APS-3.3.2.1.0

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

ADVANCED PHOTON SOURCE
EXPERIMENTAL BEAMLINE
SAFETY ASSESSMENT DOCUMENT

ADDENDUM TO THE
ADVANCED PHOTON SOURCE
ACCELERATOR SYSTEMS
SAFETY ASSESSMENT DOCUMENT
(APS-3.2.2.1.0)

January 1995

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ABSTRACT

This Safety Assessment Document (SAD) addresses commissioning and operation of the experimental beamlines at the Advanced Photon Source (APS). The purpose of this document is to identify and describe the hazards associated with commissioning and operation of these beamlines and to document the measures taken to minimize these hazards and mitigate the hazard consequences.

The potential hazards associated with the commissioning and operation of the APS facility have been carefully identified and analyzed. Physical and administrative controls mitigate identified hazards. No hazard exists in this facility that has not been previously encountered and successfully mitigated in other accelerator and synchrotron radiation research facilities. This document is an updated version of the APS Preliminary Safety Analysis Report (PSAR). During the review of the PSAR in February 1990, the APS was determined to be a Low Hazard Facility. On June 14, 1993, the Acting Director of the Office of Energy Research endorsed the designation of the APS as a Low Hazard Facility, and this Safety Assessment Document supports that designation.

This document is an addendum to the APS Accelerator Systems Safety Assessment Document (APS-3.2.2.1.0 Rev.1).

1.0 INTRODUCTION

1.1 Objective of Document

This Safety Assessment Document (SAD) covers the Advanced Photon Source (APS) experimental beamlines. It is an addendum to the APS Accelerator Systems Safety Assessment Document (ANL 1994a). The APS Accelerator Systems SAD was approved by the Laboratory Director and the APS Accelerator Systems Safety Envelope was approved by the U. S. Department of Energy (DOE) in January 1995.

This document has been prepared in accordance with the DOE Order 5480.25, "Safety of Accelerator Facilities" (DOE 1992b). The document provides the results of a systematic effort to identify the hazards associated with the commissioning and operation of the APS experimental beamlines, and it describes the measures taken to control and/or mitigate these hazards. The document evaluates the probability, risk, and potential consequences posed by the APS experimental beamlines to the public, facility workers, and the environment. It addresses both normal and abnormal operating conditions. The SAD also defines the safety envelopes for the APS experimental beamlines. The purpose of this SAD is to demonstrate that the hazards posed by the APS experimental beamlines functioning at the safety envelope are acceptable and in compliance with existing applicable U.S. Department of Energy (DOE) Orders and guidelines and statutes of the State of Illinois.

1.2 Advanced Photon Source Facility Description

The Advanced Photon Source is designed to be a major national user facility providing high-brilliance x-ray beams for users from Argonne National Laboratory (ANL), other national laboratories, academic institutions, governmental bodies, and industrial firms. During the past decade, synchrotron radiation emitted by circulating electron beams has come into wide use as a powerful, versatile source of X-rays for probing the structure of matter and for studying various physical and chemical processes. Several dedicated synchrotron radiation facilities are now in routine operation throughout the world. The APS uses recently developed insertion-device technology to produce high-brilliance beams of high-energy x-rays.

Figure 1.1 shows a plan view of the Advanced Photon Source. The main feature of the APS facility is the experiment hall building, an annular structure with an exterior radius of 191.4 meters, an inner radius of 164.6 meters, and a height of 9.8 meters. The experiment hall building houses the experiment hall, where x-ray beamlines and

Figure 1.1 Plan view of the Advanced Photon Source

experimental equipment are located, and a storage ring contained within a concrete-shielding enclosure. Around the periphery of the experiment hall building are laboratory and office modules, which provide office and laboratory space for visiting scientists performing experiments at the APS. A central laboratory and office building (CLO) is located at the northern periphery of the experiment hall building. The CLO houses the facility staff, who are responsible for operating and maintaining the facility and supporting the experimental program. Adjoining the CLO is the multifunction wing, providing facilities for meetings and conferences. Separating the CLO from the experiment hall building is the control center, which provides a central location for controlling the operation of the facility. To the southeast of the CLO is the utility building, which provides the electrical power, deionized water, and other utilities for the APS facility.

The storage ring is contained within a concrete-shielding enclosure located at the inner radius of the experiment hall building. The storage ring consists of magnets, vacuum systems, and other equipment necessary to maintain the circular orbit and energy level of a beam of positrons (the positively charged "antiparticles" of electrons) that is circulating within the storage ring. As the positrons are bent around the circular orbit, they release energy in the form of x-rays. The x-ray production can be greatly enhanced by the inclusion of magnetic insertion devices in the storage ring. Two types of insertion devices currently exist: wigglers, which produce very intense x-ray radiation over a wide range of energies, and undulators, which yield x-ray radiation over a narrow energy range at high brilliance. The x-rays are transmitted from the storage ring through a front end, which provides a means for defining and/or stopping the x-ray beam before the x-ray beam enters the experimental beamline. The experimental beamline is located in the experiment hall, between the outside of the concrete-shielding enclosure and the outer wall of the experiment hall building. The beamlines include shielded enclosures, vacuum systems, optical elements and experimental apparatus that contain the beam, modify its properties, and provide the apparatus for conducting experiments.

The positrons within the storage ring are continually "lost" at a low rate due to interactions with gas molecules and other loss mechanisms and need to be restocked at a regular rate. The supply of positrons is provided by the APS injector system, consisting of the linac system, a positron accumulator ring (PAR), a 7-GeV synchrotron, and associated beam transfer lines. The APS injector system is contained in buildings located within the infield of the experiment hall building. The accelerator systems are able to accelerate positrons or electrons with no impact on the safety assessment. In this document, the term positrons is used to denote either of these particles, unless specifically excluded.

1.3 Scope of Document

This document covers the experimental beamlines located on the floor of the experiment hall. The configuration of the storage ring permits a total of 70 beamlines to be installed in the experiment hall. Thirty-five beamlines utilize the x-ray radiation from insertion devices. The remainder use x-ray radiation produced by the storage ring dipole magnets. Each beamline is unique and utilizes components that provide the best match between the type of radiation source, the required characteristics of the x-ray radiation, and the type of experiments to be performed on the particular beamline.

This document describes the components and hazards associated with the commissioning and operation of a "generic" or representative example of a beamline using an insertion device x-ray radiation source and a "generic" or representative example of a beamline using a storage ring dipole as the x-ray radiation source. The document explains the guidance and requirements that are placed by the APS on the users, the process by which users gain access to the APS for performing experiments at the APS, and the review process by which the APS facility ensures that all specific hazards for each beamline are identified, analyzed, and appropriately mitigated. The document does not attempt to discuss the actual experiments that will be performed by users on the beamlines. The diversity and complexity of the individual experiments cannot be adequately analyzed and presented in this type of document. A process and procedures already exist within ANL for reviewing and approving experiments that are performed in laboratory conditions. Approved experiments are currently being conducted using x-ray generators in laboratory environments. This SAD treats the APS facility and beamline as the laboratory environment consisting of an x-ray generator and appropriate ancillary equipment and provides a safety assessment of this laboratory environment.

This document is an addendum to the APS Accelerator Systems Safety Assessment Document and, as such, does not address any of the components that have already been included in the APS Accelerator Systems SAD. This document also does not restate the general descriptions of the ANL and APS sites nor does it address the general facility hazards, such as those from natural phenomena. The sections explaining the APS Conduct of Operations, Quality Assurance Program, and Environmental Monitoring Program are also not included in this document. All of these items are addressed completely in the APS Accelerator Systems SAD.

The Experimental Beamline SAD does not replace any of the requirements stated in the Accelerator Systems SAD. The Accelerator Systems SAD includes the safety

assessment of the components contained within the shielded accelerator systems enclosure and the consequences of off-normal events occurring within the enclosure and the impact on the areas outside the accelerator systems enclosure. The Experimental Beamlines SAD addresses the consequences of creating a beamline opening in the storage ring enclosure and transporting a photon beam through the opening and down the beamline. It also addresses the hazards associated with beamline equipment. Under the beamline operating conditions, as described in the Experimental Beamlines SAD, a situation cannot occur which would exceed the Maximum Credible Incident (MCI) scenario for the storage ring and experiment hall as explained in the Accelerator Systems SAD. Section 4.2.4 of the Experimental Beamline SAD discusses a beamline worst-case scenario of a loss of vacuum incident in the storage ring and the resulting consequences in the beamline.

2.0 SUMMARY AND CONCLUSIONS

2.1 Hazard Analysis Methodology

The hazard analysis process began with a study of potential hazards associated with the generic APS experimental beamlines, including radiation, energy sources, and hazardous materials. Credible hazards with potential on-site or off-site consequences were analyzed to assess associated risk. The analyses were based on a bounding event approach. The most severe case of each category was analyzed to identify the worst-case result. Each event analysis included determination of the initiating occurrence, possible detection methods, safety features that could prevent or mitigate the event, probability of occurrence, and possible consequences.

2.2 Summary of Results

Analyses according to the hazards analysis methodology described in Chapter 4 were carried out for various categories of hazards. Table 2.1 summarizes the results of the analyses. The probability and consequence levels are presented in Table 2.2 and Table 2.3, respectively. The risk determination methodology is shown in Figure 2.1.

Other potential hazards have been analyzed, and appropriate design or administrative controls have been developed to mitigate them. Procedures and methodologies for controlling these hazards have been drawn from the broad experience base gained through the operation of similar facilities and from available, published accelerator safety guidelines. External experience and expertise have been utilized in both the design and safety reviews in accordance with DOE Order 5480.25 (DOE 1992b). Control measures are incorporated into the design of the facility and systems to mitigate or eliminate all identified potential hazards. In some cases, administrative procedures are established to ensure that facility operation can be conducted in accordance with DOE Order 5480.25 (DOE 1992b).

Table 2.1 APS Beamline Risk Determination Summary

HAZARD	SECTION	PROBABILITY LEVEL	CONSEQUENCE LEVEL	RISK LEVEL
Ionizing Radiation	4.2	Low	Medium	Low
Nonionizing Radiation	4.3	Extremely low	Low	Negligible
Electrical	4.4	Low	Medium	Low
Fire	4.5	Medium	Low	Low
Vacuum and Pressure	4.6	Medium	Low	Low
Magnetic Fields	4.7	Low	Low	Negligible
Cryogenic	4.8	Low	Low	Negligible
Chemical	4.9	Medium	Low	Low
Oxygen Deficiency	4.10	Extremely low	Medium	Negligible
Noxious Gases	4.11	Low	Medium	Low
Mechanical	4.12	Medium	Low	Low

Table 2.2 Hazard Probability Rating Levels

CATEGORY	ESTIMATED RANGE OF OCCURRENCE PROBABILITY (YR ⁻¹)	DESCRIPTION
High	$>10^{-1}$	Event is likely to occur several times during the facility or operation lifetime.
Medium	10^{-2} to 10^{-1}	Event may occur during the facility or operation lifetime.
Low	10^{-4} to 10^{-2}	Occurrence is unlikely or the event is not expected to occur, but may occur during the life of the facility or operation.
Extremely low	10^{-6} to 10^{-4}	Occurrence is extremely unlikely or the event is not expected to occur during the life of the facility or operation. Events are limiting faults considered in design.
Incredible	$<10^{-6}$	Probability of occurrence is so small that a reasonable scenario is inconceivable. These events are not considered in the design or SAD accident analysis.

Table 2.3 Hazard Consequence Rating Levels

CONSEQUENCE LEVEL	MAXIMUM CONSEQUENCE
High	Serious impact on-site or off-site. May cause deaths or loss of the facility / operation. Major impact on the environment.
Medium	Major impact on-site or off-site. May cause deaths, severe injuries, or severe occupational illness to personnel or major damage to a facility / operation or minor impact on the environment. Capable of returning to operation.
Low	Minor on-site with negligible off-site impact. May cause minor injury or minor occupational illness or minor impact on the environment.
Extremely Low	Will not result in a significant injury or occupation illness or provide a significant impact on the environment.

Figure 2.1 Risk Determination

3.0 APS ORGANIZATION, FACILITY AND OPERATION DESCRIPTION

3.1 Policy and Organization

3.1.1 APS Safety Policy

It is the policy of Argonne National Laboratory that its activities will be conducted in a manner such that all reasonable measures are taken to protect the health and safety of employees and the public and to minimize accidental damage to property and the environment. The laboratory will comply with the health and safety policy regulations and requirements of the Department of Energy and other applicable government agencies as directed by DOE. All pertinent aspects of DOE Order 5480.25 (DOE 1992b) have been taken into account in setting the APS safety policy, and all designs, construction and operation of APS facilities are governed by DOE Order 5480.25 requirements and guidance.

Safety at Argonne National Laboratory is a line responsibility extending from the director to all employees. The APS management is fully aware of its responsibility to conduct operations in a manner that reduces the risk of injury and potential harm to personnel, property, the public, and the environment. Operations believed to be unsafe or not in compliance with established safety procedures will not be permitted to proceed. It is APS policy that new or modified systems must be reviewed for safe operations by an APS or external safety committee before authorization is given by the appropriate division director or his designee to energize the system.

The Advanced Photon Source safety policy is to give priority to environment, health, and safety concerns in its operations and to operate within DOE Order 5480.25 requirements. It is the intent of APS management to minimize safety risks to employees and visitors and to assure adherence to applicable safety codes and regulations. Integrated into the APS design and operations policy are the criteria given in Section 9 (Accelerator Facility Design and Operation Requirements) of the Order:

- a. Each accelerator facility shall have a reasoned combination of active, passive, and administrative measures appropriately designed and used to:
 - (1) Maintain personnel exposure to prompt ionizing radiation well below radiological standards and as low as reasonably achievable; and

- (2) Permit bypassing in whole or in part only by means that are stringently controlled.
- b. The operator of each accelerator facility shall be required to document and implement a plan for control of access to the facility during commissioning, during operations, and while nonoperational.
- c. To provide for the protection of personnel, the contractor shall be required at each accelerator facility to:
 - (1) Use physical barriers and/or radiation detectors, interlocked with the particle beam or other protective features as feasible, to prevent exposure of personnel in excess of the most current DOE standards for ionizing and nonionizing radiation and other injurious environments.
 - (2) Escort all persons entering the facility unless they have received those portions of the general safety orientation and facility-specific training necessary to ensure they can safely accomplish their missions.
 - (3) Have a written statement of its shielding policy for ionizing and non-ionizing radiation.
 - (4) Have a documented personnel dosimetry program, as required by DOE 5480.11 (DOE 1988a), which follows the practices specified in DOE's Radiological Control Manual and which specifically addresses those radiations and energies encountered in facility operation that are not covered by DOE 5480.15 (DOE 1987).
 - (5) Characterize, post, periodically monitor, and document the hazardous environments in and around the facility.
 - (6) Determine and document the adequacy of the shielding and other components of the personnel protection system prior to initial use and after significant modifications. This requirement shall include the capability of the system to handle the effects of errant particle beams and interceptions of the beam.
- d. The contractor shall be required to submit to DOE a hazard class determination evaluation of the accelerator facility that is suitable for DOE's deliberations leading to a designation of the hazard class of the proposed operation.

- e. An independent review of the provisions for personnel safety and health shall be conducted by a DOE-appointed ad hoc panel of technical experts during the design phase of each new accelerator facility of moderate- or high-hazard class and during the design of significant modifications to all existing accelerator facilities.
- f. Accelerators shall be required to be operated in accordance with written procedures that cover activities that could adversely affect the safety and health of persons or the safe operation of equipment. The procedures shall be kept current and shall be approved by the most senior line manager in the contractor's organization who has knowledge of the day-to-day operation of the accelerator. The procedures shall be critically reviewed prior to approval and at intervals not to exceed 3 years thereafter to reaffirm their continued validity.
- g. Routine operation of accelerators shall be executed only by trained and qualified operators, or by trainees under the direct supervision of a qualified operator.
- h. During commissioning of an accelerator and during development programs employing an accelerator, the particle beam shall be controlled only by trained and qualified operators or duly designated accelerator specialists and physicists.
- i. Experimenters at accelerator facilities shall be required to adhere to written and approved safety procedures appropriate to address the environmental, safety and health concerns identified by a safety analysis. These safety procedures shall be approved by designated senior managers in the accelerator operating organization and the research organization and shall be reviewed annually to reaffirm their continued validity.
- j. Accelerator development programs that have a potential to exceed the approved Accelerator Safety Envelope shall be permitted only after a review conducted and documented by the contractor has found the proposed safety and health precautions to be taken during the development activities are adequate, and an exemption from specific requirements of the Order has been issued by the responsible PSO.

An important part of the APS safety policy is to implement an ALARA program for radiation exposure. ALARA goals for APS personnel are set each year, and every effort is made in the operation of the APS to ensure that these goals are met.

3.1.2 ANL and APS Organizations

Argonne National Laboratory, operated by The University of Chicago for the U.S. Department of Energy under Contract No. W-31-109-Eng-38, is the institution designated by DOE as responsible for the design, construction, commissioning and operation of the APS. An organization chart of the laboratory is shown in Figure 3.1., and the APS organization is shown in Figure 3.2.

The Associate Laboratory Director for the Advanced Photon Source (ALD-APS) is responsible for the development and operation of the APS as a national user facility. The ALD-APS 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 the implementation of the safety program has been delegated to divisional line management, managers, and staff. The ALD-APS has appointed an Environment, Safety and Health Program Manager to advise him and to guide the APS divisions in their respective safety efforts.

Within the APS organization, the Experimental Facilities Division (XFD) has the primary role in facilitating the effective use of the APS by the user community. To accomplish this objective, the division staff develops state-of-the-art insertion devices, and provides users with infrastructure; technical components; support for beamline design, construction, and installation activities; technical and safety reviews; safety support; and operational support. The XFD staff also conduct research to advance the state of the art of synchrotron radiation instrumentation in accordance with the unique capabilities of the APS.

Additionally, a safety organization has been established with members appointed from the APS organization. An APS Safety Review Committee, consisting of experienced individuals from other departments within ANL and other DOE facilities, was appointed by the Laboratory Director to review safety documentation and monitor APS facility progress to assure him that no area of safety has been overlooked. This independent review committee has the responsibility of reviewing this SAD.

3.1.3 APS Users

3.1.3.1 User Organization

The APS users are organized into Collaborative Access Teams (CATs) to develop and manage APS sectors. A sector consists of an insertion-device beamline and a bending-magnet beamline. Prospective users submit letters of intent to the APS requesting one

Figure 3.1 Argonne National Laboratory Organization Chart

NATIONAL LABORATORY

Location

9700 South Cass Avenue

Operations Office

Argonne, Illinois 60439

Contract Number

Chicago

W-31-109-Eng-38

Approved

Alan Schriesheim

Director

August 1, 1994

January 1995

Figure 3.2 Advanced Photon Source Organization Chart

ADVANCED PHOTON SOURCE

or more sectors. Letters of intent are also submitted by potential users requiring less than one sector. The APS assists these users in forming associations among several groups whose combined needs would justify the use of a whole sector.

Letters of intent are evaluated by the APS Proposal Evaluation Board (PEB), which makes recommendations to APS management. Evaluations are based on the need for the unique capabilities of the APS and the quality of the proposed scientific program. Groups whose letters of intent are approved are then invited to submit full proposals.

As part of the proposal process, the CAT elaborates on the proposed scientific program, provides a summary of key personnel, conceptual designs for the proposed beamlines, a financial strategy encompassing the construction, installation and operation of the beamlines, and a management plan. The management plan is covered in detail in section 3.1.3.3.

The next step in the approval process is the signing of a Memorandum of Understanding (MOU) between the APS and the CAT. The MOU provides the CAT with access to specific APS sector numbers for the construction and operation of beamlines. Prior to signing the MOU, the CAT must have met the following four prerequisites:

1. Approval of the CAT proposal in accordance with the recommendations of the PEB.
2. Approval of the Conceptual Designs of the CAT beamlines.
3. Approval of the CAT Management Plan.
4. Receipt of appropriate documentation with respect to the funding intents of the organizations identified by the CAT as sources of financial support.

A legally binding User Agreement is executed between each CAT member institution and ANL to define the legal rights and requirements of all participants. In this document, the "User" (i.e., the member institution) is required to "take all reasonable precautions in the installation of equipment and performance of experiments to protect the safety and health of others and to protect the environment and shall comply with all applicable safety and health regulations and requirements of APS, Argonne, and the Department [DOE]. In the event that User fails to comply with said regulation or requirements, Argonne may, without prejudice to any other legal or contractual rights, issue an order stopping all or any part of User's activities at the APS." Each employee

of the "User," prior to participating in experiments at ANL under the User Agreement, must execute an Acknowledgement of the Agreement.

The CATs must also undergo a formal review process by a Beamline Review Committee established by the Experimental Facilities Division. The reviews extend from preliminary beamline design through the operation of the beamline. The process is described in detail in Section 3.1.4.

3.1.3.2 User Access and Safety Training

All APS users are required to register with the APS User Office, complete a user hazard checklist, and receive appropriate orientation and training before they can receive an ANL/APS access badge for unescorted access to the experiment hall. During registration, the user is provided GERT training and APS site-specific orientation and is then issued a personal dosimeter. The experiment hall is classified as a radiologically controlled area. All personnel are required to wear personal dosimetry when on the floor of the experiment hall. The users are not allowed unescorted access into the accelerator buildings or the storage ring shielded enclosure.

The user hazard checklist identifies potential hazards that the user expects to encounter and assists both the APS and the CAT management to determine the required level of additional safety training. The APS continues to work with the Training Section of ANL's ES&H Division to identify existing and new courses that users must take to satisfy the identified training requirements.

The final phase of orientation (sector-specific training) is conducted by each CAT for its members and users according to the procedures outlined in each CAT management plan.

3.1.3.3 CAT Management Plan

As part of the proposal process, each CAT must submit, and have approved by the APS, a management plan. The APS has prepared a "generic" management plan, using a fictitious CAT name of TOM-CAT, to serve as a model for the CATs. This plan may be adopted "as is," modified as needed, or replaced with a different plan. Any plan used, however, must include the following elements:

- a. A CAT management organization chart, identifying the CAT director and clearly indicating where the decision-making authority resides.

- b. A detailed work breakdown structure.
- c. A quality assurance (QA) and quality control (QC) plan.
- d. Plans for procurement and fabrication of major beamline components.
- e. Funding plan for the CAT.
- f. A plan for cost, schedule, and performance control.
- g. Safety requirements specific to the CAT.
- h. Methods for facilitating communication among CAT members and plans for reporting activities to CAT member and the APS.

The "generic" management plan provided to the users contains the following statements in regards to safety requirements for the CAT:

The management of TOM-CAT assumes responsibility for safety, which extends from the Director of TOM-CAT to all its members, users, and visitors. All the TOM-CAT construction and operation activities will be conducted such that reasonable measures are taken to protect the health and safety of all the TOM-CAT members, the users of the beamlines, and the public, as well as to minimize accidental damage to property and the environment.

The TOM-CAT members and the users of the TOM-CAT beamlines will comply with the health and safety policy regulations and requirements of Argonne National Laboratory and the APS facility. The TOM-CAT management fully understands that its activities at the APS facility will not be allowed to proceed if they are considered unsafe or are not in compliance with established safety procedures.

The Director of TOM-CAT is responsible for the safe operation of the TOM-CAT beamlines and the associated experimental facilities. A TOM-CAT Safety Committee will advise the TOM-CAT Director on the development of safe operating procedures pertaining to the beamline operation and other day-to-day safety requirements. Documented procedures will be approved by the APS prior to operation of the TOM-CAT beamlines.

The Director of TOM-CAT will request beamline design reviews starting from the

conceptual design stage, through the engineering design stage, the construction stage, to the operation stage as requested by the APS. TOM-CAT will accept APS-designed safety interlocks and will allow the APS staff to install these on the TOM-CAT beamlines and other experimental facilities as appropriate.

The TOM-CAT will also comply with the requirement of the APS to review and approve the safety aspects of all the experimental programs on the beamline in advance of their execution.

The members of TOM-CAT and the users of the beamlines and other experimental facilities will attend and comply with requirements of safety orientation training as specified by the APS Safety Organization prior to beginning work on the experimental floor of the APS or in other associated buildings.

3.1.3.4 CAT Safety Responsibilities

The management of the CAT must accept responsibility for all activities undertaken by the CAT personnel or Independent Investigators. The implementation of Health and Safety Policy from ANL, through the APS and to the CAT, is shown in Figure 3.3.

Prior to starting any installation or operation activities at the APS, the CAT must submit a CAT Safety Manual. The manual states the CAT safety policy, defines the responsibilities of the CAT safety organization, and lists all of the applicable CAT safety procedures. The manual is a supplement to the standard policies and practices described in the ES&H documents of the respective CAT member institutions, the XFD and ANL ES&H Manuals, and the APS Conduct of Operations Manual. The APS has prepared a "generic" CAT safety manual, "Safety and Environmental Protection Policies and Practices for the TOM-CAT." It can serve as the model for the CAT. The proposed content includes:

1. TOM-CAT Safety and Environmental Protection Organization
2. Policies and Procedures
3. Hazard Assessment and Control
4. Safety and Protective Equipment
5. Inspections, Reviews, and Program Assessments
6. Training and Instruction Programs and Resources
7. Emergencies
8. Program Requirements Specific to Beamline Construction Activities
9. Program Requirements Specific to Commissioning Phase Activities

Figure 3.3 Health and Safety Policy Implementation at the Advanced Photon Source

3.1.3.5 Independent Investigators

The objective of the APS Independent Investigator (II) program is to provide opportunities for productive use of the APS by qualified researchers who are not currently in a position to become members of CATs. Access will be determined by a proposal process in which the CATs will make the ultimate judgment of the scientific merit and feasibility of the proposals. Each CAT will begin to provide beam time to IIs after its beamlines are fully commissioned and operational experience has been gained. In general, each CAT will allocate 25% of its bending-magnet beam time and 25% of its insertion-device beam time to IIs; the actual percentage will be established on a case-by-case basis. Each CAT will develop its own written II Access Plan as an element of its CAT Management Plan.

The research proposals submitted by Independent Investigators will be required to include sufficient information so that reviewers can thoroughly evaluate the environmental, safety, and health aspects of the proposed work.

The home institutions of IIs will be required to sign User Agreements that have the same safety provisions as those described in Section 3.1.3.1, and the IIs will be required to execute Acknowledgements of these Agreements prior to participating in experiments at the APS.

3.1.4 Beamline Review Process

3.1.4.1 Introduction

The APS/XFD has created a Beamline Review Committee (BRC), which provides the primary means of reviewing the design and operation of each beamline. The BRC membership consists of APS scientists and engineers who are familiar with beamline technical requirements. It is chaired by the group leader of the User Technical Interface Group. Advisors from other areas of ANL are added as issues are identified for which adequate expertise does not exist within the committee. The BRC reports to and advises the Associate Division Director for Operations within XFD, who has the final APS responsibility of approving the commissioning and/or operation of the beamline.

Beamlines are reviewed to ensure that their components and equipment (1) are optimized for the proposed scientific program and (2) satisfy all APS, ANL, and DOE

requirements for safe operation. The documents developed for the reviews and during the review process are kept on file in the APS User Office, permanently accessible for reference whenever information about the beamline is required. In addition, at each review stage, drawings of the beamline and its components are filed in the APS Design Exchange (DX), which enables current electronic or paper copies of beamline layout to be accessed as needed. Any action items resulting from the reviews must be resolved before APS grants the approvals required to begin beamline installation, commissioning, and/or operation.

The BRC reviews the beamline at several stages:

1. Preliminary Design Review
2. Final Design Review
3. Commissioning Readiness Review
4. and as part of the ongoing Beamline Configuration Control, at regular operation intervals or whenever significant modifications are to be made. Significant modifications are those which may change the safety aspects of the beamline, such as shielding, additional beamline sections, etc.

Each of these reviews are described in the subsequent sections.

The APS oversight of the beamline operation is provided by Floor Coordinators. The Floor Coordinators are members of the User Technical Interface Group, and each Coordinator is assigned responsibility for, typically, four sectors. Floor Coordinators are required to familiarize themselves with the operation of the beamlines within their areas of responsibility and have the authority to suspend beamline operation if they feel that unsafe conditions may exist. They also provided assistance and/or guidance to the CATs for resolving any issues that may arise regarding the users and other ANL services, such as health physics, waste management, etc.

Floor Coordinator coverage will be available during off-shift hours, whenever the facility is operating or whenever beamlines are undergoing significant modification.

3.1.4.2 Preliminary Design Review

The preliminary design of the beamline represents an approximately 30% design level of each of the beamline components. This level of design permits the CAT to develop cost estimates for the construction of the beamline, as well as a realistic timeline for completion of the construction tasks. Following guidelines provided by the APS, the CAT prepares a Preliminary Beamline Design Report (PDR) for APS review. The

PDR must include the following elements (ANL 1994c):

Beamline layout

- Layout of the beamline within the sector, showing components and support equipment.
- Life Safety Code compliant egress aisles.
- Some indication of the plans for survey and alignment of the beamline components.

Component designs

- Appropriate specification of components that are not APS-developed standard components.
- Compliance with APS policies, such as the vacuum policy.
- Description of the optical and shielding apertures with ray-tracing analysis and the existence of a reasonable safety margin for white-beam components.

Management issues

- Demonstration of a Work Breakdown Structure with preliminary costs and schedules.

Additional Operation Requirements

- Identification of any special requirements and compatibility with the installed conventional facilities.

Preliminary Safety Analysis

- Provision of an analysis of the shielding design for compliance with APS shielding standards.
- Definition of the proposed modes of beamline operation, together with the expected requirements of the Personnel Safety System.
- Description of the beamline Equipment Protection System and an indication of compliance with the APS policy on white-beam beamline components.
- An ozone mitigation plan with a preliminary analysis for ozone production within the beamline.
- Identification of and preliminary mitigation plans for program-specific hazards, such as hazardous gases, radioactive materials, etc.

3.1.4.3 Final Design Review

The next phase of the APS beamline review process focuses on the Final Beamline Design Report (FDR), which is submitted when approximately 90% of the total design

effort has been completed. APS approval of the CAT's designs described in the FDR is required prior to installation of beamline components in the APS experiment hall. Items that have a long lead time for design or procurement may be reviewed separately from the remainder of the beamline, but enough information must be provided so that reviewers can understand the context in which these components are to be used. Those components that are part of the APS standard component list are not reviewed for their individual performance; however, the components are reviewed in the general scheme of the total beamline performance.

The review of the Preliminary Beamline Design Report focused on the layout of the beamline as a whole and at a level that would permit the beamline components to be designed independently of each other. The FDR review focuses on aspects of safety, scheduling, required APS support, and updating the information provided in the PDR. The topics to be addressed in the FDR are as follows:

Layout

- Identification of changes from PDR layout.
- Provision of a survey plan, including expected APS survey and alignment support.
- Update of the ray traces provided in the PDR.

Component design

- Provision of component final designs.
- Assurance of compliance with the APS Vacuum Policy.

Schedule, Cost, & WBS

- Provision of installation schedule with the expected APS craft support.
- Provision of the survey and alignment schedule.
- Update of the PDR WBS-based schedule.

Safety

- Provision of final PSS requirements.
- Provision of EPS logic and interface requirements.
- Description of final shielding design.
- Identification of chemical, electrical, fire, and other hazards that impact beamline design, and means to be used for mitigation.
- Identification of program-specific hazards (e.g., high-powered lasers, biohazards, etc.)

Special operating requirements

- Identification of special conventional-facilities requirements.

3.1.4.4 Commissioning Readiness Review

Prior to the start of commissioning, the CAT must prepare a commissioning plan that is reviewed and approved by the BRC. The plan identifies the commissioning staff and the required training for this staff. It presents a hazard analysis of the expected hazards to be encountered during beamline commissioning and describes the means by which the hazards are mitigated. The plan presents the operating conditions (i.e., beam current, power density, etc.) that the CAT requires to commission the beamline components. The CAT also prepares a proposed schedule for commissioning, which is then finalized in consultation with the APS to include the APS testing of safety systems. Prior to introduction of any beam into the beamline, the BRC conducts a visual inspection of the beamline, reviews the APS-conducted test of the PSS interlocks, and reviews the results of the APS shielding validation. This test is conducted by the APS with the support of ESH-HP and follows a consistent and predefined procedure. The results are used to determine if any additional supplemental shielding must be added. Once the BRC determines that the requirements have been met, the commissioning plan is approved. The BRC also develops the beamline operation limits, which define the conditions under which the beamline may operate. These include, but are not limited to, the inclusion of hard stops on the insertion device gap, minimum supplemental shielding requirements, identification of beamline zones that may not be modified without BRC approval, etc. The beamline operation limits provide to the Floor Coordinator the necessary information for him to effectively oversee beamline operation. The BRC, having completed the review and development of the operation limits, recommends to the XFD Associate Division Director for Operations that the commissioning can proceed. When he is assured that all requirements have been met, formal approval is then provided to the CAT to proceed.

3.1.4.5 Beamline Configuration Control

The BRC conducts reviews of the beamline at regular intervals that are determined by the BRC based on the complexity or potential safety hazards associated with the beamline. Reviews are also held when a modification requiring BRC approval is requested by the CAT, if a Floor Coordinator has a safety concern that he cannot resolve, or if a safety incident (such as an accident or exceeding the beamline operation limits) occurs. This review will be conducted under similar requirements as the Commissioning Readiness Review and may require a reevaluation and reapproval of the beamline operation limits. The findings of the BRC review, whether regularly scheduled, or not, are reviewed and approved by the XFD Associate Division Director for Operations.

3.2 Beamline Technical Description

3.2.1 Introduction

Generally, an experimental beamline consists of four functional sections. The first section is the source of the x-rays, where x-rays are produced from the circulating positron beam inside the storage ring. The APS provides the x-ray radiation from two types of sources: one is insertion devices and the other is dipole magnets of the storage ring. The insertion device, located in the storage ring straight section, can be further tailored to provide radiation with specific characteristics required by each beamline user. The radiation from the bending magnet source, whose primary function is to bend the positron beam into a circle, cannot be individually tailored.

The second section, immediately outside the technical components of the storage ring but still inside the concrete storage ring shielding tunnel, is the front-end section. This section contains safety shutters, photon beam stops, and other components to coarsely define the emerging x-ray beam and, if required, to stop the x-ray beam and provide adequate radiation protection to areas outside the concrete shielding tunnel. Each x-ray source requires a front end, although there are minor differences between the front ends used with an insertion device and those used with a bending-magnet source.

The third and fourth sections of the beamline are located on the experiment hall floor, outside the storage ring tunnel. The third section contains hard x-ray optical elements, such as crystal monochromators, filters and/or mirrors, which are designed to handle the power loads and tailor the characteristics of the photon beam to satisfy the user requirements. The beam transports, which define and shield the beam path between the optical elements and the fourth section, are also included here. The fourth section is the experimental station. This station contains the sample under investigation, additional optics that may be needed to analyze and characterize the scattering, absorption, or imaging process, and the detectors. Each photon beam can be split into several, so that each beamline can have multiple transports and experimental stations.

The APS has defined a pair of beamlines as a sector. The sector includes a beamline based on an insertion device and an adjacent bending-magnet-based beamline. The APS provides the source and front end (section one and two) for each sector. Sections three and four are the responsibility of the CAT, which will design, build, and operate the beamlines in their sector with funds independently obtained from their home institutions and/or various funding agencies.

3.2.2 Beamline Elements

Each beamline constructed by the CATs will be unique and each may be used for different types of research. Similar components may be used in more than one beamline, but these components will frequently have different mechanical, operational, or scientific characteristics appropriate for the research being conducted on that particular beamline. Even identical components will be used at different positions along a beamline. In the following description of the various components, only the common elements of the components will be discussed.

The x-ray beam produced by an insertion device or a storage ring bending magnet and transported through the beamline front end requires some modification before it can be used as a tool to study the structure of materials. The beam is tailored by optical elements, located at various positions in the beamline, which allow the x-ray beam to be stripped of unwanted energies, or split, or concentrated in a specific plane to better suit the research requirements. Because an interaction of the full energy x-ray beam with any material, even air, will result in scattered radiation, the optical elements are generally located within shielded enclosures to prevent access by personnel when the x-ray beam is on. A shielded enclosure is also used to surround the experimental sample location. To ensure that radiation on the experiment hall floor is minimal, the vacuum beampipe through which the x-ray beam is transported is shielded to provide radiation protection.

A typical insertion device beamline is shown in Figure 3.4.

3.2.2.1 First Optics Enclosure (FOE)

The first optics enclosure is located just outside the storage ring shielding and contains the optical elements that provide the initial definition of the x-ray beam. The enclosures are shielded structures (see Figure 3.5). Their size varies from beamline to beamline, depending on the type and number of optical elements that will be contained within the enclosure. Due to the relatively high radiation levels within these enclosures during beamline operation, personnel access to this area is restricted and controlled by the beamline Personnel Safety System (PSS). The radiation shielding integrity of the enclosure is extremely important to ensure that acceptable radiation levels are maintained outside the enclosure. All openings, for utilities, cabling, and ventilation, are constructed to minimize scattered radiation and prevent a direct line-of-sight into the enclosure.

Figure 3.4 Layout of a Typical Insertion Device Beamline

Figure 3.5 Typical First Optics Enclosure

3.2.2.2 Experimental Station

The experimental station in its construction is similar to the first optics enclosure. Its size and complexity varies from beamline to beamline, depending on the types of components that will be contained inside (Figure 3-6). It may also contain optical elements, but its primary function is to contain the experiment being performed on the beamline. If the x-ray beams are split, the station may contain a beampipe transport for the beam to another experimental station, located further downstream. An experimental station may contain beamstops or shutters similar to those found in the front end to stop the x-ray beam within the station and allow personnel access into a downstream station.

3.2.2.3 Shielding Enclosures

Small shielding enclosures are located at multiple positions along the beamlines to provide radiation shielding for beamline components that intercept the x-ray beam and thereby produce radiation. These enclosures are secured and inaccessible during beamline operation.

3.2.2.4 Optical Elements

The optical elements are used to tailor the x-ray beam for the precise requirements of each experiment performed on a beamline. Typical optical elements are 1) monochromators, which select precise energies out of the beam and reject the others, 2) mirrors, which perform some energy selection and focusing or redirecting of the beam, and 3) pinholes and slits, which define and control the boundaries of the x-ray beam. All of these devices interact with the beam and therefore are contained within shielded vacuum enclosures. Most optical elements require some form of cooling, either with deionized water or other coolant, to dissipate the energy deposited by the x-ray beam. In addition, the optical elements require precise position control to within a few microns with respect to the x-ray beam. The position of some the optical elements will need to be precisely altered during or between beamline experiments requiring precision motion mounts and readouts. All of these optical element ancillary systems are integrated into the vacuum enclosure and the mechanical support structures.

Figure 3.6 Typical Experimental Station

3.2.2.5 Beamline Interlock and Safety Systems

The beamlines have sophisticated interlock systems incorporated in their designs to guard against incidents that could damage or incapacitate equipment (Equipment Protection System, EPS) and also to protect personnel (Personnel Safety System, PSS) from radiation in the beamline. The EPS system is designed by the CAT and reviewed by the APS to ensure that adequate protection is provided to the front-end and storage-ring components from equipment failures or accidents (such as vacuum breaks). The PSS is designed by the APS to meet CAT and APS requirements. This safety system is also installed and maintained by the APS. The PSS is described in Section 3.3.

3.2.2.6 Beamline Vacuum System

The beamline vacuum is designed to be a combination of both a UHV system in the same vacuum range as that of the storage ring (1×10^{-10} Torr) and a HV system in the range of 1×10^{-6} Torr. The beamline vacuum is monitored by the beamline Equipment Protection System. All beamline vacuum system designs must conform to the APS Vacuum Policy (ANL 1994c).

3.2.2.7 Beamline Utilities

Utilities in the beamline include deionized (DI) and chilled water, pressurized air, and electric power. These utilities are distributed along the beamline by header systems. Power utilities in the beamline include the utility power and clean power provided via two power strip lines. A cable tray system is provided for distribution of control, interlock, and instrumentation cabling.

Provisions for ventilation of the FOE or experimental stations are provided within the experiment hall (Davey 1993).

3.3 Engineered Safety Systems

3.3.1 Introduction

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 possible PSS system fault is detected.

The PSS for each beamline interfaces directly with the Accelerator Systems 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 PSS system of other beamlines.

Each beamline PSS is designed by APS/XFD staff to meet the requirements of the individual CAT after review and concurrence by the BRC. The APS/XFD staff is also responsible for the installation, verification and regular testing, and any required 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 will remain the same. Specialized control panels will be designed to incorporate any special features. The system documentation, test procedures, and training will include all basic as well as specialized equipment and operating modes.

The PSS is designed to comply with the following:

- DOE Order 5480.25, "Safety of Accelerator Systems" (DOE 1992b).
- "APS Preliminary Safety Analysis Report" (ANL 1990).
- SLAC 327, "Health Physics Manual of Good Practices for Accelerator Facilities" (SLAC 1988).
- NBS Handbook 107, "Radiological Safety in the Design and Operation of Particle Accelerators," ANSI N43.1 (NBS 1979).

- NCRP Report No. 88, "Radiation Alarms and Access Control Systems" (NCRP 1986)

Among the more important aspects of conformance, the PSS satisfies the following requirements:

- The system is designed to be fail safe, so common failures (e.g., shorts to ground or open wires) leave the system in a safe, beam-off state.
- The designs incorporate redundant protection, ensuring that no single component or subsystem failure leaves the system in an unsafe, beam-on condition.
- Provisions for testing are included, so the proper component and system functions may be completely verified.
- Access and egress controls are incorporated so that personnel are not exposed to x-ray radiation. These include emergency shut-off devices, status signs, search and secure procedures, and emergency exit mechanisms.
- A document control and review system is incorporated for keeping documentation complete, accurate, and current.
- A strict configuration control system protects the circuits and software against unauthorized and inadvertent modification. Critical devices are clearly labeled to note that tampering is strictly forbidden.
- User training for proper system operation is incorporated and users are made aware of the consequences of tampering or improper use of the PSS.

3.3.2 Beamline Personnel Safety System (PSS) Description

3.3.2.1 Overview

Each beamline PSS employs two independent interlock chains, referred to below as Chain A and Chain B, providing system-wide 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.
- 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 (for storage ring shutdown), and the front-end Equipment Protection System (EPS) and the EPICS control system (for status and monitoring).
- Equipment racks, conduit, cable trays, and cables.

The concern of common cause failures in redundant protection systems is addressed by using different hardware and software platforms for the two chains. Chain A uses an Allen Bradley PLC with ladder logic software, and Chain B is controlled by GE/Fanuc PLC hardware and state machine logic software. The probability of a common cause failure is further reduced by using different programmers to develop the software for each chain.

A programming key is required to program the PLC or to operate the PLC in a non-normal mode and once this key is removed from the PLC crate, the PSS program cannot be modified by any external means.

Each PLC crate has a unique hardwired address. This associates a crate with a particular beamline. During software execution, one of its regular tasks is to verify, via the crate ID number, that it is operating in the intended crate (and therefore the proper

beamline). The crate address insures that the software written for another beamline is not installed in a crate for which it was not intended.

A watchdog timer on each PLC allows monitoring of cessation of operation. This software settable timer provides two means to detect such a failure. The first is a timer utility: if it times out, all PLC I/O modules are turned off. Communication with all remote I/O modules is also stopped, and this action results in those modules being turned off as well. Second, an on-board hardware verification, which checks the integrity of the data and address busses, is executed periodically. A detected fault causes all local and remote outputs to be de-energized. These outputs control critical devices and the permits to the ACIS. The fault will abort the stored beam and insert all safety shutters.

In addition, the PSS implementations have been provided with watchdog circuits external to the PLCs, which also require periodic stimulation. If these timers are not triggered periodically by the PLC, the critical device relays will be turned off and the stored beam will be aborted.

The PLCs, UPS, and interface modules for the ACIS, EPS, EPICS, and front-end components for both chains are located in locked relay racks located on the top of the storage ring tunnel and are inaccessible to the users.

Equipment to which the user needs access, such as door access controls and mode controls, are located in equipment cabinets located on or near the experiment stations. The equipment cabinets are locked to prevent uncontrolled access to wiring, but the fronts are open to allow operation of the front panels of the various control chassis. These cabinets also contain the I/O modules for the PSS equipment at the station location.

APS experimental station control panels provide:

- a logical visual indication of the beamline status
- beamline safety shutter controls
- the means to switch shutter control between stations on a beamline
- the mechanisms to administratively take stations off-line and bring them back on-line

3.3.2.2 Station Control Panel

A station control panel is used to open and close safety shutters, gain safe access to the experimental station, and provide visible feedback regarding the states of the accelerator, other experimental stations, and the shutters. Figure 3.7 shows a typical panel for two stations with two sets of safety shutter controls. Primary panel features are described below.

The status display consists of a chain of LED indicators that are laid out in a manner consistent with the beamline layout. Lamps are green if the related devices or systems permit the beam to be propagated down the beamline and are red if configured to stop the beam. The beamline safety-shutter and station-enable controls are located on the panel next to the appropriate indicators.

The Station APS Enable key is used by the APS facility to administratively put a station on-line (enable the station for User control) or take it off-line (shutters closed and disabled). This is the key used by the Floor Coordinator to shut down a beamline or section of a beamline due to safety, operational, or other concerns.

The Station User key(s) allows a user to lock out the shutter control for an active on-line station and allows administrative control by the user on the operation of a beamline or section of the beamline.

The Beam Mode indicators show the type of beam that is in the station. The mode of the beamline is the hardware configuration identified by the type of radiation (e.g., white beam or monochromatic beam) that will be propagated as well as where the radiation can be propagated (e.g., down a particular branch line or through a bypass). The mode is determined by the positions of instruments, such as mirrors, monochromators, shielding, stops, etc.

3.3.2.3 Mode Control Panel

For each ID or bending-magnet beamline that has more than one interlocked mode of operation, a mode selection panel is provided. This panel captures the PSS Kirk keys for stops, shutters, etc., when they are released from matching locks located on the devices when beamline operating modes are changed. The PSS monitors not only the position of mode changing devices (stop or shutter position) but also the location of the

Figure 3.7 Typical Station Control Panel

Kirk keys. The device positions and keys must match a predetermined state for the particular mode to be enabled. When the interlocks have been satisfied for a mode, this will be indicated on the Mode Selection Panel as well as on the Station Control Panels. The complexity and variability of beamline operation will determine the number and location for the mode control panels. The front panel for a typical mode selection panel is shown in Figure 3.8.

Depending on the design and operating requirements of the beamline, certain mode changes may require APS intervention/concurrence through the use of a facility-controlled key.

3.3.2.4 Station Door Control Panel

This panel provides pushbuttons with visual indicators for releasing the magnetic door locks and opening the door. The buttons are inactive if the proper access conditions have not been established. The number of these panels at each beamline is determined by the position of the stations, the number of doors at each station, and other design requirements.

3.3.2.5 System Control Panel

Each beamline requires a single system control panel. This panel is not used by the users. The system control panel provides the means to reset PSS faults. Two categories of faults have been determined, and each is reset by its own key. The two keys are for minor and major fault resets.

Major Fault (results in an APS storage ring abort). Typical faults include:

- one of the PLC Chains fails
- a PLC major fault (heartbeat)
- I/O Rack failure

Minor Fault (no abort). Typical faults include:

- FE EPS permit off
- Safety Shutter air manifold pressure low

A major fault is reset with a key by the PSS System Manager. A minor fault is reset with a key by the User Technical Interface Group Leader or his designate.

Figure 3.8 Typical Mode Control Panel

3.3.2.6 Experimental Station Hardware

The experimental station doors may be operated manually or by powered means, such as with an air cylinder. However, the PSS hardware for the door is the same in all cases and consists of:

- A door lock to hold the door fixed in place.
- Door status switches, provided for each chain, indicating that the door is closed.
- One or more emergency shutdown switches ("crash buttons") that inhibit storage-ring operation when depressed if the shutters are open. The number of emergency shutdown switches is determined during the BRC design review process and is based on the design of the enclosure and the equipment it will contain to ensure easy accessibility from any location within the enclosure.

Emergency entrance and egress mechanisms are located on the inside and outside of the station door. The PSS door hardware does not interfere with the access/egress mechanism operation.

The inside of the station contains one or more search buttons with visual and audible indicators of a search in progress. The number of search buttons is determined during the BRC design review process and is based on the design of the enclosure and the equipment it will contain. The search buttons must be depressed in the correct sequence, and the search must be completed and the door closed within a predetermined interval for the search to be considered successful by the PSS logic. At the completion of a successful search, the safety shutter buttons are activated if the other interlock conditions (keys, mode control, etc.) are satisfied. The PSS logic diagram showing the conditions that need to be satisfied for opening the safety shutters is shown in Figure 3.9.

Figure 3.9 PSS Logic Diagrams

3.3.3 Storage Ring ACIS and PSS Interface

All beamlines have a Global on-line/off-line keyswitch located in a junction box associated with each storage-ring sector and located atop the storage ring shielding enclosure. The junction box is the interface point for the two PSS systems associated with each sector and the ACIS system. Because the enclosure contains circuitry for both the storage ring ACIS and PSS, access requires two keys - one maintained by the ACIS System Manager and the other maintained by the PSS System Manager.

Inside the junction box are located the on-line/off-line keyswitches, one for each of the two beamlines associated with the sector. When the keyswitch for a beamline is set to off-line, its safety shutters and the second photon shutter are prevented from opening and the PSS beam-dump signal is ignored. When the keyswitch is set to on-line, the shutters are allowed to be opened under PSS control and the ACIS monitors and reacts to the beam-dump signal from the PSS. The keyswitches are under the control of the ACIS System Manager, and their use is strictly governed by administrative procedures. The keyswitch is set off-line until the beamline has been authorized to begin commissioning/operation. The keyswitch is also set off-line when the PSS is undergoing maintenance or testing during storage-ring operation.

3.3.4 PSS Testing and Configuration Control

3.3.4.1 PSS Testing Overview

The PSS implementation provides a means to operate the system in a test mode with the critical front-end safety and photon shutters disabled in the closed position. This is referred to as the Global Off-Line State and allows main ring operations to continue while the beamline is being tested.

System testing provides the single most important contribution to safe operation. Since few failures arise during operation, a rigorous testing program must be developed that includes all the protective elements of the system. Further, the program must also verify the systems integrity following any maintenance, addition of new components, or software changes.

The test verifies that the PSS operates as designed and that abnormal or out-of-sequence events do not result in an unsafe condition. Testing of the system is performed before the system is placed in service, after any major fault is detected, and at periodic intervals of at least every six months consistent with DOE Order 5480.25 (DOE 1992b). The PSS test procedures are under document control.

3.3.4.2 PSS Configuration Control

The configuration is controlled by the directives of DOE Order 5480.25 (DOE 1992b). Hence any change in the PSS operational or functional configuration or any related procedure must be approved by a committee appointed by the XFD Director and independent of the group within XFD responsible for the PSS. All proposed changes must be presented and justified before any implementation effort is undertaken. The detail of the review and the level of approval are commensurate with the degree of hazard involved.

A notable example of functional modification is the bypassing of an interlock. This is permitted only if equivalent safety is provided, either by procedures or by alternate equipment. The proposed bypassing requires review and approval, and the interlock system is tested with the bypass in place and again after it has been removed.

Testing procedures for the modified system are reviewed, approved, and demonstrated before the new configuration is approved for operation. Any change to the PLC software triggers a system verification process.

In the case of an identical component replacement, a formal review is not necessary. However, the functionality of the component must be checked and verified by the PSS System Manager or his designate in writing before the system can be reactivated.

3.3.4.3 PSS Documentation

The following documentation is prepared and maintained by the PSS System Manager:

- A description of the document control and review system for keeping documentation complete, accurate, and current
- A written functional description of each beamline PSS
- The physical and electrical configuration of each PSS
- An auditable record of PSS test results
- Records of management review and approval of the PSS
- PSS key management and replacement records

- Software requirements document and functional specifications
- Software implementation, acceptance, integration, and test plans
- Media control and security records

3.4 Shielding Policy and Radiation Monitoring

3.4.1 Shielding Policy

Shielding for the APS will be such that individual APS radiation worker dose will be ALARA and less than 5mSv/yr (500 mrem/yr). The APS shielding policy requires that the average facility radiation worker dose be below 2 mSv/yr (200 mrem/yr).

The APS policy for on-site nonradiation workers (which includes the APS users) in the vicinity of the APS facilities requires that the average nonradiation worker dose be below 0.2 mSv/yr (20 mrem/yr). In addition, the dose at the site boundary from all pathways is required to be below 0.1 mSv/yr (10 mrem/yr). Present estimates of the annual doses for these two categories of exposure indicate that these requirements are met. For future modifications of the facility, the doses will be reevaluated and additional shielding provided if necessary to meet the policy requirements.

Worker dose is monitored, and frequent area surveys are performed by health physics personnel. For cases in which surveys indicate elevated dose rates at a location that may impact upon worker exposure, the cause of the radiation will be investigated and additional local shielding will be provided, as needed, to reduce the radiation field to an acceptable level. Monitoring results are reviewed, and significant exposures, an unexpected increase in an individual's exposure, or a trend of increasing exposure over a period of time triggers an investigation into the cause of the increase. Corrective measures are then taken as needed. Passive monitors are used throughout the facility to integrate dose in various areas. The results will be analyzed for objectionable doses and trends of increased doses, and shielding in these areas will be reevaluated and improved, as appropriate.

Shielding guidelines and requirements have been developed and submitted to the CATs to provide the basis for their beamline shielding designs (Ipe et al. 1993, Job et al. 1994). These requirements also form the basis for the ionizing radiation hazard analyses described in Section 4.2. The BRC will reevaluate all shielding designs that

do not conform to the criteria presented in the above referenced documentation. The APS policy for placement and maintenance of shielding requires formal configuration control. XFD implementation of this policy includes:

- Maintenance of controlled documentation of shielding penetrations and supplemental shielding configuration.
- Independent verification of removal and replacement of shielding before operation of the beamlines.
- Independent review of CAT beamline supplemental shielding design and calculations by experts in APS/XFD, APS/ASD, ANL ESH or other CATs.
- Determination of efficacy of shielding by radiation measurements during normal operation as well as during controlled simulation of worst-case photon beam loss scenarios.
- Administrative and hardware control of the beamline operating limits to prevent operation of the beamline outside the verified capability of the shielding.
- Ongoing review of the radiation environment and implementation of challenging but realistic ALARA goals by XFD and CAT managements.

All applicable beamline shielding design documentation and pertinent correspondence will be maintained as part of the Beamline Review Committee files for each beamline. A logbook of the beamline shielding configuration shall be maintained by the Floor Coordinator responsible for the beamline. Regular walkthroughs will be performed to verify that the shield logbook reflects the actual shielding configuration and that the required shielding security measures are in place.

The shielding guidance and requirements include the shielding provided by white beam stops and/or safety shutters located in the beamlines. Because of the high thermal loads, these devices require active cooling to maintain the shielding integrity. To ensure that the photon beam is shut off upon a decrease or loss of coolant, each channel of the PSS will be used to monitor an independent loss-of-cooling sensor. These two channels, together with the independent monitoring, in most cases, by the Equipment Protection System, provide two to three levels of protection redundancy. These requirements are stated in the APS White Beam Policy and the implementation will be reviewed and approved by the BRC.

3.4.2 Radiation Monitoring

The APS implements personnel and area radiological monitoring within the APS facility. It also participates in the ANL-E External Radiological Monitoring Program. This program, referred to as the ANL-E Environmental Monitoring Program, has been in operation since 1948, and monitoring results have been published in a series of annual reports (Golchert et al. 1992). These data provide a baseline for measuring impacts of present and future projects. The Environmental Monitoring Program is discussed in Chapter 8 of the APS Accelerator Systems Safety Assessment Document (ANL 1994a).

The radiation levels around the experimental beamlines are not expected to exceed levels that would require personnel monitoring devices as required by DOE/EH-0256T (DOE 1994). However, until all of the potential radiation hazards have been thoroughly analyzed and quantified, all workers will be required to wear personnel monitoring devices. These devices are issued, processed, and analyzed by the Dosimetry and Analysis Group of the ANL-E ESH Division (ESH-DA).

When not in use, the monitoring devices issued at the APS are returned to the designated rack. In compliance with ANL-E procedures, assigned personnel monitors are exchanged quarterly for new ones, and the used ones are read by ESH-DA personnel.

All visitors will be escorted while in the experiment hall. Temporary monitors are issued to APS visitors who will be present for short periods of time or on an irregular basis. Groups of visitors in the experiment hall use a single monitor assigned to the tour guide for the period. The monitoring device is returned to the Floor Coordinator or designee, with the names of the guide and the individuals in the tour.

4.0 HAZARD ANALYSIS

4.1 Hazard Analysis Methodology

The design and development of the APS and its technical components have been the result of an iterative review process established during the conceptual stages of the project. During the conceptual development of the APS, regular meetings were held to specifically address the safety of the design and the effects of the operation of the technical components. This process began with the identification of hazards, their evaluation, development of control or alternative mechanisms to address the identified hazards, and, where necessary, a revision of the design to assure that the hazards were eliminated or appropriately mitigated. As designs progressed and became more detailed, the safety review and revision process continued. This self assessment exercise has been supplemented by several independent evaluations by reviews called by both DOE and APS itself. The result is a design in which all safety concerns have been addressed.

This review process continues with the formation of the Beamline Review Committee (BRC). From the onset, the safety of the beamline components is evaluated as the components are designed. When assembled, the beamline components will be inspected by the BRC and the appropriate APS Safety Committees. Comments and guidance from each of these reviews provide input to the iterative process of safety design and procedures improvement.

The BRC conducts its evaluation in a systematic manner using the expertise of the committee members as well as the committee advisors. The initial safety analysis for each beamline is prepared by the CAT beginning with an assessment to identify all potential hazards for each system component. The estimated effect of each hazard is evaluated by the BRC with regard to its potential impact on personnel and on the operation of the facility. The analyses are based on a bounding event approach, where the most severe of each particular category of credible accident is analyzed to obtain worst-case results. Each event analysis included determination of the initiating occurrence, possible detection methods, the safety features that would prevent or mitigate the event, the probability of the event occurring, and the possible consequences.

The probability and consequence estimates of each hazard were made on the basis of best professional judgment. The probability rating levels are shown in Table 4.1. The consequence rating levels are shown in Table 4.2. The hazard risk was determined

using the matrix shown in Figure 4.1. The analysis was used to determine the adequacy of the facility and systems designs and formed the basis for the development of needed administrative controls. The following text provides a narrative description of the hazards.

The consequences of the APS operation, including conceivable accidents, present barely detectable off-site or environmental impacts. As a result, the APS has been designated as a low-hazard facility in accordance with DOE Order 5480.1B (DOE 1991a) by Dr. James F. Decker, Acting Director of the Office of Energy Research, on June 14, 1993.

Table 4.1 APS Beamline Risk Determination Summary

HAZARD	SECTION	PROBABILITY LEVEL	CONSEQUENCE LEVEL	RISK LEVEL
Ionizing Radiation	4.2	Low	Medium	Low
Nonionizing Radiation	4.3	Extremely low	Low	Negligible
Electrical	4.4	Low	Medium	Low
Fire	4.5	Medium	Low	Low
Vacuum and Pressure	4.6	Medium	Low	Low
Magnetic Fields	4.7	Low	Low	Negligible
Cryogenic	4.8	Low	Low	Negligible
Chemical	4.9	Medium	Low	Low
Oxygen Deficiency	4.10	Extremely low	Medium	Negligible
Noxious Gases	4.11	Low	Medium	Low
Mechanical	4.12	Medium	Low	Low

Table 4.2 Hazard Probability Rating Levels

CATEGORY	ESTIMATED RANGE OF OCCURRENCE PROBABILITY (YR ⁻¹)	DESCRIPTION
High	$>10^{-1}$	Event is likely to occur several times during the facility or operation lifetime
Medium	10^{-2} to 10^{-1}	Event may occur during the facility or operation lifetime.
Low	10^{-4} to 10^{-2}	Occurrence is unlikely or the event is not expected to occur, but may occur during the life of the facility or operation.
Extremely low	10^{-6} to 10^{-4}	Occurrence is extremely unlikely or the event is not expected to occur during the life of the facility or operation. Events are limiting faults considered in design.
Incredible	$<10^{-6}$	Probability of occurrence is so small that a reasonable scenario is inconceivable. These events are not considered in the design or SAD accident analysis.

Table 4.3 Hazard Consequence Rating Levels

CONSEQUENCE LEVEL	MAXIMUM CONSEQUENCE
High	Serious impact on-site or off-site. May cause deaths or loss of the facility / operation. Major impact on the environment.
Medium	Major impact on-site or off-site. May cause deaths, severe injuries, or severe occupational illness to personnel or major damage to a facility / operation or minor impact on the environment. Capable of returning to operation.
Low	Minor on-site with negligible off-site impact. May cause minor injury or minor occupational illness or minor impact on the environment.
Extremely Low	Will not result in a significant injury or occupation illness or provide a significant impact on the environment.

Figure 4.1 Risk Determination

4.2 Ionizing Radiation Hazards

4.2.1 Introduction

Both bremsstrahlung and synchrotron radiation will be present in the experiment hall. These two types of radiation have been further broken down (e.g., primary and secondary bremsstrahlung, white and monochromatic synchrotron radiation, etc.) for hazard analysis. Both bremsstrahlung and synchrotron radiation are produced behind the ratchet wall and reach the experiment hall floor by either coming through the ratchet wall or through a ratchet-wall penetration. Radiation coming through the ratchet wall was covered in the Storage Ring SAD (ANL 1994a) and will not be discussed here.

The synchrotron radiation coming through the ratchet-wall penetration is used by experimenters and, obviously, cannot normally be stopped behind the ratchet wall. A portion of the bremsstrahlung will be coincident with the synchrotron radiation and will make it through the ratchet-wall penetration whenever synchrotron radiation is being used. In what follows, the hazards associated with each radiation component will be identified, and the mitigation of the hazard discussed for the typical case of the Sector 1 insertion-device and bending-magnet beamlines.

The shielding requirements for the different types of radiation will depend on both the current and the energy of the stored particle beam. In each case, shielding analysis has been done for the potential operational parameters that require the greatest amount of shielding. The bremsstrahlung calculations have been performed for a beam current of 300 mA and a beam energy of 7.0 GeV. This corresponds to the operating envelope of the storage ring. But the shielding recommendations are scaled for a beam energy of 7.7 GeV and a beam current of 327 mA, which corresponds to the accelerator safety envelope. The synchrotron radiation (SR) calculations are for a beam current of 200 mA and for the beam energy of 7.5 GeV. However the recommended shielding for SR includes a tenth value layer more of the shielding material, which adequately covers operation at the accelerator safety envelope. Therefore for operation at the accelerator operating envelope, the shielding recommendations are conservative.

4.2.2 Bremsstrahlung

Bremsstrahlung is produced when the positron beam scatters from storage-ring components or residual-gas molecules in the storage-ring vacuum. Interactions with components occur primarily during injection or beam dumps. Scattering from residual gas occurs continually during storage ring operations.

Primary bremsstrahlung (PB) is defined as bremsstrahlung created by the particle beam and is, for the most part, unmodified by interactions with beamline components. Secondary bremsstrahlung (SB) is created when PB is scattered from beamline components resulting in a change in direction and energy distribution. The mitigation of the hazards associated with PB and SB is somewhat different and will be discussed separately.

For bremsstrahlung calculations, a storage-ring energy of 7 GeV and a storage-ring current of 300 mA have been used unless explicitly noted otherwise (Ipe et al. 1993). This corresponds to a stored beam energy of 7735 Joules, which is defined as the accelerator operating envelope. The accelerator safety envelope is 20% more than the operating envelope (9280J) and appropriate allowance in the bremsstrahlung shielding recommendations is given. The design dose rate depends upon occupancy and will be taken to be 2.5 $\mu\text{Sv/h}$ (.25 mrem/h) where 2000 h/year is assumed. For situations of limited occupancy, the assumed occupancy will be noted and the design dose rate given.

4.2.2.1 Primary Bremsstrahlung

Description

Primary bremsstrahlung (PB) consists of photons with an energy spectrum that approximately follows a $1/E$ form (where E is the photon energy), with the maximum energy being equal to the storage-ring particle energy. PB emerges in a very narrow cone tangential to the positron-beam path with a characteristic emission angle of 73 μrad . Hence, the PB beam will be a few millimeters in diameter anywhere along the beamline. The total beam integrated gas bremsstrahlung dose rate from the insertion-device vacuum chamber was calculated by the semiempirical equation (Job et al. 1994):

$$D = f N I / \pi \alpha^2 X_0 L (L+1),$$

where:

D = total beam integrated dose rate for the gas bremsstrahlung in Sv/h
 f = an effective flux-to-dose conversion factor for bremsstrahlung photons,
(3×10^{-6} Gy/h. ϕ)
 α = ratio of positron rest mass to its kinetic energy
 $= 0.511 / 7000. = 7.3 \times 10^{-5}$,

N = the number of positrons for the beam current 300 mA,

$$\begin{aligned} &= (1.8726 \times 10^{18} \text{ /sec}) \\ X_0 &= 2.34 \times 10^{16} \text{ cm, radiation length of air at } 10^{-9} \text{ torr} \\ l &= \text{effective length of the straight section} \approx 1500 \text{ cm} \\ L &= \text{distance from the end of the straight section to the observation point} \\ &= 2460 \text{ cm} \end{aligned}$$

The total beam-integrated gas-bremsstrahlung dose rate is calculated to be 2.2 Sv/h (220 rem/h) in an unshielded ID beamline. The bending-magnet dose rate can be deduced by scaling by the appropriate effective straight-section length. This factor is estimated as approximately 33. There are other semiempirical formulae available to calculate this quantity. The calculated values have also been compared with the measurements. The measurements so far show that the semiempirical predictions are conservative.

Mitigation

Personnel are protected from PB by the use of shutters, stops, collimators, enclosures, and beam pipes.

Safety Shutters

A safety-shutter system is located in the front end of all APS beamlines and can be closed by the APS (during injection for example) or the user. When closed, the safety shutter allows essentially no PB to come through the ratchet wall penetration, making it possible for the user to access areas not otherwise protected from PB or synchrotron radiation (e.g., the inside of the FOE). Obviously, no experiments utilizing synchrotron radiation can be carried out while the safety shutters are closed. The composition and size of the safety shutters are covered in the Storage Ring SAD.

Bremsstrahlung Stops

During experimental operations, the PB is contained by bremsstrahlung stops, which are an integral part of all beamlines. Typically, a stop consists of a cooled photon stop to catch the synchrotron beam and a block of lead or tungsten to stop the bremsstrahlung. The PB will scatter from both components and create SB, whose mitigation is discussed in the next section.

A recent APS technical bulletin (Job et al. 1994) details the calculations used to design bremsstrahlung stops at the APS. A summary of the calculations and results is provided here.

A characteristic of interactions of high-energy photon beams and thick targets is that an electromagnetic shower is produced. A Monte Carlo computer program EGS4 (Nelson et al. 1985) was used to track the various products of the shower through given targets. A difficulty arises when trying to determine the amount of transmission through the very thick targets that are needed for bremsstrahlung stops. For a block of tungsten or lead 20 cm or 25 cm thick, the dose from PB is reduced several orders of magnitude, making it very difficult to get enough events to calculate dose values with reasonable levels of statistical errors. To carry out a thorough study of several potential bremsstrahlung stops would require a prohibitive amount of computer resources.

To alleviate the statistical difficulties, the transmission through various thicknesses of 20 cm by 20 cm blocks (of lead or tungsten) was estimated by using EGS4 to estimate the transmission through a 10-cm thick block and then using a simple exponential absorption formula to calculate the amount of photons absorbed in the remaining portion of the block. It was assumed that 10 cm would be sufficient for the shower to fully develop and that additional material would only cause pure attenuation. The validity of the process was checked by using a full EGS4 calculation of transmission through blocks of 15 cm and 20 cm. The results, which are reproduced in Figure 4.2, show that the assumptions work very well. (In Figure 4.2, the error bars associated with the lead stop are smaller than the symbols used in the plot.) The results show that a tungsten block of 20 cm and a lead block of 30 cm are more than adequate to reduce the dose rates to a level of $1.25 \mu\text{Sv/h}$ ($.125 \text{ mrem/h}$) even for operation at the accelerator safety envelope, (this corresponds to an additional lead thickness of 4 mm and a tungsten thickness of 2.5 mm). Here, $1/2$ of the dose-rate limit ($1.25 \mu\text{Sv/h}$ [$.125 \text{ mrem/h}$] out of $2.5 \mu\text{Sv/h}$ [$.25 \text{ mrem/h}$]) has been left for PB-generated neutrons. The subject of generated neutrons will be covered in the section on SB.

Collimators

Most beamlines at the APS will have monochromatic beam stations downstream of the FOE or a white-beam station. In these situations, a double-crystal monochromator (typically in the FOE) will usually be used to produce a monochromatic beam parallel to, but offset from, the white beam (and hence, PB). Downstream of the monochromator, the PB will be stopped inside the FOE, while the monochromatic beam is allowed to go downstream to the monochromatic station. Experimental concerns sometimes make it desirable to minimize the amount of offset between the white and monochromatic beams.

The scatter from a tungsten block comprising a bremsstrahlung stop and a monochromatic-beam collimator was studied to determine the adequacy of shielding

Figure 4.2 Dose Rates at the Back of Thick Lead and Tungsten Targets Due to the Incident Bremsstrahlung

Dose rates at the back of the thick lead and tungsten targets due to the incident bremsstrahlung. The transverse dimensions of the solid block of metal are $20 \times 20 \text{ cm}^2$. The 30-cm -thick tissue is at 30 cm from the downstream side of the target.

(Job et al. 1994). Figure 4.3 is a schematic of such a stop/collimator. The pertinent distance for this study is not the separation of the white beam from monochromatic beam but rather the separation between the farthest possible upward excursion of the white beam and the edge of the bottom edge of the slot (assuming a positive vertical offset).

The code EGS4 was used to study a PB beam incident on a tungsten block 18 cm thick, 15 cm high, and 20 cm wide. The slot in the block was 4 cm horizontally, 1 cm vertically, and 9 cm from the bottom edge of the block. Three cases were studied, where the PB beam was 5 mm, 8 mm, and 10 mm below the bottom edge of the slot. The dose from each case was calculated for three locations in a real beamline application (the APS 1-ID beamline). These locations are shown in Figure 4.4. Table 4.4 gives the results for the three beam positions at each of the locations. For the "1" and "2" positions (shown in Figure 4.4), the assumption of 100% occupancy is too drastic, with 10% being a better, but still conservative estimate. With this occupancy assumption, a 10-mm offset is fully adequate in all calculated situations. Again, as above, 1/2 of the dose-rate limit has been left for PB-generated neutrons. For smaller offsets, the occupancy will need to be limited to less than 10% or additional shielding will need to be added.

In this study, there are some conservative a priori assumptions that should be noted. The PB will always have to go through a photon stop (typically a thick piece of copper) prior to striking the bremsstrahlung stop. Any beneficial effect of absorption by the photon stop has not been used in this study. Additionally, the PB beam is taken to be at the farthest extent of its range. The amount of time that the positron beam can be at the position to give rise to this situation is certainly well below the 100% assumed for this study.

Collimators, Enclosures, and Beam Pipes

Personnel are prevented from placing themselves into the PB beam by enclosures or beam pipes. An enclosure or beam pipe is not used to stop PB directly but does prevent access to the beam. The SB generated by the PB is stopped by enclosures and beam pipes. Collimators are used to keep the PB beam from directly striking the walls of enclosures or beam pipes. The dimensions and composition of a collimator are the same as for a bremsstrahlung stop, with a slot to allow the beam to pass through. A collimator is usually protected from the synchrotron beam by a cooled photon aperture.

Figure 4.3 Diagram of the Mono-Beam Aperture and Bremsstrahlung Stop

Diagram (side view and front view) of the mono-beam aperture and bremsstrahlung stop. This is made of tungsten and is a part of the integral shutter.

Figure 4.4 Diagram of the White-Beam Station of the 1-ID-B Beamline

Diagram of white-beam station of 1-ID-B beamline

Table 4.4 Summary Results for the Mono-Aperature

Beam offset (cm)	Dose Rates ($\mu\text{Sv/h}$)			
	at the aperture	at the back ^(a) wall of FOE	in the ^(b) beamline	outside WBS ^(c) on the pipe
0.5	300.0	37.5	27.2	0.64
0.8	200.0	25.0	18.2	0.43
1.0	100.0	12.5	9.1	0.21

(a) At the back wall of the FOE, in the white-beam enclosure, close to the beam pipe. The beam pipe is unshielded in this case.

(b) In the white-beam enclosure, right in the beamline.

(c) Outside the white-beam enclosure, on the beampipe. The beampipe is shielded by 8-mm lead.

Beamline Layout

As an example for the general beamline layout, the upstream end of the SRI-CAT Sector 1 insertion-device beamline is shown in Figures 4.5 and 4.6. Important components for PB protection are the stop/collimators (P4, P5) and the collimators (K1), as well as the white beam enclosures (1-ID-A, 1-ID-B). In Sector 1, the white-beam hutches are directly attached to the FOEs, alleviating the need for white-beam transport on the open experiment hall floor.

Ray Tracing

Bremsstrahlung ray traces for the Sector 1 ID beamline are shown in Figures 4.7 and 4.8. The source size used for these traces is essentially the line of sight from anywhere on the storage ring through the front ends. This is a very conservative assumption but was used in lieu of doing a complicated analysis to yield a smaller source.

Mirror as the First Optical Device

Some APS ID beamlines (e.g., 2-ID) will use a mirror as the first optical component and then pass the resultant "pink" beam downstream to an experimental station. The mirror in this situation separates the PB beam from the synchrotron beam and allows the PB to be stopped and the synchrotron beam to be passed downstream. In this situation, the separation between the PB beam and the synchrotron beam increases with distance downstream from the mirror (unlike the double-crystal monochromator setup described above where the two beams are parallel with a constant offset).

White-Beam Transport

The white-beam transport through the experimental floor requires collimators at definite intervals in the beamline to contain the PB depending on the bremsstrahlung ray tracing. These collimators may also require upstream and downstream collars to contain the SB (Job et al. 1994).

4.2.2.2 Secondary Bremsstrahlung

Secondary bremsstrahlung is created whenever a PB beam encounters a component. The variety of circumstances along a beamline where this can occur makes the determination and mitigation of SB somewhat complicated. In this section, several SB situations will be described and the measures to take to eliminate the hazard discussed.

Fig. 4.5 Layout of Equipment in 1-ID-B (Plan View)

Figure 1ID-16 Layout of equipment in 1-ID-B: plan view.

F2-30 - ID BL Filters
L1 - U./W. White Beam H & V Slits

V1 - APS Differential Pumping System
V2-87 - CF150-100 ID100X200 Bellows
W3 - ID BL Window CF100

K1 - ID FE Collimator
P4 - ID White M. Stop & Integral
Shutters

V2-83 - GF150 150 ID100X175 Bellows
V2-95 - CF200-200 ID150X230 Bellows
OCM1 - 1-ID Double Crystal
Monochromator

Fig. 4.6 Layout of Equipment in 1-ID-A (Side View)

Figure 4.7 Bremsstrahlung Ray Trace (Horizontal)

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Figure 4.8 Bremsstrahlung Ray Trace (Vertical, Monochromatic Beam)

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The cases studied represent the broad class of SB problems that will arise during beamline operations.

Normal Incidence Copper Targets in FOEs

The technical bulletin ANL/APS/TB-7 (Ipe et al. 1993) gives an example of how to calculate the shielding for a 5-cm-thick block of copper placed at the upstream end of an ID FOE. The copper block is meant to represent a likely beamline component, such as a slit, shutter, or valve. The dose from such a target is strongly peaked in the forward direction, hence the worst-case situation, under these conditions, is when the target is placed as far upstream as is practical.

The dose rate from the copper block was calculated as a function of angle using EGS4, and then a simple absorption formula was used to calculate the required lead thickness. The conclusion of this study was that the downstream wall of the FOE needs 100 mm of lead in an area 1 m^2 around the PB direction and 50 mm of lead for the rest of the wall. For the lateral wall and ceiling, the lead required for SB is less than that needed to shield for synchrotron radiation.

For bending-magnet beamlines, the results for the ID beamline were scaled by the effective length of the straight sections (i.e., 15 m for the ID and 0.234 m for the bending magnet). It was then found that the SB determines the shielding only for the downstream wall in an area 1 m^2 around the PB direction where 24 mm of lead is required (Ipe et al. 1993).

Bremsstrahlung Stops

The SB dose produced by a PB beam striking a lead bremsstrahlung stop is shown in Figure 4.9 (Job et al. 1994). The scattering from tungsten is similar. The only significant doses are from back scatter (i.e., in the upstream direction from the bremsstrahlung stop). For stops located inside FOEs or white-beam enclosures, the combination of distance and the shielding needed to reduce the dose from synchrotron-radiation adequately reduce the SB dose. For a stop on the open experiment hall floor, a collar of lead 4.5 cm thick will be added around the 10 cm of beam pipe immediately upstream of the stop (Job et al. 1994).

Secondary Bremsstrahlung from Mirrors

The SB generated when PB strikes a mirror presents a different set of challenges than the SB from a normal-incidence target. An analysis of the shielding for the specific

Figure 4.9 Dose Rates Due to the Back Scattering of the Bremsstrahlung
from a Thick Lead Target

Dose rates due to the back scattering of the bremsstrahlung from a thick lead target. The integrated dose over the azimuthal angle is given.

situation of the SRI-CAT 2-ID beamline is given in the APS technical bulletin (Yun et al. 1995).

The SB scatter from a glancing-incidence target, such as a mirror, is significantly different than that from a normal-incidence target. EGS4 was used to calculate the SB for the geometry shown in Figure 4.10. Calculations were made for two different mirror substrates: silicon and copper. It was found that the Si substrate produced considerably more scatter than a Cu one. In both Si and Cu, the depth that the PB beam travels is adequate to allow an electromagnetic shower to fully develop, but the absorption of the SB scatter in the silicon is smaller. This is a general trend that should hold for other materials, i.e., mirrors made of light materials will produce more scatter than those made of heavy materials. Because mirrors are replaceable items, shielding should be designed for a substrate made of a low-Z material. The calculated SB from a Si substrate hit by a PB beam at an incidence angle of 0.15° is shown in Figures 4.11 and 4.12.

As discussed above, the synchrotron beam separates from the PB beam at an angle that is twice the incident angle. Unless the synchrotron beam is redirected by another optical device, some of the SB will travel with the synchrotron beam. The shielding for this situation must be tailored for the specific beamline situation, involving tight collimation and an additional shielding collar around the downstream beam pipe.

Beam Pipes

For a beamline with white-beam transport on the open experiment hall floor, SB can normally occur in two ways, 1) by striking a component such as a slit or the beam pipe itself, or 2) by hitting gas molecules inside the beam pipe. In the first case, ray traces are used to determine where the PB beam may encounter solid objects and appropriate local shielding (e.g., shielded cabinets) is added. Proper collimation of the PB beam can substantially reduce the area where SB can be generated.

Interaction of the PB beam with gas in the beam pipe produces a negligible dose, even when the gas is at atmospheric pressure (Job et al. 1994).

Collimators

Secondary bremsstrahlung is generated when PB encounters a collimator on the open experiment hall floor. The technical bulletin ANL/APS/TB-20 (Job et al. 1994) addresses this issue. The worst case for this situation is shown in Figure 4.13. The dose from this geometry was calculated with EGS4, with the results shown in Figure

Figure 4.10 Schematic of the Geometric Parameters of the Si Mirror
Considered for Beamline Shielding

Schematic of the geometric parameters of the Si mirror considered for beamline shielding and the coordinates used in this report. The Z axis is along the direction of the primary BR.

Figure 4.11 The Results of EGS4 Calculation for SB from a Si Substrate Hit
by a PB Beam at an Incidence Angle of 0.15° (Vertical View)

Figure 4.12 The Results of EGS4 Calculation for SB from a Si Substrate Hit
by a PB Beam at an Incidence Angle of 0.15° (Horizontal View)

Figure 4.13 Diagram of the Configuration Used for the EGS4 Calculation

Diagram of the configuration used for the EGS4 calculation to estimate the dose rates on the beam pipe due to the missteered beam hitting the downstream edge of the collimator. The beam is incident at an angle of 4.5° and is 3 cm away from the edge. This allows the electromagnetic shower to fully develop.

4.14. Table 4.5 gives the additional shielding needed on the downstream side of the collimator to reduce the dose to acceptable levels.

Shielded Cabinets

A calculation of shielding for cabinets that are used to cover components on the open experiment hall floor can be made following the same procedure as that described above for targets in FOEs. The distances from target to walls must be scaled appropriately.

Bremsstrahlung Generated Neutrons

When the PB interacts with high-Z materials in the beamline, neutrons are produced. There are three modes of neutron production by the bremsstrahlung. At low energies (10 - 30 MeV), photons are absorbed by the dipole interaction (giant resonance), and the compound nucleus thus formed decays emitting protons and neutrons. At higher energies, the cross section for this interaction decreases rapidly. PB of energy between 50 - 300 MeV, interacts with the nucleus, ejecting out a deuteron, which subsequently decays producing a neutron and proton pair. At energies higher than 300 MeV, the neutron production is by an intranuclear cascade and subsequent evaporation of the nucleus. Except for the giant resonance process, the cross sections for other interactions at higher energies are not readily available. These cross sections are calculated from nuclear models. However, calculations show that the photoneutron spectra are dominated by the giant resonance component ($\geq 70\%$). These neutrons have an energy distribution between 1 to 20 MeV.

The dose rates due to the PB-generated neutrons from the tungsten stops in the APS beamlines are estimated by the PICA (Gabriel et al. 1991) code. The typical dose rate outside an ID first optical enclosure is $7.5 \mu\text{Sv/h}$ ($.75 \text{ mrem/h}$). In order to reduce this dose to $1.25 \mu\text{Sv/h}$ ($.125 \text{ mrem/h}$), 11.4 cm of a neutron-stopping material, like high density polyethylene, is necessary. The photoneutron production in the bending-magnet beamlines is small and can be scaled accordingly.

4.2.3 Synchrotron Radiation

The primary purpose of the APS is to produce high quality synchrotron radiation. This raises some radiation-hazard issues that will be addressed in this section. Synchrotron radiation at the APS falls into two categories: insertion-device (ID) radiation and bending-magnet radiation. For synchrotron-radiation calculations, a storage-ring energy of 7.5 GeV and a storage-ring current of 200 mA have been assumed in all cases. These parameters were chosen for the simulation of the synchrotron radiation

Figure 4.14 The EGS4 Results for the Dose Rates in Tissue Due to the Beam Hitting the Downstream Edge of the Collimator

The EGS4 results for the dose rates in the tissue due to the beam hitting at the downstream edge of the collimator. The tissue is in contact with the collimator. In this plot the 90° angle is the beam direction.

Table 4.5 Thickness of the Collar for the Collimators

Distance from ^(a) the collimator	Thickness of ^(b) lead collar
0.0 cm	4.9 cm
10.0 cm	3.4 cm
15.0 cm	2.6 cm
20.0 cm	1.8 cm
25.0 cm	1.8 cm
47.0 cm	1.3 cm

(a) The missteered beam hits close to the downstream edge of the collimator. The distance is from the downstream edge of the collimator.

(b) In calculating the thickness 'the angle of incidence effect' [13] has been taken into consideration.

because they proved to be a worse case than the 7.0-GeV, 300-mA case. In addition, to accommodate operation at the accelerator safety envelope, the recommended shielding thicknesses include an additional tenth value layer of the shielding material.

The specifications for bending-magnet radiation is straightforward, as it is defined by the storage-ring energy and current. The ID radiation is harder to define, because of the ability to use different IDs (i.e., wigglers, undulators), and to change the gap of an ID once installed. It is an APS policy to use the spectrum for the APS Wiggler A at a gap of 21.5 mm for all ID synchrotron-radiation shielding analyses. Wiggler A at this gap is taken as the worst likely operating condition. Exceptions to this policy, when warranted, are explicitly noted.

Undoubtedly, situations will arise at the APS where creative use of x-ray optics produces beams that do not fall cleanly into one of the categories described above. An example of this would be the use of multilayers to produce a wide-energy bandpass beam. In these situations, an analysis will be made to ensure that the various aspects of the beamline (i.e., stops, shutters, transport, enclosures) are adequate to mitigate the radiation hazard. This analysis will be made using the same basic tools (e.g., PHOTON, Chapman et al. 1988) that were used for the studies that are discussed below.

The mitigation of synchrotron radiation hazards will be discussed in two parts: direct synchrotron radiation and scattered synchrotron radiation.

4.2.3.1 Direct Synchrotron Radiation

White Beam

The unmodified white beam is always coincident with the primary bremsstrahlung beam. The steps that need to be taken to handle the PB are much more than adequate to stop the synchrotron white beams. Usually, a photon stop will be used to protect the bremsstrahlung stop from the heat carried in the synchrotron beam. As in the PB case, personnel are prevented from placing themselves into the white beam by enclosures or beam pipes.

Monochromatic Beam

For the purposes of radiation safety analyses, a monochromatic beam is defined as a beam with an energy bandpass ($\Delta E/E$) of 0.1% and includes all the higher harmonics of

the beam (i.e., if a 111 Bragg reflection produces a diffracted beam at 8 keV, the 222 will give a beam at 16 keV, the 333 at 24 keV, etc.).

Stops/Shutters

At the APS, shutters are always redundant; that is, there are two blocks of shielding material that are actuated with independent mechanisms whenever a shutter is closed or opened. The status of each block will be monitored by two or more limit switches for additional security. Any fault read by the limit switches will cause the PSS to trip. For a stop, which by definition is not moveable during operations, only one block of material is used. (A stop may have its position changed during a change of "mode", in which case it is controlled through use of Kirk keys or similar lockout devices.)

For routine operations, both blocks of a shutter system are assumed to be in place and the dose must be limited to less than $2.5 \mu\text{Sv/h}$ ($.25 \text{ mrem/h}$). In an abnormal situation in which only one block is providing protection, a conservative occupancy factor of 10% is assumed and each block must be capable of reducing the dose rate to $25 \mu\text{Sv/h}$ (2.5 mrem/h) by itself.

The PHOTON program was used to calculate the required amount of tungsten for monochromatic stops and shutters. ID monochromatic beam stops require 7.7 cm of tungsten and shutters 6.5 cm of tungsten. Bending-magnet stops and shutters require 2.1 cm and 2.7 cm of tungsten, respectively.

Transport

If a monochromatic beam hits the wall of a beam pipe, the shielding for the beam pipe is much more than sufficient to stop the direct synchrotron beam. This is due to the large increase in effective thickness of the shielding when the beam hits the shielding at a glancing angle.

Enclosures

Bragg-scattered beams will be scattered out of the beam path and hit the sides of an enclosure on a regular basis. However, for angles greater than a few degrees, the radiation in these beams is relatively soft ($< 50 \text{ keV}$) and will not make it through the shielding present for Compton-scattered photons.

Mirror-Modified Beam (Pink Beam)

Stops/Shutters

Mirrors essentially work as low-pass beam filters. Downstream of the mirror, the number of photons in the beam with energies above the mirror's energy cutoff (typically 20 keV, rarely above 30 keV), will be reduced by several orders of magnitude. Normally, this will reduce the stop and shutter thickness required for a "pink" beam to less than that for a monochromatic beam. The exact amount of shielding needed depends upon the minimum possible reflection angle from the mirror and will be calculated for each case.

Transport

The same comments for the pink-beam stops/shutters apply to the transport.

4.2.3.2 Scattered Synchrotron Radiation

The direct synchrotron radiation traveling down a beamline will scatter from every component it strikes. For the purposes of this discussion, scattering is considered to be inelastic scattering; i.e., it does not include Bragg scattering. To determine the necessary shielding for the scattered synchrotron radiation, the PHOTON program was used.

PHOTON calculates doses using the following procedure:

1. Calculate the photon flux as a function of energy and vertical opening angle of the synchrotron beam.
2. Attenuate the beam for any filters.
3. Scatter from a chosen target.
4. Convert the resulting photon flux to dose.

Within PHOTON, several assumptions are made.

The scattered photons are assumed to come from Compton scattering. With regards to shielding, only relatively high-energy photons (> 50 keV) are of much consequence. For these photons to scatter at significant angles (i.e., to hit the side of a hutch), Compton scattering is by far the dominant process.

In PHOTON, an isotropic point scatterer is assumed and the total angle-integrated

Compton cross-section is used to calculate the scattered photon spectrum. The isotropic-point assumption is reasonable for measurements well away from the source. This is true for most cases in beamline shielding (transport is an exception). In fact, Compton scattering is not isotropic; the scattering becomes increasingly forward directed for higher energies. This assumption will tend to overestimate the scattering at large angles and underestimate the scattering in the forward direction.

Additionally, no polarization dependence of the incident beam is recognized. Because the synchrotron beam is normally highly polarized in the horizontal plane, the horizontal scattering will be overestimated and the vertical scattering underestimated (especially at angles approaching 90°). Because personnel are usually located in the horizontal direction from the scattering source, the omission of polarization dependence becomes a conservative estimate.

The "narrow-beam" attenuation coefficient of the shielding material is used. This will ignore build-up factors of scattered photons. For photons up to several hundred keV shielded by lead, the use of the narrow beam coefficient will have a small effect on the calculation.

Finally, PHOTON calculates the flux for a bending-magnet source. This can be used to approximate a wiggler by multiplying the spectrum by the number of poles (twice the number of periods). This overestimates the horizontally off-axis flux. The PHOTON2 program is a modified version of PHOTON that calculates the wiggler spectrum using the proper wiggler horizontal beam distribution. A comparison of the results is shown in Figure 4.15. (PHOTON2, at the time of these calculations, could not do all the shielding estimates that are part of PHOTON. Therefore it was only used for comparative purposes.)

The combination of all these factors indicates that use of PHOTON should overestimate the scattering in the horizontal plane from a wiggler. Experimental results confirm this (Braeuer et al. 1988).

Experimental Enclosures

PHOTON was run for three targets (air, copper, and lead), with several thicknesses for each. Based on the results, a target of copper 30 cm in length was chosen to be representative. (The scattering from 3-cm and 30-cm targets was essentially the same.) The modeled experimental enclosure had the scatterer 1 m from the walls (lateral, upstream, and downstream) and 1.5 m from the roof. Because of the PHOTON assumptions

Figure 4.15 Comparison of PHOTON and PHOTON2 Spectrums
for the APS Wiggler A

Comparison of PHOTON and PHOTON2
spectrums for the APS Wiggler A.

discussed above, the scatter in the forward direction (toward the downstream wall) may be underestimated. To account for this, the amount of shielding needed to reduce the dose an order of magnitude (one tenth value layer), was calculated and added to the specification for shielding of the downstream wall.

Transport

PHOTON was used to calculate two scenarios for beamline-transport shielding: air scattering due to loss of vacuum and the scatter from the beam hitting a solid object (including the beam pipe).

The vacuum-loss calculations were made with the equivalent 30 cm of air at 1 atm as a target. The beam pipe was assumed to be 10 cm in diameter. Under normal conditions, negligible scattering will result from residual air in an evacuated beam pipe. However, because the vacuum level for beamline transport will not normally be part of the personnel safety system, the accidental venting of a beamline must be considered.

It is highly probable that a vacuum loss will be detected after a short time because of the resulting diminished flux to the user. In any case, significant scattered radiation will be found by periodic beamline radiation surveys. Using an estimated 10% occupancy in a vacuum loss situation leads to a design limit of 25 $\mu\text{Sv/h}$ (2.5 mrem/h).

For beamline transport, if ray tracing shows that the beam will not strike a solid object, only the vacuum-loss shielding is necessary. Where a solid object may be encountered, the experimental enclosure results (given above) can be scaled to determine the appropriate shielding.

Shielding Recommendations

White Beam

ANL/APS/TB-7 (Ipe et al. 1993) gives shielding recommendations for a model FOE. Many white-beam enclosures closely resemble this situation and can use the recommendations directly. For enclosures that differ significantly, the analysis for the model FOE can be easily modified using different scatterer-wall distances. The following specifications are for the model FOE.

For ID white-beam enclosures, the shielding of the downstream wall is determined by bremsstrahlung. The PHOTON analysis of the synchrotron radiation shows that a lead thickness of 16 mm and 12 mm for the lateral wall and roof, respectively. In

ANL/APS/TB-7, an additional 3 mm of lead is added to the lateral wall for a safety margin, leading to a recommended value of 19 mm of lead for lateral walls. If the upstream wall of the enclosure is not the ratchet wall, the same amount of lead must be used there as in the lateral walls.

For bending magnet white-beam enclosures, only the area 1 m^2 around the direct beam direction is determined by bremsstrahlung. For synchrotron radiation, PHOTON analysis was used to recommend lead of 9 mm for the downstream wall, 8 mm for the lateral wall (and upstream wall if required), and 6 mm for the roof.

Monochromatic Beam

The ID monochromatic enclosures of model size require lead of 12.5 mm for the downstream wall, 10 mm for the upstream and lateral walls, and 6 mm for the roof. Similarly, the bending-magnet monochromatic enclosures require lead of 7 mm for the downstream wall, 6 mm for the upstream and lateral walls, and 4 mm for the roof.

Pink Beam

The comments above on pink-beam direct stops/shutters apply to the pink-beam enclosures. Monochromatic-beam station shielding is adequate for pink-beam enclosures.

4.2.4 Loss of Vacuum Incident in the Storage Ring

The primary gas bremsstrahlung produced in the ID beamlines is a function of the gas pressure in the storage ring. Bremsstrahlung scattering calculations reported in ANL/APS TB-20 (Job et al. 1994) corresponds to an ID chamber vacuum of 10^{-9} torr. A loss of vacuum in the storage ring can considerably increase the bremsstrahlung dose rates in the beamlines. The total dose received by a person outside of an FOE, near a bremsstrahlung stop, has been calculated in the event of a complete loss of vacuum in the storage ring. For the calculations reported here, the storage ring is assumed to be at a pressure of 760 torr and the entire stored beam energy of 9282 Joules, the accelerator safety envelope, passes through one of the ID chambers.

The total beam-integrated bremsstrahlung power has been estimated as 1.97 mwatts for the storage ring vacuum of 10^{-9} torr and for a beam current of 300 mA at the positron energy of 7 GeV. The beamline bremsstrahlung stops are designed in such a way that the dose rates at any given time during operation is $2.5 \text{ } \mu\text{Sv/h}$ (0.25 mrem/h) outside the enclosure. The dose rates can be scaled appropriately for the dose rates

corresponding to an instantaneous energy deposition of 9282 Joules. It is conservatively assumed in this calculation that all the kinetic energy of the beam is converted into bremsstrahlung. The calculated instantaneous dose outside the enclosure in the event of a loss of vacuum in the storage ring will not exceed 350 mrem. This is assumed to be the worst-case scenario because :

- The calculations are for the maximum beam energy and current at the accelerator safety envelope.
- All the kinetic energy of the positron beam is converted into bremsstrahlung.
- All the bremsstrahlung is produced from one insertion device.
- The loss of vacuum takes place instantaneously.

4.2.5 Ionizing Radiation Hazard Summary

A significant amount of guidance on shielding requirements has been provided to the CATs for shielding design. This guidance is based on the shielding criterion adopted at the APS, which requires that the dose rates be $\leq 2.5 \mu\text{Sv/h}$ (0.25 mrem/h) at 30 cm from the secondary radiation sources at the accelerator safety envelope operation. However, for shielding the scattered synchrotron radiation, the recommended shielding thicknesses include an additional tenth value layer of the shielding material. This makes the shielding recommendations extremely conservative.

The shielding requirements provide the basis for the criteria that must be met by the CATs in the design of their beamlines. The beamline designs are subject to the BRC reviews at the preliminary and final design levels. The APS designs the Personnel Safety System interlocks, which ensure that personnel will not enter the interlocked areas. The APS will maintain a continuous surveillance of the beamline operating conditions. Personnel will be trained to understand the specific radiation hazards and specific procedures for each beamline operation. Therefore the probability of occurrence of a serious radiation hazard has been determined to be low. The ionizing radiation doses have also been determined to be low. Consequently the risk factor from ionizing radiation is deemed to be extremely low.

4.3 Nonionizing Radiation Hazards

4.3.1 Laser Hazards

Low power (Class I) lasers may be used for alignment of beamline components. These low power devices do not present safety problems and will be used in compliance with the existing ANL ES&H Manual (ANL 1991a). Other uses for lasers may be included in the various beamline designs. These will be addressed as part of the beamline review process to ensure compliance with the existing ANL ES&H Manual.

The users of all lasers will be required to complete appropriate operator training, and operating procedures will be required to be in place. Therefore, the probability of occurrence of a nonionizing radiation hazard has been determined to be extremely low. The nonionizing radiation hazard consequence has been determined to be low. Therefore the risk is negligible.

4.4 Electrical Hazards

The electrical power distributed to the beamlines is available primarily from a 115/208 volt system. The installation of this system conforms to all applicable codes and requirements. All beamline equipment must also conform to codes and requirements. Any noncommercial equipment used on the beamlines must pass an electrical inspection by the CAT safety personnel and must conform to ANL requirements.

High power or high voltage equipment may be included in the design of certain beamlines. The beamline review process will identify such equipment, and additional safety requirements (such as emergency shutdown buttons) will be placed on the CAT to comply with all necessary regulations.

All personnel performing service on beamline equipment will be required to receive training in and to adhere to ANL lockout/tagout policies. Compliance with the electrical safety requirements will be strictly enforced. Therefore, the probability of occurrence of an event due to electrical hazards has been determined to be low. The consequence from an electrical hazard has been determined to be medium. Therefore the risk is low.

4.5 Fire Hazards

No significant fuel sources for fire are located or will be permitted on the floor of the experiment hall. All potential fire sources will be reviewed during the review process, and, if required, additional methods for minimizing the fire hazard will be implemented by the CAT. All APS buildings have been provided with fire alarm and detection systems and automatic sprinkler systems, which are adequate to minimize the fire hazard. See Section 3.1.5 of the APS Accelerator System Safety Assessment Document for a complete description of the facility fire protection.

Although the probability of a fire has been determined to be medium, the existing fire protection together with any additional protection resulting from the review will ensure the consequences of a fire will be low. Therefore the risk due to fire is low.

4.6 Vacuum and Pressure Hazards

The beamline will generally be maintained and operated under vacuum. The vacuum requirements for the beamline are not as stringent as they are for the storage ring; therefore, for most beamlines, the required vacuum will be between 1×10^{-4} and 1×10^{-9} Torr. Implosion of any vacuum component could pose a possible health risk from small flying objects. All vacuum components in the system are made of heavy wall material and pose little threat of implosion when evacuated.

Vacuum gate valves are driven by compressed air. Should the connections fail, compressed air could escape, possibly resulting in small flying objects. Adequate protection will be required in all compressed air lines to prevent over pressurization.

The CAT will be responsible for identifying potential hazard locations and providing the proper posting, operator training, and operating procedures. The APS will review the adequacy of the CAT training and procedures.

Mechanical-type hazard events generally have a higher probability of occurring; therefore, the probability of occurrence of vacuum- or pressure-hazard events has been determined to be medium. The hazard event consequence has been determined to be low. Therefore the risk is low.

4.7 Magnetic Fields

No magnetic devices, other than standard small motors or vacuum pumps, are expected to be used in beamlines. However, specialized beamlines may include devices capable of producing magnetic fields capable of posing a safety hazard. These devices will be reviewed by the APS, and, if required, the CAT will prepare posting plans and any other necessary methods for mitigating the hazards.

The probability of occurrence has been determined to be low. The consequence has been determined to be low. Therefore the risk of magnetic field hazards is negligible.

4.8 Cryogenic Hazards

Cryogenic systems may be utilized as part of the operation of the beamlines. Primary applications consist of liquid nitrogen transfer from various size dewars for use in vacuum leak detectors, cryogenic vacuum pumps, etc. The APS will provide appropriate procedures, as well as insulated gloves and safety goggles and/or face shields, at main transfer locations. All personnel involved in these operations will be required to take a cryogenic safety course and to comply with both the APS and the CAT safety procedures. Any other nonstandard cryogenic systems that may be included in a beamline design will be reviewed by the APS beamline review process.

The probability of occurrence of a cryogenic hazard event has been determined to be low. The consequence has been determined to be low. Therefore the risk of cryogenic hazards is negligible.

4.9 Chemical Hazards

Flammable materials and chemical storage cabinets will be required at all applicable beamline locations. These will be determined during the beamline review process. Waste accumulation areas will be established as needed, and the responsible CAT personnel will be required to receive the appropriate training. Strict requirements are placed on the CATs to control the types and volume of chemicals stored and used in work areas. Material Safety Data Sheets (MSDS) will be required to be made available for all chemicals used. All CAT personnel will be trained in the proper use of the MSDS and will receive training, as necessary, in specific chemical handling and use.

The probability of a chemical hazard event occurrence has been determined to be

medium. The consequence has been determined to be low. Therefore the risk of chemical hazards is low.

4.10 Oxygen Deficiency

Any components that have the potential for containing an oxygen-deficiency hazard will be reviewed during the beamline review process. Appropriate protection, training, and procedures will be required to be put in place to ensure that the hazard is appropriately mitigated.

The probability of oxygen-deficiency hazard events are extremely unlikely; therefore, the probability of occurrence has been determined to be extremely low. The consequence has been determined to be medium. Therefore the risk of oxygen-deficiency hazards is negligible.

4.11 Noxious Gases

There are two typical situations in which ozone (O_3) may be produced by a beamline. The obvious case is an experiment in which the white beam travels through an air path. In this situation, the ozone concentration can quickly exceed the Threshold Limit Values - Short-Term Exposure (TLV-STEL) if appropriate steps are not taken. A second case occurs 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. Although the rate of production for ozone from scattered radiation is much lower than that for the open white beam, the levels can exceed the TLV-STEL if the ozone concentration is allowed to reach saturation with no ventilation.

Monochromatic beams (defined as below 0.1% bandpass) 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.

The APS experiment hall has provisions for installing exhaust systems to provide ventilation of first optic and experiment enclosures. The APS is also investigating several methods of filtering or "destroying" ozone. The APS has prepared a document "Guidelines for Ozone Mitigation at the APS" as part of the APS Beamline Design and Construction Requirements (ANL 1994c). The guidelines provide information to CATs for calculating the potential ozone production. It also states the APS Ozone Mitigation Policy. The Beamline Review Committee will review the ozone producing potential of each beamline and will require the CAT to install appropriate mitigating

and/or detection systems, as necessary. The CAT will also need to provide operator training and operating procedures for beamlines with ozone-producing potential.

The use or generation of other noxious gases is not anticipated as part of the beamline operation. The potential for creation of a noxious gas hazard will be identified during the beamline review process, and an adequate control strategy will be required to be implemented prior to operation of the beamline.

The probability of occurrence of an exposure to ozone or other hazardous gas levels above allowable limits has been determined to be low. The consequence has been determined to be medium. Therefore the risk of hazardous gas hazards is low.

4.12 Mechanical Hazards

Beamline components are supported on girders. The girders have to provide positional stability to the components; therefore, the designs need to be conservative. A mechanical hazard event may occur when these components are installed or relocated as part of beamline installation or modification. Use of lifting equipment is governed by ANL safety requirements and procedures (ANL 1991b). Hoisting operations will only be performed by properly licensed operators using certified lifting equipment.

Beamlines may contain rotating machinery, such as pumps, blowers, and fans. Proper guarding will be required to be in place, and the CATs will be required to prepare procedures requiring the equipment to be locked/tagged out before guards are removed for servicing of the machinery.

All potential pinch points will be required to be identified by appropriate warning signs, and the CATs will be required to prepare appropriate servicing procedures.

Mechanical-type hazard events generally have a higher probability of occurring; therefore, the probability of occurrence of a mechanical hazard event has been determined to be medium. The hazard event consequence has been determined to be low. Therefore the risk is low.

5.0 SAFETY ENVELOPE

5.1 Introduction

The safety envelope is a set of physical and administrative conditions that define the bounding conditions of safe operations at an accelerator facility. The accelerator safety envelope for the APS Accelerator Systems is defined in the APS Accelerator Systems Safety Assessment Document. The beamline safety envelope presented in this document does not replace but supplements the accelerator safety envelope. The hazard analysis in this SAD is based on operation of the beamlines within the complete, all-inclusive, safety envelope. Variations in operating conditions are permitted as long as consequences of the variations do not exceed the bounds imposed by the safety envelope. These variations of the operating conditions include unplanned events, such as power outages, which may interrupt operations but do not compromise the safety of the facility. Variations beyond the boundaries of the safety envelope are to be treated as reportable occurrences, as defined by DOE Order 5000.3B (DOE 1993a).

The requirements specified in the safety envelope are binding for operation of the APS beamlines. Significant revisions of these requirements resulting from changes in operating conditions or any modifications that involve an unreviewed ES&H issue will require a revision or supplement to this SAD. Revision of this SAD may also be required if the accelerator safety envelope is revised.

5.2 Beamline Safety Envelope

The beamline safety envelope is specified to ensure that the APS design and shielding policy goals for ionizing-radiation exposure limits are not exceeded. The APS policy for users or any on-site nonradiation workers in the vicinity of the APS facilities requires that the average nonradiation worker dose be below 0.2 mSv/yr (20 mrem/yr). The envelope also includes the review process, which ensures that all potential hazards are identified, analyzed, reviewed, and adequately mitigated. To that end, the safety envelope is defined as follows:

- All x-ray photon beams are contained within adequately shielded beam transports and enclosures.
- All beamline enclosures that require frequent, CAT-controlled personnel access

are protected by the APS designed, installed, and maintained Personnel Safety System (PSS).

- All bremsstrahlung shielding and exclusion zones are in place whenever the beamline is operating.
- The front-end safety shutters are closed whenever a beam is injected into the storage ring.
- The APS maintains a review process that ensures that all beamlines are reviewed to identify all potential beamline hazards and ensures that the CATs properly mitigate the hazards and operate within the other safety envelope requirements.

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