# Safety Assessment Document
# for the
# Advanced Photon Source

**APS-3.1.2.1.0**
(APS_1188832)

**Revision 6**

**2024-03-11**

**Effective Date: March 2024**

# HISTORY OF REVISIONS

| Rev. No. | Description of Change | Effective Date |
|---|---|---|
| 0 | Initial issue | June 1996 |
| 1 | Added the top-up operating mode and documented the conversion to operation with electrons. The Safety Envelope was not changed. | May 1998 |
| 2 | Added several APS improvements and many minor updates to keep the descriptions and safety analysis consistent with the current APS configuration. Also included many minor language clarifications. The Safety Envelope was not changed. | Feb 2005 |
| 3 | Documented the removal of the third, hardwired interlock chain from the Access Control Interlock System (ACIS) as reviewed and approved by the APS Radiation Safety Policy and Procedure Committee in April 2006. Also updated the acronyms referring to APS divisions and the mission descriptions for the three APS divisions due to the APS reorganization of April 2006. The Safety Envelope was not changed. | July 2006 |
| Addendum to Rev 3 | Defined the APS facilities (including APS controlled operations located outside of the 400 Area), described radioactive materials used or stored in APS facilities along with associated hazards and controls, and updated operating envelope for PAR, synchrotron, and storage ring in Sections 3.1.4, 3.5.4, and Table 5.1. | Feb 2009 |
| 4 | Updated accelerator system descriptions to be consistent with the current APS configuration. Deleted various beamline descriptions that were superfluous to the hazard analysis and accelerator safety envelope. Also included many editorial changes and updates. Updated references to reflect current DOE requirements. | June 2012 |
| 5 | Documented the removal of the LEUTL and the inclusion of the Linac Extension Area (LEA). Also updated Safety Interlocks description to be consistent with current configurations. Also included many minor and editorial changes. | June 2017 |
| Addendum 1 to Rev 5 | Updated descriptions of the Personnel Safety System to be consistent with Personnel Safety System Gen 4 systems. | Sept 2019 |
| 6 | Major rewrite for the APS Upgrade (APS-U) Project and installation of the new storage ring. Changes include:<br>• Changed the format and content to be consistent with current guidance (DOE G 420.2-1A and LMS-PROC-381, *Preparing or Updating an Accelerator SAD and ASE*).<br>• Updated the facility descriptions to be consistent with the facility configuration following the APS Upgrade Project. | Mar 2024 |

| Rev. No. | Description of Change | Effective Date |
|---|---|---|
| | • Updated the safety analysis to be consistent with current guidance (DOE G 420.2-1A and LMS-PDESC-2).<br>• Prepared a separate Accelerator Safety Envelope (ASE) document. | |

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# 1. EXECUTIVE SUMMARY AND CONCLUSIONS

This Safety Assessment Document (SAD) is for the Advanced Photon Source (APS), which is operated by the Photon Sciences (PSC) Directorate at Argonne National Laboratory. This introductory chapter provides a high-level overview of the APS complex, the safety analysis methodology, the hazards associated with the APS, and the controls that make a significant contribution to risk reduction.

## 1.1 INTRODUCTION

This Safety Assessment Document (SAD) and the associated Accelerator Safety Envelope (ASE) were developed to operate the APS complex after completion of the APS Upgrade (APS-U) Project. This SAD addresses the entire APS complex (injector complex, storage ring, x-ray beamlines, and support facilities). The purpose of this SAD is to provide a description of the facility and analyze the hazards associated with its operation such that the necessary controls and risks associated with operating the facility are clearly understood and described. The SAD uses the safety analysis process described in Chapter 3 to identify credited controls and serves as the technical basis for the separate ASE document (Ref. 1).

### 1.1.1 Applicable Requirements/Guidance

This SAD was prepared as required by DOE O 420.2D, *Safety of Accelerators* (Ref. 2). The format and content of this document follow the format and content guidance in:

- DOE G 420.2-1A, Accelerator Facility Safety Implementation Guide for DOE O 420.2C, Safety of Accelerator Facilities (Ref. 3)
- LMS-PROC-381, Preparing or Updating an Accelerator SAD and ASE, Rev. 0 (Ref. 4)
- DOE-HDBK-1163-2020, *Integration of Hazard Analyses*, October 2020 (Ref. 5).

### 1.1.2 Facility Mission and Goals

The mission of the Advanced Photon Source (APS) is to deliver world-class science and technology by operating an outstanding synchrotron radiation research facility accessible to a broad spectrum of researchers.

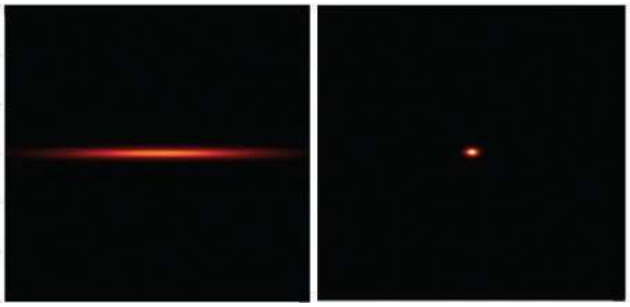
The goals of the APS are:

- Operate a highly reliable third-generation synchrotron x-ray radiation source
- Foster a productive environment for conducting research
- Enhance the capabilities available to users of the APS facility
- Assure the safety of the facility users and staff and the environment
- Maintain an organization that provides a rewarding environment that fosters professional growth and
- Optimize the scientific and technological contribution to the Department of Energy and society from research carried out at the APS.

### 1.1.3 APS Upgrade Project

Rev 6 of this document coincides with a major upgrade to the APS which replaces the old 7 GeV electron storage ring with a new 6 GeV, 200 mA low-emittance storage ring that uses a "multi-bend achromat" (MBA) lattice. The term "lattice" refers to the sequencing and types of electromagnets positioned along the path (vacuum chamber) where the electron beam travels.

The MBA lattice reduces the horizontal spread (emittance) of the electron beam, which in turn reduces the horizontal spread of the x-ray beam that increases the x-ray brightness (the number of photons concentrated on a spot per unit of time) and coherent flux by 2 to 3 orders of magnitude over current values. This increase in brightness and coherence in the hard x-ray region will revolutionize imaging and microscopy capabilities and techniques and allow researchers to gather more data in greater detail in less time. Shown below are simulated x-ray beam profiles produced by the old storage ring (on the left) and the upgraded storage ring (on the right) using the new MBA lattice. The upgrade includes new storage ring control systems and data analysis capabilities.



Photons (x-rays) are emitted by the electrons as the path they are traveling is diverted by magnetic fields (magnets) in the storage ring. The properties of the electron beam and magnets determine the properties of the resulting x-ray beam. The lower emittance electron beam allows other components, such as the vacuum chamber where the electrons travel through the magnet lattice and the associated magnet gaps, to be scaled down in size from the former APS storage ring.

The upgrade also replaced and retrofitted x-ray beamlines to be compatible with the new storage ring, handle the additional heat load, and provide new capabilities. The upgrade included nine new feature beamlines and 15 enhanced and improved beamlines. The beamline upgrades included extending two beamlines through the outer wall of the Experiment Hall to the new Long Beamline Building (Building 444). The front ends, that transport and control the x-ray beams from the storage ring to the beamlines in the experiment hall were modified or replaced.

The injector complex (consisting of the linac, particle accumulator ring (PAR), booster synchrotron, and associated transport lines) will remain operational during the upgrade process. However, the new storage ring requires electrons to be injected into the storage ring more frequently (every 7 to 21 seconds depending on the mode) to maintain the stored beam current. The new swap-out injection scheme, where the old (depleted) electron bunch is extracted simultaneously as a new (fresh) electron bunch is injected, requires the injector complex to repeatedly deliver electron bunches with 100% of the required charge on each injection cycle. This requires significantly higher beam currents in the PAR and booster synchrotron. The most significant changes in hazards associated with the upgrade include a significant increase in the charge of each electron bunch injected into the storage ring to support swap-out injection, and an increase in radiation in Zone F of the storage ring due to extracting depleted electron bunches into a swap-out beam dump. To support high charge injection, additional shielding was required on the storage ring mezzanine near Sectors 36, 37, and 38 due to increased radiation from the Booster to Storage Ring (BTS) transport line, and additional shielding was added inside and outside of Zone F of the storage ring tunnel due to the increased radiation from the new injector higher-charge operation and swap out beam dump.

## 1.2 SUMMARY OF SAFETY ANALYSIS

The safety analysis methodology and results are described in detail in Chapter 3 of this document.

The safety analysis process consists of two main steps. The first step was to identify the hazards associated with the APS facilities, processes, and operations, and then screen the identified hazards to determine which need further consideration (per Section 2.2.3 of DOE G 420.2-1A (Ref. 3)). Industrial and laboratory hazards that are adequately managed by a Safety Management Program (SMP) that meets safety and health standards invoked in 10 CFR 851 need not be analyzed further (can be screened out) unless they can initiate or contribute to an accident related to specific accelerator processes. The hazard identification and screening methodology is described in more detail in Section 3.1.1, and the hazard identification and screening process is documented in Table 3-4, *Hazard Identification and Screening Table*.

The second step was to assess the accelerator-specific hazards that did not screen out and develop a set of off-normal and accidental events that could produce the hazard of concern or expose people to the hazard of concern. This is where the safety analysis transitions from evaluating operating hazards to evaluating off-normal and accidental events. Each event was then evaluated to determine the likelihood of occurrence, potential consequence, and associated risk. Then controls were selected to adequately prevent the event or mitigate the consequences commensurate with the associated risk (per Section 2.2.3 of DOE G 420.2-1A (Ref. 3). The off-normal and accidental event evaluation methodology is described in more detail in Section 3.1.2, and Table 3-5, *Off-Normal and Accidental Event Evaluation Table*, was used to organize and document the results of this process. The outcome of this process is a set of controls that is carried forward to the separate Accelerator Safety Envelope (ASE) document (Ref. 1).

### 1.2.1 Summary of Significant Hazards

The process of creating, accelerating, and steering an electron beam involves a wide variety of hazards. The hazards can generally be divided into accelerator-specific hazards and industrial and laboratory hazards.

The main accelerator-specific hazard discussed in this document is ionizing radiation. The primary source of ionizing radiation is the electron beam in the accelerator systems and storage ring. The electron beam is contained inside accelerator systems and the storage ring, but various types of ionizing radiation are generated when the electron beam is on or present. Synchrotron radiation (x-ray photons) is emitted when the direction the electrons are traveling is diverted by a magnetic field. Bremsstrahlung radiation (gamma ray photons) is produced when electrons suddenly decelerate as they interact with residual gas molecules in the vacuum chamber, accelerator structures, or any material in its path. Secondary radiation including electrons, positrons, neutrons, x-rays, and gamma rays are produced when electrons, or bremsstrahlung radiation interact with accelerator or beamline components, stray air molecules, or other matter. The magnitude of radiation hazards associated with a particle beam increases as the beam power increases.

See Table 3-4 for a more detailed discussion of hazards.

### 1.2.2 Summary of Credited Controls

The safety analysis in Chapter 3 identifies the credited controls that are essential for safe operation and are directly related to the protection of workers, the public and the environment. Table 1-1 provides a summary of the credited controls. **See Section 3.2.2.2 for a more detailed discussion of the controls**.

**Table 1-1. Credited Controls**

| Control / Type | Condition/Requirement/Control | Reason for Credited Control |
|---|---|---|
| ACIS – Access Control Features<br>Credited Engineered Active System | ACIS is validated (including meeting surveillance interval) and enforcing Accelerator Enclosure Access requirement | Access Control: ACIS protects people by removing an existing hazard if access restrictions are violated. |
| ACIS – Area Radiation Monitors<br>Credited Engineered Active System | Radiation Monitors tied into ACIS are required in accordance with Design Limits set by Radiation Protection. | Directly protects people by terminating beam operations when excessive radiation is detected, which mitigates consequences to personnel outside shielding structures. |
| Radiation Shielding<br>Credited Engineered Passive System | Shielding is maintained in accordance with Radiation Protection Processes and Surveillances. | Radiation Shielding protects people by limiting radiation dose from accelerator produced radiation. |
| Personnel Safety System (PSS) – Access Control Features | Prevents entry into a beamline station when prompt x-ray radiation may be present. | Access Control: PSS directly protects people by removing an existing hazard if access restrictions are violated. |

**Table 1-1. Credited Controls**

| Control / Type | Condition/Requirement/Control | Reason for Credited Control |
|---|---|---|
| Oxygen Deficiency Monitors Combined Audio and Visual Alarms. | Requires ODH risk assessment for any proposed installation of use of asphyxiant cryogens or gasses and establishes methods for mitigating the hazards.<br>Areas that have been evaluated and determined to have a potential of oxygen concentrations of less than 19.5% oxygen will have fixed oxygen monitors along with visual and audible alarms as required by Argonne's Oxygen Deficiency Program and this Safety Analysis.<br>When a monitor has been reported to be defective and a potential ODH hazard exists access to areas identified as potentially oxygen deficient areas will not be authorized except for qualified emergency response personnel. | While ANL's Worker Safety and Health Program does include ODH, there is sufficient concern regarding ODH throughout the Department of Energy that a conservative safety management approach indicates that ODH is not screened out. |
| Main Control Room Operators | One crew chief or one qualified operator is required to be in the Main Control Room or alternate control position except for intermittent use of restrooms or breakrooms when the accelerator is running reliably. | Minimum personnel to ensure safe operations at the facility. |

The safety analysis in Chapter 3 also identifies Safety Management Programs that are relied upon to manage industrial and laboratory hazards at APS. See Chapter 4 for a more detailed discussion of the Safety Management Programs.

## 1.3 SAFETY ANALYSIS CONCLUSIONS

The APS is a complex, high-energy synchrotron radiation facility. Due to the nature of the operations and associated hazards at the APS, off-normal and accidental events have mostly localized consequences with very little to no impact outside the facility boundary. The analysis in Chapter 3 shows that unmitigated consequences from certain off-normal or accidental events could have a significant impact on personnel (facility workers and users) in the immediate work area. Off-normal or accidental events pose negligible to no consequences to co-located workers outside the facility boundary, and no consequences to the public beyond the site boundary.

This SAD identifies the controls that reduce risk to an acceptable level. These credited controls and their purpose are described in Chapter 3 and are carried forward to the separate Accelerator Safety Envelope (ASE) document, which defines the bounding conditions and credited controls for safe operation and is the primary document used by operations personnel.

The safety analysis shows, with reasonable assurance, that the safety envelope defined by the SAD provides adequate protection for facility workers and users, the public, and the environment for continuing APS operations.

## 2. DESCRIPTION OF SITE, FACILITY, AND OPERATIONS

This chapter is an overview of the site, facility and operations, for a full description see "Advanced Photon Source Upgrade Project Final Design Report" (Ref. 6) Advanced Photon Source Upgrade Accelerator Functional Requirements Document (Ref. 7) and 'APS Injection Complex (Ref. 8).

### 2.1 FACILITY OVERVIEW

An aerial view of the APS complex is shown below in Figure 1-1. The APS consists of a number of buildings that contain electron injection systems, electron storage ring systems, x-ray beamline systems, and support systems. At a high level, the APS can be thought of as three parts: accelerating electrons, producing photons, and using photons, as discussed below.

**Figure 2-1. Aerial View of APS Complex**

**Accelerating Electrons (Injector Complex)**

The injector complex (consisting of the linac, particle accumulator ring, booster synchrotron, and associated transport lines) supplies individual electron bunches at the right time and the right energy to the storage ring. An electron gun fires bunches of electrons into a linear accelerator (linac) that accelerates the electrons to an energy of approximately 450 MeV. Multiple electron pulses from the linac are accumulated into a single bunch in the particle accumulator ring and then transferred to the booster synchrotron. The booster synchrotron accelerates the single electron bunch to an energy of 6-GeV before it is injected into the storage ring. The electrons are accelerated using radiofrequency electromagnetic waves in resonant cavities and the electron beam is directed and focused by electromagnets.

### Producing Photons (Storage Ring)

Individual electron bunches from the injector complex are injected into the circular multi-bend achromat storage ring, where many (e.g. 48 to 324) equally spaced bunches are kept circulating. The electron bunches are kept circulating (stored at a constant energy) in the storage ring while they emit high energy photons (x-rays) called synchrotron radiation as their direction of travel is diverted by magnets (bending magnets and undulators). Some nominal parameters of the storage ring are shown in Table 2-1.

**Table 2-1. Nominal Operating Parameters of Multi-Bend Achromat Storage Ring (Ref. 7)**

| Quantity | Timing Mode | Brightness Mode | |
|---|---|---|---|
| | | Flat Beam | Round Beam |
| Electron energy (GeV) | 6 | 6 | 6 |
| Stored beam current (mA) | 200 | 200 | 200 |
| Stored energy (J) | 4418 | 4418 | 4418 |
| Number of bunches | 48 | 324 | 324 |
| Injected charge per bunch (nC) | 16.1 [1] | 2.4 [2] | 2.4 [2] |
| Beam lifetime (hrs) | 2.81 [3] | 7.3 [3] | 15.0 [4] |
| Injection mode | swap-out | swap-out | swap-out |
| Injection interval (sec) | 21 [3] | 8.1 [3] | 13.7[4] |
| Average injected power (W) | 4.58 [3] | 1.8 [3] | 1.0[4] |

[1] High bunch charge
[2] Low bunch charge
[3] Nominal values based on minimum estimated beam lifetime assuming large injection loss (low injection efficiency)
[4] Uses 10th-precentile lifetime

### Using Photons (X-ray Beamlines)

Beamline systems capture the x-rays emerging tangentially from the storage ring, manipulate and define the x-ray beam, and direct the x-ray beam to experiment stations where users' experiments are set up. The x-rays interact with atoms in samples being studied and allow users to obtain very detailed atomic-scale images of the structure of materials and perform very detailed chemical analysis. Many different scattering (diffraction), spectroscopic (absorption), and other imaging techniques are used. The APS has 35 different beamline sectors (or user areas) that each have access to one or more beamlines.

## 2.2 OPERATIONS DESCRIPTION

### 2.2.1 Accelerator Operations

Operations are performed in accordance with the Conduct of Operations Program (Refs. 9,10, and 11), which provides a disciplined and formal method for safely operating the facility and ensuring quality and uniformity of operational activities. The program is based on the concept that workers are trained on operational requirements and are disciplined in observing these requirements.

Strict adherence to operating procedures is required to operate the linac, PAR, LEA, booster synchrotron, RF Area, and storage ring under the control of their respective ACIS for each area. Proper execution of other related procedures is required for activities that the ACIS cannot control or guarantee, such as the tunnel search and secure process and monitoring personnel entering and exiting the tunnels during the controlled access mode using CCTV.

Examples of routine accelerator operations include:

- Operating, monitoring, and controlling accelerator systems, support systems, and utilities. This includes starting up, shutting down, or adjusting systems and equipment as needed to support operations.
- ACIS operations.
- Accessing accelerator shielded enclosures (tunnels).
- Surveying and using low-power (Class 1, 2, and 3a) lasers, adjusting, aligning, and fiducializing (transferring a component’s magnetic centerline position to external fiducials) magnets, insertion devices, and other accelerator components.
- Testing systems and equipment in Test Mode.
- Transitioning tunnels from being occupied to a secure state with no human occupancy.
- Linac/PAR Operations (energizing Controlled Equipment after Linac/PAR ACIS reaches “Beam Permit Mode”).
- Linac/PAR Interleaving Operations (once swap-out is established, Interleaving Mode can be started, where Linac beam will be switched from the thermionic cathode gun (for the Storage Ring swap-out mode operations) to the Photo cathode gun (for LEA operations).
- LEA Operations (energizing the controlled bending magnets that transport beam to the LEA and opening the BTL radiation stop in the booster synchrotron alcove after LEA ACIS reaches “Beam Permit Mode”).
- Booster Synchrotron Operations (energizing controlled equipment after the booster synchrotron ACIS reaches “Beam Permit Mode”).
- Storage Ring Operations (energizing Controlled Equipment depending on mode after the storage ring ACIS reaches “Beam Permit Mode”).
- Changing modes of operation (e.g., Injection Mode, Stored Beam Mode, Swap-Out Mode, changing positions of waveguide switches, using storage ring’s RF3 to backup booster synchrotron’s RF5, RF Conditioning Mode, Building 420 RF Test Stand (RFTS) Operation, etc.).

- Test Stand (e.g., 411 Injector Test Stand, and 420 RF Test Stand) operations conducted in accordance with approved work instructions.
- Test cage (e.g., EAA power supply test cage, 412 power supply test cage, and 400A solid state RF test cage) operations conducted in accordance with approved work instructions.
- Ad hoc tests may also be set up for particular purposes and conducted in accordance with approved work instructions.

### 2.2.2 Beamline Operations

Examples of routine beamline operations include.

- Operating, monitoring, and controlling beamline systems, support systems, and utilities. This includes starting up, shutting down, or adjusting systems and equipment as needed to support operations.
- PSS operations.
- Accessing beamline stations.
- Surveying and using low-power (Class 1, 2, and 3a) lasers to align front end and beamline components.
- Setting up and testing experimental equipment.
- Providing technical services and support for users performing experiments at APS.
- Transitioning stations from being occupied to a secure state with no human occupancy.
- Opening shutters and Manual Beam Stops to allow beam to enter stations.
- Performing experiments (See Section 2.2.3 below).

### 2.2.3 User Experiments

The x-ray experimental facilities are available to a community of researchers (users) from Argonne and external research organizations, including researchers who send samples to the APS for analysis. User is a collective term that refers to anyone who participates in synchrotron radiation-based research activities at the APS.

The overall process of setting up and performing an experiment includes:

- Experiment safety review process (see Section 4.8 for a description of Experiment Safety Reviews).
- Receive experiment equipment and samples from user.
- Prepare experiment equipment and samples and set up in beamline station and remote monitoring/control area. This includes opening station doors, running cables, and opening penetration labyrinths.
- Verifying that the controls, training, and safeguards specified in the Experiment Hazard Control Plan (EHCP) are in place.
- Receiving authorization to proceed from the APS Floor Coordinator.
- Performing the experiment and collecting data from the interaction of x-ray beam with the sample. This may involve scattering (diffraction), spectroscopic (absorption), or other imaging processes.

- Disassembling and removing experiment equipment and samples.
- Shipping experiment equipment and samples back to user site.

### 2.2.4 Inspecting, Testing, and Maintenance Activities

Inspections, testing, and maintenance activities are performed throughout the life of the facility to keep the facility safe, habitable, functional, and compliant with applicable requirements.

These activities include:

a. Performing preventive or corrective maintenance to preserve or restore operability/functionality of structures, systems, and components. This includes controlling hazardous energy sources (e.g., closing valves, opening breakers, and lock out/tag out), troubleshooting, repairing or replacing components, and returning to service. This also includes activities like filling/recovering/testing refrigerant and SF6, calibrating and aligning equipment.
b. Inspecting and testing systems and equipment to ensure that they are operating properly. This includes routine inspections and testing (e.g., ACIS operability testing, and inspecting/testing fire protection systems), as well as post maintenance testing to verify operability/functionality of a system or component before returning it to service.
c. Validating shielding.
d. Routine Health Physics activities needed to support operations, such as dose and exposure rate surveys, contamination surveys, checking radiological instruments, annual calibration of radiation monitors, six month source check of the radiation moinitors, leak checking sealed sources, preparing radiological work permits, updating postings, etc.
e. Filling liquid nitrogen, helium, diesel fuel, and other tanks.
f. Receiving and storing supplies, equipment, replacement parts, tools, and other equipment.
g. Conducting facility tours and inspections (e.g., work planning, fire protection, radiological protection, safety, and housekeeping walkthroughs) and hosting groups that are performing assessments or observing ongoing activities.
h. General housekeeping, including removing and monitoring combustible materials and industrial materials (e.g., cleaning supplies, maintenance supplies).
i. Hazardous material abatement/remediation (e.g., asbestos, lead).

## 2.3 MANAGEMENT ORGANIZATION

The Advanced Photon Source is operated by the Photon Sciences (PSC) Directorate at Argonne National Laboratory. The Director of the Advanced Photon Source (APS Director) heads the Photon Sciences Directorate and is responsible for developing and operating the APS as a national user facility. The APS Director also provides overall scientific and managerial leadership for the APS organization and has line responsibility for all aspects of safety within the organization. The responsibility for implementing safety programs has been delegated to divisional line management, managers, and the staff. A simplified APS organization chart is shown in Figure 2-2.

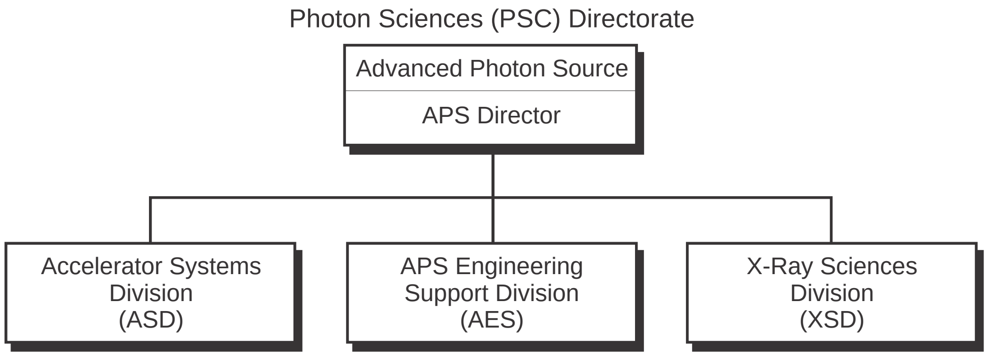


**Figure 2-2. APS Organization Chart**

The APS Director oversees the following divisions:

**Accelerator Systems Division (ASD):** ASD is responsible for operating and maintaining the APS accelerator systems. ASD includes the Accelerator Operations and Physics Group, the Main Control Room (MCR) Group, and other operations support groups (Diagnostics, Magnetic Devices, Power Systems, RF). The Main Control Room (MCR) operators are responsible for safely operating the accelerator systems (linac, particle accumulator ring, booster synchrotron, and the storage ring).

Commissioning and operations of the Advanced Photon Source accelerator complex are under the control of two main control room staff consistent with previous safe operating experience at the APS. One staff member will be a qualified Crew Chief who shall maintain authority and responsibility for all accelerator operations and is responsible for maintaining safe accelerator operations, a second qualified or trainee Main Control Room Operator is responsible for adhering to operating procedures and technical specifications. These responsibilities are captured in the Main Control Conduct of Operations Manual (Ref. 10). The APS has set up an alternate control location in the 401 building where the accelerators can be operated during emergencies (e.g. weather related). To ensure safe facility operations as well as being able to respond to unforeseen events, the crew chief or qualified main control room operator will be present in the Main Control Room or or the alternate control location at all times. By design, when the accelerators are operating reliably, direct intervention by the operators is not expected as the engineered safey systems will disable beam if needed. Consequently, during reliable operations, intermittent breaks that leave the MCR or alternate control location unattended for the purposes of accessing the restroom or break room contributes to ensuring operator readiness without loss of safety.

**X-Ray Science Division (XSD):** XSD is responsible for operating and maintaining the x-ray beamlines. The Beamline Operations Groups operate 36 APS-managed x-ray beamlines and pursue research in physical, chemical, environmental, and materials sciences. XSD also provides technical services and administrative support to users of XSD beamlines. The X-Ray Science Technologies Groups support a program of research and development into cutting-edge x-ray instrumentation and techniques.

**APS Engineering Support (AES) Division:** The AES Division provides technical support for the accelerator systems, beamlines, and the APS plant. The Mechanical Operations and

Maintenance Group provides engineering and maintenance support. The Information Solutions and Information Technology Groups develop and maintain the APS computing infrastructure, and the Safety Interlocks Group designs, installs and maintains radiation safety and equipment protection systems. The Floor Coordinators (in the Experimental Facilities Operation Group) are responsible for operations on the Experiment Floor, including operating PSS and beamline equipment. They are responsible for monitoring user operations and for providing necessary safety support and guidance to users.

To ensure safe operations on the experiment floor, one qualified Floor Coordinator will be on duty either at the facility or on call. Responsibilities are outlined in the Conduct of Operations Manual APS User Experiments Operations Group (Ref. 11). Onsite responsibilities may be shared with the Main Control Room Operations Group.

A variety of committees have been appointed for safety purposes. Some of the key committees related to APS safety are listed below, the most up to date list can be found on the APS website (Ref. 12).

The APS **Experiment Safety Review Board** (ESRB) advises APS Management on safely performing user experiments on the Experiment Hall floor. The ESRB reviews experiments that are submitted to APS via the Experiment Safety Assessment Form (ESAF). The experiment review process is described in APS_1187022, *APS Experiment Reviews* (Ref. 13).
The APS **Radioactive Sample Safety Review Committee** (RSSRC) reviews plans for an any radioactive sample that a user is considering bringing to the APS, and the adequacy of the controls while at APS. Approval by both the RSSRC and the experimental facilities management is required to bring radioactive samples to the Argonne site and use them in experiments at the APS.

The **Photon Sciences (PSC) Design Review Committee** (PDRC) reviews the design of new or modified systems or components at APS to determine the adequacy of a design to meet its performance, safety, and operational objectives. This includes new or changed accelerator, beamline, mechanical, pressure, cryogenic, electrical, safety, structural, and shielding systems and components. The PDRC reviews are integral part of the design review process as described in APS_000031, *APS Design Reviews* (Ref. 14) and APS_1685081, *Change Control for Radiation Safety Shielding* (Ref. 15). The committee ensures that safety aspects of the design are considered.

The **APS Laser Safety Committee** advises APS management on laser safety matters, participates in project reviews as requested, recommends laser safety policy, reviews accident investigation conclusions, and evaluates plans to protect personnel where laser activities are expected to take place.

The **PSC Radiation Safety Committee** (PRSC) advises PSC management on radiation safety matters. It evaluates the design of radiation shielding, functional changes to the Access Control Interlock System (ACIS) and Personnel Safety System (PSS). The committee also provides recommendations to PSC Management regarding changes to the operating and safety envelope and provides technical advice on radiation safety and shielding issues. The committee works as a member of the PDRC for reviews of beamline design changes.

The **Commissioning Readiness Review Team** (CRRT) reviews and verifies that the approved designs were implemented in the installation process. It verifies that mechanical and vacuum systems are operational and validated prior to shielding verification of a new or modified installation. The review will ensure that the hardware, personnel, and documentation are in place to ensure safe reliable operations.

# 3. SAFETY ANALYSIS

This chapter identifies and assesses the hazards associated with APS operations, identifies and evaluates the risk of off-normal and accidental events, and identifies the controls necessary to prevent (reduce the likelihood) or mitigate (reduce the consequences of) off-normal and accidental events.

## 3.1 SAFETY ANALYSIS METHODOLOGY

This section describes the methodology used to perform the safety analysis, which follows the guidance in DOE G 420.2-1A (Ref. 3) and DOE-HDBK-1163-2020 (Ref. 5). The safety analysis process consists of two main sub-processes or steps:

- Hazard Identification and Screening
- Off-Normal and Accidental Event Evaluation

### 3.1.1 Hazard Identification and Screening Methodology

The hazards associated with the APS facilities, processes, and operations are identified and evaluated using a Hazard Identification and Screening Table (Table 3-4). This is a non-scenario-based preliminary hazard evaluation. This process consists of the following steps:

1. Identify the full range of hazards associated with the accelerator facilities, processes, and operations; for both normal operations and credible accidents.
2. For each hazard identified determine if they are industrial and laboratory hazards that are safely managed by other DOE approved applicable safety and health programs.
    - If the hazard is managed by a DOE approved program, the hazard is ‘screened out’ and can be removed from further consideration.
    - Hazards that are not managed by an existing program are considered ‘accelerator specific hazards’ and require further consideration. This process is described in Section 2.2.3 of DOE G 420.2-1A (Ref. 3).

    However, the Safety Management Program(s) relied upon to reduce the potential for harm related to the hazard is an important part of safely operating the facility and must be identified. Accelerator-specific hazards are carried forward for a more in-depth, frequency and consequence-based off-normal and accidental event evaluation as discussed in Section 3.1.2.

Hazards associated with accelerator facilities, processes, and operations were identified by reviewing design and safety documentation such as the previous Safety Analysis Document (Ref. 16), the Advanced Photon Source Upgrade Project Final Design Report (Ref. 6), the Advanced Photon Source Upgrade Project Hazard Analysis Report (Ref. 17), and other documents. Site walk-downs and interviews were also conducted with safety personnel, system engineers, operations staff, and support personnel (e.g., fire protection program, radiological protection program) to develop a comprehensive list of hazards. The identified hazards were rolled up into one table (Table 3-4, *Hazard Identification and Screening Table*).

The identified hazards were then evaluated to determine if they were adequately managed by Safety Management Programs, or if they can initiate or contribute to an accident related to an accelerator specific process (accelerator-specific accident). This screening process accomplishes two functions: (1) it screens out low-level hazards from further consideration, and (2) it screens out hazards that are generally well understood and covered by existing codes, regulations, or other consensus standards (e.g., Building Codes, National Fire Protection Association, National Electric Code, ASME pressure vessel code, 10 CFR 835 Occupational Radiation Protection Program requirements).

The results of the hazard identification and screening process are discussed below in Section 3.2.1. The Safety Management Programs that are relied upon to manage hazards at APS and screen them from further evaluation are identified in Table 3-4 and listed in Section 3.2.1.1. Note that these Safety Management Programs are important for safe operations at APS. They are identified in the SAD and committed to in the ASE, but the SAD and ASE do not need to duplicate the programs and are not the drivers for the programs.

The hazards that did not screen out in Table 3-4 are listed in Section 3.2.1.2. These hazards will be carried forward and evaluated further, and the SAD and ASE are the drivers for managing these hazards.

### 3.1.2 Off-Normal and Accidental Event Evaluation Methodology

The next step in the safety analysis process is to evaluate the accelerator-specific hazards that did not screen out in the screening process. This is a scenario-based hazard evaluation. This process consists of the following steps.

1. Evaluate the accelerator-specific hazards that did not screen out in the screening process above and develop a set of off-normal and accidental events related to those hazards. These events or scenarios could produce the hazard of concern or expose people to the hazard of concern. This is where the safety analysis transitions from evaluating hazards to evaluating off-normal and accidental events or scenarios. The off-normal and accidental events are identified using a simple What-If Analysis while reviewing the hazards along with possible equipment malfunctions, human errors, and other initiating events that could result in the various events. System design information was also reviewed since most, if not all, of these events have already been considered in system designs. The results of this process are the off-normal and accidental events listed in Section 3.2.2.
2. The next part of the process is to evaluate the likelihood of occurrence, potential consequence, and associated risk of each event. This involves multiple steps and is an iterative process that is done using an Off-Normal and Accidental Event Evaluation Table (Table 3-5). An initial risk evaluation is performed for each event assuming that no preventive or mitigative controls are in place other than the Initial Condition Assumptions that help define the scenario. The controls applicable to each event are listed. Once the controls are selected, a residual risk evaluation is performed assuming that the controls are in place. The off-normal and accidental event evaluation is based on a simple What-If Analysis but may reference and rely upon more detailed radiation shielding analyses, layer of protection analyses, or failure mode analyses. The outcome of

this process is a set of controls that is carried forward to the separate Accelerator Safety Envelope (Ref. 1).

**Credited Controls:** Controls determined through Safety Analysis to be essential for safe operation directly related to the protection of workers, the public, and the environment. (Ref. 2, Attachment 2) A subset of the defined controls are determined to be the credited controls if they are mitigating the consequences of an imminent hazard.

**Layers of Protection** is an approach to managing or controlling hazards that uses several layers of controls to protect against an accident so that no one layer by itself, no matter how robust or effective, is exclusively relied upon. Layers of Protection include Credited Controls that were selected in Table 3-5 to be elevated to the ASE and uncredited controls that are available and provide additional layers of protection but were not elevated to the ASE. Uncredited layers of protection can include control systems, interlocks, or administrative controls and may be implemented as part of a Safety Management Program (e.g., Radiological Protection Program, Worker Safety Program, Conduct of Operations).

The remainder of this section describes the methodology for completing the evaluation in Table 3-5.

### 3.1.2.1 Frequency Category Estimates

The frequency (or likelihood) for each event was qualitatively estimated and categorized (or assigned bins) based on the criteria in Table 3-1 below, which was derived from Figure C-2 in DOE-HDBK-1163-2020 (Ref. 5). For unprevented frequency estimates, events were assessed assuming that passive Design Features (e.g., concrete shielding structures) are available as an initial condition if appropriate since the scenarios would not make sense without the structures.

**Table 3-1. Frequency Bin Designations**

| Bin | Likelihood Range (/year) | Description |
|---|---|---|
| **Anticipated** | More than once/yr to once/100 yrs | Events that may occur several times during the lifetime of the facility. |
| **Unlikely** | once/100 yrs to once/10,000 yrs | Events that are not anticipated to occur (but could potentially occur) during the lifetime of the facility. |
| **Extremely Unlikely** | once/10,000 yrs to once/1,000,000 yrs | Events that will probably not occur during the lifetime of the facility. |
| **Beyond Extremely Unlikely** | less often than once/1,000,000 yrs | Events whose probability of occurrence is so small that it is not considered reasonable. |

Accident scenario frequencies were estimated using engineering judgment and simulations to evaluate the various factors for the initiating event for the scenario. Some of the major factors considered for the initiating events were:

- The number of failures required for the scenario,

- The credibility of the particular failure mode(s),
- The dependency of any of the failures,
- Human factors,
- Credibility of the energy source or challenge,
- Period of time the energy source or challenge is present, and
- Historical occurrences or near misses.

#### 3.1.2.2 Consequence Category Estimates

Due to the nature of the operations and associated hazards at the APS (e.g., no target collisions, no volatilization of targets, no collider experiments, and small radionuclide inventories), off-normal and accidental events have little to no impact outside the facility boundary. Direct ionizing radiation is largely attenuated by shielding structures, and the intensity of remaining radiation drops off quickly with the distance from the source. There are no significant quantities of hazardous or radioactive materials that can be dispersed by spills, fires, or explosions. The hazards can result in significant localized consequences (inside the facility) but have little to no consequences outside the facility boundary. Therefore, the consequence estimates will focus on involved facility workers (workers in the facility near the source of the hazard).

The consequence to an involved facility worker for each event was qualitatively estimated and categorized (or assigned bins) using the criteria in Table 3-2 below, which was derived from Figure C-1 in DOE-HDBK-1163-2020 (Ref. 5). However, note that to be conservative since APS hosts large numbers of outside users and because any onsite workers can access the Experiment Hall floor, Table 3-2 uses the more conservative Offsite (public) consequence criteria from DOE-HDBK-1163-2020 for the facility worker consequence criteria.

**Table 3-2. Consequence Bin Designations**

| Bin | Facility Worker Consequence* |
|---|---|
| **High** | **Radiological:** Total effective dose > 25 rem<br>**Other Hazards:** Loss of life or serious injury that requires extensive professional medical attention. |
| **Moderate** | **Radiological:** Total effective dose between 5 and 25 rem<br>**Other Hazards:** Moderate (but not life threatening) injuries that require professional medical attention. |
| **Low** | **Radiological:** Total effective dose between 0.5 and 5 rem<br>**Other Hazards:** Minor injuries that require only superficial medical attention. |
| **Negligible** | Negligible or no measurable impact. |

* Although quantitative radiological thresholds are provided for involved facility worker consequences, the consequences may be estimated using qualitative or semi-quantitative techniques.

Facility worker consequences were qualitatively estimated by evaluating various factors that affect the sequence of events and magnitude of the consequences, such as:

- Types of processes in the facility (radiation levels, energy levels in processes).
- Types of material in the facility (e.g., chemicals, cryogenic liquids, radioactive materials).

- How fast an event progresses (energies, thermodynamics, and changes in radiation fields over time) and how that affects ability of facility workers to take self-protective actions.
- Building configuration, compartments, enclosures, fire barriers, obstacles, ventilation, and other considerations.
- Barriers to radiation exposure (shielding structures, removable shielding, separation distances, etc.).
- Ease of egress from all operations areas.
- Obstacles, topography, and potential exposure once a facility worker egresses the hazard area.

Conditions where off-normal and accidental events might result in high consequences include:

- Exposure to direct radiation, radioactive material, or toxic material of sufficient magnitude that death or ongoing large-scale medical intervention may reasonably be expected.
- Energetic release of a large amount of energy, radioactive material, or toxic material where the facility worker would normally be immediately present and therefore unable to take self-protective actions.
- Deflagrations or explosions within process equipment, operations areas, or confinement/containment structures or vessels where grievous injury or death to a facility worker may result from the fragmentation of the process equipment or failure of the confinement (or containment) in the vicinity of areas occupied by facility workers.
- Chemical or thermal burns to a facility worker not covered by the Argonne Hazardous Material Protection Program that could reasonably cover a significant portion of the facility worker body where self-protective actions are not reasonably available due to the speed of the event or where there may be no reasonable warning to the facility worker of the hazardous condition.
- Leaks from process systems not covered by the Argonne Oxygen Deficiency Hazard Program that could result in asphyxiation of a facility worker (considering occupancy factor).
- Electrical hazards not specifically covered by the Argonne Electrical Safety Program that cause grievous injury or death to a facility worker due to electrocution, shock, burns, or arc flash/blast.

#### 3.1.2.3 Risk Rankings

Once the frequency and consequence bins were determined, the risk rank was assigned using the matrix in Table 3-3 below, which was derived from Figure C-3 in DOE HDBK-1163-2020 (Ref. 5). Risk ranking provides a useful tool for risk-based decisions, such as identifying risk-dominant scenarios and selecting and evaluating preventive or mitigative controls for adequacy. The risk rankings are a qualitative or semi-qualitative exercise to gain perspective and confirm for the DOE approval authority that the overall mitigated risk of facility operations is sufficiently low.

**Table 3-3. Risk Ranking Bins**

| Consequence | Beyond Extremely Unlikely | Extremely Unlikely | Unlikely | Anticipated |
|---|---|---|---|---|
| **High** | 3 | 2 | 1 | 1 |
| **Moderate** | 4 | 3 | 2 | 2 |
| **Low** | 4 | 4 | 3 | 3 |
| **Negligible** | 4 | 4 | 4 | 4 |

**Frequency**

The risk ranking categories (or bins) and the associated control selection guidelines are summarized below:

| | |
|---|---|
| Risk Rank 1 | Unacceptable Risk (Major Concern) – Controls are required to prevent (reduce frequency) or mitigate (reduce consequences) as necessary to achieve a risk rank of 3 or 4. |
| Risk Rank 2 | Marginal Risk (Marginal Concern) – Controls must be considered to prevent or mitigate as necessary to achieve a risk rank of 3 or 4. Controls for unique hazards that are not adequately covered by SMPs should be elevated to ASE-level controls. |
| Risk Rank 3 | Acceptable Risk (Minor Concern) – Generally protected by Safety Management Programs. However, controls for unique hazards that are not adequately covered by SMPs should be considered for ASE-level controls. |
| Risk Rank 4 | Negligible Risk (Minimal Concern) – Managed by Safety Management Programs (additional controls are not required). |

### Initial (Unmitigated) Risk Evaluation

An initial evaluation of frequency, facility worker consequence, and risk was performed for each event (in the Initial Risk Evaluation column in Table 3-5). The initial risk evaluation assumes that no preventive or mitigative controls are in place other than the Initial Condition Assumptions that help define the scenario. The Initial Condition Assumptions are listed in the "Event Description" column.

The Initial Conditions are:

- **Beam Intensity Limits** – Limits the potential radiation fields produced by particle beams by limiting the beam power and stored beam energy.
- **Radiation Shielding** – Provides shielding to protect personnel in areas outside shielded structures or enclosures. Limits dose rates outside shielded structures or enclosures and provides a physical boundary for preventing access to the shielded structure or enclosure.

Radiation Shielding is maintained in accordance with Radiation Protection Processes and Surveillances. (e.g. Tunnel enclosures)

- **Radiation Shielding Management Program –** Ensures that shielding is in place prior to and during beam operations.
- **Safety Management Programs –** Although not specifically identified as an initial condition when evaluating off-normal and accidental events, a fundamental assumption is that the Safety Management Programs relied upon to manage the various hazards that were previously screened out have been established, implemented, and maintained as described in Section 5.2.

**Control Selection**

The available preventive and mitigative features that were considered for the event are listed in preventive and mitigative features columns in Table 3-5. The subset of controls that are credited will be indicated in the table. The control selection strategy/hierarchy is summarized below:

- Minimize the hazard (first priority)
- Prevention over mitigation (rather not have an accident)
- Engineered Structure, System or Components (SSCs) over Administrative Controls (ACs) (uncertainty of human performance)
- Passive over active (greater reliability)
- Engineered SSCs over personal protective equipment (rather not risk exposure)
- Choose controls closest to the hazard (provides protection for more receptors)
- Choose controls that are effective for multiple hazards (more resource-effective)

**Residual (Mitigated) Risk Evaluation**

Once the controls are selected, the frequency, consequence, and risk are re-evaluated (in the Residual Risk Evaluation column in Table 3-5) assuming that the Initial Condition Assumptions and preventive and mitigative controls are in place.

A basic premise applied throughout the analysis is that the Safety Management Programs (SMPs) provide formal, disciplined, and consistent methods for conducting activities with the purpose of reducing the potential for harm to the workers, public, and the environment. There are many layers of controls contained in the SMPs. Each hazard control is managed by a specific SMP (e.g., Radiological Protection, Fire Protection, Hazardous Material Protection, Conduct of Operations). Therefore, the cumulative effect of the programmatic details is implicitly relied upon in the hazard analysis for providing significant layers of safety against postulated accidents and is an integral part of the facility safety envelope. This overall commitment to SMPs is carried forward to the ASE.

## 3.2 SAFETY ANALYSIS RESULTS

This section presents the results of the safety analysis process, which consists of two separate steps as described in the methodology section above.

- Hazard Identification and Screening
- Off-Normal and Accidental Event Evaluation

### 3.2.1 Hazard Identification and Screening Results

The results of the hazard identification and screening process are shown below in Table 3-4, *Hazard Identification and Screening Table*.

Note that Table 3-4 identifies hazards, which are sources of danger (i.e., energy source, hazardous material, radiation). Table 3-4 does not evaluate off-normal or accidental events or scenarios, which involve an initiating event (or sequence of events) that produces the hazard of concern or exposes people to the hazard of concern. Off-normal and accidental events are identified and evaluated in Section 3.2.2.

The results of Table 3-4 are summarized into the following topics of interest.

#### 3.2.1.1 Safety Management Programs identified in Table 3-4

Based on the results in Table 3-4, the following ANL Safety Management Programs are specifically relied upon to manage hazards at APS and screen them from further evaluation. While ANL’s Worker Safety and Health Program does include ODH, there is sufficient concern regarding ODH throughout the Department of Energy (Ref. 18) that a conservative safety management approach indicates that ODH are not screened out:

- Integrated Safety Management System/Worker Safety and Health Program (abbreviated in Table) (Ref. 24)
- Cryogenic Liquid Safety Program (Ref. 28)
- Oxygen Deficiency Hazard Program (Ref. 19)
- Electrical Safety Program (Ref. 20)
- Fire Protection Program (Ref. 45)
- Radiological Protection Program (Ref. 21)
- Waste Management Program (Ref. 22)
- Experiment Safety Review (Ref. 13)
- Radioactive Material Inventory Management Program (Ref. 38)
- Hoisting and Rigging Program (Ref. 23).

These programs must be established, implemented, and maintained to ensure that the associated hazards are adequately managed. Note that additional overarching Safety Management Programs indicated by DOE G 420.2-1A and the Argonne Accelerator Safety Program (e.g., Quality Assurance, Configuration Management, and Conduct of Operations) will also be included in the Safety Management Program commitments.

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| **1. Chemicals/Toxic Material** | | | | | | |
| Lead | Lead is used for beam stops, collimators, and other accelerator and beamline components. Lead bricks, sheets, shot, and wool are used for shielding in various parts of the facility (klystron housing, RF cavities, accelerator systems, concrete shielding penetrations, beam pipes, beamline station panels, and radiation shielding). The total lead inventory is estimated to be in the hundreds of tons.<br>Work activities involving cutting, machining, and working with lead (soldering, fabricating shielding) are frequently performed. Activities that manipulate lead are performed in accordance with applicable requirements to minimize emissions and also tracked for EPA purposes. Lead manipulation activities in 2019 involves about 4,442 lbs of lead, mostly for fabricating and installing shielded beamline station panels.<br>Inhalation of lead dust or fumes is the primary hazard of concern. Lead in solid form presents few hazards because it cannot be suspended in air or readily absorbed. Hazards associated with processing lead (cutting, grinding, sanding, melting) are adequately controlled by Worker Safety and Health Program. Lead vapor or lead oxide could be released during a fire involving lead, but this is primarily a risk for fire fighters. Toxic exposure to fire fighters is managed by Argonne Fire Department Pre-Fire Plans. | Personnel exposure | Yes | Worker Safety and Health Program (Ref. 24)<br>(APS_1201511, APS Lead Handling [Ref. 25]; LMS-PROC-201, Safe Handling of Lead (Ref. 26)) | No | No |
| | Lead dust/contamination in accelerator tunnels, around radiation shielding, shielded equipment, and fabrication area due to handling lead components or shielding (e.g., bricks, sheets, shot, or wool) or fabrication activities. | Personnel exposure | Yes | Worker Safety and Health Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | Inhalation of lead dust is the primary hazard of concern. Hazards associated with working around lead contamination or processing lead (cutting, grinding, sanding, melting) are adequately controlled by Worker Safety and Health Program. | | | | | |
| Lead-acid batteries | Lead-acid batteries are used in various panels (fire panel and emergency lights), equipment, and vehicles (forklifts, transport vehicles, etc.)<br>Does not represent a significant toxicological hazard due to solid physical form and no processing. | Personnel exposure | Yes | Worker Safety and Health Program | No | No |
| Mercury | Ignitrons in Building 450, which act as rectifiers for converting AC to DC, contain mercury. Ignitrons are large gas-filled steel container with a pool of mercury in the bottom that acts as a cathode. There are approximately 20 pounds of mercury in ignitrons and another 20 pounds of mercury stored in Building 450.<br>The crowbar cabinets that provide overcurrent protection for RF systems have components that contain mercury.<br>There are trace amounts of mercury in fluorescent lights, thermostats, relays, and other components, but no other significant amounts. | Personnel exposure | Yes | Worker Safety and Health Program | No | No |
| Beryllium | Beryllium windows are used to separate the vacuum of the storage ring from the x-ray beamline. Maintenance activities (e.g., changing beryllium windows) could result in exposure.<br>Be compounds are also used in some contactors.<br>Inhalation of beryllium dust or fumes is the primary hazard of concern. Beryllium in solid form presents few hazards because it cannot be suspended in air or readily absorbed. Hazards associated with | Personnel exposure | Yes | Worker Safety and Health Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | maintenance activities involving beryllium are adequately controlled by Worker Safety and Health Program. | | | | | |
| Solvents and cleaners | Ultrahigh vacuum components are cleaned to remove traces of molecular and particulate contaminants, and to remove oxide layers and carbon that increase photo-stimulated desorption. Satisfactory cleaning processes for the different vacuum chamber materials have been devised over the years. Most of these processes involve the use of organic solvents such as methyl chloroform (1, 1, 1 trichloroethane) and perchloroethylene, which are flammable and have other safety concerns. Alkaline cleaners (e.g., Almeco 18, Bonderite-C-AK18, and Brulin 815GD), acid cleaners (e.g., Citranox), alcohol, chlorofluorocarbons (e.g., CFC-113), and other cleaning agents are also used. | Personnel exposure | Yes | Worker Safety and Health Program<br>Laboratory Chemical Hygiene Plan (Ref. 27) | No | No |
| Transformer oil | Transformer oil is used in oil filled transformers and klystrons. Transformer oil is highly refined and formulated to be electrically insulating and provide good heat transfer. The oil used in klystrons (Shell Diala) is stored in 330 gallon totes and 55 gallon drums). Transformer oil does not present any significant health hazards but is combustible. | Fire and Personnel exposure | Yes | Worker Safety and Health Program | No | No |
| Lubricants and other chemicals | Dielectric oil used in electrical components.<br>Hazardous chemical supplies are consistent with those used in general industry and are present in typical end-user quantities. | Personnel exposure | Yes | Worker Safety and Health Program | No | No |
| Toxic gases | SF6 is used in electrical power distribution equipment and the linac buncher waveguide is pressurized to ~32 psig with sulfur hexafluoride (SF6), which is a colorless, odorless, non-toxic, nonflammable gas used as a gaseous insulator. However, toxic byproducts are produced in SF6 filled equipment due to electrical stress during normal use. | Exposure to SF6 toxic byproducts can irritate eyes/nose/throat, cause rashes/ burns, bronchitis, or | Yes | Worker Safety and Health Program | No | No |

### Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | SF6 is used in general industry and there are guidelines and regulations for safe use and handling. Also a potent greenhouse gas. | pulmonary edema. | | | | |
| Corrosives | No bulk acids or caustics are required to support APS operations. Chemical supplies are consistent with those used in general industry and are present in typical end-user quantities. | Personnel exposure | Yes | Worker Safety and Health Program | No | No |
| Reactives | Many battery types are used in variety of tools, laptops, and equipment. For example, lithium reacts violently when exposed to water. | Explosion, toxic gas exposure | Yes | Worker Safety and Health Program | No | No |
| **2. Cryogenic Hazards/Extreme Cold (Note: Oxygen Deficiency Hazards are handled separately in Section 3 below)** | | | | | | |
| Large Liquid Nitrogen Dewars (3,000 gal or more) in outdoor gas yards | The main liquid nitrogen storage dewars are housed outside in well-ventilated gas yards. Liquid nitrogen is inert, colorless, odorless, noncorrosive, nonflammable, and extremely cold (kept in the liquid state by very low temperatures). The vapors and gases released by cryogenic liquids as they evaporate also remain very cold and can accumulate near the floor/ground. They often condense the moisture in air, creating a highly visible fog.<br>The storage dewars are commercially procured items designed in accordance with industry standards (e.g., pressure vessel, relief valve requirements) and housed in well-ventilated areas. Filling and operations involving liquid nitrogen require proper PPE and safety practices in accordance with applicable requirements in the *Argonne Cryogenic Liquid Safety Procedure, LMS-PROC-331* (Ref. 28) and associated procedures. | Leak, rupture, vent.<br>Exposure to cold temperatures can cause cold burns<br>Over pressurization due to expansion of small amounts of liquid into large volumes of gas | Yes | Cryogenic Liquid Safety Program | No | No |
| Liquid Nitrogen transfer and distribution lines in Experiment Hall | The transfer line from each dewar connects to a sub-cooler then enters the building, crosses the experimental hall floor just below ceiling level, and | Leak, rupture, cold burns, over pressurization | Yes | Cryogenic Liquid Safety Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | feeds the distribution line circling the storage ring mezzanine.<br>The potential for contacting the transfer line and causing a release of liquid nitrogen is unlikely since the line is vacuum jacketed (3” diameter stainless steel line surrounding a 1” stainless steel line carrying the LN2) and the line is located near the ceiling or above the storage ring tunnel. | | | | | |
| Liquid Nitrogen Drop Stations | There are drop stations on top of the storage ring tunnel, on the experiment hall floor (near each ID beamline), inside many beamline stations, and in the truck locks. | Spill, cold burns | Yes | Cryogenic Liquid Safety Program | No | No |
| Portable Dewars | Dewars are filled at various stations and used throughout the facility. Liquid dewar flasks are non-pressurized, vacuum-jacketed vessels that allow excess pressure to vent. Dewars are designed in accordance with industry standards and cryogenic operations are performed in accordance with the *Argonne Cryogenic Liquid Safety Procedure, LMS-PROC-331* (Ref 28) and associated procedures.<br>Small quantities of liquid nitrogen are used for maintenance and testing in accelerator enclosures. The main hazard occurs while filling small dewars from large liquid nitrogen storage dewars. | Spill, leak, vent, cold burns, over pressurization | Yes | Cryogenic Liquid Safety Program | No | No |
| Cryostats and Cryomodules | Cryostats and cryomodules are thermally insulated containers with devices mounted inside that are kept extremely cold. Superconducting undulators and other equipment (Bunch Lengthening System (BLS) RF cavity in Sector 38) are housed in cryostats that are located in the storage ring tunnel and other parts of the facility (beamline stations). Cryostats are designed in accordance with industry standards and cryogenic operations are performed in accordance with the | Spill, cold burns, over pressurization | Yes | Cryogenic Liquid Safety Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | *Argonne Cryogenic Liquid Safety Procedure, LMS-PROC-331* (Ref. 28) and associated procedures. | | | | | |
| Cryocoolers and Cryopumps | A cryocooler is a closed cycle refrigerator designed to reach cryogenic temperatures. A cryopump is a vacuum pump that traps gases and vapors by condensing them on a cold surface. The condensing surface of a cryopump can be cooled using a coolant (LN2 or LHe) or a cryocooler. Cryocoolers and cryopumps are commercially procured items designed in accordance with industry standards and cryogenic operations are performed in accordance with the *Argonne Cryogenic Liquid Safety Procedure, LMS-PROC-331* (Ref. 28) and associated procedures. | Spill, cold burns, over pressurization | Yes | Cryogenic Liquid Safety Program | No | No |
| BLS cryogenic plant (liquified helium) in Building 420 and Experiment Hall | Unlike the liquid nitrogen system, the liquified helium is a closed system. It consists of a 250 psi helium tank in infield, compressors in Bldg. 420, BLS cryomodule in storage ring tunnel, and refrigerator (cold box) and dewars in Experiment Hall. The refrigerator (cold box) and dewars are commercially procured items designed in accordance with industry standards and cryogenic operations are performed in accordance with the *Argonne Cryogenic Liquid Safety Procedure, LMS-PROC-331*and associated procedures. | Leak, rupture, vent, cold burns, over pressurization | Yes | Cryogenic Liquid Safety Program | No | No |
| Beamline station cryogenic equipment | There are drop stations inside beamline stations, liquid nitrogen lines automatically topping up cryogenic equipment inside stations, roof decks on top of stations with cryopumps, and other cryogenic equipment. | Leak, rupture, vent, cold burns, over pressurization | Yes | Cryogenic Liquid Safety Program | No | No |
| Cold surfaces, liquid, or gas | Contact with cold surfaces, liquid, or gas | Cold burns, frostbite | Yes | Cryogenic Liquid Safety Program | No | No |
| **3. Oxygen Deficiency Hazards** | | | | | | |
| SF6 | SF6 is used in electrical power distribution equipment and the linac buncher waveguide is pressurized to ~32 psig with sulfur hexafluoride (SF6), which is a | SF6 and toxic byproduct exposure can | Yes | Oxygen Deficiency Hazard Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | colorless, odorless, non-toxic, nonflammable gas used as a gaseous insulator. SF6 is 5 times denser than air and will settle in low lying areas. The total volume of the buncher waveguide is small compared to the surrounding klystron gallery or the linac tunnel, so asphyxiation by displacement of oxygen is not a significant concern. SF6 recovery systems cut SF6 emissions and ventilation systems are adequate to dissipate any released gas. | cause headache, dizziness, pulmonary edema, and asphyxiation. | | (Ref. 19) | | |
| | The APS vacuum systems and vacuum chambers are small and inaccessible and do not represent an oxygen deficiency hazard. A dry nitrogen purge may be used when a vacuum system is vented for repairs, but the vacuum chambers are small compared to the surrounding areas, so asphyxiation by displacement of oxygen is not a significant concern. | Asphyxiation | Yes | Oxygen Deficiency Hazard Program | No | No |
| Stored and piped inert gases | Gaseous helium is supplied to the liquid helium cryo plant in Building 420 from a compressed (230 psig) helium tank in the infield. The volume of helium that can be released into the building is limited by the failsafe valves, which close when the oxygen monitoring system detects an oxygen concentration of 19.5%. The remaining amount of helium that will enter the building is given by the volume of the lines between the storage tank failsafe valves and the building. | Asphyxiation | Yes | Oxygen Deficiency Hazard Program | No | **No** |
| Other stored and piped inert gases | Piped gases: nitrogen, helium<br>Compressed gas cylinders for over pressure on transformers. | Asphyxiation | Yes | Oxygen Deficiency Hazard Program | No | No |
| Liquid Nitrogen Distribution System | The Liquid Nitrogen Distribution System (LNDS) is a once through system that releases nitrogen to the atmosphere as the liquid nitrogen warms up (evaporates). When cryogenic liquids evaporate and form a gas, the gas is very cold and usually heavier than air. This cold, heavy gas does not disperse very | Asphyxiation | Yes | Oxygen Deficiency Hazard Program | No | **YES See O-1** |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | well and can accumulate near the floor. When there is not enough air or oxygen, asphyxiation and death can occur. Oxygen deficiency can be a more prevalent in enclosed or confined spaces. Small amounts of liquid can evaporate into very large volumes of gas. For example, one liter of liquid nitrogen vaporizes to 695 liters of nitrogen gas when warmed to room temperature.<br>None of the enclosures or areas that can be occupied is normally inerted, so there would have to be a LNDS malfunction or accident (large leak, spill, or rupture) to present an oxygen deficiency hazard.<br>Oxygen deficiency hazards associated with the LNDS are evaluated in APS_1265728(Ref. 29), Oxygen Deficiency Hazard Analysis for the APS LNDS. The analysis concludes that:<br>• rupture of a LN2 line filling a storage dewar in the truck lock requires protective measures (oxygen deficiency monitors).<br>• that rupture of a LN2 line inside in a beamline station poses an ODH if the door is closed. Although doors are not allowed to be closed when a person is in a station and is an administrative control for radiation safety, it recommends locating cryopump outside enclosure to vent inert gas outside or installing oxygen deficiency monitor.<br>Oxygen deficiency hazards are managed in accordance with applicable requirements in the *Oxygen Deficiency Hazard (ODH) Manual* and associated procedures. | | | | | |
| Liquid Helium System | The BLS cryogenic plant includes equipment in the infield (250 psig helium tank), in Bldg. 420 (compressors, vacuum pump), EAA (refrigerator, | Asphyxiation | Yes | Oxygen Deficiency Hazard Program | No | **YES**<br>**See O-1** |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | dewars), and inside storage ring tunnel (cryomodule for RF cavity).<br>APSU_2019934 evaluated the oxygen deficiency hazards (based on the proposed system design). Since the liquid helium system is a closed system, it poses less oxygen deficiency hazard than the open the liquid nitrogen system (bounded by more dominant liquid nitrogen system oxygen deficiency hazard). However, leaks or ruptures could lead to oxygen deficiency hazard and require engineered system to protect workers.<br>Oxygen deficiency hazards are managed in accordance with applicable requirements in the *Oxygen Deficiency Hazard (ODH) Manual* and associated procedures. | | | | | |
| | Superconducting undulators in Storage Ring tunnel (No superconducting undulators are part of current installation. This is left as a placeholder to ensure USI screening if this changes) | Asphyxiation | Yes | Oxygen Deficiency Hazard Program | No | No |
| | Cryogenic equipment in beamline stations | Asphyxiation | Yes | Oxygen Deficiency Hazard Program | No | **YES See O-1** |
| Confined spaces | Pits in 400A and where labeled | Asphyxiation | Yes | Worker Safety and Health Program<br>(confined space entry permits) | No | **No** |
| **4. Electrical Hazards** | | | | | | |
| High voltage equipment (480V or higher) | 13.2kV overhead lines, power distribution centers, 13.2kV/480V transformers, switchgear, and 480VAC panels. | Shock, arc flash, burn, electrocution, fire | Yes | Electrical Safety Program (Ref 20) | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | High voltage electrical hazards are located throughout APS facilities, including power supplies for magnets, other equipment in racks, RF systems (13.2 kVAC to 100 kVDC), ion pumps, PC gun laser, etc.<br>Electrical hazards are managed in accordance with<br>• Designing and installing electrical equipment in accordance with applicable electrical codes, regulations, and standards.<br>• Ensuring that equipment that has been determined to be safe by a Nationally Recognized Testing Laboratory or APS Designated Electrical Equipment Inspector.<br>• Following electrical safety practices in Argonne Electrical Safety Manual. | | | | | |
| Electrical equipment (120V to 480V). | Distribution panels, cable runs, conduit and wiring, breaker panels, and outlets.<br>Electrical hazards are located throughout APS facilities, including power supplies, electronics, controls, lighting, motors, pumps, UPS systems, etc.<br>Electrical hazards include the potential for inadequate wiring, overloaded circuits, improper grounding, damaged insulation, and wet conditions. | Shock, arc flash, burn, electrocution, fire | Yes | Electrical Safety Program | No | No |
| DC Power | DC power supplies for magnets. | Shock, arc flash, burn, electrocution, fire | Yes | Electrical Safety Program | No | No |
| Batteries | Batteries are used throughout the facility in UPS systems, emergency lights, lab equipment, various panels, vehicles (forklifts, carts, man lifts, etc.), diesel generators, and other equipment and tools. | Shock, burn, electrocution, fire | Yes | Electrical Safety Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| Stored energy | Capacitors and inductors in various panels and equipment.<br>Large capacitor bank inside Station 6-ID. Capacitor bank is electrically isolated from personnel by plexiglass panels. However, mineral oil inside represents a potential fire hazard. | Shock, burn, electrocution, fire | Yes | Electrical Safety Program | No | No |
| Power tools | Various types of power tools (battery and plug-in) used for maintenance and operations. Includes the potential for damaged tools and equipment. | Shock, burn, electrocution, fire | Yes | Electrical Safety Program | No | No |
| Exposed conductors and electrical components in accelerator tunnels | Exposed (uncovered) high-voltage bus bars and equipment inside accelerator tunnels.<br>• PAR dipole and quadrupole magnet are operated without bus covers.<br>• Synchrotron dipole, quadrupole, and sextupole magnets are operated without bus covers.<br>• BTS magnets are operated without bus covers.<br>Exposed bus bars are not uncommon, but are specifically covered by code or entirely covered by the Electrical Safety Program. | Shock, burn, electrocution, fire | Yes | Electrical Safety Program | **No** | No |
| **5. Fire Hazards** | | | | | | |
| Fixed combustible material | The facilities are constructed of non-combustible materials where feasible. However, electrical insulation, plastic equipment and components, paint, transformer oil, and other items are combustible.<br>OSHA bulletin – Accelerators with high-voltage electrical systems and extensive enclosures should have a comprehensive fire protection and life safety program. Appropriate precautions include conducting a fire and egress hazard analysis and complying with OSHA's Occupational Safety and Health Standards, subpart E (Exit Routes and Emergency Planning, 29 | Fire or smoke inhalation | Yes | Fire Protection Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | CFR 1910.33-39) and subpart L (Fire Protection, 29 CFR 1910.155-165) (Ref. 30, 31). | | | | | |
| Transient combustible material | Paper/wood products<br>Plastics | Fire or smoke inhalation | Yes | Fire Protection Program | No | No |
| Combustible/ flammable liquids | Vehicle fuel tanks (e.g., gasoline, diesel, and propane)<br>Diesel generator fuel tanks.<br>Solvents, lubricants, and paint<br>Hydraulic fluid (forklifts, electric lifts, elevators, and other hydraulic systems)<br>Transformer oils (transformers, klystrons) in equipment and stored in totes and drums.<br>Flammable liquid supplies consistent with those used in general industry are present in typical end-user quantities. Flammable storage cabinets are provided throughout facility. Flammable materials and chemicals are used materials are stored in accordance with the *Argonne Environment Safety and Health Manual*, Chapter 11.3, “Flammable and Combustible Liquids” (Ref. 32). | Fire or smoke inhalation | Yes | Fire Protection Program | No | No |
| Flammable gases | Maintenance - Propane, oxygen, and acetylene for maintenance activities.<br>Gases for experiments handled separately in Section 19. | Explosion, fire, smoke inhalation | Yes | Fire Protection Program | No | No |
| Electrical ignition sources | Electrical faults (e.g., transformer failure, equipment circuit failure, electrical motor failure, battery failure) | Fire or smoke inhalation | Yes | Fire Protection Program | No | No |
| Welding/cutting/ hot work | Open flame or spark producing operations can ignite a fire. Managed in accordance with Argonne open flame permit and fire watch. | Fire initiator | Yes | Fire Protection Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| Lithium batteries | Lithium batteries are used in variety of tools, laptops, and equipment. Lithium batteries are known for overheating and causing combustion events. This is generally because lithium anodes are prone to forming needle-like projections called dendrites during charging that can penetrate into and eventually pierce the polymer separating the anode and cathode, which causes an internal short circuit that can cause a chain reaction of shorting and heating. | Fire | Yes | Fire Protection Program | No | No |
| Heat sources | Electric heaters<br>Steam lines/heaters<br>Welding/cutting/hot work<br>Vehicle exhaust systems<br>Motors overheating | Burns, fire, or smoke inhalation | Yes | Fire Protection Program | No | No |
| Lasers | Various lasers present a potential fire hazard:<br>• Laser for linac photocathode RF electron gun | Burns, fire | Yes | LMS-PROC-285, Laser Safety (Ref. 33) | | |
| **6. Radiation (Ionizing) – Accelerator Systems** | | | | | | |
| Radiation sources inside accelerator tunnels during normal operations | Radiation sources inside accelerator tunnels (Linac, LEA and other test stands, PAR, booster synchrotron, and storage ring/front ends) during normal operations:<br>• Accelerator systems (linac traveling wave accelerating structures, RF cavities) emit a spectrum of x-rays. The high power levels generated by RF cavities extract electrons from the cavity vacuum chamber walls and accelerate them to several hundred keV before they strike the opposite chamber wall, which produces x-rays. Radiation fields of several hundred mrem/h at 1 m are produced. | Direct radiation exposure | No<br>An accelerator-specific radiation hazard is presented by radiation sources inside accelerator tunnels during normal operations | Not specifically addressed by Shielding or Radiological Protection Program | **Yes**<br>Personnel entry into accelerator tunnel while electron beam or RF is on is considered an accelerator-specific accident | **Yes**<br>**See Rad-1** |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | • During normal operation, intense, broad band synchrotron radiation is created when the electron beam is diverted by bending magnets or undulators.<br>• During normal operation, prompt radiation is produced when the electron beam interacts with beam stops, septum magnets, other accelerator components (due to orbital excursions), or stray air molecules in vacuum chamber. This radiation consists mainly of bremsstrahlung (x-rays), gamma rays, and neutrons. Muons are also produced at high energies (>1000 MeV), mainly in beam stops.<br>• Secondary (or fluorescent) x-rays are produced when certain materials are excited by being bombarded with high-energy x-rays.<br>Areas inside of accelerator and storage ring shielding structures (tunnels) can be very high radiation areas during normal operations. | | | | | |
| Ionizing radiation from neighboring accelerator system or zone | Different zones or areas of accelerator tunnels are accessible while there are radiation fields in neighboring accelerator zones or areas. | Direct radiation exposure | No<br>An accelerator-specific radiation hazard is presented by radiation sources inside accelerator tunnels | Not specifically addressed by Shielding or Radiological Protection Program | **Yes**<br>Personnel entry into an accelerator area while electron beam or RF is on in a neighboring area is considered an accelerator-specific accident | **Yes**<br>**See Rad-1** |
| Radiation sources outside tunnels during normal operations | Radiation sources <u>outside accelerator tunnels</u> (klystrons, SLED cavities) during normal operations. | Direct radiation exposure | Yes | Shielding and | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
|  | • Klystrons produce x-ray radiation (shielded housing integral to the klystrons and radiation shielding reduce the dose to acceptable levels.)<br>• SLED cavities in RF waveguides can generate x-rays (¼ in. of lead shielding and additional shielding reduce the dose to acceptable levels).<br>Periodic surveys are made by the Radiological Protection Program during operations to evaluate radiation levels. Non-controlled areas are maintained below the criteria of a radiation area (< 0.005 rem/hr) during normal operations.<br>Radiation from sources outside accelerator tunnels (e.g., klystrons, SLED cavities, and other shielded equipment) is appropriately shielded, has been evaluated and found to be acceptable, is managed by the Radiological Protection Program, and does not need to be evaluated further in the SAD. |  |  | Radiological Protection Program (Ref. 21) |  |  |
| Radiation in occupied areas outside injector complex and storage ring tunnels during normal operations | Radiation in occupied areas outside injector complex and storage ring tunnels (e.g., klystron gallery, Building 412, Experiment Hall floor, mezzanine on top of storage ring) during normal operations, including normal faults that are expected during normal operation.<br>Shielding enclosures are designed to reduce the dose during normal operations to acceptable levels. Periodic surveys are made by the Radiological Protection Program during operations to evaluate radiation levels. Non-controlled areas are maintained below the criteria of a radiation area (< 0.005 rem/hr) during normal operations.<br>Radiation in occupied areas outside accelerator tunnels during normal accelerator operations (e.g., normal use of beam stops/dumps, full beam dumps | Direct radiation exposure | Yes | Shielding and Radiological Protection Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | into collimators or beam stops, beam aborts), normal electron losses (e.g., injection inefficiency, Touschek, and gas scattering), and normal faults expected during normal operation has been evaluated and found to be acceptable, will be verified during commissioning, are managed by the Radiological Protection Program, and do not need to be evaluated further in the SAD. | | | | | |
| Radiation in occupied areas outside injector complex tunnels during off-normal events | Off-normal events in the injector complex due to electron beam dynamics and steering problems can allow the electron beam to strike accelerator equipment, which results in increased radiation in occupied areas outside the tunnel. Significant fractions of the beam can be inadvertently lost within the linac, PAR, booster synchrotron, and transport lines. Prompt radiation (bremsstrahlung x-rays, gamma rays, and neutrons) is produced when the electron beam interacts with matter. | Direct radiation exposure | No<br>An accelerator-specific-radiation hazard is presented by elevated radiation levels in occupied areas outside accelerator tunnels during off-normal events | Not completely addressed by Shielding or Radiological Protection Program | **Yes**<br>Personnel exposure to elevated radiation levels outside accelerator tunnels is considered an accelerator-specific accident | **Yes**<br>**See Rad-2** |
| Radiation in occupied areas outside storage ring tunnel during off-normal events | Off-normal events in the storage ring due to beam dynamics and steering problems can allow the electron beam to strike storage ring equipment, which results in increased radiation in occupied areas outside the storage ring tunnel. Significant fractions of the beam can be inadvertently lost within the storage ring. Prompt radiation (bremsstrahlung x-rays, gamma rays, and neutrons) is produced when the electron beam interacts with matter. | Direct radiation exposure | No<br>An accelerator-specific-radiation hazard is presented by elevated radiation levels in occupied areas outside the storage ring tunnel | Not completely addressed by Shielding or Radiological Protection Program | **Yes**<br>Personnel exposure to elevated radiation levels outside the storage ring tunnel is considered an accelerator-specific accident | **Yes**<br>**See Rad-3** |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | | | during off-normal events | | | |
| Radiation in occupied areas outside storage ring tunnels or beamlines due to swap-out safety fault | Swap-out safety faults that can allow an electron to escape the storage ring and travel down a beamline before striking a beamline component. A swap-out safety fault could result in increased radiation in occupied areas outside a beamline station or beam pipe.<br>There are two scenarios that could allow an electron bunch injected into the storage ring to travel down the front end and escape the storage ring shielded tunnel before striking a component:<br>• A malfunction or loss of a storage ring bending magnet could allow stored electron bunches to continue straight (rather than bending) and travel down a photon beamline and strike a beamline mask, mirror, or shutter.<br>• A beam energy mismatch between the booster synchrotron and the storage ring could potentially cause an injected electron bunch to travel down a photon beamline. The booster is a ramping machine, and if the extraction comes at the wrong time, the energy may be off (too high) and the injected bunch could somehow travel straight (rather than bending) and travel down a photon beamline. | Direct radiation exposure | No<br>An accelerator-specific-radiation hazard is presented by elevated radiation levels in occupied areas outside the storage ring tunnel or beamlines due to a swap-out safety fault | Not completely addressed by Shielding or Radiological Protection Program | **Yes**<br>Personnel exposure to elevated radiation levels outside the storage ring tunnel or beamlines is considered an accelerator-specific accident | **Yes**<br>**See Rad-4** |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| **7. Radiation (Ionizing) – X-Ray Beamlines** | | | | | | |
| Radiation inside beamline stations during normal operations | Radiation <u>inside x-ray beamline stations</u> (FOE, experiment stations) during normal operations.<br>• Synchrotron radiation (x-ray beamlines) represents an intense radiation source.<br>• X-ray beam interaction with safety shutters, photo beam stops, windows, other beamline components, and stray air molecules produces bremsstrahlung (x-rays), gamma rays, and neutrons.<br>• X-ray interactions with specimens or shutters/stops can produce radiation fields.<br>• Gas bremsstrahlung (GB) produced in the storage ring traveling coincident with the synchrotron radiation beam represents a significant radiation source.<br>• Secondary bremsstrahlung (SB) is created whenever a GB beam encounters matter.<br>• Secondary (or fluorescent) x-rays are produced when certain materials are excited by being bombarded with high-energy x-rays.<br>• Neutrons generated by the interactions of GB.<br>Areas inside of beamline enclosures can be very high radiation areas during normal operations. | Direct radiation exposure | No<br>An accelerator-specific-radiation hazard is presented by radiation sources inside x-ray beamlines stations during normal operations | Not completely addressed by Shielding and Radiological Protection Program | **Yes**<br>Personnel entry into beamline station while beam is present is considered an accelerator specific accident | **Yes**<br>**See Rad-5** |
| Radiation in occupied areas outside beamline stations and beam pipes during normal operation | Ionizing radiation outside beamline shielded enclosures (experiment hall floor) during normal operations. Personnel are protected from the GB beam by shielded beam pipes and enclosures, shutters, stops, and collimators.<br>Periodic surveys are made by the Radiological Protection Program during operations to evaluate radiation levels. Non-controlled areas around beamlines are maintained below the criteria of a | Direct radiation exposure | Yes | Shielding and Radiological Protection Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | radiation area (< 0.005 rem/hr) during normal operations.<br>Radiation outside x-ray beamline stations/beam pipes during normal operations, including radiation from normal use of front ends (e.g., crotch absorbers, safety shutters, photon shutters, collimators, and masks) and x-ray beamlines (e.g., beam stops, shutters, and beam interaction with samples) has been evaluated and found to be acceptable for planar undulators, will be verified during commissioning, will be managed by the Radiological Protection Program, and does not need to be evaluated further in the SAD. | | | | | |
| Radiation in occupied areas outside beamline stations and beam pipes during off-normal events | Ionizing radiation in occupied areas outside beamline stations/beam pipes due to loss of x-rays in the beamline.<br>• Loss of vacuum resulting in increased radiation from x-ray interactions with gas molecules.<br>• Focusing and steering problems result in x-ray beam striking vacuum chamber or other beamline structure resulting in increased radiation from interactions with equipment.<br>• Significant fractions of the x-ray beam can be inadvertently lost in the beamline front ends.<br>• Radiation associated with monochromatic beams is much less than radiation associated with white beams.<br>Loss of x-ray beamlines and beamline strikes are common and beamline shielding is designed to be adequate for beamline strikes and other normal faults. Loss of x-ray beamlines and beamline strikes are considered normal faults (not an off-normal or accidental event), have been evaluated and found to be acceptable, will be verified during commissioning, are managed by the shielding design process and the | Direct radiation exposure | Yes | Shielding and Radiological Protection Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
|  | Radiological Protection Program, and do not need to be evaluated further in the SAD.<br>Note: This does not cover hazards associated with electrons escaping the storage ring and traveling down an x-ray beamline. See swap-out safety faults in Section 6 for hazards associated with electrons traveling down a beamline. |  |  |  |  |  |
|  | Ionizing radiation in occupied areas outside beamline stations/beam pipes due to excessive gas bremsstrahlung entering x-ray beamlines.<br>Gas bremsstrahlung becomes very important for straight sections in the storage ring since the contribution from each interaction adds up to produce a narrow beam traveling down the storage ring along with the synchrotron radiation. | Direct radiation exposure | No<br>An accelerator-specific-radiation hazard is presented by excessive gas bremsstrahlung entering x-ray beamlines | Not completely addressed by Shielding or Radiological Protection Program | **Yes**<br>Excessive gas bremsstrahlung entering x-ray is considered an accelerator specific accident | **Yes**<br>**See Rad-6** |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| **8. Other Accelerator/Beamline System Hazards** | | | | | | |
| Activated components | Bremsstrahlung and secondary particles induce radioactivity in materials (including metals, concrete, air, and water) when atomic nuclei capture free neutrons resulting in radioactive nuclei.<br>Neutrons are generated when the electron beam interacts with materials such as scrapers and collimators. Photons with energies above the typical binding energy of nucleons (>5-15 MeV) such as primary bremsstrahlung can also interact with a nucleus and lead to emission of photoneutrons or photoprotons. Activated structures and components (e.g., concrete shielding, lead shielding, accelerator components and structures, shutters, and beam stops) will be produced by accelerator operations.<br>Accelerator components are periodically surveyed for activation, especially prior to performing maintenance or modifications. Components with a potential of becoming activated are generally designed to facilitate simple and fast disassembly and removal.<br>Activated components do not represent a significant radiological hazard and are adequately managed by Worker Safety and Health Program and Radiological Protection Program, including clearance protocol for activated material (RS-TBD-003, Ref. 34). | Direct radiation exposure | Yes | Radiological Protection Program (Ref. 21) | No | No |
| Activated loose particulates (contamination) | Activated loose particulate matter is not anticipated since beam stops, shielding, and other components are solid metal (e.g., aluminum, lead, iron, tungsten, Inconel 625, and copper). Operating experience has shown that activated particulates (contamination) are not an issue. | Radioactive particulate inhalation | Yes | Radiological Protection Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| Activated deionized water | Deionized water is used for thermal regulation of the linac prebuncher and buncher, accelerating structures, transmission waveguides, klystrons, SLEDs, RF reference and drive lines, and magnets. Operating experience demonstrates that deionized water is not significantly activated. Accumulation of radiation in the deionized water mixed bed polishing canisters and filter elements is monitored. The mixed bed, cation bed, anion bed, and carbon bed resins are monitored to ensure that there has been no added radioactivity. Any activated material will be disposed of in accordance with applicable requirements. | Release of radioactive water or material | Yes | Waste Management Program (Ref. 22) | No | No |
| Activated sprinkler water | Standing water in the fire protection sprinkler pipes could potentially become activated; however, the production of relatively long-lived radionuclides (Be-7, H-3) in water requires neutrons with energy greater than 25 MeV. Production of neutrons above 25 MeV will occur when accelerated beams hit accelerator components or the downstream beam stops. The water sprinkler pipes are located on the tunnel wall more than a meter away from the beam. The radiation fields at this location are about four orders of magnitude lower than those irradiating the cooling water and thus negligible activation is expected. | Release of radioactive water or material | Yes | Waste Management Program | No | No |
| Activated gases | The primary source of airborne radionuclides at the APS is electron collisions with accelerator components in the linac. These collisions result in bremsstrahlung radiation that interacts with air resulting in activated gases, primarily through photodisintegration (γ, n) ,(n, γ ) and (γ, 2n) and photospallation reactions. Various short-lived radionuclides are formed, but $^{41}$Ar was most significant effluents (Activation of Air and Soil in APS-U Environment, Ref. 35).<br>Small amounts of activated gases are produced in the accelerator tunnels at a relatively constant rate during | Release of radioactive gas to atmosphere<br>Inhalation exposure | Yes | Environmental Monitoring (Ref. 36) | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | operations. Air (including small amounts of activated gases) is exhausted at a relatively constant rate from the accelerator tunnels to the atmosphere by exhaust systems. Production and release of radiogases by the other accelerator systems are relatively minor compared to Bldg. 411/415. Activated gases are produced at a relatively constant rate during operations, are a normal byproduct of operations rather than an off-normal or accidental event, levels will be monitored, and does not need to be evaluated further in the SAD. | | | | | |
| Noxious gases from accelerator operations | Accelerator operations Ozone (O3) and other noxious gases (nitrogen oxides) are produced in the linac, PAR, booster synchrotron, and storage ring as the result of photon irradiation of air molecules.<br>Most of the synchrotron radiation produced in booster synchrotron bending magnets is absorbed by the vacuum chamber walls, but the radiation that does escape produces small amounts of noxious gases and nitric acid (Ref. 37).<br>Noxious gas is produced at a relatively constant rate during operations, is a normal byproduct of operations rather than an off-normal or accidental event, will be monitored, and does not need to be evaluated further in the SAD. | Irritant<br>Inhalation exposure | Yes | Worker Safety and Health Program<br>National Institute for Occupational Safety and Health | No | No |
| Noxious gases from beamline operations | Ozone (O3) can be produced by an x-ray beamline when a white beam travels through an air or when a white beam inside a vacuum chamber strikes a component and the consequential scatter ionizes some of the oxygen in the air surrounding the vacuum chamber. The ozone concentration from an open white beam can quickly exceed the threshold limit value (TLV) if appropriate steps are not taken and the concentration from a white beam inside a vacuum chamber is much lower. | Irritant<br>Inhalation exposure and asphyxiation | Yes | Worker Safety and Health Program<br>National Institute for Occupational Safety and Health | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | Monochromatic beams do not present an ozone problem. Beams that have been reflected from mirrors ("pink beams") will usually produce ozone in a way similar to white beams from the same source.<br>Noxious gas is produced at a relatively constant rate during operations, is a normal byproduct of operation rather than an off-normal or accidental event, will be monitored, and does not need to be evaluated further in the SAD. | | | National Emission Standards for Hazardous Air Pollutants reporting | | |
| Activated gas (and noxious gas) in accelerator tunnels | Small amounts of activated gases (and noxious gases) are produced in the accelerator tunnels at a relatively constant rate during accelerator operations. Air is exhausted at a relatively constant rate from the accelerator tunnels to provide fresh air and minimize buildup of activated or noxious gases.<br>Personnel that enter an accelerator tunnel immediately after accelerator operations could be exposed to low levels of activated or noxious gases. Activated gas is produced at a relatively constant rate during operations, is a normal byproduct of operation rather than an off-normal or accidental event, will be monitored, and does not need to be evaluated further in the SAD. | Inhalation exposure | Yes | Worker Safety and Health Program<br>Radiological Protection Program | No | No |
| Activated gas effluent entering an occupied facility through HVAC air intakes | Small amounts of activated gases (and noxious gases) are produced in the accelerator tunnels at a relatively constant rate during accelerator operations. Air is exhausted at a relatively constant rate from the accelerator tunnels to provide fresh air and minimize buildup of activated or noxious gases. Air containing small amounts of activated gas is exhausted from an accelerator tunnel could potentially enter a nearby occupied facility through the HVAC air intakes. | Inhalation exposure | Yes | Environmental Monitoring and Radiological Protection Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | However, activated gas is produced at a low and relatively constant rate, exhausted to atmosphere at a relatively constant rate, and diluted and potentially taken up by neighboring air intake/supply systems at much lower rates. The half-life of the main radioactive emissions is relatively short, and the air intake/supply systems have relatively low air changes and cannot build up high levels of activated or noxious gases in occupied facilities. Activated gases are a normal byproduct of operations rather than an off-normal or accidental event, levels will be monitored, and this hazard does not need to be evaluated further in the SAD. | | | | | |
| Test Stand Activities | Test stands (411 Injector Test Stand, and 420 RF Test Stand) produce radiation. The have their own shielded enclosures and ACIS to prevent radiation exposure. | Direct Radiation Exposure | No<br>An accelerator-specific radiation hazard is presented by radiation sources inside test stand shielded enclosures during normal operations | Not completely addressed by Radiological Protection Program | Yes<br>Personnel entry into a test stand shielded enclosure while electron beam or RF is on is considered an accelerator-specific accident | Yes<br>**See Rad-1** |
| Test Cage Activities | Test cages (EAA power supply test cage, 412 power supply test cage, and 400A solid state RF test cage) and ad hoc tests do not produce radiation and do not require shielded enclosures or ACIS systems. Test cage operations are controlled by the technical group performing the test and are conducted in accordance with approved work instructions. | Various | Yes | Worker Safety and Health Program | No | No |

**Table 3-4. Hazard Identification and Screening Table**

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| Restricted access and egress | Access to shielded structures (e.g., linac, LEA, PAR, booster synchrotron, storage ring, and beamline stations) are restricted during operation.<br>Egress from shielded structure is limited to shielded access door and may be long or convoluted. | | Yes | Worker Safety and Health Program | No | No |
| Mechanical (moving shutters, valves, and actuators) | | Physical injury | Yes | Worker Safety and Health Program | No | No |
| Beryllium windows | Covered elsewhere | | | | | |
| **9. Radioactive Material** | | | | | | |
| Radioactive materials and samples used by researchers | APS tracks radioactive materials brought in by researchers in accordance with LMS-PROC-45 (Ref. 38) using the CURIE database. The CURIE database calculates the HC3 Sum of Fractions (HC3-SOF) values using the "sum of the ratios" methodology described in DOE-STD-1027-2018 (Ref. 39) using the revised threshold quantities in NWM-CALC-2014-002 (Ref. 40). The APS has an administrative limit of 0.01 HC3-SOF. As of 5/18/2020, the radioactive material inventory at APS was 3.44E-3 HC3-SOF.<br>Radioactive materials do not represent a significant radiological hazard due to the small amounts and forms. Risk is adequately managed by experiment reviews and Radiological Protection Program. | Contamination or radioactive material release | Yes | Experiment Safety Review<br>Radioactive Material Inventory Management Program (Ref. 38)<br>Radiological Protection Program | No | No |
| **10. Fissionable Material** | | | | | | |
| Fissionable materials and samples used by researchers | APS tracks fissionable materials brought in by researchers in accordance with LMS-PROC-45 (Ref. 38) using the CURIE database. The CURIE database calculates the Pu-239 Fissile Gram Equivalent (Pu239-FGE) values as described in Exhibit A of LMS-PROC-45. The APS has an administrative limit of 10 Pu239-FGE. As of 5/18/2020, the fissionable material inventory at APS was 0.1 Pu239-FGE. | Criticality | Yes | Experiment Safety Review<br>Radioactive Material Inventory Management Program | No | No<br>A criticality is not considered credible and not |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | Fissionable material is tracked and controlled in accordance with the Argonne Criticality Safety Program (Ref. 41). An inadvertent criticality is precluded by maintaining the fissionable material inventory well below the single parameter subcritical mass limit of 450 Pu239-FGE specified in ANSI/ANS-8.1-2014. Therefore, a criticality is not considered credible and not analyzed further. | | | | | analyzed further. |
| **11. Radiation (Non-Ionizing)** | | | | | | |
| Laser | Lasers used for survey, alignment, and leveling | Laser Exposure | Yes | Worker Safety and Health Program<br>LMS-PROC-285, Laser Safety (Ref. 33) | No | No |
| | Lasers used in Experiment Hall (Experiment Stations) (e.g. Dynamic Compression) | Laser Exposure | Yes | Worker Safety and Health Program<br>LMS-PROC-285, Laser Safety | No | No |
| | Photocathode Gun Laser | Laser Exposure | Yes | Worker Safety and Health Program<br>LMS-PROC-285, Laser Safety | No | No |
| Radiofrequency fields | RF systems at Linac, PAR, booster synchrotron, and Storage Ring for accelerating and storing electron beams.<br>Klystrons | Nonionizing Radiation Exposure | Yes | Worker Safety and Health Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | RF waveguides and equipment<br>Linac traveling wave accelerator structures<br>RF cavities<br>RF test stands in 400A.<br>Radiofrequency sources are heavily shielded to eliminate detectable leakage. The sources are tested for leakage when first assembled and are retested whenever work is done that disrupt the shielding. Electromagnetic radiation hazard warning signs are posted and warning lights are used to indicate when the equipment is energized. Additional hazard controls are prescribed by ESH Manual Section 6.1 " Nonionizing Radiation Protection - Radiofrequency and Microwave Radiation."<br>Radiofrequency radiation guidelines and standards are set by International Commission on Nonionizing Radiation Protection and the American National Standards Institute (ANSI) | | | LMS-PROC-233, Radiofrequency and Microwave Fields (Ref. 42) | | |
| Magnetic and Electric Fields | Accelerator systems (e.g., focusing, steering, and bending magnets; and switch magnets) and the experimental equipment (e.g., examples) generate magnetic fields<br>High magnetic fields, permanent magnets, and electromagnets.<br>Generally perceived as harmless but potentially adverse health effects from prolonged exposure to strong fields. Dangerous for pacemakers – need to post signs as needed | Nonionizing Radiation Exposure | Yes | Worker Safety and Health Program<br>LMS-PROC-234, Electric and Magnetic Fields (Ref. 43) | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| Infrared, Visible and Ultraviolet Light | May be used to align and focus optical components. | Nonionizing Radiation Exposure | Yes | Worker Safety and Health Program<br>LMS-PROC-285, Laser Safety | No | No |
| **12. Maintenance Hazards** | | | | | | |
| Slips/trips/falls | Walking and Working Surfaces | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Overexertion | Walking and Working Surfaces | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Contact with moving objects or equipment | Walking and Working Surfaces | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Pinches, squeezed, crushed | Work Areas and Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Vibration | Work Areas and Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Welding | Work Areas and Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Elevated Work (scaffolding, ladders, mezzanines, man-lifts, roofs) | Work Areas and Activities | Personal Injury | Yes | Worker Safety and Health Program | No | No |
| Confined spaces | Work Areas and Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |

### Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| Material Handling | Work Areas and Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Utility interfaces, (electrical, steam, chilled water) | Work Areas and Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Silica dust | Silica dust may result from concrete, coring, cutting, or drilling activities.<br>Activities with potential silica exposure are reviewed by the Argonne Industrial Hygiene group and comply with the requirements in LMS-PROC-152, Blind Penetration of Floors, Walls, Ceilings, and Exterior Foundations (Ref. 44). | Personnel Exposure | Yes | Worker Safety and Health Program | No | No |
| High Noise | Work Areas and Activities | Personnel Exposure | Yes | Worker Safety and Health Program | No | No |
| Power tools | Work Areas and Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Slips/trips/falls | Work Areas and Walking Surfaces | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Weather-related conditions | Work Areas and Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Hot surfaces | Work Areas and Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Cold surfaces | Work Areas and Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| Radiation Generating Devices (RGD) | Work Areas and Activities | Ionizing Radiation Exposure | Yes | Worker Safety and Health Program and Radiation Protection Program | No | No |
| Janitorial activities | Hazardous materials needed to support APS operations (e.g., cleaning supplies, maintenance supplies) are consistent with those used in general industry and are present in typical end-user quantities. were screened from further analysis. | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| **13. Material Handling Hazards** | | | | | | |
| Cranes/hoists | Work Areas ad Activities | Drops, impacts | Yes | Worker Safety and Health Program<br>Hoisting and Rigging Program (Ref. 23) | No | No |
| Hoisting & Rigging | Work Areas ad Activities | Drops, impacts | Yes | Worker Safety and Health Program<br>Hoisting and Rigging Program | No | No |
| Elevators | Work Areas ad Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Forklifts | Work Areas ad Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| Carts, dollies, pallet jacks | Work Areas and Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Manual material handling (overexertion) | Work Areas and Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Delivery vehicles | Work Areas and Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Transportation incidents | Work Areas and Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| **14. Mechanical/Noise/Thermal Hazards** | | | | | | |
| Rotating equipment | Motors, belts, pulleys, fans, drills, grinders, etc. | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Reciprocating equipment | Saws, doors, | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Moving equipment | Moving shutters, valves, and actuators | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Tools (maintenance) | Hand tools, compressed air tools, electric tools, etc. | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Machine Shop Tools | Rotating and cutting tools | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Pinch points and sharps | Work Areas and Activities | Personnel Injury | Yes | Worker Safety and Health Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| Vibrating tools and equipment | Power tools (e.g., saws)<br>Vibrations from operations of mechanical equipment (e.g., ventilation system, crane, elevator, pumps, etc.) | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Vehicles | Vehicles (e.g., trucks, cars, transport vehicles, forklifts, manlifts, etc.) located around facilities in truck locks, and in facilities. Includes gasoline, diesel, propane, and electric vehicles. | Inadvertent motion, accidents, exhaust, fires, etc. | Yes | Worker Safety and Health Program | No | No |
| Industrial Vehicles | Vehicles in Work Areas | Inadvertent motion, accidents | Yes | Worker Safety and Health Program | No | No |
| Drilling, Cutting, Grinding | Work Activities and Areas | Personnel Exposure or Injury | Yes | Worker Safety and Health Program | No | No |
| High Temp Equipment (Bake-outs) | Heat tape on PAR and vacuum backout<br>Water | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Compressors/ turbines | Stored Energy Hazards | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| Hot surfaces | Steam lines, steam heaters, electric heaters, | Personnel Injury, exposure to hot surfaces | Yes | Worker Safety and Health Program | No | No |
| Toppling | Work Activities and Areas | Personnel Injury | Yes | Worker Safety and Health Program | No | No |
| High-noise | Tools<br>Motors and equipment (e.g., pumps, motors, compressors, generator, etc.) | Personnel Exposure | Yes | Worker Safety and Health Program | No | No |

**Table 3-4. Hazard Identification and Screening Table**

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| **15. Natural Phenomena Hazards and External Events** | | | | | | |
| Seismic | Seismic event could result in structural damage to buildings, damage to accelerator systems and equipment, electrical shorts, pipe breaks, loss of safety systems (e.g., fire protection systems) and loss of utilities (electrical, water). | Physical damage, collapse, loss of power, fire | Yes | Building Codes | No | No |
| Heavy precipitation | Heavy rains could lead to flooding. Heavy snow or ice could accumulate could cause a roof collapse. | Flooding or roof collapse | Yes | Building Codes | No | No |
| High wind/ Tornado | High winds and flying debris could cause damage to the building structures, roofing, doors and windows, and equipment (e.g., cooling towers). Could also cause loss of electrical power or other utilities. | Physical damage, loss of power | Yes | Building Codes | No | No |
| Lightning | A lightning strike could damage buildings, equipment, or systems, and could cause shock/electrocution, power outages, or fire.<br>The facilities are equipped with lightning protection systems (roof top air terminals with conductors connected to ground) designed per NFPA 780 (Ref. 45). | Shock, electrocution, power outage, or fire | Yes | Building Codes<br>Fire Protection Program (Ref. 45) | No | No |
| External Fire | A wildland fire or other type of external fire (e.g., caused by lightning, grass fire, downed power lines, transformer or electrical fire, vehicle or generator fuel leak, flammable gas fire/explosion) involves an APS facility.<br>A wildland fire risk assessment was performed in FMS-FTS-005 (Ref. 46). As the predominant vegetation in the vicinity of APS facilities consists of mowed grasses, the likelihood of a wildland or other external fire propagating to an APS facility due to vegetation is low. | Fire | Yes | Fire Protection Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| Man-Made External Hazards | External man-made events (e.g., dropped load, vehicle accident/crash with fire, tanker truck fire, fire from downed power line, explosion, crane collapse/impact) could result in spill, facility damage, fire, or explosion. | Spill, physical damage, fire, explosion | Yes | Fire Protection Program | No | No |
| Aircraft Crash | Aircraft crash into APS facility due to commercial, military, or general aviation or on-site aviation activities could result in explosion and fire.<br>Aircraft crash into APS facility is extremely unlikely and no further controls. No easily implemented controls can mitigate the consequences and it does not initiate or contribute to an accelerator accident. | Explosion, fire | Yes | *Aviation Safety* LMS-PROC-261 (Ref. 47) | No | No |
| Drone Crash | A lightweight unmanned aerial system (UAS) or drone (under 10 pounds) does not have enough mass or kinetic energy to penetrate roofs or walls of buildings or cause significant damage, and battery shorts or fires would not challenge facilities or equipment.<br>Specific UAS models have received Federal Aviation Administration (FAA) authorization for use at Argonne. | Physical damage | Yes | Work Control Program<br>*Aviation Safety* LMS-PROC-261<br>Building Codes | No | No |
| **16. Pressure and Vacuum Hazards** | | | | | | |

### Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| Pressurized systems | Compressed air systems provide 90-100 psi air to operate technical equipment.<br>There are two water systems that provide low conductivity water (LCW) at the APS. The “Aluminum” systems operate at 35 psi and the “Copper” systems operate at 150 psi (named for the primary type of component that is being cooled). There are 20 of each of these systems. Each system supplies headers from the mechanical mezzanine that extend into the SR tunnel. The Copper water system also supplies cooling water to the SR mezzanine power supply cabinets and beamline components.<br>Various other systems (e.g., steam, hydraulic systems, compressed gases), including pressure vessels, piping, valves, pumps, gauges, pressure relief devices. | Over pressurization and rupture | Yes | Installed per codes/standards<br>*Argonne Pressure Safety Manual*, LMS-MNL-13 | No | No |
| Vacuum systems | RF waveguides, RF accelerating structures, RF cavities, accelerator vacuum chambers, front ends, and x-ray beamlines require high vacuums.<br>Cryomodules – BLS cryomodule is a Category II vacuum vessel as defined in the Argonne Pressure Systems Safety Manual, Appendix M, Vacuum Systems Consensus Guideline, since the pressure across the boundary cannot exceed 15 psid (pressure drop) through the use of engineering controls such as pressure relief devices | Over pressurization and rupture | Yes | Installed per codes/standards<br>Argonne Pressure Safety Manual, LMS-MNL-13 | No | No |
| Over pressurization | Over pressurizing hydraulic systems, pneumatic systems, water systems, steam systems, etc. | Over pressurization and rupture | Yes | Installed per codes/standards<br>Pressure Safety Manual, LMS-MNL-13 | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| Compressed gas cylinders | Compressed gas cylinders, systems, and associated equipment<br>Hazards are managed in accordance with compressed gas procedures for identification, storage, handling, and use. | Rupture | Yes | Worker Safety and Health Program<br>*Argonne Pressure Safety Manual*, LMS-MNL-13 | No | No |
| Backfill | Work Areas and Activities, Vacuum systems. | Overpressure, Rupture | Yes | *Argonne Pressure Safety Manual*, LMS-MNL-13 | No | No |
| Damaged pressure relief valve/system | Work Areas and Activities, Vacuum systems | Overpressure, Rupture | Yes | Pressure Safety Manual and BPSC/ASME code of record | No | No |
| Equipment failure | Work Areas and Activities | Rupture | Yes | *Argonne Pressure Safety Manual*, LMS-MNL-13 | No | No |
| Contact with released fluids, parts, or flying debris | Work Areas and Activities | Rupture | Yes | Worker Safety and Health Program | No | No |
| **17. Hazardous Waste** | | | | | | |
| Hazardous (toxic) waste | Hazardous materials needed to support APS operations (e.g., cleaning supplies, maintenance supplies) are consistent with those used in general industry and are present in typical end-user quantities. were screened from further analysis. | Spill, release, and personnel exposure | Yes | Waste Management Program (Ref. 22) | No | No |
| Radioactive waste | Accelerator tunnels and Experimental Enclosures | Spill, release, and personnel exposure | Yes | Waste Management Program | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| Mixed (radioactive and hazardous) waste | incompatible chemicals in mixed waste | Spill, release, and personnel exposure | Yes | Waste Management Program | No | No |
| Effluent (atmospheric, water, etc.) | Laboratory hoods, Accelerator ventilation | Release to environment | Yes | *Environmental Monitoring Plan*<br>EM-EMP Rev 2 | No | No |
| Oil | Vacuum Pump Oil | Spill, release, and personnel exposure | Yes | Waste Management Program | No | No |
| Non-Hazardous Waste | Universal waste (Batteries, Mercury-containing equipment, fluorescent bulbs) | Spill, release, and personnel exposure | Yes | Waste Management Program | No | No |
| **18. Experimental Operations Hazards (Beamline and Non-Beamline)** | | | | | | |
| Research with electrical hazards | Various electrical components and hazards in beamline stations. | Personnel Exposure | Yes | Experiment Safety Review (Ref. 13)<br>**Note: Experiment Safety Review incorporates Worker Safety and Health and Radiological Protection Program** | No | No |
| Research with hazardous material | Contact with hazardous materials in beamline | Personnel Exposure | Yes | Experiment Safety Review | No | No |
| Research with biological materials | Contact with biological agents | Personnel Exposure | Yes | Experiment Safety Review | No | No |

### Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| Research with flammable/ combustible material | Gasoline and diesel fuel used for experiments in Sector 7.<br>Other combustible/flammable material used for experiments in beamline stations. | Personnel Exposure | Yes | Experiment Safety Review | No | No |
| Research with pathogens | Infectious substances | Personnel Exposure | Yes | Experiment Safety Review | No | No |
| Research with chemicals: corrosive, reactive, toxic, flammable | Range of chemicals used in experiments | Personnel Exposure | Yes | Experiment Safety Review | No | No |
| Research with particulates and nanomaterials | Range of particulates and nanomaterials used in experiment. | Personnel exposure or inhalation | Yes | Experiment Safety Review | No | No |
| Research with radioactive samples | Small amounts of radioactive material (including depleted uranium) are used in experiments (in experimental samples). Radioactive materials are evaluated in Experiment Safety Reviews and radioactive materials brought in by researchers are tracked in accordance with LMS-PROC-45 (Ref. 38) using the CURIE database.<br>In Program Descriptions - The CURIE database calculates using the HC3 Sum of Fractions (HC3-SOF) values using the “sum of the ratios” methodology described in DOE-STD-1027-2018 (Ref. 39) using the revised threshold quantities in NWM-CALC-2014-002 (Ref. 40). The APS has an administrative limit of 0.01 HC3-SOF. As of 5/18/2020, the radioactive material inventory at APS was 3.44E-3 HC3-SOF.<br>Radioactive materials do not represent a significant radiological hazard due to the small amounts and forms. Risk is adequately managed by inventory controls, experiment reviews, and Radiological Protection Program. | Personnel exposure or inhalation | Yes | Experiment Safety Review<br>Radioactive Material Inventory Management Program LMS-PROC-45<br>APS_1187383, Radioactive Samples (Ref. 48) | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| Research with fissionable material samples | Users may bring in small amounts of fissionable materials as part of their research/experiment.<br>Fissionable material is tracked and controlled in accordance with the Argonne Criticality Safety Program (Ref. 41). APS tracks fissionable materials for criticality control purposes in accordance with LMS-PROC-45 (Ref. 38) using the CURIE database. The CURIE database calculates Pu239 Fissile Gram Equivalent (Pu239-FGE) values as described in Exhibit A of LMS-PROC-45. The APS has an administrative limit of 10 Pu239-FGE. As of 5/18/2020, the fissionable material inventory at APS was 0.1 Pu239-FGE.<br>An inadvertent criticality is precluded by maintaining the fissionable material inventory well below the single parameter subcritical mass limit of 450 Pu-239 FGE specified in ANSI/ANS-8.1-2014 (Ref. 49). Therefore, a criticality is not considered credible and not analyzed further. | Criticality | Yes | Experiment Safety Review<br>Radioactive Material Inventory Management Program LMS-PROC-45 | No | No<br>Not considered credible and not analyzed further. |
| Research with extreme temperatures and pressures | Laser pulse to ablative layer generates a shockwave that causes extreme temperature and pressure in sample. | Personnel exposure | Yes | Experiment Safety Review | No | No |
| Lasers | Sector 35 laser | Personnel Exposure | Yes | Experiment Safety Review<br>LMS-PROC-285, Laser Safety (Ref. 33) | No | No |
| Research with gases: corrosive, reactive, toxic, flammable | Experiments with noxious gases such as CO. | Toxicity | Yes | Experiment Safety Review | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | Experiments using flammable gases such as hydrogen, natural gas, and methane (CH4).<br>Experiments using oxidizers like oxygen. | Fire | Yes | Experiment Safety Review | No | No |
| | Experiments using inert gases (nitrogen, liquid nitrogen, helium) | Oxygen deficiency | Yes | Experiment Safety Review | No | No |
| Research with explosive and energetic material | Experiments may involve small quantities (e.g., 10 mg) of explosive or energetic material for beamline analysis. Samples are typically encased in high-pressure containment device (e.g., Diamond Anvil Cell) | Personnel Injury | Yes | Experiment Safety Review<br>Safe Use of Explosives LMS-PROC-88 | No | No |
| Research with pyrophoric materials | Experiment may include small quantities of material. | Personnel Injury | Yes | Experiment Safety Review | No | No |
| Research with Carcinogens, Mutagens, Teratogens | Experiments may use carcinogens, mutagens or teratogens. | Personnel Exposure | Yes | Experiment Safety Review | No | No |
| Working at elevation | Work in and around the beamlines could be on ladders or elevated platforms. | Personnel Injury | Yes | Experiment Safety Review | No | No |
| Ozone production | White X-Ray mean may create ozone when propagated through air. | Personnel Exposure | Yes | Experiment Safety Review | No | No |
| Slips, trips, falls | Work Areas | Personnel Injury | Yes | Experiment Safety Review | No | No |
| Machine tools/hand tools | Incidental tool use | Personnel Injury | Yes | Experiment Safety Review | No | No |
| Stray static magnetic fields | Work Areas and Activities | Personnel Exposure and Nonionizing Radiation | Yes | Experiment Safety Review | No | No |
| Activated research equipment and materials | Radiological Hazard | Personnel Exposure | Yes | Experiment Safety Review<br>Radiological Protection | No | No |

## Table 3-4. Hazard Identification and Screening Table

| Hazard | Sources, Location, Form, Quantity | Concern | Managed by existing SMP? | SMP that manages hazard | Initiates or contributes to accelerator accident? | Evaluate Further? |
|---|---|---|---|---|---|---|
| | | | | Program, including clearance protocol for activated material (RS-TBD-003). | | |

#### 3.2.1.2 Accelerator-Specific Hazards that Did Not Screen Out

Based on the results in Table 3-4, the following hazards are not fully addressed by institutional Safety Management Programs. Oxygen Deficiency Hazards will be analyzed in this section, and off-normal radiological hazards will be evaluated further in Section 3.2.2.

Note that accelerator-specific hazards are identified with an abbreviated hazard name and number (e.g., **Rad-1**). Off-normal or accidental events related to that hazard are identified in Section 3.3.2 below using the same hazard ID plus a letter (e.g., **Rad-1a**).

**Oxygen Deficiency Hazards – Accelerator Systems and X-Ray Beamlines**

**O-1 – An accelerator-specific hazard is presented by situations where the potential for an oxygen deficient condition (e.g. < 19.5% $O_2$) exists for routine operations or < 17.2% for accident scenarios.**

Argonne's Oxygen Deficiency Hazard Manual (LMS-PROC-19 Ref. 19) specifies the action criteria that is to be taken sitewide when there is the credible potential for an oxygen deficient atmosphere. For the purposes of the APS Safety Assessment Document, APS is adopting the criteria stated in LMS-MNL-19 Revision 0 dated February 14, 2022. All systems and operations at the Advanced Photon Source are designed and reviewed to prevent the creation of an oxygen deficient condition. This is in compliance with the referenced version of LMS-MNL-19 which states:

- For intentional releases of asphyxiant cryogens or gases: An oxygen-deficient working environment below 19.5% oxygen is unacceptable.
- For unexpected releases of asphyxiant cryogens or gases during unattended operations when an individual may unknowingly enter an unsafe atmosphere: An oxygen-deficient working environment below 17.2% is unacceptable, and the environment must return to a safe atmosphere (≥19.5%) within 30 minutes or less. The ACGIH minimal oxygen content recommendation to prevent minor, reversible physiological effects of oxygen deficiency in healthy adults is 17.2% oxygen at sea level.

APS has identified three situations which require analysis for Oxygen Deficiency Hazards and these are identified below.

1) The Bunch Lengthening System is a Liquid Helium cooled cryo-cavity inside the storage ring. It is fed from a Liquid Helium Plant located in Building 400. Accident scenarios and oxygen deficiency calculations are provided in APSU_2178501(Ref 50)APS-U Bunch Lengthening System Oxygen Deficiency Hazard Evaluation. The results of this analysis indicate that the operation of the Bunch Lengthening System does not create an ODH environment below 19.5% $O_2$. A risk analysis and accelerator specific controls are therefore not required.
2) Scenarios related to the Liquid Nitrogen Distribution system are provided in APS_1265728(Ref. 29) Oxygen Deficiency Hazard Analysis for the APS LNDS. As

OSHA characterizes ODH atmospheres below 19.5% $O_2$ as immediately dangerous to life or health (IDLH), the consequence of an ODH atmosphere gives a facility consequence of HIGH in accordance with Table 3-2 at the IDLH level in both scenarios below:

a. **O-1a:** There are liquid nitrogen fill stations within the truck locks at the APS. The truck locks have no direct interaction with the accelerator or the x-ray beam. These areas have the potential for creating an ODH environment if the feed line to the commercial fill stations is breached in an accident scenario and could create ODH working conditions. These pipes are part of the LNDS system and the breach scenario is extremely unlikely given the history of operations within the truck locks. This places the unmitigated risk at Marginal Risk in accordance with Table 3-3. Commercial ODH sensors and alarms identical to those in O-1b are installed and maintained in the truck locks under the Laboratory's Oxygen Deficiency Program. The presence of these existing sensors and alarms will alert personnel to an ODH hazard so that they may exit. With the Laboratory's program mitigating the frequency of ODH environment exposure to personnel, the frequency of adverse effects due to an LNDS breach becomes beyond extremely unlikely and reduces the risk to Bin 3 – Acceptable Risk.

b. **O-1b:** Liquid nitrogen from the external tanks is piped into many of the experimental enclosures of the APS. This includes filling the dewar side of liquid nitrogen pumps that are used to cryogenically cool beamline optics as well as providing liquid nitrogen to experimental equipment. The scenario "RUPTURE OF A FILL LINE" in APS_1265728(Ref. 29) incorporates all scenarios where liquid nitrogen is flowing into a closed experimental enclosure. Personnel access to all closed enclosures is prohibited at the APS as a matter of policy and is part of the training that personnel who access the experimental enclosures receive. This policy is always in effect and is driven by radiological protection concerns and the requirement to prevent access of personnel to the APS x-ray beam (see **Rad-5**). Closing the enclosure doors while personnel are inside is only permitted when maintaining specifically approved facility equipment (e.g. Personnel Safety System equipment). At these times, the valves to the liquid nitrogen distribution system are closed which removes the hazard. When the experimental enclosure doors are open, the air volume in the enclosure is directly connected to the volume of the experiment hall and this situation is the same as the one for "LN2 SPILL FROM OVERFLOW OF CRYO-PUMP INTO THE EXPERIMENTAL HALL DURING NORMAL OPERATION" in APS_1265728 where no controls are required.

   The primary hazard to personnel is opening an enclosure door and entering an ODH environment. Unmitigated, the creation of an ODH condition is unlikely to occur during the lifetime of the facility due to the design of the LNDS system and the beamline review process. Given the consequence, this places the initial O-1b risk at Bin 1 - Unacceptable Risk in accordance with Table 3-3.

A control is required to alert personnel when an ODH condition exists inside of a closed enclosure. The control will consist of a commercial ODH monitoring system with both visual and audio alarms. In addition, training and signage will exist to inform personnel to leave the enclosure door closed if the alarm goes off. This control reduces the frequency further to Extremely Unlikely. These measures will mitigate the frequency to beyond extremely unlikely. This reduces the risk to Bin 3 – Acceptable Risk. The oxygen monitoring system, alarms and signage provide direct notification and protection to personnel and will be credited controls.

ODH monitoring systems can issue false positive alarms. Consequently, the initial response to an ODH alarm will be initially identified to the APS Floor Coordinator or Main Control Room operator who will investigate to determine if an ODH event exists. This recovery will be governed by procedure and the work planning and control process. This will ensure appropriate subject matter review to ensure worker safety during the investigation as well as an approved process to assess the situation.

APS has deployed Alpha-Omega 1000-R Oxygen Deficiency Monitors with visual and audio indicators at the following enclosures:
3-ID-B, 4-ID-B, 04-ID-G, 5-ID-A, 5-ID-B, 5-BM-D, 6-ID-A, 7-BM-B, 9-ID-A, 10-ID-A, 11-BM-B, 12-BM-B, 12-ID-A, 13-ID-A, 14-BM-C, 14-ID-B, 16-BM-B, 16-ID-A, 17-BM-B, 17-ID-A, 17-ID-B, 19-BM-D, 19-ID-D, 20-ID-A, 21-ID-C, 21-ID-D, 21-ID-E, 21-ID-F, 21-ID-G, 22-BM-D, 22-ID-C, 22-ID-D, 23-BM-B, 23-ID-A, 23-ID-B, 23-ID-C, 23-ID-D, 24-ID-B, 23-ID-C, 24-ID-D, 24-ID-E, 26-ID-A, 26-ID-B, 30-ID-B, 31-ID-D, 31-ID-E, 33-ID-D, 33-ID-E, 34-ID-A,
The Alpha-Omega 1000-R has a monthly manufacturer test interval.

### Radiation (Ionizing) – Accelerator Systems (electrons)

- **Rad-1** – An accelerator-specific radiation hazard is presented by radiation sources inside accelerator tunnels (Linac, LEA and other test stands, PAR, booster synchrotron, storage ring/front ends) during normal operations.
- **Rad-2** – An accelerator-specific radiation hazard is presented by elevated radiation levels in occupied areas outside injector complex tunnels (Linac, LEA, PAR, and booster synchrotron) during off-normal events.
- **Rad-3** – An accelerator-specific radiation hazard is presented by elevated radiation levels in occupied areas outside the storage ring tunnel during off-normal events.
- **Rad-4** – An accelerator-specific radiation hazard is presented by elevated radiation levels in occupied areas outside the storage ring tunnel or beamlines due to a swap-out safety fault.

**Radiation (Ionizing) – X-Ray Beamline (photons)**

- **Rad-5** – An accelerator-specific radiation hazard is presented by radiation inside x-ray beamline stations (FOE and experiment stations) during normal operations.
- **Rad-6** – An accelerator-specific radiation hazard is presented by excess radiation in occupied areas outside x-ray beamline stations (FOE and experiment stations) during off-normal events.

### 3.2.2 Off-Normal and Accidental Event Evaluation Results for Rad Events

This section evaluates the accelerator-specific hazards that did not screen out in the hazard identification and screening process above in Table 3-4. This evaluation process is done in accordance with the methodology described in Section 3.1.2.

The first step in this process is to evaluate the accelerator-specific hazards that did not screen out and develop off-normal and accident scenarios related to those hazards. The scenarios were developed using a What-If process. The scenarios were identified by subject matter experts as part of the iterative process of designing and analyzing the new storage ring and the increased duty placed on the injector complex. The distance to the radiation source point varies with each scenario based on the geometry of the machine and shielding, each is the location with the highest dose for the event. Other scenarios were taken from past operating experience or lessons learned at other facilities. The accelerator-specific hazards and associated off-normal and accidental events that could result from those hazards that came out of this process are listed below.

**Radiation Hazard (Accelerator Systems)**

- **Rad-1** – Scenarios that could result in personnel being exposed to radiation sources inside accelerator tunnels (Linac, LEA, PAR, booster synchrotron, storage ring/front ends) during normal operations were considered. A single representative (or generic) scenario was developed related to this hazard.
    a. A person is inside an accelerator tunnel when the electron beam or RF systems are turned on, or a person gains access to an accelerator tunnel (Linac, LEA, PAR, booster synchrotron, or storage ring) while the electron beam or RF systems are on and is exposed to high radiation levels.
- **Rad-2** – Scenarios that could result in personnel being exposed to elevated radiation levels in occupied areas outside injector complex tunnels (Linac, LEA, PAR, and booster synchrotron) during off-normal events were considered. The following scenarios were developed related to this hazard.
    a. Electron beam loss in Linac due to beam dynamics and/or steering problems.
    b. Electron beam loss in PAR due to beam dynamics and/or steering problems.
    c. Electron beam loss in booster synchrotron due to beam dynamics and/or steering problems.
    d. Electron beam loss in LEA due to beam dynamics and/or steering problems.

- **Rad-3** – Scenarios that could result in personnel being exposed to elevated radiation levels in occupied areas outside the storage ring tunnel during off-normal events were considered. The following scenarios were developed related to this hazard.
    a. Full power injected beam (126W) strikes horizontal collimators in Zone F.
    b. Full power injected beam (126W) strikes swap out dump.
    c. Full power injected beam (126W) strikes S40B:M1 vertical collimator in Zone F.
    d. Full power injected beam (126W) strikes upstream or downstream multiplet.
    e. Full power injected beam (126W) strikes insertion device vacuum chamber.
    f. Full power injected beam (126W) strikes septum magnet.
- **Rad-4** – Scenarios that could result in personnel being exposed to elevated radiation levels in occupied areas outside the storage ring tunnel or beamlines due to a swap-out safety fault were considered. The following scenarios were developed related to this hazard.
    a. An electron bunch (20nC pulse) strikes the A:CA1 crotch absorber, directed toward an open beamline aperture.
    b. An electron bunch (20nC pulse) strikes the B:CA1 crotch absorber, directed toward an unused bending magnet beamline.
    c. An electron bunch (20nC pulse) strikes a fixed mask in a beamline front end.
    d. An electron bunch (20nC pulse) strikes a closed photon shutter.
    e. An electron bunch (20nC pulse) escapes the storage ring tunnel and strikes the exit mask in a beamline first optics enclosure.
    f. An electron bunch (20nC pulse) escapes the storage ring tunnel and strikes a mirror in a beamline first optics enclosure.

**Radiation Hazard (X-ray Beamline Systems)**

- **Rad-5** – Scenarios that could result in personnel being exposed to radiation inside x-ray beamline stations (FOE and experiment stations) during normal operations were considered. A single generic scenario was developed related to this hazard.
    a. A person is inside, or gains access to, a beamline station while the x-ray beam is on and is exposed to high radiation levels.
- **Rad-6** – An accelerator-specific radiation hazard is presented by excess radiation in occupied areas outside x-ray beamline stations (FOE and experiment stations) during off-normal events. A single generic scenario was developed related to this hazard
    a. Excessive gas bremsstrahlung entering x-ray beamline.

Once the off-normal and accidental events were identified, the next step in the process is to evaluate each event by estimating the likelihood of occurrence and potential consequences of each event, and then selecting controls that adequately prevent or mitigate the consequences commensurate with the associated risk, if necessary.

An initial evaluation of frequency, facility worker consequence, and risk was performed for each event (in the Initial Risk Evaluation column in Table 3-5). The initial risk evaluation assumes that no preventive or mitigative controls are in place other than the Initial Condition

Assumptions that help define the scenario. The Initial Condition Assumptions are listed in the "Event Description" column.

The available preventive and mitigative features that were considered for the event are listed in preventive and mitigative features columns in Table 3-5. The controls available are then selected with preventing or mitigating the consequences of a scenario. The control selection hierarchy is discussed in the methodology (Section 3.1.2).

Once the controls are selected, the frequency, consequence, and risk are re-evaluated (in the Residual Risk Evaluation column in Table 3-5) assuming that the Initial Condition Assumptions and preventive and mitigative controls are in place.

Each event is evaluated directly in the Table 3-5, *Off-Normal and Accidental Event Evaluation Table*.

### Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation Freq | Initial Risk Evaluation Conseq | Initial Risk Evaluation Risk | Available Preventive Features | Residual Risk Evaluation Freq | Residual Risk Evaluation Conseq | Residual Risk Evaluation Risk |
|---|---|---|---|---|---|---|---|---|---|
| **Rad-1a** | **Personnel exposed to radiation sources inside accelerator tunnel during normal operations (ionizing radiation exposure in controlled area)**<br>This scenario assumes that personnel are in an accelerator shielded enclosure or that personnel inadvertently enter an accelerator tunnel when the beam or RF systems are on.<br>**Location:**<br>• Linac/LTP<br>• LEA and other Test Stands<br>• PAR/PTB<br>• Booster Synchrotron/BTS<br>• Storage Ring<br>**Initial Consequence Estimate:**<br>Doses in some areas inside accelerator shielded enclosure could be lethal.<br>Lethal = High consequence per Table 3-2. | **Hazard**<br>• Radiation sources inside accelerator tunnels during normal operation.<br>• Various types of ionizing radiation are generated inside tunnels when the electron beam or RF systems are activated.<br>**Initiators**<br>• Personnel are in an accelerator tunnel when the beam/RF is turned on.<br>• Personnel inadvertently open door or gain access to accelerator tunnel while beam/RF is on. | A | High | 1 | **Engineered:**<br>ACIS–Access Control Feature (Credited)<br>**Administrative:**<br>ACIS Storage Ring Tunnel Search<br>Radiological Protection Program<br>Conduct of Operations Program (Procedures, Training, Work Control) | BEU | High | 3 |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation | | | Available Preventive Features | Residual Risk Evaluation | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Freq | Conseq | Risk | | Freq | Conseq | Risk |
| **Rad-2a** | **Electron beam loss in Linac**<br>The maximum credible incident for the Linac assumes 50nC/pulse at 60Hz rep rate accelerated to 450 MeV for a beam power of 1.35 kW.<br>**Location:**<br>• Linac<br>**Initial Consequence Estimate:**<br>From Ref. 51, this beam power would produce 40.8 mrem/hr 6m from the beamline, shielded by 2m of concrete.<br>40.8 mrem/hr x 20 min = 13.6 mrem, which is a Negligible consequence per Table 3-2.<br>**Initial Condition Assumptions:**<br>• Immovable Shielding, i.e. Tunnel enclosure | **Hazard**<br>• Bremsstrahlung radiation produced when electrons suddenly decelerate when they interact with matter (e.g., vacuum pipes, accelerator components).<br>• Secondary radiation produced when Bremsstrahlung interacts with matter (e.g., air molecules, accelerator components)<br>**Initiators**<br>• Electron beam strikes vacuum chamber or other components due to beam dynamics and steering problems.<br>• Part or all of the beam can be lost and the loss can be localized or spread over a large area. | A | Neg | 4 | **Engineered:**<br>Area Radiation Monitors – ACIS (Credited)<br>Radiation Shielding (Credited)<br>Software Permissives<br>– Injection efficiency monitor<br>– Detecting and diagnosing machine conditions outside acceptable limits<br>**Administrative:**<br>Conduct of Operations Program (Procedures, Training)<br>Radiological Protection Program<br>Radiation Shielding Management Program | A | Neg | 4 |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation | | | Available Preventive Features | Residual Risk Evaluation | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Freq | Conseq | Risk | | Freq | Conseq | Risk |
| **Rad-2b** | **Electron beam loss in PAR**<br>The maximum credible incident for the PAR assumes a beam energy of 500 MeV with 20W of beam power.<br>**Location:**<br>• PAR<br>**Initial Consequence Estimate:**<br>From Refs.52 And 53, a loss of 20 W of beam power would produce 163 mrem/hr radiation dose at a point 7.2-8.6 m from the loss region and is protected by 1.3 m of concrete and 5.08 cm of Steel.<br>163 mrem/hr x 20 min = 54.3 mrem which is a Negligible consequence per Table 3-2.<br>**Initial Condition Assumptions:**<br>• Immovable Shielding, i.e., Tunnel enclosure | **Hazard**<br>• Bremsstrahlung radiation produced when electrons suddenly decelerate when they interact with matter (e.g., vacuum pipes, accelerator components).<br>• Secondary radiation produced when Bremsstrahlung interacts with matter (e.g., air molecules, accelerator components)<br>**Initiators**<br>• Electron beam strikes vacuum chamber or other components due to beam dynamics and steering problems.<br>• Part or all of the beam can be lost and the loss can be localized or spread over a large area. | A | Neg | 4 | **Engineered:**<br>Area Radiation Monitors – ACIS (Credited)<br>Radiation Shielding – (Credited)<br>Software Permissives<br>– Injection efficiency monitor<br>– Detecting and diagnosing machine conditions outside acceptable limits<br>**Administrative:**<br>Conduct of Operations Program (Procedures, Training)<br>Radiological Protection Program<br>Radiation Shielding Management Program | A | Neg | 4 |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation | | | Available Preventive Features | Residual Risk Evaluation | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Freq | Conseq | Risk | | Freq | Conseq | Risk |
| **Rad-2c** | **Electron beam loss in booster synchrotron**<br>The maximum credible incident for the booster assumed a beam energy of 7700 MeV for a total beam power of 308 W and that the full beam is lost.<br>**Location:**<br>• Booster Synchrotron<br>**Initial Consequence Estimate:**<br>From Ref. 37, a loss of the 308 W of beam produces 1.12 rem/hr at a point 3.34 m above the loss region and is shielded by 1.0 m of concrete and partially shielded by 10.16 cm of Fe.<br>1.12 rem/hr x 20 min = 0.373 rem which is a Negligible consequence per Table 3-2.<br>**Initial Condition Assumptions:**<br>• Immovable Shielding, i.e., Tunnel enclosure | **Hazard**<br>• Bremsstrahlung radiation produced when electrons suddenly decelerate when they interact with matter (e.g., vacuum pipes, accelerator components).<br>• Secondary radiation produced when Bremsstrahlung interacts with matter (e.g., air molecules, accelerator components)<br>**Initiators**<br>• Electron beam strikes vacuum chamber or other components due to beam dynamics and steering problems.<br>• Part or all of the beam can be lost and the loss can be localized or spread over a large area. | A | Neg | 4 | **Engineered:**<br>Area Radiation Monitors – ACIS (Credited)<br>Radiation Shielding (Credited)<br>Software Permissives<br>– Injection efficiency monitor<br>– Detecting and diagnosing machine conditions outside acceptable limits<br>**Administrative:**<br>Conduct of Operations Program (Procedures, Training)<br>Radiological Protection Program<br>Radiation Shielding Management Program | A | Neg | 4 |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation | | | Available Preventive Features | Residual Risk Evaluation | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Freq | Conseq | Risk | | Freq | Conseq | Risk |
| **Rad-2d** | **Electron beam loss in LEA**<br>The maximum credible incident at the test stand assumes a beam energy of 700 MeV with a beam power of 1000W.<br>**Location:**<br>• LEA<br>**Initial Consequence Estimate:** From Ref. 54, a loss of 1000 W of beam produces a maximum of 13.1 rem/hr when the total beam dumps along the length of the 4m region. This results in the highest dose rate in the booster synchrotron mezzanine. The dose point is 2.443 m perpendicular distance from the loss region and is shielded by 0.16 cm of Fe and 100 cm of concrete. 13.1 rem/hr x 20 min = 4.4 rem which is a Low consequence per Table 3-2.<br>**Initial Condition Assumptions:**<br>• Immovable Shielding, i.e., Tunnel enclosure | **Hazard**<br>• Bremsstrahlung radiation produced when electrons suddenly decelerate when they interact with matter (e.g., vacuum pipes, accelerator components).<br>• Secondary radiation produced when Bremsstrahlung interacts with matter (e.g., air molecules, accelerator components)<br>**Initiators**<br>• Electron beam strikes vacuum chamber or other components due to beam dynamics and steering problems.<br>• Part or all of the beam can be lost and the loss can be localized or spread over a large area. | A | Low | 3 | **Engineered:**<br>Area Radiation Monitors – ACIS (Credited)<br>Radiation Shielding (Credited)<br>LINAC BESOCM (limits maximum beam power)<br>Software Permissives<br>– Injection efficiency monitor<br>– Detecting and diagnosing machine conditions outside acceptable limits<br>**Administrative:**<br>Conduct of Operations Program (Procedures, Training)<br>Radiological Protection Program<br>Radiation Shielding Management Program | A | Neg | 4 |
| | | | | | | | Radiation monitors terminate event after 2 minutes, which reduces the dose to 0.44 rem. | | |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation | | | Available Preventive Features | Residual Risk Evaluation | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Freq | Conseq | Risk | | Freq | Conseq | Risk |
| Rad-3a | **Loss of injected beam inside storage ring vacuum chamber (beam strikes horizontal collimator in Zone F)**<br>This scenario assumes that an off-normal fault results in a full power injected beam (126 W) striking horizontal collimators in Zone F of the storage ring (full beam dump) resulting in increased radiation outside Zone F of the storage ring tunnel.<br>**Location:**<br>• Storage Ring<br>**Initial Consequence Estimate:** The calculated dose rate assuming that initial conditions are in place is 186 mrem/hr in occupied area outside Zone F of the storage ring. 186 mrem/hr x 1 hr = 186 mrem which is a Negligible consequence per Table 3-2 (Ref. 55).<br>**Initial Condition Assumptions:**<br>• Safety envelope for injected beam at 6.3 GeV.<br>• Immovable shielding | **Hazard**<br>• Bremsstrahlung radiation produced when electrons suddenly decelerate when they interact with matter (e.g., collimator, vacuum chamber, accelerator components).<br>• Secondary radiation produced when Bremsstrahlung interacts with matter (e.g., accelerator components, air molecules)<br>**Initiators**<br>• Steering error in BTS transport line or storage ring due to magnet power supply fault, RF system fault, other equipment failure, or human error. | A | Neg | 4 | **Engineered:**<br>Area Radiation Monitors – ACIS (Credited)<br>Radiation Shielding (Credited)<br>BTS BESOCM (limits maximum average storage ring beam power)<br>**Administrative:**<br>Conduct of Operations Program (Procedures, Training)<br>Radiological Protection Program<br>Radiation Shielding Management Program | A | Neg | 4 |
| | | | | | | | With controls the dose is reduced to 34 mrem/hr. | | |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation |  |  | Available Preventive Features | Residual Risk Evaluation |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Freq | Conseq | Risk |  | Freq | Conseq | Risk |
| **Rad-3b** | **Loss of injected beam inside storage ring vacuum chamber (beam strikes swap out dump)**<br>This scenario assumes that an off-normal fault results in a full power injected beam (126W) striking the swap out dump resulting in increased radiation outside Zone F of the storage ring tunnel.<br>**Location:**<br>• Storage Ring<br>**Initial Consequence Estimate:**<br>The calculated dose rate assuming that initial conditions are in place is 18.4 mrem/hr in occupied area outside Zone F of storage ring. 18.4 mrem x 1 hr = 18.4 mrem which is a Negligible consequence per Table 3-2 (Ref. 55).<br>**Initial Condition Assumptions:**<br>• Safety envelope for injected beam at 6.3 GeV.<br>• Immovable shielding, i.e., Tunnel enclosure.<br>• Radiation shielding of concrete blocks. | **Hazard**<br>• Bremsstrahlung radiation produced when electrons suddenly decelerate when they interact with matter (e.g., collimator, vacuum chamber, accelerator components).<br>• Secondary radiation produced when Bremsstrahlung interacts with matter (e.g., accelerator components, air molecules)<br>**Initiators**<br>• Steering error in BTS transport line or storage ring due to power supply fault, other equipment failure, or human error. | A | Neg | 4 | **Engineered:**<br>ACIS–Area Radiation Monitors (Credited)<br>Radiation Shielding (Creditied)<br>BTS BESOCM (limits maximum average storage ring beam power)<br>**Administrative:**<br>Radiological Protection Program<br>Conduct of Operations Program (Procedures, Training)<br>Radiation Shielding Management Program (Credited) | A<br>6.4 mrem\hr with the additional concrete and steel shielding, and BTS BESOCM | Neg | 4 |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation | | | Available Preventive Features | Residual Risk Evaluation | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Freq | Conseq | Risk | | Freq | Conseq | Risk |
| **Rad-3c** | **Loss of injected beam inside storage ring vacuum chamber (beam strikes vertical collimators in Zone F)**<br>This scenario assumes that an off-normal fault results in a full power injected beam (126W) striking the S40B:M1 vertical collimator in Zone F of the storage ring resulting in increased radiation outside Zone F of the storage ring tunnel.<br>**Location:**<br>• Storage Ring<br>**Initial Consequence Estimate:** The calculated dose rate assuming that initial conditions are in place is 129.9 mrem/hr in occupied area outside Zone F of storage ring. 129.9 mrem x 1 hr = 129.9 mrem which is a Negligible consequence per Table 3-2 (Ref. 55).<br>**Initial Condition Assumptions:**<br>• Safety envelope for injected beam at 6.3 GeV.<br>• Immovable shielding, i.e., Tunnel enclosure.<br>• Radiation shielding of concrete blocks. | **Hazard**<br>• Bremsstrahlung radiation produced when electrons suddenly decelerate when they interact with matter (e.g., collimator, vacuum chamber, accelerator components).<br>• Secondary radiation produced when Bremsstrahlung interacts with matter (e.g., accelerator components, air molecules)<br>**Initiators**<br>• Steering error in BTS transport line or storage ring due to power supply fault, other equipment failure, or human error. | A | Neg | 4 | **Engineered:**<br>ACIS–Area Radiation Monitors (Credited)<br>Radiation Shielding (Credited)<br>BTS BESOCM (limits maximum average storage ring beam power)<br>**Administrative:**<br>Radiological Protection Program<br>Conduct of Operations Program (Procedures, Training)<br>Radiation Shielding Management Program | A | Neg | 4 |
| | | | | | | | With controls the dose is reduced to 47 mrem in an hour on the Mezzanine and 24.0 mrem in an hour in EAA. | | |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation | | | Available Preventive Features | Residual Risk Evaluation | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Freq | Conseq | Risk | | Freq | Conseq | Risk |
| **Rad-3d** | **Loss of injected beam inside storage ring vacuum chamber (beam strikes upstream or downstream multiplet vacuum chamber)**<br>This scenario assumes that an off-normal fault results in a full power injected beam (126 W) striking an upstream or downstream multiplet vacuum chamber resulting in increased radiation at the nearest front end ratchet door.<br>**Location:**<br>• Storage Ring<br>**Initial Consequence Estimate:** The calculated dose rate assuming that initial conditions are in place is 564.4 mrem/hr maximum in occupied areas outside front end ratchet door. 564.4 mrem x 1 hr = 564.4 mrem which is a Low consequence per Table 3-2 (Ref. 55).<br>**Initial Condition Assumptions:**<br>• Safety envelope for injected beam at 6.3 GeV.<br>• Immovable shielding, i.e., Tunnel enclosure. | **Hazard**<br>• Bremsstrahlung radiation produced when electrons suddenly decelerate when they interact with matter (e.g., collimator, vacuum chamber, accelerator components).<br>• Secondary radiation produced when Bremsstrahlung interacts with matter (e.g., accelerator components, air molecules)<br>**Initiators**<br>• Steering error in BTS transport line or storage ring due to power supply fault, other equipment failure, or human error. | A | Low | 3 | **Engineered:**<br>ACIS–Area Radiation Monitors<br>Radiation Shielding (Credited)<br>BTS BESOCM (limits maximum average storage ring beam power)<br>**Administrative:**<br>Radiological Protection Program<br>Conduct of Operations Program (Procedures, Training)<br>Radiation Shielding Management Program | A<br>BTS BESOCM reduces to 54 mrem/hr. | Neg | 4 |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation | | | Available Preventive Features | Residual Risk Evaluation | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Freq | Conseq | Risk | | Freq | Conseq | Risk |
| **Rad-3e** | **Loss of injected beam inside storage ring vacuum chamber (beam strikes insertion device vacuum chamber)**<br>This scenario assumes that an off-normal fault results in a full power injected beam (126W) striking an insertion device vacuum chamber resulting in increased radiation inside to the first optics enclosure.<br>**Location:**<br>• Storage Ring<br>**Initial Consequence Estimate:** The calculated dose rate assuming that initial conditions are in place is 822 mrem/hr in occupied areas adjacent to first optics enclosure. 822 mrem x 1 hr = 822 mrem which is a Low consequence per Table 3-2 (Ref. 55).<br>**Initial Condition Assumptions:**<br>• Safety envelope for injected beam at 6.3 GeV.<br>• Immovable shielding, i.e., Tunnel enclosure. | Hazard<br>• Bremsstrahlung radiation produced when electrons suddenly decelerate when they interact with matter (e.g., collimator, vacuum chamber, accelerator components).<br>• Secondary radiation produced when Bremsstrahlung interacts with matter (e.g., accelerator components, air molecules)<br>Initiators<br>• Steering error in BTS transport line or storage ring due to power supply fault, other equipment failure, or human error. | A | Low | 3 | **Engineered:**<br>ACIS–Area Radiation Monitors (Credited)<br>Radiation Shielding (Credited)<br>BTS BESOCM (limits maximum average storage ring beam power)<br>**Administrative:**<br>Radiological Protection Program<br>Conduct of Operations Program (Procedures, Training)<br>Radiation Shielding Management Program | A<br>BTS BESOCM reduces to 78 mrem/hr. | Neg | 4 |

### Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation Freq | Initial Risk Evaluation Conseq | Initial Risk Evaluation Risk | Available Preventive Features | Residual Risk Evaluation Freq | Residual Risk Evaluation Conseq | Residual Risk Evaluation Risk |
|---|---|---|---|---|---|---|---|---|---|
| **Rad-3f** | **Loss of injected beam inside storage ring vacuum chamber (beam strikes the septum magnet)**<br>This scenario assumes that an off-normal fault results in a full power injected beam (126W) striking the septum magnet resulting in increased radiation in the Experiment Assembly Area (EAA).<br>**Location:**<br>• Storage Ring<br>**Initial Consequence Estimate:** The calculated dose rate assuming that initial conditions are in place is 16 mrem/hr in occupied areas adjacent to first optics enclosure. 16 mrem x 1 hr = 16 mrem which is a Low consequence per Table 3-2 (Ref. 55).<br>**Initial Condition Assumptions:**<br>• Safety envelope for injected beam at 6.3 GeV.<br>• Immovable shielding, ex. Tunnel enclosure.<br>• Radiation shielding - 36” of concrete blocks outboard and 8” lead (outboard) or 12” lead (above) for the septum | **Hazard**<br>• Bremsstrahlung radiation produced when electrons suddenly decelerate when they interact with matter (e.g., collimator, vacuum chamber, accelerator components).<br>• Secondary radiation produced when Bremsstrahlung interacts with matter (e.g., accelerator components, air molecules)<br>**Initiators**<br>• Steering error in BTS transport line or storage ring due to power supply fault, other equipment failure, or human error. | A | Neg | 4 | **Engineered:**<br>ACIS–Area Radiation Monitors (Credited)<br>Radiation Shielding (Credited)<br>BTS BESOCM (limits maximum average storage ring beam power)<br>**Administrative:**<br>Radiological Protection Program<br>Conduct of Operations Program (Procedures, Training)<br>Radiation Shielding Management Program | A<br>BTS BESOCM reduces to 1.5 mrem/hr. | Neg | 4 |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation | | | Available Preventive Features | Residual Risk Evaluation | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | **Freq** | **Conseq** | **Risk** | | **Freq** | **Conseq** | **Risk** |
| **Rad-4a** | **Swap-out safety fault allows injected beam to escape the storage ring (electron pulse strikes A:CA1 crotch absorber)**<br>This scenario assumes that a swap-out safety fault allows an electron bunch (20nC pulse) to strike the A:CA1 crotch absorber at the entrance to an open beamline resulting in increased radiation on the outboard side of the storage ring tunnel.<br>**Location:**<br>• Storage Ring/Beamline<br>**Initial Consequence Estimate:** The calculated dose assuming that initial conditions are in place is 0.1 mrem/pulse x 3,600 pulses/hr = 335.5 mrem/hr in occupied areas on outboard side of storage ring tunnel. 335.5 mrem is a Negligible consequence per Table 3-2 (Ref. 55).<br>**Initial Condition Assumptions:**<br>• Safety envelope for injected beam at 6.3 GeV.<br>• Immovable shielding, i.e., Tunnel enclosure. | **Hazard**<br>• Bremsstrahlung radiation produced when electrons suddenly decelerate when they interact with matter (e.g., crotch absorber or beamline components).<br>• Secondary radiation produced when Bremsstrahlung interacts with matter (e.g., beamline components, air molecules)<br>**Initiators**<br>• Magnet fault or power supply fault<br>• Booster timing error causes energy mismatch between booster and storage ring | A | Neg | 4 | **Engineered:**<br>ACIS–Area Radiation Monitors (Credited)<br>ACIS - Stored Beam Monitor Interlock<br>ACIS – Booster Extraction Fast Interlock (BEFI)<br>Radiation Shielding (Credited)<br>Storage Ring A:M1 Dipole Current Interlock<br>Storage Ring A:M1 Dipole Voltage Interlock<br>Software Permissives<br>– Injection efficiency monitor<br>– First-turn BPM<br>– All magnet current permissives<br>**Administrative:**<br>Radiological Protection Program<br>Conduct of Operations Program (Procedures, Training)<br>Radiation Shielding Management Program | EU | Neg | 4 |
| | | | | | | | Radiation monitors terminate event after 2 minutes (120 pulses), which reduces the dose to 11.2 mrem. | | |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation Freq | Initial Risk Evaluation Conseq | Initial Risk Evaluation Risk | Available Preventive Features | Residual Risk Evaluation Freq | Residual Risk Evaluation Conseq | Residual Risk Evaluation Risk |
|---|---|---|---|---|---|---|---|---|---|
| **Rad-4b** | **Swap-out safety fault allows injected beam to escape the storage ring (electron pulse strikes B:CA1 crotch absorber)**<br>This scenario assumes that a swap-out safety fault allows an electron bunch (20nC pulse) to strike the B:CA1 crotch absorber at an unused bending magnet beamline resulting in increased radiation on the outboard side of the storage ring tunnel. Bending magnet beamlines with a front end will have a significantly lower dose and therefore are not discussed here.<br>**Location:**<br>• Storage Ring/Beamline<br>**Initial Consequence Estimate:**<br>The calculated dose assuming that initial conditions are in place is 0.463 mrem/pulse x 3,600 pulses/hr = 1,667 mrem/hr in occupied areas on outboard side of storage ring tunnel. 1,667 mrem is a Low consequence per Table 3-2 (Ref. 55).<br>**Initial Condition Assumptions:**<br>• Safety envelope for injected beam at 6.3 GeV.<br>• Immovable shielding, i.e., Tunnel enclosure. | **Hazard**<br>• Bremsstrahlung radiation produced when electrons suddenly decelerate when they interact with matter (e.g., crotch absorber or beamline components).<br>• Secondary radiation produced when Bremsstrahlung interacts with matter (e.g., beamline components, air molecules)<br>**Initiators**<br>• Magnet fault or power supply fault<br>• Booster timing error causes energy mismatch between booster and storage ring | A | Low | 3 | **<u>Engineered:</u>**<br>ACIS–Area Radiation Monitors (Credited)<br>ACIS - Stored Beam Monitor Interlock<br>ACIS – Booster Extraction Fast Interlock (BEFI)<br>Radiation Shielding (Credited)<br>Storage Ring A:M1 Dipole Current Interlock<br>Storage Ring A:M1 Dipole Voltage Interlock<br>Software Permissives<br>− Injection efficiency monitor<br>− First-turn BPM<br>− All magnet current permissives<br>**<u>Administrative:</u>**<br>Radiological Protection Program<br>Conduct of Operations Program (Procedures, Training)<br>Radiation Shielding Management Program | EU<br>Radiation monitors terminate event after 2 minutes (120 pulses), which reduces the dose to 56 mrem. | Neg | 4 |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation | | | Available Preventive Features | Residual Risk Evaluation | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Freq | Conseq | Risk | | Freq | Conseq | Risk |
| **Rad-4c** | **Swap-out safety fault allows injected beam to escape the storage ring (electron pulse strikes a fixed mask in beamline front end)**<br>This scenario assumes that a swap-out safety fault allows an electron bunch (20nC pulse) to travel down a front end and strike a fixed mask resulting in increased radiation on the outboard side of the storage ring tunnel.<br>**Location:**<br>• Storage Ring/Beamline<br>**Initial Consequence Estimate:** The calculated dose assuming that initial conditions are in place is 0.36 mrem/pulse times 3,600 pulses/hr = 1.28 rem/hr in occupied areas on outboard side of storage ring tunnel. 1.28 rem is a Low consequence per Table 3-2 (Ref. 55).<br>**Initial Condition Assumptions:**<br>• Safety envelope for injected beam at 6.3 GeV.<br>• Immovable shielding, i.e., Tunnel enclosure. | **Hazard**<br>• Bremsstrahlung radiation produced when electrons suddenly decelerate when they interact with matter (e.g., mask or beamline components).<br>• Secondary radiation produced when Bremsstrahlung interacts with matter (e.g., beamline components, air molecules)<br>**Initiators**<br>• Magnet fault or power supply fault<br>• Booster timing error causes energy mismatch between booster and storage ring | U | Low | 3 | **Engineered:**<br>ACIS–Area Radiation Monitors (Credited)<br>ACIS - Stored Beam Monitor Interlock<br>ACIS – Booster Extraction Fast Interlock (BEFI)<br>Radiation Shielding (Credited)<br>Storage Ring A:M1 Dipole Current Interlock<br>Storage Ring A:M1 Dipole Voltage Interlock<br>Software Permissives<br>− Injection efficiency monitor<br>− First-turn BPM<br>− All magnet current permissives<br>**Administrative:**<br>Radiological Protection Program<br>Conduct of Operations Program (Procedures, Training)<br>Radiation Shielding Management Program | EU | Neg | 4 |
| | | | | | | | Radiation monitors terminate event after 2 minutes (120 pulses), which reduces the dose to 42.5 mrem. | | |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation | | | Available Preventive Features | Residual Risk Evaluation | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Freq | Conseq | Risk | | Freq | Conseq | Risk |
| **Rad-4d** | **Swap-out safety fault allows injected beam to escape the storage ring (electron pulse strikes a closed beamline shutter)**<br>This scenario assumes that a swap-out safety fault allows an electron bunch (20nC pulse) to travel down a front end and strike a closed photon shutter resulting in increased radiation on the outboard side of the storage ring tunnel.<br>**Location:**<br>• Storage Ring/Beamline<br>**Initial Consequence Estimate:**<br>The calculated dose assuming that initial conditions are in place is 1.68 mrem/pulse and 3,600 pulses/hr = 6.0 rem/hr next to the nearest front end ratchet door. 6.0 rem is a Low consequence per Table 3-2 (Ref. 55).<br>**Initial Condition Assumptions:**<br>• Safety envelope for injected beam at 6.3 GeV.<br>• Immovable shielding, i.e., Tunnel enclosure. | **Hazard**<br>• Bremsstrahlung radiation produced when electrons suddenly decelerate when they interact with matter (e.g., shutter or beamline components).<br>• Secondary radiation produced when Bremsstrahlung interacts with matter (e.g., accelerator components, air molecules)<br>**Initiators**<br>• Magnet fault or power supply fault<br>• Booster timing error causes energy mismatch between booster and storage ring | U | Low | 3 | **Engineered:**<br>ACIS–Area Radiation Monitors (Credited)<br>ACIS - Stored Beam Monitor Interlock<br>ACIS – Booster Extraction Fast Interlock (BEFI)<br>Radiation Shielding (Credited)<br>Storage Ring A:M1 Dipole Current Interlock<br>Storage Ring A:M1 Dipole Voltage Interlock<br>Software Permissives<br>− Injection efficiency monitor<br>− First-turn BPM<br>− All magnet current permissives<br>**Administrative:**<br>Radiological Protection Program<br>Conduct of Operations Program (Procedures, Training)<br>Radiation Shielding Management Program | EU | Neg | 4 |
| | | | | | | | Radiation monitors terminate event after 2 minutes (120 pulses), which reduces the dose to 201.6 mrem. | | |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation | | | Available Preventive Features | Residual Risk Evaluation | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Freq | Conseq | Risk | | Freq | Conseq | Risk |
| **Rad-4e** | **Swap-out safety fault allows injected beam to escape the storage ring shielded enclosure (electron pulse strikes the exit mask in first optics enclosure)**<br>This scenario assumes that a swap-out safety fault allows an electron bunch (20nC pulse) to travel down a front end and strike the exit mask in a first optics enclosure resulting in increased radiation on the first optics enclosure.<br>**Location:**<br>• Storage Ring/Beamline<br>**Initial Consequence Estimate:**<br>The calculated dose assuming that initial conditions are in place is 39.4 mrem/pulse times 3,600 pulses/hr = 141.8 rem/hr in occupied areas outside the first optics enclosure. 141.8 rem is a High consequence per Table 3-2 (Ref. 55).<br>**Initial Condition Assumptions:**<br>• Safety envelope for injected beam at 6.3 GeV.<br>• Immovable shielding, i.e., Tunnel enclosure. | **Hazard**<br>• Bremsstrahlung radiation produced when electrons suddenly decelerate when they interact with matter (e.g., beamline exit mask other beamline components).<br>• Secondary radiation produced when Bremsstrahlung interacts with matter (e.g., beamline components, air molecules)<br>**Initiators**<br>• Magnet fault or power supply fault<br>• Booster timing error causes energy mismatch between booster and storage ring | EU | High | 2 | **Engineered:**<br>ACIS–Area Radiation Monitors (Credited)<br>ACIS - Stored Beam Monitor Interlock<br>ACIS – Booster Extraction Fast Interlock (BEFI)<br>Radiation Shielding (Credited)<br>Storage Ring A:M1 Dipole Current Interlock<br>Storage Ring A:M1 Dipole Voltage Interlock<br>Software Permissives<br>− Injection efficiency monitor<br>− First-turn BPM<br>− All magnet current permissives<br>**Administrative:**<br>Radiological Protection Program<br>Conduct of Operations Program (Procedures, Training)<br>Radiation Shielding Management Program | BEU | Low | 4 |
| | | | | | | | Radiation monitors terminate event after 2 minutes (120 pulses), which reduces the dose to 4.7 rem. | | |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| | | | Initial Risk Evaluation | | | | Residual Risk Evaluation | | |
|---|---|---|---|---|---|---|---|---|---|
| **Event No.** | **Event Description** | **Hazard/ Initiators** | **Freq** | **Conseq** | **Risk** | **Available Preventive Features** | **Freq** | **Conseq** | **Risk** |
| **Rad-4f** | **Swap-out safety fault allows injected beam to escape the storage ring shielded enclosure (electron pulse strikes a mirror in first optics enclosure)**<br>This scenario assumes that a swap-out safety fault allows an electron bunch (20nC pulse) to travel down a front end and strike a mirror in a first optics enclosure resulting in increased radiation on the outside the first optics enclosure.<br>**Location:**<br>• Storage Ring/Beamline<br>**Initial Consequence Estimate:**<br>The calculated dose assuming that initial conditions are in place is 492.2 mrem/pulse times 3,600 pulses/hr = 1,772 rem/hr in occupied areas outside the first optics enclosure. 1,772 rem is a High consequence per Table 3-2 (Ref. 55).<br>**Initial Condition Assumptions:**<br>• Safety envelope for injected beam at 6.3 GeV.<br>• Immovable shielding, i.e., Tunnel enclosure. | **Hazard**<br>• Bremsstrahlung radiation produced when electrons suddenly decelerate when they interact with matter (e.g., beamline mirror or other beamline components).<br>• Secondary radiation produced when Bremsstrahlung interacts with matter (e.g., beamline components, air molecules)<br>**Initiators**<br>• Magnet fault or power supply fault<br>• Booster timing error causes energy mismatch between booster and storage ring | EU | High | 2 | **Engineered:**<br>ACIS–Area Radiation Monitors (Credited)<br>ACIS - Stored Beam Monitor Interlock<br>ACIS – Booster Extraction Fast Interlock (BEFI)<br>Radiation Shielding (Credited)<br>Storage Ring A:M1 Dipole Current Interlock<br>Storage Ring A:M1 Dipole Voltage Interlock<br>Software Permissives<br>− Injection efficiency monitor<br>− First-turn BPM<br>− All magnet current permissives<br>**Administrative:**<br>Radiological Protection Program<br>Conduct of Operations Program (Procedures, Training)<br>Radiation Shielding Management Program | BEU | High | 3 |
| | | | | | | | Radiation monitors terminate event after 2 minutes (120 pulses), which reduces the dose to 59.1 rem | | |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation | | | Available Preventive Features | Residual Risk Evaluation | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Freq | Conseq | Risk | | Freq | Conseq | Risk |
| **Rad-5a** | **Personnel inside beamline station while x-ray beam is on (ionizing radiation exposure in controlled area)**<br>This scenario assumes that personnel are in a beamline station or that personnel inadvertently enter a beamline station when the x-ray beam is on.<br>**Location:**<br>• Any beamline<br>**Initial Consequence Estimate:**<br>Doses in some areas inside shielded beamline stations could be lethal. Lethal = High consequence per Table 3-2 (Ref. 56, 57, 58, 59, 60).<br>**Initial Condition Assumptions:**<br>• Immovble shielding, i.e., Hutch | **Hazard**<br>• X-ray and other radiation inside beamline stations during normal operation.<br>• Unmodified white beam with coincident primary bremsstrahlung is the most hazardous (higher radiation levels).<br>• White beams are more hazardous than monochromatic beams.<br>**Initiators**<br>• Personnel are in a beamline station when beam is turned on.<br>• Personnel inadvertently open door or gain access to a beamline station while beam is on. | A | High | 1 | **Engineered:**<br>PSS–Access Control Feature and Emergency Shutdown Buttons<br>ACIS - Shutters<br>**Administrative:**<br>Search and Secure Procedure<br>Radiological Protection Program<br>Conduct of Operations Program (Procedures, Training, Work Control) | BEU | High | 3 |

## Table 3-5. Off-Normal and Accidental Event Evaluation Table for Rad Events

| Event No. | Event Description | Hazard/ Initiators | Initial Risk Evaluation Freq | Initial Risk Evaluation Conseq | Initial Risk Evaluation Risk | Available Preventive Features | Residual Risk Evaluation Freq | Residual Risk Evaluation Conseq | Residual Risk Evaluation Risk |
|---|---|---|---|---|---|---|---|---|---|
| **Rad-6a** | **Excessive gas bremsstrahlung entering x-ray beamline**<br>This scenario assumes that a drop in vacuum level (increase in pressure) in the storage ring results in an increase in gas bremsstrahlung that accompanies the synchrotron radiation into the beamline. An excessive amount of gas bremsstrahlung entering an x-ray beamline can produce elevated radiation levels in occupied areas outside the beamline stations or pipes.<br>**Location:**<br>• Any beamline<br>**Initial Consequence Estimate:** The radiation dose outside the beamline hutches could reach 5 to 25 rem if there were no controls and the event continued for 1 hour (Ref. 61).<br>**Initial Condition Assumptions:**<br>• Safety envelope for injected beam at 6.3 GeV.<br>• Immovable shielding, i.e., Hutch | **Hazard**<br>• Bremsstrahlung radiation is emitted by the deceleration of a charged particle when it strikes another charged particle.<br>• Excessive gas bremsstrahlung produced in the storage ring straight section will accompany the synchrotron radiation into the beamline.<br>**Initiators**<br>• Drop in vacuum level (increase in pressure) in storage ring due to outgassing of NEG coating, beam heating of the vacuum chamber, slow vacuum leak, etc. | A | Mod | 2 | **Engineered:**<br>ACIS–Area Radiation Monitors (Credited)<br>ACIS – Shutters<br>Machine Protection System–Vacuum Monitors<br>Radiation Shielding (Credited)<br>**Administrative:**<br>Radiological Protection Program<br>Conduct of Operations Program (Procedures, Training, Work Control)<br>Radiation Shielding Management Program<br>Beamline Internal Readiness Review Program (Credited) | A<br>With shielding controls the dose is reduced to 0.5 mrem/hr (Ref APSU_2217654) | Neg | 4 |

### 3.2.2.1 Discussion of Off-Normal and Accidental Event Results

This section provides additional discussion on each scenario in Table 3-5, including the basis for frequency, consequence, risk determinations, and the safety functions provided by the selected controls.

**Rad-1** – Personnel exposed to radiation sources inside accelerator tunnel during normal operations (ionizing radiation exposure in controlled area).

**Scenario Development:** This is a generic scenario that covers all the accelerator systems and test stands. Various types of ionizing radiation are generated inside the tunnels or shielded enclosures during normal operations when the RF systems are activated or the electron beam is on. This scenario assumes that personnel are inside an accelerator tunnel or test stand enclosure when the beam/RF is inadvertently turned on, or personnel open the door or gain access to an accelerator tunnel or test stand enclosure while the beam/RF is on.

**Initial Risk Evaluation: Risk Bin 1 (Unacceptable Risk)**
In addition to providing shielding that limits dose rates outside the tunnels, the radiation shielding structures provide a physical boundary that prevents access to the areas inside except through access doors. Without some type of control on the access doors, it is **Anticipated** that personnel could be inside an accelerator tunnel/test stand or inadvertently access an accelerator tunnel/test stand when the beam or RF systems are on. The consequence can vary widely depending on which accelerator tunnel is involved, where the person is located, if only the RF Systems are on or if the beam is present, and the duration of the exposure. However, doses in some areas inside shielded structures could be lethal, which is considered **High** consequences per the criteria in Table 3-2. An Anticipated frequency with High consequences results in an initial risk evaluation of **Risk Bin 1** (Unacceptable Risk) based on the criteria in Table 3-3. Therefore, additional controls are required to either prevent (reduce the frequency) or mitigate (reduce the consequence of) this scenario to achieve a risk rank of 3 or 4.

**Control Selection:** The controls that were selected to prevent this scenario are:

- ACIS-Access Control Feature (Credited) – prevents access to tunnels while beam or RF systems are on. Access is prevented by locking the doors, and monitoring devices and interlocks stop or disable RF systems and beam operation (disables Controlled Equipment) if a locked door is somehow opened, or improper access is gained (Ref. 56, 57, 58, 59, 60). Features of the ACIS that directly protect personnel include the door switches, access control gates and doors, the programmable logic controllers and the beam shutdown interfaces.

- ACIS Storage Ring Tunnel Search – Sweeps tunnels prior to locking doors and energizing equipment. This is a manual search that works in conjunction with ACIS-Access Control Feature, which provides a means to search tunnels and transition from being occupied to a secure state with no personnel inside (Ref. 62).

- Radiation Protection Program – Provides the link between the requirements of 10CFR 835 and its implementation at Argonne (Ref. 21).
- Conduct of Operations – Supports mission success and promotes safety and environmental protection with goal to minimize the likelihood and consequences of technical or organization system failures (Ref. 9, 10, and 11).

These controls reduce the likelihood of the event and are purely preventive (shifts frequency).

**Residual Risk Evaluation: Risk Bin 3 (Acceptable Risk)**
With the initial condition assumptions and additional controls in place, the frequency is reduced from Anticipated to Beyond Extremely Unlikely. Consequences are unchanged since it is impossible to reduce the radiation dose inside the accelerator tunnel while the electron beam or RF is on. From Table 3-3, a frequency of BEU with High consequence results in a Risk Bin 3 (Acceptable Risk).

**Rad-2** Scenarios that could result in personnel being exposed to elevated radiation levels in occupied areas outside injector complex tunnels (Linac, LEA, PAR, and booster synchrotron) during off-normal events were considered.

**Scenario Development:** The electron beam can be lost at any point in the machine and at any time in the acceleration cycle due to beam dynamics and steering problems. This loss can be spread out over a large region or confined to a localized area. Losing the beam in the injector complex produces excess radiation in occupied areas outside injector complex tunnels. (Linac, LEA, PAR and booster synchrotron)

**Initial Condition Assumptions**

- Radiation Shielding (credited) – provides shielding that limits dose rates in occupied areas outside shielded structures or enclosures.

**Initial Risk Evaluation: Risk Bin 3-4**
The initial risk evaluation assumes that only the initial condition assumptions are in place. Beam dynamics and steering problems are not unusual, so it is **Anticipated** that the beam can strike the vacuum chamber and produce excess radiation. Details on the radiation risk for each part of the injector complex can be found in Ref. 37, 51, 52, and 54.

**Control Selection:**

- ACIS-Area Radiation Monitors (credited) – Area Radiation Monitors tied into ACIS monitor the radiation levels in occupied areas outside shielding structures and will shut down or inhibit beam generation if a radiation trip limit is exceeded, which mitigates consequences to personnel outside shielding structures (Ref. 56).

- LINAC BESOCM - Reduces the maximum average power that leaves the LINAC (Ref. 57).

- Radiation Shielding Management Program – Protects people from accelerator produced radiation by ensuring that the shielding is in place. Shielding reduces the consequence (Ref. 63).
  Software Permissives – Monitors injection efficiency and detects machine conditions outside acceptable limits (Ref. 64).
- Radiation Protection Program – Provides the link between the requirements of 10CFR 835 and its implementation at Argonne (Ref. 21).
- Conduct of Operations – Supports mission success and promotes safety and environmental protection with goal to minimize the likelihood and consequences of technical or organization system failures (Ref. 9, 10, and 11).

**Residual Risk Evaluation: Risk Bin 4 (Negligible Risk)**
With the controls in place the dose is reduced below 0.5 rem. With an Anticipated event, and Negligible consequence all scenarios have a residual risk evaluation of 4 (Negligible Risk)

**Rad-3** – Loss of injected beam inside storage ring vacuum

**Scenario Development:** The electron beam can be lost at any point in the storage ring. This loss can be spread out over a large region or confined to a localized area. Losing the beam in the storage ring produces excess prompt radiation in occupied areas outside the storage ring tunnel (e.g., in the Experiment Hall outside the outboard tunnel wall, in the utility corridor outside the inboard tunnel wall, on the roof/mezzanine of the storage ring tunnel). This scenario assumes that an off-normal fault results in a full power (126 W) injected beam striking the storge ring vacuum.

**Initial Condition Assumptions**

- Safety envelope for injected beam energy and charge(credited) - Engineering and administrative limits to keep energy below 6.3 GeV and the charge per bunch below 20nC.
- Radiation Shielding (credited) – provides shielding that limits dose rates in occupied areas outside shielded structures or enclosures. Concrete blocks were added to Zone F. This reduced the dose rate from an injected beam loss on the swap out dump or vertical collimators.

**Initial Risk Evaluation: Risk Bin 3 (Minor Risk)**
The initial risk evaluation assumes that only the initial condition assumptions are in place. Beam dynamics and steering problems are not unusual, so it is **Anticipated** that the injected beam will be lost at some point around the ring. Initial calculations put the consequence at between 16 mrem and 822 mrem in an hour, this puts the consequence at Negligible or Low, see Table 3-2 for details. Simulations of dose rates were completed at the operating limits (6 GeV beam, and 16 nC/bunch, for a total of 96 W), dose rates were scaled linearly to the Safety Envelope of 126 W.

**Control Selection:**
The following controls were selected to prevent and mitigate the consequences of this scenario:

- ACIS-Area Radiation Monitors (credited) – Area Radiation Monitors tied into ACIS monitor the radiation levels in occupied areas outside shielding structures and will shut down or inhibit beam generation if a radiation trip limit is exceeded, which mitigates consequences to personnel outside shielding structures (Ref. 56).
- Radiation Shielding Management Program(credited) – Protects people from accelerator produced radiation by ensuring that shielding is in place. (Ref 63).
- BTS BESOCM – reduces the maximum average power injected into the storage ring to 12W/hr, which reduces the potential consequences to personnel outside shielding structures (Ref. 65).
- Radiation Protection Program – Provides the link between the requirements of 10CFR 835 and its implementation at Argonne (Ref. 21).
- Conduct of Operations – Supports mission success and promotes safety and environmental protection with goal to minimize the likelihood and consequences of technical or organization system failures (Ref. 9, 10, and 11).

None of these controls limit the frequency of injected beam loss.

**Residual Risk Evaluation: Risk Bin 4 (Negligible Risk)**
With the controls in place the dose is reduced below 0.5 rem. With an Anticipated event, and Negligible consequence all scenarios have a residual risk evaluation of 4 (Negligible Risk)

**Rad-4** – Swap-out safety fault allows injected beam to escape the storage ring

**Scenario Development:** This scenario assumes that a swap-out safety fault allows an electron bunch (20nC pulse) to strike an accelerator or beamline component and direct radiation outside the storage ring.

There are two faults that could result in a swap-out event where an electron bunch injected into the storage ring travels down the front end before striking a component:

- A malfunction or loss of a storage ring bending magnet could allow stored electron bunches to continue straight (rather than bending) and travel down a photon beamline and strike a beamline mask, mirror, or shutter.
- A beam energy mismatch between the booster synchrotron and the storage ring somehow causes an injected electron bunch to travel down a photon beamline. The booster is a ramped machine, and if the extraction comes at the wrong time, the energy may be off (too high) and the injected bunch could somehow travel down a photon beamline.

These faults create the possibility that an electron bunch could travel toward an open beamline and strike a front end component located inside the storage ring shielded enclosure (e.g., crotch absorber at the entrance to a beamline, fixed mask beamline shutter) or travel further down the front end and escape the storage ring shielded enclosure before it strikes a component in the first optics enclosure (e.g., exit mask, mirror). The likelihood of an electron bunch traveling down the front end decreases significantly the further it goes down the front end due to increasing interaction with absorbers, masks, and other front end components and the lower likelihood of trajectories that would allow it to travel further.

Simulations of swap out safety studied the minimum and maximum of electron beam energy (Ref. 66) which could send electrons down a beam line due to errors. Electrons with energy below the operating energy have a smaller bending radius than the storage ring which could increase the electrons probability to travel, down a beamline.

### Initial Condition Assumptions

- Safety envelope for injected beam energy and charge - Engineering and administrative limits to keep energy below 6.3 GeV and the charge per bunch below 20nC.
- Radiation Shielding (credited) – provides shielding that limits dose rates in occupied areas outside shielded structures or enclosures.

### Initial Risk Evaluation: Risk Bin 2 (Marginal Risk)

The initial risk evaluation assumes that only the initial condition assumptions are in place (i.e., Beam Intensity Limits, and immovable shielding structures). Without additional controls, it is **Anticipated** that an electron bunch (20nC pulse) could strike the A:CA1 crotch absorber at the entrance to an open beamline. The likelihood of an electron bunch traveling down the front end decreases significantly the further it goes down the front-end due to increasing interaction with absorbers, masks, and other front end components and the lower likelihood of straighter trajectories that would allow it to travel further. The likelihood of an electron bunch reaching a mirror in the first optic enclosure, the furthest down the beamline is **Extremely Unlikely**. The consequence is calculated as the dose per bunch lost, then multiplied by 3,600 pulses, this assumes that it takes 1 hour for someone to notice that there is no beam injected into the storage ring. The resulting dose rate increases the further down the front end the bunch is able to travel. These consequences range from **Negligible** to **High**, see Table 3.5 for the dose for each loss scenario. Simulations were completed at the operating limits (6 GeV beam, and 16 nC/bunch), dose rates were scaled linearly to the Safety Envelope, 6.3 GeV beam and 20 nC/bunch.

### Control Selection:

The following controls were selected to prevent and mitigate the consequences of this scenario:

- ACIS-Area Radiation Monitors (credited) – Area Radiation Monitors tied into ACIS monitor the radiation levels in occupied areas outside shielding structures and will shut down or inhibit beam generation if a radiation trip limit is exceeded, which mitigates consequences to personnel outside shielding structures. For swap out faults it is assumed it takes 2 minutes (120 pulses) to trip the beam. This is a conservative estimate (Ref. 56).
- Radiation Shielding Management Program – Protects people from accelerator produced radiation by ensuring that shielding is in place. Shielding reduces the consequence (Ref. 63).
- Radiation Protection Program – Provides the link between the requirements of 10CFR 835 and its implementation at Argonne (Ref. 21).

- Stored Beam Interlock – Prevents swap-out injection into the storage ring when there is no stored beam, which reduces the probability of an injected electron beam traveling down an x-ray beamline (Ref. 60).
- Storage Ring A:M1 Dipole Current Interlock – Ensures that A:M1 dipole magnets have adequate magnetic field, which reduces the probability of a swap-out safety fault involving insertion device beamlines (Ref. 60).
- Storage Ring A:M1 Dipole Voltage Interlock – Detects shorted magnets or coils in A:M1 magnet string, which reduces the probability of a swap-out safety fault involving insertion device beamlines (Ref. 60).
- Booster Extraction Fast Interlock (BEFI) – Constrains injected beam energy, which reduces the probability of an energy mismatch that allows the injected electron beam to enter front end or beamline (Ref. 67).
- Software Permissives – Monitors storage ring parameters such as magnet current, vacuum levels, injection efficiency, and first-turn BPM readings to reduce the frequency of swap out faults (Ref. 64).
- Conduct of Operations – Supports mission success and promotes safety and environmental protection with goal to minimize the likelihood and consequences of technical or organization system failures (Ref. 9, 10, and 11).

**Residual Risk Evaluation:**
With the initial condition assumptions and the controls in place, the frequency is reduced to **Extremely Unlikely (EU)** and **Beyond Extremely Unlikely (BEU)**. Consequences still range from **Negligible** to **High**, but by reducing the frequency all the scenarios are a Risk of 3 (Acceptable Risk) and 4 (Negligible Risk).

**Rad-5** – Personnel inside beamline station (FOEs and experiment stations) while x-ray beam is on (ionizing radiation exposure in controlled area)

**Scenario Development:** This is a generic scenario that covers all the x-ray beamlines. This scenario assumes that personnel are in a beamline station when the beam is allowed to enter, or personnel open the door or gain access to a beamline station while the beam is on or present.

**Initial Risk Evaluation: Risk Bin 1 (Unacceptable Risk)**
In addition to providing shielding that limits dose rates outside the beamline stations, the beamline enclosures provide a physical boundary that prevents access to the areas inside except through access doors. Without some type of access controls, it is **Anticipated** that personnel could be inside a beamline station or inadvertently access a beamline station when the beam present. The consequence can vary widely depending on the beamline, where the person is located, the duration of the exposure, etc. However, doses in some areas inside beamline stations could be lethal, which is considered **High** consequences per the criteria in Table 3-2. An anticipated frequency with high consequences results in an initial risk evaluation of **Risk Bin 1** (Unacceptable Risk) based on the criteria in Table 3-3. Therefore, additional controls are required to either prevent (reduce the frequency) or mitigate (reduce the consequence of) this scenario to achieve a risk rank of 3 or 4.

**Control Selection:** The controls that were selected to prevent this scenario are:

- Personnel Safety System (PSS-Access Control Feature – prevents access to beamline stations while the beam is on. Access is prevented by locking the doors, and monitoring devices and interlocks stops or disables beam operation (disables Controlled Equipment) if a locked door is somehow opened or improper access is gained) (Ref. 68). Features of the PSS that directly protect personnel include the door switches, the programmable logic controllers and the beam shutdown buttons.
- Radiation Protection Program – Provides the link between the requirements of 10CFR 835 and its implementation at Argonne (Ref. 21).
- ACIS-Shutter Control – Prevents a beamline from opening an x-ray shutter unless safety measures have been met (Ref. 56).
- Search and Secure Procedure – sweeps beamline stations prior to locking doors and energizing equipment. This is a manual search that works in conjunction with PSS-Access Control Feature, which provides a means to search tunnels and transition from being occupied to a secure state with no personnel inside (Ref. 62).
- Conduct of Operations – Supports mission success and promotes safety and environmental protection with goal to minimize the likelihood and consequences of technical or organization system failures (Ref. 9, 10, and 11).

**Residual Risk Evaluation: Risk Bin 3 (Acceptable Risk)**
With the initial condition assumptions and the controls in place, the frequency is reduced from Anticipated to BEU. Consequences are unchanged since the consequences would still be High if someone were in a beamline station while the beam is on. From Table 3-3, a frequency of BEU with High consequence results in a Risk Bin 3 (Acceptable Risk).

**Rad-6** – Excessive gas bremsstrahlung entering x-ray beamline resulting in excess radiation outside beamline station/beam pipe.

**Scenario Development:** This is a generic scenario that covers all the beamlines. The amount of primary gas bremsstrahlung produced in accelerator systems is a function of the gas pressure in the vacuum chamber. A drop in vacuum level (increase in pressure) in a vacuum chamber results in an increase in bremsstrahlung. This scenario assumes that a drop in vacuum level (increase in pressure) in the storage ring results in increased gas bremsstrahlung entering an x-ray beamline, which results in an increased dose rate outside a beamline station or beam pipe. The drop in vacuum level could be due to outgassing, beam heating of the vacuum chamber, a slow vacuum leak, or other causes. Gas bremsstrahlung produces a narrow primary bremsstrahlung beam traveling down the storage ring that accompanies the synchrotron radiation into the beamline. The dose rate outside a beamline station or beam pipe can vary widely depending on how much the pressure increases, beamline shielding, where the person is located outside the beamline, and the duration of the exposure. This scenario assumes that:

- The worst-case scenario is due to an increase in pressure in a straight section of the electron storage ring that causes an increase in primary bremsstrahlung in a beamline. An increase of pressure in a straight section of the storage ring bounds the bremsstrahlung associated with an increase of pressure in the front end or beamline. A slight increase in the base pressure in the storage ring also bounds more significant loss of vacuum events (e.g., vacuum system breach, beam striking a Burn Through Fixed Mask causing a vacuum breach), which are not as likely and have lower dose consequences because they cause a beam dump and the single burst of radiation results in a smaller dose than an ongoing situation.

- The storage ring is operating at the maximum safety envelope beam energy and current.
- A person is standing outside the FOE for a beamline near a bremsstrahlung stop.

### Initial Condition Assumptions

- Beam Power Limits – limits the beam current and stored beam energy, which limits the intensity of associated radiation fields.
- Radiation Shielding(credited) – provides shielding that limits dose rates in occupied areas outside shielded structures or enclosures.

### Initial Risk Evaluation: Risk Bin 2 (Marginal Risk)

The initial risk evaluation assumes that only the initial condition assumptions are in place (i.e., beam power limits, and Radiation Shielding). An increase in the base pressure in the storage ring due to outgassing, beam heating of the vacuum chamber, a slow vacuum leak, or other initiator is expected from time to time, and excessive gas bremsstrahlung entering an x-ray beamline is considered **Anticipated**. Doses in some area outside an FOE near a bremsstrahlung collimator or stop could fall in the **Moderate** consequence bin per Table 3-2 (between 5 to 25 rem) if there were no additional controls and the event continued for an extended period of time (1 hour). An Anticipated frequency with Moderate consequences results in an initial risk evaluation of Risk Bin 2 (Marginal Risk) based on the criteria in Table 3-3.

**Control Selection:** Based on an initial risk of Risk Bin 2, additional controls are required to prevent or mitigate this scenario.

- ACIS-Area Radiation Monitors(credited) – Area Radiation Monitors tied into ACIS monitor the radiation levels in occupied areas outside shielding structures and will shut down or inhibit beam generation if a radiation trip limit is exceeded, which mitigates consequences to personnel outside shielding structures (Ref. 56).
- Radiation Protection Program – Provides the link between the requirements of 10CFR 835 and its implementation at Argonne (Ref. 21).
- ACIS-Shutter Control – Prevents a beamline from opening an x-ray shutter unless safety measures have been met (Ref. 56).
- Beamline Readiness Review Program – Provides a process that validates the effectiveness of beamline shielding to maximum achievable operating conditions (Ref. 69).
- Conduct of Operations – Supports mission success and promotes safety and environmental protection with goal to minimize the likelihood and consequences of technical or organization system failures (Ref. 9, 10, and 11).

**Residual Risk Evaluation: Risk Bin 4 (Negligible Risk)**
With the initial condition assumptions and controls in place, the consequence is reduced from Moderate to Negligible. Frequency is unchanged. From Table 3-3, a frequency of Anticipated with Negligible consequence results in a Risk Bin 4 (Negligible Risk).

#### 3.2.2.2 Summary of Controls

This section summarizes the Credited Controls selected in Table 3-6 as well as features that provide uncredited layers of protection. These controls apply to normal operations, off-normal conditions, and accident situations.

**Table 3-6. Credited Controls**

| Control / Type | Condition/Requirement/Control | Reason for Credited Control |
|---|---|---|
| ACIS – Access Control Features (Ref. 56, 57, 58, 59, 60)<br>Engineered Active System | ACIS is validated (including meeting surveillance interval) and enforcing Accelerator Enclosure Access requirement | Access Control: ACIS directly protects people by removing an existing hazard if access restrictions are violated. |
| Radiation Shielding<br>Engineered Passive System | Radiation Shielding is maintained in accordance with Radiation Protection Processes and Surveillances. | Radiation Shielding directly protects people by limiting radiation dose from accelerator produced radiation. |
| ACIS – Area Radiation Monitors (Ref. 55)<br>Engineered Active System | Radiation Monitors tied into ACIS are required in accordance with Design. Limits set by Radiation Protection to meet ALARA requirements and Surveillances | Terminates beam operations when excessive radiation is detected, which mitigates consequences to personnel outside shielding structures. |
| Personnel Safety System (PSS) – Access Control Features (Ref. 68)<br>Engineered Active System | Prevents entry into a beamline station when prompt radiation may be present.<br>The PSS – Access Control Features shall meet the following operability criteria:<br>• All beamline enclosures that require frequent, controlled personnel access are protected by the PSS.<br>• Prevents entry into a beamline enclosure when prompt radiation may be present.<br>Shuts down beam when improper access is gained. | Directly protects people by removing an existing hazard if access restrictions are violated. |
| Oxygen Deficiency Monitors with Audio and Visual Alarms. | Requires ODH risk assessment for any proposed installation of use of asphyxiant cryogens or gasses and | While ANL's Worker Safety and Health Program does include ODH, there is sufficient concern regarding |

**Table 3-6. Credited Controls**

| Control / Type | Condition/Requirement/Control | Reason for Credited Control |
|---|---|---|
| | establishes methods for mitigating the hazards.<br>Areas that have been evaluated and determined to have a potential of oxygen concentrations of less than 19.5% oxygen will have fixed oxygen monitors along with visual and audible alarms as required by Argonne's Oxygen Deficiency Program and this Safety Analysis.<br>When a monitor has been reported to be defective and a potential ODH hazard exists access to areas identified as potentially oxygen deficient areas will not be authorized except for qualified emergency response personnel. | ODH throughout the Department of Energy that a conservative safety management approach indicates that ODH is not screened out. |
| Main Control Room Operators / Administrative Requirement | One crew chief or one qualified operator is required to be in the Main Control Room or alternate control position except for intermittent use of restrooms or breakrooms when the accelerator is running reliably. | Minimum personnel to ensure safe operations at the facility. |

Should a permanently installed Area Radiation Monitor failure occur, accelerator beam will be prevented in that accelerator module until the monitor is repaired or replaced with either a temporary or permanent monitor. If the repair introduced a temporary monitor, then the properly functioning permanent monitor should replace the temporary monitor at the earliest opportunity to return the temporary monitor back to a standby position..

Additional uncredited layers of protection are available to further prevent or mitigate off-normal and accidental events. As these controls are important to accelerator safety, they are subject to appropriate configuration management.

**Table 3-7. Uncredited Layers of Protection**

| Control | Function |
|---|---|
| Stored Beam Interlock | Prevents swap-out injection into the storage ring when there is no stored |

**Table 3-7. Uncredited Layers of Protection**

| Control | Function |
|---|---|
| (interlocked with ACIS and BEFI) (Ref. 60)<br>Engineered Active System (Part of swap-out injection safety) | beam, which reduces the probability of an injected electron beam being directed toward an x-ray beamline front-end.<br>Detects the presence of a stored beam in the Storage Ring and sends a "beam permit" signal to the Storage Ring ACIS, which enables swap-out injection (with beamline shutters open) only when stored beam is detected |
| BTS BESOCM (Ref. 65) | Limits average storage ring beam power to 12W averaged over an hour, which further limits consequences of analyzed events. |
| Radiation Protection Program (Ref. 21) | Provides the link between the requirements of 10 CFR 835 and its implementation at Argonne |
| Conduct of Operations (Ref. 9, 10, and 11) | Supports mission success and promotes safety and environmental protection with goal to minimize the likelihood and consequences of technical or organization system failures |
| Storage Ring M1 Dipole Current Interlock (Ref. 60)<br>Engineered Active System (Part of swap-out injection safety) | Restricts the current range in the series-connected A:M1 dipole magnets located between ID sources and ID front ends to reduce the probability (frequency) of possible swap-out faults. |
| Storage Ring A:M1 Dipole Voltage Interlock (Ref. 60)<br>Engineered Active System (Part of swap-out injection safety) | Detects shorted magnets or coils in A:M1 magnet string, which reduces the probability of the electron beam being directed toward an ID beamline front-end. |
| Booster Extraction Fast Interlock (Ref. 67) | Restricts the range of extracted beam energy from the booster synchrotron, which reduces the probability of an energy mismatch between storage ring |

**Table 3-7. Uncredited Layers of Protection**

| Control | Function |
|---|---|
| Engineered Active System<br>(Part of swap-out injection safety) | and injector that could allow the injected electron beam to be directed toward a front end when combined with other faults. |
| Software permissives (Ref. 64)<br>(Part of swap-out injection safety) | Constrains storage ring magnet settings, which further reduces the probability of the injected electron beam being directed toward a front end. |
| Storage Ring Tunnel Search (Ref. 62)<br>Administrative Control (works in conjunction with ACIS – Access Control Features) | Verifies that no one is in a radiation shielding structure or enclosure prior to closing and locking access doors and activating the access control system. |
| Machine protection system/ Beam Position Limit Detectors<br>(part of swap-out injection safety) | Constrains stored beam trajectory, which further reduces the probability of the injected electron beam entering a front end or beamline. |
| Radiation Shielding Management Program (Ref. 15) Administrative System | Shielding management program protects people from accelerator produced radiation by ensuring that the shielding is in place. |

### 3.2.2.3 Detailed Description of Engineered Controls and Administrative Measures

Tables 3-6 and 3-7 list the controls listed in the Accelerator Safety Envelope as well as the Layers of Protection controls that are used to support risk reduction as well as provide assurance for holding the bounding conditions in the Accelerator Safety Envelope.

#### 3.2.2.3.1 ACIS (Access Control and Interlock System)

The APS facility is designed to allow the major systems, i.e., LINAC/PAR, injector synchrotron, LEA, and storage ring, to run independently of one another under specific conditions. This is accomplished by the partitioning of areas with concrete shielding, beam stops and other safeguards. Five complete and independent ACIS implementations, one for the linac-PAR tunnel area, one for the synchrotron tunnel area, one for the LEA tunnel area, one for the rf area of the storage ring (zone-F), and one for the remainder of the storage ring (zones A through E) are provided. Except for the equipment controlled by the ACIS to disable the production of prompt radiation, the number of maze-entry doors, and the number of beam shutdown stations provided for each implementation, the designs are nearly identical.

The ACIS satisfies the following requirements:

- Fail-safe design, so common failures leave the linac, PAR, synchrotron, LEA, and storage ring in a safe, beam-inhibited state.
- Redundant protection, so no single component or subsystem failure renders the accelerator or storage ring systems unsafe, that is, in a beam-permissive state in violation of the ACIS logic.
- Provisions for testing, so that proper component and system functions may periodically be completely verified, as well as demonstrating “end to end” responses for all critical functions.
- Lockout, preventing access to the tunnel area when prompt radiation is potentially present.

The ACIS systems are designed around safety PLC based systems and as noted above is of a fail safe design.

The ACIS incorporates the following equipment:

- Programmable Logic Controllers (PLCs) installed in each chain to perform the system’s decision logic (original ACIS).
- Safety certified Programmable Logic Controller to perform the system’s decision logic (updated ACIS).
- PLC input/output (I/O) modules that interface the PLCs with the switches, lights, locks, relays, and other devices used by the ACIS. Safety certified I/O modules used for all safety functions in the update ACIS.
- Uninterruptible power supplies (UPSs), some centralized and some dedicated to ACIS equipment, to protect against short-term AC power loss.

- Control panels and status displays.
- Maze door hardware (status switches, magnetic locks, emergency exit crash bars, emergency entry buttons, and status message displays).
- Ratchet and super door status switches, augmented with administrative Kirk-key-type locks.
- Controlled access key banks.
- Beam shutdown stations (BSSs) installed in the linac/PAR, LEA, synchrotron, and storage ring tunnels and outside the maze doors of these tunnel areas.
- Beam stop mechanism installed in the low energy transport (LET) beamlines between the PAR and the synchrotron (PtB), a triple-block beam stop installed between the PAR and the synchrotron.
- Radiation stop mechanisms installed in the booster bypass beamline between the synchrotron tunnel and the LEA tunnel (BTL) and between the linac and the LEA (LTL).
- Radiation stop mechanisms installed in the high energy transport (HET) beamline between the synchrotron and storage ring.
- Interlocked beam current transformer systems which measure linac-accelerated beams.
- Interlocked beam current detectors which monitor stored beam current.
- Interlocked RG2 α magnet current monitors to disable guns while RG2 α magnet is ramping during Interleaving mode.
- Visible and audible warning indicators.
- Radiation monitors to sense gamma and neutron radiation levels located in the klystron gallery and outside the PAR, synchrotron, LEA, and storage ring tunnel areas.
- Interfaces to the linac's electron gun and klystron systems and to the PAR, synchrotron, and storage ring main dipole power supplies and rf systems.
- Interfaces to the rf waveguide shutters in the rf building.
- Interfaces to the booster bypass beamline vertical-bend magnet and the horizontal switch magnet, which is the magnet used to transport beam to the LEA.

- Interface to alpha magnet current levels
- Interface to gate valve position statuses
- Equipment racks, conduit, cable trays, and cables (multiconductor and fiber optic).

All ACIS circuits and subsystems are designed to be fail-safe. That is, failures due to loss of a power supply, loss of a UPS, disconnected interface connectors, open field component wiring, open relay coils or contacts (either in the ACIS or the affected controlled-equipment), open communication wiring, missing controlled-equipment connectors, missing I/O modules, or halted PLC program execution, will cause the controlled linac/PAR, synchrotron or storage ring systems to be disabled and a beam shutdown to occur. The ACIS is not fault-tolerant in that it will not continue to enable equipment operation in the presence of faults.

#### 3.2.2.3.2 Radiation Shielding

The shielding design for the APS accelerators was based on conservative assumptions. Consideration of several types of operations that involve normal beam loss mechanisms as well as certain abnormal beam loss scenarios were included in the shielding calculations. The scenarios applied were drawn from experiences and assumptions used at other accelerator and synchrotron radiation facilities throughout the world, as well as a walk-down of the APS injector components. The shielding calculations were based on well-known modeling formulas (Moe 1991) and accepted attenuation characteristics. Machine codes, such as EGS4, have been used to verify that the results from the modeling are appropriately conservative (Moe 1994).

The shielding requirements are satisfied by using standard and dense concrete for immovable shielding to ensure adequate attenuation of the bremsstrahlung, giant resonance neutrons, and the high-energy hadronic component produced in the particle-photon showers. The concrete is supplemented by earth berms, steel, lead, dense polyethylene, and castable shielding mixtures to reinforce the shielding at localized regions of high radiation.

X-ray beamline structures are are constructed from panels where lead is sandwiched between two steel skins. The panels are permanently affixed together to create enclosures. Door openings and shielded doors are provided for personnel access. X-ray beam transport on the experiment hall floor is provided through vacuum transport pipes that are also shielded.
All shielding criteria stem from DOE requirements. Argonne’s shielding policy is stated in LMS-PROC-339. Radiation shielding also contains all shielding which is not part of the immovable shielding infrastructure. Typically, this shielding involves static shielding such as stacks of lead bricks and concrete, but the program tracks all shielding that is is under the formal configuration management program.

Each shield is tagged with a Configuration Control tag and the shielding is tracked through both the Radiation Protection Program and the Experimental Facilities Operations Group. The data is held formally by the Radiation Protection Program with support from the APS. Prior to the startup of each accelerator and each beamline, the approved shielding is verified to be in place.

Shielding is subject to the configuration management program and beam is approved to be present in an area where the shielding is providing protection.

### 3.2.2.3.3 ACIS – Area Radiation Monitors

In order to protect against off-normal losses in the injector complex. A series of commercial gamma and neutron detectors are distributed around the accelerator complex. These detectors are positioned in places which will detect off normal events and trigger a shutdown of the beam. The detectors and their setpoints are maintained by the Radiation Protection Program. The detectors are tied directly into the ACIS system for the machine that they are protecting.

**Table 3-8 Area Radiation Monitor Locations**

| **Monitor** | **Location** | **Interface** | **Gamma Probe Limit (mRem/hr)** | **Neutron Probe Limit (mRem/hr)** |
|---|---|---|---|---|
| 1 BM through 34 BM (FHT-6020) | Electronics are located in the xx-01 Mezzanine rack above the BM beamline's ratchet door. Remote alarm indicators are located adjacent to BM ratchet door. | Sector 1 through 34 ASIEs | 1.0 | 1.0 |
| 1 ID through 33 ID (ADM-610) | Experimental floor near the exit port of the ID beamlines | Sector 2 through 34 ASIEs | 1.0 | 1.0 |
| F1 (ADM-610) | Gate F | A005 Rack 3 (Ignored when Zone F and the Storage Ring are secure) | 10.0 | N/A |
| F2 (ADM-610) | Maze Door F | A005 Rack 3 | 3.0 | 3.0 |
| 34ID (ADM-610) | 34 ID | Sector 35 ASIE (Ignored when the Storage Ring is not secure) | 1.0 | 1.0 |
| 35BM | 35BM | Sector 35 ASIE | 1.0 | 1.0 |

| | | | | |
|---|---|---|---|---|
| (FHT-6020) | | | | |
| 38AD (FHT-6020) | 35 ID Inst. Room | Sector 36 Enc. | 1.0 | 1.0 |
| F3 (FHT-6020) | 35ID-A door | Sector 36 Enc. | 1.0 | 1.0 |
| F4 (FHT-6020) | 35 ID shop | Sector 36 Enc. | 1.0 | 1.0 |
| F5 (ADM-610) | Column 53 EAA | Sector 36 Enc. | 3.0 | 3.0 |
| F6 (ADM-610) | Column 55.5 EAA | Sector 36 Enc. | 3.0 | 3.0 |
| F7 (FHT-6020) | Mezzanine above Septum | | 10.0 | 10.0 |
| F8 (ADM-610) | Column 56 EAA | Sector 36 Enc. | 3.0 | 3.0 |
| F9 (FHT-6020) | Column 56 mezzanine | Sector 36 Enc. | 10.0 | 10.0 |
| F10 (ADM-610) | Gate A | A005 Rack 3 (Ignored when Zone F and the Storage Ring are secure) | 10.0 | N/A |
| F11 (FHT-6020) | Column 58 EAA | Sector 36 Enc. | 1.0 | 1.0 |
| F12 (FHT-6020) | Column 59 EAA | Sector 36 Enc. | 1.0 | 1.0 |
| F13 (ADM-610) | optics shop | Sector 36 Enc. | 3.0 | 3.0 |
| Above and aside the concrete shielding in Buildings 412 and 420 (Booster) (ADM-610) | | | 10.0 | 3.0 |
| Booster downstream radiation enclosure (ADM-610) | | | 10.0 | 3.0 |
| LEA downstream radiation enclosure (ADM-610) | | | 10.0 | 3.0 |

| | | | | |
|---|---|---|---|---|
| In the LEA end station building (ADM-610) | | | 10.0 | 3.0 |
| Within the LEA Tunnel – upstream end (ADM-610) | | | 10.0 | 3.0 |

Each radiation monitor has a different setpoint value based on its location around the accelerator. Set points for the ADM-610 and FHT-6020 radiation monitors are in Table 1 of Ref. 70 and Ref. 71 respectively. These setpoints are the same as the above table. The values indicated are standard values to be used during normal beam operations for x-ray beam delivery to the Experiment Hall Floor.

Higher setpoints to a maximum of 1 Rem/hr combined gamma/neutron may be applied during studies or commissioning periods while there is support from the Radiation Protection Program including monitoring and any additional required controls to ensure the protection of personnel. Setpoint changes are at the discretion of the Radiation Protection Program. Setpoints are required to be adjusted back to their standard values after the study/commissioning period is complete.

#### 3.2.2.3.4 Personnel Safety System

The APS has the potential of operating with up to 70 beamlines. Each beamline includes multiple shielded enclosures containing optics and experimental equipment. Personnel access into these enclosures will be controlled during beamline operation. The APS Personnel Safety System (PSS) is the engineered safety system for each beamline for controlling access into the enclosures, ensuring that access is allowed only under safe conditions (i.e., beam is off in the enclosure), and to disable storage ring operation if improper access is gained or a PSS system fault is detected that could potentially endanger personnel. The PSS system enables and operates the beamline shutters which brings x-rays into the experimental enclosures.

The PSS for each beamline interfaces directly with the accelerators Access Control and Interlock System (ACIS) for disabling storage-ring operation. Each PSS is totally isolated from the PSS of any other beamline to prevent a fault from one beamline affecting the operation of other beamlines.

Each PSS is designed by APS staff to meet the requirements of the beamline after review and concurrence by the Photon Sciences Design Review Committee and approval by APS management. APS staff are responsible for the installation, verification, validation, and maintenance of the system. Although beamline designs require some flexibility in possible modes of operation, types of devices to be interlocked, and other operational requirements, the basic configuration and control aspects remain the same. Custom control panels are designed to incorporate any special features. The system documentation, test procedures, and training include all basic as well as specialized equipment and operating modes.

Each beamline PSS employs two independent Emergency Shutdown chains, referred to below as Chain A and Chain B, providing safety system redundancy. The PSS incorporates the following equipment:

- Programmable Logic Controllers (PLCs) installed in each chain to perform the system's decision logic.
- PLC input/output (I/O) modules which interface the PLCs with the switches, lights, locks, relays, and other devices used by the PSS.
- Centralized Uninterruptible power supplies (UPSs), to protect against short-term AC power loss.
- Control panels and status displays.
- Station door hardware (status switches, locking mechanisms).
- Station search-and-secure hardware (search buttons, visible and audible warning indicators, emergency shutdown buttons).
- Interfaces to beam shutdown safety devices, such as front-end or beamline safety shutters and photon shutters (position-indicating switches and position-controlling solenoids).
- Interfaces to the ACIS, the Front-End Equipment Protection System (FEEPS), the Beamline Equipment Protection System (BLEPS), and the Experimental Physics and Industrial Control System (EPICS)
- Dedicated equipment racks, conduit, cable trays, and cables.

#### 3.2.2.3.4 Oxygen Deficiency Monitors Combined with Signage and Audio Visual Alarms (ODM)

The APS ODM provides monitoring and audio and visual alarms in areas where atmospheric oxygen levels are less than 19.5% $O^2$.

The system is made of commercially available Oxygen Monitors installed in areas that the potential for oxygen deficiency requires mitigation in accordance with Argonne National Laboratory’s Oxygen Deficiency Hazard Manual (LMS-MNL-19). The system is installed and operated in accordance with the manufactures instructions.

The system incorporates the following equipment:

- An Oxygen Deficiency Monitor
- Remote sensor(s)
- Remote horn strobe units in locations where there are multiple entrances to an area

#### 3.2.2.3.4 Administrative Procedures

The administrative processes for safe operations are contained in the Conduct of Operations Manuals of the Photon Sciences Directorate (PSC) [Ref 9,10,11] a PSC wide Conduct of Operations manual defines administrative processes and flows down administrative requirements into procedures. Two more specific Conduct of Operations manuals define activity level processes for the accelerator complex (through the Main Control Room Conduct of Operations) and the Experiment Hall Floor. The MCR and the EFOG conduct of operations manuals designate procedures for beam authorization and as well as configuration control of systems important to accelerator safety.

#### 3.2.2.4 Safety Analysis Conclusions

The APS is a complex, high-energy synchrotron radiation facility. The hazards associated with APS facilities and operations primarily affect the immediate work area or the facility. The safety analysis shows that unmitigated consequences from certain off-normal or accidental events could have significant consequences to personnel (facility workers and users) in the immediate work area or the facility. Off-normal or accidental events pose minor or negligible consequences outside the immediate work area or facility boundary, and negligible to no offsite impacts.

The SAD identifies the controls that make a contribution to reducing risk to an acceptable level. The APS safety envelope consists of the Credited Controls listed in Table 3-6, which include shielding, and access controls. These controls are carried forward to the separate Accelerator Safety Envelope (ASE) document (Ref. 1), which formally defines the APS safety envelope. Note that the operating envelope is set below the bounding conditions that are part of the safety envelope.

The safety analysis shows, with reasonable assurance, that the safety envelope defined by the SAD provides adequate protection for facility workers and users, the public, and the environment for continuing APS operations. All risks have been reduced to acceptable levels through limits on operations (beam intensity limits) and other controls (e.g., shielding, access controls, and shutdown systems).

# 4. SAFETY MANAGEMENT PROGRAMS

This chapter describes key Safety Management Programs (SMPs) that are relied upon to ensure safety of workers, the public, and the environment.

Operations at the APS are performed in accordance with Safety Management Programs (SMPs) that provide formal, disciplined, and consistent methods for conducting activities with the purpose of ensuring safe operation of the facility. Hazards listed in Table 3-4 that were screened from further evaluation are managed in accordance with national consensus codes and standards that are implemented through Safety Management Programs. The key Safety Management Programs that are relied upon to manage the hazards associated with operations at the APS are summarized below. The SMPs provide the basic infrastructure relied upon for worker safety and the safety envelope assumes that the safety infrastructure provided by the SMPs exists.

The following SMPs shall be established, implemented, and maintained:

## 4.1 INTEGRATED SAFETY MANAGEMENT SYSTEM / WORKER SAFETY AND HEALTH PROGRAM (INTEGRATED SAFETY MANAGEMENT SYSTEM/WORKER SAFETY AND HEALTH PROGRAM DESCRIPTION [REF. 24])

The national Worker Safety and Health Program, 10 CFR 851 (Ref. 72) outlines the requirements for a worker safety and health program to ensure that DOE contractors and their workers operate a safe workplace. The Argonne Integrated Safety Management System (ISMS)/Worker Safety and Health Program complies with the requirements in 10 CFR 851 and provides a formal approach to integrating all existing safety requirements into one coordinated program. The Integrated Safety Management System (ISMS) forms the foundation of the Safety Management Programs and is a formal approach to integrating all existing safety requirements into one coordinated program. ISMS requires processes and operations to be examined for hazards so that controls can be proactively instituted to manage risks inherent to the facility mission. The core functions of ISMS are:

1. define the scope of work,
2. analyze the hazards,
3. develop and implement hazards controls,
4. perform the work within the controls, and
5. provide feedback for continuous improvement.

In conjunction with ISMS principles, the Worker Safety and Health Program (WSHP) manages many workplace hazards associated with operational and maintenance activities, including:

- Lead Safety (APS_1201511, APS Lead Handling [Ref. 25], and LMS-PROC-201, Safe Handling of Lead [Ref. 26])
- Chemical Safety (LMS-PROC-236, Laboratory Chemical Hygiene Plan [Ref. 27])
- Laser Safety (LMS-PROC-285, Laser Safety [Ref. 33])
- RF Power System Safety (LMS-PROC-233, Radiofrequency and Microwave Fields [Ref. 42])
- Magnetic Safety (LMS-PROC-234, Electric and Magnetic Fields [Ref. 43])
- Pressure Safety (*Argonne Pressure Safety Manual*, LMS-MNL-13 [Ref. 73])
- Compressed Gas Cylinder Safety (*Argonne Pressure Safety Manual*, LMS-MNL-13 [Ref. 73])
- Radioactive Samples (APS_1187383, Radioactive Samples [Ref. 48])
- Biological Safety (LMS-PROC-128, Working with Biological Materials, and Argonne Biosafety Manual [Ref. 74])
- Hoisting and Rigging Safety (LMS-MNL-12, Hoisting and Rigging [Ref. 23])

## 4.2 UNREVIEWED SAFETY ISSUE PROCESS (LMS-PROC-383, FACILITY-SPECIFIC IMPLEMENTATION OF UNREVIEWED SAFETY ISSUE (USI) PROCEDURE)

The Unreviewed Safety Issue (USI) Process is not strictly a safety management program, however a USI Process must be implemented as part of the accelerator safety programs per DOE O 420.2D and DOE G 420.2-1A. The USI Process either screens out or evaluates changes to documents, systems, structures, components, and activities at APS. Changes that do not screen out are evaluated using an Unreviewed Safety Issue Evaluation to determine if the changes significantly affect the safety of the accelerator facility and require DOE approval. Configuration Management processes are used as a tool to direct significant changes in documentation, systems, or components to the USI Process. The USI Process also evaluates discovered conditions that impact safety. The USI Process also supports Configuration Management efforts to ensure that safety documentation is periodically updated as necessary to be consistent with the actual facility configuration, procedures, or activities.

APS follows Argonne’s site-wide USI Process (LMS-PROC-383, Ref. 75), which allows facility-specific screening criteria to be provided or referenced within the Safety Assessment Document. The APS-specific USI screening criteria are listed below:

1. Does the proposed activity or discovered condition temporarily or permanently modify or change the configuration of the following systems/components from that described or relied upon in the SAD (not including routine maintenance that restores a system/component to its original condition)?
    a. Radiation Shielding Structures (Accelerators and Beamlines)
    b. ACIS – Access Control Features
    c. ACIS – Tunnel key access switch
    d. ACIS – Area Radiation Monitors
    e. ACIS - Shutters
    f. Stored Beam Monitor (or interlock with ACIS)
    g. PSS – Access Control Features
2. Does the proposed activity or discovered condition temporarily or permanently change how the safety function of the following systems/components is performed (e.g., different materials, different logic, different interfaces)?
    a. Radiation Shielding Structures (Accelerators and Beamlines)
    b. ACIS – Access Control Features
    c. ACIS – Tunnel key access switch
    d. ACIS – Area Radiation Monitors
    e. ACIS - Shutters
    f. Stored Beam Monitor (or interlock with ACIS)
    g. PSS – Access Control Features
3. Does the proposed activity or discovered condition change or modify the following procedures (not including minor or administrative changes that do not change the intent or process for performing the procedure)?
    a. Search and Secure Procedure
    b. Radiation Shielding Control

4. Does the proposed activity or discovered condition introduce new hazards that are not adequately addressed by the current SAD and approved ASE? In other words, are there any hazards associated with the proposed activity or discovered condition that are not covered by one of the following:
    a. A Safety Management Program described in Section 4 of the SAD adequately guides safe design and operational practices to adequately manage the hazard. (Industrial Hazards)
    b. The Safety Analysis in Chapter 3 of the SAD considered the hazard and identifies controls that adequately manage the hazard. (Accelerator Specific Hazards)
5. Does the proposed activity or discovered condition have the potential to meet or exceed the bounding conditions in the ASE? (Beam Intensity Limits and other controls)

If the answers to the questions above are all “No,” the proposed activity screens out and a USI Evaluation does not need to be performed.

## 4.3 RADIOLOGICAL PROTECTION PROGRAM (ARGONNE NATIONAL LABORATORY RADIOLOGICAL PROTECTION PROGRAM [REF. 21])

The Radiological Protection Program implements the occupational radiation protection requirements of 10 CFR 835, *Occupational Radiation Protection* (Ref. 76). The Radiological Protection Program includes the following programmatic elements:

- defines roles and responsibilities for radiation protection;
- establishes requirements for radiation protection training;
- provides policies and procedures to maintain radiation exposures As Low As Reasonably Achievable (ALARA), including:
    - ALARA Committees that assists with workplace controls; and
    - ALARA Committees that review new facility designs and facility modifications to ensure that facility designs meet Argonne’s ALARA program and Argonne’s shielding policy (see LMS-PROC-339) .
- establishes radiological monitoring requirements (e.g., dose rate surveys and contamination surveys), posting requirements, and access controls;
- develops Radiological Work Permits (RWPs), including control limits, training requirements, personal protective equipment, engineering controls, dosimetry, Health Physics coverage, and radiological practices aimed at optimizing worker protection;
- establishes requirements for surveying and managing potentially activated materials;
- establishes requirements for radiological protection instrumentation;
- establishes a program for maintaining radiological records;
- monitors occupational radiation exposures; and
- establishes a sealed-source control program.

## 4.4 RADIOACTIVE MATERIAL INVENTORY MANAGEMENT (LMS-PROC-45, MANAGING RADIOACTIVE MATERIAL INVENTORIES [REF. 38], AND APS_1410269, RADIOACTIVE MATERIAL USE AT THE APS)

APS tracks radioactive materials, including check sources and radioactive material brought in by researchers, in accordance with APS_1410269 (Ref. 77) and LMS-PROC-45 (Ref. 38) using the CURIE database. The CURIE database calculates the Hazard Category 3 Sum of Fractions

(HC3-SOF) values using the “sum of the ratios” methodology described in DOE-STD-1027-2018 (Ref. 39) using the revised threshold quantities in NWM-CALC-2014-002 (Ref. 40). The APS has an Administrative Control Limit of 0.01 HC3-SOF. Limiting the amount of radioactive material in the facility constrains the potential consequences of a bounding radioactive material release.

APS also tracks fissionable materials for criticality control purposes in accordance with LMS-PROC-45 (Ref. 38) using the CURIE database. The CURIE database calculates Pu239 Fissile Gram Equivalent (Pu239-FGE) values as described in Exhibit A of LMS-PROC-45. The APS has an Administrative Control Limit of 10.0 Pu239-FGE. As of 5/18/2020, the fissionable material inventory at APS was 0.1 Pu239-FGE. Limiting the amount of fissionable material in the facility prevents a criticality.

## 4.5 QUALITY ASSURANCE PROGRAM (ARGONNE NATIONAL LABORATORY QUALITY ASSURANCE PROGRAM PLAN)

The Quality Assurance (QA)(Ref. 78) Program ensures that projects adhere to applicable requirements and procedures through audits, assessments, and surveillances. Issues are identified, graded, tracked, corrected, and evaluated for trends so that recurrence is avoided and performance can be improved.

The Quality Assurance Program includes the following programmatic elements:

- identifies the principles, requirements, and practices used to establish, implement, and maintain an effective Quality Assurance Program, including:
  - Organizational structure and management processes
  - Personnel training and qualification
  - Identification, control, tracking and correction of issues
  - Document control and records management
  - Work planning and control
  - Design change control
  - Procurement control
  - Inspection and acceptance testing
  - Assessments
  - Software management and software quality assurance
- performs or ensures performance of audits, management assessments, and surveillances as part of the process to ensure:
  - compliance with applicable laws, regulations, national standards, DOE directives and requirements, and other contractually mandated requirements;
  - adherence to Argonne policies, procedures, processes, and work control documents; and
  - readiness to perform Accelerator Readiness Reviews.
- implements a corrective action program to ensure that appropriate corrective actions are identified to rectify issues or deficiencies, provide mechanisms for tracking issues to closure, and provide assurance that corrective actions are completed; and

- controls and maintains documents and records important to maintaining a viable QA program.

## 4.6 FIRE PROTECTION PROGRAM (ARGONNE NATIONAL LABORATORY FIRE PROTECTION PROGRAM DESCRIPTION [REF. 45])

The Argonne Fire Protection Program identifies the requirements for a comprehensive fire safety and emergency response program to protect workers and minimize property loss commensurate with the nature of the work that is performed. The Fire Protection Program maintains the fire prevention and fire control measures outlined below for the protection of personnel and facilities.

Fire Prevention:

- Combustible/flammable material control program;
- Facility inspections and resolution of findings; and
- Oversight of open flame/spark operations (through open flame permits).

Fire Control:

- Fire protection systems (sprinklers and fire alarm systems);
- Testing of fire protection systems;
- Fire Department response;
- Pre-fire plans and fire ground management; and
- Fire barriers and opening protectives (e.g., fire doors and fire dampers).

The Fire Protection Program includes the following programmatic elements:

- defines roles and responsibilities for fire protection including major organizational interfaces;
- establishes requirements for fire protection training;
- evaluates fire hazards for each facility;
- establishes applicable fire protection requirements, including fire barriers, automatic sprinkler systems, fire detection and alarm systems, egress paths, and emergency lighting;
- establishes and maintains an Argonne Fire Department to facilitate prompt and effective emergency response;
- establishes and maintains water supply systems to provide adequate flow to installed sprinkler systems, hose stations, and fire hydrants to fight facility fires;
- establishes requirements for inspecting and configuration control of fire barriers, including penetrations and doors that are part of the fire barriers;
- establishes requirements for controlling open flame and spark producing activities;
- establishes requirements for a combustible/flammable material control program;
- ensures that personnel egress routes are properly identified and maintained, and emergency lighting is available;
- reviews and approves fire protection system impairments and associated compensatory measures;

- maintains surveillance and maintenance programs to ensure high availability and reliability of fire protection systems, including portable fire extinguisher inspection, testing, and servicing.

## 4.7 CRYOGENIC LIQUID SAFETY PROGRAM (LMS-PROC-331, CRYOGENIC LIQUID SAFETY [REF. 28]

The *Argonne Cryogenic Liquid Safety Procedure* establishes the process for using cryogenic liquids. Programmatic elements include:

- Pressure system design and overpressure protection.
- Fabrication, testing, inspection, maintenance, repair, and operation of cryogenic systems.
- Onsite transportation of cryogenic liquids.
- Use of dewar carts, use of cryogenic liquids, and use of fill stations.
- PPE and managing cryogenic liquid hazards, oxygen deficiency hazards, flammability hazards, and explosion hazards.

## 4.8 OXYGEN DEFICIENCY HAZARD PROGRAM (LMS-MNL-19, OXYGEN DEFICIENCY HAZARDS [REF. 19])

The Oxygen Deficiency Hazard (ODH) Program establishes the process for identifying and controlling oxygen deficiency hazards. Programmatic elements include:

- Prepare an ODH Risk Assessment when necessary for areas with asphyxiant cryogenic systems or gases (piped or stored), including ODH calculations to estimate oxygen concentrations and determine the ODH hazard severity.
- Establish engineered controls as necessary to prevent or mitigate unacceptable oxygen deficiency levels, such as release prevention devices, release minimization devices, ventilation systems, permanently installed or portable oxygen monitors, and ODH alarms. This includes periodically verifying that the engineered controls are working properly and/or calibrated.
- Establish controls for limited egress areas, such as training requirements, buddy rule, 3 man rule/unexposed observer, 2-way communications, and self-contained emergency escape respirators.
- Establish signage and notification requirements, and guidance for responding to unplanned events.

## 4.9 ELECTRICAL SAFETY PROGRAM (ARGONNE ELECTRICAL SAFETY MANUAL [REF. 20])

The Electrical Safety Manual establishes the minimum requirements for identifying and controlling electrical hazards to prevent fatalities and injuries to personnel from hazardous electrical energy. It works in conjunction with Integrated Safety Management System (ISMS) to safely work on or around electrical equipment. Programmatic elements include:

- Establishing electrical system installation requirements. Electrical systems must be designed and installed in accordance with applicable codes and standards. Electrical equipment must either be listed by a Nationally Recognized Testing Laboratory (e.g., Underwriters Laboratories (UL), Factory Mutual, NSF International) or evaluated and approved for use by a Designated Electrical Equipment Inspector (DEEI).

- Establishing electrical safe work practices at Argonne. Electrical repair work must be performed deenergized and in an electrically safe work condition unless approved through an Energized Electrical Work Permit. Electrical work must be performed only by qualified and approved electrical workers, with approved tools/equipment and PPE, using the electrical safe work practices outlined in this program (e.g., Lock Out/Tag Out, Zero Voltage Verification, Shock Protection, Arc Flash Protection, etc.).
- Establishing electrical inspection and maintenance requirements.
- Establishing electrical training requirements.
- Maintaining an Electrical Safety Committee (ESC) that supports implementation of Argonne's electrical safety program and provides overarching guidance for the electrical safety program.

## 4.10 WASTE MANAGEMENT PROGRAM (WM-PP-01, WASTE MANAGEMENT PROGRAM PLAN [REF. 22])

The Waste Management Program is executed by the Waste Management Department in Argonne's Nuclear and Waste Management Division. The Waste Management Program establishes the processes and practices required to generate, document, stage/store, characterize, package, and ship hazardous and radioactive waste in accordance with applicable regulations to protect workers, the public, and the environment. Waste Management policies, plans, and procedures are established and maintained to implement applicable requirements, regulations, and standards. Waste Management is a site-wide organization that provides the services necessary to compliantly manage and ship hazardous, radioactive, and mixed wastes while ensuring the health and safety of Argonne personnel and the public.

## 4.11 CONDUCT OF OPERATIONS (APS_1275680, CONDUCT OF OPERATIONS APPLICABILITY MATRIX, AND CONDUCT OF OPERATIONS MANUALS [REF. 9, 10, AND 11])

The Conduct of Operations Program (Ref. 79) provides a disciplined and formal method for safely performing work and ensuring quality and uniformity of operational activities. The program is based on the concept that workers are provided with adequate knowledge of requirements and are disciplined in observing these requirements. The Conduct of Operations Program includes the following programmatic elements:

- Workers performing safety-related activities are trained and qualified (when required) and have adequate knowledge of requirements. Training is tracked through Argonne's TMS System (Ref. 80).
- Procedures are developed, reviewed, validated, and approved for conducting normal, abnormal, and emergency operations (APS_1001409, Managing APS Facility Procedures [Ref. 81]).
- Document Control practices ensure that the latest versions of procedures are used, and that records are retained and disposed of in a systematic fashion.
- Operations are performed in accordance with formal and controlled procedures, and personnel are disciplined in performing the activities in accordance with procedures.

- Activity-level work activities (e.g., maintenance activities, changes to the facility) are performed in accordance with a Work Control Program that defines the scope of work, analyzes the hazards, develops hazard controls, and ensures that the work is carried out in accordance with applicable requirements (LMS-MNL-10, Work Planning and Control [Ref. 82, 83]).
- The status of equipment and systems is tracked and controlled.
- Abnormal events, conditions, and trends are investigated.

## 4.12 CONFIGURATION MANAGEMENT (APS_1693025, APS CONFIGURATION MANAGEMENT PLAN)

The Configuration Management Program (Ref. 84) establishes requirements for managing and controlling the configuration of systems, structures, and components, with specific emphasis on accelerator, beamline, and support systems related to safety. Configuration Management ensures that the physical and functional characteristics of the systems, structures, and components are consistent with the design and administrative requirements and are properly identified, controlled, and incorporated into facility documentation. Configuration Management is not so much a separate Safety Management Program as a way of doing business that integrates other programs (e.g., work control, engineering design, and document control) to ensure that the following are consistent with each other:

- physical configuration (including actual physical configuration and work control documents that change the physical configuration).
- design documentation (including engineering analysis, design specifications, as-built drawings, eTravelers, and Component Database (CDB) for safety-related systems).
- facility documentation (including the SAD/ASE, operating procedures, and other controlled documents).

## 4.13 EXPERIMENT SAFETY REVIEWS (APS_1187022, APS EXPERIMENT SAFETY REVIEWS [REF. 13])

The Experiment Safety Review process ensures that a safe work environment is maintained while performing experiments at APS. This process applies to APS staff and non-APS researchers performing experiments on x-ray beamlines and other experimental facilities (e.g., laboratories) at APS. All users must meet applicable APS and Argonne requirements and procedures for safely performing their experiments and associated activities at the APS. Elements of this process include:

- Researchers log into an APS web-based system and define the scope of their experimental activities on an Experiment Safety Assessment Form (ESAF). The researchers must identify the material, equipment, processes, and hazards associated with the experiment.
- Once the ESAF is submitted, it automatically generates an Experiment Hazard Control Plan (EHCP) that identifies all controls required to mitigate the hazards to an acceptable risk level for the scope of work in the experiment.
- The EHCP is reviewed by Experiment Operations Management for the beamline or the laboratory where the experiment is to be conducted and the APS Experiment Safety

Review Board (ESRB) or ESH Coordinator. The EHCP is reviewed for consistency with anticipated hazards for the experiment and consistency of the safeguards with APS and Argonne requirements and procedures.

- Elements of the hazard analysis and selection of controls include: following requirements of beamline-specific ESH programs, design and readiness reviews of experimental facilities constructed by or for users, analysis of each experiment for hazards and controls, ensuring that the risks of activities are mitigated to levels acceptable to APS/Argonne, required registration of users with the APS, and that users complete APS/Argonne-provided safety training tailored to their activities.
- Once the EHCP is approved:
  - The experimenter must verify that EHCP accurately identifies all material, equipment, and activities.
  - Personnel designated in the EHCP must verify that the specified controls, training, and safeguards are in place.
  - APS Floor Coordinator authorizes the experiment to proceed.
  - Experimenters conduct experiment in accordance with the EHCP.

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