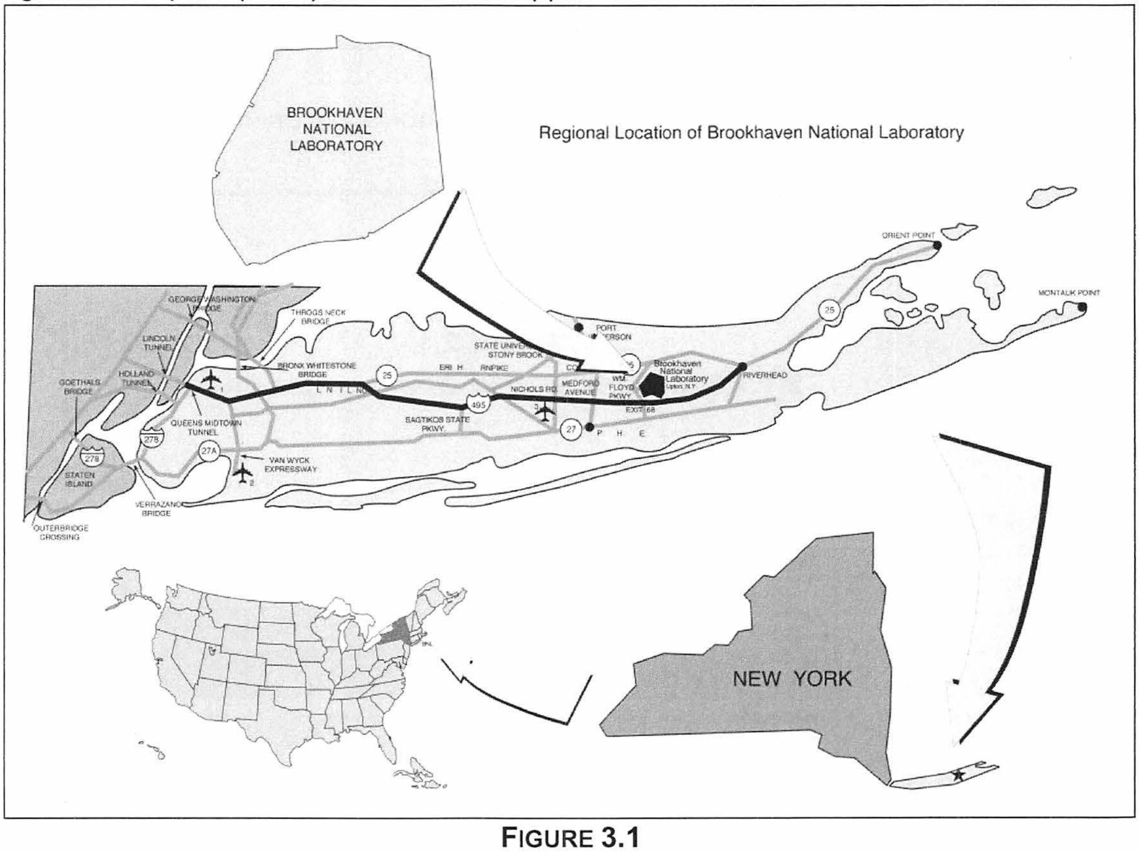


Figure 3.1

3.1 Regional View of the Location of Brookhaven National Laboratory

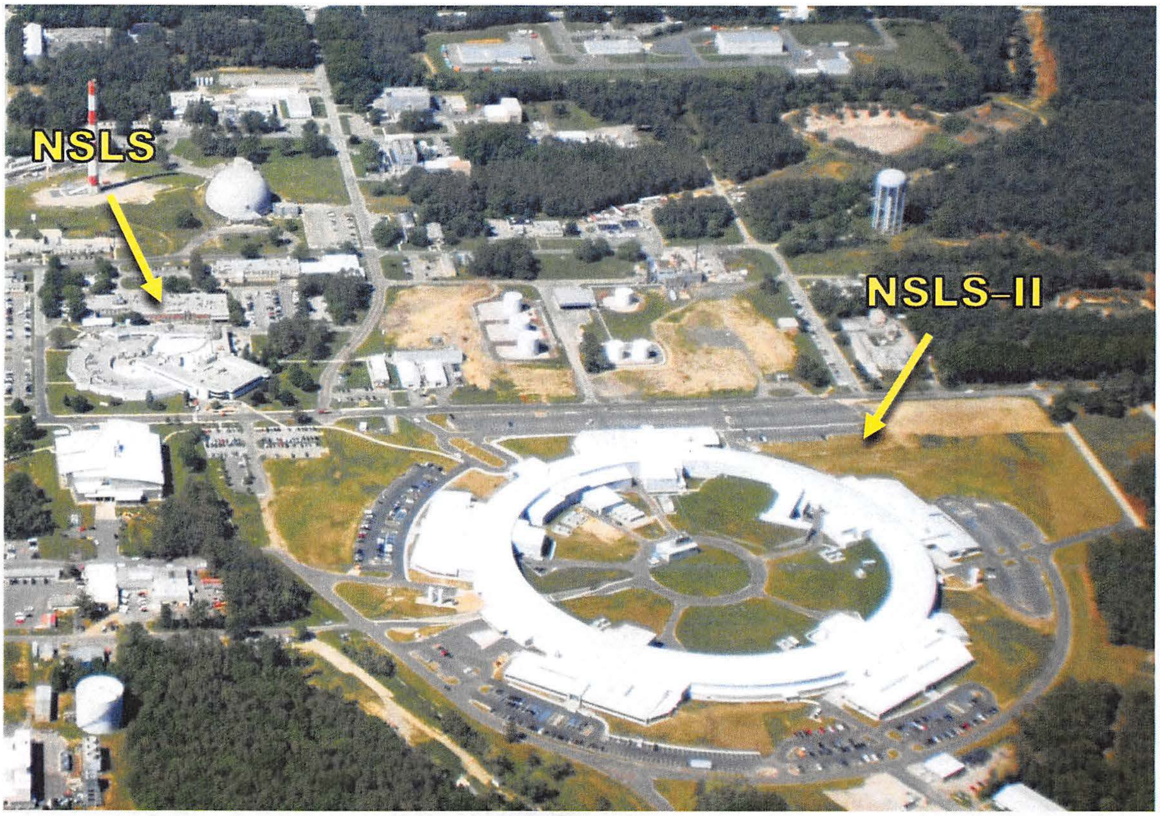


FIGURE 3.2
3.2 AERIAL VIEW OF BNL (SPRING 2013) SHOWING THE FORMER NATIONAL SYNCHROTRON LIGHT SOURCE (NSLS) AND THE NSLS–II SITE

3.1.2 Location of NSLS–II Accelerator Facilities

NSLS–II (Bldg. 740) consists of the ~47 acre area immediately south and east of the existing NSLS (Bldg. 725). This location is desirable because a) the area to the south and east of that site is largely undeveloped and can accommodate long Beamlines extending out from the NSLS–II building; b) the existing NSLS building with the NSLS–II Control Room and Accelerator Division (AD) staff offices is diagonally across the Brookhaven Avenue intersection; and c) the Center for Functional Nanomaterials, Physics, Chemistry, Condensed Matter Physics & Materials Science, Instrumentation Division and Biosciences Departments are nearby. The NSLS–II Ring Building property itself is bounded on the north by Brookhaven Avenue, on the west and south by the NSLS-II Ring Road, and on the east by Fifth Street. Additional facilities are located north of Brookhaven Avenue on either side of Renaissance Street and include buildings 726–727 (mechanical, utility and magnet technical spaces), Bldg. 728 (offices) and Bldg. 729 Source Development Lab.

3.2 Conventional Facilities

3.2.1 Building Design

NSLS–II has distinct components that make up the building plan. Included are the Ring Building, five Laboratory Office Buildings, five Service Buildings, the Injection Building, the RF Building and its associated Compressor Building and the Cooling Tower Building (CTB) (Figure 3.3 below). Each of these buildings has separate space and utility requirements. Additional buildings around the BNL campus are used to provide administrative/engineering office, workshop and technical spaces that support the needs of the NSLS-II.

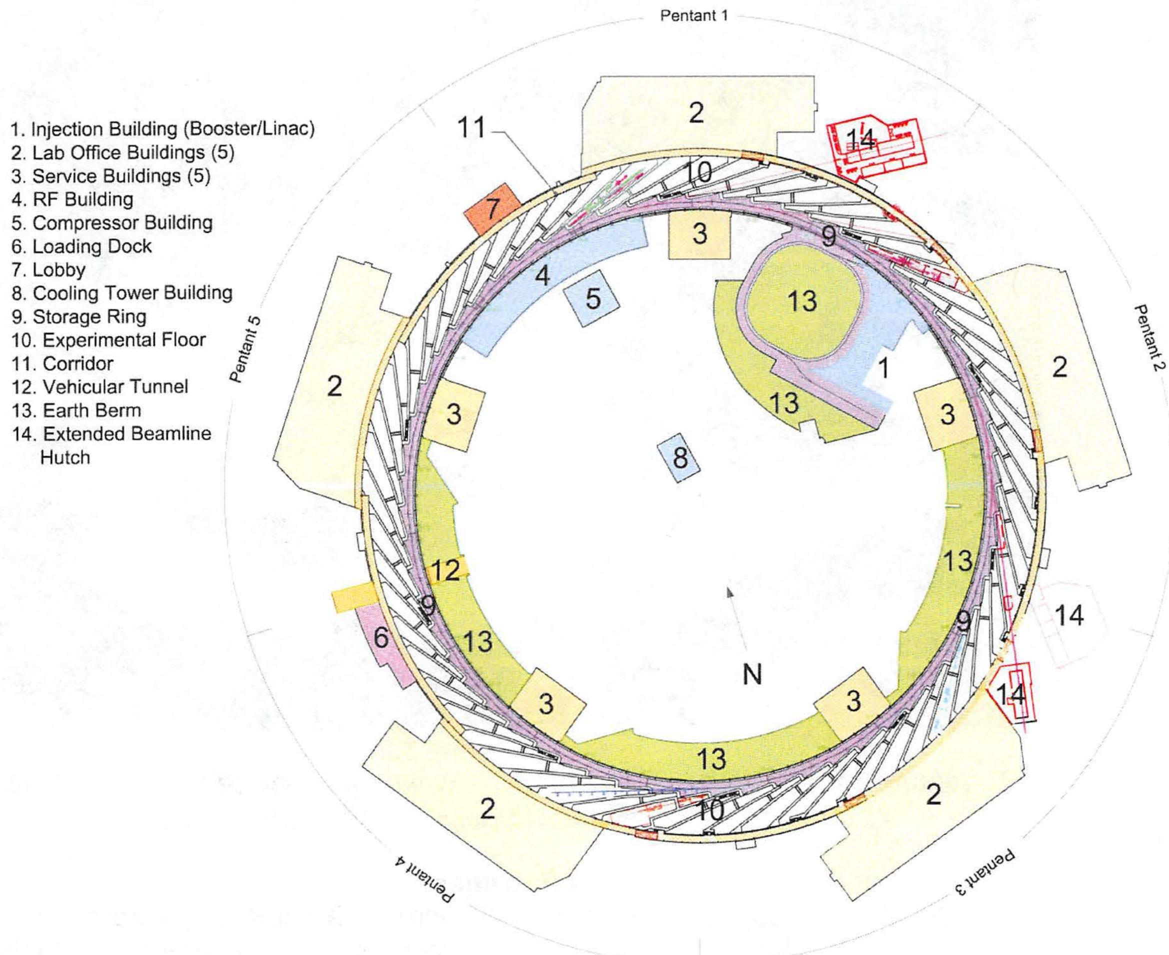


FIGURE 3.3

3.3 SITE PLAN OF NSLS–II BUILDING WITH PROJECTED LOCATIONS FOR LONG BEAMLINES

3.2.2 Injection Building

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

TABLE 3.1

3.1 SPACE SUMMARY FOR INJECTION BUILDING

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

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

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

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

The following equipment is located in the Injection Service Area:

- One Inductive Output Tube (IOT) transmitter (80 kW), modulator, power supply and waveguide structure
- Booster power supplies
- Vacuum pump power supplies and electronics
- Diagnostics and instrumentation electronics
- Controls electronics

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

The Booster is housed inside radiological shielding, which is provided by a combination of concrete, lead, polyethylene and berms of soil, the latter external to the Booster tunnel and outside the Injection Building. The Booster Tunnel contains the Linac–to–Booster Transport Line, the Booster Ring, the Booster–to–Storage Ring transfer line, a beam dump and other safety systems including a safety shutter and local supplementary shielding around high radiation scatter components. Each of the penetrations into the Booster enclosure bulk shielding for RF wave guides, cable trays and mekometer ports, etc. has been evaluated. Shielding requirements have been calculated on a case–by–case basis and the penetrations "walked down" to assure the proper shielding is in place and tested through performance of Fault Studies to assure shielding effectiveness. These shielding components have been designed by the NSLS–II Mechanical Engineering group. Design/fabrication drawings have also been prepared.

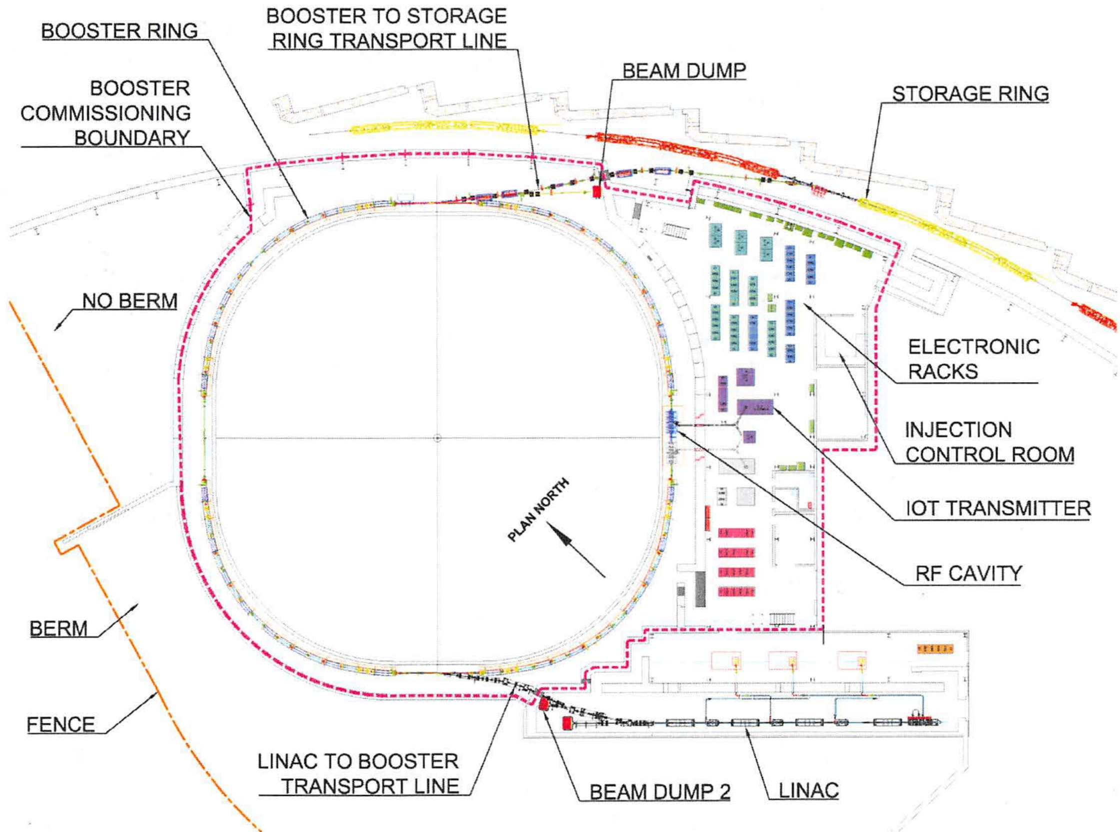


FIGURE 3.4
3.4 INJECTION BUILDING SHOWING LINAC, BOOSTER RING AND PARTIAL VIEW OF STORAGE RING

3.2.3 Storage Ring Building

The Storage Ring Building is the largest circular component (916 meters outer perimeter) of the NSLS–II accelerator building complex (see Figure 3.3 above); it is divided into five sections called pentants. Five two–story Service Buildings are attached to its inner perimeter (see section 3.2.3 below); each servicing one pentant. Five Laboratory Office Buildings (LOBs) are attached to its outer perimeter, each serving one pentant (see section 3.2.4 below). The Storage Ring RF area is housed in its own two–story building (see section 3.2.5 below) attached to the inner perimeter of Storage Ring Building between Service Buildings 1 and 5. The Injector Area is housed in its own two–story building attached to the inner perimeter of the Storage Ring Building between Service Buildings 4 and 5. The Storage Ring Building houses the Storage Ring tunnel, the mezzanine situated on the tunnel roof, the experimental floor where the Beamlines and their hutches are located, the corridor on the outer perimeter of the experimental floor and a number of other areas (see Table 3.2). The mezzanine supports the power supplies, controls and utilities for the Storage Ring. The Storage Ring Building is framed in structural steel with a composite acoustical steel deck with concrete topping. The roof consists of acoustical steel roof decking with a standing–seamed metal roof system. The Storage Ring tunnel is constructed of poured–in–place concrete. The exterior walls of the Storage Ring Building, which does not have a concrete exterior wall, have a pre–formed metal siding system with fiberglass insulation, interior vertical metal liner panel and metal girts and ground face–block at the base.

TABLE 3.2

3.2 SPACE SUMMARY FOR THE STORAGE RING BUILDING

Storage Ring Building	278,900
▪ Storage Ring Tunnel	42,132
▪ Tunnel Mezzanine Floor	57,968
▪ Experimental Floor	138,544
▪ Perimeter Corridor	37,450
▪ Fire Service Rooms (4)	700
▪ Loading Dock	820
▪ Stockroom	786
▪ Hazardous Material Storage	500

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

The Storage Ring itself is housed inside a shielded tunnel, constructed from a combination of standard and high density concrete with added supplemental shielding that consists for the most part of lead, but also includes in some cases polyethylene or iron. Each of the penetrations into the Storage Ring enclosure bulk shielding for RF wave guides, cable trays and mekometer ports, etc. has been evaluated in terms of causing the radiation hazard. Shielding requirements have been calculated on a case–by–case basis and the penetrations inspected to assure the proper shielding is in place. These shielding components have been designed by the NSLS–II AD Local Shielding Design Coordination group for supplemental shielding. As-built drawings and travelers have been prepared to document the installation of these shields.

3.2.4 Service Buildings

There are five two–story Service Buildings (~11,000 GSF each) located along the inner perimeter of the Storage Ring Building (see Figure 3.3). The Service Buildings house mechanical and electrical equipment for the Storage Ring and adjoining buildings. The first floor of Service Buildings provide personnel and equipment access to the Storage Ring tunnel through shielded labyrinths, as well as access to the Ring Building's inner road. The first floor also contains the main air handling unit for the Storage Ring tunnel, the steam–to–glycol system, the steam–to–hot water system, fan coil units for temperature control of the Service Building first floor and the secondary deionized (DI) system. The second floors of the Service Buildings allow access onto the mezzanine level above the Storage Ring and are serviced by an equipment hoist and double exterior doors located on the second floor. The mezzanine is also accessible via temporary stairs from the first floor. These stairs will be relocated or removed as Beamlines demand the spaces where they are currently located. The mezzanine is also accessible via a walking bridge from the second floor of the main lobby. Second floor equipment includes two air handling units for the experimental floor; the process chilled water system which provides cooling to Storage Ring power supplies and fan coil units for temperature control of the Service Building second floor. The Service Buildings are steel frame structures with the lower level constructed of poured–in–place concrete walls with a soil berm to the height of the second level on one wall. The remaining exterior walls are a pre–formed metal siding system with fiberglass insulation, interior vertical metal liner panel and metal girts and ground face–block at the base. The roof is a sloped thermo setting poly–olefin (TPO) membrane roofing system.

3.2.5 Laboratory Office Buildings

The five (LOB; ~38,000 GSF each; see Figure 3.3) provide scientific and technical staff and users with offices, conference rooms, wet and dry laboratories, technical and assembly areas, loading docks, machine shops and access onto the experimental floor.

At the start of routine operations, three LOBs (for pentants 1, 3 and 5) will be fully fitted out, including spaces for office, laboratories and machine shops, one LOB (for pentant 4) will be fully fitted out including offices and a new NSLS–II main Control Room and one remains a shell for pentant 2, which will be fitted out at a future date. Each LOB has a mezzanine which houses that building's mechanical equipment. Mezzanine equipment includes two air handling units for the offices and one air handling unit for laboratories. The LOBs are steel frame structures with metal siding exterior walls with fiberglass insulation and painted interior gypsum wall board. Exterior also includes aluminum windows and hollow metal curtain walls. The roof is a combination of sloped standing–seam metal roof and TPO membrane roof.

3.2.6 RF Building

The RF Building (~16,000 GSF; see Figure 3.3), bracketing pentants 5 and 1 on the inside perimeter of the Storage Ring building, houses the RF system for the Storage Ring. The first floor contains two 310 kW klystrons, two independent wave guides and two circulators, four 350 kW loads, two klystron supply unit (KSU) transformers, two heat exchangers located above the KSUs and supplied with process chilled water. The test equipment, i.e., klystrons, loads and circulators are supplied with DI water for cooling purposes. The lower mezzanine contains a cold box, a 3500 liter liquid helium (LHe) Dewar, manifold, vaporizer, phase separator and cryogenic system instrumentation. The upper mezzanine will contain RF instrumentation for the Storage Ring RF systems. Mezzanine equipment also includes two air handling units. A four ton hoist is used in the RF Building to move equipment between the floor level and the two mezzanines. Operational details for this RF system are provided in section 3.3.4 below. A computer room is located on the first floor at the east end of the building. The RF Building is a steel frame structure with pre–formed metal siding system with fiberglass insulation, interior vertical metal liner panel and metal girts and ground face–block at the base. The roof is a sloped standing–seam metal roof.

3.2.7 Facility Access Control

For programmatic reasons, the entrances to the Storage Ring Building, the Service Buildings and the RF Building are equipped with encoded card readers or use keys to restrict entry only to authorized personnel. The Compressor and CTBs are restricted access using keys. Access to the LOB exterior entrances will be controlled with card readers after hours. However, access from the LOBs to the experimental floor is via card reader. The laboratories inside the LOBs are also accessed via card readers. The card reader control system is located in the Facility Manager's Office located in LOB 3 (Building 743). Radiological controls are described in section 3.10.2.

3.3 Accelerator Systems

3.3.1 Injector

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

3.3.2 Linac Layout and Location

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

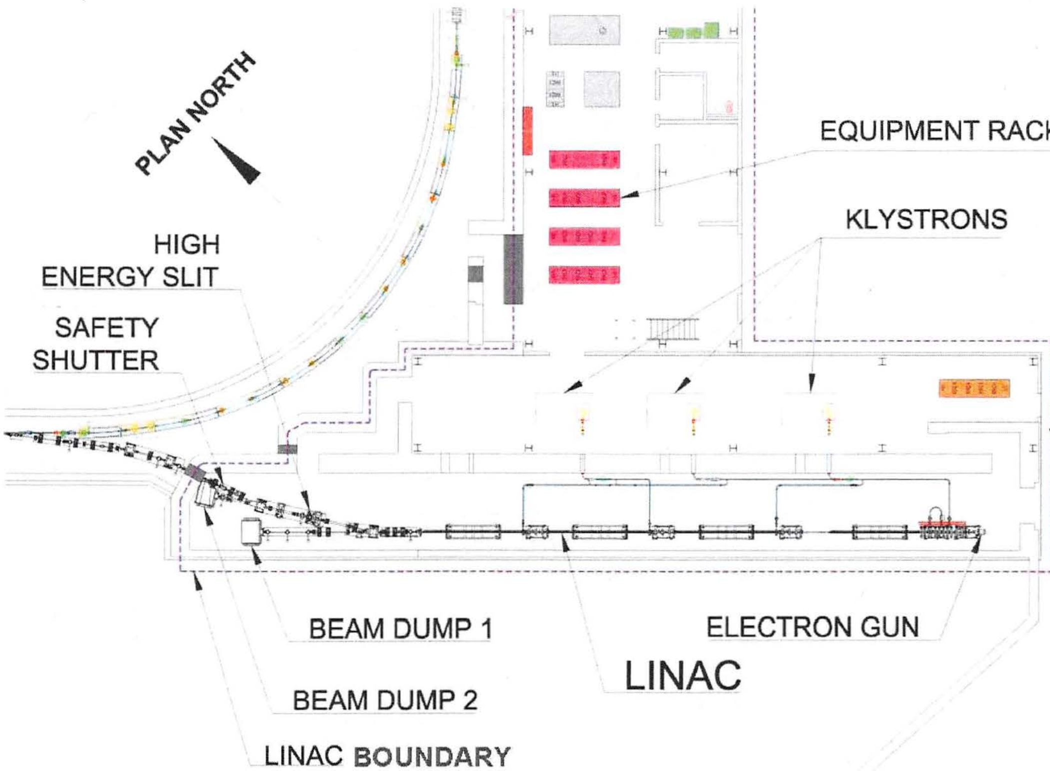


FIGURE 3.5
3.5 PLAN VIEW OF THE LINAC, KLYSTRON GALLERY AND LINAC AREA
(The Injection Control Room is outside this view and is seen in Figure 3.4)

3.3.2.1 Linac Performance Specification Overview

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

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

The main parameters of the Linac system are given in Table 3.3.

TABLE 3.3

3.3 PARAMETERS FOR THE NSLS–II LINAC DURING ROUTINE OPERATIONS

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

The following equipment is located downstream of the Linac:

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

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

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

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

Solenoid and quadrupole focusing is applied to focus the electron beam. Beam diagnostic elements such as current transformers, fluorescent screens, Faraday cups, wall current monitors and beam position monitors are used to monitor current and beam position. The essential parameters of the Linac are specified in Table 3.3.

3.3.2.2 Linac RF System

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

RF power generated in the klystrons is supplied to the Linac accelerating structures through waveguides penetrating the Linac shield wall. The feeder waveguide is thick wall WR 284 and is constructed using standard waveguide components. The waveguide is evacuated to avoid arcing at high power. There is monitoring of forward and reverse power in each klystron's output waveguide line. Arc detectors are included at each RF vacuum window.

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

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

The modulator has a number of interlocks. All electrical components within the modulator as well as cooling water flow are monitored and controlled. If one component fails or shows unspecified values, the modulator's state will fall back to a safe state. The modulator interlock system monitors all critical temperatures (transformer, rectifier, water, oil, etc.). If over–temperature is detected, the corresponding module is tripped and the modulator is switched to STANDBY mode.

The klystrons are a critical device within the NSLS–II PPS and are interlocked to prevent RF waves from being applied to the Linac accelerating structures when required by the PPS. Signals from the PPS are used to disable RF power generation in the Klystron by removing the high voltage supply to the modulator. To achieve this, the 480 Volt input to the DC power supplies of the modulators are opened by two independent Safety Integrity Level rated (safety–rated) contactors. These contactors are part of the PPS system and are mounted in a separate box which is labeled and subject to configuration control.

3.3.2.3 Linac Magnets

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

3.3.2.4 Linac Control System, Interface and Interlocks

All parameters essential for the operation of the Linac are monitored and controlled by the Linac control system. The Linac control system is integrated into the NSLS–II control system based on the Experimental Physics and Industrial Control System Systems with water and/or air cooling generating interlocks for system protection in case of failures in the cooling system. These interlocks are monitored by the Linac control system. Several subsystems (magnet power supplies, RF system, cooling system, gun high voltage, etc.) shall have additional interlocks. Interlocks are fail safe. A safe state is indicated by a closed contact sending a DC voltage. An unsafe state is indicated by an open contact that blocks the DC signal. On power failure, the system indicates an unsafe state. In case an interlock has been tripped, the system or subsystem is not operational, even if the cause of the interlock trip has been cleared, until the operator has reset the interlock, either manually when in local mode or remotely when in remote mode. The error conditions must be identified both by the operator and the control system. The interlock system includes "first fault" logic to "catch" the first fault in a cascade for post–mortem. This is an equipment safety interlock system.

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

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

3.3.3 Booster

3.3.3.1 Booster Layout

The Booster Ring is located in its dedicated Injection Building tunnel, shown in Figures 3.4 above and 3.6 below. The Booster Ring contains four quadrants and four straight sections located inside the Booster tunnel with the beam height centered at 1.2 m. Each straight section is 8 meters long and is used for the following functions:

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

The transport line downstream of the Booster extraction region consists of two sections:

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

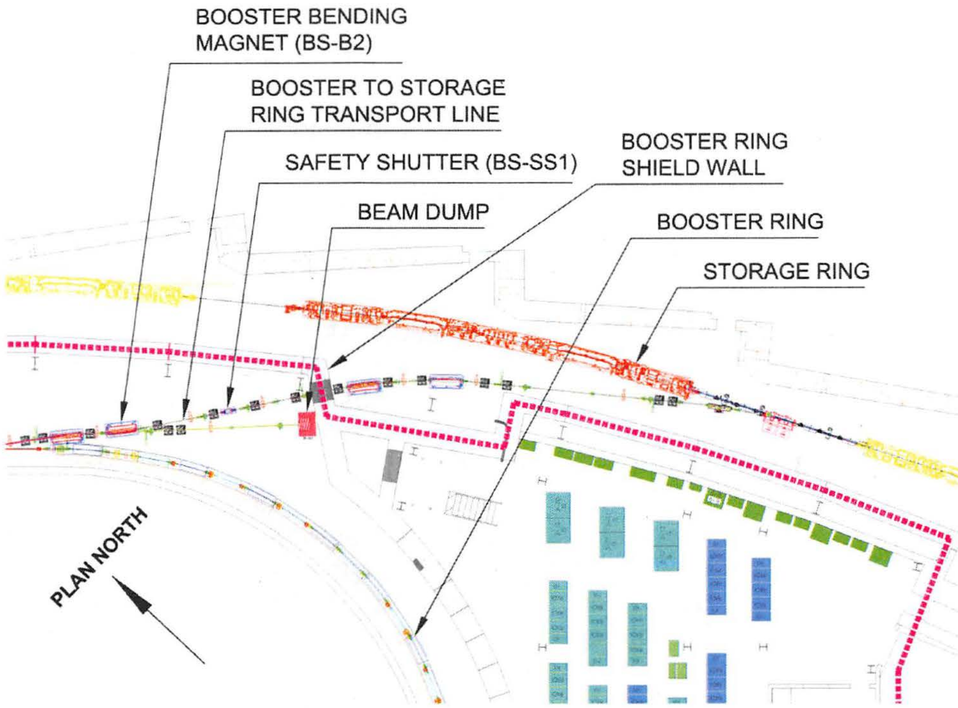


FIGURE 3.6
3.6 PLAN VIEW OF BOOSTER RING EXTRACTION REGION AND BOOSTER TO STORAGE RING TRANSPORT LINE AREA

3.3.3.2 Booster Performance Specification Overview

The main parameters of the Booster system are given in Table 3.4.

TABLE 3.4
3.4 PARAMETERS FOR THE NSLS–II BOOSTER DURING ROUTINE OPERATIONS

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

3.3.3.3 Booster and Diagnostics Transport Line Beam Diagnostics

The diagnostic systems available for Booster operation include:

- Fluorescent screens monitors
- Faraday cup (F–cup)
- Fast Current Transformer (FCT)
- Integrating Current Transformer (ICT)
- DC Current Transformer (DCCT)
- BPM
- Synchrotron Radiation Monitor

Diagnostics devices are synchronized via trigger cables with the main injector timing signals. The diagnostic components interface with the NSLS–II control system.

3.3.3.4 Booster RF System

The Booster RF system consists of a Petra 500 MHz 5 cell RF cavity, an 80 kW IOT transmitter and associated sub–systems. The IOT driver amplifier is a 500 Watt solid state amplifier with input power of 10 mW. The maximum charge the Booster RF system is capable of accelerating to 3.2 GeV is 22 nC/pulse.

Radiofrequency waveguides from the IOT transmitter to the cavity pass through holes in the tunnel wall above head height; shielding is provided over these holes on the outside of the tunnel wall to minimize the escape of radiation down the waveguide paths.

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

The IOT serves as a critical device in the Booster PPS. If the logic of the Booster PPS is not satisfied, signals from the PPS will disable the AC power contactor feeding the IOT, eliminating the power source and the ability to generate RF power for the Booster accelerating cavity.

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

3.3.3.5 Booster Magnets and Power Supplies

Each of the four quadrants of the Booster ring contains the following magnetic elements:

- 8 combined function defocusing dipole magnets (BD) with 8.39° bending angle
- 7 combined function focusing dipole magnets bend focusing with 3.27° bending angle
- 6 quadrupole magnets to adjust the tune point
- 4 sextupole magnets arranged in two families for correction of chromaticity and optimization of the dynamic aperture
- 9 dipole corrector magnets for fine adjustments of beam position (5 horizontal and 4 vertical corrector magnets.

The combined function dipoles are grouped in 3 sets each set powered by a power supply located in the Injector Service Area. The maximum currents available from these power supplies limit the maximum energy of the Booster Ring to 3.2 GeV. The ability to cycle these power supplies limits the repetition rate to 2 Hz. Three quadrupole power supplies feed 3 sets of quadrupole magnets with 8 magnets in each set. Sixteen sextupole power supplies feed 16 sextupole magnets as separate circuits. Thirty–six corrector magnets (20 horizontal and 16 vertical) are fed by 36 power supplies of the same design. The DC extraction septum power supply feeds the magnet located in the extraction straight section. The power supplies for all magnets are located in the cabinets in the Injector Service Area. The connections between the magnets in the Booster tunnel and the power supplies are accomplished using cable trays and shielded labyrinths.

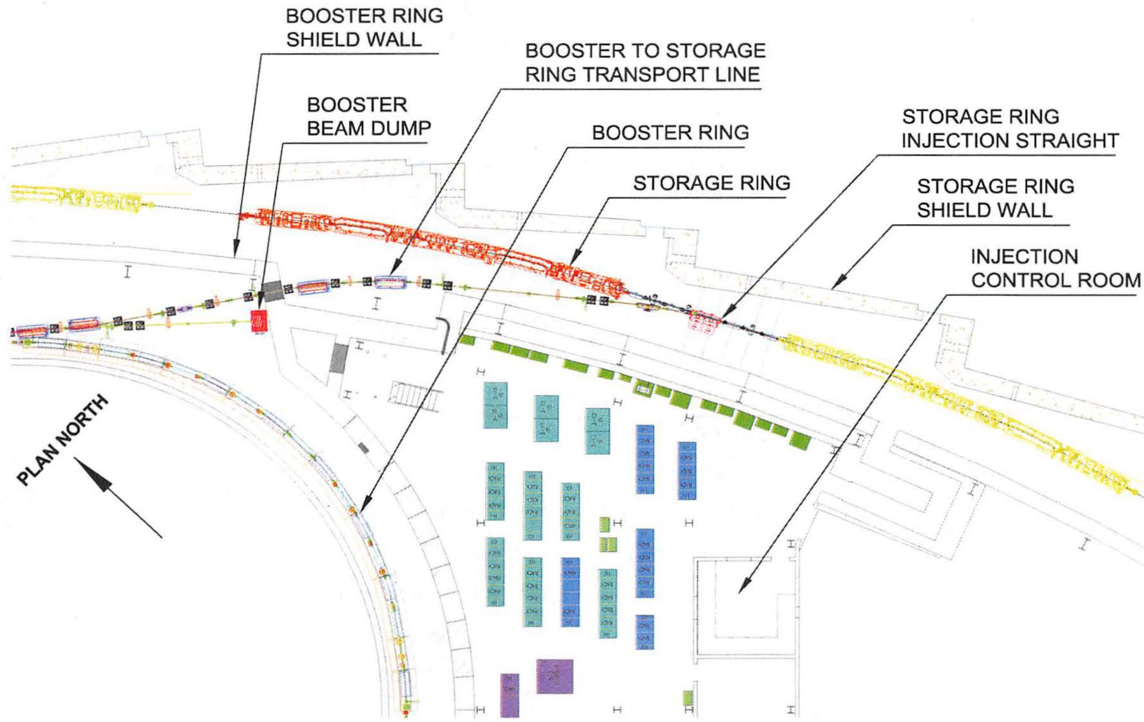


FIGURE 3.7
3.7 Plan View of the Booster Ring, Booster to Storage Ring Transport Line and Storage Ring Injection Area

3.3.3.6 Storage Ring

The overall layout of the Storage Ring and Beamlines is shown in Figure 3.3 and a part of the ring is shown in more detail in Figure 3.4.The Storage Ring lattice consists of 30 double bend achromat (DBA) cells, with straight sections alternating in length between 6.6 m and 9.3 m. There are thus 15 super–periods for the lattice. The lattice functions of one DBA cell (one half super–period) are shown in Figures 3.8 and 3.9. Each straight section is achromatic and has three quadrupoles at each end. These quadrupoles provide for appropriate matching of the optic functions (β_x, α_x and β_y, α_y) and betatron phase advances ($\Delta\nu_{x,y}$) in the straights to compensate for the strong influence of the magnetic insertion devices (ID) on the beam optics.

In order to accommodate a number of three–pole wigglers (TPW) as additional sources of hard x–rays, a 0.6–m long straight is inserted at the downstream end of all dispersion sections. In order to maintain the symmetry of these dispersion straights, the same empty spaces are also added at the upstream end of the section. Although insertion of TPWs in these non–achromatic sections impacts

the effort of reducing the emittance, the impact is estimated to only about 10% for 15 such insertions around the ring.
The total number of quadrupole (linear focusing) magnets per cell is 10. Each cell also has three sextupole magnets for chromaticity correction and six further sextupole magnets are needed to optimize the dynamic aperture. There are two dipole magnets in each cell, each providing a 6 degree bend. All quadrupole magnets in the Storage Ring have individual power supplies, which gives the flexibility for correcting variation of field gradients of individual magnets and performing beam–based alignment with high precision for optimizing the beam properties. The sextupole magnets are powered by nine families in each pentant. The main parameters of the Storage Ring are summarized in Table 3.5 below.

TABLE 3.5

3.5 PARAMETERS FOR THE NSLS–II STORAGE RING DURING ROUTINE OPERATIONS

PARAMETER	UNIT	VALUE
Beam Energy	GeV	3
Design Maximum Beam Current	mA	500
Circumference	m	792
Lattice Type		DBA
Number DBA Cells		30
Lattice Periodicity		15
Bending Magnets		60
Number Quadrupole Magnets		300
Maximum Quadrupole Gradient	T/m	22
Number of quadrupole circuits/power supplies		300
Number of Sextupole magnets		270
Number of sextupole families/power supplies		54
Short ID straight sections		15
Length of short ID straight sections	m	6.6
Long ID straight sections		15
Length of long ID straight sections	m	9.3
Number of DC dipole correctors/per plane		180
Maximum corrector kick at 3 GeV	mrad	0.8
Number of AC dipole correctors/plane		90
RF Frequency	MHz	499.68
RF Voltage	MV	4.8(9.6*)
Number of superconducting cavities		2(4*)
Passive 3rd harmonic, 1.5GHz cavities		1(2*)
Harmonic Number		1320
Total Peak Power Consumption (installed devices)	MW	~18

*At full build–out.

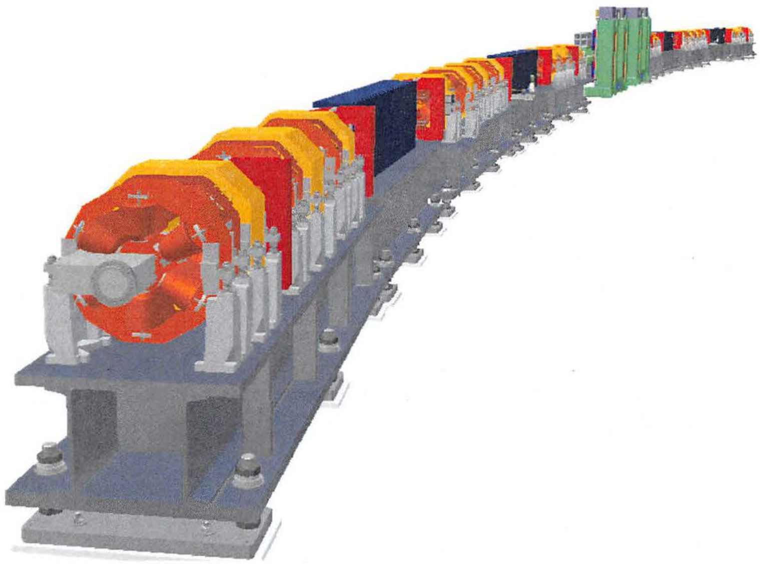


FIGURE 3.8
3.8 3D–View of the Storage Ring super–period which is comprised of two DBA cells and two straight sections.
Shown is the 6.6m long straight section in between the two DBA cells with an insertion device (not shown: the 9.3m long straight section at the beginning or end)

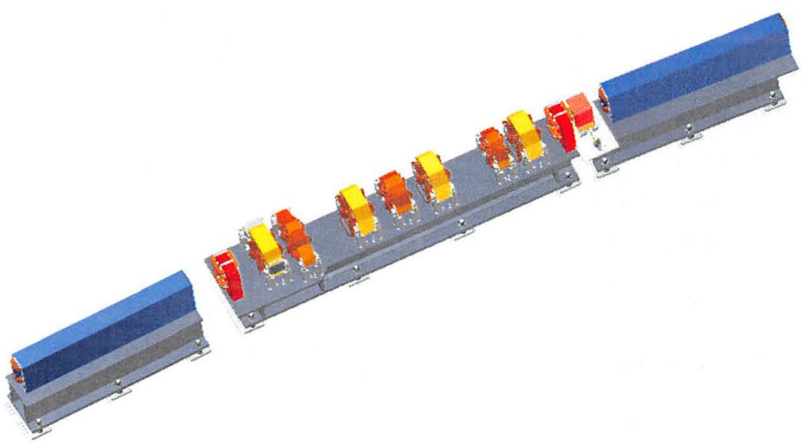


FIGURE 3.9
3.9 3D–View of the double bend achromat consisting of two dipoles, with four quadrupole magnets and three sextupole magnets in between. The grouping of quadrupole and sextupole magnets is mounted on a single rigid girder 3D view of the double bend achromat consisting of two dipoles, with four quadrupole magnets and three sextupole magnets in between. The grouping of quadrupole and sextupole magnets is mounted on a single rigid girder

The girders are designed with natural resonant frequencies >30 Hz to avoid amplification of low–frequency floor vibrations. The orbit feedback system is designed to damp beam motion at frequencies below 100 Hz keeping the orbit motion below 10% of the electron bunch transverse dimensions.

Beam Diagnostics installed in NSLS–II Storage Ring
The NSLS–II Storage Ring is equipped with a full set of beam diagnostics and feedbacks necessary for prompt commissioning and reliable operation of this cutting–edge facility. The diagnostics monitor position of the closed beam orbit, tunes, beam current and lifetime, filling pattern, beam emittances, bunch length and positions of the photon beam in insertion devices, coherent bunch instabilities and distribution of beam losses around the ring. It allows for the measurement and study of parameters for the linear and nonlinear optics (including lattice functions, chromaticities, local and global coupling, momentum compaction and magnet and RF system parameters), to measure the beam

energy spread as well as impedances of vacuum chambers and to use beam–based alignment relative to the quadrupoles and sextupoles. Beam diagnostics and feedbacks are listed in Table 3.6. It should be noted that two diagnostic Beamlines will be used during the NSLS-II routine operations. One will utilize synchrotron x–rays with all optical elements inside the Storage Ring tunnel and does not require a hutch. The purpose of this x–ray Beamline is to provide high resolution imaging of the electron beam cross section. The second diagnostic Beamline utilizes the visible portion of the synchrotron spectrum. Mirrors, located inside the front end, will direct the light through the ratchet wall to further optics located in an access controlled room (no ionizing radiation) on the experimental floor, located at cell 30. The purpose of this diagnostic Beamline is to provide time–resolved measurements to characterize electron beam properties.

TABLE 3.6

3.6 NSLS–II STORAGE RING INSTALLED BEAM DIAGNOSTICS

DIAGNOSTICS	QUANTITY
High Precision DCCT	1
Bunch to Bunch Current Monitor	1
Beam Position Monitors (accelerator) – 6 per cell	180
Fast Orbit Correctors with INCONEL chambers	90
Slow Orbit Correctors with aluminum chambers	90
Beam Position Monitors (insertion devices)	2 per device
Monitors of both transverse tunes and synchrotron tunes	1 monitor
Visible synchrotron light monitor	1
Focused x–ray diagnostic Beamline	1
Dual Sweep Streak Camera	1
Beam loss control monitoring system (scrapers & loss monitors)	1
Bunch–by–bunch transverse feedback system	1
Injection SS Flag	1

With the exception of the Injection Flag and scrapers, the diagnostics listed above do not intercept the electron beam. A few other interceptive diagnostics (such as additional flags) will be used for commissioning purposes.

3.3.3.7 Magnets

In total there are 16 types of Storage Ring Magnets as listed in Table 3.7.

TABLE 3.7

3.7 LIST OF STORAGE RING MAGNETS

DESCRIPTION	REQUIRED IN STORAGE RING
100mm Corrector	90
100mm Corrector + Skew Quad	30
156mm Corrector	60
Fast Corrector	90
35mm Dipole	54
90mm Dipole	6
Single Coil Short Quad	30
Double Coil Long Quad	30
Long Double Kinked Quad	30
Double Coil Short Quad	90
Large Aperture Quad	60
Single Coil Short Wide Quad	30
Double Coil Wide Quad	30
Symmetric Sextupole	165
Wide Sextupole Magnet	75
Large Aperture Sext	30
TOTAL:	**900**

The injection straight section contains five pulsed magnets used during electron injection, four bump magnets and a pulsed septum. The bumps were designed and built at BNL with a titanium coated ceramic vacuum chamber and a ferrite yoke installed in air outside the chamber.

3.3.3.8 Photon Sources

The set of insertion devices included for the start of routine operations of NSLS–II consists of hard x–ray and soft x–ray undulators, x–ray damping wigglers and three–pole wigglers. Taken together, these IDs produce high–brightness radiation spanning a large photon energy range, from the soft x–ray (~200 eV) to the very hard x–ray (~300 keV).

TABLE 3.8

3.8 INSERTION DEVICES INCLUDED IN THE BASELINE CONFIGURATION OF NSLS–II

TYPE OF DEVICE	PURPOSE	QUANTITY
Damping Wiggler (DW90): 90 mm period, 1.85 T, 2 × 3.4–m long, 12.5mm pole gap	Broadband	3 (8)
In–Vacuum Undulators (IVU):	Hard X–ray	
IVU20: 20–mm period, 1.05 T (5.0 mm min. vertical aperture), 3–m long		2
IVU21: 21–mm period, 0.91 T (6.2 mm min. vertical aperture), 1.5–m long, canted		1
IVU22: 22–mm period, 0.76 T (7.2 mm min. vertical aperture), 2 × 3–m long		1
Elliptically–polarizing undulator (EPU49): 49–mm period, 0.94 T (11.5 mm min. magnet gap), 2 × 2–m long, optionally canted by ~0.16 mrad	Soft X–ray	1
Three–Pole Wiggler: 1.14 T peak field, 20–cm long*	Broadband	1

*Not installed in the baseline project scope

The complement of insertion devices included in the NSLS–II baseline configuration is listed in Table 3.8. This set is not meant to be complete for the built–out NSLS–II facility. Rather, these devices represent a set that initially seeks to optimize the performance of the Beamlines included in the NSLS–II baseline configuration. These IDs have been chosen consistent with the philosophy of building Beamlines dedicated to a given technique, which requires that the source also be individually optimized for each application, as appropriate.

There will also be Beamlines in the future which utilize the NSLS–II bending magnets, which will have a relatively low critical energy: ~2.4 keV. It is expected that the available bend magnet ports will be allocated primarily to VUV and soft x–ray uses, as well as infrared uses. The NSLS–II bend magnets and three–pole wigglers will provide very stable beams. The relatively low emitted power from these sources simplifies the cooling requirements on the optics, although it does not eliminate the need to provide cooling. The brightness provided by the NSLS–II dipole sources will be two orders of magnitude higher than that of the present NSLS dipoles (extending up to ~12 keV) and their flux will also show some improvement (extending up to ~4 keV).

The basic parameters characterizing the IDs, bending magnet and three–pole wiggler sources are listed in Table 3.9.

TABLE 3.9

3.9 BASIC PARAMETERS OF NSLS–II RADIATION SOURCES FOR STORAGE RING OPERATION AT 3.0 GeV AND 500 mA

	U20	EPU49	DW90	SCW60	Bend Magnet	Three–Pole Wiggler
Type	IVU	EPU	PMW	SCW	Bend	PMW
Photon energy range [keV]	Hard x–ray (1.9 – 20)	Soft x–ray (0.18 – 7)	Broadband (<0.01–100)	Very hard x–ray (<0.01–200)	Soft and low–energy x–ray (<0.01 –12)	Hard x–ray (<0.01 –25)
Type of straight section	Low–β	Low–β	High–β	Low–β		
Period length, λ_U [mm]	20	49	90	60		
Total device length [m]	3.0	4.0	7.0	1.0		0.25
Number of periods	148	2 x 39	75	17		0.5
Minimum magnetic gap [mm]	5.2**	11.5	12.5	15		28
Peak magnetic field in linear mode, B [T]	1.03	0.94	1.85	3.5 (6)	0.40	1.14
Max K_y* in linear mode	1.83	4.34	15.7	19.6 (33)		
Peak magnetic field in circular mode, B [T]		0.57				
Max $K=\sqrt{2}\,K_x=\sqrt{2}\,K_y$* in circular mode		3.69				
Minimum hν fundamental [keV]	1.6	0.17				
hν critical [keV]			11.1	21 (36)	2.39	6.8
Maximum total power [kW]	7.9	8.8	67	34 (101)		0.32
Horizontal angular power density [kW/mrad]			16	6.6 (11)	0.023	0.067
On–axis power density [kW/mrad²]	66	32.8	62	25 (44)	0.088	0.26

*$K = 0.934\,B[T]\,\lambda_u[cm]$; effective K values listed

** Physical vertical aperture must be minimum 5.0mm

From the point of view of safety, an important parameter is the total power of the synchrotron radiation beam produced by the source. Table 3.9 gives the maximum total output power of the NSLS–II radiation sources. The total power radiated by the undulators at their maximum K settings is in the 8–10 kW range. The total power output from the NSLS–II wigglers is higher than that of the undulators, at nearly 70 kW for DW90, while that of the NSLS–II bend magnets and TPWs is very much less, at only ~23 W and ~67W per horizontal mrad.

Insertion devices in the NSLS–II Storage Ring generate radiation with high power density capable of damaging components of the vacuum system if incident on surfaces without adequate water cooling. Under normal operating conditions, the electron orbit is positioned in a manner assuring proper illumination of the user Beamlines and avoiding unwanted incident power on un–cooled surfaces. In the absence of faults, the electron orbit is highly stable exhibiting variations of only a few microns. However, in the event of the failure of a magnet power supply or other hardware fault, the electron orbit can move by millimeters causing the insertion device radiation to be incident upon un–cooled surfaces. To prevent this from occurring, the equipment protection interlock system must kill the electron beam when the orbit variation exceeds predetermined limits. The definition of tolerable limits within which the beam positions and angles are allowed to vary depends on (list not necessarily complete):

- details of the geometrical constraints of the vacuum system
- the mechanical tolerances and the stability of the vacuum system
- the alignment tolerances and alignment stability
- the long term and short term stability of the detection systems which measure the beam positions and angles

To define the limitations we must understand

- the power distribution within the photon beam matters
- the maximum power which can be tolerated on components of the vacuum system
- the cooling capacity
- and special vulnerabilities such as vacuum seals, RF fingers, shielded bellows

The resulting constraints on the beam coordinates are further limited by necessary beam steering to launch the photon beam into the Beamlines which depends on Beamline alignment tolerances and stability as well as on mechanical tolerances in the Beamlines.

The resulting remaining free space for the beam positions and angles in the insertion devices must be compatible with robust and stable operating conditions which imply a certain tolerance against small anomalies, instabilities and minor hardware failures as they occur from time to time in a real accelerator. Thus the magnetic and mechanical design of insertion devices and the downstream system of absorbers and vacuum components are closely related to highly reliable operation of the facility.

3.3.3.9 Control System

The control system provides all the hardware and software necessary to monitor and control the Linac, Booster ring, transport lines, Storage Ring and Beamlines. All parameters essential for the operation of facility (e.g. magnet power supplies, RF systems, vacuum, cooling systems) are monitored and controlled by the control system.

The control system interfaces with the EPS. This system provides equipment protection for the Storage Ring front end components. Another branch of the EPS will provide protection and command/control on the experimental lines. The EPS protects equipment from the thermal effect of the synchrotron beam by monitoring the position of components, cooling supply and temperature. When a condition puts components in jeopardy of being damaged, the EPS will shut the RF systems down, causing the beam to dump or shut off power supplies to stop the flow of current in an overheating conductor.

These interlocks are not for personnel protection, but are important to prevent programmatic loses and are designed to be fail safe. A safe state is indicated by a closed contact sending a DC voltage. An unsafe state is indicated by an open contact that blocks the DC signal. On power failure, the system indicates an unsafe state. In case an interlock has been tripped, the system or subsystem is not operational, even if the cause of the interlock trip has been cleared, until the

Operator has reset the interlock. Control Room procedures provide guidance to the Operator for responding to equipment trips and systems alarm.

3.3.3.10 Top Off Operation

The traditional way of operating a storage ring based light source is in the "decay mode". In the "decay mode", beam is injected into the storage ring with frontend safety shutters closed. Neither x-rays nor injected beam can enter the user beamlines during injection. Once injection is completed, the stored beam current begins to decay due to beam loss from Touschek scattering, collision with residual gas, etc. The radiation flux and brightness are changing with stored beam current, as is the heat load on beamline optics which impacts the quality of experimental data.

Top–Off mode refers to injecting into the Storage Ring with the beamline photon and safety shutters open to maintain a near–constant stored beam current in the ring. The frequent injection of electron beam into the Storage Ring maintains the stored beam current at a near constant level. This provides for the stable operation of the accelerator and user beamlines without interrupting user experiments. Because stored beam intensity is maintained at a quasi-constant level and the shutters are continuously open, the x-ray flux to experiments and heat load on beamline optics are kept extremely stable, which is highly preferred by users. This mode of operations is supported by the design of the injection systems in most modern electron synchrotrons such as the Advanced Light Source, Advanced Photon Source, and Stanford Synchrotron Radiation Lightsource.

The NSLS-II large design beam current of 500 mA and the low emittances imply large Touschek scattering rates which limit beam lifetime to approximately 3 hours. This short lifetime requires electron injection of 8 nC every minute to maintain beam intensity within the specified limits. The injection system is designed to provide a maximum capability of delivering up to 15 nC per booster cycle.

Injection with open safety shutters introduces a special radiological risk caused by injected 3 GeV electrons which could enter the experimental floor via the open shutters during injection. This would cause unacceptably high radiation doses on the experimental floor, as discussed in Section 4.15.10 – Radiological Hazards Associated with Top Off Operations. To guarantee the safety of Top-Off injection, one must assure that, for all possible fault conditions, all errant injected particles are lost before a safe point within the Storage Ring tunnel. At NSLS-II, each beamline will have a designated safe point beyond which no injected beam can be allowed to pass through all physical apertures and enter the First Optics Enclosure (FOE).

The safety of Top-Off injections has been extensively studied and reviewed by panels of experts from across the DOE community. Particle tracking analysis has been performed to assure that injected electrons cannot pass the safe point and several interlocks will be used to ensure that top off injections only occur when the stored beam is stable. These interlocks include stored beam current, dipole current and voltage, injected beam energy and injection current. A description of each of these interlocks is provided in Section 4.15.10.

Top–Off operation is now part of the scope of this document. During a fill of the Storage Ring from zero current, the Top Off Safety System (TOSS), would not permit electron injections to be made with front end safety shutters open at currents < 50 mA. Injection with the safety shutter open at currents < 50 mA will trigger the USI process and will require additional review and approval beyond this document. Additionally prior to authorizing top–off mode of operation for beamlines not already covered within this document a USI will be prepared to assure the beamline and front end meet the requirements for Top-Off. Decay mode refers to injection into the Storage Ring with the beamline photon and safety shutters closed, allowable under the original Authorization Basis. The Top Off Safety System (TOSS) is not necessary for this mode of operation since the shutters are closed. If the critical devices, preventing Storage Ring injection with the Beamline safety shutters open, changed state fast enough, one could implement near Top Off operation under the prior Authorization Basis (allowing for any changes in the critical devices involved). Originally, the critical devices for preventing injection into the Storage Ring were the power supply for a dipole in the BTS line (BS-B2) and the BTS transport line shutter (BS-SS). As part of the transition for implementation of Top-Off mode, a change of the critical devices used to prevent injection into the Storage Ring is made. The changed devices are the Booster AC extraction septum and Storage Ring AC injection septum. The injection and extraction septa would be disabled if any photon shutter is open when not in Top-Off mode or when other conditions indicate storage ring injection should be inhibited.

3.3.4 Storage Ring RF System

The NSLS–II Storage Ring RF system consists of the 500 MHz superconducting radiofrequency (SCRF) cavities, their associated klystron tube amplifiers and power supplies. In addition, passive cavities operating at the 3rd harmonic (1.5 GHz) are used to increase the bunch length and improve the beam lifetime. The superconducting cavities are supported by a liquid helium cryogenic plant (see section 3.3.4.1 below). When the facility is fully built out with insertion devices, there will be two RF straight sections with a total of four 500 MHz RF cavities and two 1500 MHz harmonic cavities.

SCRF Cavities – The RF cavities are Cornell Electron–Positron Storage Ring–B (CESR) type superconducting RF 500 MHz cavities. The CESR–B cavity consists of a bulk niobium SCRF single cell with waveguide coupler, a special fluted beampipe to extract the lowest frequency dipole modes, warm–to–cold transition spool pieces for thermal isolation, water–cooled C48 ferrite high order mode (HOM) dampers and long tapers to transition from the 240 mm cavity bore to the elliptical beampipe. The CESR–B cavity is a "single–mode" cavity. All higher–order modes with the exception of the TM110 dipole mode propagate through the cylindrical beampipe. A fluted beampipe at the opposite end of the cavity has a lower cutoff frequency to allow the TM110 to propagate to the ferrite load. This has only a small effect on the fundamental mode. This allows a shorter attenuation length in the beam tube and a more compact cavity. The SCRF modules are planned to be situated in two neighboring straight sections of the Storage Ring at ~50 m apart in two groups of three SCRF cavities: two 500 MHz fundamental cavities and one 1500 MHz harmonic cavity.

Transmitter – The two main ring cavities of each RF straight section are driven by a single 310 kW klystron amplifier through a 350 kW rated circulator and load to establish a RF gradient up to 5MV. The klystron beam power is provided by a pulse step modulator (PSM) switching power supply at 55 kV and 12 A. The RF transmitter has local programmable logic controller (PLC) control, with system parameters and controls available to the main control system via an Ethernet link. The PLC also monitors the PSM switch modules, so that failed modules are logged and transmitter repairs can be scheduled for the next maintenance period.

3.3.4.1 RF Cryogenic System design

Two Storage Ring cells (nos. 22 and 24) approximately 50m apart have been dedicated to RF cavities. Each cell will contain two 500 MHz (fundamental) superconducting RF cavities and one 1,500 MHz (harmonic) superconducting RF cavity. An additional area is also designated for testing and development of either type module which technically will bring a total of seven modules fully loaded with liquid helium and flow of liquid nitrogen at full build out. The 500 MHz and 1,500 MHz modules have 500 L and 22 L storage capacities, respectively and run with 416 L and 16 L LHe during operation. Both these modules have thermal radiation shields cooled by flow of liquid nitrogen (LN_2). Therefore, a combined total of up to 2,012 L of LHe may be stored in all these 7 modules in addition to a stored reserve in the buffer Dewar and flow–through transfer lines.

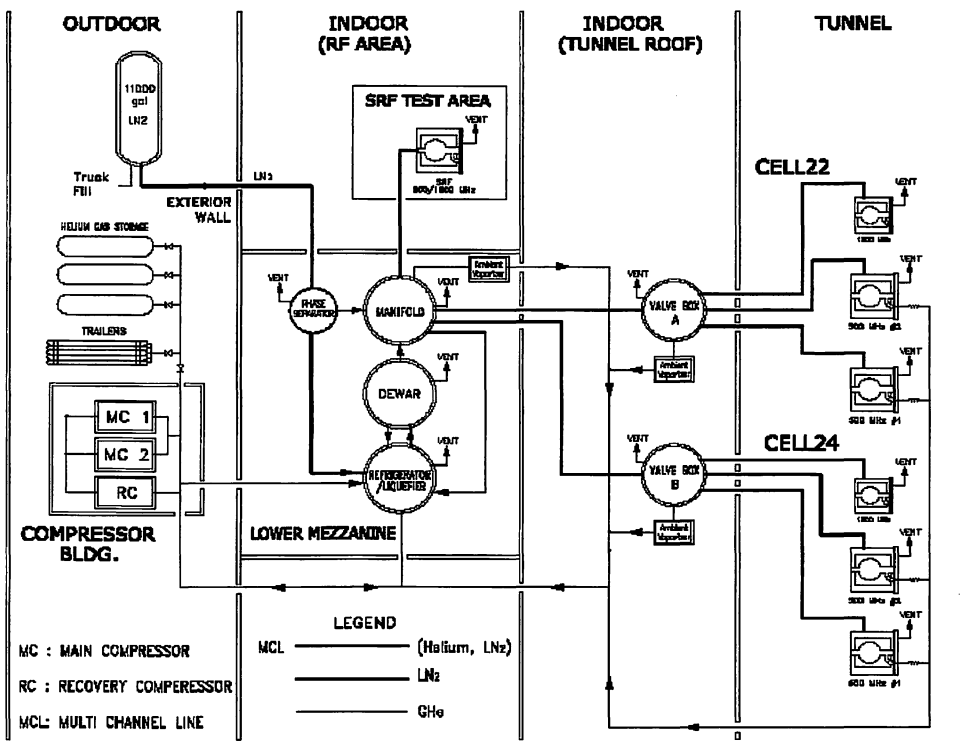
A cryogenic system is necessary to provide liquid helium to the superconducting RF cavities at approximately 4.5K and 1.28 bara during operation (see Figure 3.10 below). The cryogenic system consists of a fully closed–cycle liquid helium system and an open liquid nitrogen system. The helium system consists of the following sub–systems. Three warm gaseous helium tanks are located outside the Compressor Building. Located inside the Compressor Building are two redundant main compressors and one recovery compressor with oil removal systems. Inside the RF Building on the lower mezzanine, there are a commercial refrigerator/liquefier cold box for converting gaseous helium (GHe) to LHe, a 3,500 liter capacity LHe buffer Dewar, one main vacuum jacketed (VJ) distributing manifold box and one 300 L LN_2 phase separator. On the Storage Ring roof tunnel, each cell has one VJ distribution valve box and an assortment of multichannel and single VJ transfer lines, warm pipes and vaporizers. An independent 11,000 gallon (gal) liquid nitrogen storage Dewar, located outside the ring building adjacent the facility LN_2 storage Dewar, provides low pressure LN_2 via VJ transfer lines to the phase separator located on the RF building lower mezzanine.

Initial operation will require one 500 MHz (fundamental) superconducting RF (SCRF) module. The full build–out operation will require four 500 MHz and two 1,500 MHz modules for a total of six modules. The cryogenic system must be able to operate continuously for at least a full year before scheduled downtime. The design goal, therefore, is to provide a highly reliable and stable cryogenic system supported with required monitoring, alarms, interlocks, equipped with safety devices and sophisticated control system. As the cryogenic system must supply LHe to all of the Storage Ring RF cavities, redundancy of vulnerable components, such as the helium main compressor, was included in the design to ensure that continuous operations can be maintained effectively.

Total refrigeration cooling requirements are based on two sets of operating conditions: an initial baseline during the start of routine operations and eventual full operations. Note that the cooling requirements for the full operation condition are considerably larger compared with the baseline, due to additional required modules. Therefore, the cryogenic system must minimally provide refrigeration power of ~290 W during baseline operation and ~520 W for the eventual full operating conditions. The Refrigerator–Liquefier (R/L) is oversized (150% margin) to enhance reliability and account for contingencies on additional heat loads.

BNL has performed independent structural and safety device calculations for all pressurized systems in order to verify vendors' full compliance to BNL specifications. The Laboratory ESH Cryogenic and Pressure Safety Review Sub–Committee, has reviewed and approved the Storage Ring RF helium and nitrogen cryogenic systems. Minutes are available on the Committee's web site. A summary of the hazards and safeguards for this cryogenic system are provided in section 4.6.

Installation and commissioning of the cryogenic systems have been performed prior to use within the Storage Ring in a carefully planned sequential fashion using procedures developed by the vendor and NSLS-II staff members. The overall design goal is to have a near fully automated system via a dedicated PLC control system which will ensure safety under any operation scenarios or emergency cases. However, the cryogenic system is fully, passively protected against all failure scenarios with pressure burst disks and pressure relief valves. NSLS-II has dedicated, trained technical staff members to operate and maintain these systems.



Simplified RF cryogenics system Layout

FIGURE 3.10
3.10 LAYOUT OF STORAGE RING RF CRYOGENIC SYSTEM

3.3.5 Beamline Front Ends

Beamline front–ends connect the Storage Ring, via an assembly of UHV–compatible components, to the user Beamlines. The front ends provide radiation protection to personnel and bring synchrotron radiation to the Beamlines. Some of the front–end components are used to trim the x–ray beams in order to reduce heat loads on the Beamline optical components. The front–end components reside within the Storage Ring's shield wall, upstream of the ratchet shield wall and downstream of a dipole or insertion device vacuum chamber. As with insertion devices, front–ends will be continually added as NSLS–II expands. For devices of similar design to those already installed as part of the NSLS–II project, the devices will be designed, reviewed and installed in accordance with NSLS-II standard operating procedures. For devices of differing design, a USI evaluation will be performed prior to their installation to ensure there are no new or significantly different hazards associated with that device. Any device (or series of devices) resulting in a positive USI will be submitted to the Laboratory ESH committee for review and then to BHSO for approval prior to operation.

3.3.5.1 Function of Front Ends

The major front end components are shown in Figure 3.11 and described in section 3.3.5.2 below. For the bending magnet Beamlines, the front–end designs can differ according to the angle (in mrad) of radiation and number of apertures (and therefore Beamlines) in each heat absorber that allows synchrotron radiation to pass through. For insertion device front ends, the type of insertion device used (e.g., undulator or wiggler) and its magnetic properties (field strength, length of field, periodicity, etc.) determine the radiation output parameters (e.g., radiation fan, output power density and total radiated power). The heat–absorbing–components in each front end therefore need to be chosen according to the radiation source parameters. These parameters are selected according to the research needs of the scientific program served by each Beamline. The front–end components and the arrangement of components may therefore differ somewhat according to the specific front end. Vacuum isolation valves are included to allow the removal and replacement of front–end components. Since there is no vacuum isolation during operations between the front ends and the Storage Ring (except for some bending magnet front ends with beryllium windows), the front ends share machine vacuum from the exit of the Storage Ring chamber.

Each Beamline and front end will contain a series of specialized safety devices referred to as shutters, masks/slits and collimators. These devices are important to control radiation exposure to personnel working along the Beamlines or in the downstream enclosures from bremsstrahlung or synchrotron radiation. A shutter is a remotely actuated device which is inserted into the beam to permit access into an enclosure or to protect other components from over–heating from exposure to synchrotron radiation. Safety shutters are secured and fixed in position at the end of a Beamline to permanently block bremsstrahlung radiation from entering an occupied area. Collimators/masks are designed to permit bremsstrahlung/synchrotron radiation through the pipe while absorbing off–axis radiation. Safety shutters, which are not water–cooled, are shielded from the x–ray power by an upstream water–cooled photon shutter. The photon shutter and the safety shutters when inserted, in conjunction with front end collimators must completely block the downstream occupied region from synchrotron radiation and the bremsstrahlung shower.

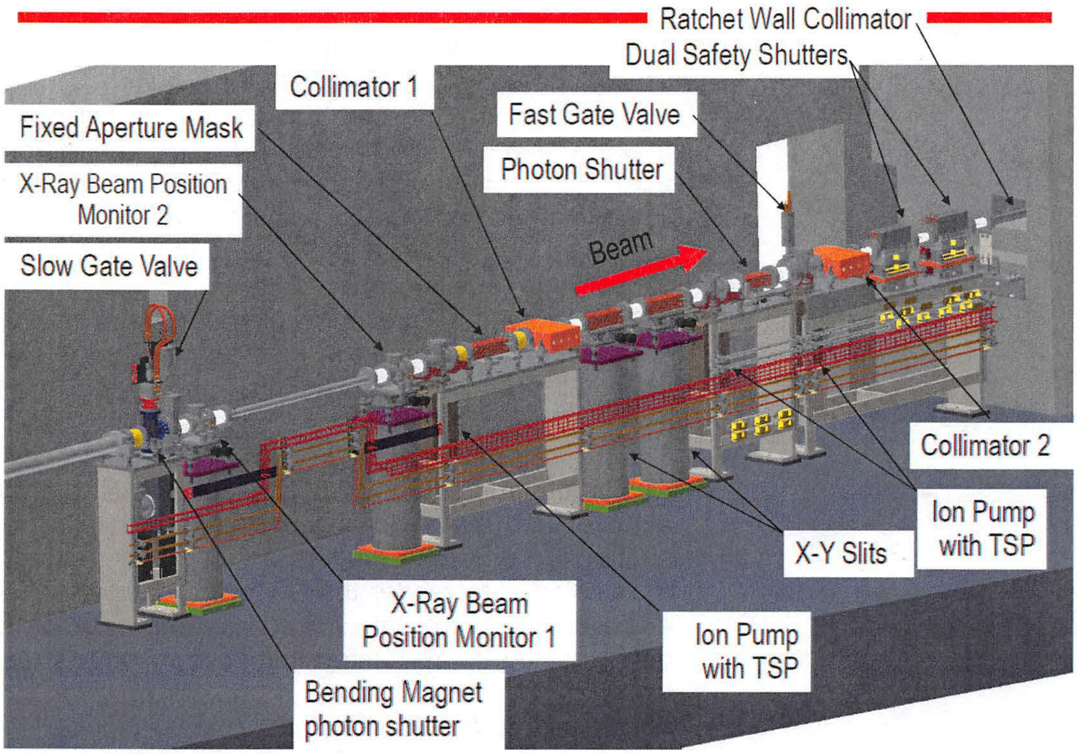


FIGURE 3.11
3.11 TYPICAL STORAGE RING BEAMLINE FRONT END CONFIGURATION

3.3.5.2 Front End Components

The major front end components consist of the following, going in a downstream direction:

- The "Bending Magnet Photon Shutter" and "Slow Gate Valve" are part of the Storage Ring vacuum system. The start of the front end is defined as the downstream flange of the all metal slow gate valve. The Slow Gate Valve is used to isolate the front end vacuum components from the accelerator vacuum. The Bending Magnet Photon Shutter protects the closed Slow Gate Valve from bending magnet radiation. In the case of an insertion device front end, the insertion device must first be retracted to eliminate its high power output before the Bending Magnet Photon Shutter can be closed.
- "X–Ray Beam Position Monitors 1 and 2" are used to measure the horizontal and vertical locations of the x–ray beam passing through the front end. The BPMs include tungsten blades that protrude into the periphery of the x–ray beam. The present plan calls for installing only one XBPM in a typical front end to save cost.
- The "Fixed Aperture Mask" trims the horizontal and vertical size of the x–ray beam from the full fan of the insertion device to the nominal size required by the Beamline. The water–cooled Fixed Aperture Masks are manufactured from Glidcop.
- "Collimator 1" and "Collimator 2" consist of short beam pipes enclosed in lead shields. The purpose of these devices is to limit the bremsstrahlung radiation exiting the downstream ratchet wall.
- "XY Slits" are movable apertures that allow remote control of the horizontal and/or vertical size of the x–ray beam as required for the experiment. These

devices are water–cooled Glidcop bodies mounted on precision X–Y stages and supported by thermally stable Invar stands.

- The water–cooled Glidcop "Photon Shutter" is used to completely block the x–ray beam. It is designed to accept the full power of the insertion device beam exiting the Fixed Aperture Mask. The Photon Shutter is pneumatically actuated and is the primary way to stop x–rays from exiting the ratchet wall. The water–cooled photon shutter is interlocked through the Beamline PPS with the safety shutters and is used to protect them from overheating by the synchrotron radiation when closed
- "Safety Shutters" are movable lead shields that block bremsstrahlung radiation from entering the first optics enclosure (FOE) when the FOE is open. To protect the safety shutters from exposure to the synchrotron beam, the PPS requires that the Photon Shutter be closed before the Safety Shutter can be closed. The Safety Shutters consist of a short beam pipe with lead mounted above it. The pipe and lead are mounted on a pneumatic actuator and move down together to block the radiation, thus closing the shutter. Dual Safety Shutters are used for redundancy. The safety shutters are designed to render the Beamline downstream experimental end station enclosures (EESE) safe for access and must be closed whenever there is access to the FOE located immediately downstream of the forward ratchet wall
- The "Ratchet Wall Collimator"; a beam pipe extending through the ratchet wall from the front end into the FOE is surrounded by a combination of upstream lead with polyethylene, intermediate concrete and downstream lead which limits the bremsstrahlung radiation entering the FOE.

3.3.6 Experimental Beamlines

The Beamlines on the experimental floor are positioned in such a manner that their centerlines are tangential to the electron orbit in the insertion devices or dipole magnets within the Storage Ring. Thus, synchrotron radiation, generated when the high–energy electrons are bent by the magnetic fields of dipole or insertion devices, emerges through the beam port of the Storage Ring and into one or more individual Beamlines where the radiation is used for experimental purposes.

Beamlines transport the synchrotron radiation (x–rays, ultraviolet (UV), visible or infra–red light) produced by the bending magnets and insertion devices in the electron Storage Ring to experimental stations where it is used for scientific research programs. The NSLS–II project includes an initial suite of Beamlines on the Storage Ring, as follows:

- IXS: Hard X–ray inelastic scattering – 0.1 meV resolution (uses IVU22 installed in #10 ID)
- HXN: Hard X–ray nanofocusing – 1nm spatial resolution (Uses IVU20 installed in #3ID
- CHX: Hard X–ray coherent scattering and imaging (#11 ID; Uses IVU20 installed in #11ID)
- CSX: Soft X–ray coherent scattering and imaging (#23 ID; EPU 49mm period – 2m long x 2 devices): comprised of two independently operating Beamlines
- SRX: Hard X–ray sub–micron resolution x–ray spectroscopy (#5 ID; IVU 21mm period – 1.5m long)
- XPD: Hard X–ray powder diffraction (#28 ID; DW 100mm period – 3.4m long x 2 devices): comprised of a main branch and provisions for a simultaneously operating side station to be developed in the future.

Although not included in the scope of the NSLS–II construction project, components from a number of Beamlines will be upgraded and moved from the NSLS facility in Building 725 using early NSLS–II operations funding. Additional Beamlines will be funded through other DOE and non–DOE sources for a total of ~58 Beamlines at full build–out. Two IDs sharing a single straight section which produce two separate photon beams (i.e. canting) may increase the Beamline total.

3.3.6.1 Beamline Hutch Structures

The Beamline hutches are used to shield personnel from ionizing radiation. Because of the higher occupancy factor around Beamline enclosures and the desire to maintain all exposures to beam line personnel to << 100 mrem/y, a design goal of ≤0.05 mrem/h at contact with the external surfaces of the hutch walls was initially adopted. In some cases because of complexity of shielding in the forward direction close to beam lines, this goal has been relaxed to 0.05 mrem/h at 30 cm from the wall. The hutches are typically constructed from steel or steel/lead/steel panels of varying thicknesses depending on the energy and intensity of the x–rays present inside a particular hutch. Hutch specifications include sliding and swing doors, labyrinths (used for passing cables and pipes from inside to the outside), guillotines (used for tightly shielding around the beampipes as they pass through the wall of a hutch), windows, air flow and exhaust systems, temperature control and lights. Typically hutches weigh many tens of tons and have integrated handrails, stairs, internal cranes, bridges between hutch roofs and attachment points for utility systems, as required; all designs meet, as applicable, the requisite building codes or safety standards, e.g., BCNYS, Occupational Safety and Health Administration (OSHA).

There are several types of hutches. The first hutch in any Beamline is known as the FOE; this hutch is shielded with typically 18mm of lead for the walls transverse to the beam path due to the high energy bremsstrahlung interaction with Beamline components. The FOE contains, typically, a number of optical elements such as mirrors and monochromators; the beam passing out of this enclosure normally has a significantly reduced bandwidth, upper and lower energy cut–offs and reduced spectral flux. Access to the FOE is protected by the Beamline PPS and requires that the front end water cooled photon mask and safety shutters be closed before the door can be opened.

One or more hutches housing the experimental equipment are normally located downstream of the FOE. A separate dual shutter system located in the FOE must be closed for access into the EESE. Depending on the energies and fluxes present, downstream components may be located in a white beam hutch; in a monochromatic beam hutch; or, for very low energies where the vacuum vessels themselves provide adequate shielding, in no hutch at all. Some Beamlines may require hutches that are external to the Storage Ring Building walls (for optical geometry reasons or for stations handling dangerous or difficult samples or extremely large samples or in order to obtain high levels of vibration isolation). The Hard X–ray Nanoprobe (HXN) Beamline is such an example, where the remote station consists of a concrete hutch on a 1 m–thick foundation having extreme thermal and vibrational stability.

3.4 Electrical Power

3.4.1 Building 603 Substation Expansion

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

3.4.2 Distribution to Building 740

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

3.4.3 NSLS–II Site Distribution

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

3.4.4 Interior Power Distribution

3.4.4.1 Service Building Power Distribution

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

3.4.4.2 Storage Ring Building Power Distribution

There are eight substations located in the central court yard of the Storage Ring Building. They are fed by a 13.8 kV feeder system coming from the main substation for the complex located at Building 603. Each substation consists of fault protection switch gear and a 13.8 kV to 480 V step–down transformer rated at 2.5 MVA. The substations are located at each of the five Service Buildings, two for the RF Building and one for the Linac/Booster Service Building. These eight substations supply power for all building systems, accelerator systems, Beamlines and Laboratory Office Buildings. The output of the substations is routed to electrical distribution equipment rooms that are located in each of the Storage Ring Service Buildings, RF Building and the Linac/Booster Service Building. 480 VAC load centers are located in each of these electrical distribution equipment rooms. The load centers use electrically operated circuit breakers to distribute the power to the various systems.

3.4.4.3 Storage Ring Accelerator Power Distribution

480 VAC electrical power is routed from each of the Service Building electrical distribution equipment rooms to various load panels. There are separate load panels for the Storage Ring building systems. Power for the accelerator system and Beamlines are routed to integrated power centers (IPC) located on the Storage Ring mezzanine inside the building.

There are six main IPCs for each Storage Ring pentant (total of 30 main IPCs). There are two auxiliary IPCs for each main IPC (total of 60 auxiliary IPCs). The main IPCs have motorized 480 VAC circuit breakers that are used to feed 480 VAC to 208 VAC distribution transformers, located in both the main and auxiliary IPCs. The transformers are either 75 or 45 kVA depending on the load application.

There is a remote control operator panel associated with each main IPC. The operator panel is located away from the arc flash hazard zone on the 480 VAC breakers of the main IPC. Also associated with each of the IPCs are multiple universal power alerts (UPA) units. There is one UPA connected to each 480 VAC circuit. The UPAs are used to assist personnel in determining that a circuit has been de–energized. Both the motorized circuit breakers and UPAs are part of a strategy to minimize arc flash hazards and make it easier for personnel to identify the 480 circuits located in the IPCs. All the motorized circuit breakers have provisions to apply a pad lock to the motorized operator which will prevent it from being turned on in manual or remote modes.

The outputs of the distribution transformers are routed to 208 VAC panel boards located in the IPCs for accelerator systems and circuit breakers for remote sub–panels that are used for the Beamlines. These sub–panels are located along the Beamlines. The accelerator systems panel boards have a main breaker and a number of different 3– and single–phase branch circuit breakers for the different loads located in the electrical equipment enclosures. The panel boards all have Transient Surge Suppressers units connected to the 208 VAC lines.

One of the 45 kVA distribution transformers powers a 30 kVA UPS. There are 30 UPSs distributed on the Storage Ring mezzanine. These UPSs are used only for accelerator systems (smaller UPSs for the Beamlines will be sized for their reduced load). The 30 kVA three–phase UPS output is routed to a panel board which is used to distribute power to the equipment enclosures on the mezzanine. All the UPSs have manual MBSA that can completely electrically isolate the UPS from the AC power to allow internal repairs and maintenance without interrupting the power to the load.

There are two locations where separate power is distributed to the Main Dipole Power Supplies and the Injection Straight area on the mezzanine. The main Dipole Power Supplies have two individual 500 Amp 480 VAC motorized circuit breakers. These circuit breakers are connected directly to the substation for Service Building 2. The circuit breakers use a common remote operator panel to open and close the breakers. UPAs are also used to indicate the status of the 480 VAC lines. There is also a small 30 kVA 480 to 208 VAC distribution transformer that is fed from an IPC. This is used to supply power to a panel board that is used for Main Dipole controls. The Injection Straight area has two additional stand–alone 75 kVA transformers powered by circuit breakers located in the main IPC in that area. These transformers feed three phase 208 panel boards and a 30 kVA UPS. The UPS feeds its own three phase 208 panel board. The panel boards have main breakers and branch three and single phase circuit breakers that feed various equipment enclosures used for the Injection Straight systems.

There are 120 VAC single phase convenience outlets throughout the Storage Ring building. They are used mainly for maintenance and repair tasks. There are three phase 100 Amp 480 VAC outlets located in the Storage Ring tunnel. These outlets are fed from a remote motorized circuit breaker located outside the tunnel. A remote operator panel is located near the 480 VAC outlet. There is also a lockable safety switch that is between the circuit breaker and the outlet and it is located adjacent to the outlet. A UPA is also connected to the safety switch line side. This allows the safety switch to be operated under no voltage conditions which greatly minimizes the arc flash hazard. There are 30 of these 100 Amp outlets distributed around the Storage Ring tunnel.

3.4.4.4 RF Building Power Distribution

The power from the two RF Substations is fed to two separate 480 VAC switchgears, one switchgear per substation. The switchgear supplies power for building loads and accelerator system RF equipment loads. The RF building has provisions for four large RF transmitters. Each transmitter requires 560 kVA at a line voltage of 480 VAC. A 750 Amp motorized wall mounted circuit breaker is used for each transmitter. This is the same type of configuration used throughout all the accelerator systems that is designed to reduce arc flash hazards.

In addition to the transmitters there are a number of control systems equipment enclosures that are powered from two distribution transformers (one 75 kVA and one 45 kVA) and panel boards. The transformers are fed from motorized circuit breakers located in 480 VAC panel boards that are in the electrical distribution equipment room of the RF building. The remote operator panels for these circuit breakers are located by the 208 VAC panel boards.

There is also a single 30 kVA UPS for all of RF controls. It is fed from an 75 kVA distribution transformer. The transformer is fed from an Automatic Transfer Switch (ATS) which is connected to emergency generator power. The output of the UPS feeds a panel board which has a main circuit breaker and branch breaker that feeds various loads in the RF system.

The computer room is part of the RF building. The power requirements for the Accelerator System Control Systems computer equipment is ~45 kVA. For reliable operation, the system uses three 30 kVA UPSs. Two of the UPSs are fed from (480 to 208 VAC) 45 kVA transformers; the third UPS is from a different manufacturer and has a direct 480 VAC input. All the outputs of the UPSs go to three different 208 three phase panel boards. In addition to UPS power there is a 30 kVA 480 to 208 VAC distribution transformer that powers a panel board for normal power requirement for the computer room.

3.4.4.5 Laboratory Office Building Power Distribution

Power to the LOBs originates in the Service Building of the associated pentant. Each pentant has a normal source of power of 800 A at 480 V. There is also a source of emergency power of 100 A at 480 V.

3.4.5 Emergency Power

Two diesel emergency power generators are provided, one at Service Building #3 and one at the RF Building. The size of each generator is 700 kW. The emergency power requirements are distributed almost equally between the two units which have been located to minimize the cable runs between the emergency generators and the electrical components requiring emergency power. A sub–base fuel tank in compliance with 6NYCRR Parts 613 and 614 provides a 12–h full load operation capacity. To reduce noise and vibration, a weatherproof, sound attenuated reach–in enclosure is provided. Emergency Generator #1 will be used to support the northern portion of the NSLS–II site, including the Cryogenic System Recovery Compressor and the Controls Computer System. Emergency Generator #3 will support the southern portion of the site.

The emergency power is provided for key safety systems, including the emergency address system (through the fire alarm panels), egress and exit lighting, the fire alarm system, fire suppression system, smoke exhaust fans; and important utility systems such as selected lab exhaust and make–up systems, sump pumps (sanitary and storm) and select HVAC control systems. The generators start when normal power is lost. The loads are switched to the generators within 10 seconds. Power is transferred to the critical systems by ATS.

Since the emergency generators do not provide power directly to the Storage Ring, loss of electrical power will result in the Storage Ring shutting down, including the permit to operate provided by the PPS. Once power is restored, all areas requiring search and secure prior to beam operation will require an additional search. Critical controls for some components and RF will be connected to a UPS (see 3.4.4.3 and 3.4.4.4 above) for orderly shutdown in the event of a prolonged power outage. The emergency generators and transfer switches are tested monthly as per NFPA.

3.4.6 Grounding

3.4.6.1 Grounding Electrode System

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

3.4.6.2 Power System Grounding

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

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

3.4.6.3 Lightning Protection

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

3.4.7 Cable Tray and Cable Routing

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

3.4.8 Electrical Equipment Racks

Transport Line, Booster RF and Storage Ring standard 19–inch equipment chassis are mounted in sealed National Electrical Manufacturing Association (NEMA) 12 electronics racks with water–to–air heat exchangers cooling a set of four, three or two racks. Cooled air flows through the electrical equipment racks and circulates back to the heat exchanger. The heat exchanger uses chilled water and has the outlet temperature regulated. The majority of these racks are located on the mezzanine above the Storage Ring roof shielding.

3.5 Heating, Ventilation and Cooling Systems

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

3.5.1 Utility Systems

3.5.1.1 Chilled Water

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

3.5.1.2 Steam

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

3.5.1.3 Process Cooling Tower Water

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

3.5.2 HVAC Systems

3.5.2.1 Storage Ring Tunnel

The Ring Tunnel HVAC systems consist of five constant–volume custom packaged air handling units located along the tunnel in the five Service Buildings. The AHUs have 4–inch double–wall construction, galvanized steel inner lining and stainless steel condensate drain pan (sloped and the curb high enough to properly trap the unit). The supply and return fans have adjustable frequency drives (AFDs) to compensate for filter loading, allow future flexibility and provide ease of adjustment during balancing. Supply air is cooled if needed for dehumidification and reheated by the fan heat and hot water reheat coil below the required discharge temperature. The final discharge temperature to the tunnel is controlled by the electric reheat coil. Four high–precision temperature sensors per AHU are located in the tunnel. Temperature is controlled by any individual sensor or by the average of the four. Cooling coil discharge temperature is reset based on the tunnel relative humidity (RH), to maintain RH set–point with minimum energy consumption. The BNL Fire Rescue Group has the ability to control the ventilation system to exhaust smoke inside the tunnel. The controls are at the fire alarm system panels in the five Service Buildings.

3.5.2.2 Experimental Hall/Mezzanine

The Experimental Hall HVAC systems consist of ten constant air volume packaged AHUs located in the Service Buildings, two units per pentant. The units have 4–inch double–wall construction with stainless steel condensate drain pans (sloped and curbed) and galvanized steel interior liner. The supply and return fans have adjustable frequency drives. Cooling coils are sized to cool the air for dehumidification. Return registers are located above the ring tunnel in order to remove the heat generated by the equipment. Hutches are served by independent fan coils and will have one exhaust drop per hutch. The hutch exhaust systems are sized for an average of 350 cubic feet per minute (cfm) per Beamline, with a maximum for any Beamline of 750 cfm. The exhaust system has redundant fans. The hutches in each pentant are served by their own common exhaust system. Dedicated exhausts shall be provided for individual hutches when determined necessary by experiment review. These dedicated exhausts will exit the hutches overhead and be directed across the Ring Tunnel Mezzanine and through the building wall to the outside between Service Buildings, where a platform will support the exhaust fan and direct the exhaust upward per code requirements.

The BNL Fire Rescue Group has the ability to control the ventilation system to exhaust smoke from the experimental floor/mezzanine area. The controls are at the fire alarm system panels in the main lobby and at each of the four other pentant main entrances.

3.5.2.3 RF Service Building

The RF Service Building is served by three floor–mounted packaged HVAC units sized for the total sensible equipment load.

3.5.2.4 Lab Office Building

Each LOB is served by three AHUs located in the penthouse, two to serve the office area and one to serve the laboratory area. The office area AHU is a variable volume unit and the laboratory area AHU is a constant volume unit. Both AHUs have 4–inch double wall construction, galvanized steel inner lining and stainless steel condensate drain pan (sloped and curbed). Both AHUs utilize AFD to compensate for filter loading, allow future flexibility and provide ease of adjustment during balancing. Variable volume air terminal units with hot water re–heat coil are used for office area temperature zone control and constant volume air terminal units with hot water re–heat coil are used for laboratory area temperature zone control.

In laboratories, a minimum of six air changes per hour is used, providing 2 cfm/sq. ft. based on 10–ft. ceiling height. Assuming no external heat gain, 1.5 W/sq. ft. for lighting and 165 sq. ft. /person for people load, this design allows 9.5 W/sq. ft. miscellaneous heat gain from equipment. The BNL Fire Rescue Group has the ability to control the ventilation system to exhaust smoke. The controls are at the Fire Alarm Control Panels in each pentant.

3.5.3 Air Distribution

3.5.3.1 Ductwork

All ductwork is constructed in accordance with SMACNA standards. Supply air ducts are galvanized steel, insulated on the exterior. Exhaust and return ductwork is non–insulated except in areas where condensation on duct surfaces may occur. No internal duct lining is used. Galvanized steel is used for all lab main exhaust ductwork.

3.5.3.2 Air Terminal Units

Temperature control of individual spaces is by variable–volume terminal units with reheat coils.

3.5.3.3 Pressurization

The entire building is kept at positive pressure. A negative pressurization of 100 cfm per door is maintained in the laboratories by exhausting more air from the rooms than is supplied.

3.5.3.4 Ventilation

Ventilation is provided as follows:

- Offices, conference rooms and other occupied areas are provided a minimum of 20 cfm per person outside air
- The Experimental Hall is provided 20 cfm per person outside air
- Laboratories are provided six air changes (entire lab volume) per hour minimum
- The Storage Ring tunnel is provided six air changes per hour
- The RF Building is provided 20 cfm per person and air quantity based on thermal load

3.5.4 Exhaust Systems

3.5.4.1 Exhaust Fans

Exhaust fans are provided for the following:

- Fume hoods
- General laboratory exhaust
- Toilet rooms
- Mechanical and electrical rooms
- Process equipment
- Hazardous storage
- Beamline hutches via a common exhaust system
- Other areas requiring exhaust

3.5.4.2 Chemical Fume Hoods

Chemical fume hoods are designed for a maximum airflow based on a 100 fpm face air velocity with the sash open to an 18–in. height. All hoods have flow alarms. The Laboratory HVAC system is described above. Fume hoods identified for nanomaterial's research are provided with high efficiency particulate air filter (HEPA) filtration rated at 99.97% efficiency. At least one such hood is furnished for each LOB. Wet laboratories are also to be provided with ventilated chemical storage cabinets integral to the fume hood. All fume hoods shall be configured for HEPA filtration. Hoods shall be tested in the "As–Installed" condition.

3.5.4.3 Bio–Safety Cabinets

No need has been determined for bio–safety cabinets as yet, but they will be provided as warranted as the program develops. Review of bio–safety cabinets will be performed in accordance with BNL SBMS standard practices.

3.6 Process Systems

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

3.6.1 Liquid Nitrogen

Liquid nitrogen is stored in two 11,000–gallon tanks, one between LOBs 4 and 5 and the second between LOBs 2 and 3. Pipes from these two tanks transfer the LN_2 to the Ring Building. These pipes connect to a continuous pipe located in a rack above and around the Storage Ring mezzanine with connection points available for pipes to bring the LN_2 to every Beamline. In addition, fill stations are provided in the LOB-1 and LOB-3 Receiving Rooms with provisions for the installation of additional fill stations in the other LOB Receiving Rooms or other locations within the experimental hall. These fill stations permit LN_2 storage Dewars to be filled at those locations. The piping distribution system consists of vacuum-jacketed piping with a static vacuum. The piping contains an inner carrier tube and an exterior jacket. The annular space is under vacuum and has appropriate spacers. The system components (piping, fittings, valves, etc.) are products manufactured by or provided by a single manufacturer In addition, a separate 11,000–gallon LN_2 tank, located between LOBs 4 and 5, is provided to serve the needs of the Storage Ring superconducting RF cavity cryogenic system discussed in Section 3.3.4.1.

3.6.2 Nitrogen Gas

The source for ~30 psi gaseous nitrogen (GN_2) is a vaporizer operating from the 11,000 gallon liquid nitrogen tank between LOBs 4 and 5 (the Laboratory ESH Cryogenic and Pressure Safety Review Sub–Committee has reviewed and approved this nitrogen gas distribution system; minutes are available on the Committee's web site). A supply pipe from this tank provides primary GN_2 distribution to the Ring Building to a continuous pipe located in a rack above and around the Storage Ring mezzanine with connection points available for pipes to bring the LN_2 to every other Beamline (tees may be inserted into this GN_2 pipe to supply intermediate Beamlines). Secondary mains from the mezzanine pipe serving the LOBs and its laboratories are valved to permit isolation for maintenance and modifications. Branches serving individual laboratory modules are valved. Piping material is type L hard–drawn copper, oxygen cleaned tubing with wrought copper fittings and solder joints utilizing 95–5 tin–antimony solder. The GN_2 distribution system is designed to maintain a maximum pressure drop of ~10% from the point of discharge to the farthest outlet.

3.6.3 Process Cooling Water

3.6.3.1 Scope

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

3.6.3.2 Design of the Deionized Cooling Water System

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

Each of the five Service Buildings houses two stainless steel water systems. One cooling system discharges heat from copper photon absorbers, copper coils of the electromagnets, as well as copper components of the front ends and Beamlines. The second cooling system discharges heat from the extruded aluminum vacuum chambers. Both systems are stainless steel to meet deionized water requirements and the two are kept isolated from one another to prevent galvanic interactions.

The total designed power consumption for the copper component cooling system in the Storage Ring is approximately 2.7 MW or about 530 kW per Service Building in each of the five pentants. The copper component cooling systems in each of the Service Buildings are secondary hydronic systems coupled to a single primary cooling system located in the CTB in the center of the NSLS–II courtyard. There is also a slip stream polishing loop located within the CTB which deionizes the water for all copper component systems. The supply temperature of DI water is set to 85°F and 97.6°F. Each Service Building is expected to have a capacity of around 300 GPM for a finished pentant. This includes a nominal service of 12 gallons per minute to a typical Beamline.

The total designed power consumption for the aluminum vacuum chamber cooling system in the Storage Ring is approximately 30 kW or about 6 kW per Service Building in each of the five pentants. The aluminum vacuum chamber cooling systems are closed loop systems and contain their own deionization capabilities. Supply DI water temperature is set at 78 °F. Each Service Building is expected to have a capacity of around 14 GPM for a finished pentant.

3.6.3.3 Process Water Quality Control

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

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

3.6.3.4 Process Chilled Water

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

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

3.6.4 Compressed Air

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

3.7 Vacuum System

3.7.1 Linac Booster

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

The vacuum system complies with the requirements outlined in the BNL SBMS subject area Pressure Safety in the section entitled "Vacuum Systems Consensus Guideline for Department of Energy Accelerator Laboratories." The vacuum system is designed such that the pressure throughout the Linac, Booster, the two beam transport lines (Linac–to–

Booster and Booster–to–Storage Ring) is less than $5.0x10^{-8}$ mbar. The eight Booster vacuum sections and the eight transport line vacuum sections are isolatable from each other with pneumatically operated all–metal gate valves. NSLS-II approved procedures are used during vacuum venting/backfilling that specify the use of overpressure devices to prevent components from being pressurized to 15 psig. In addition, all vacuum systems that can be backfilled pressurized (that has internal cooling water or gases), have either overpressure protection devices or are monitored for leak protection and procedures that will quickly isolate the source.

Diode–type ion pumps are used as high–vacuum pumps in the Linac/Booster and the beam transport lines. Inverted magnetron cold cathode gauges are used as primary vacuum gauges. For venting the Booster and the transport line vacuum systems, dry nitrogen from the boil–off outlet valve of a commercial LN_2 Dewar is used to back fill the vacuum section volumes. The LN_2 Dewar will have an American Society of Mechanical Engineers (ASME) certified relief valve to provide overpressure protection and will relieve at <15 psig.

3.7.2 Storage Ring

The Storage Ring vacuum system is an all–metal system and is designed to maintain a vacuum pressure of less than $1x10^{-9}$ mbar in the presence of a beam current of 500 mA. To guarantee the necessary low out–gassing and photon desorption rates, ultrahigh vacuum practice, as specified in NSLS–II specification LT–ENG–RSI–SR–VA–002, is used in the design, assembly and conditioning of the vacuum chambers and components.

In each DBA cell, there are five long chambers made of extruded aluminum with antechambers and a few short chambers made of aluminum and Inconel. They are connected together with RF shielded bellows. The straight sections between the cells also have aluminum chambers prior to the installation of insertion devices. The straight sections can be isolatable from DBA vacuum cells by pneumatically controlled all metal RF shielded gate valves at both ends, thus 60 vacuum sections. Diode–type sputter ion pumps, titanium sublimation pumps, non–evaporable getter (NEG) strips housed in antechamber and NEG cartridges are used as ultrahigh vacuum pumps in the Storage Ring. Inverted magnetron cold cathode gauges are used as primary vacuum gauges and residual gas analyzers are used as partial pressure gauges. During vacuum system installation and commissioning, each vacuum sector is in–situ baked with external heating jackets and cal rods to 130°C for 24 hrs. to remove the absorbed gas and achieve the designed ultrahigh vacuum level. Turbopumps backed by 'dry' mechanical pumps will be used for pump down and during bakeout of the vacuum sectors. For venting the vacuum sectors, dry nitrogen from the boil–off outlet valve of a commercial LN_2 Dewar is used to back fill the vacuum volumes. The LN_2 Dewar will have an ASME certified relief valve to provide overpressure protection and will relieve at <15 psig.

Prior to beam being introduced into the Storage Ring the vacuum sections will have been pumped down, in–situ baked and conditioned. All the pumps and gauges are powered by IPC and VGC located at mezzanine to achieve ultrahigh vacuum during integrated testing and are kept on continuously. Affected GVs are closed and kept closed during local access or long maintenance periods. The GVs will then be opened by the operators through Experimental Physics and Industrial Control System (EPICS) vacuum pages (or PLC touch panel locally at PLC chassis) to allow for beam operation, after all the pressure readings are satisfactory and below their set points. In the event of vacuum faults, the vacuum sensors will quickly detect the pressure rise and tripped the vacuum interlock system through dedicated vacuum PLC, which will in–turn dump the beam and close the gate valves through EPS PLC. The status of all vacuum devices are logged at 1 Hz rate through Control System Studio channel archieve system and the offending devices or sections can thus be identified and resolved.

For initial commissioning of the beam or after significant maintenance the vacuum inside the ring is expected to be higher than the design goal of 10^{-9} Torr. The initial setpoints for the vacuum interlocks will be high enough to allow low current beams into the machine. As the vacuum improves the beam current will be allowed to increase and the vacuum setpoints adjusted. This process will be controlled by experience staff and protocols will be develop for operations to ensure proper restarts after maintence periods and shutdowns.

The vacuum system complies with the requirements outlined in the BNL SBMS *Pressure Safety* subject area in the section entitled "Vacuum Systems Consensus Guideline for Department of Energy Accelerator Laboratories."

3.7.3 Front End Vacuum System

The front end vacuum system is all–metal with an expected pressure ranging from $1x10^{-9}$ mbar at the upstream end to $1x10^{-8}$ mbar at the downstream end at the designed beam current of 500 mA. To guarantee the necessary low out–gassing and photon (ph) desorption rates, ultrahigh vacuum practice, as specified in NSLS–II specification LT–ENG–RSI–SR–VA–002, is used in the design, manufacture, assembly and conditioning of the vacuum chambers and components.

Most components in the front end are made of either stainless steel or Glidcop. Diode–type ion pumps and titanium sublimation pumps are used as ultrahigh vacuum pumps. Inverted magnetron cold cathode gauges are used as primary vacuum gauges and residual gas analyzers are used as partial pressure gauges. Each front end starts at the Storage Ring vacuum system pneumatically controlled all metal gate valve adjacent to the Storage Ring vacuum chambers and ends at the pneumatically controlled front end all metal gate valve just outside of the ratchet wall. During front end installation and commissioning, each front end component is in–situ baked with external heating jackets to 130°C for 24 hrs. to remove the adsorbed gases and achieve the designed ultrahigh vacuum level. Turbo–pumps backed by 'dry' mechanical pumps will be used for pump down and during bakeout of the front ends.

3.7.4 Beamline Vacuum System

The vacuum system for each Beamline is treated as a separate system, connected to the Storage Ring via the Front End. Beamline vacuum levels vary slightly depending on whether the Beamline is for hard x–rays or soft x–rays (where carbon contamination of mirrors can be a very significant problem). Additionally, vacuum levels in the hard x–ray monochromators tend to be slightly lower due to the high surface area and complexity of wiring and mechanics. The Beamlines need to maintain good vacuum levels for several reasons:

- If there is no window between the Beamline and the front end, then vacuum systems must be designed to avoid contamination of the front end and Storage Ring. This is of great importance since poor vacuum in the Storage Ring can cause elevated Bremsstrahlung levels.
- Vacuum quality needs to be good in the optical elements to prevent contamination and consequent deterioration of the reflecting or diffracting surfaces. In some cases, e.g. soft x–ray Beamlines, the vacuum level in the optical elements will be better than in the front end.
- To minimize attenuation and scattering of the synchrotron radiation beam as it travels from the source to the end station.

Individual Beamlines are divided into a number of vacuum sections which may be automatically isolated by gate valves with a PLC–based Equipment Protection System (EPS) in the event of a vacuum fault (leak).

The document *Standard Technical Specifications for NSLS–II Beamline Components* (LT–C–XFD–SPC–COM–001; 19May2012) sets standards for vacuum levels in the various

Beamlines and components and also defines the vacuum pumps gauges and controllers to be used.

As a brief summary, it is expected that;

- Ion Pumps are used to maintain the Beamline vacuum (roughing pumps are used, where needed, for initial evacuation only). A few, very specialized pieces of End Station equipment may be fitted with large capacity pumps such as a Roots blower with backing pump for fast pump down of large volume flight paths with a high duty cycle.
- Cold cathode and Pirani gauges are used for measurement of the vacuum levels in each vacuum section. These are connected to the Beamline EPS and used to check that valves may safely be opened and closed in a fault condition.
- A fast valve sensor is provided in the Beamline that is wired directly to the fast valve in the front end. This will enable the front end and Beamline to be isolated before the pressure wave travels along the Beamline and front end and contaminates the Storage Ring.
- Bakeout heaters may be used on some equipment to assist in removal of impurities and water vapor prior to use of the equipment.
- When required, a PPS rated vacuum switch will be used as a part of the beamline PPS to automatically shut the safety shutter when high vacuum is detected in a beamline housing in-vacuum experiments.

3.8 Fire Protection

The NSLS–II fire protection system is described in detail in the *NSLS–II Fire Protection Assessment / Fire Hazard Analysis* (FPA/FHA) – see Appendix 2. This SAD limits itself to describing the salient design features of that system.

The NSLS–II buildings are classified as “Business” occupancy per the BCNYS and “Industrial, General Purpose” occupancy per NFPA Standard 5000, *Building Construction and Safety Code*.

- The overall building construction classification is IIB (BCNYS) and Type II – 000 (NFPA).
- Two 700 kW emergency generators are provided, one at Service Building #3 and one at the RF Building
- Fire Service Rooms (FSR) are located on the exterior walls of the five Service Buildings and another five FSRs are located along the exterior walls of the Ring Building. The latter FSRs also serve the LOBs. The RF Building is provided with a “hot box” located on the outside of the building wall.
- Fire Department Connections (FDC) are located on the Service Building exterior walls and on the outside exterior wall of the Storage Ring Building. The latter FDCs also serve the LOBs. The RF Building and Injection Buildings are provided with their own FDC located on the outside of the building wall.
- Hydrants are located between 40 feet and 300 feet from the FDCs.
- A dual water service fed wet pipe automatic sprinkler system with flow alarms serves the Storage Ring Building. The LOBs and the RF Building have a single water service fed automatic sprinkler system. A single water service fed wet pipe automatic sprinkler system with flow alarms serves the Booster Ring/Linac Zone.
- An adequate water source is provided to supply sprinkler protection for NSLS–II. The underground mains are provided with sectional control valves and provide a loop around the NSLS–II complex, as well as in the “infield” of the Ring Building.
- Each Storage Ring Building pentant, each Service Building and each Lab Office Building has a fire alarm panel. The RF Building has a fire alarm panel that also serves the Compressor Building and the CTB. The Injection Building also has a fire alarm panel making a total of 17.
- Automatic audio–visual alarm devices are provided throughout. Manual pull stations for fire alarms are installed at all building exits and at all exit stairs.

- Highly Sensitive Smoke Detection (HSSD) systems are installed in the Storage Ring tunnel, above the mezzanine and in the experimental hall. The LOBs have smoke detectors in the laboratories in inside the air supply ducts. The RF Building has an HSSD system in the computer room and duct smoke detectors for the rest of the building. HSSD systems are installed in the Linac enclosure/Klystron Gallery area, the Injection Building main floor and in the Booster enclosure.
- Fire extinguishers are installed throughout the NSLS–II facility.
- Beamline hutches will have strobe alarms on or near their external walls and smoke detectors inside. The need for sprinkler protection inside the hutches will be based on the results of the Experimental Safety Reviews (ESR).

3.9 Radiation Protection Systems

Radiation exposure to staff, users and the public is limited by shielding, PPS, engineered controls and administrative controls. Potential sources include direct exposure to the beam, radiation created by high energy electron interactions, x–rays generated by High voltage (HV) devices, radioactive sources and residual radioactivity. The SBMS provides the standards that are used to evaluate and mitigate these potential hazards to acceptable levels.

3.9.1 NSLS-II Shielding Policy

All shielding at NSLS–II facilities is designed to meet the requirements of this policy. The primary goal of the shielding policy is to reduce anticipated exposure levels to below the 10CFR835 requirements, the BNL Radiological Control Manual Program requirements and action levels and be ALARA. It should be understood that reduction of radiation exposure in potentially occupied areas may often combine passive shielding with other control measures allowed under 10 CFR Part 835 such as; establishment of posted radiological areas, reduced occupancy requirements, administrative procedures or engineered systems. The primary objectives for achieving the NSLS-II Shielding Policy are as follows:

- Annual site boundary ambient dose is less than 5 mrem.
- Annual on–site ambient dose shall not exceed 25 mrem to any individual not involved in the operation of the facility.
- For areas continuously occupied by an individual involved in the operation of the facility, the maximum ambient dose rate under normal operating conditions is ALARA and shall be less than 0.5 mrem (based on an occupancy of 2000 hrs/year) in an hour or one rem in a year. It is understood that occupancy restrictions may be necessary when ambient dose rates are > 0.5 mrem/h during normal operation.
- Ambient dose rates where occupancy is not continuous shall be ALARA, but shall not exceed 1 rem whole body or 3 rem to the lens of the eye or 10 rem to any organ in one year.
- Shielding and other controls for areas where access is not controlled for radiological purposes will be designed so that the ambient dose in an unplanned abnormal condition will not exceed 20 mrem during the fault condition. The use of administrative controls or engineered interlock systems in meeting this objective is allowable but must be fully defined and must be consistent with other guidance provided in this policy.
- Shielding and other controls for areas where access is controlled for radiological purposes will be designed so that the ambient dose in an unplanned abnormal condition shall not exceed 100 mrem during the fault condition. The use of administrative controls or engineered interlock systems in meeting this objective is allowable but must be fully defined and must be consistent with other guidance provided in this policy.

Further discussion of the Shielding Policy, including implementation guidance is included in appendix 30.

3.9.1.1 Accelerator Shielding

The Linac, Booster and Storage Ring shielding has been designed to include two primary components, bulk and supplemental shields. The bulk shielding was designed to reduce the external radiation for routine operational losses to less than 0.5 mrem/hr (see Appendix 4). The bulk shielding is primarily poured in place light concrete with a density of 2.35 g/cc. The injection region of the Storage Ring will have higher routine losses and a section of the outside wall was consequently constructed of heavy concrete with a density of 3.8 g/cc. The bulk shielding defines the accelerator enclosures and with the associated gates and barriers prevents personnel from access to the enclosure when radiation hazards are present. The bulk shielding performs the primary shielding function for most areas around the accelerators. Supplemental shields augment the bulk shields in regions of high beam loss.

The bulk shielding design must meet several functional criteria. The most important aspect is it provides the basis for the shielding design to satisfy the NSLS-II shielding policy. It must accommodate access to the machine components including sufficient space on the inside aisle way to move spare magnets into the ring. The outside wall must accommodate the installation of the Beamlines, which are constructed for the scientific research. The enclosure must have entrances/exits for personnel servicing the equipment, installation of spares or new equipment and satisfy life–safety code for emergency egress.

The bulk shielding is very repetitive. Therefore a few simple examples focusing on the Storage Ring will illustrate the bulk and supplemental shields. There are five service buildings that interface with the Storage Ring interior wall. Each service building has a labyrinth to allow personnel and equipment into the Storage Ring enclosure. Figure 3.12 displays the architectural drawing of the bulk shielding between the Storage Ring and one of the service buildings.

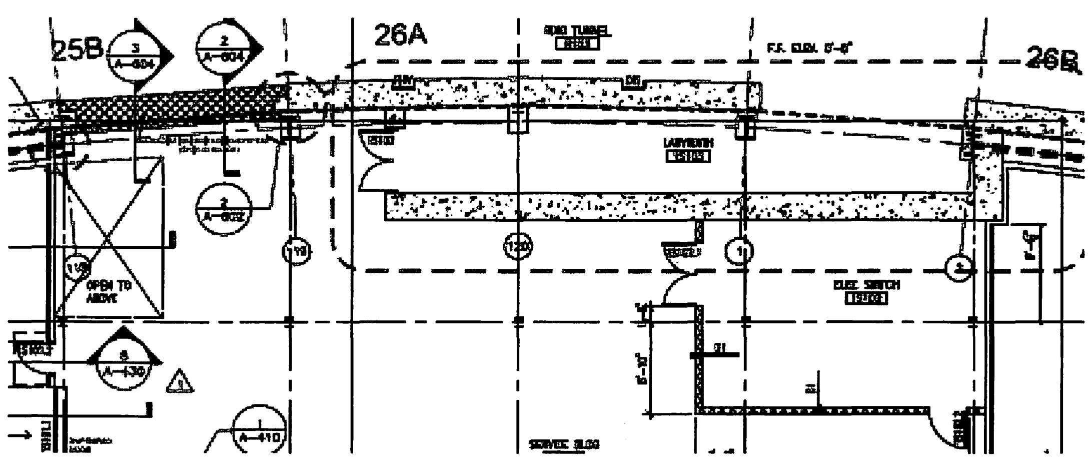


FIGURE 3.12

3.12 PLAN VIEW OF THE INTERFACE BETWEEN THE STORAGE RING ENCLOSURE AND ONE OF THE SERVICE BUILDINGS FROM DRAWING A101–B

Figure 3.12 shows a construction portal that has been sealed with heavy concrete (noted in cross-hatched section), the labyrinth and other Storage Ring interior walls. The analysis in chapter 4 will demonstrate that these areas are expected to meet the shielding policy. The other four service buildings have the identical arrangements.

A section of the exterior wall of the Storage Ring is shown in Figure 3.13. As a means to reduce construction costs the walls have a tapered thickness as the distance between the beam and the exterior wall increases. . Each side wall has a door portal. Some have been closed with shielding blocks but most have a sliding door with interlocks. The forward wall is designed for the installation of the Beamlines where the users will conduct their research.

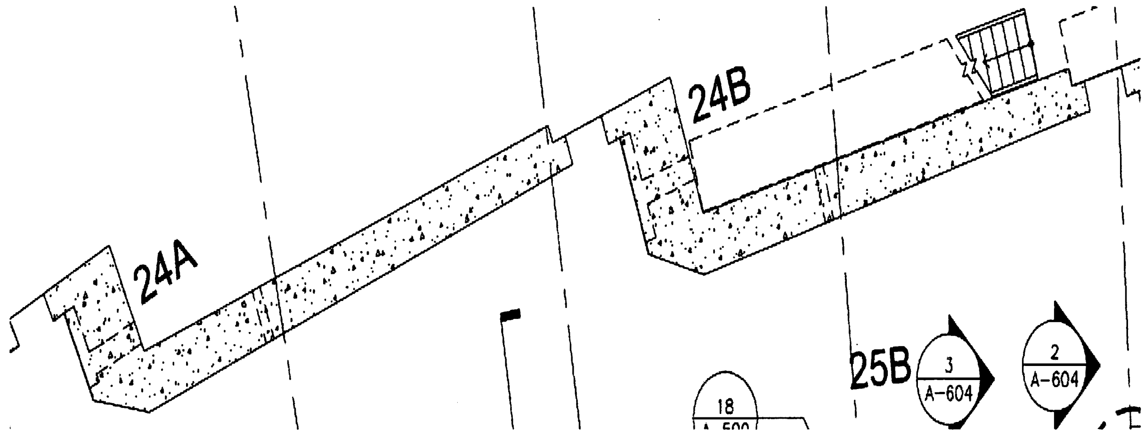


FIGURE 3.13
3.13 THE OUTSIDE WALLS FOR CELL 24
The dashed lines in the concrete indicate cutouts and penetrations. The penetrations in the side wall are for utilities. The cut–out in the front walls are for Lead (Pb) Shielding and the Beam Pipe for a Beamline. The Side Doors are not shown. The Stairs to the Storage Ring Mezzanine are shown on the top right.

The roof of the Storage Ring is an equipment mezzanine. The floor space on the outside of the bulk shielding is reserved for Beamlines. The power supplies, electronics and other Storage Ring support equipment are distributed around the Storage Ring on the roof. The roof has a series of small penetrations that are three–legged labyrinths to allow services into the Storage Ring enclosure from the equipment. Figure 3.14 shows the roof for cell 24.

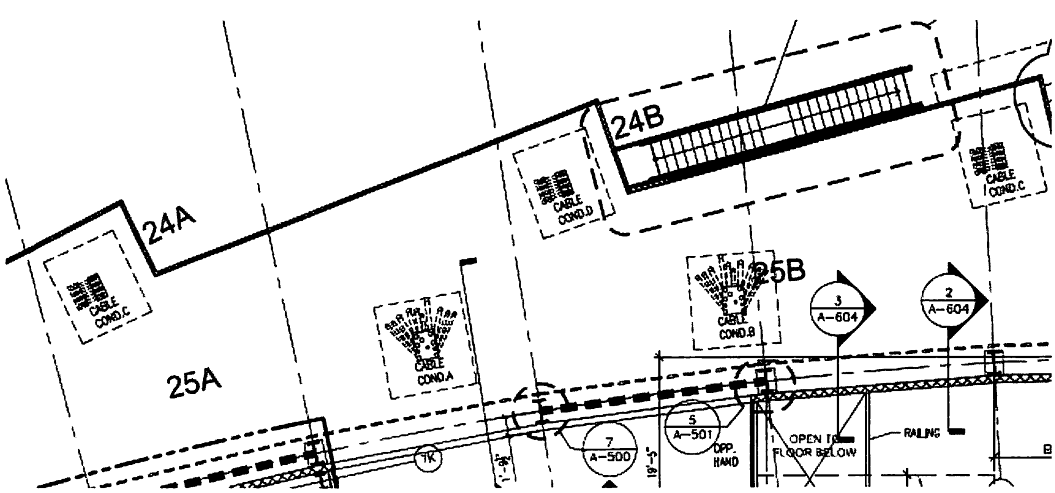


FIGURE 3.14

3.14 AE DRAWING SHOWING THE LOCATION OF THE UTILITY PENETRATIONS THROUGH THE STORAGE RING ROOF

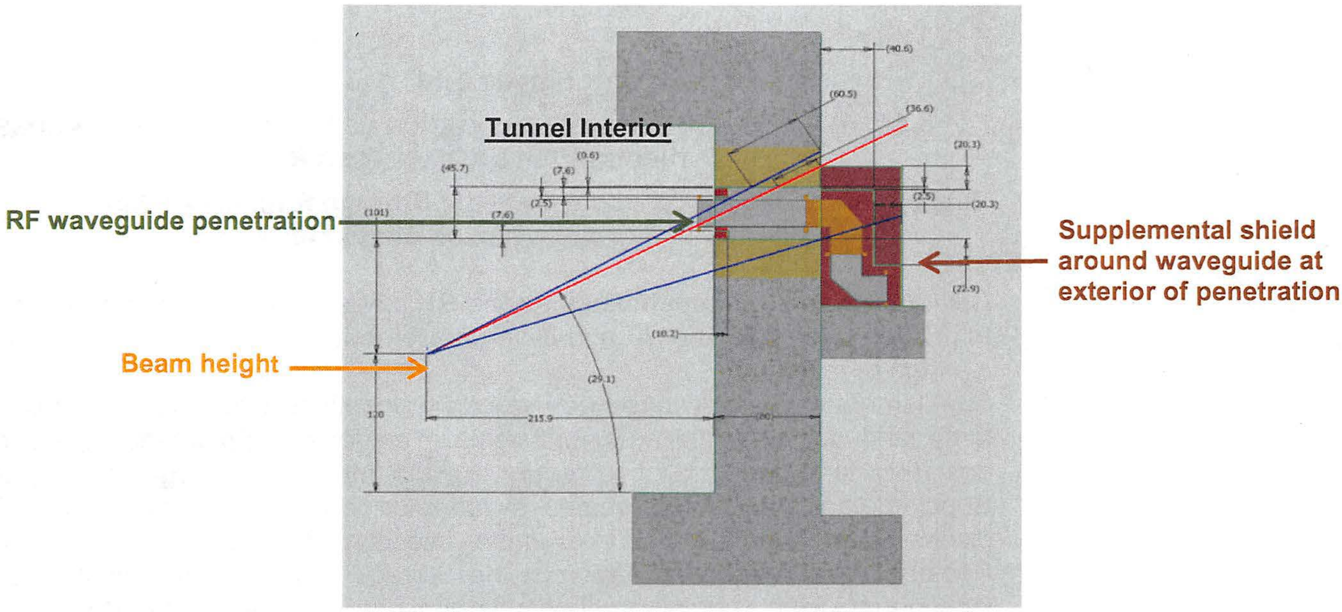
A group of penetrations occur over the Storage Ring Magnets and another group over the Beamline

Cell 24 has a set of penetrations for the RF cavity. These penetrations are used to provide utilities for the RF and have supplemental shielding to reduce potential leakage of radiation.

Supplemental shielding has been placed in locations where routine losses are large and concrete alone is unsuitable. The local supplemental shielding is designed to reduce radiation levels to ≤0.5 mrem/h for large routine losses Supplemental shielding estimates based on normal beam losses were initially discussed in Appendix 5 For example, injection and extraction regions in the Booster and the injection region in the Storage Ring are good examples of a location requiring supplemental shields because of higher losses during normal operation. Local shields are also used for penetrations through the bulk shields for cable trays or RF wave guides. The local shielding is primarily located inside the accelerator enclosures as close to the beam loss location as practicable. In addition to providing additional shielding transverse to the beam loss point, local shielding is often used to reduce the forward bremsstrahlung dose which is dominated by gamma radiation. Lead is typically the material of choice for the supplemental shielding, but other materials have been used (e.g. polyethylene for neutrons, steel)

In addition to using supplemental shields to shield high normal losses; locations have been identified where abnormal operating conditions (e.g. beam mis–steered by improperly set magnets) can cause large beam losses and create unacceptable radiation levels outside the bulk shielding. Regions downstream of dipole magnets in transfer lines are a good example of this type of local shield. Detailed reports describing the location and the basis of supplemental shields for the Linac, Booster and Storage Ring are provided in Appendices 6a, 6b and 6c. A few examples of the supplemental shields are shown in Figures 3.15 to Figure 3.17.

The design of the shielding for the RF waveguide penetration is shown in Figure 3.15. This penetration is one of the larger of this type and the associated supplemental shield is very important in mitigating the potential dose from beam losses within the Storage Ring. The outside of the penetration is in the RF building and is located on the inside of the ring at an elevation of approximately eight feet. The penetration has large dimensions for a 80 cm thick wall .The RF waveguide has a 90 degree turn down after it exits the concrete wall allowing shielding to be placed around the penetration exit.



3.15 Supplemental Shield for RF Waveguide

Figure 3.15 displays a portion of the Booster to Storage Ring transfer line, the supplemental shielding and the Storage Ring magnets. The dipoles B3 and B4 have supplemental shields that are intended to reduce the potential radiation due to events where the beam is miss–steered. The supplemental shield downstream of B4 is for operational losses on the energy slits in the transport line.

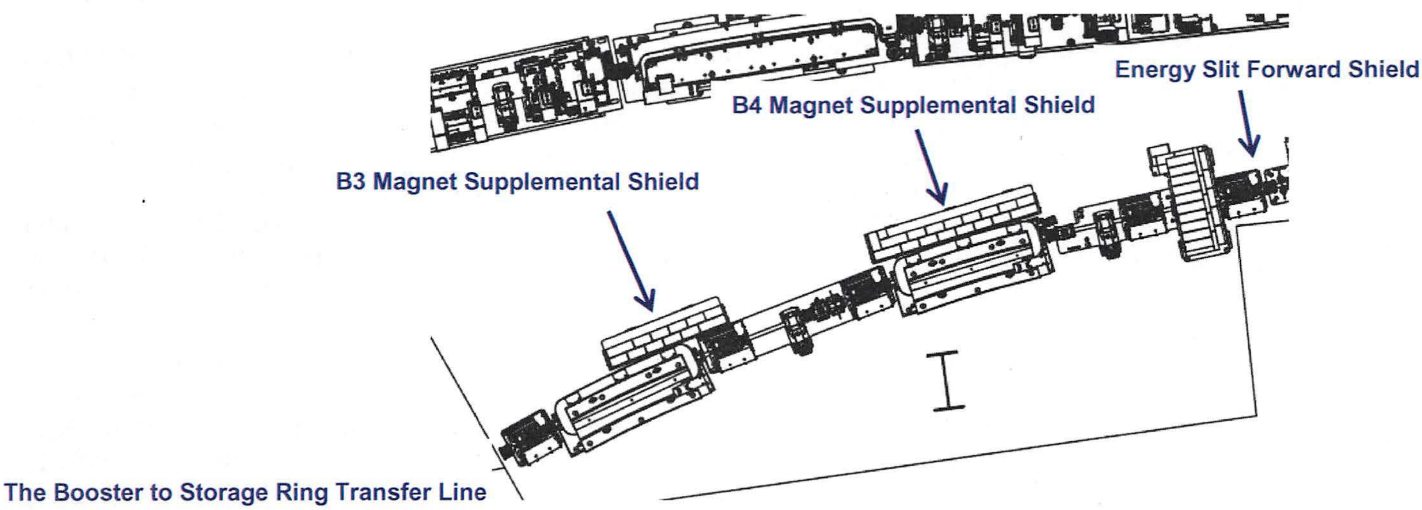


FIGURE 3.16

3.16 B3 and B4 with their associated Shadow Shields

The injection region of the Storage Ring is expected to have large operational losses. The side shield to reduce dose to the exterior Storage Ring wall is shown in Figure 3.13.

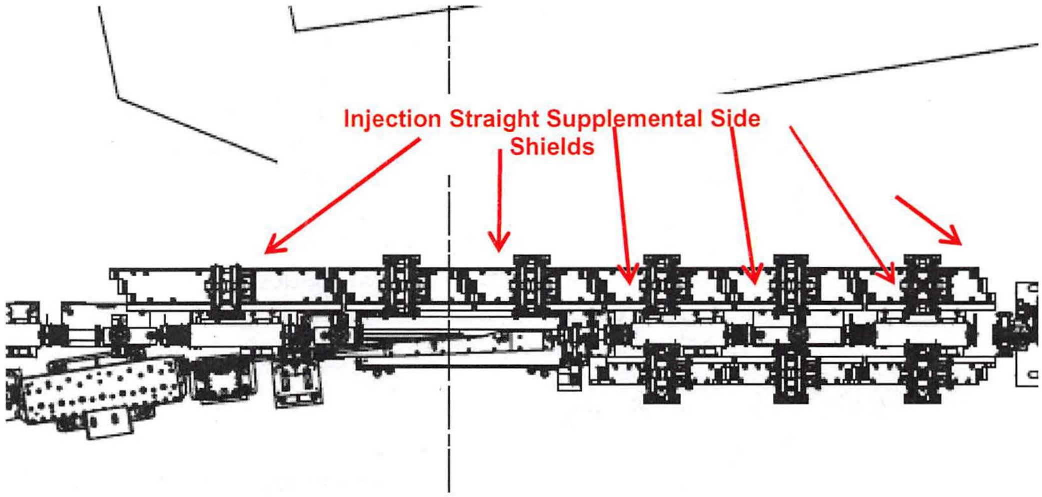


FIGURE 3.17
3.17 The Injection Shielding for Operational Losses and Mis–steering Events

During commissioning, the adequacy of the shielding was evaluated by a series of Fault Studies and is discussed later in Section 4.15. The final configuration of the facility supplemental shields was determined using the results of these studies. Supplemental shielding changes will be managed through configuration control to assure their integrity including USID process for changes.

3.9.2 Radiation Controls

Radiation levels measured during commissioning activities and Fault Studies have been used to determine the postings and other area controls required to meet Part 835 and BNL requirements.

During early phases of commissioning activities including establishing full circulation and optimization of beam orbit, radiation levels on the mezzanine and around the Storage Ring enclosure were routinely found to be detectable but < 1 mR/hr Injection at low current and frequency was key to maintaining radiation levels low. Radiological survey data collected during Fault Studies performed during these low energy periods showed the shielding to be effective at maintaining dose rates < 2 mR/hr. The one exception is the seams at the movable doors located at the ID sections of the ratchet wall. Dose rates at these locations ranged from 5–7 mR/hr. Extrapolating these results to maximum expected injection energies (i.e.,15 nC/s) yields dose rates of 315 mR/hr. Since actual injection charges are only expected to be half of the maximum and since these areas are protected with Area Radiation Monitors, the dose rates are consistent with the NSLS-II Shielding Policy. The placement of the ARM detectors will be optimized to ensure these areas are fully protected against such faults.

It is anticipated during routine operations that portions of all areas immediately adjacent to the accelerators in the Injection Building, Ring Building experimental floor and mezzanine will be posted as a radiological Controlled Area. In addition, portions of the first and second floors of the 5 Service Buildings and the interior courtyard and its entrance tunnel beneath the Storage Ring may also be posted. All postings will be as required by the BNL Radiological Control Manual and based on radiological surveys.

Personnel entering all radiological Controlled Areas shall be trained as specified in the BNL Radiological Control Manual and wear if required, TLDs. During initial operations with stored beam currents routinely above 25 mA, the experimental floor, accelerator enclosures and adjoining areas will be posted as TLD areas. As operational experience is gained and dosimetry data collected, these requirements will be reviewed and modified with concurrence of the Radiological Controls Division. Only personnel with appropriate training and authorization shall be allowed access to the Controlled Areas during commissioning unless escorted by qualified, trained personnel. During maintenance periods or other periods without operation with beam, areas may be down-posted.

Areas within the Controlled Areas and the accelerator enclosures may have additional postings, such as Radioactive Material Areas and Radiation Areas, as required. A Radiological Work Permit shall be issued by Radiological Control Division personnel as required in accordance with the criteria in the BNL Radiological Control Manual. Access to the accelerator enclosures during operation shall be controlled by the PPS interlocks described in Section 3.10.4 below.

3.9.3 Radiation Monitoring

Radiological Control Personnel

A major activity during commissioning was confirmation of the adequacy of the shielding. For routine operations, a radiation monitoring program has been established for the Controlled and non–Controlled Areas to protect personnel and to assure that all doses are kept ALARA. Radiation surveys are performed by Radiological Control Technicians (RCTs) from the Radiological Control Division (RCD) in accordance with approved procedures. RCD personnel work in cooperation with NSLS-II ESH staff to ensure that areas are properly posted and have radiological surveys conducted periodically to ensure that personnel in areas adjacent to the Storage Ring are appropriately protected. As discussed in Section 4.15, Fault Studies conducted during the commissioning have demonstrated that these areas are adequately protected and require no additional controls.

Passive Area Monitors

In addition to active monitoring of the experimental floor, RCD and NSLS-II have established a set of passive area monitors using TLDs to record the integrated dose to areas around the Storage Ring. This monitoring program provides important data for determining the final configuration of area postings and controls. The goal of the area monitoring program is a retrospective verification of the radiological survey program that insures the appropriate posting and control program. The routine surveys conducted by the RCTs will provide additional evidence that the areas are properly managed for radiation exposure.

Active Area Monitors

Active–interlocking radiation monitors are an important component of the radiation monitoring system. Fail–safe radiation monitors sensitive to both neutrons and photons are located around the facility. The monitors provide visual and audible alarms both locally and in the Control Room. Personnel working near these monitors receive training regarding their response to alarms. The monitors are mounted at approximately 30 locations around the external Storage Ring shield wall near anticipated loss points. In addition, each FOE will have a monitor mounted on the wall. Seven monitors installed in the Injector Service Area (ISA) as part of the Booster system will monitor for radiation levels providing protection for personnel in the ISA and associated areas. The klystron gallery will have three monitors. Each monitor has two alarms that annunciate locally and in the Control Room. The low level radiation alarm provides an early warning of elevated radiation levels and a high level radiation alarm will interlock further injection when a pre–

set threshold is exceeded. The initial specification of the Storage Ring radiation monitors can be found in Appendix 7.

The locations of the active radiation monitors have been established based on the results of the Fault Studies and operational experience during commissioning. It is expected that some locations of the monitors and the total number of monitors required for a fully operating facility will change over time as the machine matures and as operating patterns change. These monitors and their locations are subject to a formal configuration control program.

Control Room Monitors

Accelerator operators have a set of additional instrumentation that provides information relating to the performance of the accelerators that may impact the dose rates exterior to the shielding. The electron beam charge transported into the Storage Ring and total stored charge are monitored by the operators. Although the instrumentation systems providing this information are not credited controls, they do provide information for the operators to detect non–optimal operating conditions and permit diagnosis and correction of conditions which could result in beam losses creating elevated radiation levels. The operators are an important part of the safe operation of the Storage Ring. An experienced and trained operator on duty is a credited control identified in the ASE.

The charge per injection pulse being transported from Booster into the Storage Ring is measured by an ICT, located in the Booster to Storage Ring Transport line. The total charge stored in Storage Ring is measured by a DCCT located in the Storage Ring. A comparison of the injection pulse charge in the transport line to the change in DCCT charge provides a measure of Storage Ring injection efficiency. The rate of charge delivered by the Booster is a parameter of interest to Accelerator Operators, since beam losses at high charge rates can result in elevated radiation levels. All devices including the ICTs and DCCTs have visual displays in the Control Rooms. The NSLS-II Storage Ring (SR) design calls for the maximum (nominal) circulating current of 500 mA. An operational limit for circulating current in the storage ring has been established of 550 mA (providing a 10% margin on top of the nominal value) The operators are charged with not exceeding this limit, and receive specific training focused on the operating limits on the beam energy and intensity (circulating current).

In addition, two engineering systems provide additional back-up to the operators for defense in depth. These engineering systems include:

A) DCCT limiter. This is a software interlock that disables the linac gun by turning off High Voltage in the case if accumulated SR current will be equal to 550 mA in operations. This system is operational and successfully tested during SR commissioning in April 2014.

B) Storage Ring EPS circuit. This circuit limits circulating beam current and orbit to prevent damage to the vacuum chambers from synchrotron and ID radiation. The EPS system will disable the linac gun by turning off HV on the gun deck if the SR DCCT current equals to a present limit, which will be always below 550 mA.

The ICT in the LtB transport line has been upgraded and is designated as a “safety–rated” device. It is identified as a credited control in the Operations ASE and it or its approved alternative will be in operation when the Linac runs. This device will interlock Linac injection through the Linac PPS if beam current exceeds an established threshold.

Additional description of radiological credited engineered and administrative controls is provided in Section 4.15.3 and Section 5.

3.9.4 Personnel Protection System

NSLS–II produces intense radiation fields within the accelerator enclosures. This section describes the design for the NSLS–II Personnel Protection System (PPS). An operational PPS for radiation hazards is an engineered credited control. Testing and maintenance of PPS for radiation hazards are credited control supports.

The PPS is designed to meet the following requirements:

Document Number	**Document Title**
NFPA 70	National Electrical Code
BNL SBMS subject area	Interlock Safety for High Risk Hazard

In addition, the following documents were used in developing the PPS specifications:

ANSI/ISA 84.00.01, 2004 (IEC 61511 modified)	Functional Safety: Safety Instrumented Systems for the Process Sector
	Interlock System Failure Rate Report, National Synchrotron Light Source II, Brookhaven National Laboratory, Rev. A, 5/5/10
BNL Radcon Manual	Appendix 3A, section 4e: Bypassing the Security System
DOE 420.2B	Safety of Accelerator Facilities

The NSLS–II PPS uses two independent chains of PLCs and sensors to provide the necessary protective functions. The guidance in the ANSI/ISA Standard 84 provides approach techniques that if followed aids in providing a system with a low failure rate to unsafe conditions and increased system up–time. The NSLS–II PPS is designed with safety rated PLCs being utilized in two independent chains. Initially all safety functions have been incorporated into each chain, although some functions may not be required to be redundant. One of the most important aspects of a safety system is to prevent inadvertent changes and to carefully control any changes.

The interface to the PPS is tightly controlled through limited physical access, locked cabinets and engineering controls. The safety PLCs are write–protected and do not directly interface with the control system. There is an intermediate PLC that is read–only that transfers the safety system data and does not allow any writing to the safety PLCs. In addition to this, the control system has its own cyber security protection plan and does not interface with the BNL campus network directly.

The initial design of the system has been overseen by the Accelerator Division and the accelerator safety systems group which is part of the Accelerator Division. Independent review has been initially performed by the Interlock Coordination Group. Since the formation of the NSLS-II Radiation Safety Committee, independent review has been performed by this committee. Modifications to the initial system are configuration managed under NSLS-II standard operating procedure. Modifications to the PPS are requested through a Technical Change Request (TCR). The design of PPS modification is then submitted to the RSC for independent review. After USI screening the Technical Authority approves the design.

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

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

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

The PPS provides a means to support a thorough and systematic process to ensure that no personnel are inside an enclosure when the potential for radiation is activated. To secure an enclosure prior to introduction of beam (or RF), a search of the area is first performed by a qualified staff member(s). "Search boxes" inside the enclosure must be visited in proper sequence as part of the search. The search boxes are strategically placed to ensure that during the search all parts of the enclosure are either visible or visited by the search personnel and no person is left behind inside the area. The search is completed with the closing of the enclosure door, and the actuation of the Search Complete button.

Once the search process is completed, the PPS subsystem starts a beacon and audio signal inside the secured area, warning all personnel that a radiation hazard is imminent. This signal lasts a minimum of 30 seconds after the door is closed and the Search Complete button pressed. The function of the beacon and audio signal is to alert any personnel inside the secured area who have been overlooked by the search person. Distinct emergency shutdown buttons are placed inside the enclosure to instantly remove or prevent the radiation hazard when pressed.

All parameters of the PPS are available for monitoring in the accelerator Control Rooms through the EPICS control system. Changes of device status in the PLC system are recorded in databases. These databases can be used to provide analysis on system reliability.

Linac

The Linac PPS provides area security for the Linac vault and interfaces with the Booster and the Storage Ring PPS.

To immediately stop the production of radiation, AC power to the modulator and gun power supplies are removed simultaneously. This is accomplished through the use of AC contactors, one for chain A and one for chain B.

Two of the three critical devices which control the injection from the Linac to the Booster are: a bending magnet (LB–B2) and a safety shutter (LB–SS) located downstream of the bending magnet. The LB–SS safety shutter has three switches for the A chain to monitor the shutter position. Two switches monitor the closed position and one monitors the open position. The LB–B2 bending magnet is redundantly monitored for current by chain B. When the magnet is not powered (i.e., Off) it prevents electrons from entering the Booster tunnel area and provides the safety function. When Off the beam is delivered to a beam dump. The status of these critical devices is monitored through the PPS. In addition, the LB–B1 dipole is monitored and interlocked to the electron gun to ensure that whenever the transport to the Booster is enabled that the electron energy is within the specified range. The third device is an Accumulating Charge Monitor Interlock (ACMI) which prevents injection of a maximum electron charge integrated over an hour exceeding 360 uC.

Access to the Linac enclosure requires that the power to the Linac gun and the modulators is off. Power to these devices cannot be turned on unless the Linac enclosure has been searched and secured as described above. Once secured, opening the doors to the enclosure requires that the power to these devices be turned off before the Control Room can authorize a release to open the door. If the door is forced open while the enclosure is secured, the PPS interlocks the power to the gun and modulators to "Off". All Linac doors are monitored with four switches, two each for chains A and B.

The two area radiation monitors in the Klystron Gallery are part of PPS A chain logic and inhibit the power to the Linac gun and RF if preset trip levels are exceeded.

The Linac enclosure must be searched and secured before the Linac electron gun can be turned on and accelerating structures can be powered with RF.

Safety functions as implemented in the Linac PPS are described in Table 3.10

TABLE 3.10

3.10 LINAC SAFETY FUNCTIONS

ID	SAFETY FUNCTION DESCRIPTION
SF1	Prevent electron beam in Linac when Booster is occupied or when current for B1 is not in specified range
SF2	Turn off Linac electron gun upon alarm of Linac ARMs
SF3	Shut down Linac–critical devices when Linac–to–Booster injection–critical devices are open and Booster ring security is breached
SF4	Shut off interlocked devices on activation of an ESTOP
SF5	Terminate search on activation of an ESTOP
SF6	Support the search and securing of the Linac prior to introduction of radiation.
SF7	Prevent unauthorized access to searched areas of the Linac tunnel
SF8	Provide visual indications of secured and unsecured conditions to the searched areas
SF9	Provide audible warning of pending unsafe status of Linac enclosure
SF10	Inhibit entry to Linac if redundant chains do not agree with each other on status of critical device safety functions
SF11	Prevent injection of an integrated electron charge of over 360 uC in an hour from Linac to Booster

Booster

The Booster PPS provides area security for the Booster tunnel and interface with the Linac and the Storage Ring PPS.

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

The active interlocked area radiation monitors around the Booster tunnel shield wall are monitored by the A chain logic and inhibit the gun AC power supply which terminates injection into the Booster if ARMs preset trip levels are exceeded.

The BPPS must be fully functional when the Booster IOT transmitter is being tested with RF; in this case the Booster enclosure has been searched and secured.

The BPPS also monitors the current in the BtS dipoles and ensures that the energy of the electrons transported to the SR is within predetermined range.

The BPPS requires that Storage Ring Pentants 1 and 2 are searched and secured before injection from Linac into the Booster is allowed. Access to the Storage Ring Pentants 3 –5 is permitted during Booster operations if the Booster to Storage Ring Safety shutter and B2 dipole magnet power supply are in the safe state. These PPS controls require that the Storage Ring be secured prior to permitting the safety shutter to be opened and the dipole power supply be energized. Forced entry into the Storage Ring will drop these critical devices and shut down the injection system.

During Storage Ring operations in the decay mode, once the Storage Ring is filled, access to the Booster enclosure may be allowed provided fault studies conducted during Storage

Ring commissioning show radiation levels in the Booster enclosure to be within acceptable levels. These fault studies will be performed during the later stages of Storage Ring commissioning once 25 mA of stored beam is documented and well controlled.
During Storage Ring operations in the Top-Off mode; the maximum electron charge injected into the Storage Ring shall not exceed 2.7 uC integrated over the previous hour as measured by an Accumulating Charge Monitor Interlock (ACMI) (representing a maximum rate of 45 nC/min x 60 minutes).

As described above, operation of the Linac requires the Booster to be secured. In the future and pending final analysis of all Fault Studies, access to the Booster may be allowed during Linac operation providing the LB–B2 is off and LB–SS is closed. Similarly, future access to the Booster may be permissible during storage of accumulated beam in the Storage Ring provided BS–B2 is off and BS–SS is closed.
Safety functions as implemented in the Booster PPS are described in Table 3.11.

TABLE 3.11

3.11 BOOSTER SAFETY FUNCTIONS

ID	SAFETY FUNCTION DESCRIPTION
SF1	Prevent electron beam transport from Booster to Storage Ring when occupied
SF2	Terminate injection into Booster upon alarm of Booster area radiation monitors
SF3	Shut down Booster interlocked devices when open for injection into Storage Ring and Storage Ring security is breached
SF4	Shut off interlocked devices on activation of an ESTOP
SF5	Terminate search on activation of an ESTOP
SF6	Support the search and securing of the Booster tunnel prior to introduction of radiation
SF7	Prevent unauthorized access to searched areas of the Booster tunnel
SF8	Provide visual indications of secured and unsecured conditions to the searched areas
SF9	Provide audible warning of pending unsafe status of Booster tunnel
SF10	Support the safe operation of the dipole magnets for testing purposes while inhibiting injection into the Booster tunnel
SF11	Inhibit entry to Booster tunnel if redundant chains do not agree with each other on status of safety functions
SF12	Terminate injection to Storage Ring if energy of B1 and B2 bending magnets are out of a predetermined current range
SF13	Terminate injection into Storage Ring if energy in range signal from Storage Ring energy limiter is out of range
SF14	Allow beam in Booster ring with no delivery to Storage Ring when Pentant 1 and Pentant 2 only are secured
SF15	Prevent injection of an integrated electron charge of over 2.7 uC in an hour from Booster to Storage Ring (while in Top Off mode).

Storage Ring

The Storage Ring Personnel Protection System (SPPS) provides area security for Pentants 1 through 5 of the Storage Ring, including the front–ends, and interfaces with the Linac, Booster, and beamlines PPS.
The activation of emergency stop buttons removes the permission to inject beam and removes stored beam. The stored beam is removed by opening an AC contactor for each power supply for the main dipole magnets. In addition, AC power to the Storage Ring RF amplifiers is removed via contactors in the AC. Both the RF and dipoles are shutoff by each of the PPS logic chains, referred to as chain A and chain B. The operators must enter the area and determine the cause of emergency stop activation and reset the button if appropriate.

The RF cavity is located in pentant 1 and can be operated provided the PPS detects the correct conditions. The RF system has a test mode that allows the cavity to be operated provided that the test mode is selected, pentants 1 and 5 have been secured, the emergency stop buttons in pentants 1 and 5 are functional, and the RF load switch is properly set for either the waveguide in place or dummy load in place. This mode of operation allows testing and conditioning of the RF cavity while other sections of the Storage Ring are occupied. The RF system and cavity can also be operated if all pentants are secured.

The PPS logic allows for a test mode of the ring magnets. The Storage Ring dipole power supply is allowed to operate if the magnet test mode is selected and the emergency stops are okay. The test mode sends a signal to the Booster PPS which requires the Storage Ring critical devices to be in the safe state.

Personnel are allowed in the Storage Ring when the Booster operates with beam except for Pentants 1 and 2. These pentants must be searched and secured for the Booster PPS to be satisfied. Access to the other pentants is allowable with Booster operational provided the two critical devices in the injection line from the Booster to Storage Ring are in the safe state. Booster bending magnet (BS–B2) and a Booster safety shutter located downstream of the bending magnet are the critical devices. The Booster–to–Storage Ring transport safety shutter (BS–SS) has three switches for the A chain to monitor the shutter position. Two switches monitor the closed position and one monitors the open position. The shutter safe state for the Storage Ring is the closed position. The bending magnet upstream of the safety shutter is redundantly monitored for current by chain B. When the magnet is not powered (i.e. OFF) it prevents electrons from entering the Storage Ring tunnel area and provides the safety function. The B2 bending magnet bends the beam 8.8 degrees and is more than 10 meters from the shielding wall between the Booster and Storage Ring. Since Pentants 1 and 2 secured are one of the conditions required by the PPS to turn Booster on, a failure of the BS–B2 interlock does not create a risk of excessive dose to personnel. When BS–B2 is OFF the beam is delivered to the Booster beam dump. The status of these critical devices is monitored through the Booster PPS.

The Storage Ring PPS also monitors the currents in the ring magnets in two ways. The PPS system monitors currents in select BTS dipole magnets to assure that energy of the injected beam is above ASE minimum threshold. If the currents in the dipoles are not within bounds during storage ring injection, then the Booster extraction AC septum and the storage ring AC septum triggers are inhibited via the PPS. This change in critical devices is part of the transition to incorporate Top-Off while also applying during decay mode operations. The second window monitors the energy of the stored beam for compliance with the ASE specified limit for stored beam. The ring RF and magnet power supply is turned off if this limit is reached. The PPS also monitors the status of the beam line safety shutters and requires that they be closed at the time of injection.

In Top-Off mode the Storage Ring relies upon specific controls for protection against unacceptable radiation hazards. These include: designated Credited Apertures, required Interlocks, minimum specified response times, and designated Critical Devices. Descriptions of these items may be found in Section 4.15.10 – Radiological Hazards Associated with Top-Off Operations, with detailed information contained in PS-C-ASD-RSI-001, “Top-Off Safety Requirements for the National Synchrotron Light Source II”.

The Storage Ring is divided into 5 separately searchable pentants. This allows access to individual sections of the Storage Ring and reduces the search time. There is no controlled access; each pentant is brought to the ground state and completely re–searched when access is required. Each pentant is controlled by its own redundant PLCs. This allows changes in programming to be made without having to re–test the whole ring at once. The PPS also interfaces with the experimental end stations as described below.

Access to all Storage Ring tunnel pentants requires that the power to the RF system and dipole power supplies must be off, and the Booster–to–Storage Ring critical devices must be in a safe state. In addition, access to Pentant 1–2 requires that the Booster be unsecured.

The active interlocked area radiation monitors around the Storage Ring outer shield wall are monitored by the A chain logic and inhibit the gun AC power supply which terminates injection if ARMs preset trip levels are exceeded.

The operators will respond to the radiation monitor high and low alarms using an approved procedure.

Safety functions as implemented in the Storage Ring PPS are described in Table 3.12.

TABLE 3.12

3.12 STORAGE RING/FRONT END SAFETY FUNCTIONS

ID	SAFETY FUNCTION DESCRIPTION
SF1	Prevent electron beam transport from Booster to Storage Ring when occupied
SF2	Prevent Electron beam transport from Storage Ring to beam line FOE/EESE
SF3	Prevent Photon beam transport from Storage Ring to FOE/EESE when occupied
SF4	Shut down Booster interlocked devices when open for injection into Storage Ring and FOE/EESE security is breached
SF5	Shut off interlocked devices on activation of an ESTOP
SF6	Terminate search on activation of an ESTOP
SF7	Support the search and securing of the Storage Ring prior to introduction of radiation
SF8	Prevent unauthorized access to searched areas of the Storage Ring
SF9	Provide visual indications of secured and unsecured conditions to the secured areas
SF10	Provide audible warning of pending unsafe status of Storage Ring enclosure
SF11	Support the safe operation of RF cavities for testing proposes while inhibiting injection into the Storage Ring
SF12	Terminate injection into the Storage Ring upon alarm of area radiation monitors
SF13	Close safety shutters on alarm of FOE radiation monitor and shut down beam if front end shutter does not close in specified time
SF14	Provide physical separation of the pentants and allow passage for emergency egress
SF15	Provide lock out function for beam lines to prevent operation of safety shutter and ignore signals from FOE/EPPS while monitoring safety shutter position
SF16	Monitor position of the safety shutters relative to the photon shutter to ensure safety shutter integrity
SF17	Close all beam line safety shutters at the time of injection
SF18	Shut off interlocked devices when FOE/EESE is breached while beam is being delivered to an enclosure or if an emergency shutdown is pressed with the FOE/EESE secured
SF19	Inhibit entry to FOE/EESE if redundant chains do not agree with each other on status of safety functions
SF20	Shut down the RF if Storage Ring energy exceeds the ASE limit, implemented by measuring the main dipole current
SF21	Shut down injection into the Storage Ring if Storage Ring dipole is not set to a current corresponding to 3 GeV +/– 2%
SF22	Provide unique permits to Booster PPS when P1 and P2 are secured for Booster operation with beam
SF23	In Top-Off mode TOSS will prevent transfer of electron beam past the apertures in the front-end and into the First Optics Enclosure (FOE) on the experiment floor.

Beamlines

NSLS–II will produce intense light ranging from IR, UV, and hard x–rays. Beamlines are designed to use either radiation sources from bending magnet or insertion devices installed in the straight sections of the Storage Ring. Beamlines may have more than one experimental enclosure along the Beamline for every port. These enclosures may be in use in parallel or sequentially.

The role of the Beamline PPS is specifically to protect personnel from the radiation generated by the stored electrons in the Storage Ring. The PPS is an engineered interlock system which monitors the various safety devices installed in the Beamline and provides shutdown of the ring and injected beam when the PPS requirements are not satisfied.

As described previously, Beamlines consist of the enclosures and connecting vacuum pipe where synchrotron radiation is admitted. Access to these enclosures is made safe through the monitoring of the PPS of the critical devices which must be closed for access. All Beamlines have two redundant safety shutters in the front–end area inside the Storage Ring shield wall to stop bremsstrahlung radiation. The synchrotron beam, consisting of very high total power and power density, is stopped by a device that is water cooled, made of copper or alloys of copper, and referred to as the photon shutter. These two devices, the dual front end safety shutter and the photon shutter, form a shutter cluster whose positions are monitored by the PPS. Access to the first optical enclosure (FOE) requires that the PPS confirm that both front end safety shutters and the photon shutter are closed before the doors to the FOE can be opened.

Within the FOE are Beamline optical elements that condition the beam, including, for example, monochromators and mirrors. These devices change the characteristics of the synchrotron radiation. The radiation passing through the monochromator is, in most cases, displaced in either the vertical plane or the horizontal plane from the incident radiation and only a small fraction of the incident radiation with a band pass (of about 0.1% or less) is passed, with little or no power. In such cases the shutters, located downstream of the monochromator, are called monochromatic shutters. They are made of heavimet and are much shorter than the safety shutters. Once again, these monochromatic shutters for safety are monitored by the PPS and access to the next experimental station requires that the PPS confirm that both shutters are closed.

A major role for the PPS is to provide a means of ensuring that no personnel are inside the Beamline enclosures when the Beamline is opened to synchrotron radiation. Prior to admitting the synchrotron radiation inside these stations, a search of the area has to be performed by trained personnel. There are PPS devices called "search boxes" inside the enclosure which must be visited as part of the search. Search boxes are strategically placed to ensure that during the search all parts of the enclosure are either visible or visited by the search personnel and no person is left behind inside the enclosure. The search is completed when the enclosure door is closed. The PPS then locks the door.

Once the search process is started the PPS will start a beacon and audio signal inside the enclosure, warning all personnel to exit. This signal is expected to last for some time, on the order about 30 seconds (minimum) after the enclosure door is closed. The function of the beacon and audio signal is to warn any personnel overlooked by the search person of impending danger. There are distinctive emergency shutdown buttons placed inside the enclosure which, when pressed, instantly break the secure status of the enclosure, thereby ensuring that the beam shutters are closed. In addition, these also act as emergency egress buttons inside the enclosure to unlock and open the door.

The Beamline PPS also monitors beam line components downstream of the front end requiring protection against overheating from the white beam in two ways:

1. For devices requiring cooling water flow for protection during normal operation with beam, the PPS will close the safety shutters on receipt of a low water flow alarm. If shutters do not close within a designated time interval, the PPS will turn off stored and injected beam.
2. Some surfaces are protected against overheating during abnormal operation by pressurized burn through devices. The PPS will turn off injected beam and dump stored beam on receipt of a low pressure signal from these devices.

The Beamline PPS also monitors vacuum pressure in beam lines with in-vacuum experiments. The purpose of vacuum monitoring is to provide a means of detecting when the beam line has been brought up to atmospheric pressure. When a vacuum switch opens on high vacuum pressure, the safety shutter for the beam line will be closed by the PPS. A reset by an authorized person is required before the PPS will provide permission to open the safety shutter for the beam line. The purpose of the reset is to require confirmation by the authorized person that the beam line configuration has not been altered in an unsafe way while the beam line was at atmospheric pressure.
Area radiation monitors interlocking through the PPS are mounted on the wall of each FOE. These monitors have two set–points. The low level set point will close the front end safety shutters for the affected Beamline. The high level alarm will stop injection.

TABLE 3.13

3.13 BEAMLINE SAFETY FUNCTIONS

SF1	Prevent Photon beam transport from Storage Ring to FOE/EESE when occupied
SF2	Terminate search on activation of an ESTOP
SF3	Shutdown Storage Ring when FOE/EESE emergency stop is pressed and safety shutter and photon shutter is open
SF4	Support the search and securing of the EESE area or FOE area prior to the introduction of radiation
SF5	Provide redundant FOE/EESE status to the main BLPPS
SF6	Support search functions, lights and audio warning of pending unsafe status of FOE/EESE enclosure and indicators
SF7	Provide visual indication of beam on status
SF8	Prevent unauthorized access to searched areas of the FOE/EESE. (door lock control)
SF9	Provide visual indications of secured and unsecured conditions of the secured areas
SF10	Provide audible warning when required
SF11	Close beamline shutters on low flow alarm from beam line components requiring water flow to prevent overheating . If shutters do not close within designated period interval following low flow alarm, turns off stored and injected beam
SF 12	Turn off stored and injected beam on low pressure alarm from beam line burn through devices
SF13	Close beamline safety shutter on high vacuum pressure alarm and prevents re-opening of safety shutter without approval by authorized personnel for beam lines with in-vacuum experiments
SF14	Provide signals for the operation of automatic door operators
SF15	Pass status of both chains to BLEPS system
SF16	Inhibit entry to EESE if redundant chains do not agree with each other on status of safety functions and photon shutter position
SF17	Close front end safety shutter on low level alarm from FOE radiation monitor
SF18	Turn off Linac electron gun on high level alarm from FOE radiation monitor

3.10 Integrated Safety Management

ISM is the basis for performing work safely at BNL. The NSLS-II ESH program described in this section is intended to ensure that work is conducted efficiently and with full protection of the workers, public and environment. Its foundation is set on the core functions and guiding principles of the DOE ISM program. The NSLS-II ISM program seeks to ensure that:

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

3.10.1 ESH Roles and Responsibilities

Responsibility for ESH at the NSLS-II lies with the Directorate's Associate Laboratory Director. This responsibility flows down to the worker through the various Division Directors and their supervisory chains. The NSLS-II ESH Manager assists the Divisions and their staff members through the management of the various safety program elements discussed below to ensure their operations and programs comply with Institutional ESH requirements.

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

To provide ESH support to workers and supervisors and to provide oversight for Directorate activities, an ESH Group exists within the Directorate. Managed by the NSLS-II ESH Manager, it is staffed with appropriate personnel to discharge its responsibilities effectively. This staff also includes representatives from BNL Safety and Health Services, Environmental Protection and Radiological Control Divisions, all assigned to the Directorate through service level agreements.

The NSLS-II manages a number of ESH–related committees and groups, such as:

- Environmental Management System and Occupational Health and Safety Management Committee
- ESH Improvement Committee
- Work Planning Committee
- Interlock Coordination Group
- NSLS-II Safety and Operations Council
- Instrument Readiness Review Team
- Radiation Safety Committee
- Local Shield Design Coordination Group

A major role for these committees and work groups is to ensure that on–going work is properly planned and carried out and that changes in the facility are compliant with BNL requirements and do not result in a deviation from the approved Authorization Basis Documents such as this SAD and its accompanying ASE. Membership for these committees is drawn from Directorate, BNL–at–large and also external to BNL when expertise is required. Three of these committees/groups serve significant radiation protection functions and are described in more detail.

ESH reviews are conducted to ensure that hazards have been identified and that applicable codes and standards have been properly defined and applied. ESH Design Reviews of the accelerator systems were conducted to assure compliance with 10 CFR Part 851.21, *Hazard Identification and Assessment* and 851.22, *Hazard Prevention and*

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

Beneficial Occupancy Readiness Evaluations are performed prior to initial occupancy of buildings and Operational Readiness Evaluations are performed once equipment is in place and before operations commence. These are conducted by the ESH Directorate, led by a representative from the Safety Engineering Group with NSLS-II representation which are performed in accordance with the BNL SBMS *Readiness Evaluations* subject area. Commissioning activities associated with operation of an accelerator or Beamline are subject to the Accelerator Readiness Review requirements of DOE 420.2C *Safety of Accelerator Facilities* and the BNL SBMS *Accelerator Safety* subject area.

3.10.1.1 Radiation Safety Committee

This committee is charged to carry out reviews and to provide expert advice on radiological issues associated with design, construction, accelerator commissioning and accelerator operations. Routine meetings are held to permit review and evaluation of radiation safety issues, including but not limited to, design of shielding (bulk and supplemental), new or modified facilities or Beamlines, procedures with potential radiological impacts, events and reports concerning radiation and accelerator authorization basis documents and violations of radiation protection requirements. Requestors seeking RSC review schedule a time to present to the RSC and provide supporting documentation for preview. Recommendations made by the RSC are presented to the requesting party for consideration and resolution. The recommendations are then tracked in the NSLS-II Family Action Tracking System.

3.10.1.2 Interlock Coordination Group

The AD is responsible for the design construction and operation of the PPS system. System responsibility is delegated to the Leader of the Accelerator Safety Systems Group (ASSG). In this capacity the ASSG is supported by the Interlock Coordination Group. This group is comprised of experienced NSLS-II staff with knowledgeable in the design and operation of the PPS system and requirements. The group provides guidance and advice to the ASSG in areas of system design and operations to help avoid non–optimum design decisions by providing expert knowledge and continuous review while the work is progressing.

3.10.1.3 Local Shield Design Coordination Group

The LSDGC is made up of staff from the AD, ESH and other BNL organizations. Their scope includes developing procedures for the design of local shielding, evaluation of potential beam losses, perform ray tracings, specify and provide conceptual designs for supplemental shielding, design shielding, procure shielding materials and ensure the shielding is installed to the design requirements. The group leader for the Local Shield Design Coordination Group (LSDCG) has responsibility for the deliverables of the group including management of the budget and schedule for installation of the supplemental shielding.

3.10.2 Policies and Standards

Policies and requirements that apply to work are defined in the NSLS-II Policies and Procedures. The contents of these policies and procedures are based on BNL SBMS ESH subject areas and standards. They are maintained and augmented to ensure that ESH requirements that apply to Directorate activities are fully developed at the time of commissioning and initial operation. Reviewed below are a number of key ESH programs that are intended to ensure the proper identification and control of hazards and ensure compliance with ESH requirements at the operational level.

3.10.2.1 Work Planning and Control

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

3.10.2.2 Experiment Safety Reviews Overview

All activities at the NSLS–II are executed within careful documented work planning and control processes. All experimental activities are reviewed for ESH concerns before being authorized. The experiment program requires special attention as it involves a varied population of visitors who study and use many diverse materials and processes. Guests or facility users are trained and oriented before beginning work at the Beamlines and are expected to act responsibly and to understand that NSLS–II is a shared facility that may require precautions that do not apply at their home institutions. All facility staff and users are required to follow the same experiment review procedures.

All experiment proposals are reviewed by the NSLS–II ESH staff and Beamline staff and must be approved (authorized) before the experiment work is permitted to commence. Experimenters are required to report their intended activities to the NSLS–II staff to allow for an appropriate risk assessment and to determine what measures may be necessary to control those risks. Experimenters are responsible for their actions and for disclosing their experiment plans and associated risks.

Experiments receive individual scrutiny. Experimenters are required to report specific materials and equipment they intend to use and to provide a detailed task analysis. Risk assessment and control definition are based on this and other information and requires an open and straightforward dialog between the experimenter and the staff. Some experimental plans might be modified to reduce the risk presented to both personnel and equipment. The NSLS–II safety review is focused on controlling risks to personnel and the environment and to compliance with regulatory requirements.

Requirements Management

Experiment hazard control assessment is a process that requires knowledge of the proposed operations and of the facilities available at the NSLS–II. Decisions about appropriate work practices include consideration of the nature of the materials to be used, the proposed process, the availability of engineering controls such as exhaust ventilation systems and storage facilities, specific experiment needs and the unique concerns associated with working in an open facility.

The following information is the minimum collected for each experiment safety review.

- Lists of experimenters, materials and equipment needed.
- Task and hazard analysis (outline of material and equipment use with a focus on hazards presented and required controls).
- Emergency response / contingency planning.
- Waste generation as appropriate

Routine Experiment Envelope

Routine wet chemistry laboratory precautions are adequate to control the risks presented by use of:

- Common, non–hazardous samples and materials
- Milligram quantity samples that are prepared at the experimenter's home institution with varied chemical composition
    - Samples can be sealed in capillary tubes, cuvettes, holder assemblies, frozen or taped to glass slides. There is little or no direct manipulation of the sample material. The preassembled samples are placed in the synchrotron beam for data collection and then returned to the experimenter's home institution.
- Small quantities (<500 ml) of typical laboratory solvents such as ethanol, methanol, acetone, etc.
- Small quantities (<500 ml)of dilute (millimolar) electrolytes such as sulfuric acid, nitric acid, sodium hydroxide, etc.
- Compressed inert gases, liquid Nitrogen and liquid Helium

Experiments involving materials and tasks outside of the routine envelope require additional review by the NSLS–II staff and might require additional engineered or administrative controls at the Beamline or sample preparation laboratory. Any experiment involving unusual ESH risks will be subject to the USI process described in 3.10.2.6.

3.10.2.3 Self–Assessment

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

3.10.2.4 EMS / OHSAS

The BNL requirements are implemented as defined in the current NSLS-II EMS/OHSAS program.

3.10.2.5 Emergency Plan

PS–ESH–PRM–9.1.0, *Local Emergency Plan,* describes the emergency plans that have been prepared and implemented for current facilities. The NSLS-II ESH Manager is responsible for the emergency planning program and has appointed a Local Emergency Coordinator (LEC) who has primary responsibility for Pre–Emergency Planning and coordination of emergency response. The LEC ensures that the emergency plans are reviewed and updated as needed or at least annually, particularly after the occurrence of accidents or emergency situations. The LEC also schedules annual drills for those buildings that require them. In addition, the LEC provides this information to the Facility Complex Manager to update the Firehouse Response Cards.

3.10.2.6 Unreviewed Safety Issues

The NSLS-II has established a process for evaluating activities that have the potential to significantly impact accelerator safety. The USI is a structured process to identify and evaluate whether planned or as–found conditions, equipment or processes may exceed the bounds of an accelerator's ASE or if the conditions differ significantly from that described in this SAD. Activities that exceed the bounds of the ASE must be stopped immediately and not be performed until restart is approved by the NSLS-II management and DOE/BHSO is notified. The USI process is described in the BNL SBMS *Accelerator Safety* subject area and is further described in the approved NSLS-II procedure.. As NSLS–II builds out, many additional insertion devices and other radiation sources and beam lines will be developed. These new sources and beam lines will be evaluated using the NSLS-II USI evaluation procedure prior to installation so the hazards associated with these devices is understood. Sources determined to result in a positive USI evaluation will be submitted to the BNL Environment Safety and Health Committee for review and then to DOE for approval prior to their operation.

Any activity that may increase the level of a known hazard or may introduce a new type of hazard not examined in a Safety Assessment Document and therefore may impact the items below, must be evaluated through the NSLS-II USI determination process:

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

3.10.3 Safety Training

The NSLS-II adheres to BNL training policies and standards. The ESH PRM 8, *NSLS-II Training Program*, maintained by the Directorate Training Manager, supplements the minimum training requirements defined by BNL. Personnel working in NSLS-II facilities are assigned job training analysis (JTA) that define their training needs based on job duties, tasks and site access requirements. Training is documented through the Brookhaven Training Management System database.

3.11 User Management

NSLS–II enables research goals for a large community of scientists using photons (light) who carry out research in diverse scientific disciplines such as energy and environmental sciences, physics, materials science, chemistry, biology and medicine. The scientists and technical staff who make use of NSLS–II facilities, 'Users' are awarded access to the NSLS–II through a peer–review process described in the NSLS–II User Access Policy. Under this policy, there are three modes of user access to beam time at NSLS–II: General User (GU) access, Partner User (PU) access and Beamline Discretionary Time access. Users include researchers from Brookhaven National Lab and other non–Brookhaven organizations. This includes on–site Beamline support personnel, other BNL staff, researchers who remotely run experiments at NSLS–II and researchers who send samples to NSLS–II for analysis. Regardless of which access mode or type of user, a user cannot perform work at the NSLS–II until approved. The process that authorizes users to perform their work includes execution of a User Agreement between the

User's home institution and the Brookhaven National Lab, completion of training requirements and an approved work plan. This work plan will generally be executed through the Experiment Safety Approval process where the user is required to disclose all materials and processes they intend to use during their visit, as well as any risks associated with their work. Users are required to meet the standards established by the Brookhaven National Lab for safety for their specific activities. These standards may be found in the BNL SBMS and will be supplemented with additional policies and procedures established by NSLS–II for good work practices.

Remote beam line experiment operation is an additional feature for scientific investigation and presents no added risk to personnel. In all circumstances, scientists operating remotely can only open a shutter to illuminate a sample when the PPS interlocks have been satisfied by trained personnel present at the beam line. With the PPS access control interlocks satisfied, personnel are excluded from the radiation source and operation of the beam shutter can proceed locally or remotely with no additional controls.

3.11.1 User Agreement

Under the terms of the User Agreement, the User will be granted access to and use of the facility to conduct proprietary or non–proprietary research, which must first receive programmatic approval of the facility director. It is understood that to receive such approval, the User is obligated to provide a proposal disclosing a functional description of the experimental work, since such information is essential to safely operate the facility. Users are subject to the administrative and technical supervision and control by NSLS–II and must comply with all applicable rules with regard to admission to and use of the User Facility, including safety, operating and health physics procedures, environment protection, access to information, hours of work and overall conduct. Failure to comply with these regulations and requirements may result in sanctions or revocation of a user's privileges to access and use the NSLS–II.

3.11.2 Safety Training

All users are required to register with the NSLS–II and receive orientation provided by NSLS–II prior to access. In addition, before performing hands–on work at any NSLS–II facility, users must also complete ESH training required for hazards associated with their work. NSLS–II will provide oversight to assure that all activities are safely performed and in compliance with requirements. Any person has the responsibility and authority to stop activities that are unsafe or environmentally unsound. If work is halted for these reasons, NSLS–II approval to resume work is required.

3.11.3 Other Requirements

All users must comply with configuration control of shielding systems. No safety system under configuration control is to be modified without NSLS–II approval. Procedures for configuration control have been established and shall be strictly followed. Users who propose to use new or modified equipment must have NSLS–II approval prior to energizing the equipment. Work plans that represent reviewed activities must be approved by NSLS–II prior to the start of work.

3.12 Beamline Installation and Operations

Design, construction and operation of NSLS–II Beamlines follows a standard process to ensure these devices and associated facilities are installed/constructed and operated in a manner that is fully protective of staff, the public and the environment.

3.12.1 Design

Design of the Beamlines including enclosures, components and safety systems is performed in accordance with BNL Standards Based Management requirements and NSLS-II standard operating procedures including the Engineering Design Review subject area and NSLS-II SOPs Design Review, Engineering Design Plans and Travelers. During the progression of Beamline conceptual design to operations, many reviews are performed to ensure the Beamline, components and facilities conform to specifications and design requirements. These reviews include the conceptual design, preliminary design and final design. These reviews are supplemented with periodic review meetings with equipment vendors and component suppliers to assure that the components/systems meet design requirements and technical specifications.

At the initial stages of the design, radiation and industrial safety aspects of the Beamline design are reviewed and requirements developed. These requirements are then incorporated into the preliminary and final design documents and tracked through the progression of the design to ensure the final design reflects these requirements.

Technical specifications, statements of work (SOW) and drawings are developed for custom Beamline components. The technical specifications and SOWs are developed by NSLS-II scientists and engineers and are reviewed and approved by NSLS-II engineers, scientists, ESH, QA, NSLS-II management and Controls and Procurement, as applicable. Preliminary and final design reviews are held with the Contractor to assure all design requirements are met before commencing fabrication. Periodic inspection of the equipment is performed at the Vendor's facility and on–site at BNL.

3.12.2 Construction

During construction, oversight of the technical installation is provided by the Photon Division Group Leader and technical support staff assigned to the specific Beamline. The NSLS-II Beamline staff work closely with vendors and subcontractors to ensure components are installed per design and that vendor staff abide by NSLS-II safety standards. NSLS-II ESH staff support the installation activities by providing construction and industrial safety and industrial hygiene services including review of project specific health and safety plans, material handling training/oversight, monitoring of work to ensure compliance with SBMS requirements and to ensure activities do not present a hazard to NSLS-II staff or vendors.

Using standard quality assurance procedures, completed facilities and components are subject to acceptance and test inspections performed in accordance with NSLS-II standard operating procedures. Fabrications or components that do not meet technical specifications or requirements are subject to rejection. Discrepancy reports are prepared which document the deficiency. Accepted components and installations are documented through a traveler. The traveler is used to assure that methods used in the fabrication, assembly, inspection and test conform to specifications and design requirements.

3.12.3 Authorization for Beamline or Accelerator Start Up Operations

Authorization to operate a Beamline or accelerator component (e.g., front end or new insertion device) follows performance of a successful review process defined by an approved procedure (Appendix 32 - NSLS-II Process Description: Review Process for Facility Additions and Modifications). This review process includes: 1) the completion of a Conceptual Design Review (CDR), a Preliminary Design Review (PDR), and a Final Design Review (FDR), 2) a USI screening and/or evaluation; 3) the development and execution of a Instrument Readiness Plan (IRP); and 4) the implementation of an Instrument Readiness Review (IRR). Upon the successful completion of these reviews, including the ESH Manager's concurrence that all Pre-start findings identified during the performance of the IRR are complete, the beamline or accelerator component is authorized for commissioning and subsequent operations by the NSLS-II Director. This process, as described, is intended to be generic and to be tailored for each approved facility addition and modification based on the considerations described in section 1.0 of appendix 32.

Appendix 32, Section 10 *Beamline Readiness Review Process*, specifically discusses the review process for a completed beamline meeting the safety envelope prescribed in the NSLS-II Safety Assessment Document (SAD). It also notes that for beamlines that exceed the safety envelope of this SAD, an Accelerator Readiness Review may be required by the NSLS-II Director.

The process follows closely with the description provided above, but has been detailed due to the number of beamlines expected to be developed at the NSLS-II over its lifetime. The process includes design reviews, USI screenings/evaluations, an IRP, and an IRR. The Beamline Readiness Criteria in the IRP will be limited to only those elements of "documentation, hardware and people" that are necessary for the start of commissioning.

A Beamline Commissioning Plan must also be a part of the documentation required by the beamline readiness criteria. The Commissioning Plan will describe the actions to be taken through the commissioning phase, including additional readiness criteria that must be met, and safety reviews that will be conducted during commissioning, before beamline operations with users will be authorized.

Please see Appendix 32 for a full description of the beamline readiness review process.

3.12.4 Beamline Commissioning

Following authorization to commission a Beamline, a detailed radiation safety survey plan is established in accordance with a defined procedure (see Appendix 33; "NSLS-II Beamlines Radiation Safety Commissioning Plan") The commissioning plan defines the activities performed during the initial turn-on of a NSLS-II beamline to determine if the installed radiation shielding at NSLS-II beamline enclosures (hutches) is adequate. This document also provides radiological safety guidance and establishes hold points for safety reviews prior to progression to the next commissioning step. Upon determination of satisfactory shielding, the NSLS-II PD Director, with concurrence from the NSLS-II ESH Manager, gives Beamline Staff permission to proceed with scientific commissioning of the beamline. The maximum allowable beamline current during commissioning for scientific purposes is no more than 3 times the maximum beamline current evaluated during the execution of the Beamline Radiation Survey Plan. RCD Staff will perform routine operational surveys during the commissioning periods.

Upon completion of the beamline enclosure shielding analysis, the beamline enclosures are placed under configuration control to ensure the shielding remains in place and are not altered without prior review. Configuration management of the enclosures is provided through standard operating procedure for Radiation Safety Components.

4.0 SAFETY ANALYSIS

The focus of this Routine Operations Safety Assessment Document is to evaluate hazards by identifying the initiator of the hazard and its consequences, establishing a pre–mitigation risk category, recognizing design features to mitigate that risk and then establishing a post–mitigation risk category. Appendix 3 defines the risk methodology/categories and provides a summary of the analyses. The SAD documents the residual risk after incorporating the planned mitigations.

This section discusses the risks and controls of fifteen hazard types that could be involved with NSLS–II during routine operations. In the case of standard industrial hazards where there are no circumstances that would exacerbate that hazard, the mitigation and control of that hazard is by following BNL SBMS subject area and NSLS-II requirements and further elaboration is not warranted in the document. As defined in DOE G 420.2–1, standard industrial hazards are those that are routinely encountered and accepted in general industry and for which national consensus codes and/or standards exist to guide safe design and operation. Where circumstances could exacerbate a hazard, these hazards are discussed in more detail. Other hazards not covered in SBMS, such as natural phenomena, are also discussed. The Maximum Credible Incident involves ionizing radiation hazards; therefore controls for these hazards are included in the Routine Operations Accelerator Safety Envelope.

The hazard analysis described in this section is intended to ensure that work is conducted with full protection of workers, the public and the environment. Its foundation is set on the core functions and guiding principles of the DOE ISM program as described in section 3.11 above. In addition, the hazard analysis establishes controls that follow the requirements set by BNL SBMS as well as by DOE Order 10 CFR 851, *Worker Health and Safety Program*.

The following hazards are addressed in this assessment: natural phenomena; environmental; waste; fire; electrical; cryogens; chemical and hazardous materials; vacuum system; accelerator cooling water and compressed air; material handling and ionizing radiation. The following are considered routine Storage Ring and Beamline industrial hazards and are covered by BNL SBMS requirements: non–ionizing radiation which includes lasers, radiofrequency, ultraviolet, infrared, visible light and magnetic fields; noise; and ozone.

The risks of credible accidents involving these hazards are summarized in Appendix 3. These assessments show that the risks following mitigation are low or routine (risk chart based on Risk Screening Matrix provided in the BNL SBMS *Hazard Analysis* subject area) for the listed hazards. In addition, the hazards and risks associated with work activities are evaluated through OHSAS 18001 Job/Facility Risk Assessments. These analyses support the conclusions drawn in this document: that adequate controls are in place to reduce the risk of injury to a low level for personnel working within the NSLS–II facility.

4.1 Natural Phenomena Hazards

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

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

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

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

Management and control of NPH follow the requirements in:

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

Design criteria and operational controls incorporated to mitigate these risks are given in Table 1 of Appendix 3. The pre–mitigation risk is categorized as Low and the post–mitigation risk is categorized as Routine.

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

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

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

Earthquakes on Long Island are extremely rare. The probable occurrence of an earthquake sufficiently intense (>5.6 on the Richter scale) to damage buildings, accelerators and reactor structures in the BNL area was investigated during planning before construction of the Brookhaven Graphite Research Reactor, High Flux Beam Reactor and Relativistic Heavy Ion

Collider. These investigations remain valid and seismologists expect no significant earthquakes in the foreseeable future. No active earthquake–producing faults are known in the Long Island area.

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

4.1.1 Design Loads

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

4.1.1.1 Live Loads Design

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

Storage Ring Building

- Storage Ring Tunnel 250 psf
- Mezzanine 250 psf
- Experimental Floor 250 psf

Laboratory Office Building

- Office spaces 100 psf
- Laboratory spaces 100 psf
- Mezzanine 150 psf
- **RF Building** 150 psf
- Office mezzanine 100 psf
- Equipment mezzanine 150 psf
- Compressor Building 150 psf
- **Service Buildings** 150 psf
- **Cooling Tower Building** 150 psf

4.1.1.2 Snow Loads

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

4.1.1.3 Wind Loads

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

4.1.1.4 Earthquake Loads

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

4.1.2 Summary of Natural Phenomena Hazard Considerations

The design and construction of the NSLS–II buildings meet applicable requirements for natural phenomena. Any impact of an NPH event would be mission related and would not pose a hazard to the public or the environment.

4.2 Environmental Hazards

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

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

Management and control of environmental hazards for NSLS–II follow the requirements in:

- DOE *National Environmental Policy Act* (10 CFR 1021)
- NYSDEC *Handling and Storage of Petroleum* (6NYCRR 613)
- NYSDEC *Standards for New and Substantially Modified Petroleum Storage Facilities* (6NYCRR 614)
- *National Emission Standards for Hazardous Air Pollutants* (NESHAP) (40 CFR 61–Subpart A)
- NYSDEC *Prevention and Control of Air Contamination and Air Pollution* (6 NYCRR 200–234)
- Code of Federal Regulations, *National Pollutant Discharge Elimination System* (40 CFR 122–131, 133)
- NYSDEC *State Pollutant Discharge Elimination System (SPDES) Permits* (6 NYCRR 750)
- Code of Federal Regulations, *Hazardous Waste Management Regulations* (40 CFR 260–262, 264–265)
- NYSDEC *Hazardous Waste Management Regulations* (6 NYCRR 270–374–2)
- International Organization for Standardization – *Environmental Management System*–ISO 14001
- BNL SBMS Accelerator Safety subject area
- BNL SBMS *Environmental Aspects and Impacts* subject area
- BNL SBMS *Environmental Assessments and ESH Management Revi*ew subject area
- BNL SBMS *Liquid Effluents* and numerous other subject areas
- BNL SBMS *Storage and Transfer of Hazardous and Non–Hazardous Materials* subject area

Design criteria and operational controls incorporated to mitigate these risks are given in Table 2 in Appendix 3. The pre–mitigation risk is categorized as Moderate and the post–mitigation risk is categorized as Low.

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

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

While some accelerator components will become locally activated as a result of operations, the potential for soil activation is limited and no mitigation is required. Calculations (see Appendix 8) have shown that NSLS–II operations will generate tritiated water or sodium–22 below the BNL–defined Action Levels. Periodic sampling of the cooling water systems, soils near high loss points and the groundwater will be performed to confirm that tritium and sodium–22 concentrations remain below their respective BNL – defined Action Level.

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

Oil from the facility is minimized, where possible, by the use of oil–free pumps. Oil–filled pumps are operated within secondary containment, where necessary, to protect against leaks and spills. Aerosolized oil is exhausted through filters to the exterior of the facility.

Experiments conducted at the NSLS–II are reviewed for environmental issues prior to the start of the experiment through the ESR process. Beamlines using radioisotopes and/or biological material will be controlled by specific facility procedures, rendering remote the likelihood of these materials entering the sanitary or groundwater systems. Any work with potentially airborne radioactive material, biological materials or unbound engineered nanomaterials will be conducted within a laboratory exhaust hood or Beamline enclosure equipped with HEPA filtration. Radioactive emissions will undergo a NESHAPS assessment by the Lab's Subject Matter Expert for Radiological Emissions in order to determine any applicable NESHAP permit requirements.

Exhaust hoods are installed in laboratories that utilize chemicals. Certain Beamline hutches also will be connected to a general exhaust ventilation system if the experimental program warrants it. The products emitted to the ambient air from hoods or hutches typically will consist of trace emissions of evaporated solvents, acids and other chemicals. Any need to exhaust toxic or highly toxic materials will necessitate the design and installation of dedicated exhaust ventilation systems. These emissions will be associated with research and development and therefore, would be exempt from Federal and New York State permitting requirements. Experiments and work undertaken at NSLS–II will be reviewed with input from the Environmental Compliance Representative (ECR), to identify and manage the types and quantities of chemicals used. The ECR will ensure that all safety reviews are undertaken for each activity and that any issues will be addressed. The ECR is knowledgeable in environmental compliance areas and will be responsible for identifying and assisting in resolving any environmental problems. An active pollution prevention program at NSLS–II will consider alternatives to the chemicals used that might reduce the emissions released. The quantities of chemicals brought to NSLS–II will be kept to the minimum necessary to complete an experiment and to remain within the limits established for the building occupancy and ESR requirements (see Chemicals and Hazardous Materials, section 3.2.9).

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

Two emergency diesel generators at 700 kW each supply backup power to the facility. They are designed according to 6NYCRR Parts 613 and 614 secondary containment criteria in order to prevent release of the fuel oil to the environment. Each generator is equipped with a 450–gallon fuel oil tank.

Hazardous waste storage areas will meet NYSDEC/RCRA design criteria.

The NSLS–II environmental program is overseen by the NSLS-II ISO 14001 EMS, as documented in the NSLS-II EMS/OHSAS web site.

4.2.1 Summary – Environmental Hazard Considerations

The operation of the NSLS–II accelerators and Beamlines pose minimal risk to the environment. Proper implementation of the NSLS-II EMS ensures that the risk is low for releasing, in amounts beyond regulatory limits, of oils, solvents and radioactive material to the soil, surface water, groundwater, air or sanitary system.

4.3 Waste Hazards

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

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

- BNL SBMS Hazardous Waste Management subject area
- BNL SBMS Industrial Waste Management subject area
- BNL SBMS Radioactive Waste Management subject area
- BNL SBMS *Mixed Waste Management* subject area
- BNL SBMS Regulated Medical Waste Management subject area
- BNL SBMS *Nanoscale Particle ESH* subject area

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

Waste oils historically have represented a significant fraction of the industrial wastes generated at the NSLS–I facility. Waste oil from mechanical pumps is reduced due to the use of oil–free pumps to back the turbomolecular pumps for roughing down accelerator vacuum systems and during system conditioning. Oily rags will be disposed of as industrial waste. Other waste streams will be addressed as follow: Deionizing resins are recharged off site by a vendor, thus recharge waste waters are not being created on site. Solvents will be used for cleaning surfaces; liquid waste will be limited. Cooling tower water and process chilled water systems will be drained at infrequent intervals into the BNL sanitary and storm water systems. These waters contain anti–corrosion chemicals approved for use by BNL Facilities and Operations

Cradle–to–grave management of chemicals is documented by the ESH Coordinator and the Environmental Compliance Representative through work planning processes and the use of Process Assessment Forms (PAF). The NSLS-II participates in the BNL pollution prevention program and uses the Environmental Management System to set goals for environmentally friendly design techniques and waste reduction, where practical. Machining scrap from machining operations would be recycled to the extent possible.

Waste hazards and controls associated with the use of hazardous chemicals and materials for experimental purposes at the Beamlines will be evaluated through the ESR process. Every effort will be made to keep waste materials to a minimum. Experimenters work with the Experimental Review Coordinator during the review process to anticipate, report and minimize waste materials. Wastes from the experimental program (hazardous, biological, radiological) that are considered hazardous are disposed through the BNL Hazardous Waste Management Facility.

90–day Waste Accumulation Areas and local Satellite Accumulation Areas will be established to ensure compliance with Federal and Local waste regulations.

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

4.3.1 Summary – Waste Hazard Considerations

The operation of the NSLS–II accelerators and Beamlines is anticipated to generate limited quantities of waste materials. These could include used solvents, oils and oily rags, greaser, sealants. The risk of significant incident involving hazardous waste is categorized as low.

4.4 Fire Hazards

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

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

- *Building Code of New York State*
- Occupational Safety and Health Administration (OSHA) 1910, *Subpart E, Exit Routes, Emergency Action Plans and Fire Prevention*
- ANSI A–17.1, *Safety Code for Elevators and Escalators*
- DOE Standard 1066–99, *Fire Protection Design Criteria*
- DOE Order 420.1C, *Facility Safety*
- 10 CFR Part 851, Appendix A, Functional Area 2, *Fire Protection*
- BNL SBMS *Fire Safety* subject area
- BNL SBMS *Lockout/Tagout* subject area
- See the *NSLS–II Fire Protection Assessment/Fire Hazard Analysis* (Appendix 2) for a list of NFPA standards

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

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

As discussed in Section 3.8, the Linac tunnel, Klystron Gallery, the Booster tunnel, Injection Service Building, the Storage Ring tunnel, mezzanine, experimental floor and Laboratory Office Building are 100% sprinklered with a hydraulically designed wet pipe system and are equipped with smoke detection (HSSD for the Klystron Gallery, the Booster tunnel, Injection Service Building, Storage Ring tunnel, mezzanine and experimental floor) and alarm systems. To minimize the potential for damage created by water discharge on high value electrical equipment the racks chosen for the facility and Beamline electronics are drip tight. The false discharge risks are minimized by the qualified engineers' careful designs, the high quality of installation materials, pressure testing before placing the system into service and following all NFPA inspection testing and maintenance requirements of the fire protection systems.

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

Components subject to high temperatures (e.g. Linac modulators, RF structure, high field magnets, power supplies) are cooled by water systems. If component temperatures exceed pre–established thresholds or water flows drop too low, water flow and temperature sensors on the components alert operational staff to take action. Smoke control management systems conforming to Section 909 of BCNYS and NFPA 92B are provided in the Booster ring, Storage Ring tunnel and mezzanine and experimental floor. The sequence of operation of the smoke control management system covering these areas is a) if one Storage Ring zone goes into exhaust, the four other zones go into 100% supply; and b) if one experimental floor zone goes into exhaust, only the two adjacent zones go into 100% supply. The air for the Storage Ring zones is supplied from the first floor of the Service Buildings. The air for the experimental floor is supplied from the second floor of the Service Buildings.

The NSLS–II facility complies with the design requirements in BCNYS and NFPA for egress requirements with the exceptions noted below; this also satisfies OSHA 1910 requirements. The BCNYS and NFPA includes designing egress routes to ensure the safe exit of occupants from fires by imposing limitations on the maximum travel distance, maximum dead–end path lengths, protection of egress paths, emergency lighting of egress paths and egress signage. Design analysis indicates that travel distances of common paths are not exceeded for NSLS–II buildings with two exceptions: The travel distance of common path of 300 feet is exceeded by 37 feet from the Storage Ring tunnel pentant midpoints to the Service Building exits. This exceedance was reviewed and the equivalency approved by the BNL Fire Safety Committee on April 16, 2008. For the experimental floor, duck–unders (approved April 28, 2012 by the BNL Fire Safety Committee) would be provided for every other Beamline within the first 60 feet of the Beamline front end (ratchet wall) or ladders meeting code over Beamlines would be provided (duck–unders, keeping personnel at floor level, are preferable due to the height of the Beamline roofs). The 60 foot common path of travel is acceptable to the BNL Fire Safety Committee (April 28, 2008) with early warning systems provided on the experimental floor by the HSSD. The Storage Ring tunnel will undergo evacuation drill exercises to ensure that building occupants respond adequately to such emergencies. All other egress requirements in the BCNYS and NFPA are met for the NSLS–II design.

4.4.1 Summary – Fire Hazard Considerations

Fire–related hazards have been minimized through the design and operational features described above. The post–mitigation risk of significant loss due to fire is categorized as Low.

4.5 Electrical Hazards

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

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

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

Design criteria and operational controls incorporated to mitigate these risks are given in Table 5 in Appendix 3. The pre–mitigation risk is categorized as High and the post–mitigation risk is categorized as Low.

The NSLS–II accelerator and Beamline areas have large amounts of high–power and high–voltage electrical equipment (e.g. RF transmitter, magnet power supplies and pulse power systems). Lower voltage systems include vacuum gauges, beam diagnostics and controls. Power distribution systems are designed in strict compliance with NFPA 70. Systems are grounded and necessary components are bonded to ground. With correct grounding of the input power of systems, the AC circuit breakers will trip if there is a short to ground for all 208 VAC three phase and 120 VAC single phase circuits. The trip of a circuit breaker is remotely monitored and alarmed for all accelerator operation critical systems (e.g. power supplies, RF, controls, vacuum systems). The 480 VAC has remote monitoring for ground faults. All AC power systems have local monitoring for ground faults using UPA on the distribution equipment. The DC outputs of all power supplies are remotely monitored and alarmed if there is a ground fault.

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

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

Arc flash analyses are required prior to operation to ensure the proper labeling of all electrical panels and switch boxes and to assure that proper personal protective equipment (PPE) has been designated for workers. To reduce arc–flash hazards, the sizes of the transformers have been reduced and electrically operated breakers at a 480 volt panel have been provided with push buttons outside the arc flash hazard zone of the 480 volt panels. The 480 volt breakers de–energize the associated transformer and 208Y/120 volt panel. Design of electrical equipment provides LOTO capability (in compliance with the BNL SBMS LOTO subject area for simple and complex equipment) and prevents the need to service energized components.

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

Accelerator system electrical enclosures (racks) have high temperature detection and smoke detection that alarm in the Control Room. For critical systems, where water hoses are nearby, water leak detection systems are available for use which interlock pump skids and alarm in the Control Room.

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

Major electrical systems (such as substations and the emergency generators) undergo preventive maintenance as scheduled by BNL Facilities and Operations personnel and by a NSLS-II tracking system.

4.5.1 Summary – Electrical Hazard Considerations

Electrical hazards have been minimized through the design and operational features described above. The post–mitigation risk of significant incident due to electrical hazards is categorized as Low.

4.6 Cryogenic Hazards, Including Oxygen Deficiency Hazards

Cryogens are used in NSLS–II with superconducting RF cavities in the Storage Ring and many LN_2 cooled Beamline components and endstations located throughout the experimental floor. Liquid nitrogen is stored in fixed tanks outside the building and is delivered throughout sections of the NSLS–II facility through vacuum-jacketed piping systems. In addition, Dewar vessels will be used locally in experiments. As such, cryogenic and ODH hazards may exist on the experimental floor and in hutches, the Storage Ring, the RF Building, the Compressor Building, and the two LN_2 fill stations located in the Receiving Rooms of LOB 1 and 3. These hazards are described below.

In addition to the ODH hazards created by a major loss of cryogenic fluids at fill stations and at hutches, there is the potential for splash of LN_2 or cold gas onto skin or other exposed body parts. Usage of these systems will be limited to trained personnel; PPE (gloves, goggles, face shields) will be supplied at the station and their use required. Written operator instructions will be posted at the fill station and used when training staff and users. Training and PPE, as mandated by the SBMS, will be required for all personnel handling cryogenic liquids in Dewars. NSLS-II will provide general hazard awareness training for all personnel requiring unescorted access to the experimental areas and all service and support buildings.

Linac/Booster ODH Hazards

The Linac/Booster systems in the Injection Building do not require large–scale cryogenic systems. Should there be a need to bleed up a vacuum section of the Linac or Booster, that section would first be valved off and then bled up with nitrogen gas boil–off from a LN_2 Dewar. This operation would be limited to trained personnel using appropriate PPE and standard operating procedures. It is anticipated that the need for a bleed–up will be infrequent. The volume of the Linac tunnel is about 475 m^3 and the Booster tunnel is 1700 m^3. Therefore, the maximum volumes of LN_2 that may be introduced into the Linac tunnel and the Booster tunnel for maintenance activities and still be above the ODH-0 threshold (18% oxygen) can be calculated. The maximum volumes of LN_2 that can be brought into the Linac tunnel and the Booster tunnel without exceeding the ODH-0 threshold are calculated to be 113 liters of LN_2 in the Linac tunnel and 405 liters of LN_2 in the Booster tunnel.

Storage Ring ODH Hazards

The potential ODH hazards associated with the Storage Ring are restricted to the vicinity of the RF straight, where two 500 MHz SCRF cavities and one smaller 1500 MHz SCRF cavity will be installed. All cryogens associated with the RF cavities are contained in code–certified transfer lines and pressure vessels. Several failure modes of this system and the resulting consequences are described in Appendix 9 of this report. It has been decided, based on the approved analyses of all possible bounding events, that: 1). a small zone around the RF modules in the NSLS–II Storage Ring extending 10 m in both directions will be classified and posted as ODH–0, 2). all workers entering the zone will be trained to ODH–0 qualifications and 3). the ODH–0 zone will be monitored by a fixed–area oxygen monitor with both audible and visual alarms.

RF Building ODH Hazards

The NSLS–II RF Building is the main operations center for operation of the RF systems in the NSLS–II Storage Ring. The RF Building is two levels high and can be entered from the Storage Ring mezzanine in the Experimental Hall or from outside on the ground floor. Although the building is segmented into five zones (upper mezzanine, lower mezzanine, high bay, XMTR 1–2 and XMTR 3–4), these zones are openly connected, so the RF Building has been considered as one volume for ODH evaluations.

A number of failure modes associated with these systems is described in Appendix 9. On the bases of the LN_2 and LHe accident events considered for the RF Building, it was concluded that none of the events was sufficiently severe to require ODH classification of the RF Building. Nevertheless, due to the large inventories of liquid cryogens in the RF Building, it has been decided to treat the RF Building as an ODH–0 zone and to monitor the oxygen concentration on the lower mezzanine of the RF Building with a fixed–area oxygen monitor with both audible and visual alarms throughout the RF Building and at all entrances to the building.

RF Building Blockhouse ODH Hazards

The NSLS–II RF Building contains a Blockhouse that has been constructed on the ground floor for the purpose of conducting tests on operating superconducting RF systems prior to installation in the Storage Ring. The Blockhouse is a very compact, enclosed room with a total volume of 147 m^3. Failure modes of the cryogenic systems tested in the Blockhouse and their consequences are described in Appendix 9. On the basis of these analyses, it has been decided that: 1). the Blockhouse would be classified and posted as ODH–0 when LHe is in the Blockhouse, 2). ODH–0 qualifications will be required for all workers in this area, 3). work in the Blockhouse will be controlled by written work planning documents and 4). the oxygen concentration in the Blockhouse will be monitored by a fixed–area oxygen monitor with both audible and visual alarms.

NSLS–II Compressor Building ODH Hazards

The NSLS–II Compressor Building is a separate structure close to the RF Building. The Compressor Building is not normally occupied and has limited utilities such as ventilation, heat and air conditioning. Most of the airflow through the Compressor Building is actually provided to cool the large compressors, about 5000 m^3/hr of air for air-cooling one compressor, which is then discharged to the environment. This airflow is only operable when the compressor is running. At times when the compressor is not operating, ventilation in the Compressor Building is minimal at best.

Failure modes of the cryogenic and gas systems tested in this building and their consequences are described in Appendix 9. On the basis of these calculations, it has been decided that: 1). the Compressor Building would be classified as ODH–0, 2). ODH–0 qualifications will be required for all workers in this area, 3). work in the Compressor Building will be controlled by written work planning documents and 4). the oxygen concentration in the Compressor Building will be monitored by a fixed–area oxygen monitor with both audible and visual alarms inside the building and at each entrance to the building. On those occasions when a compressor is not operating, a procedure for working in the Compressor Building will specify the required training, PPE and appropriate work controls and hold points. When personnel are in the Compressor Building and the compressors are not running (meaning that there will be no ventilation), the procedure will ensure that the three GHe tanks located outside the Compressor Building will be manually isolated.

Beamline ODH Hazards

The ODH hazards associated with the LN_2 systems on the experimental floor are described and analyzed in Appendix 10. All Beamline enclosures in the six PROJECT Beamlines, the six NEXT Beamlines, and the ABBIX Beamlines that will have LN_2 piped in from the main distribution piping were evaluated. The conclusions from this study will apply to all future Beamline enclosures. The consequences of low oxygen concentration in a hutch following a rupture of the LN_2 supply line with and without ventilation were determined and found to be unacceptable in all cases. Due to the potential for low oxygen concentration in hutches with piped in LN_2, the following safeguards are required: 1). all hutches with LN_2 piped in will be classified as ODH-0 and 2). a fixed-area oxygen monitor will be installed in each hutch classified as ODH-0. FOE hutches that are serviced by a cryocooler may have a limited inventory of LN_2 in the high pressure cooling loop and are therefore may not be classified as ODH areas. Each cryocooler will be evaluated individually to determine if ODH controls are needed.

Cryogenic Dewar Fill Station ODH Hazards

ODH calculations were conducted as described in Appendix 10 for the two fill station locations, LOB–1, and LOB–3. A third station located in the Loading Dock was eliminated due to the potential exposure of untrained staff to an ODH condition (e.g., delivery drivers). Assuming continuous LN_2 release with or without ventilation operating, the oxygen concentration could drop to 10% in a LOB Receiving Room in 12 minutes in the event of a large pipe rupture and would bottom out at 1% in 60 minutes. Due to the potential for low oxygen concentration in fill stations, the fill stations are being managed as ODH-0 locations and each will be equipped with an oxygen monitoring system. Staff accessing these areas will be appropriately trained. .

Experimental Hall ODH Hazards

ODH calculations were conducted for the Experimental Hall as described in Appendix 10 with ventilation operating because the Series 200 air handling units are on emergency back–up power. Three cases were considered:

- Continuous LN_2 release into the entire Experimental Hall with all 10 air handling units operating
- Continuous LN_2 release confined to one pentant of the Experimental Hall with two air handling units operating
- Discharge of 22,000 gallons of LN_2 into the Experimental Hall with no ventilation

Analysis showed no potential for low oxygen concentration in the Experimental Hall even in the event of the worst–case unmitigated LN_2 release due to rupture of the one–inch vacuum–jacketed transfer line. Therefore, the Experimental Hall will not be classified as an ODH area. There are two isolation valves on the ring header that can be activated to isolate the 800–m ring header from the two 11,000–gallon LN_2 tanks to terminate an accidental release if necessary.

GN_2 ODH Hazards

A GN_2 supply is also provided, originating from an ambient vaporizer operating at the 11,000-gallon LN_2 tank between LOBs 4 and 5. A. supply pipe from this tank provides GN_2 distribution to the Ring Building to a continuous pipe located in a rack above and around the Storage Ring mezzanine with connection points available for pipes to bring the GN_2 to every other Beamline (tees may be inserted into this GN_2 pipe to supply intermediate Beamlines). Secondary mains from the mezzanine pipe serving the LOBs and the laboratories are valved to permit isolation for maintenance and modifications. The consequences of rupture of a GN_2 supply line were analyzed for the Experimental Hall and hutches in Appendix 10. In those cases in which LN_2 is also piped in, the consequences of a GN_2 release were bounded by the LN_2 consequences.

For hutches with GN_2 supplied for the bleed-up of vacuum systems that do not have LN_2 piped in, the GN_2 line will be valved off outside the hutch and use of the GN_2 will be limited to Beamline staff and controlled by a procedure. In those cases in which GN_2 is to be used continuously during experimental activities, those hutches so affected will require a fixed-area oxygen monitor if one is not already installed due to LN_2 piped in.

Summary Cryogenic Hazards

- ODH conditions will be effectively managed with a combination of engineering and administrative controls. Systems to mitigate accidental LN_2 releases in ODH areas by detection and isolation will be provided.
- There are shut–off valves on the 800–m ring header inside the Experimental Hall that can be signaled to close; this will isolate the ring header from the LN_2 supply in the event of a downstream line rupture.
- All hutches with LN_2 piped in will be posted as ODH–0 and require a fixed–area oxygen monitor with audible and visual alarms. FOE hutches using cryo coolers will be evaluated individually.
- Entry into a previously closed hutch will be controlled by a procedure that requires verification that the ventilation is operating. An Authorized Alternative to be implemented in the event a fixed–area oxygen monitor is out–of–service will be a personal oxygen monitor for each entrant or other alternate oxygen monitoring device.

- LN2 shut-off pushbuttons are provided for each of the beamlines with LN2 supply piping to close beamline LN2 supply valves in the event of an emergency.

4.7 Confined Space Hazards

Hazards from confined spaces could result in personnel injury due to exposure to a hazardous atmosphere or the presence of radiation fields.

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

- BNL SBMS *Confined Space* subject area

Design criteria and operational controls incorporated to mitigate these risks are given in Table 7 in Appendix 3. The pre–mitigation risk is categorized as Moderate and the post–mitigation risk is categorized as Low.

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

Types of confined spaces in the NSLS–II facility include those associated with the facility's support/maintenance and typically includes pipe pits, sump pits, elevator pits and HVAC plenums that are only accessed by Facility and Operation's maintenance personnel or vendor personnel.

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

4.7.1 Summary – Confined Space Considerations

Confined space hazards have been minimized through the design and operational features described above. The post–mitigation risk of significant incident due to confined spaces is categorized as Low.

4.8 Ozone/Hydrogen Hazards

Synchrotron radiation produced by the Storage Ring dipole bending magnets and insertion devices can generate significant levels of ozone when the unattenuated beam passes through air. Experience at the existing NSLS has demonstrated that in some instances, ozone concentrations may approach or exceed the threshold limit value (TLV) if a synchrotron radiation beam is permitted to pass through air within a hutch. Other sources of ozone production, for example, high energy electron interactions with accelerator components or vacuum chamber wall, have only a limited capability to produce ozone from secondary radiation produced at beam loss points.

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

- BNL SBMS Work Planning and Control subject area
- NSLS–II engineered controls established during ESRs

Design criteria and operational controls incorporated to mitigate these risks are given in Table 8 in Appendix 3. The pre–mitigation risk is categorized as Low and the post–mitigation risk is categorized as Low.

Transmission of the synchrotron beams from the Storage Ring to the experimental end stations occurs within either vacuum enclosures or enclosures containing an inert gas. These beam paths present no ozone concern. The experimental end stations in x–ray Beamlines are enclosed in metal hutches that act as an exclusion zone for personnel. For some experiments, the synchrotron beam passes through air within these hutches and can produce ozone in these instances. The air path length, the energy spectrum and the flux of the beam and the physical size of the beam determine the amount of ozone generated. Several configurations have been implemented to reduce or eliminate the production of ozone inside these hutches. An outline of those controls follows.

- The entire experiment can be contained within an evacuated or inert gas–filled chamber, thus the full photon beam (commonly called a "white" beam) does not pass through air.

- The white beam path can also be contained within a "flight tube", i.e. a tube, sealed at both ends, under vacuum or filled with an inert gas, thus minimizing or eliminating exposure of the white beam to air.
- The beam dimensions can be minimized so that there is very little beam interacting with the air and the interactions are localized.
- If the experiment can tolerate such a change, the beam can be filtered to reduce the flux of the low X–ray energies that are responsible for the highest ozone production rates, i.e. use silicon to filter out the 3–15 keV X–rays, thus reducing the overall ozone production.
- The beam path length through air can be minimized and the air adjacent to the beam path can be scrubbed using an appropriate filter.

Ozone concentrations generated by an experiment are measured to determine potential exposures and a delayed entry time can be established when needed to allow the ozone concentration within the hutch to diminish to acceptable levels. In addition, where needed, hutches can be vented through charcoal filters to reduce concentrations within the hutch and to minimize releases into the experimental area.

Hydrogen gas production in NSLS-II cooling waters has also been evaluated. Measurements made at SLAC have demonstrated that significant hydrogen gas generation requires energy deposition in water many orders of magnitude higher than will be possible during NSLS-II operation. Hydrogen evolution in the storage ring cooling water system or in the synchrotron radiation component cooling system will be negligible at NSLS-II.

4.8.1 Summary Ozone/Hydrogen Hazard

Ozone hazards have been minimized through the design and operational features described above. The post–mitigation risk of significant incident due to ozone hazards is categorized as Low. Risk of significant hydrogen gas generation in cooling system water is also low.

4.9 Chemical and Hazardous Materials

Chemical, biological and nano–materials used during NSLS–II routine operations could result in injury, death or exposures that exceed regulatory limits. Initiators could be experimental operations, transfer of material, failure of packaging, improper marking/labeling, failure of fume hood/glove box, reactive or explosive event, improper selection of or lack of PPE, improper procedure or a natural phenomenon.

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

- BNL SBMS subject area Chemical Safety
- BNL SBMS subject area Biosafety in Research
- BNL SBMS subject area Beryllium
- BNL SBMS subject area Nanoscale Particle ESH
- BNL SBMS subject area Work Planning and Control for Experiments and Operations
- BNL SBMS subject area Bloodborne Pathogens
- BNL SBMS subject area Compressed Gas Cylinders and Related Systems
- BNL SBMS subject area Electrical Safety
- BNL SBMS subject area Exhaust Ventilation
- BNL SBMS subject area Pressure Safety
- BNL SBMS subject area Piping Systems, Identification of
- BNL SBMS subject area Lead
- BNL SBMS subject area Explosives Safety
- BNL Radcon Manual
- Biosafety in Microbiological and Biomedical Laboratories fifth edition – USDHHS
- 49 CFR, Department of Transportation
- ANSI Z358.1–2004, Emergency Eyewash and Shower Equipment

- 29 CFR 1910 Subpart H, Hazardous Materials
- 10 CFR Part 851, Appendix A, functional areas 2, Fire Protection; 3, Explosives Safety; 4, Pressure Safety; 6, Industrial Hygiene; 7, Biological Safety; 8, Occupational Medicine; and 10, Electrical Safety

Design criteria and operational controls incorporated to mitigate these risks are consistent with these requirements. The pre–mitigation risk is categorized as High and the post–mitigation risk is categorized as Low.

Due to the wide variety of chemicals that will be utilized and the potential to introduce new hazardous materials at NSLS–II for the experimental programs, rigorous programs to control chemical inventory and usage are in place. The BNL Chemical Management System will be utilized to inventory and track chemicals.

Experimental activity undertaken at NSLS–II will be fully reviewed under the ESR process, including review and approval from the ERC and other Subject Matter Experts as needed (e.g., representatives from Environmental Compliance, Industrial Hygiene and Industrial Safety), to identify and manage the hazards of each experimental operation. The Principal Investigators for each experiment are responsible to ensure that all safety reviews take place for each activity and that any issues are appropriately addressed. The ESR process will document these reviews, define the necessary controls and provide management approval to proceed.

The experimental program is expected to require small quantities of corrosive, reactive, pyrophoric, flammable, explosive, toxic and highly toxic materials. The program also will involve the study and use of nano–particles, biological and radioactive materials. The use of all hazardous materials will be strictly controlled as required by OSHA, DOE and BNL requirements. It is noted that safety requirements are continually evolving for nano–materials and that design and handling requirements may continue to evolve. Conservative features will be provided during design to take these potential changes into account and to ensure that nano–materials can be handled as required at the time of operation. This includes the installation of HEPA filtered lab hoods or glove boxes in the LOB laboratories and may include HEPA filtration on hutch exhaust. Close contact will be maintained with the BNL nano–material community to ensure awareness of changing requirements that may have impact on the NSLS–II design and operations.

The use of biological materials in NSLS–II has also been reviewed at the conceptual stage and no use beyond Bio–safety Level 2 is anticipated at this time. Laboratory design will accommodate Bio–safety Level 2 requirements. The use of Bio–safety Level 2 materials has been successfully addressed at NSLS without problem. Biological hazards are addressed by a Brookhaven National Laboratory subject area entitled "Biosafety in Research". The BNL subject area describes the procedures users of biological materials must follow to perform research at BNL and covers biological materials, including microorganisms such as bacteria, protozoa, mycoplasma and viruses and other potentially infectious materials such as recombinant DNA. Currently, no Biosafety Level 4 (Biological Safety Level (BSL)–4) work is allowed at BNL and there are no BNL facilities that currently conduct Biosafety Level 3 (BSL–3). Future work at the Beamlines that may involve BSL–3 work will require approval from the Laboratory Director, the Institutional Biosafety Committee and DOE. In addition the Environmental Assessment for NSLS–II would need to be updated and approved prior to moving to a BSL–3. A comprehensive program of work planning and experimental review is in place for the NSLS-II that will evaluate all experiments involving biological materials. Detailed procedures will be developed to cover specific protocols for transport, testing, treatment and disposal of these materials. The total inventory of chemical and hazardous material utilized on the experimental floor is governed by the number of active Beamlines and the number of users. The quantity utilized in an experiment is small, typically in the milligram or milliliter range, as only the amount required for experimental operations will be allowed in the facility and storage will be restricted to short–term periods.

The use of small quantities of radiological materials including trans–uranic radionuclides can be expected at NSLS–II.

All radioactive materials will be strictly controlled via procedure that will be based on material, quantity and form of the materials and include specific review processes by the Experimental Safety Review Committee.

Two factors will limit material inventories; building occupancy fire limitations and the Experiment ESR. The former (See Fire Hazard Analysis section 3.2.4) will cover chemicals for both facility support and experimental support. The quantities for the individual fire control zones will be strictly controlled via the BNL Chemical Management System to ensure that inventories do not exceed the building occupancy limits. Experimental chemicals and materials will be controlled via the ESR process that evaluates all hazardous materials for the experimental programs to ensure that the least hazardous material is used, quantities are minimized and proper handling and storage requirements are applied.

There will be no bulk storage of flammable or combustible liquids; corrosive, reactive or toxic chemicals; nano–materials or biological materials within the facility. All liquid and solid chemicals for experimental use will either be stored in the main designated chemical storage location close to the loading dock area or at satellite locations. Chemicals in use will be stored in designated cabinets at the Beamlines or at the Beamline support laboratories. All locations where chemicals are used or stored will be evaluated and equipped as needed with combination safety shower/eyewashes compliant with ANSI. These areas also will have automatic sprinklers.

Small quantities (milliliters) of toxic or highly toxic gasses may be used for experiments. Provision for ventilation and exhaust will be evaluated and determined during Beamline design. Exhausted and sprinklered gas cabinets may be required; and depending on the type of toxic material, gas leakage detection and automatic shutdown may be necessary. The small quantities of toxic or highly toxic gases that will be used will follow BNL guidelines for handling and using toxic materials.

Flammable and non–flammable gases that will be used for the research program, including instrumentation support, will be kept in DOT cylinders in quantities limited to the minimum required for that particular process. Gas segregation and the use of flash arrestors will be evaluated as needed.

Exterior storage areas for gas cylinders are provided close to the main and LOB delivery docks. They will allow the segregation of flammable gasses from oxidizers. The storage areas are protected from the weather and vehicular traffic.

Emergency planning and procedures will be established and used if needed to evacuate/shelter in place in the event of a chemical or hazardous material release.

Beryllium windows are often used in Beamline applications; failure of these windows could cause a beryllium contamination issue. All work with beryllium articles requires work planning and is subject to controls specified in SBMS Beryllium Subject Area.

4.9.1 Summary – Chemical and Hazardous Materials

Hazards associated with the use of chemical and hazardous materials have been minimized through the design and operational features described above. The post–mitigation risk of significant incident due to ozone hazards is categorized as Low.

4.10 Vacuum System Hazards

Poor or loss of vacuum during NSLS–II routine operations could result in damage to equipment, enhanced radiation levels in the accelerator tunnel, in the FOE and in adjacent occupied areas, programmatic impact or injury to personnel. Initiators could be equipment or material failure, design error, improper procedure, natural phenomena, fire or operator error.

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

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

Design criteria and operational controls incorporated to mitigate these risks are given in Table 10 in Appendix 3. The pre–mitigation risk is categorized as Moderate and the post–mitigation risk is categorized as Low.

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

The design of synchrotron radiation facilities must address several types of potential vacuum accidents: rupture of vacuum windows/view ports, breakage of the ceramic insulator of an electrical feed–through, damage of a vacuum wall of a cooling channel by mis–steered beam and failure of pneumatic devices. With the exception of vacuum–to–atmosphere window breakage most of these failures are slow to develop in the absence of a pressure shock wave and are handled by the vacuum interlock systems through dedicated vacuum programmable logic controllers.

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

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

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

4.10.1 Summary – Vacuum System Hazard Considerations

Vacuum hazards have been minimized through the design and operational features described above. The post–mitigation risk of significant incident due to vacuum hazards is categorized as Low.

4.11 Accelerator Cooling Water System & Compressed Air System Hazards

Hazards for the accelerator and Beamlines include the loss of control of the cooling water or compressed air systems. Failure of any of these systems could potentially result in damage to the accelerator due to component overheating or fire or cause injury to personnel due to high temperatures or pressures. Initiators could include cooling water heat exchange and pump failures, compressed air supply failures, improper design, inadequate installation or procedure and operator error.

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

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

Design criteria and operational controls incorporated to mitigate these risks are given in Table 11 in Appendix 3. The pre–mitigation risk is categorized as Moderate and the post–mitigation risk is categorized as Low.

Temperature regulation accomplished by various closed cooling water loops, is necessary for the NSLS–II facility to assure mechanical and beam stability, to prevent overheating that could result in damage to components, cause injury to personnel or have a programmatic impact. Proper temperature levels are also required to provide the full cooling capacity of the cooling tower system. If cooling water flow meters, located throughout the accelerator, sense a drop in flow, interlocks will automatically turn off the RF power, causing dumping of the electron beam. In addition, if elevated temperatures are sensed by temperature sensors on the ring pipe, crotches, photon shutters, safety shutters or water–cooled masks, the RF is automatically dropped. Sensors sensing elevated temperature in a magnet automatically turn off the power supply to that magnet; the electron beam would dump as a result. In addition, temperature sensors detecting deviations from preset temperature limits will alarm in the Control Room, initiating an investigation. Water temperature to the ring vacuum chamber is also sensed in the pump room itself; if measured high, then the RF is automatically dumped. Power supplies on the accelerator tunnel mezzanine have their temperature controlled by air–to–water heat exchangers. Deviations from preset temperature limits are monitored by temperature sensors and will cause an alarm in the Control Room, also resulting in investigation. These temperature sensors are primarily to protect equipment from over–heating and therefore the interlocking function is through EPICS or the Equipment Protection System, rather than the Personnel Protection System.

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

4.11.1 Summary – Water and Air System Hazard Considerations

Hazards with water and air system failures have been minimized through the design and operational features described above. The post–mitigation risk of significant incident due to failure of the water and air systems is categorized as Low.

4.12 Material Handling Hazards

The consequences of hazards encountered in material handling include serious injury or death to equipment operators and bystanders, damage to equipment and interruption of the program. These hazards could be initiated by a dropped or shifted load, equipment failure, improper procedures or insufficient training/qualification of operators. Operational experience across the DOE complex and with BNL accelerators with material handling related occurrences and injuries suggests the need for strict operational controls.

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

- BNL SBMS subject area *Lifting Safety*

Design criteria and operational controls incorporated to mitigate these risks are given in Table 12 in Appendix 3. The pre–mitigation risk is categorized as Moderate and the post–mitigation risk is categorized as Low.

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

A review has been made of material handling requirements for NSLS–II and it has been determined that rigging needs can be met without requiring an overhead crane system extending throughout the Ring Building. Two ton hoists are installed in the Service Buildings for moving materials between the two floors. A three ton hoist is used in the RF Building to move equipment between the floor level and the two mezzanines. Hoists, typically one metric ton will also be used inside certain hutches to position Beamline equipment. Equipment lifts are installed along by–pass corridors to provide continuous rolling access around the experimental floor.

The NSLS–II staff has sought through design to reduce the amount of manual material handling. For example, a major source of potential injury at research facilities is moving cylinders of compressed gas. NSLS–II will pipe in nitrogen gas, thereby reducing the number of cylinders that must be handled manually. Material receiving and storage will be located close to the facility loading/delivery dock. A staging area will be available to break material down into manageable quantities for distribution throughout the experimental areas. To facilitate material handling throughout the facility, wide aisles are incorporated to allow the passage of at least a fork truck with palletized equipment. Tight radiuses and blind corners are kept to a minimum. Aisles are designated and will be marked to prevent the storage of materials/equipment and to ensure that gas cylinders, hazardous storage areas, flammable material lockers, electrical equipment, etc., are adequately protected.

BNL has instituted extensive training and qualification requirements and significantly limited the number of personnel who have access to mechanical material handling equipment. Personnel requiring authorization to use material handling devices unsupervised must complete laboratory specified training and pass a qualification practical exam conducted by a skilled operator; only then are they deemed “responsible” and given access to the equipment.

4.12.1 Summary – Material Handling Hazard Considerations

Hazards from material handling have been minimized through the design and operational features described above. The post–mitigation risk of significant incident due to inadequate material handling is categorized as Low.

4.13 Noise Hazards

Hazards from noise include overexposure of personnel to American Conference of Governmental Hygienists (ACGIH) and OSHA occupational exposure limits due to pumps, mechanical system and HVAC systems. These overexposures could induce permanent hearing loss, also known as Permanent Threshold Shift (PTS). The overall design goal for NSLS–II is to achieve Noise Criteria 60 or better in the majority of spaces; mechanical spaces will have higher noise levels.

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

- BNL SBMS *Noise and Hearing* subject area

Design criteria and operational controls incorporated to mitigate these risks are given in Table 13 in Appendix 3. The pre–mitigation risk is categorized as Moderate and the post–mitigation risk is categorized as Low.

NSLS–II utilizes a wide variety of equipment that produces a range of noise levels. Support equipment such as pumps, motors, fans, machine shops and general HVAC all contribute to point source and overall ambient noise levels. While noise will typically be below 85 dBA (decibels with A–weighting), certain personnel could exceed that criterion in mechanical equipment areas; these areas would require periodic monitoring, posting and the use of PPE. Ambient background noise is a greater concern from the standpoint of workers’ and users’ comfort, stress level and fatigue. Background noise in the accelerator and experimental areas at the existing NSLS is a common quality–of–life complaint and may be distracting and tiring.

Methodologies to reduce noise have been incorporated into the NSLS–II design. These techniques include using low–noise producing equipment, especially for fans in the HVAC and scientific equipment, isolating the noise producing equipment by segregating or enclosing it (equipment racks with front and rear doors) and using sound deadening materials on the walls and ceilings. Sound level reduction is designed into air and water flow rates as well as pipe and ducting dimensions. Power supplies located on the accelerator tunnel mezzanine will be cooled by air–to–water heat exchangers; this will contribute to a reduction in noise levels. Noise–producing Intermittent Energy Releases are possible at the locations of high pressure reliefs and exhausts for the Storage Ring RF cryogenic system. Exhausts for the reliefs will be located away from personnel to minimize the potential impact on those personnel.

Baseline and periodic personnel dosimetry and area surveys of noise will be conducted in accord with OSHA requirements. Based on dosimetry results in certain areas of high noise, employees working there may be put on a medical hearing protocol.

4.13.1 Summary – Noise Hazard Considerations

Hazards from noise have been minimized through the design and operational features described above. The post–mitigation risk of injury due to noise is categorized as Low.

4.14 Non–ionizing Radiation Hazards

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

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

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

Design criteria and operational controls incorporated to mitigate these risks are given in Table 14 in Appendix 3. The pre–mitigation risk is categorized as Moderate and the post–mitigation risk is categorized as Low.

4.14.1 Lasers

During routine operations in the NSLS facilities Class 1, 2, 3A(R), 3B and 4 lasers will be used for survey, alignment and experiment purposes at the Beamlines. Some lasers occupy permanent locations, while others are part of short–term Beamline experiments and in place for just days to weeks at a time. Still others may be used at a variety of locations for alignment purposes. Lasers are controlled as required in the BNL SBMS *Laser Safety* subject area and are reviewed by the BNL Laboratory Laser Safety Officer. Locations for long–term use of class 3B and class 4 lasers will be identified during design, Beamline review or experimental review and appropriate safety features will be incorporated into the design of the laser facility. Class 3B and 4 lasers require written standard operating procedures for each device to control exposure and associated electrical and industrial hygiene hazards (e.g., exposure to solvents, dyes and halogen gases). Class 4 laser controlled areas are required to be interlocked. Laser systems requiring toxic gases as a lasing medium (e.g., fluorine) will require the use of exhausted gas cabinets; additional building HVAC needs will be evaluated during design of these facilities.

4.14.2 Static Magnetic Fields

NSLS–II devices that generate static magnetic fields have numerous and diverse uses. Dipole, quadrupole, sextupole and trim electromagnets guide electrons during injection and in orbit. Dipole magnets and magnetic insertion devices (up to 6 Tesla at the core) are used on the Storage Ring to generate synchrotron radiation. The ring magnets are typically powered only when personnel have vacated the area and the Storage Ring tunnel is secured. Infrequently, personnel may be in the vicinity of these powered electromagnets, during hi–potting, for example; personnel are covered by procedures and work planning in these cases. The accelerator RF systems utilize electromagnets with fields <5 gauss inches away from contact. Ion pumps used on all evacuated accelerator and Beamline pipes and chambers contain permanent magnets of ~1800 gauss at contact. Some experiments may employ superconducting magnets with core fields rated up to 16 Tesla. The concern with all these devices is the strength and extent of the fringe fields and how they may affect persons with medical electronic and ferromagnetic devices and ferromagnetic equipment, such as tools, in their vicinity. It has been demonstrated at the NSLS and other synchrotron facilities that these devices can be safely used. Magnetic field surveys, postings, medical evaluation requirements and training will be implemented as defined in the BNL SBMS *Static Magnetic Fields* subject area. Based on experience at the NSLS, entrance ways to Linac /Booster/Storage Ring are posted with warning signs on the entry doors.

On the experimental floor, we will provide marked boundary lines for any equipment which generates a magnetic field above 5 Gauss. For small magnet generating devices, such as ion pumps, the 5 Gauss field is generally within 6 inches of the device. There will be a warning sticker affixed to such devices.

4.14.3 RF and Microwaves

The NSLS–II facility utilizes high–power RF systems at all three accelerators for accelerating and storing the electron beams. These devices are operated and maintained such that the RF fields are contained by well–secured wave guide mechanical joints and therefore, personnel are not exposed to RF fields above relevant standards referenced in the BNL SBMS *Non–ionizing Radiation Safety* subject area. Trained engineering and technical staff, work planning and surveys maintain control over RF hazards. Procedures require the LOTO of sources prior to disassembly of the waveguide system and for monitoring for non–ionizing radiation after reassembly of the waveguide system. The klystron transmitter and its power supply unit contain a number of internal machine protection interlocks related to temperature control, cooling water flow rates, RF power levels, arc detection and vacuum. For protection against electrical hazards, a captive key system is used that is interlocked to a grounding switch that grounds all high voltage switching units in the HVPS prior to extracting the key necessary to open the HVPS doors.

4.14.4 Infrared, Visible and Ultraviolet Light

As NSLS–II Beamlines are built out, Storage Ring bending magnet or 3PW Beamlines may use the visible portion of the synchrotron radiation spectrum to align and focus optical components. To do this, light is focused through a glass window that transmits wavelengths from 280 to 3,000 nm (i.e., mostly in the visible spectrum) and will include IR and UV wavelengths. Controls which have been successfully used at the NSLS include covers with caution signs for view ports that can transmit the direct or reflected visible portion of the synchrotron beam; work planning for visible beam alignment, roping off (with caution signs) the area the visible beam traverses, thus preventing inadvertent access and backstopping within the roped off area. Caution signs would be placed along the barriers and surveys conducted as required. Beamlines utilizing synchrotron radiation in the UV and IR spectra and equipment generating UV and IR spectra are reviewed and controls established through both the Beamline Safety Review and Experiment Safety Review processes.

4.15 Ionizing Radiation Hazards during Routine Operations

Potential hazards from ionizing radiation during routine operations include prompt radiation (gamma–rays, neutrons, bremsstrahlung) associated with electron beam losses and synchrotron radiation produced by the Storage Ring radiation sources. To a much lesser extent, induced activity in Storage Ring components, cooling water, tunnel air and soil must also be considered.

The primary source of radiation exposure is created by electron beam losses during the injection cycle or by loss of the stored beam. Radiation created by beam loss during normal operations is shielded by the accelerator tunnel walls, by supplementary shields and by labyrinths at wall openings. Beamlines are protected against bremsstrahlung produced in the straight section by lead collimators within the front end, safety shutters when access to the FOE is required and lead shielding along the walls and roof of the FOE. A second Beamline radiation hazard is the synchrotron radiation. The synchrotron radiation is extremely intense and exposure must be rigorously prevented, but because of its lower energy is more readily shielded.

The PPS system, radiation monitors and operations procedures protect personnel against increased radiation levels produced during abnormal operation.

It should also be noted that there are two other radiation sources associated with Storage Ring components. Significant x–ray fields are created within the Storage Ring enclosure by electrons released and accelerated by high electric field gradients when the RF cavities are powered. To prevent exposure to these radiation fields, the RF cavity(s) can only be powered when the appropriate sections of the Storage Ring have been secured. The klystrons located within the RF Building generate x–ray fields. Klystron shielding has been installed and confirmed during acceptance testing and commissioning.

Activities during routine operations also include handling radioactive check sources and activated components. The potential for radiation exposure is limited from these activities and is controlled by the BNL Radiological Control personnel through the sealed source program and work planning.

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

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

Design criteria and operational controls incorporated to mitigate these risks are given in Tables 15a and 15b of Appendix 3. The pre–mitigation risks are categorized as Low and High and the post–mitigation risks are categorized as Routine and Low, for routinely occupied areas and within shielded enclosures, respectively.

4.15.1 Introduction

Ionizing radiation hazards associated with a high–energy electron beam are significant and must be carefully considered. The electron beam is accelerated and transported within vacuum systems, but significant fractions of the beam can be lost inadvertently within the Linac, the Linac to Booster transport line, the Booster, the Booster–to–Storage Ring (BTS), the Storage Ring or the Beamline front ends during injection and stored beam operation. Whenever high–energy electrons strike matter an electromagnetic shower is produced with bremsstrahlung as the major component. The high energy bremsstrahlung can further interact and create additional secondary radiation fields of photons, electrons, positrons and neutrons. In general, the unshielded secondary radiation fields from such beam losses are dominated by high energy photons, particularly in the more forward direction.

A second and very significant radiation hazard is associated with the synchrotron radiation (SR) produced by the insertion devices and ring dipoles. While very small in cross–sectional area, the beams are quite intense, and exposure to them must be rigorously prevented. Because the synchrotron radiation is typically much lower energy than the radiation produced by electron interactions at beam loss locations, it is more readily shielded and requires less lead to reduce scattered radiation to design levels in occupied areas.

The level of radiological hazard and its associated controls are discussed for normal and abnormal operations of the accelerators first. In addition, hazards associated with induced radioactivity in accelerator components, air, water, and soil are considered. Beamline radiation hazards and controls will be discussed in the final portions of this section.

4.15.2 Radiological Hazards Associated with the Accelerators

4.15.2.1 Linac

The Linac can operate with energies ranging from the electron gun energy of 0 keV to a maximum energy of 250 MeV with three klystrons. The Linac is designed to routinely operate at 200 MeV with two or three klystrons. The third klystron may be used to lower the stress on the klystron components or be used as a spare unit. It is possible for the Linac to operate at energies nearly spanning the complete energy range from 0 keV at the electron gun to 250 MeV at the output of the Linac. However, it is expected that nearly all the operating time during routine operations will occur at 200 MeV. Some operations at lower energy (such as 100 MeV) may be conducted during studies and it is anticipated that after shutdowns the Linac will be tuned at lower energies before operating at the routine energy of 200 MeV.

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

4.15.2.1.1 Linac Radiological Design Parameters for Bulk Concrete Shields

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

TABLE 4.1

4.1 LINAC DESIGN PARAMETERS USED IN BULK SHIELDING CALCULATIONS

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

4.15.2.1.2 Linac Beam Loss Summary

The beam loss assumptions used to calculate bulk concrete and supplemental lead shielding requirements were developed in conjunction with NSLS–II accelerator physicists and are conservative for normal operation. To accommodate the need for Linac studies at energies greater than the normal 200 MeV and 15 nC/s current, supplemental shields at high loss points are based on energies up to 230 MeV and 22 nC/s. A summary of these beam loss assumptions for shield design is provided in Table 4.2.

TABLE 4.2

4.2 BEAM LOSS ASSUMPTIONS USED FOR LINAC CALCULATIONS

ACCELERATOR SYSTEM	ENERGY (MeV)	CHARGE LOSS (nC/s)
Linac – General	200	1
First bending magnet	230	2.5
Energy slit	230	11
Beam dumps	230	22

4.15.2.1.3 Linac Bulk Shielding Requirements

Based on the design parameters and the beam loss assumptions described above, the shielding requirements to satisfy the shielding policy are listed in Table 4.3. The methodology used for calculating the bulk shielding requirements is described in Appendix 5 (BNL–79774–2008–CP, *Shielding Requirements for NSLS–II,* P.K Job and W.R. Casey, January 2008).

TABLE 4.3

4.3 CONCRETE SHIELDING REQUIREMENTS FOR THE LINAC ENCLOSURE TO REDUCE RADIATION LEVELS TO 0.5 mrem/h

LOCATION	LATERAL WALL CONCRETE EQUIVALENT THICKNESS (cm)	ROOF CONCRETE EQUIVALENT THICKNESS (cm)
Klystron Gallery side*	100	118
Berm side wall*	130	
Linac downstream wall**	235	
Linac/Booster wall***	220	

*Based on 1 nC/s lost at 200 MeV.
**Based on 2.5 nC/s lost at first dipole; as constructed, the wall has 100 cm of concrete and a minimum thickness of sand (berm) of 270 cm.
***Based on 11 nC/s lost at the energy slit; as constructed, the wall has 100 cm of concrete with a 25 cm thick, 2 ft x 2 ft lead collimator centered on the beam pipe through the wall.

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

4.15.2.1.4 Linac Supplemental Shielding Requirements

The bulk shielding defined above is based on point loss of 1 nC/s at 200 MeV operation. Local supplemental shielding to reduce radiation levels to 0.5 mrem/h was provided initially at the higher loss points identified in Table 4.2. A substantial lead wall collimator is provided around the transport line pipe that passes through the concrete wall into the Booster enclosure.

Supplemental shielding requirements were initially defined in Appendix 5.These calculations were updated to higher energy (230 MeV) and higher current (22 nC/s) in notes authored by P.K. Job dated January 27, 2010. Additional work was performed later by a working group chaired by S. Kramer. This group examined the consequences of mis–steering the Linac beam by improperly set dipole and quadrapole magnets. Their work is reported in the document attached as Appendix 6a).

The final specification of supplemental shields in Linac are shown in Table 4.4.

TABLE 4.4

4.4 OPERATIONAL AND STEERING ERROR SUPPLEMENTAL SHIELDING SPECIFICATION FOR THE LINAC AND LBT–P1 TRANSPORT LINE

Shield Name	Location	Energy [MeV]	Beam Current [nC/sec]	Forward Shield		Transverse Booster Shield		Transverse Berm Shield	Roof Shield
OPERATIONAL SHIELDS – Specified in Appendix 5									
LB–B1 forward shield	45 cm DS of B1	230	22	15 cm Pb	25 cm W x12 cm H (klystron side) 7.5 cm W x 12 cm H (berm side)	None		None	None
Energy Slit	After LB–Q5	230	11	15 cm Pb		10 cm Pb, 10 cm Poly		10 cm Pb	10 cm Pb 10 cm Poly
Beam Dumps 1 & 2	End of LD and LBT–P1	230	22	15 cm Fe, 30 cm Pb, 20 cm Poly	20 cm x 20 cm Fe, Pb, and Pol, close packed	20 cm Pb, 25 cm Poly		20 cm Pb, Poly 5 cm Dump1, 20 cm Dump2	20 cm Pb, 25 cm Poly
Cable and Waveguide Penetration	4 each Klystron Gallery Wall	200	1			10 cm Pb	33 cm W x 1 cm H		
ADDITIONAL OPERATIONAL SHIELDS – Results of Commissioning Studies									
Flag VF2	After LB–VF2	200	15	10 cm Pb	60 cm W x 46 cm H				
Cable tray 3 penetration	End of Klystron Gallery	200	1			10 cm Pb	33 cm W x 3 cm H		
STEERING ERROR LOSS SHIELDS – Specified in appendix 6a									
LB–B1 Extended	Between the LB–B1 and LB–B1 forward shield, tightly packed toward LB–B1	200	22	20 cm Pb	50 cm W x12 cm H (klystron side) 7.5 cm W x 12 cm H (berm side)	20 cm Pb thick	50 cm L x 15 cm H		
LB–Q6 Forward	Ahead of LB–Q7	200	22	20 cm Pb	40 cm W x 40 cm H				
LB–Q6 Side	Between LB–Q6 and LB–B2, not tightly packed	200	22			20 cm Pb thick	60 cm L x 15 cm H		
LB–B2 Forward	DS edge LB–B2 in mid–plane	200	22	10 cm Pb	20 cm W x 15 cm H				
LB–SS mask	US of Shutter around flange	200	22	5 cm Pb	40 cm W x 40 cm H				

4.15.2.2 Booster

The Booster serves as the intermediate accelerator for the facility, providing electron bunches to the Storage Ring, and is designed to produce 15 nC/s at 3.0 GeV at 1 Hz. Linac is the Booster's source of 200 MeV electron bunches. Power for accelerating the electron bunches in the Booster is provided by an IOT transmitter. When fully powered and tuned, the transmitter is capable of producing electrons at energies up to 3.2 GeV. During normal operations, the Booster will be regulated to operate at 3.0 GeV. Its rate of injection will vary from 1 Hz during initial fill of the Storage Ring and during studies to much reduced frequency once a stored beam in the ring is established. At a stored beam of 500 mA with a lifetime of ~ 3 hours, the Booster will need to inject once every 60 seconds.

The Booster bulk and supplemental shielding are based on the following parameters.

4.15.2.2.1 Booster Radiological Design Parameters for Bulk Concrete Shields

The shielding specification for the lateral walls and ceiling of the Booster tunnel are based on the design parameters identified in Table 4.5 below.

TABLE 4.5

4.5 BOOSTER DESIGN PARAMETERS USED IN BULK SHIELDING CALCULATIONS

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

4.15.2.2.2 Booster Beam Loss Summary

The beam loss assumptions used to calculate bulk concrete and supplemental shielding requirements were developed in conjunction with NSLS–II accelerator physicists and are conservative for normal operation. Table 4.6 provides the beam loss assumptions used for bulk shielding and supplemental shielding for the Booster enclosure.

TABLE 4.6

4.6 BEAM LOSS ASSUMPTIONS USED FOR BOOSTER CALCULATIONS

ACCELERATOR SYSTEM	LOSS (%)	ENERGY (MeV)	POWER LOSS (W)	CHARGE LOSS
Bulk Shielding				
Booster	2	3000	0.015	0.3 nC/min
Bulk + supplementary				
shielding	50	200	1.5	7.5 nC/sec
Injection septum	20	3000	9.0	3 nC/sec
Extraction septum	100	3000	45.0	15 nC/sec
Beam dump				

4.15.2.2.3 Bulk Shielding Requirements

Based on the design parameters and the beam loss assumptions described above, the shielding requirements to satisfy the shielding policy are described in this section (See Table 4.7). The methodology used for calculating the bulk shielding requirements is described in Appendix 4 (LT–ESHDES–08–002–Rev2, *Bulk Shielding Requirements for Final Design of NSLS–II Accelerator Enclosures,* P.K Job and W.R. Casey, February 2008).

TABLE 4.7
4.7 CONCRETE SHIELDING REQUIREMENTS FOR THE BOOSTER ENCLOSURE TO REDUCE RADIATION LEVEL TO 0.5 mrem/h

LOCATION	LATERAL WALL CONCRETE EQUIVALENT THICKNESS (cm)	ROOF CONCRETE EQUIVALENT THICKNESS (cm)
Booster outboard side	70	75
Booster inboard side	85	
Booster forward wall	100	

Table 4.8 below provides the as-built configuration for the Booster shields. In several locations, the earth berm enclosing the Booster was used to reduce the required thickness of concrete. In all cases the shielding provided is greater than the shielding specified in Table 4.7.

TABLE 4.8
4.8 AS BUILT CONFIGURATION FOR THE BOOSTER SHIELDS

LOCATION	LATERAL WALL CONCRETE THICKNESS (cm)	ROOF CONCRETE THICKNESS (cm)
Booster outboard side (ISA region)	99	51 + 61 cm of soil
Booster outboard side (arc 2)	99	
Booster outboard side (adjacent SR)	99	
Booster outboard side (Injection region)	36 + 1492 cm soil	
Booster inboard side	36 + soil	
Booster to SR forward wall	99	

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

HVAC supply and return ducting for the Booster enclosure penetrates the ceiling of the personnel access labyrinth (from the second or mezzanine floor of the Injection Building) at the southeast corner of the Booster enclosure; the labyrinth provides a shielded path from the Booster enclosure to the Injection Building Service Area floor. The HVAC penetrations are also designed to the two–bounce configuration of the personnel labyrinth.

Booster Supplemental Shields

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

Table 4.8 and at locations within the ring where the beam may be mis–steered and strike the wall.

Supplemental shielding requirements were initially analyzed in Appendix 5. Additional work has been performed by a working group. This group examined the consequences of mis–steering the beam by improperly set dipole and quadruple magnets. Their work is reported in Appendix 6b. The final set of specifications for Booster supplemental shields contained in that report is shown in Table 4.9.

TABLE 4.9

4.9 BOOSTER SUPPLEMENTAL SHIELDING SPECIFICATIONS

Booster Tunnel Supplemental Shielding									
Shield Name	Location	Ref	Energy [GeV]	Beam Curr. [nA]	Forward Shield [cm]		Transverse Outside ISA or SR side [cm]	Transverse Inner Berm [cm]	Roof or Top shield [cm]
Operational Loss Shields									
Inject Septum Shield	Booster IS	[5]	0.2	7.5	15 Pb	No Poly	10 Pb	None	10 Pb,
Extract Septum Shield	Booster XS	[5]	3	3	15 Pb	No Poly	15 Pb, 20 Poly	None	15 Pb, 15 Poly
Extraction Shield Enhanced	Booster XES BR–XES	[10]	3	15	30 x 75H x 50 W Pb	7.5 Poly	15 Pb, 20 Poly	10 x 15H x 110 L Pb, 10 x15H x20L Pb lip (5cm to Beam)	15 Pb, 15 Poly
Booster Dump	BSR–P1 Dump	[5]	3	15	15 Fe, 35 Pb	35 Poly	20 Pb, 25 Poly	20 Pb, 25 Poly	20 Pb, 25 Poly
Booster Dump Enhanced	BSR–P1 Dump		3	15	15 Fe, 45 Pb	25 Poly	20 Pb, 25 Poly	20 Pb, 25 Poly	20 Pb, 25 Poly
Booster Dipole Shadow Shields	BR Arc Dipoles	[5]	3	0.3	20 Pb, 3.6cm Outward from Extreme ray	No Poly	None	None	None
Enhanced Booster Dipole SS Arc1	Arc1 Enhanced	[8]	3	5	First Arc Shield (FAS) plus next 4 SS's with 2°–3° outer ray Table 4.1.3	FAS 20 x 30 H x 90L Pb across beam pipe			
Booster Dipole Shadow Shields Arc2	ARC2 Enhance	[9]	3	5	FAS plus 14 SS's with 2°– 3° outer ray Table 4.1.3	FAS plus 14 SS's			
Shield Name	Location	Ref	Energy [GeV]	Beam Curr. [nA]	Forward Shield [cm]	Shield Name	Location	Ref	Energy [GeV]
Booster Dipole Shadow Shields Arc3	ARC3 Enhance	[9]	3	5	FAS plus 14 SS's with 2°–3° outer ray Table 4.1.3	FAS 20 x 30 H x 90L Pb across beam pipe			
Booster Dipole Shadow Shields Arc4	Arc4 Enhance	[8]	3	5	FAS plus next 4 SS's with 2°– 3° outer ray	FAS plus 4 SS's			
Cable Tray Penetration Enhanced	BR–ISA penet.		3	0.3	none	none	10 Pb inner shield, 20cm Pb outer tightly packed	None	None

BR–SR Phase 2 penetration	BSR–P2–Penet.		3	3	35 Pb	65 concrete	None	None	None
Abnormally Steered Beam shields									
BSR– B1B2 Dipole Shield	BS–SP2 to Q2	[10]	3	15			20 x 45 H x 130 L Pb		None
	BS–Q2 to B1	[10]	3	15			20 x 45 H x 160 L Pb		None
	BS–B1 to B2	[10]	3	15			20 x 68H x 180L Pb, 25 x 68H x 180L Poly		None
BSR Safety Shutter Mask	BSR–Mask	[10]	3	15	20 x 35H x35 W Pb			30 X 35H x 30W Pb	Between yoke and Dump Pb
BSR–P1 Dipole shields	BSR–B2BL	[10]	3	15	20 x 20 H x20 W Pb	BS–B2 Yoke to SR Penetration			
	BSR–B2BR	[10]	3	15	20 x 20 H x20 W Pb	Between BS–B1FWRD shield and Dump Pb			
	BS–B1FWD	[10]	3	15	20 x 20 H x30 W Pb	Between BS–B1 Yoke and Vacuum pipe			
Cable Tray Labyrinth Shield	ISA–CTL	[10]	3	15	60 x 142 H x 184 W Concrete Block	Dry Stacked in CTL			
Extract. Kicker shield	BSR–EXKic	[15]	0.15	15			5 x 20H x 150L Pb (<110 cm UPS septum, 30 cm to beam CL)		

4.15.3 Radiological Hazards Associated with the Storage Ring

4.15.3.1 Normal Operation

The Storage Ring is designed to operate with a stored beam current of 500 mA (total stored charge of 1.3 μC) at 3.0 GeV. All shielding estimates described in these sections are based on the nominal design value of 500 mA. The Booster is the Storage Ring's source of 3.0 GeV electrons and we assume that it can provide up to 15 nC/s during routine operation. The Storage Ring bulk and supplemental shielding are based on the parameters shown in Table 4.10 below.

TABLE 4.10

4.10 STORAGE RING DESIGN PARAMETERS USED IN BULK SHIELDING CALCULATIONS

PARAMETERS	VALUES
Beam energy	3.0 GeV
Beam current	500 mA
Beam life time	2 hours
Beam Orbit circumference	792 m
Stored charge	1.3 μC
Position of beam from lateral wall	1 m
Position of beam from the floor	1.2 m
Stored electrons	8.1×10^{12}
Stored energy	3962 Joules
Storage Ring width x height	3 m x 3.25 m

4.15.3.1.1 Storage Ring Radiological Design Parameters for Bulk Concrete Shields

The shielding specification for the lateral walls, ratchet walls and the roof of the Storage Ring tunnel are based on the design parameters identified in Table 4.10.

4.15.3.1.2 Storage Ring Normal Beam Loss Summary

The concrete bulk shielding has been designed to address the losses expected under routine Storage Ring operation. It is assumed that one injection period per minute totaling 18.5 nC in order to maintain a stored beam of 500 mA. The replenishment rate of beam and its routine losses were the basis for the initial shield design. After the stored beam is dumped an initial fill will be initiated when the machine is ready for the next store. At 15 nC/s it requires about two minutes to achieve a complete fill. Losses and faults during this operation are covered in the abnormal operating modes, which examines the shielding for continuous losses at 15nC/s.

The beam loss assumptions used to calculate bulk concrete and supplemental shielding requirements were developed in conjunction with NSLS-II accelerator physicists and are conservative for normal operation. Table 4.11 provides the beam loss assumptions used for bulk shielding calculations for the Storage Ring enclosure.

TABLE 4.11

4.11 BEAM LOSS ASSUMPTIONS USED FOR THE STORAGE RING CALCULATIONS*

STORAGE RING COMPONENT	BEAM LOSS (%)	ENERGY (MeV)	POWER LOSS (W)	CHARGE LOSS (nC/min)
Storage Ring Injection Region (Septum and Scrapers)	~ 70 %	3000	0.65	13
Storage Ring Enclosure at 5 different non–injection locations	~ 30 % total (~6% loss per location)	3000	0.275	5.5 total

*Bulk Shields are based on an assumed injection rate of 1/min.

4.15.3.1.3 Bulk Shielding Estimates

The design parameters and the beam loss assumptions provide the basis for the shielding thicknesses to achieve a dose rate of ≤0.5 mrem/h and are listed in Table 4.12. The methodology used for calculating the bulk shielding thicknesses is described in Appendix 4.

TABLE 4.12
4.12 CONCRETE BULK SHIELDING ESTIMATES FOR THE STORAGE RING ENCLOSURE BASED ON LOSSES SHOWN IN TABLE 4.11

LOCATIONS	OUTBOARD** WALL THICKNESS (cm)	DOSE RATES (mrem/h)	ROOF THICKNESS (cm)	DOSE RATE (mrem/h)	INBOARD WALL THICKNESS (cm)	DOSE RATES (mrem/h)
Storage Ring non–injection region	101	0.43	80	0.47	80	0.47
Booster to Storage Ring injection region	141***	0.49	80****	0.50	116	0.50
Storage Ring Ratchet Wall – forward direction at mid-plane	115 Concrete 25 cm lead	<< 0.5	—	—	—	—
Storage Ring Ratchet Wall – forward direction off mid plane	140	2.4				

*injection = 1/min.
**Experimental floor side
***Replaced by high density concrete of thickness 100 cm (density = 3.6 g/cm^3) – provides equivalent shielding
****supplemental shields required to achieve 0.5 mrem/h

The bulk shielding enclosure has six labyrinths for personnel access (one from each of the five Service Buildings and one from the Injection Building service area). These labyrinths have access doors which are secured and interlocked prior to Storage Ring operation. The personnel access labyrinths are designed according to the methodology described in NCRP Report 51 (pages 62–64). In each case the dose rates at the external door of the labyrinth are ≤0.5 mrem/h for the assumed beam losses (1.1 nC/min) during normal operation of the Storage Ring. FLUKA calculations are presented in Appendix 11a and 11b. For a typical Service Building labyrinth, a dose rate of ~ 0.06 mrem/h at the entrance was calculated for the same beam loss.

The five service buildings contain the HVAC equipment. The HVAC supply and return ducting for the Storage Ring is routed through the service building labyrinth and penetrates the enclosure over the interlocked doors of the labyrinths. The ducting does not represent an additional weakness and can be considered as a vertical extension of the labyrinth entrance. Adjacent floor areas inside the Service Building are expected to be the same as the dose at the exterior of the personnel labyrinth, ≤0.5 mrem/h.

The Storage Ring roof has a number of small three and four inch diameter pipes over the Storage Ring transport and over the Beamlines. These penetrations are three–legged labyrinths. The penetrations over the Beamline near the ratchet wall have the potential for much smaller dose rates than the ones directly over the Storage Ring beam. Assuming that the radiation is only shielded by half of the concrete then the dose rate above the pipe exit (on the mezzanine floor) would be 5000 mrem/hr for a full beam fault (15 nC/s). During Storage Ring Commissioning these penetrations were monitored during normal operations and Fault Studies. There were no increases observed at the mouth of the opening. These are small areas for which it will be easy to institute additional controls and shielding as needed. All penetrations will continue to be monitored by RCD personnel to ensure that sufficient shielding and controls have been provided to reduce leakage radiation to acceptable levels.

BNL has two important yearly dose limits that each facility must satisfy. NSLS–II must limit the dose to the nearest non–NSLS–II facility to less than 25 mrem/yr. This limit includes the contributions from activated air, direct dose and skyshine. The normal operation of NSLS–II must not expose the public off–site to more than 5 mrem/yr. This includes all pathways for exposure to the public off–site from NSLS–II operations. Based on the discussion of Appendix 12 (skyshine), section 4.15.4.2 (air activation) and 4.15.4.4 (groundwater activation) the operation of NSLS–II is well below these limits.

4.15.4 Beamlines and Beamline Front Ends

This section describes the methods used to establish the shielding for the six project Beamlines that will be commissioned during the early stages of routine operations. It establishes the methodology that will be used for all future Beamlines..

4.15.4.1 Beamline Radiation Hazards

There are two types of Beamline radiation hazards: Synchrotron Radiation (SR) and bremsstrahlung radiation created by high energy electron interactions within the ring. Both sources will produce scattered secondary radiation, but bremsstrahlung because of its much higher energy generally dominates the shielding requirements in the FOE. Both sources require evaluation of all interactions with apertures, monochromators, mirrors, windows, beam pipes or samples. Shielding, in most cases lead sheet, is needed to reduce radiation to design levels outside the FOE. Bremsstrahlung radiation is also analyzed through a ray tracing process to ensure that it is confined to the Beamline shielded enclosures by lead and/or tungsten collimators. Ray tracings are performed to ensure that all surfaces that the SR can strike are properly cooled.

Each hazard will be considered separately.

Bremsstrahlung

Bremsstrahlung in a Beamline represents a significant radiological source term and is produced from the interaction of the circulating electrons with gas molecules in the vacuum pipe or with the Storage Ring accelerator structures. Bremsstrahlung is an electromagnetic shower with photon energies that can range up to the maximum energy of the circulating electron beam. Bremsstrahlung radiation is highly peaked in the forward direction, and for a given electron beam energy the rate of production is directly proportional to the stored current and the gas pressure in the ring section that the electrons pass through. Bremsstrahlung is more important for undulator and wiggler Beamlines, which are tangential to the straight sections in the ring, thereby providing longer flight paths for bremsstrahlung production by the circulating electrons.

Because of its high energy, bremsstrahlung in the forward direction must be shielded with thick lead blocks (or with other high Z materials such as tungsten) to control personnel exposure in occupied areas during normal or abnormal operation. To ensure the adequacy of shielding, each Beamline is examined as described in Appendices 13 and 14. In these analyses, the bremsstrahlung shielding is evaluated by conducting ray traces down the length of the Beamline to confirm that the bremsstrahlung is stopped before emerging on to the experimental floor. A bremsstrahlung ray is considered stopped after it has passed through the full shield thickness specified for the bremsstrahlung stop. The stopped primary bremsstrahlung ray should not be closer than 3 Moliére Radii (3R) from the lateral edge of the collimator or stop (the Moliére Radius for lead is 12.5 mm and that for tungsten of density ~18 g/cm^3 is 8 mm).

Synchrotron Radiation

The synchrotron radiation created in the Storage Ring represents an intense, broad band radiation source; scattered radiation from beam interactions with windows and other Beamline components can produce significant radiation fields that must be considered. Synchrotron radiation is much lower energy than the bremsstrahlung radiation described above.

The full unattenuated spectrum of photons emitted from an insertion device or bending magnet is commonly called the "white" beam. White beams constitute the greatest radiological hazards and require the greatest shielding and cooling because they contain the total power of the emitted synchrotron radiation. In some Beamlines, the white beam will be deflected through the use of cooled mirrors. This results in the loss of the higher and lower energy components of the white beam and the remaining beam is typically called a "pink" beam. Such beams require additional shielding at beam scatter points, but typically less than that found for white beams.

Commonly the research conducted at a Beamline requires a single energy beam produced by the diffraction of the white or pink beam off one or more monochromator crystals. Monochromators will appear in practically all Beamlines at NSLS–II. The characteristics and magnitude of scatter hazards for these synchrotron radiation sources differ and analysis is done on a case by case basis.

4.15.4.2 NSLS–II Beamline Shielding on the Experimental Floor

The annual dose received by Beamline scientists from NSLS–II Beamline operations will be kept well below federal limits and within BNL administrative levels through shielding, operational procedures, and administrative controls.

Because of the increased working time of the user community close to the experimental stations and beam transport pipes at the Beamlines, a design goal of 0.05 mR/h contact dose on the experimental floor was used where practical. In some cases, the goal has been relaxed to 0.05 mR/h at a distance of 30 cm from the surface because of the shielding complexity. Measurements at 30 cm are more typical of those used in whole body evaluations

During operations with stored beam, all posting and controls will be based on actual measurements to maintain radiation exposures ALARA and consistent with Part 835 requirements and the BNL RadCon Manual.

4.15.4.2.1 Shielding Design Calculations

As described in Appendices 13 and 14, shielding guidelines for the six project Beamlines have been developed using the EGS4, FLUKA and STAC8 computer programs. All calculations are based on a 500 mA stored beam current at 3.0 GeV energy. Contact dose rates have been calculated at the external surface of the Beamline enclosure shield walls. The detailed methodology and results of these calculations are available in a series of NSLS-II technical notes and are summarized in appendices 13 and 14. These results are representative of the methodology process used to evaluate beam line shielding requirements and will change as parameters vary with the beam line source or configuration changes.

4.15.4.2.2 Primary Bremsstrahlung Shutters/Stops/Collimators

A series of bremsstrahlung collimators and shutters are provided in the Beamline front end to permit safe entry into the FOE. These devices are sized to stop a primary bremsstrahlung beam generated within the upstream straight section by electron interaction with residual gas molecules or from electrons striking the undulator or the walls of the vacuum pipe. When the front end shutters are open, a bremsstrahlung stop in the Beamline prevents the high intensity bremsstrahlung beam from passing through a hutch wall and exposing occupants on the experimental floor.

The thickness of the bremsstrahlung stops/shutters is calculated for a dose rate limit of <0.25 mrem/h at the downstream side of the stop/shutter. This design goal was used since these shutters or stops are situated inside the shielded enclosures. The straight beam path for bremsstrahlung production in an insertion device (ID) Beamlines is 15.5 m, and for three–pole wiggler (3PW) and bending magnet (BM) Beamlines 6.6 m. The Storage Ring vacuum assumed in all calculations is 1 ntorr.

Table 4.13 summarizes the results of the EGS4 calculations for the thickness of bremsstrahlung shutters/stops at the NSLS–II ID and 3PW/BM Beamlines and front ends.

TABLE 4.13

4.13 EGS4 RESULTS OF THE BREMSSTRAHLUNG SHUTTER / STOP CALCULATIONS

	ID Beamline	3 PW & BM Beamlines
BREMSSTRAHLUNG DOSE RATE AT 1 nT	176 rem/h	74 rem/h
LEAD THICKNESS REQUIRED	27.4 cm	25.6 cm
TUNGSTEN THICKNESS REQUIRED	20 cm	19.5 cm
DOSE RATE BEHIND THE STOP/SHUTTER	0.25 mrem/h	0.25 mrem/h

The synchrotron radiation can place a significant thermal load on bremsstrahlung shutters and collimators. Adequate thermal protection is provided to these devices in order that the shielding cannot be compromised. This protection is usually achieved in the Beamlines by appropriately designed copper photon masks or stops located upstream of the lead / tungsten safety shutters, stops or collimators. Overheating of these devices is considered in Section 4.15.9.

An offset is necessary for bremsstrahlung stop–monochromatic beam pass shutters or collimators, to prevent portions of the bremsstrahlung shower generated in the stop from entering the beamline. Primary bremsstrahlung collimators need the same thickness as bremsstrahlung stops/shutters. The transverse dimensions of the shutters/stops can be determined from the primary bremsstrahlung ray tracing adding three Moliere radii of the shutter/stop material beyond the extremal bremsstrahlung ray. Aperture dimensions of the bremsstrahlung collimators are determined based on synchrotron radiation ray tracing.

4.15.4.2.3 Source Parameters for SR Shielding Calculations

Table 4.14 gives the source parameters (unless otherwise stated) used to calculate synchrotron radiation production for each beam line photon source using STAC8. The horizontal opening angle for the ID or BM source fans in the first optics enclosures are given in column 2. These are the maximum horizontal apertures used in shielding calculations for the full synchrotron radiation fan to pass into the FOE. It should be recognized that these calculations are for the initial set of source parameters and that the results do not apply to new or modified sources with a different set of parameters. Such changes will require a new calculation to determine shielding needs.

TABLE 4.14

4.14 SOURCE PARAMETERS USED FOR SHIELDING CALCULATIONS FOR THE NSLS–II BEAMLINES

SOURCE	MAX. SOURCE OPENING ANGLE (FOE aperture)	NO. OF PERIODS	B_{eff} (T)	PERIOD (mm)	LENGTH (m)	E_c (KeV)	TOTAL POWER (KW)
DW90	3.0 mrad–H	75	1.8	90	7 m	10.8	62.2
EPU45 L. mode	1.0 mrad–H	89	1.03	45	4 m	6.52	13.8
IVU20	1.0 mrad–H	148	1.03	20	3 m	6.65	9.4
BM	10.0 mrad–H	1	0.4	—	2.6 m	2.4	0.172
3PW	4.0 mrad–H	1	1.12	—	0.25 m	6.7	0.370

Monochromatic Beam Shutter Calculations for Damping Wiggler Beamline

Monochromatic beam shutter calculations for the damping wiggler beamlines have been performed using the STAC8 program. Damping wiggler beamlines have been chosen as the most conservative case. Five higher harmonic reflections (111, 333, 444, 555, and 777) of the fundamental modes of 69 and 80 keV have been considered. The results of the calculations have been reported in Table 4.15 and the parameters used for the calculations are in Appendix 13.

TABLE 4.15

4.15 RESULTS OF BEAMLINE MONOCHROMATIC PHOTON SHUTTER CALCULATIONS

Fundamental mode (keV)	Tungsten thickness	Fundamental mono-flux (p/cm^2.s.mradh)	Dose rate at downstream end of the shutter (mrem/h)
69.0	15 mm	1.53×10^{14}	0.26
69.0	20 mm	1.53×10^{14}	0.014
80.0	15 mm	5.8×10^{13}	0.30
80.0	18 mm	5.8×10^{13}	0.04
80.0	20 mm	5.8×10^{13}	0.013

The shutter thickness under consideration is calculated for a contact dose of <0.05 mrem/h at the downstream end of the shutter. To satisfy this specified dose criterion, a minimum tungsten thickness of at least 18 mm is necessary. Being the most conservative case, this shutter thickness has been selected as the standard design for other beamlines.

4.15.5 Shielding for the FOE

Shielding must be provided in the FOE that is adequate to reduce the scattered radiation from both the bremsstrahlung and synchrotron beam sources. Table 4.16 gives the combined results of the STAC8 and EGS4 calculations for the shielding guidelines of the FOE for the project NSLS–II Beamline sources. Shielding thickness for each panel has been calculated for bremsstrahlung and synchrotron radiation and the thickness for the dominant source has been given. Enclosure dimensions are nominally taken as 2 m wide, 3 m high, and 10 m long. The lateral panel is at a distance of 1 m and the roof is at distance of 1.5 m from the Beamline in these calculations. If the final design of the stations and sources are different than the initial design the shielding estimates will need to be re–evaluated. The shielding thickness for the downstream panels of the FOEs is dominated by forward–scattered bremsstrahlung. Therefore a thickness of 50 mm for the FOE downstream panels has been recommended for the ID Beamline and 30 mm for the BM and 3PW Beamlines. Additional collimators and local shielding may be required around the beam pipe and wall penetration, depending on the Beamline configuration.

TABLE 4.16

4.16 SHIELDING GUIDELINES FOR NSLS–II FIRST OPTICS ENCLOSURES

BEAMLINE SOURCE	LATERAL PANEL (Pb)	ROOF PANEL (Pb)	DOWNSTREAM PANEL (Pb)
DW90	18 mm	10 mm	50 mm
EPU45	18 mm	5 mm	50 mm
IVU20	18 mm	6 mm	50 mm
3PW/BM	5 mm	4 mm	30 mm

4.15.6 Shielding Guidelines for the Experimental Enclosures

Shielding in the experimental enclosures will be determined by the intensity of the synchrotron beam and is calculated using the STAC8 computer program. It is assumed that bremsstrahlung has been completely stopped in the first optics enclosures. Therefore EGS4 simulations are not necessary to estimate the shielding thickness for the subsequent experimental enclosures. Five reflections (111, 333, 444, 555, and 777) with corresponding bandwidths have been considered for these calculations with the lowest energy as 22 KeV. Monochromatic beam bandwidths are determined by the optics used. There are analytical (dynamical diffraction theory) and simulation codes (e.g. XOP) that are used to calculate the appropriate bandwidth. Currently, almost all monochromatic beams have bandwidths < 1%. Furthermore, the majority of them have 0.01% bandwidths (Silicon 111). Therefore, for monochromatic beam line shielding design, the process is that the designer calculates the optics bandwidth using available tools. That information is then used as input for radiation shielding calculations using FLUKA or STAC8.

Table 4.17 gives the energies and bandwidths considered for these calculations. Enclosure dimensions are assumed to be 2 m wide x 3 m high. Side panels are at a distance of 1.0 m and the roof is 1.5 m away from the beam centerline.

TABLE 4.17

4.17 ENERGIES AND BANDWIDTHS USED FOR EXPERIMENTAL ENCLOSURE SHIELDING CALCULATIONS

MONOCHROMATIC BEAM ENERGIES CONSIDERED (KeV)	MONOCHROMATIC BANDWIDTHS CONSIDERED (keV)
22	2.2×10^{-3}
66	5.3×10^{-4}
88	5.3×10^{-4}
110	1.3×10^{-4}
154	4.0×10^{-5}

The results of these calculations for five NSLS–II sources are provided in Table 4.18. The calculated shielding thicknesses in Pb or Fe for the side panels, roof, and upstream/downstream panels have been given for the contact dose rate of <0.05 mrem/h.

TABLE 4.18

4.18 SHIELDING GUIDELINES FOR EXPERIMENTAL ENCLOSURES

BEAMLINE SOURCE	LATERAL PANELS TO SHIELD<0.05 mrem/h	ROOF TO SHIELD< 0.05 mrem/h	UPSTREAM & DOWNSTREAM PANELS TO SHIELD < 0.05 mrem/h
DW90	4 mm Pb	3 mm Pb	4 mm Pb
EPU45	6 mm Fe	3 mm Fe	6 mm Fe
IVU20	6 mm Fe	3 mm Fe	6 mm Fe
BM	2 mm Fe	2 mm Fe	2 mm Fe
3PW	3 mm Fe	2 mm Fe	3 mm Fe

In most cases, the pink beam experimental enclosures (assuming 30–50 keV mirror cut–off energy) need the same shielding thickness as the monochromatic enclosures because of the absence of higher energy harmonics in the pink beam.

4.15.7 Shielding Guidelines for the Experimental Beam Transports

The beam transport pipes between the FOE and the experimental enclosures may require shielding depending on the source and experimental–beam characteristics of the Beamline. In every case, careful ray tracing of the synchrotron radiation must be carried out to ensure that no part of the beam hits the transport pipe.

STAC8 calculations have been carried out using 10 m of air at one atmosphere as the potential scatter source inside the beam transports, simulating a vacuum loss accident. For transport shielding calculations, the same conservative beam harmonic energies and bandwidths have been used as in the experimental enclosure shielding calculations. As loss of vacuum is an accidental condition, the dose rate criteria adopted for these calculations were <5 mrem/h on contact of the transport pipe. Calculations have also been carried out for the presence of potential solid scatterers such as flags/screens, etc. inside the beam transports, as this may require additional local shielding. The dose rate criteria applied for this operating condition is <0.05 mrem/h on the surface of the transport pipe. Table 4.19 summarizes these results.

In most cases the pink beam transports (assuming 30–50 keV mirror energy cut–off) have the same shielding thickness as the monochromatic beam transports because of the absence of higher energy harmonics in the pink beam. Thermal load handling of the pink beam needs separate analysis. However, bremsstrahlung component is assumed to be completely absent in the experimental beam.

TABLE 4.19

4.19 SHIELDING GUIDELINES FOR THE EXPERIMENTAL BEAM TRANSPORTS

BEAMLINE SOURCE	SHIELDING REQUIRED FOR < 5 mrem/h DUE TO COMPLETE VACUUM LOSS IN THE BEAM TRANSPORT	SHIELDING REQUIRED LOCALLY ON BEAM TRANSPORT FOR < 0.05 mrem/h FOR A SOLID SCATTERER
DW90	3 mm Pb	7 mm Pb
EPU45	1.5 mm Pb	3.0 mm Pb
IVU20	1.5 mm Pb	3.0 mm Pb
BM	2 mm Fe	3.0 mm Pb
3PW	3.0 mm Fe	3.0 mm Pb

4.15.8 Abnormal Operating Conditions, Including Maximum Credible Incident

The combination of concrete and supplemental shielding described above for normal operation is based on the beam losses defined in those sections. Higher beam losses are possible during operation of the accelerators because of mis–set operational parameters or equipment failure. Fault Studies were conducted during commissioning to empirically measure the consequences of mis–set parameters and verify the shield design. Results of the Linac Fault Studies are reported in Appendix 15. A summary of the results of the Fault Studies and a comparison to calculations are presented in this section.

Linac

The maximum energy of the Linac assuming all three klystrons are fully tuned and powered has been calculated to be 250 MeV. During normal operation, the Linac can deliver a maximum of ~22 nC per pulse–train at a maximum rate of 1 pulse train per second. Analysis of failure modes within the Linac gun has identified highly unusual, but possible, fault scenarios in which an electron pulse of 100 nC could be produced at a repetition rate of 1 Hz or 360 μC averaged over one hour (Appendices 16 and 17). The MCI analysis for Linac assumes an electron energy of 250 MeV and a current of 100 nC/s.

The consequences of beam losses during Linac operation and transport were examined using FLUKA for beam mis–steering by quadrupoles or dipoles (see Appendix 6a). The resulting ambient dose equivalent was calculated for potentially occupied areas in the Linac Klystron Gallery and Booster enclosure, and on the berm on the top and side of the Linac enclosure. The highest calculated dose rates in each of the three regions of interest were scaled to 100 nC/s and are shown in Column 2 of Table 4.20 below. The peak measured rates for the Linac Fault Study scaled to 100 nC/s are shown in the third column.

TABLE 4.20

4.20 COMPARISON OF LINAC PEAK CALCULATED DOSE RATES TO PEAK MEASURED VALUES DURING COMMISSIONING FAULT STUDIES

(All Values Scaled to 100 nC/s) (Dose rates are in mrem/h)

LOCATION	PEAK FLUKA ESTIMATE	PEAK MEASURED DOSE RATE
Klystron Gallery (through wall)	50	5
Klystron Gallery (through penetration)	300	67
Booster Enclosure	20	42
Berm top	<2	Background

Summary of Linac Abnormal Operating Conditions and Fault Studies
The Fault Study was conducted in accordance with an approved plan. Fault conditions were created first at beam energy of 100 MeV and 13 nC/s in multi-bunch mode with a spill of beam on the B1 bending magnet. Fault conditions then followed at 200 MeV and 13 nC/s in multi-bunch mode with beam spilled at LB-GV1BD1 (Gate Valve 1), fourth accelerator structure (150 MeV), beam dump 1, beam dump 2, the LB-VF2 (flag) and finally the LB-Q6 (magnet).

Comparison of the survey data to the dose rates calculated by fault condition simulation shows all survey measurements to be a fraction of that estimated by simulation. The maximum total dose encountered during the Fault Study was 8.7 mrem/hr measured at a high penetration between the Klystron gallery and Linac. The original dose estimate was "100's" of mrem in an hour. All survey results along the beam-height in the Klystron Gallery were less than 1 mrem/hr. Dose rates within the Booster enclosure were elevated at locations above and below beam heights, which were expected.
The shielding was judged to be effective in reducing dose rates to acceptable levels since survey results show calculated dose rates to be conservative. Radiation monitors LRM-01 and LRM-02 are appropriately located to monitor these areas. No weaknesses in the Linac shields were identified.

Booster
The maximum radiation levels calculated using thick target approximations for areas adjacent to the Booster are provided in the Table 4.21 below for transverse radiation with no supplemental shielding. The numbers are based on the analysis provided in the Booster Commissioning Safety Assessment Document (BCSAD) dated 12/08/2011. The 200 MeV values are scaled with beam power based on the analysis presented in the BCSAD for 3.2 GeV and both energies presented for convenience. The numbers for the Storage Ring mezzanine and the ISA second floor have been scaled from the respective lower area dose rates using changes in the distance and effective shielding.

TABLE 4.21
4.21 PREDICTED RADIATION LEVELS AT 90° FOR 25 NC/S LOST IN A THICK TARGET (DOSE RATE IN mrem/hr)

AREA	200 MeV	3GeV
ISA first floor	30	430
ISA second floor	10	140
Roof over Injection	86	1380
SR tunnel–Booster Ring	20	370
SR mezzanine–Booster Ring	6	90
Service Building 1	2	37

Detailed Monte Carlo simulations of beam faults in the Booster were also conducted using FLUKA (see Appendix 6b). The supplemental shields and magnet yoke are included in these simulations. The dose rates for a continuous loss of 25 nC/s injected current are given in Table 4.22 for electron beam energy of 3.0 GeV. Scaling to 3.2 GeV would increase the dose rates by less than 15%.

TABLE 4.22

4.22 EXTERNAL RADIATION WITH SUPPLEMENTAL SHIELDING FOR 25 nC/s (FLUKA)

AREA	FLUKA CALCULATIONS (mrem/h)
ISA first floor	27
ISA second floor	25
Booster Berm over injection	150
Booster berm over extraction	367
SR tunnel–Booster ring	37
SR mezzanine–Booster ring	23
SR alcove–Booster	335
Cableway Vault Fence	110

Summary of Booster Fault Studies

A series of three Fault Studies as described in the approved plan was conducted during Booster commissioning to evaluate adequacy of shielding and the location of area monitors The faults were created by insertion of a gate valve or diagnostic flag or by mis–steering the beam to create losses at a particular point in the Booster ring or transport lines. Results of these Fault Studies are reported in Appendices 18a, 18b and 18c.

Phase I of the Booster commissioning Fault Studies (Appendix 18a) was conducted around the ring at 200 MeV with faults created at five locations selected to test the adequacy of the shielding at various locations around the ring. The test was conducted with an injected charge of ~ 2nC/s. All readings were close to or near background during the study except for one wall in the Linac Klystron gallery. The location read ~ 1250 mrem/h (scaled to 25 nC/s) when the gate valve in the RF straight section was closed. Additional shielding was provided which reduced the radiation levels to ~125 mrem/h (scaled to 25 nC/s). The interlocked radiation monitor positioned in the Klystron galley to monitor the Booster RF straight was moved upward ~ 1 foot to be at the location of highest dose rate for this fault.

Phase II of the Booster commissioning Fault Studies (Appendix 18b) was conducted at 3 GeV with a circulating charge of 1.25 nC/s. Surveys were performed along the ISA wall in the vicinity of the radiation monitors, Klystron gallery, Pentant1 and Pentant2 of the Storage Ring, second floor of the ISA, the mezzanine and along the berm fence and exposed Booster wall within the secured courtyard. Injection current ranged from 1.25 to 1.5 nC/s during these studies. The maximum dose rates encountered during these studies were recorded in the Klystron Gallery along the Booster wall. Dose rates ranged to a maximum of ~ 40 mrem/hr (scaled to 25 nC/s) which are within predicted maximum levels for the faults.

Phase III of the Booster commissioning Fault Studies (Appendix 18c) were conducted along the Booster to Storage Ring transport line at 3 GeV with an injection charge of 1.50 nC/s. Four locations of faults were specified for this study: along the extraction line, Gate Valve BS–GVIBD, Flag BS–VFIBD, and the Beam Dump. Radiation surveys were performed along the Booster to Storage Ring wall, the experimental area mezzanine (both along the floor and wall), the Booster wall in the Injection Service Area, the HVAC mezzanine (inside and outside wall) and along the outdoor berm. All dose rates measured were within expected levels. The highest dose rates were measured along the shield wall where the Booster transport line penetrates into the Storage Ring enclosure. The maximum dose rate measured was 4 mrem/hr, which consisted of 3.5 mR/hr gamma and 0.5 mrem/hr neutron. These maximum dose rates were within the Storage Ring enclosure which will be unoccupied during operations. The maximum dose rates measured in occupied areas was ~ 13 mR/hr (scaled to 25 nC/s), which was identified along the floor of the Storage Ring mezzanine at an expansion joint. Based upon these measurements, the shielding and area radiation monitor locations were judged to be acceptable.

Storage Ring

The radiological consequences for a series of abnormal conditions have been calculated at maximum energy and charge for both injected and stored beam conditions for a number of locations adjacent to the Storage Ring.

The Transverse Dose Rates through Storage Ring Walls for full beam loss at the nominal energy of 3.0 GeV have been evaluated in Appendix 19 using a thick target approximation. This is essentially the same technique used during initial design except the actual architectural drawings were used to find locations of interest. One table from this analysis is presented in Table 4.23 below. The transverse radiation will be 10% higher for 3.3 GeV. The calculations do not take credit for potential shielding provided by accelerator components and use conservative shielding attenuation factors.

TABLE 4.23

4.23 TRANSVERSE THICK TARGET DOSE RATES FOR SR ROOF AND OUTER WALLS

AREA DESCRIPTION	SHIELDING (cm)	DISTANCE[1] (cm)	Dose rate (mrem/hr)
Upstream tapered SR Wall	100 (LC)	257	355
Upstream tapered SR wall	100(HC)	257	24
Downstream tapered wall	80 (LC)	400	367
Downstream tapered wall	80 (HC)	400	86
Blocked in doorway	61 (HC)	400	155
Location over sliding doors	50(LC)	400	1520
Location over sliding door	50(HC)	400	362
Roof over SR	80 (LC)	376	416

[1] Field measurements were used to obtain a distance of approximately 127 cm from the beam to the wall in the upstream end and 320 cm of the downstream end. There were some variations in distance at the upstream end which could cause increases in dose outside the shield wall by 30%. Several sections of wall near injection have heavy concrete. (28B through 30 check)

FLUKA calculations for many of the same locations were also conducted and are presented in Appendix 20. These calculations are similar to the thick target approximations above but use the actual energy dependent attenuation factors for the shielding. An optimum target was used to provide maximum transverse radiation. Comparison of the results of these two sets of calculations is shown in the Table 4.24.

Table 4.24

4.24 COMPARISON OF ANALYTICAL METHOD AND FLUKA MCI CALCULATIONS FOR THE STORAGE RING (15 nC/s Loss at 3.0GeV on a Thick Target (10 X_0 of Cu)

	SHIELDING (LIGHT CONCRETE)	DISTANCE (cm)	ANALYTICAL TOTAL DOSE (mrem/h)	FLUKA TOTAL DOSE (mrem/h)	FLUKA NEUTRON DOSE (mrem/h)
Road tunnel – pavement	71 cm	688	189	60	17
Road tunnel – 3 m above pavement	71 cm	388	596	200	50
Utility tunnel – floor	66 cm	597	319	110	25
Utility tunnel – 2m above floor	66 cm	397	720	230	60
Storage Ring Mezzanine	80 cm	280	626	200	75
Storage Ring Inboard	80 cm	280	626	200	75
Storage Ring Experimental Floor side	100 cm	200	481	150	80

The results show that the analytical results are at least a factor of 3–5 conservative compared to FLUKA calculations.
A comparison of the FLUKA MCI calculations to the measurements made during Storage Ring Commissioning Fault Studies (Appendices 23a and 23b) is presented in Table 4.25.

TABLE 4.25

4.25 COMPARISON OF FLUKA MCI CALCULATIONS AND FAULT STUDIES FOR THE STORAGE RING

AREA	FLUKA TOTAL DOSE RATE (mrem/hr)	FLUKA NEUTRON DOSE RATE (mrem/hr)	FAULT STUDY RESULTS SCALED TO15 NC/S (mrem/hr) NEUTRON DOSE IN PARENTHESIS
Experimental Floor (Injection Loses)	<40		~ 10
ISA	<40		~10
Road tunnel – 3 m above pavement	200	50	~3
Utility tunnel – 2m above floor	230	60	~5
Storage Ring Mezzanine	200*	75*	~20 (31)
Storage Ring Inboard	200*	75*	~36(27)
Storage Ring Experimental Floor side	150*	80*	~120 (31)
ISA Labyrinth Entrance		40	~1
Storage Ring RF Penetration	50	32	~22

*Dose Rates are contact dose rates calculated on the shield surface

As had been anticipated the measurements of the ring shielding made during Storage Ring commissioning were generally lower than the calculated FLUKA by a factor of 5 – 10.

Mis–Steering Effects

The accelerator magnets can mis–steer the beam in the injection transport line and to a lesser degree in the Storage Ring. Such mis–steering can change the relative angle of the electromagnetic shower to the Storage Ring shielding walls or cause the shower to miss supplemental shielding if they are not designed to take such conditions into account. To provide specific calculations for mis–steering losses the FLUKA Monte Carlo program has been used to examine dose outside the shielding. These events assume the beam energy entering the Storage Ring tunnel has a range from 2.0 GeV to 3.2 GeV. Electron energies outside this range are prevented by the PPS system monitoring two dipoles and beam optics. The analysis in Appendices 21 and 22 demonstrates that the energy of electrons entering the Storage Ring enclosure can vary between 2 GeV and 3.15 GeV with bending magnets B1 and B2 operating in their designated current window of 5% centered on 3.0 GeV. For mis–steering events in the Storage Ring the beam is assumed in the analysis to have an energy ranging from 2.8 GeV to 3.3 GeV. Energies outside this range are prevented by the injection transport line interlock and a second interlock monitoring the Storage Ring main dipole current. This interlock has been set to interlock injection if the ring dipole current differs by more than 2% from that required to store 3 GeV electrons,. These settings are actually much tighter than required to satisfy the conditions assumed in the mis-steering analysis. The supplemental shields and magnets are included in the simulation. The dose rates are calculated for the maximum injection rate of 15 nC/s. Complete details of the analysis are given in Appendix 6c for both injection line and the Storage Ring mis–steering.

The results presented in Table 3.2.1 of Appendix 6c have been simplified, dose rates rounded–off, and are presented in Table 4.26 below. This table examines several locations related to five different mis–steering faults at a beam energy of 3.0 GeV. Most dose rates are quite low with a few of the larger ones being 20–70 mrem/hr. This analysis does not consider other controls to limit the beam faults such as nearby radiation monitors or operational procedures to monitor beam losses. It does suggest that the Shielding Policy requirements are satisfied by the bulk and supplemental shielding.

TABLE 4.26

4.26 FLUKA RESULTS FOR BEAM MIS–STEERED IN THE BOOSTER TO STORAGE RING TRANSPORT LINE DOSE RATES are in mrem/h for 15nC/s BEAM LOSSES

ENERGY	3 GeV	3 GeV	3 GeV	3 GeV	3 GeV
LOSS CONDITION	BSR–B3Off	BSR–B3FF	BSR–B4Off	BSR–B4FF(8.4°)	BSR–Q14maxBL
INNER WALL	2	70	5	15	<0
ALCOVE INNER WALL	20	40			<5
ROOF INNER	35	40	40	20	15
ROOF CENTER 100cm	4	2	10	4	60
ROOF OUTER	1	0.6	3	2	20
STORAGE RING OUTER WALL	2	5	5	10	40
29ID DOOR	0.5	.5	1	1	20
29ID RATCHET CORNER	0.1	0.1	0.5	0.5	10
AFTER 29ID RATCHET SHIELD	1	0.1	0.1	0.1	5
28BM DOORWAY	8	5	15		5

These abnormal operating conditions were all evaluated during the Phase I Storage Ring Fault Studies. The maximum dose rate scaled to 15 nC/s was ~55 mrem/h. Most areas were < 5 mrem/h.
The injection straight in the Storage Ring is another location where mis–steering can occur. A series of possible faults were considered for 3.0 GeV beam and an injected beam charge of 15 nC per second. The results from Appendix 6c are presented in Table 4.31 below; Table 3.2.2 in the Appendix 6c has been simplified, the numbers rounded, and four of the seven fault conditions have been selected for inclusion in Table 4.27.

TABLE 4.27

4.27 FLUKA RESULTS FOR MIS–STEERED BEAM IN THE INJECTION STRAIGHT AT 3.0 GeV AND 15 nC/s

ENERGY	3 GeV	3 GeV	3 GeV	3 GeV
LOSS CONDITION	DC septum off	DC septum FF	AC septum off	AC septum FF
ISA WALL	16	30	12	16
ROOF INNER	18	60	16	30
ROOF CENTER 100cm	26	20	20	25
ROOF OUTER	12	20	13	30
STORAGE RING OUTER WALL	3	4	0.4	16
29ID DOOR	22	2	0.3	0.2
29ID HUTCH CORNER	15	1	1	0.5
AFTER 29ID HUTCH SHIELD (INSIDE)		4	9	8

The abnormal conditions described in this table were also evaluated during the Phase I Storage Ring Fault Studies. Maximum radiation levels in any location scaled to 15 nC/s was ~ 5 mrem/h.

Consequences of possible mis–steering by the Storage Ring magnets of the injected beam were evaluated using FLUKA and are reported in Appendix 6. These results are summarized in Table 4.28 below.

TABLE 4.28

4.28 FLUKA RESULTS FOR MIS–STEERED INJECTION BEAM STRIKING A VACUUM FLANGE AT 3.0 GeV AND 15 nC/s

AREA	**mrem/h**
Forward ratchet wall	< 1
Experimental floor	30
Mezzanine floor	45
Inside wall	8

These miss–steering conditions were evaluated during the Phase II Storage Ring faults studies. Highest radiation levels found in any of the studies was on the mezzanine where levels on the order of 20 mrem/h were found scaled to 15 nC/s. An exception to this was around the seams of front end doors were levels of ~300 mrem/h (scaled to 15 nC/s) were found leaking through this location.
Penetrations The FLUKA analysis in Appendix 6c examined the supplemental shields for penetrations. Figure 4.1 below was copied from Appendix 6c, Figure 4.3.11. It displays the dose rates for the outer Storage Ring wall from the injected beam being lost near the RF cavity and the leakage through the water pipe penetration. The dose outside the penetration is 100 mrem/hr and is 90% neutrons. The analysis examines the large RF

penetrations and the dose rates with the supplemental shielding in place. For these large penetrations with 15nC/s of lost beam the dose rates can approach 1000 mrem/hr in small special locations as noted earlier. These locations were examined during the phase II Fault Studies and radiation levels were no different at the exterior of these penetrations compared to the nearby wall.

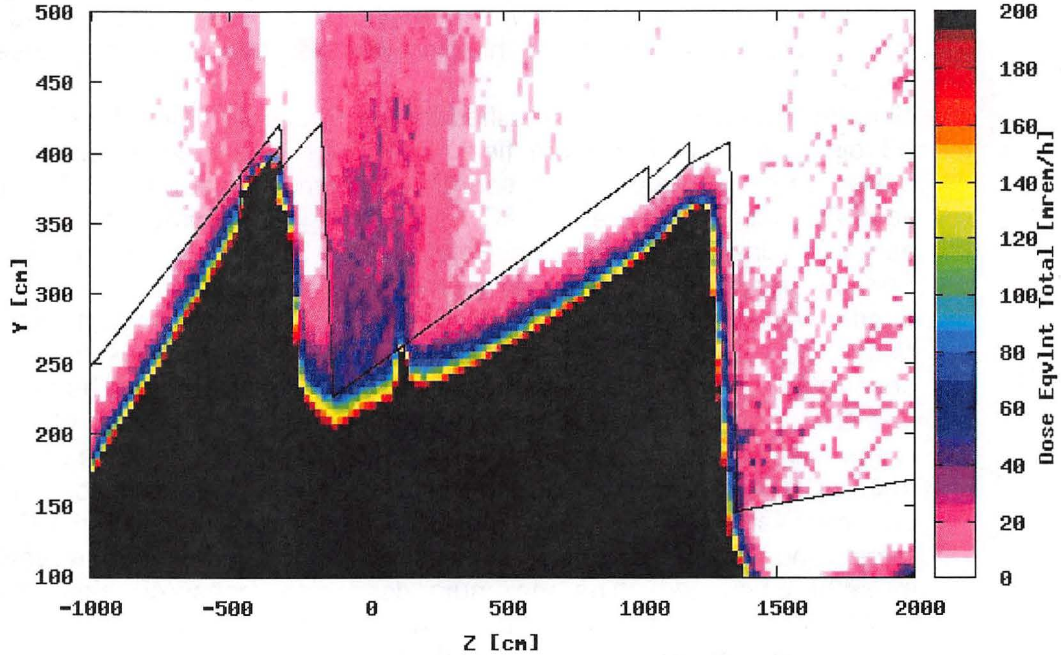


FIGURE 4.1

4.1 THE DOSE RATE THROUGH THE OUTER STORAGE RING WALL FOR INJECTED BEAM LOSS AT 15nC/s INTO THE RF CAVITY

The largest penetration in the ratchet walls is the one for the diagnostic beam line SLM, discussed in Appendix 6c. The highest level calculated for the SLM Hutch is 50 mrem/hr. The largest penetrations for the bulk shielding are the service building labyrinths. Radiation transport through labyrinths has been evaluated using FLUKA. FLUKA or other Monte Carlo simulations provide the best estimate of radiation fields emerging through these large openings. Appendix 11a provides details for 15 nC/s of 3.0 GeV electrons lost at a point near the labyrinth opening in the ring. A dose rate of 60 mrem/h at the entrance in the service building was obtained. This is substantially lower than the estimate obtained using albedo coefficients. A summary for leakage through the Service Building labyrinths is shown in Table 4.29 below.

TABLE 4.29

4.29 FLUKA CALCULATION FOR LEAKAGE AT ENTRANCE TO SERVICE BUILDING LABYRINTHS 15 nC/s LOST ON THICK IRON TARGET

AREA	PHOTON mrem/h	NEUTRON mrem/h	TOTAL mrem/h
Entrance of the Service Building Labyrinths	20	40	60

This condition was evaluated during the Fault Studies and the maximum level of ~ 25 mrem/h (scaled to 15 nC/s) at the entrance to the door.

Summary of Storage Ring Commissioning Fault Studies

Results of the Fault Studies are discussed in Appendices 23a and 23b and were included in the discussions above. This section provides more information regarding the nature of the Fault Studies. The Storage Ring Commissioning Fault Studies were performed in three phases in accordance with an approved Fault Study plan (Appendix 24) and commissioning sequence plan (Appendix 25). The Phase I studies were performed for the transport of 3 GeV beam through the BTS Injection Straight. As outlined in the Fault Study Plan, prior to authorizing progression to the next phase of commissioning, a review of radiological data taken during the previous phase was performed to ensure that all radiological dose rates was within expected ranges, the area radiation monitors were located appropriately and the shielding was effective in reducing dose rates to acceptable levels.

Nine fault conditions were specified for the Phase I study: BTS B3 dipole magnet off, BTS B3 dipole magnet maximum field, BTS B4 dipole magnet off, BTS B4 dipole magnet maximum field, Energy Slit closed, DC Septum Magnet off, DC Septum Magnet maximum field, AC Septum Magnet off, AC Septum Magnet maximum field. Radiation surveys were performed inside the Injection Service Area along the Storage Ring wall, the Injection Service Area mezzanine, the experimental area mezzanine (Cells 28 – 30), and along the ratchet wall in experimental areas cells 28 – 30. With the exception of one measured dose rate in the injection service area, all dose rates were much less than the FLUKA calculated dose rates, some by approximately a factor of three or more. The one exception was found in a corner of the Injector Service Area along the Storage Ring wall, immediately adjacent to the injection region (near dipole magnets B3 and B4); a dose rate of ~55 mR/hr (scaled to 15 nC/s) was measured during the B3 maximum field condition compared to the FLUKA predicted value of 40 mrem/hr These values compare well with the FLUKA calculated dose rates reported in the Safety Assessment Document (~ 55 mrem/hr measured vs 40 mrem/hr calculated). The maximum dose rate measured along the ratchet walls and mezzanine during all Fault Studies was 18 mrem/hr (scaled to 15 nC/s). No follow–up actions were required as a result of these studies.

Phase II Fault Studies were performed with 3 GeV beam circulating in the Storage Ring. Results of these studies are reported in Appendices 23a and 23b. Nine different areas around the ring were studied by inserting devices (e.g. flags, scrapers, or gate valves) or by mis–steering the beam into designated locations. Review of the data shows that for most locations, the dose rates are less than the FLUKA calculated dose rate for 15 nC/s lost (i.e. ~ 20 mrem/hr measured vs 130 – 180 mrem/hr calculated).

Two local exceptions to these results are noted: Exception 1 involves the gap formed in the seam between the movable plug door and the concrete bulk shielding. In that location a maximum dose rate of ~300 mrem/h (scaled to 15 nC/s) was measured. This event was created by miss–steering the beam to the outside of its normal orbit striking the ring vacuum pipe near the upstream end of a straight section. Exception 2 involves increased radiation in a corner in the shield wall created by the forward ratchet wall meeting the on–going lateral wall. In this location, radiation levels of ~150 mrem/h (scaled to 15nC/s) for a 15 nC/s loss on the closed gate valve was measured. This valve is normally open and is interlocked to the injected and stored beam through the EPS interlock system. As presented in Appendix 26, in both of these cases the radiological conditions created by these abnormal events would have been detected by the nearest radiation monitor and alarmed in the accelerator control room.

4.15.8.1 Abnormal Condition Resulting in the Maximum Credible Incident

Based on calculation the abnormal condition producing the highest radiation level in a potentially occupied area, identified as the MCI, is a 3.2 GeV injected beam at 15 nC/s lost at a point. Calculations reported in the section above were for 3.0 GeV, thereby requiring that the reported values be modified by the factor 1.07 (transverse) to 1.14 (forward). The maximum dose rates have been calculated for various regions adjacent to the Storage Ring. Using the thick target approximation the dose rates are expected to be below 500 mrem/hr for essentially all areas.

The maximum radiation level scaled to a 15 nC/s loss actually measured in an occupied area during the Fault Studies of the Linac, Booster, and Storage Ring was ~ 300 mrem/h leakage through a seam in the movable plug door. As shown in Appendix 26, the nearest radiation monitor would have detected this event and alarmed in the control room. The operators are trained and qualified to respond to radiation alarms and can be expected to take action in a short period of time. Therefore, the Shielding Policy criteria of < 100 mrem dose to an individual in a Controlled Area as the result of an abnormal event is met.

In the Storage Ring Commissioning SAD, there were several locations that were described as potential MCI events. During the Fault Studies, they were all evaluated and found to not represent significant issues.

These included: the shield wall located above the sliding ratchet wall doors, and the utility and road tunnels.

In addition, the radiological consequences of a loss of stored beam were considered. Using the thick target model, the radiological consequences of a loss of a 1000 mA stored beam at 3.3 GeV will result in a maximum dose of 23 mrem. This represents the maximum dose for a stored beam loss at a thick target. This value satisfies the shielding policy requirement that the maximum dose during an abnormal event is ≤ 100 mrem within a Controlled Area. It should be noted that an operational limit of 550 mA has been established which will maintain the maximum current stored in the ring well below the 1000 mA value used in this evaluation.

The location of radiation monitors were evaluated during low intensity Fault Studies to ensure effective coverage of the ring building during operations at higher injection charge rates and stored currents. The current locations are still assumed to be adequate, however locations will continue to be examined as higher injection and stored beam rates are established.

As was described previously, the operators play an important role in limiting beam loss conditions. In addition to radiation monitors, the operators will have other indicators and alarms which will alert them to substantial losses during injection. The operators will be trained to recognize potential consequences of these fault conditions and to respond by limiting injected beam to minimize radiation exposure until proper injection conditions are re–established.

4.15.9 Abnormal Beamline Operating Conditions, Including Maximum Credible Incident Vacuum Surges

The Beamline shielding described in the above sections is typically based on worst–case conditions, with the exception of vacuum operating pressures. Higher vacuum pressure will produce greater dose rates of bremsstrahlung, which will result in higher scattering dose rates around the FOE. Bremsstrahlung production increases in direct proportion to increases in vacuum pressure. The primary bremsstrahlung source term for NSLS–II Beamlines is calculated for a vacuum chamber pressure of 1 ntorr. However, it is possible to have higher vacuum pressure, >10 ntorr, in the Storage Ring straight sections for brief periods of time during the initial conditioning of the vacuum chamber or insertion devices. Typically, this may last for a conditioning time period of ~50 Amp–hours. During this conditioning period, higher dose rates of >5 mrem/h may be possible around the first optics enclosure shield walls at 500 mA of beam current. Vacuum pressures will be monitored in the Control Room and radiation detectors located at each FOE wall will alarm and automatically close the frontend safety shutters if radiation levels exceed a preset threshold. Radiological control personnel will be made aware of such conditions and will restrict access to the area as needed to maintain exposure to personnel ALARA.

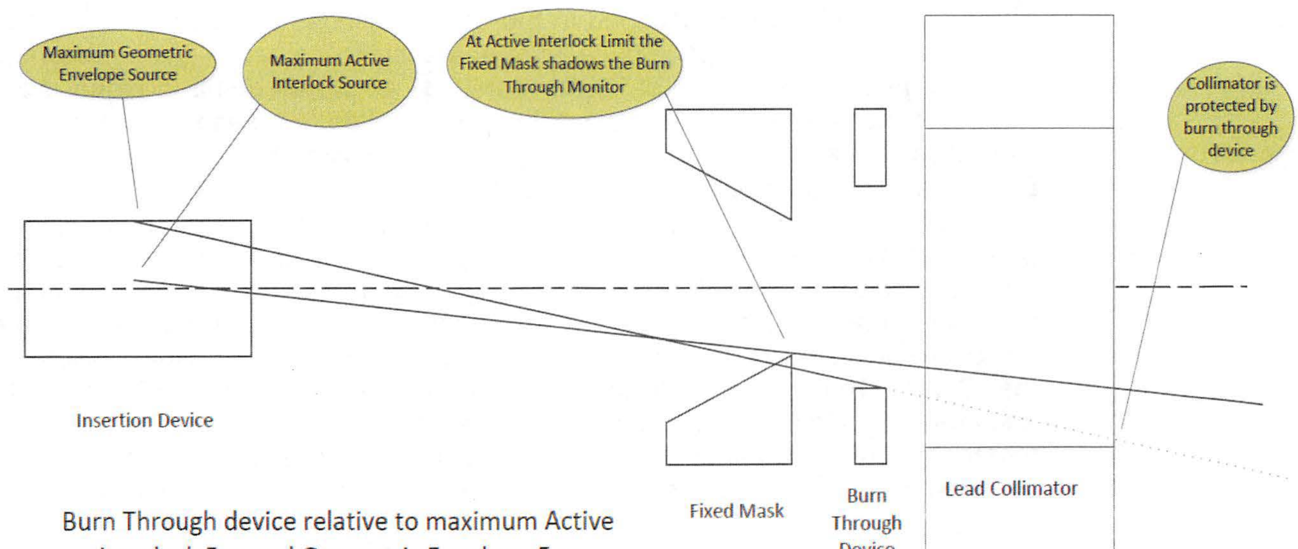
Overheating in Front End

Some of the insertion devices, particularly the damping wigglers, generate very intense synchrotron beams capable of overheating and causing significant damage to inadequately cooled components in the front end. To avoid overheating, the position of the electron beam in the Storage Ring is monitored and controlled by the Active Interlock System (AI). Safe machine operation is assured by limiting electron beam trajectories within the ring to that defined as allowable by the Active Interlock Envelope. The synchrotron radiation generated in the ID can damage uncooled beam line components when the position of the electron beam exceeds boundaries of the AIE and remains in a closed orbit. When the Active Interlock senses an aberrant beam trajectory, it will interlock injected and stored beam through the EPS. Since the EPS is not credited for personnel safety, it is important to consider the consequences of failure of the system and determine if additional measures are necessary to protect personnel.

All non–cooled surfaces within the front end and downstream beam line have been analyzed and positioned through SR ray traces to prevent contact with the synchrotron radiation beam when the electron beam is positioned within the envelope allowed by the AI system. However, since the AI system is not a credited system, ray traces were done assuming that the AI system has failed and that the electron beam could be anywhere within the geometric boundaries of the beam pipe through the insertion device. These assumptions create a larger SR fan (see Figure 4.2) which could overheat a component that would be safe otherwise during normal operation. The consequences of these assumptions have been studied and are reported in Appendix 27 (Front End Personnel Protection Task Force Final Report).

It was concluded that failure of the AI or EPS systems could result in overheating and subsequent failure of the bremsstrahlung collimators and the safety shutters in the front end. Failure of these devices would result in unacceptable doses in the FOE (and possibly beyond) and must be prevented with a credited control quality component. As provided in Appendix 27 the dose for such an event would be 9.6 mrem in the FOE. Passive protection utilizing loss of vacuum as the means of preventing failure of the lead components was chosen as the preferred protective scheme for the front end.

Burn through devices were selected to protect the lead collimators and shutters. The function of the burn through device is to intercept synchrotron rays that would strike the lead collimator. When the burn through device intercepts the beam, it will fail and vent the Beamline to atmospheric pressure (and subsequently the main ring vacuum) as a means of preventing failure of lead shielding due to over–heating (See Figures 4.2 and 4.3 below)



Burn Through device relative to maximum Active Interlock Fan and Geometric Envelope Fan

Burn–through devices have also been utilized at SLAC as a means of providing protection against failure of safety components from overheating.

FIGURE 4.2
4.2 ROLE OF BURN–THROUGH DEVICE IN PREVENTING SR EXPOSURE OF LEAD COLLIMATOR

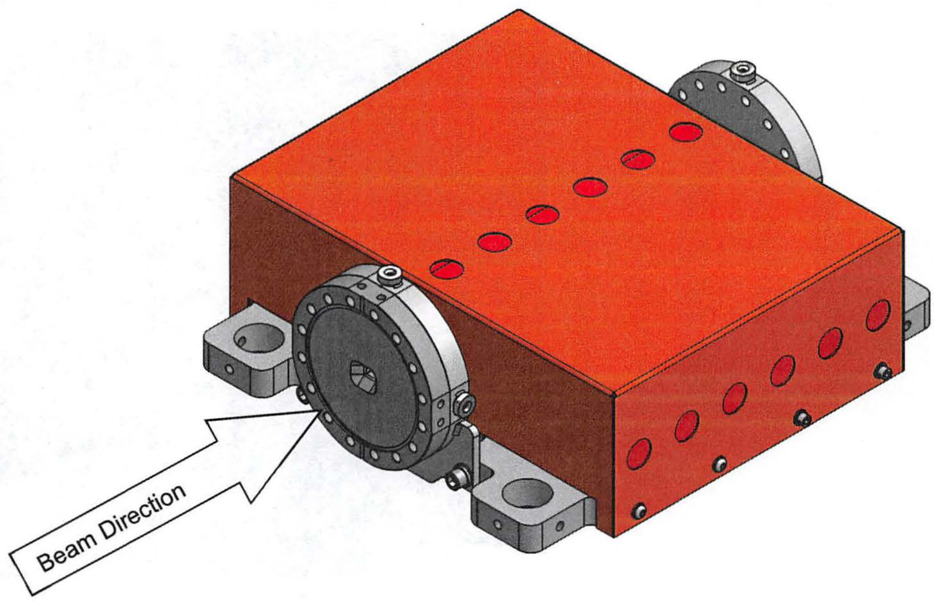


FIGURE 4.3
4.3 LEAD COLLIMATOR WITH BURN THROUGH DEVICE **(Beam direction from left to right)**

Overheating in the Beamline FOE

Despite the use of burn-through devices in the front-end to reduce the SR fan, in the case where the electrons can be anywhere within the geometrical envelope, the SR fan entering the FOE remains larger than in the case where the electrons are confined to the active interlock envelope (AIE). Thus, for some of the early project Beamlines that were designed assuming the electrons are confined to the AIE, this increased SR fan may be larger than what the beamline SR masks or stops can safely accept. For example, it may hit the copper mask at normal incidence instead of at a tapered surface, causing it to fail. If these masks/stops fail, then the radiation shielding downstream can be compromised. In these cases, burn-through devices will be needed in the Beamline to ensure that the shielding components are not damaged in the event that the electron beam is outside the AIE. Since the vacuum in beamlines may be isolated from the front end by windows, beam line burn through devices must generate an electrical signal which is transmitted to the PPS. On the Beamline, these burn-through devices are also called Personnel Protection System (PPS) apertures. It should be noted that future Beamlines may not need this device because they can design their masks and stops to accept the larger incoming SR fan.

A schematic of this Aperture is shown in Figure 4.4. The device is placed upstream of the component (mask or stop) that it is protecting so that it shadows the component from the incident SR. Because the Beamlines will have a window which separates the beam line vacuum from the front end vacuum, a different sensing mechanism is needed to detect failure of the burn through device. The PPS aperture consists of a thin-walled pressurized capsule laser welded to a flange. The pressure in the capsule is monitored by pressure sensors that are connected to the Beamline PPS. If the SR beam hits it, it will rupture and trip the pressure transducer which will interlock off the stored and the injected beam. The report from a review of this device is provided in Appendix 31 (Beamline PPS_Aperture Review). Another important difference for beam line components requiring water flow to prevent overheating is that the water flow is monitored and interlocked through the Beamline PPS. Prior to commissioning of any beamline using a burn through device, the IRP process described previously for commissioning a Beamline will be completed.

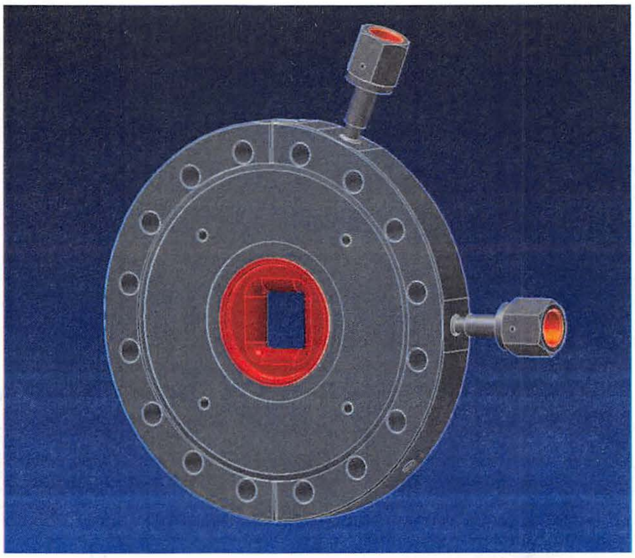


FIGURE 4.4

4.4 A SCHEMATIC OF THE PPS APERTURE FOR THE BEAMLINE

THE PRESSURIZED CHAMBER (RED) IS MADE FROM ELECTROFORMED NICKEL AND IS BRAZED ONTO THE FLANGE

Overheating in the Safety Shutters

The safety shutters are protected with a similar concept but in a different configuration. During normal operation, the safety shutters are lifted above the beam as can be seen in the Figure 4.5 below.

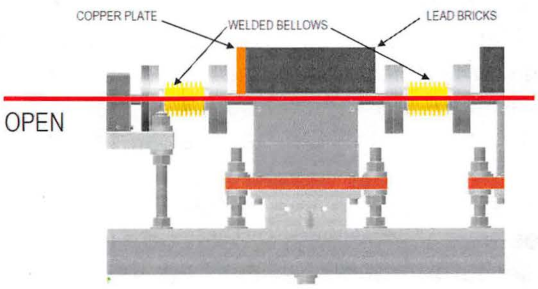


FIGURE 4.5

4.5 SAFETY SHUTTER OPEN

When the safety shutters are closed, the photon shutter directly in front of the first safety shutter must close first to protect the lead safety shutter from overheating. In the event that the photon shutter failed from overheating, the emerging synchrotron beam would eventually strike the lead shutter and qucikly cause it to fail as well. As can be seen from Figure 4.6 if the safety shutter were exposed to the SR beam, the flexible bellows pipe in front of the shutter will be exposed also. Thermal analysis has shown that the pipe will fail first and will quickly expose the Beamline to atmosphere provided that a copper plate is mounted at the leading edge of each safety shutter before the safety shutter overheats and fails.

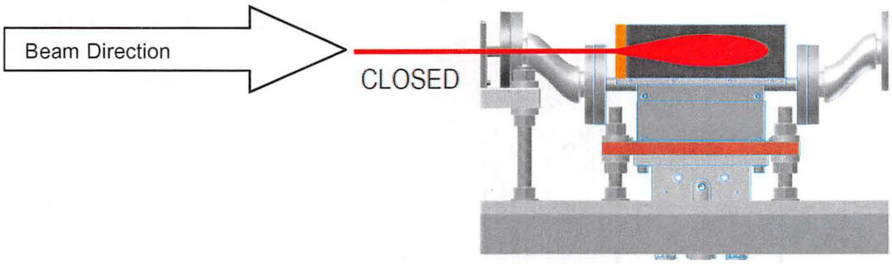


FIGURE 4.6
4.6 SAFETY SHUTTER CLOSED

A copper plate is required at the leading each of each safety shutter to protect the lead from failing from SR beams smaller than 200 microns in diameter.

These burn–through mechanisms result in the Storage Ring vacuum quickly going to atmosphere (< 1 sec), which will result in a dump of the stored beam. If we assume that 500 mA of beam is circulating in the ring, the bremsstrahlung burst from electron interactions in the air–filled ring would produce a dose of ~ 10 mrem in the FOE if it were occupied.

4.15.10 Radiological Hazards Associated with Top-Off Operations

The primary radiological safety issue for Top-Off injection with the safety shutters open is to assure that no electron beam can pass through the apertures in the front-end and enter the First Optics Enclosure (FOE) on the experiment floor. The goal of the Top-Off Safety System (TOSS) is to prevent this from occurring. Such an event can be excluded with stored 3 GeV electrons in the Storage Ring. The analysis and requirements which follow in this section focus on injected beam only. The radiation dose rate due to even one injected shot of 15 nC entering the FOE is considered unacceptable based on the analysis. The scenario that must be prevented is illustrated by the red trajectory in Figure 4.7.

In Figure 4.7, the trajectories of the stored electron beam (blue), a lost injected electron following a safe trajectory (green), and a lost injected electron following an unsafe trajectory (red) are plotted. The tracking studies described later in this report prove that the unsafe scenarios are mitigated by the redundant credited controls, such as magnet interlocks and limiting apertures. In the figure, the vertical black lines represent physical apertures. The maroon parallelogram is a dipole bending magnet; the purple rectangles are quadrupoles; the blue rectangles are sextupoles and the yellow rectangles are orbit correction magnets. A Cartesian coordinate system is used with the z-axis along the direction of the insertion straight and the x-axis in the perpendicular direction.

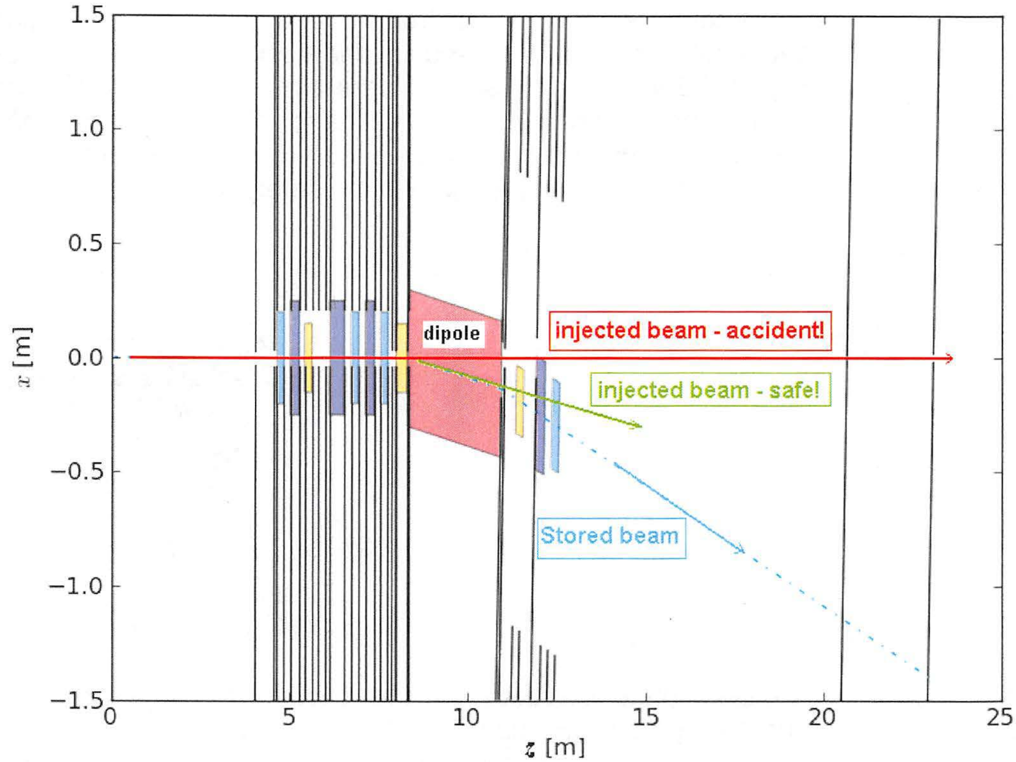


Figure 4.7 Safe and unsafe injected beam trajectories during top-off injection

If the full injected beam is conveyed to the FOE in the event of a complete failure of the top-off interlocks, the maximum total ambient dose-equivalent near the lead walls of the first optics enclosure, calculated by FLUKA, is approximately 80 mrem per pulse of 15 nC. This corresponds to an exposure rate of 288 rem/h at full injection rate for a full hour. Such high radiation dose means that the scenario of even one injected shot (15-nC charge) entering the FOE is not tolerable. Radiological analysis also showed that, with the credited controls fully operational, the beam shall not transmit beyond Front End Collimator 2, which is defined as the safe point for Top-Off injection.

Credited apertures

Based upon possible machine failure scenarios and particle trajectory simulations within NSLS-II, specified apertures in the Storage Ring and beamline frontends are designated as credited controls for the purpose of Top Off safety.

The credited apertures for NSLS-II top-off operation are detailed in PS-C-ASD-RSI-001, "Top-Off Safety Requirements for the National Synchrotron Light Source II".

Required Interlocks

The following interlocks will be implemented to assure the safety of Top-Off injection: Stored Beam Current Interlock; Storage Ring Dipole Current and Voltage Interlock; Injected Beam Energy Interlock; and Top-Off Injection Current Interlock. The required interlocks for NSLS-II Top-Off operation are detailed in PS-C-ASD-RSI-001, "Top-Off Safety Requirements for the National Synchrotron Light Source II."

Response Time

The TOSS must inhibit injection within 15 ms if the storage ring dipole current or, voltage interlocks or the injected beam energy interlock are violated. The determination of 15 ms response time is based on the storage ring dipole field decay rate when its power supply trips off;

This requirement does not apply to the Top-off Injection Current or Stored Beam Current Interlocks.

Critical Devices

There are three devices which will be inhibited to stop injection during Top-Off.

1. The booster extraction AC septum magnet
2. The storage ring injection AC septum magnet
3. The linac gun

Top-Off Injection Loss Dose Rate Analysis

FLUKA simulations included 4 mis-steering injected beam scenarios at or prior to the safe point in the front end:

Scenario1: Beam lost at 5 mm outboard side from collimator #2 aperture
Scenario2: Beam lost at 5 mm inboard side from collimator #2 aperture
Scenario3: Beam scrape outboard beam pipe 40 cm upstream of collimator #2
Scenario4: Beam scrape inboard beam pipe 40 cm upstream of collimator #2

The dose rates from the above four mis-steering scenarios are summarized as follows.

Dose rates around First Optics Enclosure (FOE) from different beam mis-steering scenarios in the front end.
(All doses are in mrem/hour.)

		Scenario1	Scenario2	Scenario3	Scenario4
Injected beam loss rate 15 nC/s	FOE downstream wall	500	1000	700	2000
	FOE lateral wall	40	50	100	100
	SR @ corner	800	800	2500	1800
Injected beam loss rate 45 nC/min	FOE downstream wall	25.5	49.5	34.5	100.5
	FOE lateral wall	1.5	3	4.5	4.5
	SR @ corner	40.5	40.5	124.5	90

- *Note: in reality, the dose rate on FOE downstream wall will be much lower than shown in the above table due to the collimators and secondary bremsstrahlung shields in the FOE, which are not included in FLUKA model for Top-Off calculation.*

As the dose rates for 15 nC/s injection loss rate at the front end either exceed or come close to the NSLS-II shielding policy, the injection rate shall be limited to 45 nC/min during Top-Off mode thus satisfying the shielding policy. The necessary injection rate for Top-Off operation is approximately 8 nC/min with the beam lifetime of 3 hours. Reducing the injection rate from the full capacity of 15 nC/s to 45 nC/min during Top-Off operation does not hamper the ability to successfully Top-Off the machine, and provides sufficient current stability while keeping doses ALARA. The maximum dose under the reduced injection rate is 100 mrem/hr for the worst case condition shown in the above table.

4.16 Environmental Radiological Issues

4.16.1 Induced Activity and Environmental Radiological Issues

High–energy (>10MeV) particle interactions with materials can produce radioactivity from spallation or from neutron capture interactions. In high–energy proton accelerators, these interactions can produce significant environmental issues. However, as has been demonstrated at current operating facilities, electron accelerators have a reduced potential for the production of induced activity compared to proton accelerators. Historically, synchrotron light sources throughout the world have not created environmental radiological issues. The results of analyses presented in this section demonstrate that NSLS–II operations will not create environmental issues of concern. Detailed calculations have been performed and are summarized below. (See also Appendix 8),

4.16.1.1 Induced Activity in Accelerator Components

Appendix 28 provides preliminary activation analysis of the accelerator components. Experience with long–time operations at NSLS as well as other light sources has demonstrated that induced activity has not been a significant source of radiation exposure. Operating cycles are unlikely to build up longer lived radionuclides. The beam dumps in Linac and Booster and the injection and extraction septum in the Booster and main ring, consisting mostly of iron and copper with lead supplementary shielding, have the maximum probability of activation due to high beam losses. During commissioning the highest activation rates found in the injection septa were 5 mr/h at contact decaying to 0.5 mr/h within an hour. Table 4.30 provides estimates exposure rates from activation of different components in the Injection straight.

The hazards associated with induced radioactivity are not substantial, but caution and control must be applied to prevent low–level personal exposures and loss of control of radioactive material. Storage Ring enclosure entry control requirements will be evaluated based on surveys conducted by RCD personnel. BNL SBMS and *Radiological Control Manual* requirements for survey and control of activated material by RCD personnel shall be applied to all work conducted and removal /replacement of the components within the Storage Ring tunnel during commissioning and operation.

TABLE 4.30

4.30 ACTIVATION ANALYSIS OF THE COMPONENTS AT THE STORAGE RING INJECTION STRAIGHT

INJECTION STRAIGHT COMPONENTS	ACTIVITY AFTER 200 HOURS OF CONTINUOUS INJECTION AT 22nC/s (mCi)	EXPOSURE RATE AT 1m IMMEDIATELY AFTER SHUTDOWN (mR/h)	EXPOSURE RATE AT 1m ONE HOUR AFTER SHUTDOWN (mR/h)
Septum steel	3.45	2.2	0.05
Septum copper	11.0	5.8	0.09
Septum lead shielding	4.28	1.6	0.44
Aluminum vacuum chamber	0.56	0.2	0.05
Total at the injection straight section	19.29	9.8	0.63

4.16.1.2 Air Activation

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

Using the methodology and assumptions described in Appendix 8, the maximum concentrations of radioactive gas in the Storage Ring during routine operation were calculated and are shown in Table 4.47 below. The highest activated air concentration is during injected beam loss on the injection septum at 3 nC/s (80% injection efficiency) with energy 3.0 GeV. The total saturation concentration of the short lived isotopes like ^{13}N, ^{15}O and ^{11}C in air for this mode of operation is 0.07 µCi/m^3 (7.0 x 10^{-7} µCi/cc), which can be compared to the occupational Derived Air Concentration of 4 x 10^{-6} µCi/cc. The Storage Ring enclosure has a recirculating ventilation system with ~8 air changes in an hour. The saturation concentration of the air activity has been calculated with the assumption of perfect mixing of the air in the Storage Ring enclosure. The results are given in Table 4.14. Although this is not a conservative assumption, because of the short–lived nature of these gases and the low levels of calculated saturation concentration, occupational exposure to the workers entering the enclosure is expected to be insignificant.

The U.S. Environmental Protection Agency (EPA) promulgated the national emission standards codified in Title 40, Part 61, Subpart H of the CFR, "*National Emission Standards for Hazardous Air Pollutants (NESHAP) for Radionuclide Emissions from Department of Energy (DOE) Facilities (EPA 1989).*" Specifically, sub–section 61.92 states that "emissions of radionuclides to the ambient air from Department of Energy facilities shall not exceed those amounts that would cause any member of the public to receive in a year an effective dose equivalent of 10 mrem." The Storage Ring enclosure has a recirculated ventilation system. The releases would be fugitive losses through the small openings and doorways in the enclosure; fresh air is brought in to make up for these fugitive losses. Because there is the potential for release to the environment, however small, the dose standard of 40 CFR Part 61 Subpart H applies. Therefore, a NESHAP evaluation was conducted by the BNL Environmental Protection Division to evaluate the dose to members of the public from operation of the NSLS–II facility. The study concluded that emissions from the NSLS–II facility during operations will be well within exposure limits established in Part 61 and no EPA permit and continuous air monitoring are required (see Appendix 29).

The source term calculations used in the NESHAP evaluation were based on the saturation concentration of activities of the short–lived gases produced in the accelerator enclosure air, which are given in Table 4.31. Using the methodology and assumptions described in Appendix 29, the effective dose equivalent (EDE) was calculated to be 1.67 E–03 mrem per year. This value is conservative as it is based on 5000 hours of injected beam loss on the injection septum at 3 nC/s at 3.0 GeV. Therefore, the overall dose impact from environmental releases is negligible.

TABLE 4.31

4.31 SATURATION ACTIVITY IN AIR AT THE STORAGE RING INJECTION SEPTUM

BEAM LOSS PARAMETERS				SATURATION ACTIVITY				
Beam Loss Location	Enclosure Volume (m^3)	Beam Energy (MeV)	Beam loss (Watts)	^{13}N (µCi)	^{15}O (µCi)	^{11}C (µCi)	Total Activity (µCi)	Concentration (µCi/m^3)
Storage Ring Injection Septum	7594	3000	9	475.2	51.4	10.1	536.7	0.07

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

4.16.1.3 Water Activation

A similar method is used to estimate magnet and other accelerator component cooling water activation. The primary reactions leading to cooling water activation are the bremsstrahlung interactions with ^{16}O in water. The most abundant of the radionuclides produced by this process is ^{15}O. Other activation products that are formed include ^{11}C (4.4% of ^{15}O), ^{3}H (at saturation, 2.2% of ^{15}O) and ^{13}N (about 1% of ^{15}O). ^{15}O has a radioactive half–life of 2.05 minutes and attains saturation during short periods of operation. Because of the long half–life of ^{3}H (half–life =

12.3 y) this radionuclide will not attain a substantial fraction of its saturation activity.

In the Storage Ring enclosure, the highest beam loss point in a component with water cooling is the Storage Ring injection septum. We assume an average beam loss of 3.0 nC/s at 3.0 GeV (9 watts). The following calculations are based on the Storage Ring septum losses, because of the closed loop cooling water circulation. The saturation activity of radionuclides in the cooling water has been estimated at the Storage Ring septum using the method described in Appendix 8. A closed loop water system with inventory of 30,000 gal (1.136 × 10^8 cm^3) of water is used to cool the Booster as well as the Storage Ring components. Table 4.32 below provides the saturation concentrations of the radionuclides in the cooling water produced by losses at the Storage Ring septum. As mentioned earlier, ^3H will attain saturation only after decades of operation. After 5,000 hours of continuous operation, the concentration of ^3H will be only 3% of the saturation value. Similar to section 4.15.4.2, this value is conservative as it is based on 5000 hours of injected beam loss on the injection septum at 3 nC/s at 3.0 GeV. Other loss points will provide additional small increments to the total inventory of tritium within the system. This cooling water system will be tested periodically, using a procedure to be developed, for tritium, once operations have begun.

TABLE 4.32

4.32 MAXIMUM SATURATION ACTIVITIES OF RADIONUCLIDES IN THE ACCELERATOR COMPONENTS COOLING WATER

Beam Loss (watts)	^{15}O (pCi/cm^3)	^{11}C (pCi/cm^3)	^{13}N (pCi/cm^3)	^3H (pCi/cm^3)*
9	**11.682**	**0.495**	**0.099**	**0.231**

* This value is more than an order of magnitude less than the Drinking Water Standard of 20 pCi/cm^3.

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

4.16.1.4 Soil Activation

Formation of radionuclides in the soil is due to neutrons created during electron beam interactions with high Z materials in the accelerator structures. In the current analysis, only the high–energy neutron component needs to be considered, because only they have the penetrating power to escape the concrete shielding. As required by the BNL SBMS *Accelerator Safety* subject area, analysis has been done to estimate the rate of formation of two radioactive isotopes, ^3H and ^{22}Na, in the soil during the operation of the Storage Ring. In the calculations, the neutron source inside the Storage Ring is assumed to be the injection septum 1.2 m above the floor. The beam loss on the injection septum at 3 nC/s (80% injection efficiency) with energy 3.0 GeV is assumed (these calculations were conducted at the routine operating conditions of the ring, not at MCI conditions). The floor thickness is 0.66 m of standard concrete in the Storage Ring. The composition and density (1.6 gm/cc) of the Long Island soil has been provided by the BNL Environmental and Waste Management Services Division.

Table 4.33 below gives the activity of ^3H and ^{22}Na created in the base soil below the concrete floor at the Storage Ring injection septum location. The high energy neutron flux is averaged over one mean free path of neutrons in the soil. Using the methodology established in the BNL SBMS *Accelerator Safety* subject area, the leachable concentration created in the soil has also been given. Leach ability of 100% and 7.5% is assumed for ^3H and ^{22}Na, respectively. A water concentration factor of 1.1 and the annual rainfall of 55 cm are assumed for this calculation. Note that the soil beneath the concrete floor is not exposed to rainfall, so the potential leach ability of radioactive isotopes from the soil to the water table at these locations will be minimal.

TABLE 4.33

4.33 ACTIVITY IN BASE SOIL AT STORAGE RING INJECTION SEPTUM LOCATION DUE TO ^{3}H AND ^{22}Na

SOIL LOCATION	ELECTRON LOSS (nC/s)	ELECTRON LOSS (e/s)	NEUTRON FLUX (n/cm^2.s)	NEUTRON FLUX (Av)* (n/cm^2.s)	^{3}H (pCi/L)	^{3}H LEACHABLE (pCi/L)	^{22}Na (pCi/L)	^{22}Na LEACHABLE (pCi/L)
Storage Ring Injection Septum 3 GeV	3	1.87E10	7.8E2	4.8E2	2.9	3.2	28.1	2.1

*Averaged over one neutron mean path in the soil

These calculated values are well within the BNL–defined Action Levels of 1,000 pCi/L and 100 pCi/L for ^{3}H and ^{22}Na, respectively. Therefore no additional engineered safeguards are required. Electron losses during commissioning are not expected to be as high as estimated for a full operating year and therefore these calculations represent upper values for soil activation and ground water contamination associated with Storage Ring commissioning.

As a monitoring tool for soil activation levels near the Storage Ring, ~1 liter soil samples are positioned within the Storage Ring enclosure near a high loss point, underneath the injection septum. These soil samples shall be tested periodically for ^{22}Na and ^{3}H. In addition, groundwater sampling wells have been established down–gradient of the Storage Ring injection area and shall be periodically sampled for ^{3}H in the groundwater as a further means of confirming no impact from Storage Ring operation on the groundwater.

5.0 Basis for Accelerator Safety Envelope

5.1 Introduction

Analyses presented in Section 4 of this SAD identify the hazards associated with routine operations of the NSLS–II Accelerators and Beamlines. These hazards are controlled through application of BNL SBMS requirements and by development of facility specific programs that define requirement implementation details. Safe NSLS–II operations depend on conformance with those requirements.

The Maximum Credible Incident (described in Section 4) involves potential for personnel exposure from a prompt ionizing radiation field produced by the loss of high energy electrons or the scattering of intense synchrotron light. Oxygen deficiency hazards, especially for experimental enclosures, have also been identified as credible. A number of engineered controls and administrative practices have been established to protect personnel against accidental radiation exposure, to maintain radiation exposure within the Shielding Policy established by the NSLS–II management and to protect staff from oxygen deficient atmospheres. These credited controls are essential to safety and must be maintained during the operation of the facility as specified in the NSLS–II Accelerator Safety Envelope. The purpose of this Section is to describe the basis for each of the credited controls.

Any proposed modification to the NSLS–II that impact the credited controls described in the ASE must first undergo a USI determination. Any increase in risk as determined by the USI process above that described in this SAD and any change to the ASE requires Laboratory management and DOE approval. These approvals must occur prior to making the modifications to the NSLS–II Facility.

5.2 Bases for Credited Controls for Operations at the NSLS–II Facility

Each of the accelerators within the facility has an established MCI. The MCI is based on radiation levels in potentially occupied areas created by electron losses at a maximum energy and beam loss rate. In some cases the accelerator cannot exceed these maximum values because they are inherently limited by the capability of the machine or component. Additional controls are established and credited if the accelerator has a capability of exceeding these values.

5.2.1 Linac Credited Controls for the MCI

- **The maximum electron charge shall not exceed 360 μC integrated over one hour**

  Basis: The MCI for the Linac was calculated using 0.1 μC/s (360 μC/h). Operation at or below this beam current satisfies all accelerator and experimental needs that are presently being planned. To maintain the operation of the Linac within the bounds of the MCI, the current output from the Linac is monitored by an Accumulating Charge Monitor Interlock (ACMI) which is a safety rated device which will turn the Linac gun beam off (via PPS) if the maximum allowed charge is exceeded. This device will alarm and interlock off the electron supply for the Linac if the electron charge rate exceeds 50 nC/shot, while allowing up to 2 shots/second. In the event that the ACMI becomes unavailable, the accelerated charge will be limited using the Authorized Alternatives. The ACMI is a component of the PPS. The Authorized Alternatives are: The LtB IT1 current transformer and at least one of the following diagnostics devices located within the Linac transport line (i.e., faraday cups in the beam dumps or LtB IT2).

- **The maximum electron energy shall not exceed 250 MeV**

  Basis: The MCI was calculated using an electron energy of 230 MeV. Most routine operations will be conducted at 200 MeV. The maximum possible electron energy that the Linac can achieve is slightly less than 250 MeV. This energy is limited by the design of the Linac accelerating cavities. The radiological consequences of a 230 MeV electron beam and a 250 MeV beam are not significantly different and additional controls are not required for a 250 MeV beam energy. Therefore the maximum energy of 250 MeV is used as the limiting case for the ASE so that the Linac cannot physically exceed the ASE energy limit.

5.2.2 Booster Credited Controls for the MCI

- **The maximum electron charge injected in an hour shall not exceed 90 μC**

  Basis: The MCI for Booster was calculated using 25 nC/s (90 μC/h). This injection rate will be limited by the ACMI installed in the LtB transport line. The ACMI is incorporated into the PPS. A different threshold established in the ACMI ensures that the Booster current limits are protected. In the event that the ACMI becomes unavailable the Authorized Alternatives will be used. The Authorized Alternatives are: The LtB IT1 current transformer and at least one of the following diagnostics devices located within the Linac transport line (i.e., faraday cups in the beam dumps or LtB IT2).

- **The maximum electron energy shall not exceed 3.2 GeV**

  Basis: The MCI was calculated using an electron energy of 3 GeV. The maximum electron energy that can be maintained in the vacuum pipe by the Booster ring magnets is 3.2 GeV. The radiological consequences of a 3 GeV electron beam and a 3.2 GeV beam are not significantly different and therefore the maximum energy that can be controlled in the ring is used as the limiting case for the ASE

- **The minimum injected electron energy shall be 150 MeV**

  Basis: The analysis of mis–steering events for electrons from the injection into Booster and the eventual extraction into the Storage Ring was over the energy range of 150 MeV to 3.2 GeV. Since the Linac could be operated at energies less than 150 MeV, the current in the last dipole in the Linac to Booster transfer line is monitored as a part of the PPS system. If the current in the magnet drops below the value that would inject a 150 MeV electron into the Booster, the current monitor will interlock the Linac electron gun off using the PPS. This credited control prevents faults that have not been analyzed and could possibility exceed the shielding policy.

5.2.3 Storage Ring Credited Controls for the MCI

- **The maximum electron charge injected into the Storage Ring shall not exceed 54 μC (54,000 nC) integrated over one hour**

  Basis: The MCI for injection into the Storage Ring is evaluated at an injection rate of 15 nC/s, which if continued for a period of 1 hour would result in 54 μC/hr. The charge injection rate of 15 nC/s allows for rapid fills of the storage ring. This injection rate will be limited by the ACMI installed in the BtS transport line. The maximum integrated injected charge per hour will be limited to 54 μC (54,000 nC). The shielding analysis has shown that the areas adjacent to the storage ring will satisfy the NSLS-II Shielding Policy even at this high hourly injection charge. Operators will be able to monitor the injected rate and hourly charge through Control room display and ensure compliance with this limit.

- **The maximum electron charge stored within the Storage Ring shall not exceed 2.6 μC (2600 nC) at 3.3 GeV**

  Basis: A stored charge of 2.6 μC circulating in the NSLS–II ring is equivalent to a 1000 mA stored beam. This current exceeds the design values for the scientific program. The radiological consequences of a loss of the 1000 mA of stored beam at a point were evaluated. The maximum dose from this event was calculated as 23 mrem which is well within the NSLS–II Shielding Policy. The NSLS-II storage ring (SR) design calls for the maximum (nominal) circulating current of 500 mA. An operational limit for circulating current in the storage ring has been established of 550 mA (providing a 10% margin on top of the nominal value) The operators are charged with not exceeding this limit, and receive specific training focused on the operating limits on the beam energy and intensity (circulating current). In addition, two engineering systems provide additional back-up to the operators for defense in depth.

- **The maximum stored electron energy shall not exceed 3.3 GeV**

  Basis: An upper ring energy PPS interlock monitoring the storage ring magnet current is established for 3.2 GeV which matches the maximum energy permissible for the Booster extraction energy. At energies higher than 3.2 GeV, the interlock will turn off the ring RF and stop further injection into the ring. The ASE upper energy limit for the Storage Ring is set at 3.3 GeV, providing a slight margin to the action of the upper ring energy interlock. Energies higher than the Booster injection energy are unlikely but could occur due to acceleration by the storage RF cavities. The MCI was calculated using an energy of 3 GeV. The radiological consequences of a 3 GeV electron beam and a 3.3 GeV beam are not significantly different.

- **The minimum stored electron energy shall not be less than 2.8 GeV**

  Basis: The radiological consequences of mis–steering electrons in the Storage Ring were evaluated over the energy range between 2.8 GeV and 3.2 GeV. To ensure that electrons with energy less than 2.8 GeV are not accepted into the ring and stored, the Storage Ring magnet-current is monitored. If the magnet current is less than the value corresponding to 2.8 GeV the PPS will turn the RF off and prevent further injection. The scientific program of the machine is operated at 3.0 GeV and at present has no needs for lower beam energy.

- **The minimum electron energy transported to the Storage Ring shall be greater than 2.0 GeV**

  Basis: BTS magnets will be monitored by the PPS and interlock the Linac gun off if the magnet currents are outside their allowed current window and the Storage Ring shutter is open. Portions of the beam phase space with energies ranging from 2.0 GeV to 3.2 GeV can be transported into the Storage Ring enclosure. This control reduces the analysis that would need to be conducted to examine potential MCIs at lower energies in the Storage Ring enclosure.

5.2.4 Credited Controls for Top-Off Operations MCI

- **The maximum electron charge injected into the Storage Ring shall not exceed 2.7 uC (2,700 nC) integrated over one hour**

  Basis: The MCI for injection into the Storage Ring is evaluated at an injection rate of 45 nC/min, which if continued for a period of 1 hour would result in 2.7 μC/hr. The charge injection rate of 45 nC/min allows for rapid Top-Off of the storage ring and exceeds other operational limit pre-sets. The maximum integrated injected charge per hour will be limited to 2.7 μC (2,700 nC). Top-Off operations are expected to be regular relatively small injections continuously. The accident analysis has shown that the areas adjacent to the storage ring will satisfy the NSLS-II Shielding Policy during Top Off Operation at this hourly injection charge. Operators will be able to monitor the injected rate and hourly charge through Control room display and ensure compliance with this limit. The injected charge will be monitored and controlled through the PPS system (i.e., ACMI in the BtS transport line and after the fourth accelerating structure in the Linac.

5.2.5 Credited Controls for Radiation Hazards

There are a number of credited controls which are required to maintain the radiological consequences within bounds of the MCI. Except as designated, these apply to the operation of all accelerators and Beamlines:

- **Each accelerator and beamline when operational must have its Personnel Protection System (PPS) and associated barriers, including gates, fencing, and berms and the area radiation monitoring system operational and certified in compliance with the approved procedure. The relevant PPS must be operational during testing of RF cavities.**

  Basis: The PPS provides protective function for personnel against inadvertent radiation exposure during RF operations, when electrons are being accelerated in an accelerator enclosure and when photon beams are permitted in a beam line. This system complies with the requirements established in the BNL Radiation Control Manual and the SBMS Interlock Subject area. The PPS is fully described in section 3.9.4. The PPS includes many barriers that are subject to routine inspection, many of which are monitored through the PPS. These barriers include gates between pentants and accelerator enclosures, and fencing and locked gates to isolate areas from public or worker access (e.g., Linac and Booster berm, cable labyrinth in the Injection Service Area). For components not monitored through PPS, inspection procedures are in place to ensure the barriers remain viable. These inspections are documented and retained in the NSLS-II records inventory.

- **All required area radiological shielding must be in place and certified in compliance with the approved inspection procedure during operation of an area with a radiation hazard.**

  Basis: The radiological shielding must be in place as prescribed for the operation of each area with radiation to reduce potential exposure to acceptable levels. This shielding has been designed to control radiation levels as described in the NSLS–II Shielding Policy and is essential to maintaining radiation exposure to personnel ALARA. The shielding and the associated bases are described in section 3.9 of this report. A standard operating procedure has been developed for the routine inspection of shielding. These inspections are documented on inspection checklists that are maintained in the NSLS-II records inventory.

- **All required burn-through devices must be in place and certified in compliance with an approved inspection procedure during operation of a front-end with the radiation hazard.**

  Basis: The burn-through devices protect the safety collimators in the front end from damage from synchrotron radiation. The function of the burn through device is to intercept synchrotron rays that would strike the lead collimator. When the burn through device intercepts the beam, it will fail and vent the Beamline to atmospheric pressure (and subsequently the main ring vacuum) as a means of preventing failure of lead shielding due to over–heating. If the lead collimator were to fail, radiation levels within the FOE could become unacceptably high and must be prevented. See section 4.15.9 for a full description.

- **At least one qualified, trained operator shall be on–duty during operation of the accelerators with electron beam.**

Basis: At least one qualified, trained Accelerator Operator shall be on duty during accelerator operation with electron beam. Operation of the accelerator in a manner consistent with operational procedures requires a knowledgeable Accelerator Operator. The on–duty operator is expected to be primarily in the Control Room, but it is understood that his/her duties may occasionally require brief absences in order to carry out the full range of assigned duties (e.g., reset an off–line piece of equipment).

- **All required TOSS apertures determined by analysis within each approved beamline front end must be in place and certified in compliance with the approved inspection procedure during Top-Off Operations.**

Basis: The TOSS apertures must be in place as prescribed for the Top-Off operation within each beamline front end to reduce the potential exposure to unacceptable radiation levels. These apertures have been designed to control radiation levels as described in the NSLS–II Shielding Policy and are essential to maintaining radiation exposure to personnel ALARA. The radiation hazards associated with Top-Off Operations are described in section 4.15.10 of this document. A Configuration Management procedure has been developed for the Radiation Safety Components and the TOSS Apertures will be included in that procedure. After initial installation and confirmation, inspections will only be required when changes are made to the apertures or maintenance performed such that the devices are disturbed, and/or every two years.

5.2.6 Credited Controls for Oxygen Deficiency Hazards

- **Experimental enclosures equipped with piped in liquid nitrogen from the main LN2 distribution system or determined to be subject to an ODH condition will have a fixed-area oxygen monitoring and alarm system installed.**

Basis: Analysis of the experimental enclosures shows that any enclosure to which liquid nitrogen is supplied via the central distribution system has the potential to have oxygen deficient atmospheres in the event of a nitrogen leak. In accordance with the BNL SBMS subject area for Oxygen Deficiency Hazards, an alarming oxygen monitoring system is required under such conditions. Authorized Alternative: If the fixed oxygen monitoring system is unavailable, personal oxygen monitors shall be used to monitor staff while working in these areas

5.2.7 Credited Control Supports for Radiation Hazards

- **All required shielding and burn through monitors specified for the start–up of each accelerator and beam line shall be maintained in its approved configuration during operation and properly restored after maintenance periods.**

Basis: All required shielding and burn though monitors must be maintained during operation and after maintenance periods. This shielding must be clearly identified as controlled for radiation protection purposes. A Work Permit approved by the NSLS-II designated person must authorize all work involving a burn through device or on required shielding. Following all work, burn through devices or the shielding shall be inspected and confirmed to have been restored to its proper configuration. A checklist of all items subject to configuration control must be maintained, as well as records of all verifications. Prior to start of operations, all radiation safety components which include shielding systems and burn-through devices will be examined and confirmed by the NSLS–II staff in accordance with standard operating procedures.

- **The accelerator and beam line PPS and associated barriers shall be maintained in its approved configuration**

Basis: The protective function provided by the PPS during operations depends on the continued integrity of the system. The components of the PPS must be clearly identified as controlled for radiation protection purposes. A work permit system approved by the NSLS-II designated person must authorize all work on these components. Following all work, the PPS system shall be tested and certified to have been restored to its proper configuration and function. Barriers such as gates and fencing are subject to a routine inspection procedure to ensure the barriers remain in their approved configuration.

- **The area radiation monitoring system interfaced with the PPS shall be maintained in its approved configuration (Beam requirement only)**

  Basis: The area monitoring system is expected to measure elevated radiation levels and stop further injection if these levels exceed established alarm points. Area monitors have been located on the basis of anticipated loss points. The area monitoring units are labeled as subject to configuration control and any change in location or set point is controlled by procedure. Only designated personnel are authorized to adjust the units. The functionality of the area monitoring system will be tested as a part of the PPS certification program. During the machine operating periods, the radiation monitors will be checked with a radiation source to confirm proper response of the monitor and the interlock. This will occur during interlock checks and b) every time a monitor is exchanged for repair or calibration. The area radiation monitoring system is not required for RF cavity testing since the shielding is adequate for protection of personnel, even for cavity worst case operations

- **The polarity of the Booster ring dipoles, the BTS transport line dipoles and all ring dipole magnets (not including corrector dipoles) must be confirmed to be correct and subject to a formal configuration control program (beam requirement only)**

  Basis: The mis–steering analyses performed the Booster, for electron transport to the Storage Ring and for stored beam within the Storage Ring assumed that all dipole magnets (except corrector dipoles) had the proper power supply polarity. The analyses are not valid and could create an unreviewed safety issue if the polarity of one or more of these magnets were reversed. A formal program has been developed to establish and maintain the correct polarities.

- **All new beamline frontends, and modifications to existing beamline frontends must be approved for Top-Off operation by designated Top-Off Technical Authority, in accordance with procedure, prior to enabling the beamline during Top-Off operation. Top-Off must be disabled prior to enabling any beamline that is not yet approved for Top-Off.**

  Basis: Review and analysis of new or modified beamline frontends by Technical Authority is necessary to assure radiation controls are in place for Top-Off operation of the beamline and that compliance with NSLS-II Shielding Policy is verified and confirmed.

5.2.8 Calibration, Testing, Maintenance and Inspection that maintain Credited Controls

- **All PPS must be functionally tested and revalidated at intervals consistent with the BNL Radiological Control Manual**

  Basis: The continued reliability of the PPS requires that it be tested and re–certified at regular intervals and following any modification of the system to confirm that no protective function degradation has occurred as a result of component failure or human error. Test intervals are specified in the BNL Radiological Control Manual (Appendix 3A). With the consent of the Manager of the BNL Radiological Control Division, the interval between tests may be extended. Records of all tests and certifications must be retained.

- **Area radiation monitors must undergo annual calibration. The time between annual calibrations shall not exceed 15 months.**

Basis: These area monitors must be calibrated annually and maintained in accordance with the requirements specified in the BNL Standards Based Management System and Radiological Control Manual. Instruments must be labeled showing the date of last calibration; calibration records must be maintained. With the consent of the Manager of the BNL Radiological Control Division, the interval between tests may be extended up to a maximum of 15 months. Records of all tests and certifications must be retained.

- **Following all major shutdowns (>15 days), radiological shielding and barriers (berms, shield blocks, fencing, etc.) must undergo visual inspection prior to operations to ensure that all required elements are in place and functional**

  Basis: Although shielding and barriers are subject to a rigorous configuration control program for any work performed upon them, this requirement provides defense in depth during periods of prolonged shutdowns when experience has shown that human error is more likely to occur. Trained personnel will use checklists which will require visual inspection of all required shielding and barriers prior to resumption of operation to confirm that all systems are intact and confirmed in place.
- **TOSS Credited Aperture locations must be certified biennially (every two years). The time between certifications shall not exceed 30 months.**

  Basis: The continued reliability of the TOSS Credited Apertures is so critical to maintenance of NSLS-II Shielding Policy that despite the rigorous configuration control program for any work performed upon them, this requirement provides defense in depth during periods of prolonged shutdowns or static conditions.
- **Oxygen monitors must undergo annual testing; the maximum time between testing must not exceed 15 months.**

  Basis: The continued reliability of the experimental enclosure oxygen monitoring system requires that the system be tested at regular intervals. Testing of the devices will be performed in accordance with manufacturer requirements and NSLS-II standard procedure. Approved alternative monitoring devices will similarly be subject to a monthly functionality check.

6 QUALITY ASSURANCE

6.1 QA Program

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

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

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

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

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

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

6.2 Personnel Training and Qualification

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

6.3 Quality Improvement

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

6.4 Documents and Records

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

NSLS II documents encompass technical information or instructions that address important work tasks, and describe complex or hazardous operations. They include plans, procedures, instructions, drawings, specifications, standards, and reports. Examples include the 6–month validation testing of the PPS interlocks procedures; safety system work permits (for accelerator changes); USI Screening Checklists and Unreviewed Safety Issue (USI) Evaluation forms.

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

6.5 Work Process

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

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

6.6 Design

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

6.7 Procurement

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

6.8 Inspection and Acceptance Testing

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

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

6.9 Management Assessment

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

6.10 Independent Assessment

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

6.11 Unreviewed Safety Issue

An important aspect of the QA program are the reviews that are conducted to determine if changes in design or operational practice that are being discussed during committee reviews would result in any change in the protective function which provides a basis for the safety margins described in the SAD. As described in Section 3.10.2.6, the Directorate incorporates the use of the Unreviewed Safety Issue Determination Procedure, which uses a USI Screening Checklist and/or an Unreviewed Safety Issue (USI) Evaluation Form to determine if a planned activity or discovered condition represents a significant increase in risk (probability of occurrence or consequence of result) over that already analyzed and accepted within the Authorization Basis Documents (SAD and ASE). All Screening Checklists and/or Determinations Forms are prepared by trained, qualified, knowledgeable personnel and reviewed by the Authorization Basis Manager.

6.12 Configuration Control

As described in Section 5.2.6 configuration control of shielding and PPS systems is important in order to maintain the safety basis described in this document. As the footing for maintaining the quality and integrity of these systems, all modification, maintenance or repair work on PPS interlock systems or required shielding shall be done only under the control of a Safety System Work Permit as provided in the *Safety System Work Permit* procedure, LS–ESH–PRM–3.4.1b. The purpose of these requirements is to ensure that all work on these credited engineered systems is approved by knowledgeable individuals prior to work and that restoration of protective function is confirmed at the end of such work.

6.13 Software Quality Assurance

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

7.0 DECOMMISSIONING PLAN

7.1 Introduction

This plan is not directly connected to the routine Operation of the NSLS-II, but is added to the SAD for the sake of completeness and to demonstrate that a concept is in place for the eventual decommissioning of the NSLS–II facility. The objectives of the NSLS–II decommissioning plan, to be developed near the end of the NSLS–II operating lifetime, will be 1) to determine the hazards and risks posed by decommissioning the NSLS–II facility at the end of its operating life and 2) to plan the activities required to complete the decommissioning. Another aspect of the decommissioning plan will be to determine the final site configuration or end–point, in which the facility or site will be left. Once baseline conditions are estimated and the alternative end–points are chosen, methods of accomplishing the decommissioning that will meet the end–point goals can be selected. Finally, the waste streams to be managed during decommissioning are to be analyzed in the decommissioning plan, their characteristics and volumes estimated and treatment and disposal options evaluated. The NSLS–II decommissioning plan shall be managed by the NSLS-II Department.

7.2 Baseline Conditions

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

7.3 End–Point Goals

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

7.4 Decommissioning Methods

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

7.5 Waste Streams

Recyclable materials and wastes anticipated from the decommissioning operation will be identified in the decommissioning plan. Initially, NSLS–II structures and process equipment will be inventoried. Accordingly, the resulting inventory will be comprised largely of process components and structures that are either potentially recyclable (e.g., scrap metal, concrete, electrical equipment or Beamline components) or are solid waste. Wastes that will require particular scrutiny include activated metals, suspect metals, sealed radioactive sources, chemicals and gases and other hazardous materials (e.g., lead and beryllium). Analyses indicate that accelerator cooling water tritium concentrations will be below the Drinking Water Standard and tritium and Na–22 concentrations in soils and ground waters will be well below the BNL–defined Action Levels. Waste treatment facilities and processes in place at the time of decommissioning will be reviewed as part of the decommissioning plan. Cost estimates for waste disposal will be made at the time the decommissioning plan is developed.

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

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

7.6 Regulatory Requirements

The decommissioning plan will delineate the applicable New York State and Federal laws, Consensus Standards, DOE directives and other requirements applicable to the activities at the time of decommissioning, especially those required to meet the end–point criteria. Examples currently consist of the following five documents:

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

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