sPHENIX Hazard Analysis Report

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Revision 2

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Revision History

Revision	Date	Description	Author
0	04-02-2019	Update from Preliminary Hazard Analysis Report	L. Stiegler
1	07-20-2020	Updated Ionizing Radiation pre-mitigation risk due to work at 1008 during RHIC run. Added new hazard Pandemic. Other minor editing changes	L. Stiegler
2	12-07-2022	Update and sign at project completion	E. O'Brien

List of Acronyms

AH	Assembly Hall
C-AD	Collider-Accelerator Department
DOE	Department of Energy
ESH	Environment, Safety and Health
HAR	Hazard Analysis Report
IR	Intersecting Region
ISM	Integrated Safety Management
JRA	Job Risk Assessment
LOTO	Lock-out/Tag-out
MIE	Major Item of Equipment
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
ODH	Oxygen Deficiency Hazard
PPE	Personal Protective Equipment
RGD	Radiation Generating Device
RHIC	Relativistic Heavy Ion Collider
SDS	Safety Data Sheet
SMD	Superconducting Magnet Division

1. Introduction

The sPHENIX Upgrade Project is comprised of distinct activities; the Major Item of Equipment and the Infrastructure and Facility Upgrade. The Hazard Analysis Report (HAR) describes an updated list of the hazards present and mitigating controls to be used during the two phases of the sPHENIX project. The hazards posed by operation of the sPHENIX detector are covered in the C-AD SAD and ASE. The parallel activities associated with the Intermediate Silicon Strip Detector and Monolithic Active Pixel Sensor Vertex Detector are included in the analysis for the Infrastructure and Facility Upgrade. This will discuss the hazards for the MIE and the Infrastructure and Facility Upgrade separately. The hazards associated with the decommissioning and repurposing of the PHENIX Detector are addressed in a separate Hazards Analysis Report and are not included in this project. Assembly and testing of the BNL built components of the sPHENIX detector will be done at BNL in Buildings 510, 912, and 1008. In addition, some parts of the detector are being built at other universities and DOE laboratories. The hazards and controls for operation of sPHENIX are expected to be similar to those previously included in the C-AD SAD for the PHENIX detector, with the exception of the helium cooled superconducting magnet. The sPHENIX Detector operations will be located at BNL in Building 1008.

Personnel safety and protecting the environment are high priorities for the sPHENIX Project. This is intended to identify those aspects of the Project that present potential hazards, to project personnel, the environment, existing pieces of the experiment, or the public at large. By determining the categories and analyses used for those hazards, this document identifies the hazards and provides the appropriate controls and practices that mitigate the hazards to acceptable levels.

The sPHENIX detector will give unprecedented precision for tracking subatomic interactions. The upgrade will offer new insight into the interactions of the smallest building blocks of matter. With a superconducting solenoid magnet at its core, state-of-the-art particle-tracking detectors, and an array of novel high-acceptance calorimeters, sPHENIX will have the speed and precision needed to track and study the details of particle jets, heavy quarks, and rare, high-momentum particles produced in RHIC's most energetic collisions. These capabilities will allow nuclear physicists to probe properties of the quark-gluon plasma at varying length scales to make connections between the interactions among individual quarks and gluons and the collective behavior of the liquid-like primordial plasma.

sPHENIX will replace the previous PHENIX Experiment at BNL's Relativistic Heavy Ion Collider (RHIC). It will utilize the existing electrical, structural and mechanical infrastructure of the Building 1008 Assembly Hall (AH) and Intersection Region (IR). One major difference of this new experiment is the addition of a liquid helium cooled Superconducting Solenoid Magnet. Evaluation of hazards and risks during construction, testing, and installation will be determined using Integrated Safety Management principles as required by 10 CFR 851, and the BNL EMS 14001 and Worker Safety and Health program requirements. These are detailed in the Environmental, Safety and Health (ESH) programs of the various departments or divisions performing the work (Physics, C-AD, and SMD). The BNL Job Risk Assessment (JRA) methodology is used to identify and screen hazards and assess the potential consequences and probabilities for the unmitigated hazard, and then determine the necessary controls in order to minimize that risk. The hazards and controls for operation of sPHENIX are expected to be similar to those previously included in the C-AD SAD for the PHENIX detector, with the exception of the new helium cooled superconducting magnet. And while PHENIX had large volumes of flammable gas, no such gasses are presently planned for use in sPHENIX.

Although not a hazard specific to the sPHENIX project, the world-wide pandemic COVID-19 will nonetheless affect workers on the project. Due to the current state of the pandemic, this risk was added to the hazard list since working in close proximity during assembly and testing is a risk factor for contracting the virus and possibly causing worker illness.

The activities performed at outside universities and locations are similar to the safety and hazards documented here, and oversight of those activities is covered by the safety organization for the institution where the work is conducted. However, BNL ESH personnel are available as a resource, and for assistance in analyzing hazards or determining safety requirements for all equipment to be delivered to BNL. BNL ESH will establish communication with ESH contacts at institutions where sPHENIX work is conducted. Any safety incidents involving sPHENIX work at participating universities and labs will be reported to BNL ESH. No sPHENIX work will be done by BNL personnel at locations outside of BNL.

2. Approach

The scientific goals of this project cannot be achieved without an effective safety and environmental protection program that is integrated into the overall management of the project. ISM is implemented to ensure that all stages of the project, planning, design, and physical work are performed with attention to potential hazards. Safety and environmental issues need to be identified and addressed early to provide for adequate planning and implementation of mitigation measures. Early identification and planning facilitate safe operation and reduce open safety issues during the project.

The hazard analysis process began concurrent with the conceptual design to ensure that all significant hazards were identified, so that that they could be adequately incorporated into the design. A National Environmental Policy Act (NEPA) review was performed to ensure all environmental aspects were in compliance, and did not introduce any new risks to the environment.

Generally, all the hazards and risks associated with the sPHENIX project as identified in this document are well known to the accelerator community and are described in the C-AD Safety Assessment Document (SAD). A detailed Design Questionnaire is used to evaluate and analyze all types of criteria during development, installation and operation. At the project completion, a separate safety analysis will be reviewed using the Unreviewed Safety Issue (USI) process at C-AD, and the sPHENIX detector will be included in the C-AD SAD. The C-AD Accelerator Safety Envelope (ASE) will also be evaluated through the USI process for any potential changes or additions.

3. Hazard Analysis

The methodology of the Hazard Analysis Report is to qualitatively evaluate each hazard area by identifying the initiator hazard, probability of occurrence, and its consequences. The consequences are evaluated as below:

A pre-mitigation risk category is established through engineering judgement and prior experience, and then design features and BNL programs are evaluated to mitigate that risk. Adequate controls are implemented in order to ensure a post-mitigation risk category of Low or Negligible. See Attachment 1 for the complete Risk Analysis Methodology.

Table 1 below shows the pre- and post- mitigation classifications for the listed hazards. Each hazard is briefly described in Sections 4 (MIE) and 5 (Infrastructure and Facility Upgrade), along with the initiating activities, mitigating factors, and control programs. The hazards identified with the sPHENIX project include:

	MIE		**Infrastructure and Facility Upgrade**	
Hazard	Pre-Mitigation Risk Category	Post Mitigation Risk Category	Pre-Mitigation Risk Category	Post Mitigation Risk Category
1. Ionizing radiation	High	Negligible	High	Negligible
2. Non-ionizing Radiation	Negligible	Negligible	Negligible	Negligible
3. Hazardous and/or toxic materials	Low	Negligible	Negligible	Negligible
4. Electrical	Moderate	Low	Moderate	Low
5. Compressed Gases	Moderate	Low	Moderate	Low
6. Cryogens/Oxygen Deficiency	Moderate	Negligible	Low	Negligible
7. Material Handling and Rigging	High	Low	High	Low
8. Working at Heights	High	Low	High	Low
9. Fire	High	Low	High	Low
10. Environmental	Negligible	Negligible	Negligible	Negligible
11. Noise/Startle Hazard	Low	Negligible	Low	Negligible
12. Pandemic	Moderate	Low	Moderate	Low

All work at sPHENIX is planned in accordance with BNL Subject Area Work Planning and Control for Experiments and Operations, and work planning falls into three main categories:

- Worker planned work – work within the normal operations performed by the group, and evaluated with Job Risk Assessments or Experimental Safety Review forms
- Prescribed work – formal documented procedures
- Permit-required work – formal work planning for tasks with high complexity or hazards evaluated by Subject Matter Experts and facility managers

Experimental Safety Review (ESR) forms are used to identify specific tasks and areas where work will be done in the Physics department. The ESR lists the hazards specific to each task, and identifies the required controls including training. The ESR is reviewed annually for any changes to tasks, hazard, required controls, or personnel. In addition, the work areas are periodically inspected for safety. This process yields a realistic assessment of the residual ESH risks posed by the sPHENIX project.

4. Hazard Analysis MIE Project

4.1 Ionizing Radiation

Hazard Initiators:
Sealed radioactive sources, or radiation generating devices (RGDs), may be used during assembly, and testing of the various components of sPHENIX. Assembly of components may occur in the 1008 Assembly Hall during RHIC operations,

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	**Pre -High**	High	Moderate	Negligible
Possible (≤ 50%)	High	Moderate	Low	Negligible
Unlikely (≤ 10%)	Moderate	Low	Low	Negligible
Rare (≤1%)	Low	Low	Negligible	**Post- Negligible**

Pre-mitigation risk: **Probability – Very likely, Consequence - High** **Risk: High**

Mitigating factors and controls:

- SBMS Subject Area *Sealed Radioactive Sources*
- SBMS Subject Area *Radiation Generating Devices*
- Federal requirements in 10 CFR 830 and BNL requirements in Radiological Control Manual
- Interlock systems (redundancy)
- Strict configuration control
- Radiological shielding
- Radiation surveys performed during operations show minimal radiation exposure
- Radiological safety training
- Operator training
- Facility specific ESH orientation

Post-mitigation risk: **Probability - Rare, Consequence – Minor** **Risk: Negligible**

4.2 Non-ionizing Radiation

Hazard Initiators:
Lasers of various classes are used in testing optical components, alignment, or other applications

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	High	Moderate	Low	Negligible
Unlikely (≤ 10%)	Moderate	Low	Low	**Pre- Negligible**
Rare (≤1%)	Low	Low	Negligible	**Post- Negligible**

Pre-mitigation risk: **Probability - Unlikely, Consequence – Minor** **Risk: Negligible**

Mitigating factors and controls:

- SBMS Subject Area *Laser Safety*
- SBMS Subject Area *Static Magnetic Fields*
- Lasers are evaluated by the Laser Safety Officer where they are in use to determine specific controls
- Laser Safety training
- Laser baseline eye exam
- Laser signs and postings, interlocks as required
- OMC evaluation for personnel with magnetic field exposure
- Magnetic field training
- Posting and barriers for magnetic fields based on measurements

Post-mitigation risk: Probability - Rare, Consequence – Minor Risk: Negligible

4.3 Hazardous or Toxic Materials

Hazard Initiators:

Most chemical use will involve cleaning and degreasing agents such as alcohol, glues, epoxies during design, testing, and fabrication. Chemical or hazardous material exposure could be initiated by spills during use, transfer, failure of packaging, or improper marking/labeling.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	High	Moderate	**Pre- Low**	Negligible
Unlikely (≤ 10%)	Moderate	Low	Low	**Post - Negligible**
Rare (≤1%)	Low	Low	Negligible	Negligible

Pre-mitigation risk: Probability – Possible, Consequence – Low Risk: Low

Mitigating factors and controls:

- SBMS Subject Area *Chemical Safety*
- SBMS Subject Area *Compressed Gas Cylinders and Related Systems*
- *SBMS Subject Area Fire Safety*
- Safety Data Sheets (SDS) available in the BNL Chemical Management System
- Chemical Management System inventory of chemicals
- Smallest needed quantities are purchased and used – not to exceed Fire Control Area limits
- SBMS Subject Area *Waste*

Post-mitigation risk: Probability – Unlikely, Consequence – Minor Risk: Negligible

4.4 Electrical

Hazard Initiators:

Electrical hazards and arc flash hazards have the potential to exist during all phases due to exposed conductors, defective or substandard equipment, lack of adequate training and procedures. sPHENIX will have a large amount of high power and high voltage electrical equipment. All electrical equipment, cables and cable trays will be protected against mechanical hazards. All electrical equipment and installations must be approved by an electrically knowledgeable person.

Particular attention is also needed to address NFPA 70E requirements to protect workers against electrical arc flash and shock hazards. Arc flash analyses will be required prior to operation to ensure proper labeling and controls are in place. Equipment specific LOTO procedures are required to ensure equipment is in a safe state.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	High	**Pre - Moderate**	Low	Negligible
Unlikely (≤ 10%)	Moderate	Low	Low	Negligible
Rare (≤1%)	Low	**Post -Low**	Negligible	Negligible

Pre-mitigation risk: Probability – Possible, Consequence – Moderate Risk: Moderate

Mitigating factors and controls:

- SBMS Subject Area *Electrical Safety*
- SBMS Subject Area *Lockout/Tagout (LOTO)*
- Compliance with NFPA 70 and 70E
- Electrical Equipment Inspections
- NRTL listed devices wherever possible
- Electrical Safety Training and Procedures

Post-mitigation risk: Probability – Rare, Consequence – Moderate Risk: Low

4.5 Compressed Gases

Hazard Initiators:

Compressed gases (both inert and flammable) may be used in component testing, and operation. Compressed gas cylinders with regulators are stored and used in various work spaces during all phases of the project. Fixed gas systems will be constructed and tested.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	High	**Pre - Moderate**	Low	Negligible
Unlikely (≤ 10%)	Moderate	Low	Low	Negligible
Rare (≤1%)	Low	**Post -Low**	Negligible	Negligible

Pre-mitigation risk: Probability – Possible, Consequence – Moderate Risk: Moderate

Mitigating factors and controls:

- SBMS Subject Area *Compressed Gas Cylinders and Related Systems*
- SBMS Subject Area *Pressure Safety*
- Compressed Gas training
- If flammable gases are required, smallest needed quantities will be used, and will not exceed the Fire Control Area limit
- Flammable gas detection may be required
- Bonding/grounding of flammable gas lines

Post-mitigation risk: Probability – Rare, Consequence – Moderate Risk: Low

4.6 Cryogens/Oxygen Deficiency

Hazard Initiators:
Liquid nitrogen is used in equipment testing, and operation. Cryogenic dewars are stored and used in various work spaces during all phases of the project.

A liquid cryogen spill could result in thermal (cold burn) hazard as well as an oxygen deficiency condition. A spill could be initiated by a failure/rupture of cryogenic systems from overpressure, failure of insulating vacuum, mechanical damage/failure, deficient maintenance, or improper procedures.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	High	**Pre - Moderate**	Low	Negligible
Unlikely (≤ 10%)	Moderate	Low	Low	Negligible
Rare (≤1%)	Low	Post -Low	**Post - Negligible**	Negligible

Pre-mitigation risk: Probability – Possible, Consequence – Moderate Risk: Moderate

Mitigating factors and controls:

- SBMS Subject Area *Cryogenic Safety*
- SBMS Subject Area *Oxygen Deficiency Hazard (ODH) Classification and Controls*
- Cryogen Training
- Oxygen Deficiency training
- Spaces are evaluated for oxygen deficiency hazard
- Oxygen monitoring devices where necessary

Post-mitigation risk: Probability – Rare, Consequence – Low Risk: Negligible

4.7 Material Handling and Rigging

Hazard Initiators:
Components and equipment may be required to be moved with forklifts, hoists, or cranes

Large pieces of equipment and components will be required to be moved, raised, and put in place. All rigging equipment will be inspected in accordance with the DOE Hoisting and Rigging Standard, and BNL requirements. Job Risk Assessments are required for general material handling as well as specific tasks. Some lifts may be considered 'critical lifts' and need analysis by the BNL SME for Material Handling. All work is evaluated through the BNL Work Planning process.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	**Pre - High**	Moderate	Low	Negligible
Unlikely (≤ 10%)	Moderate	**Post -Low**	Low	Negligible
Rare (≤1%)	Low	Low	Negligible	Negligible

Pre-mitigation risk: **Probability - Possible, Consequence – High** **Risk: High**

Mitigating factors and controls:

- SBMS Subject Area *Construction Safety*
- SBMS Subject Area *Forklift Safety*
- SBMS Subject Area *Lifting Safety*
- DOE-STD-1090-07 *Hoisting and Rigging*
- Rigging and material handling training
- Equipment specific training required
- Competent Person Equipment inspection
- Task specific work planning and control
- PPE required, such as safety shoes, hard hat, safety glasses

Post-mitigation risk: **Probability – Unlikely, Consequence – Moderate** **Risk: Low**

4.8 Working at Heights

Hazard Initiators:

Working at heights may be required due to equipment size or placement. The sPHENIX detector is designed in separate pieces and will require assembly and installation at the construction/testing locations as well as in the large Assembly Hall in 1008. Due to the size, it may be necessary for workers to work from ladders, scaffolding, aerial lifts, or elevated walkways.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	**Pre - High**	Moderate	Low	Negligible
Unlikely (≤ 10%)	Moderate	**Post -Low**	Low	Negligible
Rare (≤1%)	Low	Low	Negligible	Negligible

Pre-mitigation risk: **Probability - Possible, Consequence – High** **Risk: High**

Mitigating factors and controls:

- SBMS Subject Area *Aerial Lifts*
- SBMS Subject Area *Fall Protection*
- Fall protection training
- Competent Person Equipment inspection
- Task specific work planning and control
- PPE required, such as safety shoes, hard hat, safety glasses
- Plans to retain existing ladders, platforms, stairs in the IR
- Existing 'yellow' tagged ladders will be remediated if feasible

Post-mitigation risk: **Probability – Unlikely, Consequence – Moderate** **Risk: Low**

4.9 Fire

Hazard Initiators:
Infrastructure upgrade and component installation: Fire hazards may be due to improper storage of materials, use of open flames or spark producing equipment

Typical hazard initiators include equipment failure, accumulation of combustible/flammable materials, the use of pyrophoric or reactive materials, improper storage/use of flammable materials, inadequate or out of service fire detection and suppression, lightning storm, and electrical hazards due to static discharge. These could result in injury or death to workers, equipment damage or loss, release of hazardous materials to the environment, and programmatic impact.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	**Pre - High**	Moderate	Low	Negligible
Unlikely (≤ 10%)	Moderate	**Post -Low**	Low	Negligible
Rare (≤1%)	Low	Low	Negligible	Negligible

Pre-mitigation risk: **Probability - Possible, Consequence – High** **Risk: High**

Mitigating factors and controls:

- SBMS Subject Area *Fire Safety*
- Extensive design criteria are established through NFPA, BCNYS, and DOE
- Proper storage of materials
- Fire hazard analysis – all materials evaluated for combustion potential
- Additional fire extinguishers provided as needed
- High Sensitivity Smoke Detection in IR and AH
- Fully sprinklered building
- A fire alarm system is installed, and the Fire Rescue Group in building 599 monitors all fire alarms and system supervisory signals in all buildings. Typically the fire Rescue Group responds to the scene at a BNL facility within 5 minutes of an alarm annunciation.

- The locations where the sPHENIX components are being assembled and tested comply with design requirements in BCNYS for egress requirements; this also satisfies OSHA 1910 requirements. The building codes lay out the requirements for maximum travel distance, maximum dead-end path lengths, protection of egress paths, emergency lighting of egress paths, and egress signage.

Post-mitigation risk: **Probability – Unlikely, Consequence – Moderate** **Risk: Low**

4.10 Environmental

Hazard Initiators:
Environmental releases could occur due to spills of hazardous or environmentally sensitive materials, or equipment failure/ malfunction during all phases. Quantities used are small and are not likely to cause an environmental impact to soil or groundwater.

An Environmental Evaluation Notification Form has been completed by the BNL Environmental Protection Division, and the Categorical Exclusion was approved for the sPHENIX MIE project.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	High	Moderate	Low	Negligible
Unlikely (≤ 10%)	Moderate	Low	Low	**Pre- Negligible**
Rare (≤1%)	Low	Low	Negligible	**Post- Negligible**

Pre-mitigation risk: **Probability - Unlikely, Consequence – Minor** **Risk: Negligible**

Mitigating factors and controls:
- SBMS Subject Area *Waste*
- SBMS Subject Area *Spill Response*
- Proper storage of materials and waste
- Environmental Management System evaluation of Significant Aspects
- NEPA evaluation

Post-mitigation risk: **Probability - Rare, Consequence – Minor** **Risk: Negligible**

4.11 Noise/Startle Hazard

Hazard Initiators:
During fabrication, testing, and installation of components there will be power and impact tools used. Testing of vacuum and pressure equipment could result in burst disk rupture, piping or tubing failure, and compressed gas release.

Hazards from noise include overexposure of personnel to ACGIH and OSHA occupational exposure limits due to tools, pumps, mechanical systems, HVAC systems and intermittent energy releases. These overexposures could induce permanent hearing loss, also known as Permanent Threshold Shift (PTS).

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	High	Moderate	Low	Negligible
Unlikely (≤ 10%)	Moderate	Low	**Pre - Low**	Negligible
Rare (≤1%)	Low	Low	Negligible	**Post- Negligible**

Pre-mitigation risk: **Probability - Unlikely, Consequence – Low** **Risk: Low**

Mitigating factors and controls:

- SBMS Subject Area *Noise and Hearing Conservation*
- Baseline and periodic noise surveys
- Signs and postings in high noise/ startle areas
- Medical/hearing evaluation

Post-mitigation risk: **Probability – Rare, Consequence – Minor** **Risk: Negligible**

4.12 Pandemic

Hazard Initiators:

During fabrication, testing, and installation of components workers may have to work in close proximity, which could result in spreading of infection, particularly the virus that causes COVID-19.

Hazards from pandemic are exposure of personnel to viruses and/or bacteria and subsequent illnesses.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	High	**Pre-Moderate**	Low	Negligible
Unlikely (≤ 10%)	Moderate	Low	Low	Negligible
Rare (≤1%)	Low	**Post -Low**	Negligible	Negligible

Pre-mitigation risk: **Probability - Possible, Consequence – Moderate** **Risk: Moderate**

Mitigating factors and controls:

- Health self-screenings
- Signs and postings with health reminders
- Sanitizing supplies
- Review of work plans to increase social distancing/work schedules
- Screens installed between workers where necessary
- Maximum tele-working and virtual meetings

Post-mitigation risk: **Probability – Rare, Consequence – Moderate** **Risk: Low**

5. Hazard Analysis - Infrastructure and Facility Upgrade Project

5.1 Ionizing Radiation

Hazard Initiators:
The Infrastructure and Facility Upgrademay occur during RHIC operations. s.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	**Pre -High**	High	Moderate	Negligible
Possible (< 50%)	High	Moderate	Low	Negligible
Unlikely (< 10%)	Moderate	Low	Low	Negligible
Rare (<1%)	Low	Low	Negligible	**Post- Negligible**

Pre-mitigation risk: **Probability – Very Likely, Consequence - High** **Risk: High**

Mitigating factors and controls:

- Federal requirements in 10 CFR 835 and BNL requirements in Radiological Control Manual
- Radiological Shielding
- Radiological Interlocks – (redundant)
- Radiation surveys performed during operations show minimal radiation exposure
- Radiological safety training
- Facility specific ESH orientation

Post-mitigation risk: **Probability - Rare, Consequence – Minor** **Risk: Negligible**

5.2 Non-ionizing Radiation

Hazard Initiators:
Lasers of various classes are used in testing optical components, alignment, or other applications. Field measurements of the superconducting magnet may result in magnetic field exposures.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (< 50%)	High	Moderate	Low	Negligible
Unlikely (< 10%)	Moderate	Low	Low	**Pre- Negligible**
Rare (<1%)	Low	Low	Negligible	**Post- Negligible**

Pre-mitigation risk: **Probability - Unlikely, Consequence – Minor** **Risk: Negligible**

Mitigating factors and controls:

- SBMS Subject Area *Laser Safety*
- SBMS Subject Area *Static Magnetic Fields*

- Lasers are evaluated by the Laser Safety Officer where they are in use to determine specific controls
- Laser Safety training
- Laser baseline eye exam
- Laser signs and postings, interlocks as required
- OMC evaluation for personnel with magnetic field exposure
- Magnetic field training
- Posting and barriers for magnetic fields based on measurements

Post-mitigation risk: Probability - Rare, Consequence – Minor Risk: Negligible

5.3 Hazardous or Toxic Materials

Hazard Initiators:
Chemical use during the Infrastructure upgrade will be minimal.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	High	Moderate	Pre- Low	**Pre- Negligible**
Unlikely (≤ 10%)	Moderate	Low	Low	**Post - Negligible**
Rare (≤1%)	Low	Low	Negligible	Negligible

Pre-mitigation risk: Probability – Possible, Consequence – Minor Risk: Negligible

Mitigating factors and controls:
- SBMS Subject Area *Chemical Safety*
- SBMS Subject Area *Compressed Gas Cylinders and Related Systems*
- *SBMS Subject Area Fire Safety*
- Safety Data Sheets (SDS) available in the BNL Chemical Management System
- Chemical Management System inventory of chemicals
- Smallest needed quantities are purchased and used – not to exceed Fire Control Area limits
- SBMS Subject Area *Waste*

Post-mitigation risk: Probability – Unlikely, Consequence – Minor Risk: Negligible

5.4 Electrical

Hazard Initiators:
Electrical hazards and arc flash hazards have the potential to exist during all phases due to exposed conductors, defective or substandard equipment, lack of adequate training and procedures. sPHENIX will have a large amount of high power and high voltage electrical equipment. All electrical equipment, cables and cable trays will be protected against mechanical hazards. All electrical equipment and installations must be approved by an electrically knowledgeable person.

Particular attention is also needed to address NFPA 70E requirements to protect workers against electrical arc flash and shock hazards. Arc flash analyses will be required prior to operation to ensure proper labeling and controls are in place. Equipment specific LOTO procedures are required to ensure equipment is in a safe state.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	High	**Pre - Moderate**	Low	Negligible
Unlikely (≤ 10%)	Moderate	Low	Low	Negligible
Rare (≤1%)	Low	**Post -Low**	Negligible	Negligible

Pre-mitigation risk: Probability – Possible, Consequence – Moderate Risk: Moderate

Mitigating factors and controls:

- SBMS Subject Area *Electrical Safety*
- SBMS Subject Area *Lockout/Tagout (LOTO)*
- Compliance with NFPA 70 and 70EElectrical Equipment Inspections
- NRTL listed devices wherever possible
- Electrical Safety Training and Procedures

Post-mitigation risk: Probability – Rare, Consequence – Moderate Risk: Low

5.5 Compressed Gases

Hazard Initiators:

Compressed gases may be found in cylinders and piping throughout the 1008 IR and AH. Compressed gases may injure workers if not stored and used properly. Cylinders that are not properly supported may fall and become projectiles when the valve or regulator breaks loose. Piping systems may have unrecognized residual contents and stored pressure which can cause injury if released. Flammable gases used for cutting and welding may cause fires. Testing of new piping may result in pressure release of compressed gases.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	High	**Pre - Moderate**	Low	Negligible
Unlikely (≤ 10%)	Moderate	Low	Low	Negligible
Rare (≤1%)	Low	**Post -Low**	Negligible	Negligible

Pre-mitigation risk: Probability – Possible, Consequence – Moderate Risk: Moderate

Mitigating factors and controls:

- SBMS Subject Area *Compressed Gas Cylinders and Related Systems*
- SBMS Subject Area *Pressure Safety*

- Compressed Gas training
- If flammable gases are required, smallest needed quantities will be used, and will not exceed the Fire Control Area limit
- Flammable gas detection may be required
- Bonding/grounding of flammable gas lines when required

Post-mitigation risk: Probability – Rare, Consequence – Moderate Risk: Low

5.6 Cryogens/Oxygen Deficiency

Hazard Initiators:
Liquid cryogen piping will be changed and re-routed for use in the new configuration. Cryogenic dewars may be stored and used in various work spaces. New cryogen piping will be installed and tested.

A liquid cryogen spill could result in thermal (cold burn) hazard as well as an oxygen deficiency condition. A spill could be initiated by a failure/rupture of cryogenic systems from overpressure, failure of insulating vacuum, mechanical damage/failure, deficient maintenance, or improper procedures.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	High	**Moderate**	Low	Negligible
Unlikely (≤ 10%)	Moderate	Pre -Low	Low	Negligible
Rare (≤1%)	Low	Post -Low	**Post - Negligible**	Negligible

Pre-mitigation risk: Probability – Possible, Consequence – Moderate Risk: Moderate

Mitigating factors and controls:
- SBMS Subject Area *Cryogenic Safety*
- SBMS Subject Area *Oxygen Deficiency Hazard (ODH) Classification and Controls*
- Cryogen Training
- Oxygen Deficiency training
- Detailed work planning for piping changes and installation
- Spaces are evaluated for oxygen deficiency hazard
- Oxygen monitoring devices where necessary

Post-mitigation risk: Probability – Rare, Consequence – Low Risk: Negligible

5.7 Material Handling and Rigging

Hazard Initiators:
Components and equipment may be required to be moved with forklifts, hoists, or cranes

Cable tray, piping, and work platforms will be changed and moved to accommodate the new components. Large pieces of equipment and components will be required to be moved, raised, and put in place. The field assembly of the Detector including the Cradle, bridge and platforms involves the

movement of 900 tons of material. A detailed review of the assembly operation including specific review of hoisting and rigging activities, and critical lifts will be required.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	**Pre - High**	Moderate	Low	Negligible
Unlikely (≤ 10%)	Moderate	**Post -Low**	Low	Negligible
Rare (≤1%)	Low	Low	Negligible	Negligible

Pre-mitigation risk: Probability - Possible, Consequence – High Risk: High

Mitigating factors and controls:

- SBMS Subject Area *Construction Safety*
- SBMS Subject Area *Forklift Safety*
- SBMS Subject Area *Lifting Safety*
- DOE-STD-1090-07 *Hoisting and Rigging*
- Rigging and material handling training
- Equipment specific training required
- Competent Person Equipment inspection
- Critical lift evaluations
- Detailed engineering evaluations and stress calculations
- Task specific work planning and control
- PPE required, such as safety shoes, hard hat, safety glasses

All rigging equipment will be inspected in accordance with the DOE Hoisting and Rigging Standard, and BNL requirements. Job Risk Assessments are required for general material handling as well as specific tasks. Some lifts may be considered 'critical lifts' and need analysis by the BNL SME for Material Handling. All work is evaluated through the BNL Work Planning process.

Post-mitigation risk: Probability – Unlikely, Consequence – Moderate Risk: Low

5.8 Working at Heights

Hazard Initiators:

Working at heights may be required for cable and piping replacement/upgrade due to equipment location. It may be necessary for workers to work from ladders, scaffolding, aerial lifts, or elevated walkways.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	**Pre - High**	Moderate	Low	Negligible
Unlikely (≤ 10%)	Moderate	**Post -Low**	Low	Negligible
Rare (≤1%)	Low	Low	Negligible	Negligible

Pre-mitigation risk: **Probability - Possible, Consequence – High** **Risk: High**

Mitigating factors and controls:

- SBMS Subject Area *Aerial Lifts*
- SBMS Subject Area *Fall Protection*
- Fall protection training
- Competent Person Equipment inspection
- Task specific work planning and control
- PPE required, such as safety shoes, hard hat, safety glasses
- Plans to retain existing ladders, platforms, stairs in the IR
- Existing 'yellow' tagged ladders will be remediated if feasible

Post-mitigation risk: **Probability – Unlikely, Consequence – Moderate** **Risk: Low**

5.9 Fire

Hazard Initiators:

Infrastructure upgrade and component installation: Fire hazards may be due to improper storage of materials, use of open flames or spark producing equipment

Typical hazard initiators include equipment failure, accumulation of combustible/flammable materials, the use of pyrophoric or reactive materials, improper storage/use of flammable materials, inadequate or out of service fire detection and suppression, lightning storm, and electrical hazards due to static discharge. These could result in injury or death to workers, equipment damage or loss, release of hazardous materials to the environment, and programmatic impact.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	**Pre - High**	Moderate	Low	Negligible
Unlikely (≤ 10%)	Moderate	**Post -Low**	Low	Negligible
Rare (≤1%)	Low	Low	Negligible	Negligible

Pre-mitigation risk: **Probability - Possible, Consequence – High** **Risk: High**

Mitigating factors and controls:

- SBMS Subject Area *Fire Safety*
- Extensive design criteria are established through NFPA, BCNYS, and DOE. The building codes lay out the requirements for maximum travel distance, maximum dead-end path lengths, protection of egress paths, emergency lighting of egress paths, and egress signage.
- Proper storage of materials
- Fire hazard analysis – all materials evaluated for combustion potential
- Additional fire extinguishers provided as needed
- High Sensitivity Smoke Detection in IR and AH
- Fully sprinklered building

- A fire alarm system is installed, and the Fire Rescue Group in building 599 monitors all fire alarms and system supervisory signals in all buildings. Typically the fire Rescue Group responds to the scene at a BNL facility within 5 minutes of an alarm annunciation.

Post-mitigation risk: Probability – Unlikely, Consequence – Moderate Risk: Low

5.10 Environmental

Hazard Initiators:
Environmental releases could occur due to spills of hazardous or environmentally sensitive materials, or equipment failure/ malfunction during all phases. Quantities used are small and are not likely to cause an environmental impact to soil or groundwater.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	High	Moderate	Low	Negligible
Unlikely (≤ 10%)	Moderate	Low	Low	**Pre- Negligible**
Rare (≤1%)	Low	Low	Negligible	**Post- Negligible**

Pre-mitigation risk: Probability - Unlikely, Consequence – Minor Risk: Negligible

Mitigating factors and controls:
- SBMS Subject Area *Waste*
- SBMS Subject Area *Spill Response*
- Proper storage of materials and waste
- Environmental Management System evaluation of Significant Aspects
- NEPA evaluation

Post-mitigation risk: Probability - Rare, Consequence – Minor Risk: Negligible

5.11 Noise/Startle Hazard

Hazard Initiators:
Power and impact tools will be used for dismantling and installing piping, cable tray, and infrastructure. Testing of vacuum and pressure piping and equipment could result in burst disk rupture, piping or tubing failure, and compressed gas release. HVAC systems may contribute to noise levels.

Hazards from noise include overexposure of personnel to ACGIH and OSHA occupational exposure limits due to tools, pumps, mechanical systems, HVAC systems and intermittent energy releases. These overexposures could induce permanent hearing loss, also known as Permanent Threshold Shift (PTS).

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible

Possible (≤ 50%)	High	Moderate	Low	Negligible
Unlikely (≤ 10%)	Moderate	Low	**Pre - Low**	Negligible
Rare (≤1%)	Low	Low	Negligible	**Post- Negligible**

Pre-mitigation risk: **Probability - Unlikely, Consequence – Low** **Risk: Low**

Mitigating factors and controls:

- SBMS Subject Area *Noise and Hearing Conservation*
- Baseline and periodic noise surveys
- Signs and postings in high noise/ startle areas
- Medical/hearing evaluation

Post-mitigation risk: **Probability – Rare, Consequence – Minor** **Risk: Negligible**

5.12 Pandemic

Hazard Initiators:

During fabrication, testing, and installation of components workers may have to work in close proximity, which could result in spreading of infection, particularly the virus that causes COVID-19.

Hazards from pandemic are exposure of personnel to viruses and/or bacteria and subsequent illnesses.

	Consequence			
Probability↓	**High**	**Moderate**	**Low**	**Minor**
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	High	**Pre-Moderate**	Low	Negligible
Unlikely (≤ 10%)	Moderate	Low	Low	Negligible
Rare (≤1%)	Low	**Post -Low**	Negligible	Negligible

Pre-mitigation risk: **Probability - Possible, Consequence – Moderate** **Risk: Moderate**

Mitigating factors and controls:

- Health self-screenings
- Signs and postings with health reminders
- Sanitizing supplies
- Review of work plans to increase social distancing/work schedules
- Screens installed between workers where necessary
- Maximum tele-working and virtual meetings

Pre-mitigation risk: **Probability – Rare, Consequence – Moderate** **Risk: Low**

Attachment 1 Risk Analysis Methodology

Risk Approach is based on Consequence and Probability

Consequence→ Probability ↓	Cause multiple deaths or serious injury > 100 rem to an individual > $1,000,000 damage or 4 mos facility downtime	Cause death or serious injury > $250K damage, 3 wk to 4 mons program downtime Public impact that closes experiment	Cause multiple moderate injuries > 5rem to an individual 4 days to 3 weeks program downtime Adverse public attention, public impact	Cause minor injuries, < 2 rem to an individual < 50,000 damage, 4 days program downtime
Very Likely (>50%)	High	High	Moderate	Negligible
Possible (≤ 50%)	High	Moderate	Low	Negligible
Unlikely (≤ 10%)	Moderate	Low	Low	Negligible
Rare (≤1%)	Low	Low	Negligible	Negligible