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Lawrence Berkeley National Laboratory

Safety Assessment Document for the Advanced Light Source *(Rev. 5)*

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Approval Page for the ALS SAD Rev. 5

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SECTION 1. INTRODUCTION

This Safety Assessment Document (SAD) for the Lawrence Berkeley National Laboratory (LBNL) Advanced Light Source (ALS) provides the necessary information and analyses to assure that the operation of the ALS can be conducted in a manner that produces minimal risks to the health and safety of LBNL employees, visiting scientists, and the public, as well as adequately protect the environment.

LBNL Building 6, which was originally constructed to house the 184-Inch Cyclotron, was extensively remodeled and significantly enlarged for the ALS, a synchrotron-radiation source of x-ray and ultraviolet radiation. As a national user facility, the ALS is open to visiting researchers and to LBNL staff, who use this radiation for basic and applied scientific and technological investigations, including structural and spectroscopic studies of gases, liquids, and solids.

1.1 Objective and Scope

This SAD has been prepared in accordance with DOE Order 420.2B Safety of Accelerator Facilities to describe the physical and administrative controls that will ensure the safe operation of the ALS at LBNL. DOE Order 420.2B specifies that the SAD must "identify hazards and associated onsite and offsite impacts to workers, the public, and the environment from the facility for both normal operations and credible accidents."

The safety of the ALS is analyzed, reviewed, and documented at the SAD level commensurate with its classification as a low-hazard facility. The safety analyses documented in this report demonstrate that ALS construction and operation are consistent with a complex facility with no more than minor onsite and no more than negligible offsite impacts, as defined in DOE Guide 420.2-1 Accelerator Facility Safety Implementation Guide for DOE O 420.2B. Thus the level of on site impact is such that permanent health effects or environmental damage are not expected (Criteria: minor injuries; 1 - 25 rem effective dose equivalent), and the level of offsite impact is such that the potential for health effects or environmental damage is very slight (Criteria: injuries requiring only superficial professional medical attention; < 1 rem effective dose equivalent).

As recommended by DOE Guide 420.2-1, the analysis is not duplicative of other activities carried out in the development of a facility’s overall environment, safety, and health program such as the

development of Work Smart Standards and the implementation of a site-specific ISM system. This SAD addresses those hazards that are not routinely encountered and accepted in the course of everyday living by the vast majority of the general public.

1.2 Facility Purpose

The ALS has been constructed in the Original Laboratory Site area of LBNL on the site of the historic 184-Inch Cyclotron, which was decommissioned and disassembled. To make room for the ALS, the original cyclotron building (Building 6) was renovated, and a new 61,000 square-foot annular addition was constructed. The new building houses a 1.9-billion-electron-volt (1.9-GeV) electron storage ring and its associated injector complex for the generation of synchrotron radiation in the x-ray and ultraviolet regions of the electromagnetic spectrum. The radiation will be guided by up to 60 insertion-device and bend-magnet beamlines to experimental areas around the outside of the storage ring. Each beamline may have more than one branch with separate experimental stations. In addition there are two electron beam lines (the Beam Test Facility and the Beam-To-Storage ring beamline) for experiments involving the interaction of relativistic electron beam with plasmas, laser beams, and electromagnetic cavities.

Physicists, chemists, materials scientists, biologists, engineers, and other researchers use the radiation to investigate the structure and composition of matter in its varied gas, liquid, and solid states. In addition to the radiation itself, the ALS provides the necessary structures and support systems to carry out this type of research. Responsibility for the beamlines and the experimental equipment is divided between the ALS and those doing the research, who will come from LBNL, other DOE and federal laboratories, private industry, and universities.

1.3 Facility Description and Operation Summary

The ALS is a national user facility for the production of high-brightness and partially coherent x-ray and ultraviolet synchrotron radiation [ALS, 1986, 1989a]. A DOE-funded construction project with a total estimated cost (TEC) of $99.5 million, the ALS was completed on schedule in April 1993. Administratively, the ALS resides within the Advanced Light Source Division of LBNL.

The ALS consists of a linear accelerator and a booster synchrotron (collectively known as the injector complex) and an electron storage ring, photon beamlines from insertion-device and bend-magnet sources, and associated experimental facilities. The ALS site covers a sizable, flat hilltop with

good foundation conditions, centrally located within LBNL. The original Building 6 provided approximately 20,000 square feet of floor space, which is being used for the linear accelerator and booster synchrotron. The storage ring, beamlines, and experimental facilities required the construction of a 61,000 square foot addition to Building 6. The addition consists of a 30-foot high steel-framed structure on new concrete footings with a heavy-duty concrete floor slab.

Included in the second floor of building 6 is approximately 33,000 square feet for office, light laboratory space and support facilities for beamline assembly at the ALS. Support facilities in the ALS building include a visitors' reception area, conference rooms, utility/storage space, and toilet facilities. Building 80 (adjacent to the Building 6 addition) houses the ALS control room, offices, electrical and mechanical shops, and a conference area. It is accessible via a connecting door.

Operational activities fall into three categories: (1) generation of a 1.9-GeV electron beam by the linac and booster synchrotron and storage of the beam for several hours in the storage ring, (2) use of the x-ray and ultraviolet radiation by LBNL and visiting scientists for the research activities described in Section 1.2, and (3) use of the electron beamlines to support R&D activities of various LBNL and visiting scientists.

Operation of the injector accelerators and storage ring is accompanied by the generation of bremsstrahlung and neutron radiation for which shielding is provided. Exposure of LBNL and visiting scientists to x-rays and other ionizing radiation is prevented by fixed in-place shielding, interlocked enclosures, and active radiation interlocks. The radiation shielding design is based on the dual design goals of limiting the radiation exposure to the general public, users, and the majority of ALS staff to less than 10 mrem/year, and limiting occupational exposure to selected ALS staff to less than 250 mrem/2000-hour worker year. The shielding design allows the facility to achieve the DOE As Low As Reasonably Achievable (ALARA) radiation design objectives.

Use of the x-ray and ultraviolet radiation by LBNL and visiting scientists may be accompanied by the introduction of flammable, toxic, biologically active, and radioactive materials in gaseous, liquid, and solid form. Volumes of hazardous materials will not exceed applicable building and fire code limits, and required venting and containment systems will be provided. In some cases where the hazardous material is the sample to be investigated and is present only in minute quantities, the material will be transported and studied only in sealed containers.

All beamline apparatus and experimental equipment, including lasers used in conjunction with synchrotron-radiation experiments, are subject to a mandatory safety evaluation before installation and will be operated in accordance with published codes and standards.

1.4 Conclusions of Assessment

The results of this analysis demonstrate that there is reasonable assurance that ALS operations, as controlled by the Safety Envelope developed in Section 6 in accordance with the Safety Analysis in Sections 4 and 5 of this SAD, will be conducted in a manner that will limit risks to the health and safety of the public and employees to a "low level" and will adequately protect the environment. In particular, the results showed that the ALS facility can be operated within the risk envelope for complex facilities with no more than minor onsite and no more than negligible offsite impacts, as defined in DOE Guide 420.2-1 Accelerator Facility Safety Implementation Guide for DOE O 420.2B.

SECTION 2. SUMMARY AND CONCLUSIONS

The ALS safety analysis was prepared in accordance with the guidance provided in DOE Guide 420.2-1 Accelerator Facility Safety Implementation Guide for DOE O 420.2B. A description of the methodology used in identifying hazards, analyzing credible accident scenarios, and assessing risks is summarized in Section 2.1. The hazard-event analyses themselves are summarized in Section 2.2. Conclusions and an assessment of the overall risk associated with ALS operations are discussed in Section 2.3.

2.1 Safety Analysis Methodology

The methodology used to perform the ALS safety analysis is shown in Figure 4-1. The hazards analysis process began with a review of proposed ALS operations and research activities. Using the information obtained, a hazard analysis of proposed ALS activities was prepared. Potential hazards associated with the use of radiation sources, energy sources, hazardous materials, and from natural phenomena were studied.

Credible hazards with potential on-site or off-site consequences were then analyzed to assess associated risk. The analyses were based on a bounding event approach, where the most severe of each particular category of credible accident was analyzed to obtain worst-case results. Each event analysis included determining 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 estimates were made by the Technical Safety Subcommittee of the ALS EH&S Committee on the basis of the best professional judgment of the members of the subcommittee. The judgments were supported by statistics on occurrences at DOE accelerator facilities and by data accumulated on actual instances of exposure to radiation at LBNL. In addition, site-specific design criteria for earthquakes were used in determining the probability of these events.

Using the guidance provided in DOE Guide 420.2-1 Accelerator Facility Safety Implementation Guide for DOE O 420.2B for conducting safety analyses, the probability and consequences of each hazard were rated by levels. The overall risk associated with each specific hazard, and then for the facility as a whole, was determined using these rating levels and the risk matrix.

2.2 Hazard Event Analyses

The ALS hazards analysis identified potentially hazardous conditions that could occur during operations and during normal and abnormal operations. The analysis was used to determine the adequacy of the facility and systems designs and formed the basis for the development of necessary administrative controls.

Ionizing-radiation hazards at the ALS are due to loss of electrons at various stages of the beam acceleration and storage process and to the synchrotron radiation emerging from the insertion devices and bending magnets in the storage ring. Ionizing radiation is also produced by accelerator-related equipment, such as the klystrons that generate rf power. Hazards due to radiation exposure will be different for those working in the ALS facility and those outside the building in the general area. Hazards were analyzed for both types of personnel.

Analyses according to the methodology described was carried out for six categories of hazard events involving ionizing radiation and 19 categories of hazard events involving hazards other than ionizing radiation. Table 2-1 summarizes the results of the analyses.

2.3 Summary of Results

Operational activities planned for the ALS facility have been analyzed for hazard potential, and appropriate mitigation measures have been developed. The hazards analysis identified potentially hazardous conditions that could occur in the ALS during operations. Control measures were incorporated into the facility and systems design to mitigate most of the identified potential hazards. In other cases, administrative procedures were developed to ensure that facility operations could be conducted with a minimum of on-site and off-site consequences.

A risk analysis on six categories of hazard events involving ionizing radiation and 19 categories of hazard events involving hazards other than ionizing radiation, performed using a bounding event/worst-case approach, showed that the ALS facility can be operated within the risk envelope for complex facilities with no more than minor onsite and no more than negligible offsite impacts, as defined in DOE Guide 420.2-1 Accelerator Facility Safety Implementation Guide for DOE O 420.2B.

Table 2-1. ALS Risk-Determination Summary

No.	Hazard Event	Probability Level	Consequence Level	Risk Level
Ionizing Radiation				
1	Exposure to Ionizing Radiation at the Site Boundary	Extremely Low	Medium	Negligible
2	Exposure to Ionizing Radiation outside the Accelerator Enclosures	Low	Medium	Low
3	Exposure to Ionizing Radiation inside the Accelerator Enclosures	Low	Medium	Low
4	Exposure to Synchrotron Radiation	Low	Medium	Low
5	Exposure to Air Activation Products	Extremely Low	Medium	Negligible
6	Exposure to Ionizing Radiation from Sources Other than Accelerators	Low	Medium	Low
Fire Hazards				
1	Room Fire	Low	Low	Negligible
2	Room Fire Involving Radioactive or Hazardous Materials	Low	Medium	Low
3	Equipment Fire	Medium	Low	Low
Hazardous Materials				
1	Uncontrolled Chemical Reactions	Low	Medium	Low
2	Chemical Exposure	Medium	Low	Low
3	Cryogenic Temperature Exposure	Medium	Low	Low
4	Pressurized Gas Explosion	Low	Medium	Low
5	Gas Explosion (Hydrogen, Oxygen, Acetylene)	Low	Medium	Low
6	Inhalation, Ingestion, or Dermal Exposure to Toxic or Carcinogenic Material	Medium	Low	Low
7	Oxygen Deficient Atmosphere	Low	Medium	Low
Electrical Hazards				
1	Electrical Shock	Low	Medium	Low
2	Nonionizing Radiation Exposure	Extremely Low	Medium	Negligible
3	Exposure to High Magnetic Forces	Medium	Low	Low

Table 2-1. ALS Risk-Determination Summary (cont'd.)

No.	Hazard Event	Probability Level	Consequence Level	Risk Level
Laser Hazard				
1	Laser Light Energy Transfer	Low	Medium	Low
Visible and Near-UV Light Hazard				
1	Exposure to Visible and Near-UV Light	Low	Medium	Low
Ozone Hazard				
1	Ozone Exposure	Low	Low	Negligible
Seismic Hazard				
1	Earthquake	Low	Medium	Low
Vacuum Vessel Hazard				
1	Beamline Vacuum Vessel Implosion or Explosion	Extremely Low	Medium	Negligible
Industrial Accident				
1	Industrial Accident Involving Rotating Machinery or Falling Objects	Medium	Low	Low

SECTION 3. DESCRIPTION OF SITE, FACILITY, AND ORGANIZATION

3.1 Site Description

LBNL is centrally located in the greater San Francisco Bay Area and is situated on the western slope of the Berkeley Hills. The Laboratory overlooks the Berkeley campus of the University of California and San Francisco Bay on land within the boundaries of, and leased from, the University of California. The following sections characterize the features of the ALS site [DOE, 1989; Keller, 1987; Harding-Lawson, 1983].

3.1.1 Site Location

The site for the ALS is within and adjacent to the original Building 6. This building, whose construction was begun in 1940 and completed in 1942, was the first of approximately 30 buildings to be constructed in the so-called Original Laboratory Site of LBNL. The site is centrally located within LBNL. It is close to electromechanical and mechanical technology machine shops and technician facilities, as well as the main LBNL mechanical shops. The site is also adjacent to LBNL's fire station and to the Advanced Materials Laboratory (Building 2). An adjacent older structure, Building 80 provides space for ALS activities, and is included in this SAD. Figure 3-1 shows the LBNL site and Figure 3-2 shows the ALS site.

3.1.2 Physiographic Setting

The Original Laboratory Site covers a sizable, flat hilltop area that commands a view of most of San Francisco Bay, including the San Francisco-Oakland Bay and Golden Gate Bridges, and of much of the surrounding urbanized areas of Alameda, western Contra Costa, San Francisco, San Mateo, and Marin Counties. The land around the site slopes downward, except on the northeast, where it slopes upward. The ALS site is toward the southwest corner of this area. Cut areas near the Advanced Materials Laboratory are supported by new retaining walls.

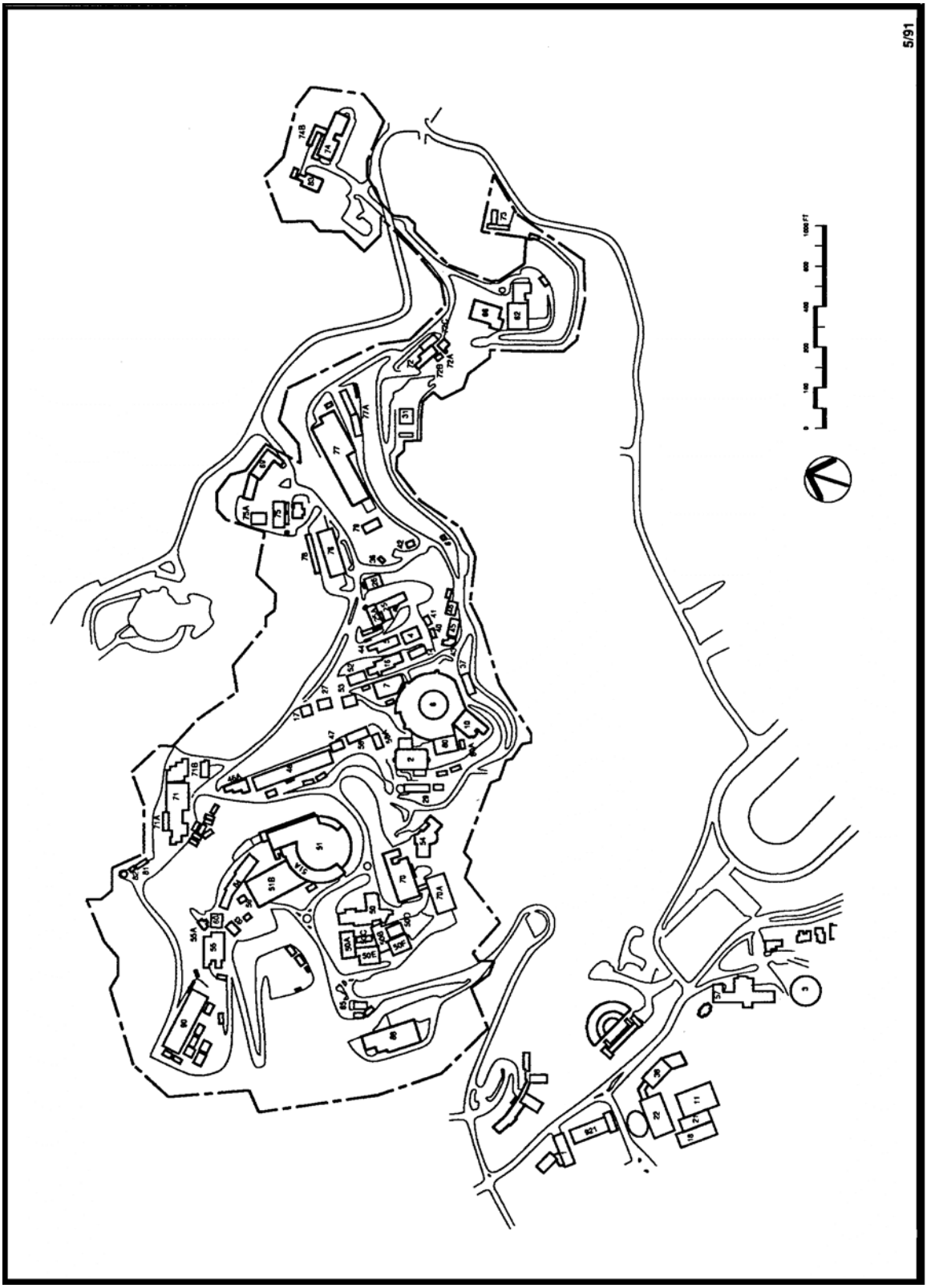


Figure 3-1. LBL site map.

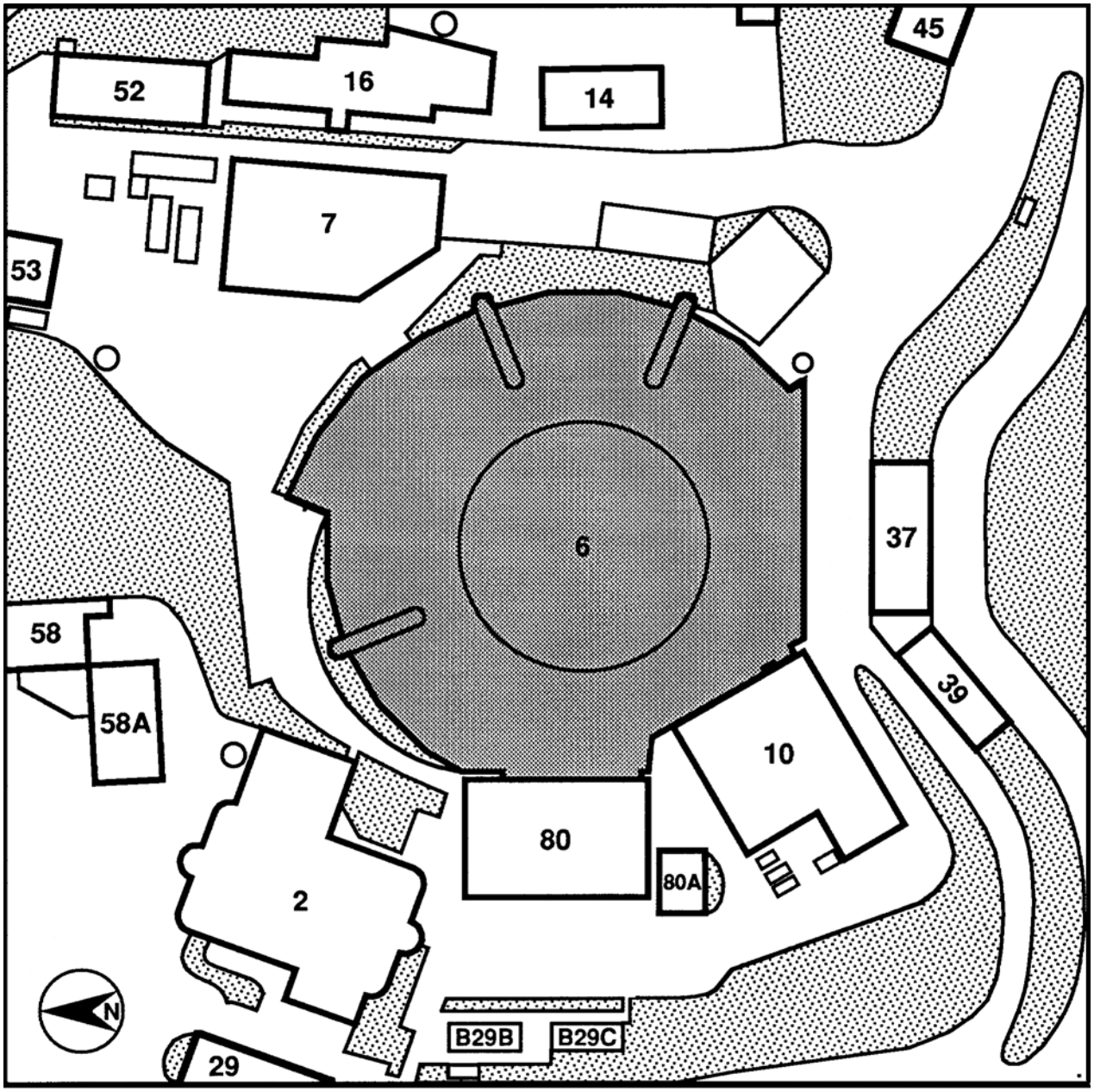


Figure 3-2. Advanced Light Source site, ground level.

3.1.3 Geology and Seismicity

The ALS site is located in the Berkeley Hills, which consist of a series of northwest-trending synclines and anticlines cut by numerous faults. The rocks are of marine, terrestrial, and volcanic

origins. Differential erosion of soil and rock materials has created a diverse topography in the area. The bedrock formations are close to the surface and consist of volcanic basalt and site flows, pyroclastic tuff beds, and a sedimentary agglomerate (i.e. clayey siltstone).

Active faulting and crustal deformation continues in the area at the present time. The closest major fault lines are the Hayward Fault, which passes about 3500 feet to the southwest of the site, the Calaveras Fault, which passes 12 miles to the east of the site, and the San Andreas Fault, which passes 18 miles to the west of the site. The maximum credible earthquake postulated for the site would occur on the Hayward Fault and would have a Richter magnitude between 6.75 and 7.25 [LBNL, 1992a, Chapter 23].

3.1.4 Soils

The bedrock at LBNL is generally relatively weak and weathers deeply, thereby producing a thick colluvial soil cover. The bearing capacity of colluvial soil is relatively low, and foundation design usually requires consideration of the potential for shrinking and swelling. In addition, ancient land-slide deposits of variable dimensions are present throughout LBNL, as are areas covered by landfill placed during site grading. The northwestern corner of the ALS site is one of these areas. Overall the foundation conditions at the ALS site are satisfactory.

3.1.5 Hydrology

The ALS site is located on a ridge that divides the Strawberry and Blackberry Creek Watershed areas on a naturally flat area that interrupts the otherwise upward sloping hillside. The site is approximately 890 feet above sea level, which precludes the ocean or water table from having effects on the site. In addition, storm sewers are provided with about 900 cfs capacity, so that buildup of rainwater from storms will not affect the site.

3.1.6 Climate

LBNL is exposed to air flow from the Pacific Ocean through the Golden Gate and across San Francisco Bay. The marine influence keeps seasonal temperature differences relatively small. Sunshine for the year averages between 65 and 70 percent of the total insolation possible, and average daytime cloudiness is about the same in summer as in winter. Except for laboratories with special temperature stability requirements, LBNL buildings are generally not air-conditioned.

3.2 Site and Facility Demography

In 1992, LBNL had approximately 3000 full-time employees and 895 part-time employees (mostly students or staff with joint appointments on the UC Berkeley campus), as well as more than 1615 guest scientists.

During operation of the ALS, approximately 200 staff will be required to support and operate the facility. Up to 60 beamlines will be fully developed, and a maximum of about 150 users are on site at any one time, of whom about 20 percent are LBNL employees.

3.3 Facility Description

The ALS is a national user facility primarily for the production of high-brightness and partially coherent x-ray and ultraviolet synchrotron radiation. The ALS facility consists of an accelerator complex, a complement of beamlines and associated experimental areas, and a building (Building 6) to house this equipment. The following sections provide a description of the ALS layout, the accelerator complex, the beamlines, the experimental areas, as well as utility systems. Safety systems are described in Sections 4 and 5.

3.3.1 Facility Layout

The ALS is located in the Building 6 area of the LBNL site. The-original Building 6, which was roughly circular with a high, domed roof, provides approximately 20,000 square feet of floor space. This space is being used for the linear accelerator and booster synchrotron. The storage ring, beamlines, and experimental facilities required the construction of a 61,000 square foot addition to Building 6. Support facilities for operations personnel include a visitors' reception area, utility/storage space, and toilet facilities. Figure 3-3 shows the ALS facility layout. Figure 3-4 shows the elevations of the ALS building. The 30-foot height of the addition includes 33,000 square feet of office and light-laboratory space on the second-floor structure over the experimental areas.

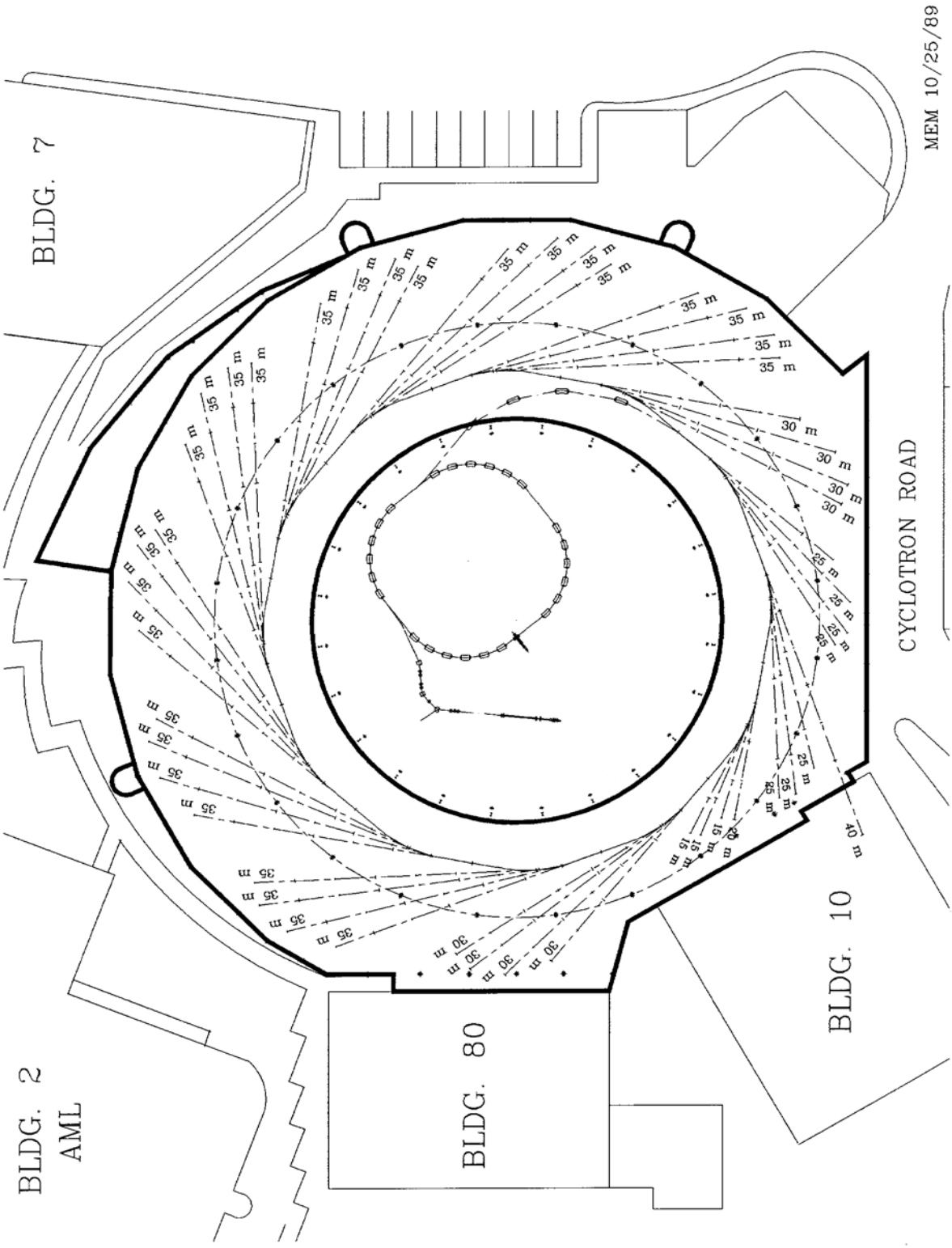


Figure 3-3. Layout of the Advanced Light Source facility showing the linac, booster synchrotron, electron storage ring, and photo beamlines within the expanded Building 6.

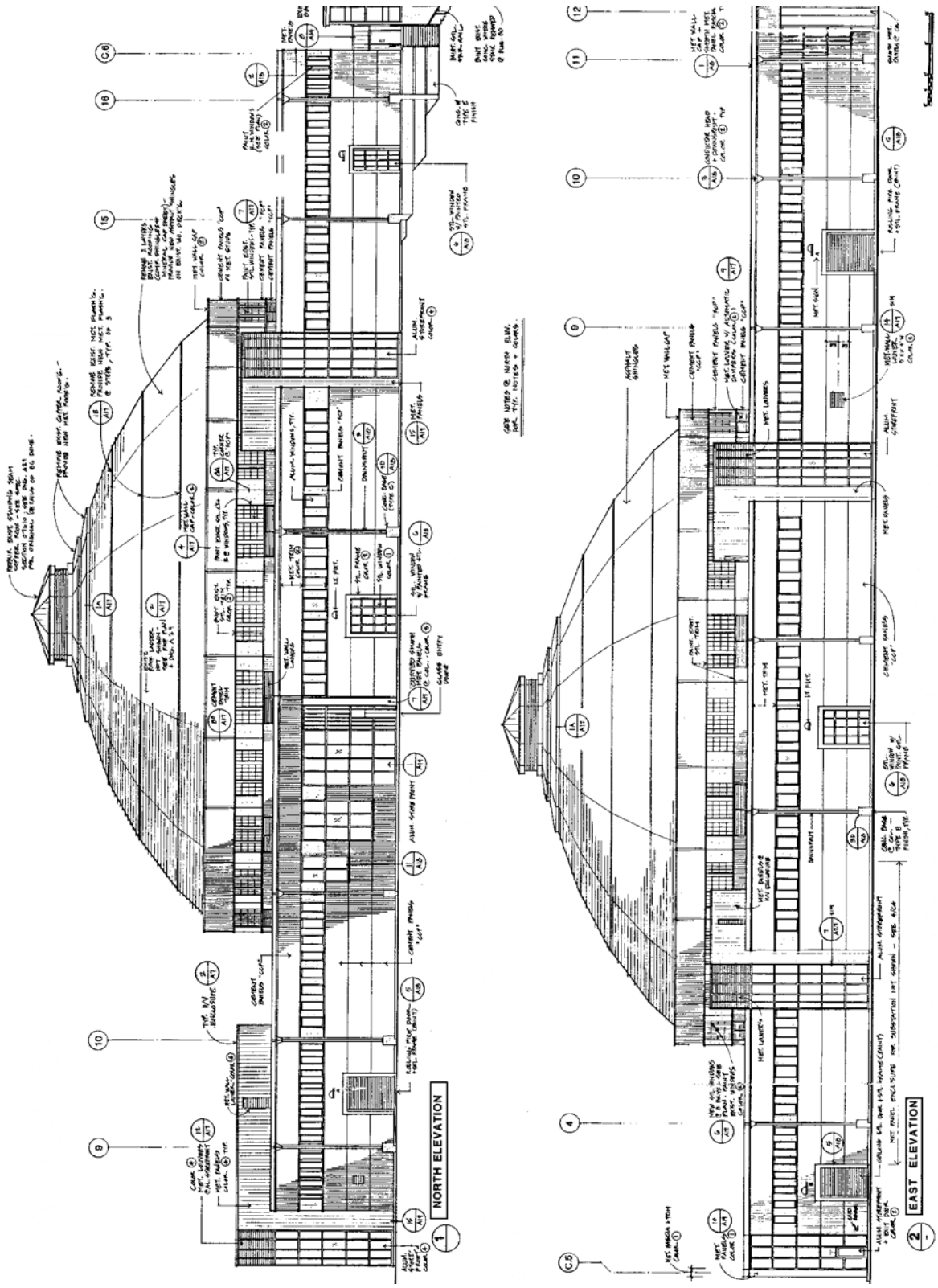


Figure 3-4. Elevations of the Advanced Light Source facility.

Buildings 80 immediately adjacent to the ALS has been modified only to the extent of window and door removals and their replacement with matching fire-rated wall materials where they are common with the new-addition walls. There is a seismic gap between the ALS and this building. The Building 6 area is surrounded on three sides by roadways and service-vehicle parking. Roadways around the site have been improved and some close-in parking has been provided.

Included in this SAD, Building 80 houses the ALS control room, staff offices, electrical and mechanical shops, some laboratory space, and a conference area. This building, which predates the ALS, comprises a basement, a main floor, and a second floor.

3.3.2 Utilities

Potable supply water and sanitary sewer wastewater treatment services for LBNL is provided by the East Bay Municipal Utility District (EBMUD). Natural gas and electricity are provided by Pacific Gas and Electric Company (PG&E).

The EBMUD water system serves about 1.3 million people in a 331 square-mile service area of Alameda and Contra Costa counties. EBMUD supplies water primarily from large-capacity reservoirs in the Sierra Nevada foothills. On average, 90 percent of the water delivered by EBMUD comes from the Mokelumne River watershed, with the remaining 10 percent originating as runoff from local watersheds within the service area. Water from the foothills is transported via 90 miles of aqueducts to a series of local reservoirs. Reservoirs nearest LBNL are Shasta Reservoir with a capacity of over two million gallons serviced by a 12-inch pipe and Berkeley View Reservoir with a capacity of over three million gallons serviced by a 6-inch pipe.. To supplement the water supply provided by EBMUD, LBNL operates and maintains three 200,000-gallon water storage tanks on-site for emergency water supply in the event of service interruption from EBMUD. During 2003, water consumption for the entire Laboratory was about 41.6 million gallons. Personal use accounted for 20.5 million gallons with process use (e.g., research, landscaping) accounting for the remainder. This total represents a 47% reduction from the 78.6 million gallons used in 1990.

LBNL's sanitary sewer system connects to the City of Berkeley system, which, in turn, terminates at the EBMUD wastewater treatment plant in Oakland near the eastern entrance to the Bay Bridge. Annual wastewater generation at LBNL is approximately 38 million gallons, with personal wastewater and process water each accounting for approximately 50% of the discharge. The EBMUD treatment

plant serves 640,000 customers and is designed to perform primary and secondary treatment of wastewater prior to releasing water to the San Francisco Bay.

The LBNL storm drain system discharges into the North and South Forks of Strawberry Creek, which are part of the Strawberry Creek Watershed. The two forks join near the western edge of the University of California Berkeley campus. At that point, Strawberry Creek then flows westward through the City of Berkeley before it reaches San Francisco Bay. The creek travels underground in the City's storm drainage piping for much of the route from campus to the Bay. Creek flow data is not measured.

PG&E provides electricity and natural gas to LBNL. PG&E serves about 15 million people in a 70,000 square mile area of northern and central California. Electricity is delivered to the Laboratory's Grizzly Substation via two 115 kilovolt transmission lines, where it is then routed through the LBNL electrical distribution network to each building. LBNL also has a number of emergency generators set to start automatically after a power failure and provide power for critical services. Total capacity of these generators is over six megawatts. Total electrical power consumption at LBNL in 2003 was 74,500 megawatt hours.

Natural gas is delivered to the Laboratory through a 6-inch PG&E line that terminates at a meter vault near the western boundary of the site. A 6-inch gas line distributes high pressure natural gas throughout the site, except for two buildings. Given their location below the UC Botanical Garden, Buildings 73 and 73A receive their gas supply directly from a separate PG&E supply line. The internal distribution system includes pipes, valves, fittings, pressure-reducing stations, earthquake emergency shut-off valves, meters, and appurtenances. Natural gas usage in 2003 was approximately 1.6 million Therms.

At the ALS, electrical power at 480 V is distributed to switchboards inside the new addition and then to 480-V process loads and 277-V area-lighting loads. Local step-down transformers are used for loads requiring lower voltage. Cranes, heating and ventilating equipment, pumps, and miscellaneous motor loads are supplied by motor control centers. High-pressure metal-halide lighting has been provided and enhanced by task lighting where appropriate. A 300-kVA emergency generator has been installed to provide emergency power to critical ALS systems. Communication is provided by a telephone system, a closed-circuit intercom in the tunnels that house the accelerators, and a local building-paging system.

Utilities provided within the facility include low-conductivity water, compressed air, dry nitrogen, natural gas, industrial cold water, a sanitary sewer, and high-pressure fire-protection water mains. The

linac, booster, and storage-ring tunnels are provided with low-conductivity water and dry nitrogen. Access to the tunnels is provided by utility trenches located at intervals around each ring.

3.3.3 Ventilation and Thermal Stability Systems

The heating and ventilating system is designed to maintain a uniform 75° F temperature in the entire building and to provide forced-air circulation during the summer. Certain areas will be temperature-controlled to ±1° C as explained in the next paragraph. Exhaust fans will be used to ventilate the tunnel areas.

Guiding the high-brightness radiation generated by the ALS through monochromators and onto samples located tens of meters from the storage ring requires exceptional stability on the part of storage-ring structures, the stored electron beam, and the experimental equipment. A major study of stability issues has showed that a 1° C temperature change perturbs the position of the electron beam in the storage ring by 1 standard deviation (σ), but stability to 0.1 σ is needed. A layered stability-control strategy was adopted that consists of kinematic mounting for mechanical stability, temperature control of the storage ring, beamlines, and experimental areas to ±1° C to bring motion within range of the electronic feedback system that controls the electron orbit.

To achieve temperature control of the storage ring and the experimental areas, a new chilled-water plant and air-conditioning system was added to the scope of the ALS project [Keller, 1990]. The chiller plant supplies chilled water necessary for air conditioning. A separate, two-story, reinforced concrete building of about 6,300 square feet (35 feet by 92 feet) has been constructed south of the ALS. The chiller plant consists of 6-MW cooling tower, chiller units, pumps, electrical equipment, and associated piping. The building provides space for an additional cooling tower and chillers.

Thermal stability in the storage-ring enclosure is accomplished through the use of chilled-water fan-coil units on the walls of the storage ring, which provide cooled air to the storage ring. Thermal stability in the experimental areas is accomplished by means of chilled-water cooling coils in the ALS roof-top air-conditioning units, which provide cooled air to the building ducted-air-distribution system. Terminal reheat coils provide final control. Each fan-coil unit, roof-top unit, and reheat-coil has a temperature sensor with associated valves and controls to maintain final building temperature within 0.5 °F.

3.3.4 Accelerator Systems

As a third-generation synchrotron source, the ALS is based on the use of an electron storage ring specifically designed to have a very low emittance and several long straight sections containing insertion devices (wigglers and undulators). The combination of a very low emittance storage ring with optimized undulators makes possible the generation of radiation with a spectral brightness that is increased by a factor of 20 or more (depending on the spectral region) over that of existing, second-generation sources.

The ALS accelerator complex consists of a 50-MeV electron linear accelerator, a 1.5-GeV, 0.5-Hz booster synchrotron, and an electron storage ring optimized to operate at 1.9 GeV. The linac and booster are located inside the storage ring to avoid interference with user beamlines and to make best use of the layout of the original building.

The ALS linac is a conventional constant-impedance structure operating at 3 GHz (S-band) with two accelerating sections. The linac is fed by a 120-kV electron gun and bunching system that forms single S-band electron bunches with a charge of greater than 2 nC per bunch. All components of this system are housed in a concrete enclosure in the center part of the ALS building.

The linac injects electrons into a 1.5-GeV, 0.5-Hz booster synchrotron, from which they are extracted after acceleration for transfer into the storage ring. The booster has a 75-meter circumference and a missing-magnet FODO lattice with four-fold symmetry. The 10.5-Hz repetition rate permits filling of the storage ring to its nominal operating current of 400 mA in less than fifteen (15) minutes. Like the linac, the booster has been installed in a concrete tunnel in the area of the ALS building under the dome.

The storage ring is designed as a third-generation synchrotron-radiation source with a small natural emittance and long, dispersion-free, straight sections for insertion devices. Performance characteristics of the ALS are determined primarily by the design of the storage ring magnet lattice—the arrangement of bend and focusing magnets in the ring. The ALS lattice is optimized for the use of insertion devices. The magnet lattice contains 9 identical segments (superperiods), each of which is an achromatic arc comprising three combination gradient-bend magnets except when replaced by super-bends, six quadrupole focusing magnets, and four sextupole magnets in the triple-bend achromat arrangement (TBA). The storage ring has a design horizontal emittance of 3.5 nm-rad when operating at 1.5 GeV. Although the original storage ring operating energy is 1.5 GeV, the ring is capable of operating over the range from 1 to 1.9 GeV. For operation at or below 1.5 GeV, the beam is injected into the storage ring at the operating energy (full-energy injection). For operation above 1.5 GeV, the beam is injected at 1.5

GeV and further accelerated in the storage ring. Table 3-1 lists the major parameters of the storage ring [ALS, 1989a].

On its way around the storage ring, the electron beam travels through 12 monolithic, machined-aluminum vacuum chambers (one for each arc), which will maintain the base pressure in the storage ring to about 0.1 to 1 nTorr, and 12 straight sections connecting the arcs. Of the 12 straight sections, one is occupied by injection hardware and one by two 500-MHz rf cavities, leaving 10 straight sections available for undulators and wigglers up to 4.5 m in length. Each arc of the storage ring is fitted with four bend-magnet ports that can be used to access bend-magnet radiation. Of the maximum of 48 ports, 24 are so-called prime ports with smaller vertical beam sizes that will be developed first.

Table 3-1. Main Parameters of the ALS Storage Ring

Beam energy [GeV]	
Nominal	1.5
Minimum	1.0
Maximum	1.9
Circumference [m]	196.8
Beam current [mA]	
Multibunch	400
Single bunch	65
Berm emittance, rms [nmárad]	
Horizontal	< 10
Vertical	< 1
Relative rms momentum spread	
Multibunch	8.0×10^{-4}
Single bunch	13.0×10^{-4}
Nominal bunch duration, FWHM [ps]	30-50
Radiation loss per turn [keV]	92
Length available for insertion devices [m]	4.5

The ALS produces electron beams that are bunched rather than continuous. The storage-ring rf system has a frequency of 500 MHz, so the spatial separation between bunches is 0.6 m and the temporal separation is 2 ns. The storage-ring lattice, the rf system, and the impedance of the vacuum-chamber hardware determine the length (spatial and temporal) of the bunches. For the ALS at the

nominal current of 400 mA, the predicted full-width-at-half-maximum (FWHM) value of the bunch length is 35 ps. To avoid trapping positive ions in the potential well of the negatively charged electron beam, the multibunch mode with a 400-mA current will have 276 consecutive bunches, followed by a gap of 52 empty buckets. For particular experiments—for example, those involving time-of-flight measurements—it can be advantageous to have only one or a few circulating electron bunches in the storage ring. In the few-bunch mode, the nominal current per bunch will be 32 mA and the bunch length (FWHM) is predicted to be 55 ps, although still larger bunch currents may be tolerated. For a single pulse, the repetition rate would be the circulation time of the beam, 656 ns.

Multibunch Mode

In the multibunch mode, the electron gun (operating at 120 kV) produces a string of pulses, each about 2 ns long, separated by 8 ns (corresponding to 125 MHz). The number of pulses in this string can be varied between 1 and 12, giving a "macro-pulse" length of 2 to 100 ns. Before entering the linac, the pulses are compressed from 2 ns to 0.2 ns by the action of two sub-harmonic bunchers, operating at 125 MHz and 500 MHz. This operation ensures efficient capture of electrons in the linac. The 50-MeV beam is then transferred into the booster synchrotron by single turn, on-axis injection by means of a full-aperture kicker magnet. After acceleration to 1.5 GeV, the electron beam is extracted, again in a single turn, and transferred to the storage ring, where it is captured in a 500-MHz accelerating structure. This highly efficient acceleration/capture process is repeated until the required current is accumulated in the storage ring. Six hundred (600) cycles (at a rate of 0.5 Hz) are required to reach 400 mA of stored current.

Few-Bunch Mode

In the single- or few-bunch mode, the electron gun produces a single pulse, rather than multiple pulses. The transfer and acceleration processes are then identical to those used in the multibunch mode. The timing system for the accelerators is designed such that the single pulse can be placed at any point around the circumference of the storage ring. In this situation the current accelerated in the booster will be about one- third that in the multibunch mode, and filling times are about 0.1mA per cycle per bunch. Therefore, about 320 cycles (at a rate of 0.5 Hz) are required to fill each bunch to 32 mA.

After filling, the injection system is turned off and the stored beam is allowed to decay naturally. After the decay process has reached the level where the beam must be replenished refilling takes place as described above. The design value of the beam 1/e-lifetime is about 10 hours. Refilling is normally done at 8-hour intervals.

The storage ring is normally operated 24 hours per day (three 8-hour shifts) five to seven days per week.

Beam Test Facility and Booster-To-Storage Ring Beamline

The Beam Test Facility (BTF) makes use of the ALS linac and the Booster-To-Storage ring (BTS) beamline makes use of the ALS booster. Between storage-ring filling operations, the 50-MeV linac electron beam can be transported via a transport line through the wall of the linac cave into an experimental vault adjacent to the linac cave [Leemans et al. 1993]. The maximum energy and current of the linac for BTF operation are identical to those of the linac for storage-ring injection. Between storage-ring filling operations the 1.5-GeV booster electron beam can be transported via a short transport line to an adjacent beamline within the booster shielding. The maximum energy and current of the booster for BTS operation are identical to those of the booster for storage-ring injection.

3.3.5 Insertion Devices

There are 10 storage-ring straight sections available for insertion devices (undulators and wigglers). The magnetic structure of an insertion device consists of an array of alternating polarity dipoles. A planar insertion device has vertically oriented poles of alternating north-south polarity which causes relativistic electrons of energy E to undergo a periodic electron trajectory of period λ_u in the horizontal plane. The resultant synchrotron radiation is linearly polarized in the horizontal plane. An elliptically polarizing undulator (EPU) has a magnetic structure with vertically and horizontally oriented periodic magnetic field arrays. The two field components are 90° out of phase, and the relative strength can be varied to control the ellipticity of the orbit and polarization of the radiated spectrum. A helical electron trajectory and circularly polarized light are produced when both components are of equal strength.

Undulators can provide radiation of unparalleled spectral brightness, with a significant degree of spatial coherence. The spectrum of undulator radiation consists of a series of narrow peaks at a fundamental photon energy and its harmonics. By varying the undulator magnetic field, which decreases as the gap between the poles of the undulator increases, the photon energy of the fundamental and the harmonics can be scanned. At the ALS, the third and fifth harmonics of the radiation spectrum are used to extend their spectral range to higher photon energies (2.5 keV) than can be reached with the fundamental alone (0.55 keV).

Radiation from a wiggler or the superconducting dipoles (superbends) are used to provide higher energy photons than are obtainable from an undulator. A wiggler produces a broadly peaked (or "white") spectrum of x-rays, which is spread into a relatively wide fan of radiation emerging from the insertion device. A wiggler has a critical photon energy ε_c , defined as the photon energy above which half the total power is radiated. At the high-energy end of the broad wiggler spectrum, the flux drops rapidly but is still one-tenth of its maximum value at photon energies near $4\varepsilon_C$, so the W11 wiggler, with a peak field of 1.85T, provides photon energies into the hard x-ray region above 10 keV, although the increased spectral range comes at the expense of reduced brightness, as compared to that of undulator radiation.

Table 3-2 provides a summary of insertion devices installed at the ALS. The U5, U8, U10, and W11 devices occupy full straight sections. The EPUs and IVID (in-vacuum insertion device) are designed to occupy half-straights. Two EPUs are installed in the sector 11 straight. A chicane magnet at the center of the straight deflects the trajectory to provide an angular separation in the fans emitted by the two devices, thus providing two sources for two independent beamlines. Chicane magnets are also installed in the sector 4 and 6 straights to accommodate future installation of a second insertion device in each straight.

Table 3-2. Insertion device parameters for devices installed by the end of FY05.

Device	Beamline	Energy Range (at 1.9 GeV) [eV]	Period Length [cm]	No. of Periods	Operating Gap Range [cm]	Peak Effective Field Range [T]
U5	8.0	80–3000	5.0	89	1.4–4.5	0.85-0.10
U5	7.0	80–3000	5.0	89	1.4–4.5	0.85–0.10
U8	12.0	20–1900	8.0	55	2.5–8.3	0.80–0.7
U10	9.0	8–1500	10.0	43	2.4–11.6	0.98–0.5
U10	10.0	12–1500	10.0	43	2.4–11.6	0.80–0.5
EPU5	4.0.1	80–3000	5.0	37	1.40–5.5	0.85–0.10 (vertical field) 0.57–0.10 (horizontal field)
EPU5	11.0.1	75–3000	5.0	37	1.38–5.5	0.86–0.10 (vertical field) 0.58–0.10 (horizontal field)
EPU5	11.0.2	75–3000	5.0	37	1.38–5.5	0.86–0.10 (vertical field) 0.58–0.10 (horizontal field)
W11	5.0	4000-18000	11.4	29	1.4	1.85
IVID	6.0.1	120-5000	3.0	48	0.55-2.3	1.5-0.2

The major subsystems of the insertion devices are (i) the magnetic structure, which consist of magnetic assemblies attached to backing beams; (ii) the support and drive system, which includes the supporting framework for the magnetic structure, the gap adjustment system, and in the case of EPUs, the mechanism for longitudinal motion of magnetic structure quadrants; and (iii) the vacuum system, which includes a vacuum chamber and its associated pumping system. Figures 3-5 through 3-8 show several of the insertion devices currently installed.

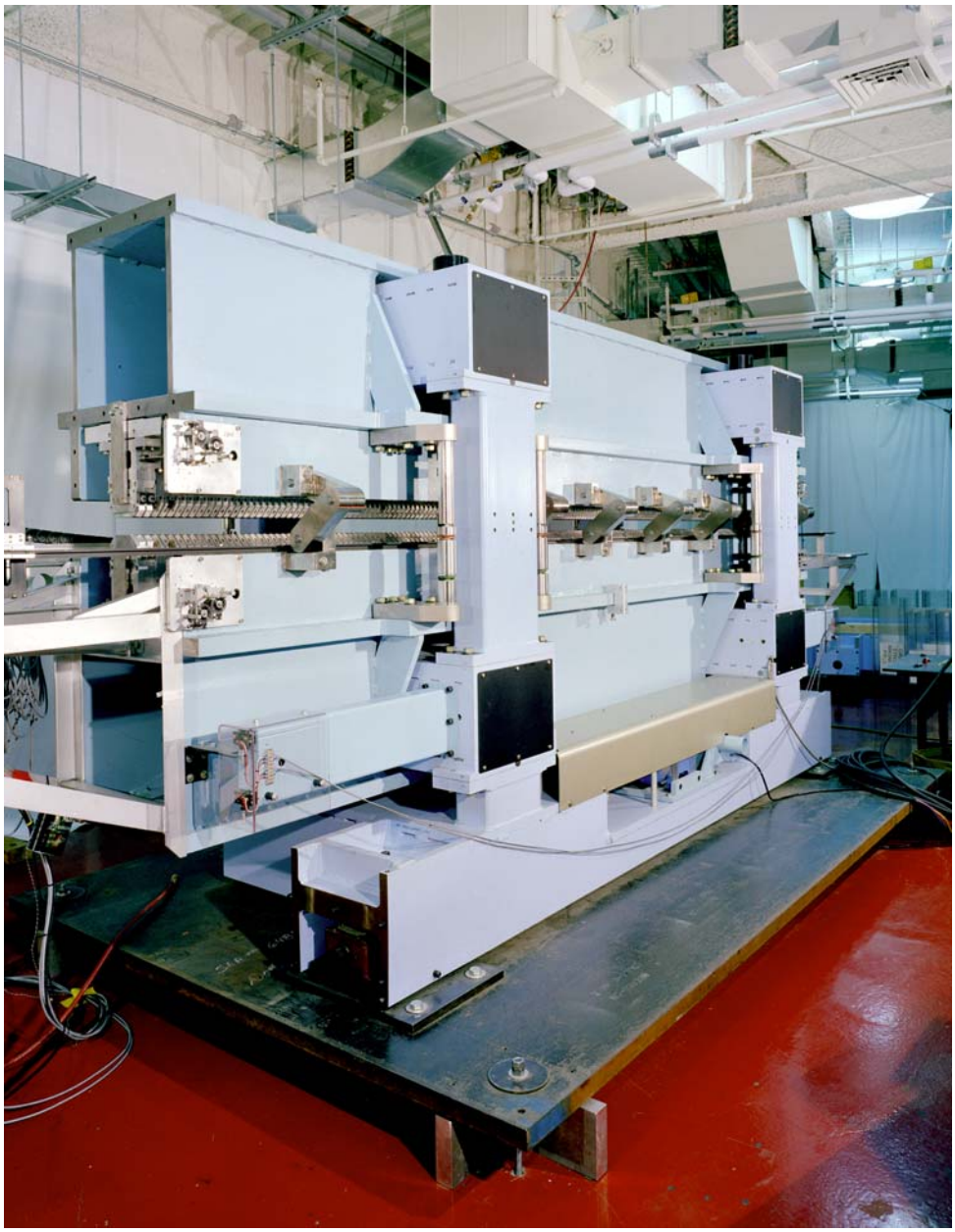


Figure 3-5. U5 prior to installation.

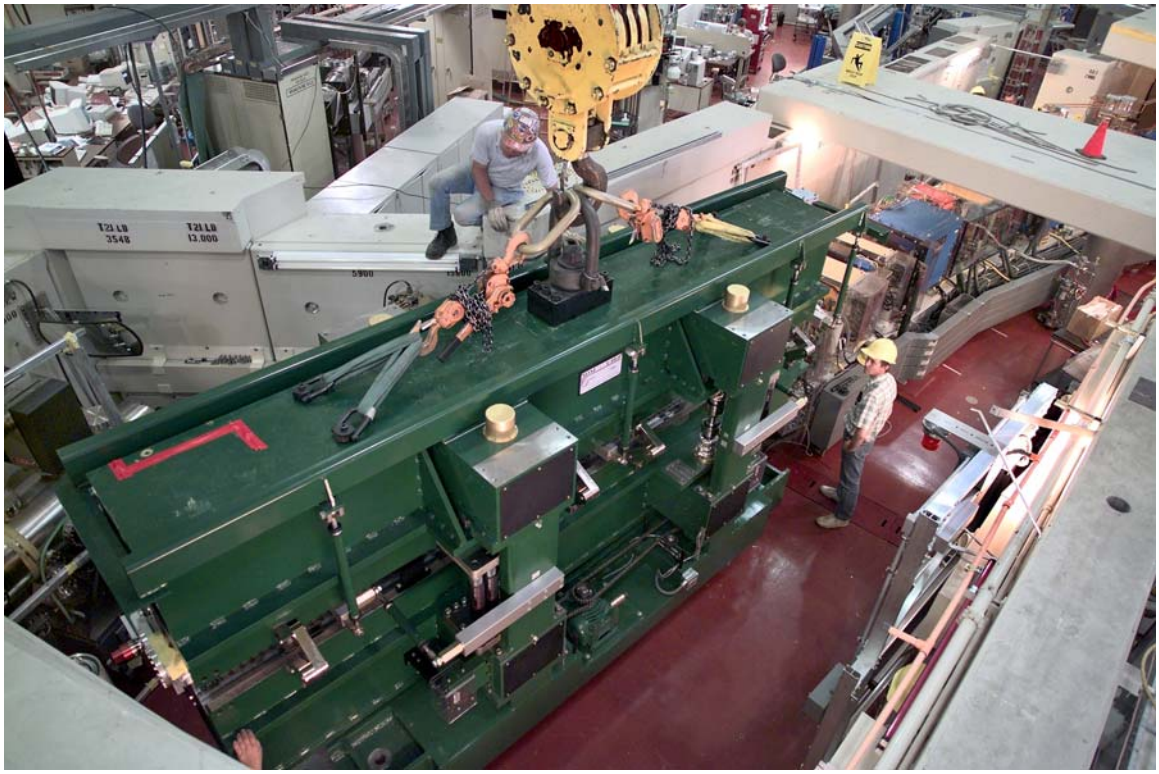


Figure 3-6. U10 being installed in the ALS storage ring.

3.3.6 ALS Beamlines

The ALS is a national user facility that is open to all qualified scientists and technologists. Instrumentation of the ALS is envisaged as a community project with the primary responsibility for experimental equipment resting with the users and the ALS, the responsibility for the beamlines resting only with the ALS or jointly with the ALS and the users, and the responsibility for the insertion devices resting solely with the ALS. (However, calibration, or verification of calibration, of instruments related to the safe conduct of experiments and the safe operation of the facility, is the responsibility of ALS.) The method of implementing this strategy is the formation of Participating Research Teams (PRTs) consisting of investigators with related research interests from one or more institutions. Members of insertion-device teams and bend-magnet teams will receive access to ALS beam time, generally over a three year period, in return for their efforts. Moreover, the mix of insertion devices and their performance characteristics that is selected for development at the ALS will depend on the needs of the user community. However, a substantial fraction of the beam time at every beamline will be available to general users who are not members of the PRTs. Included in the general users community are Approved

Programs (AP). APs are granted to general users for some limited access after a determination that the scientific program is of an extremely high caliber.

Figure 3-7. EPU5 prior to installation.

Figure 3-8. IVID prior to installation.

It is the responsibility of the Proposal Study Panels (PSPs) to evaluate beam-time proposals from general users and make recommendations on beam-time allocation. The following criteria, endorsed by

the International Union of Pure and Applied Physics (IUPAP) in the IUPAP Recommendations for the Use of Major Physics Users Facilities, will be used to evaluate beam-time proposals:

- Scientific merit
- Technical feasibility
- Capability of the experimental group
- Availability of the resources required

The General Sciences PSP and Protein Crystallography PSP meet at least twice a year to review beamtime proposals from general users. The PSP compares the individual panel members' scores for each proposal, discussing and resolving any large variance in scores. Where appropriate, the PSP provides constructive comments for beamtime proposals. PSP members are required to provide a spread in scores between highest and lowest rated proposals thereby providing the basis for the beamtime allocation process. The PSP is encouraged to maintain a balance in science among high- and low-rated proposals. Users in disagreement with their PSP score may request, in writing to the PSP Chair, a review of their proposal. Panel members who are a primary author, a co-author, or a collaborator in a proposal under study are required to recuse themselves from the discussion and grading of the proposal. Panel members are not permitted to vote or discuss proposals that are in direct competition with their own scientific program. PSP members are appointed by the ALS Director based on nominations submitted by the ALS Users' Executive Committee. Every attempt is made to have all the scientific disciplines at the ALS represented on the panel. The term of an appointment to the PSP is usually three years.

Beamline Systems

Beamline systems in this context means the radiation source, front end, and beamline photon transport system. Radiation source and front ends are designed by ALS staff. Beamlines are generally designed by ALS staff, but in a few cases have been designed by user groups. In order to have uniformity of approach and a thorough analysis of functionality and safety of these complex systems, we have developed a sophisticated set of checks and reviews at all stages of the design, production and testing process. These are described in detail in the Beamline Design Guide, LBNL Pub 3114 (see

http://www-als.lbl.gov/als/bdguide/BDG.pdf). The review process is organized under the direction of the Beamline Review Committee. The basic stages are:

- Conceptual Design Review (CDR); this assesses issues of overall concept, space, general safety issues (for example sample containment, access in case of emergency etc.)
- the Beamline Design Review (BDR); this evaluates the beamline design in detail, including mechanical safety issues such as seismic restraint, equipment protection, and radiation protection and safety systems. On passing this review, the beamline builders can proceed to procurement and construction.
- the Beamline Readiness Review (BRR); this review checks to see that the plans as described in the BDR have been correctly executed. Plans of the completed system are presented and checked against the documentation provided at the BDR and against the general criteria for an operational beamline as described in Pub 3114.
- Beamline Readiness Review Walkthrough (BRRW); this checks the plans as described at the BRR against the physical hardware on the floor, and involves keying on the beamline and equipment and radiation protection and survey checks. Samples of checklists for key enable and radiation survey are contained in Pub 3114.

These four stages of review are supplemented by engineering reviews of all major subsystems during the course of the construction project. Subsequent to authorization for operation, the critical systems are tested on a routine basis. All of these functions are described in a detailed set of procedures that are maintained and updated under the direction of the ALS Procedure Center (http://alsintra.lbl.gov/procedures/index.htm). The schedule for execution of these procedures is defined in documentation at the above link. The procedures themselves describe all of the critical processes for safe operation and protection and maintenance of equipment at ALS. The full list of these procedures is at http://alsintra.lbl.gov/procedures/procedures.htm.

Radiation sources

The ALS has over 40 beamlines (2005), and these cover from the mid infrared region (few meV energy) to the hard x-ray (50 keV). Figure 3-9 shows the range of beamlines that we have in 2005. This large

range of energies is provided by several different types of radiation sources; normal bend magnets (1.27T), superconducting bend magnets (5T), a wiggler (1.94T, 11.4 cm, 52 poles), and undulators of periods 5, 8 and 10 cm. The original suite of undulators were full length devices (around 4.5 m long) occupying the whole straight section (in straights 7, 8, 9, 10, 12). Later undulators have occupied chicaned straights (4 and 11) where 2 undulators are inclined with respect to each other and occupy a straight length of around 2m (Figure 3-10). These are all 5 cm period elliptically polarizing undulators. In general, the power, flux and brightness radiated by these devices ranges from the normal bending magnet at 15W/mrad, 10^{13} ph/sec 0.1% band 1 mrad and 10^{16} ph/sec 0.1% band mm^2 $mrad^2$ to a high field undulator at 5 KW (total), 10^{15} ph/sec 0.1% band (central cone) and 10^{19} ph/sec 0.1% band mm^2 $mrad^2$ respectively.

Front ends

Front end design differs in detail on all the above radiation sources but there are many common features that are necessary to all systems. Here we describe the chicaned undulator straight, which is the most complex front end. Such a system is shown in Figure 3-11. The function of the front end is to define the beam within designed angular ranges, to protect the storage ring in case of a vacuum problem on the beamline, and to provide a means of shutting off the storage ring from the beamline for purposes of radiation protection during injection. In Figure 3-11, beam first passes a vacuum valve that can be used for isolating the vacuum of the storage ring from the front end section. The beam is then defined in angular aperture by horizontal and vertical beam defining apertures. These are high power components and are made of a high strength copper alloy and are internally cooled. The front end shown is particularly complex as it accommodates two beams, angularly split in the horizontal direction, from 2 undulators in a chicaned straight section. The two beams are isolated in terms of radiation from the beamline by two personnel safety shutters (PSS). The shutters contain water-cooled absorbers to absorb the beam power, as well as thick blocks of tungsten to absorb high-energy gas bremsstrahlung radiation formed by collision of electrons in the storage ring with residual gas molecules. Downstream of the PSSs we have a fast valve that closes in a few msec, when triggered by an upstream sensor in the beamline. The sensor triggers when it sees a sudden rise in gas pressure. This mechanism allows time for the valve to close, before any gas from a venting problem hits the front end. Beam then passes through a regular vacuum isolation valve and onto a mirror chamber. Unlike many storage ring facilities, ALS has many of the first optics inside the storage ring shielding. This has many optical advantages and

gives more flexibility in terms of beamline design. In a chicaned undulator straight, this mirror tank contains two mirrors, shown in Figure 3-10. The mirrors face each other, so that the two beams cross downstream. These mirrors have to be remotely operated and typically have pitch, yaw and roll controls.

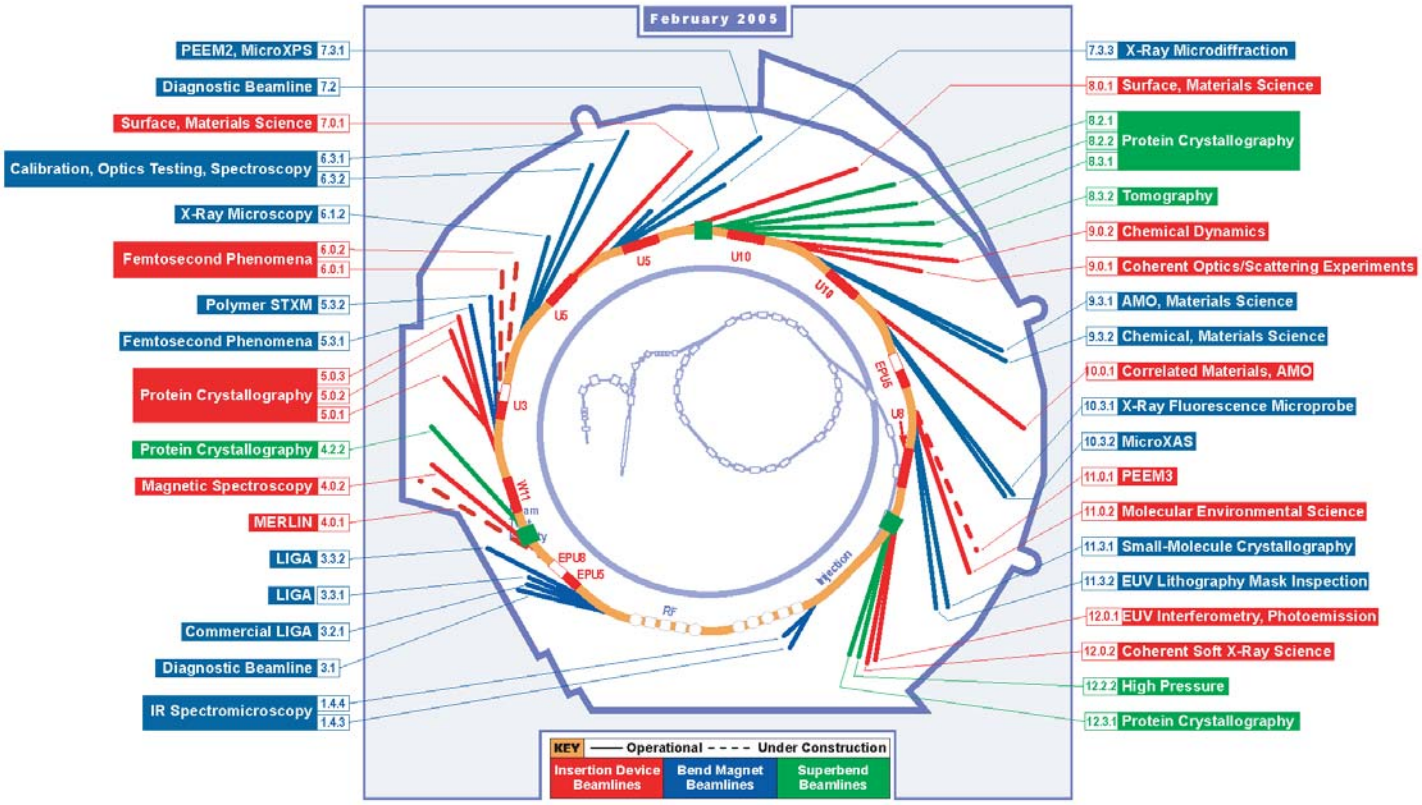


Figure 3-9. Beamlines at the ALS in 2005

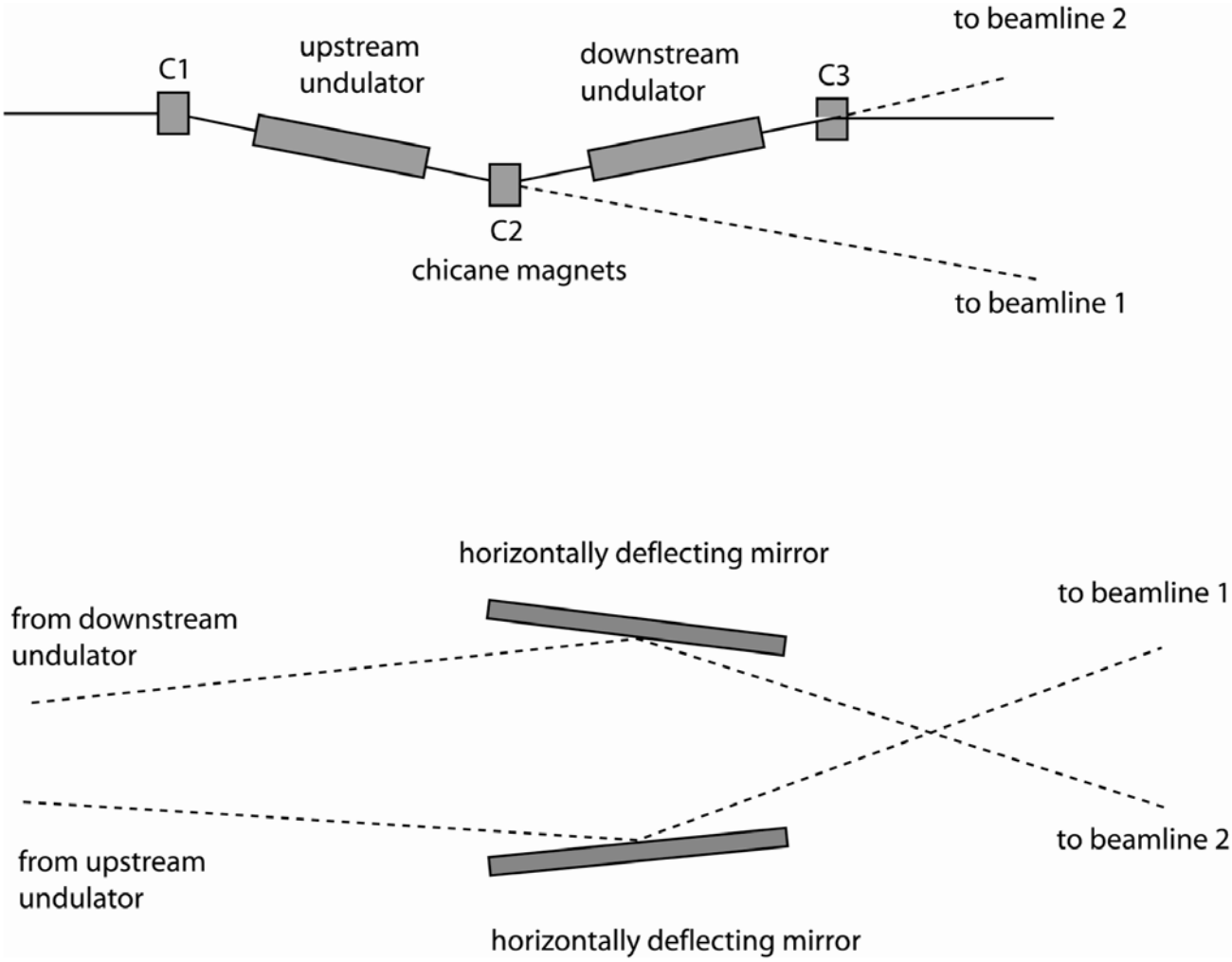


Figure 3-10. Arrangement of a chicaned straight with beamline mirrors

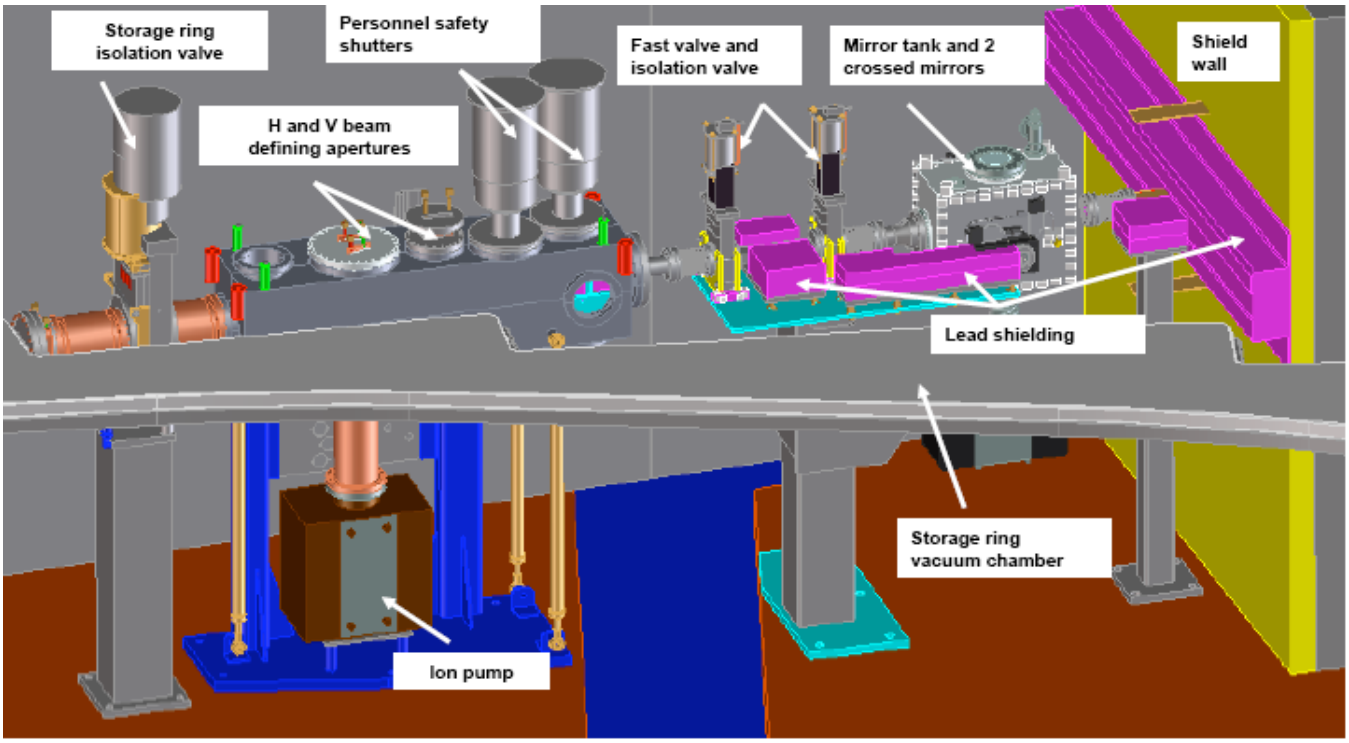


Figure 3-11. Front end section from a chicanes straight section

Again, due to the very high power densities, the mirrors are heavily water-cooled. The area around the mirror tank from just upstream to the shield wall has heavy additional lead shielding to ensure that gas bremsstrahlung cannot escape through oblique angles through the shield wall. The opening and closing of valves and shutters in the front end, together with monitoring vacuum pressure and water flow is done by a front end Equipment Protection System (EPS) that is operable from the beamline. The opening of the PSSs is done by the Radiation Safety System (RSS). The RSS has several functions. It interfaces to the storage ring control system, and in the presence of a beamline radiation fault condition, the RSS will trip off the storage ring RF system. It also allows the beamline to be disabled, by removal of a key from the beamline control racks in the experimental area. This would be done during shutdowns, and other periods when modifications were being made to beamline apparatus. In hard x-ray beamlines the end station at the end of the beamline is enclosed in a radiation hard hutch. The hutches come in two varieties, a large walk-in hutch and a mini-hutch with a sliding door. Both types have a radiation safety system that monitors the state of the hutch and the personnel safety shutter. In the

presence of a fault that indicates that the hutch is open and the PSS is open, the RSS will trip off the storage ring RF system. The last component in the front end is the shield wall. This is constructed from high density concrete and is up to 1 m thick. This shielding is supplemented by additional lead shielding at beam height on the inside of the shield wall (upstream) as well as polyethylene and lead inside the wall penetration for neutron absorption. A key part of the design procedure for beamlines and front ends is to ensure that all synchrotron radiation, direct and scattered, and gas bremsstrahlung from the storage ring is contained and collimated within tight position and angular constraints. Radiation that comes out of the shield wall is then contained within the beampipe, within an exclusion zone where access is not allowed, or dumped into a backstop or collimator downstream. All shielding is designed by a process of raytracing from all possible radiation source points.

Beamlines

Beamlines come in two fundamentally different types, windowless VUV soft x-ray beamlines and windowed hard x-ray beamlines. They are fundamentally different because of the hazards involved in each case and the safety systems we have to employ and so are described here separately.

a) VUV soft x-ray beamlines

The layout of one of the latest generation of soft x-ray beamlines is shown in Figure 3-12. As shown in Figure 3-10, this is one beamline from a chicaned straight, so there is beamline similar in design to this as a mirror image, branching towards the top of the page from the front end (from a second M1 mirror as shown in Figure 3-10). In this case, the M1 mirror is a sagittal cylinder, providing focusing to the entrance slit of a downstream monochromator. The monochromator itself is a converging beam variable line spacing plane grating monochromator, with the converging beam being provided by a spherical M2 mirror. This disperses the radiation, and focuses single wavelengths to a plane of dispersion at the exit slit of the monochromator. The photon energy is changed by simple grating rotation. The entrance slit, M2 mirror and grating are all heavily cooled. Light that has been diverging in the horizontal plane from the undulator is collected by an elliptical M3 mirror and focused close to the exit slit. Light is then further demagnified by a second elliptical mirror M4 onto the sample. In the vertical direction, another elliptical mirror refocuses the light from the exit slit and demagnified it to the sample. Most of these mirrors and grating are controlled by motors and encoders, from the beamline control system. The beamlines typically are 30 – 35 m in length from the radiation source. The physical arrangement of the system is shown in Figure 3-13 (for sector 11.0), and shows the front end, shield wall, and the two beamlines almost side by side, but in reality branching away from each other by

around 12 degrees. The left hand beamline feeds the PEEM3 end station (a photoelectron microscope), and the right hand beamline feeds the Molecular Environmental Science (MES) end stations. The PEEM3 line has one end station. The MES beamline splits into several branchlines, feeding individual end stations. The adjacent beamlines 11.3 (upper) and 10.3.2 (lower) are not shown for clarity. The safety exit (yellow stairs) from the storage ring roof, to the periphery of the ALS is shown (yellow lines). The vacuum pressure in the beamline is monitored by ion gauges and other types of low vacuum gauges, and sections are isolated by vacuum valves. Opening and closing of valves, monitoring of the vacuum pressures and monitoring of the status of water flow on cooled components are all controlled by the beamline Equipment Protection System (EPS). The Radiation Safety System (RSS) is simple in the case of all-vacuum beamlines as described here. The RSS has an enable key. The RSS checks that the redundant limit switches on the PSS are correctly enabled, and if the enable key is energized, gives a 'ready' signal. The EPS can then open the PSS if requested. The system usually has a fast valve sensor close to the experimental end station, which if activated, triggers a fast valve in the front end. This protects the storage ring from beamline vacuum accidents. Due to the very short absorption length of VUV and soft x-ray radiation in air, and to protect optics, these beamlines and endstations are always at high to ultrahigh vacuum. In the special case of soft x-ray microscopes, a very narrow beam of radiation is extracted through typically a 0.5 mm diameter 100 nm thick window into air or helium. The radiation is absorbed over a very short distance in air (~1 mm) and passive devices together with operational procedures give adequate radiation protection.

b) Hard x-ray beamlines

The layout of a typical x-ray beamline is shown in Figure 3-14. In general the front end layout is similar to that previously described for a chicaned undulator front end, but there would usually be a Beryllium window upstream of the mirrors, and in the case of the wiggler beamline in straight 5, there is a carbon filter just upstream of this window to absorb low energy light. The system drawn here in Figure 3-14 and 3-15 is specifically for the superbend protein crystallography beamlines, and is typical of the latest designs used. Light is vertically collimated by an M1 mirror inside the shield wall reflecting and focusing in the vertical direction. This mirror has remote pitch and bend controls. The beam then passes through the shield wall and onto the monochromator. This is usually a commercial system consisting of a pair of crystals (Si [111]) that define the photon energy. The energy is changed by rotation of the crystals and translation of the second crystal. Beam then passes to a vertical reflecting toroidal mirror that focuses from infinity in the vertical direction and from the real source in the horizontal direction.

The beam is focused into the end station x-ray hutch where experiments are conducted. The general arrangement of such a beamline is shown in Figure 3-15, which shows 3 beamlines in one superbend sector (8.2 and 8.3). The beam emerging from the shield wall first passes through two bremsstrahlung collimators. The beam pipe is stainless steep wrapped in lead with a stainless steel tube outer covering. Beam then enters the monochromator (large circular blue structures), which has internal shielding, and finally onto the M2 refocusing mirror chamber. Each of the 3 lines terminates in a mini-hutch. The upper hutch is shown with complete shielding and the two lower ones with shielding removed, revealing the end station goniometer and detector. X-ray end stations come in two varieties a) conventional large walk-in hutch and b) mini-hutch. The conventional hutches can be accessed using an interlocked Radiation Safety System (RSS). The shutter is requested closed, and when closed, the door may be unlocked via a pushbutton. When locking up the hutch, the hutch is first visually searched, then a search button inside the hutch is pressed, and the door closed and locked. After a minimum period of 15 seconds, during which alarms are activated inside the hutch, the RSS enables the radiation shutter to open, if all interlock chains are complete. A request from the Equipment Protection System (EPS) then opens the hutch radiation shutter. In the case of the mini-hutch, entry into the hutch is via a hatch window, and physical entry of the whole body into the hutch is not allowed in normal operation except by special lockout procedure. The hutch search button and warning period and alarm are therefore not necessary in this case and the door access key has been replaced with a push button for ease of operation. All other functions of the RSS are retained. The major difference between VUV / soft x-ray and hard x-ray beamlines is in the shielding requirements. These are described in detail in Appendix A of the Beamline Design Guide (http://www-als.lbl.gov/als/bdguide/BDG.pdf). Hard x-ray beamlines have several unique hazards:

(1) Particularly in the case of superbends, where the critical energy is high (12 keV), extremely high doses can result through multiply scattered events. Shielding for scatter as well as direct radiation has to be extremely thorough. This is done through extensive use of lead shielding along the beamline around the beam tubes, around beamline components such as beam shutters, and use of other materials (for example copper and tungsten) within vacuum enclosures (such as for monochromators).

(2) Hard x-ray beamlines usually have a vacuum isolating beryllium window in the front end. This means that we need to be especially careful when removing parts of the beamline during any type of maintenance. Although the EPS would close all the relevant valves and shutters if it sensed that part of the beamline was at atmospheric pressure, it is not part of the radiation safety system. A strict system of procedures is maintained for accessing the shielding and for re-installation and checking prior to approved operation. During these periods the beamline RSS is keyed off. Re-enabling requires a series of procedures to be activated. In addition, area radiation monitoring and routine checking of all beamlines are provided. Another supplement is the use of padlocks on flanges that are likely to be accessed frequently. The procedures are accessed through the procedure center at http://alsintra.lbl.gov/procedures/procedures.htm. In addition, information on radiation safety is available at http://als.lbl.gov/als_rad_safety/index.html.

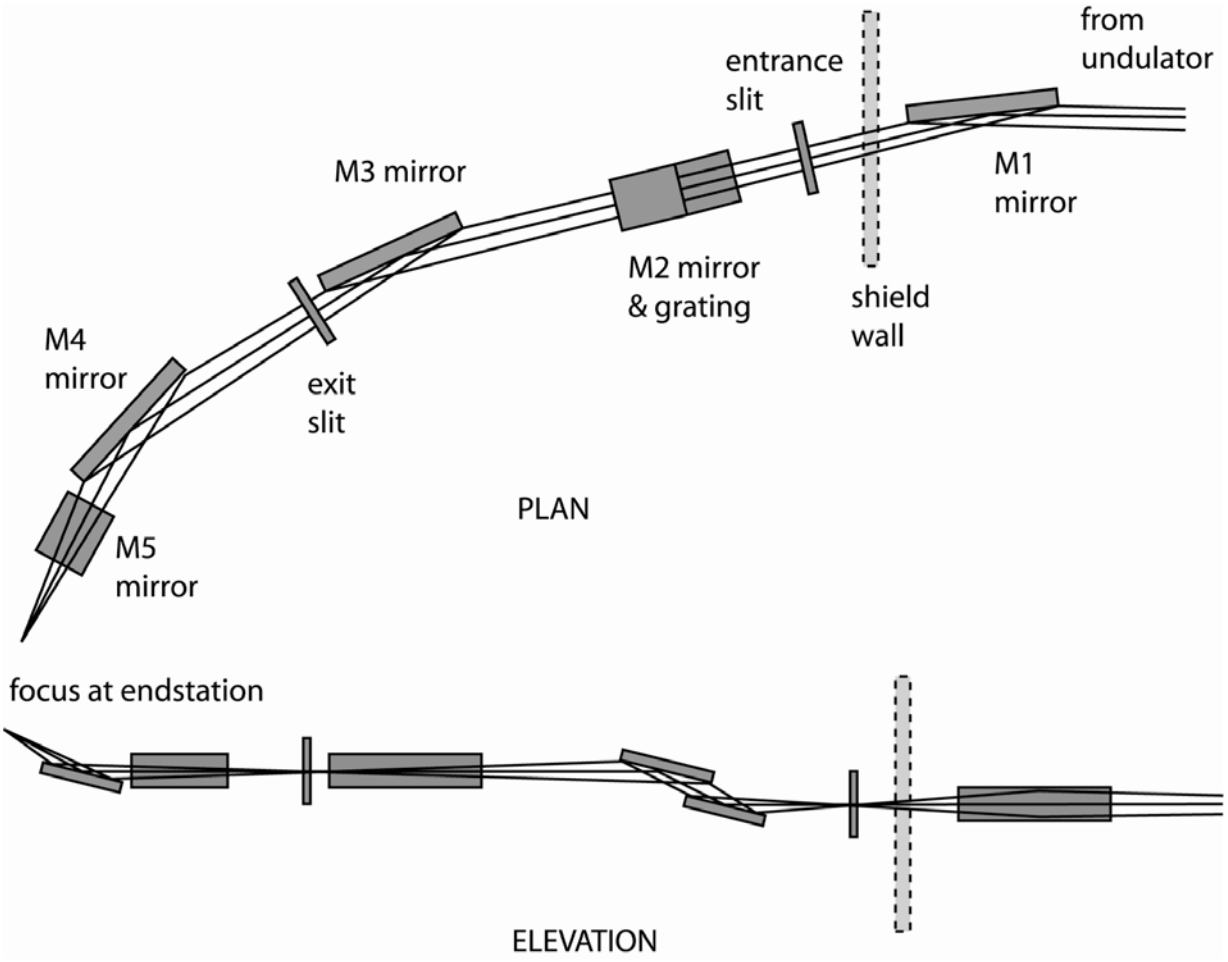


Figure 3-12. Optical layout of a soft x-ray undulator beamline: PEEM3, sector 11.0

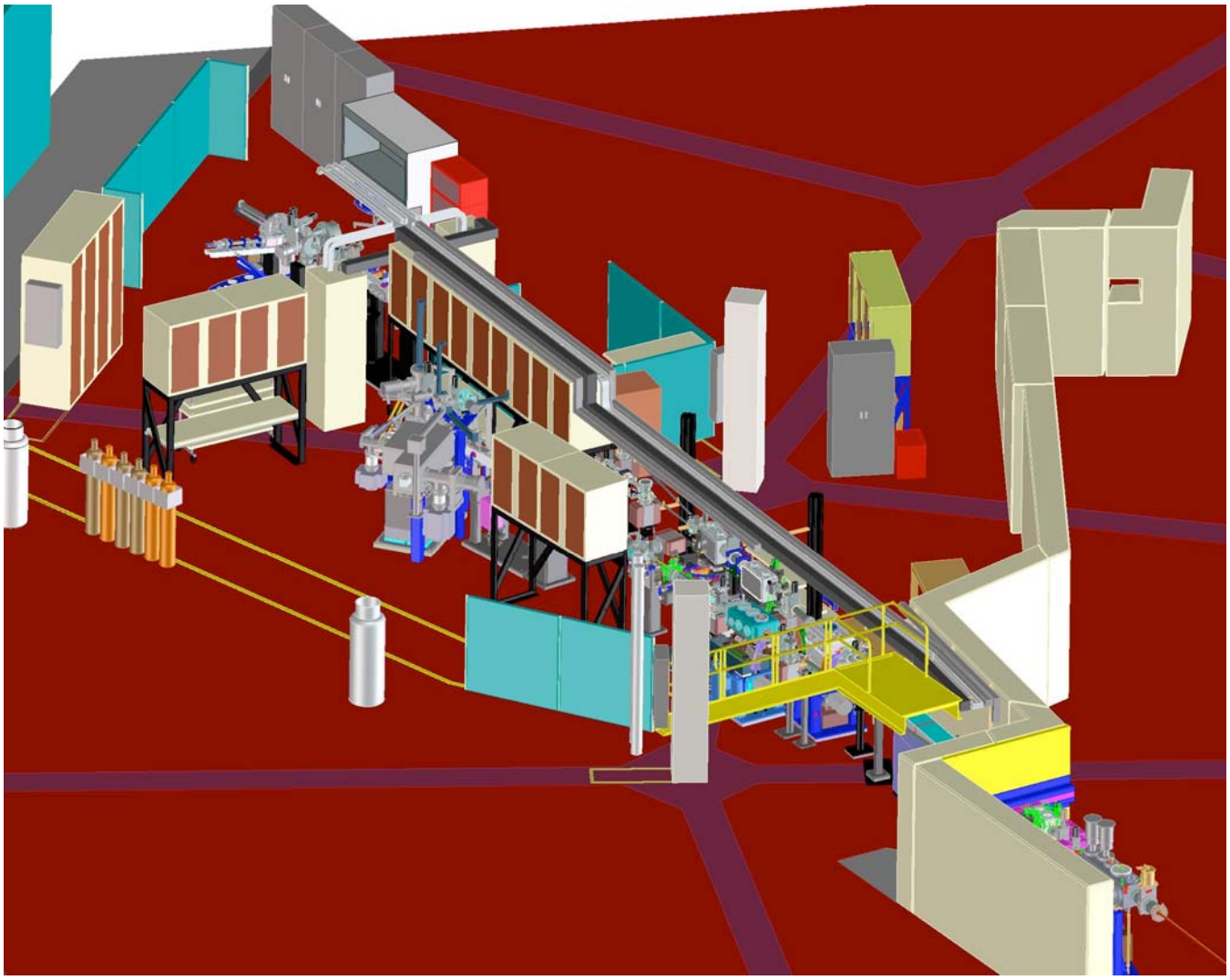


Figure 3-13. Schematic layout of a soft x-ray undulator beamline: PEEM3, sector 11.0

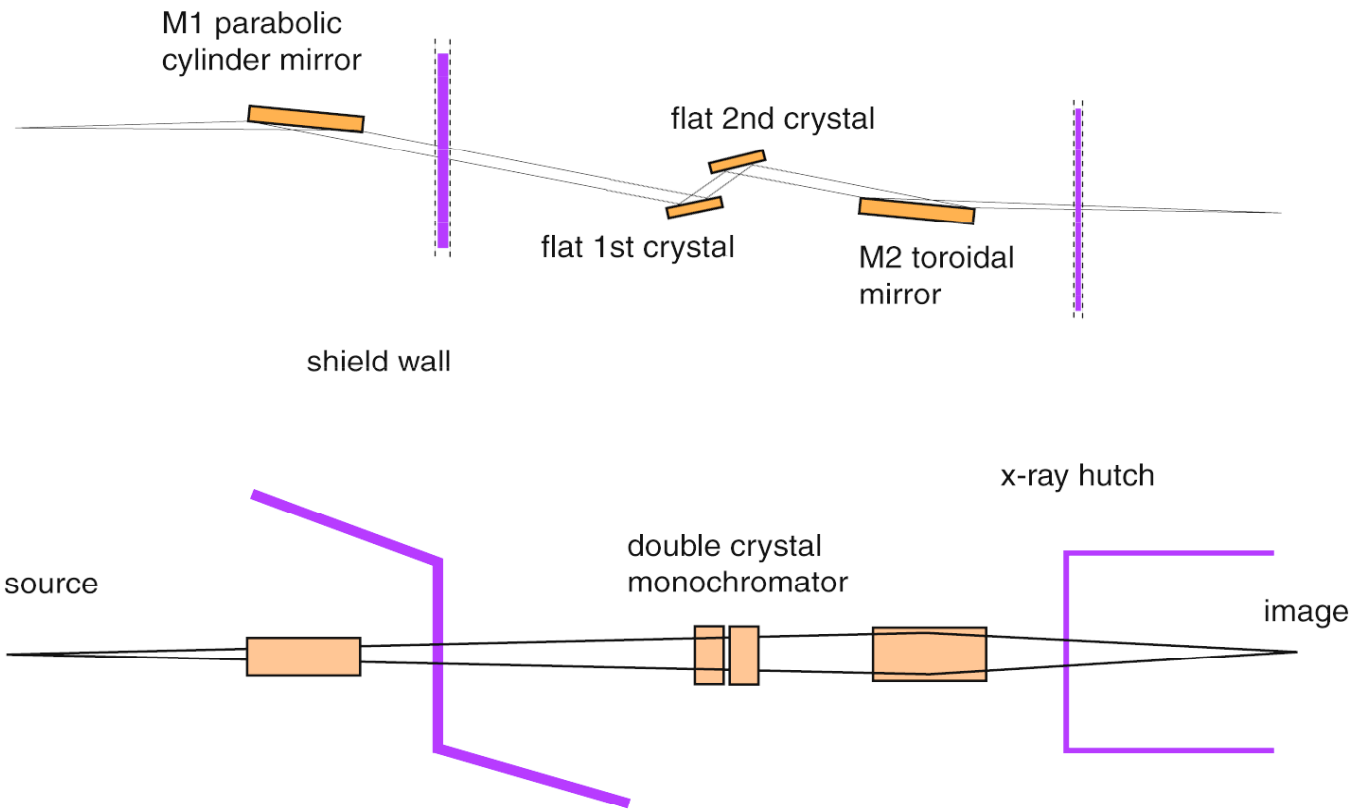


Figure 3-14. Optical layout of a hard x-ray beamline: sector 8

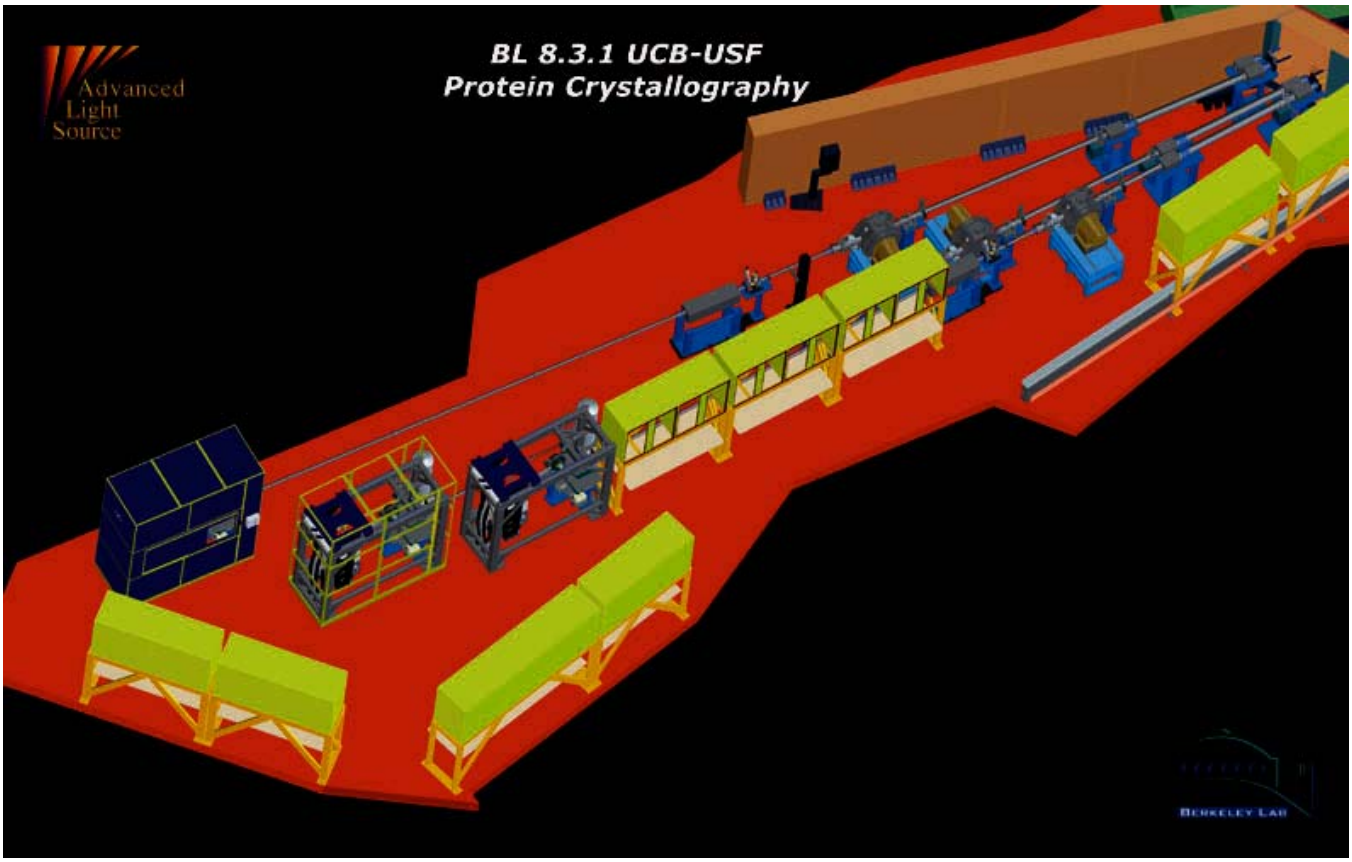


Figure 3-15. Schematic layout of a hard x-ray beamline: Sector 8.2, 8.3

3.3.7 Experiments

The beamlines guide the synchrotron radiation to the experimental areas. The beamline end station is responsible for providing the appropriate environment for experiment support and for investigator access. The end station may comprise a relatively complex set of components, such as a beam diagnostic region, plus a personnel safety shutter, and a fully shielded and interlocked hutch for experiments that use harder x-rays, or it may comprise simply an isolation valve and the experimenter's vacuum chamber.

The end station extends from the end-station interface through the experimental apparatus. Some branch lines may have several end stations in tandem and/or in parallel.

The end station instrumentation consists primarily of the experimental apparatus. It also contains minimal instrumentation to isolate the end station from the branchline. There are diagnostic components, which are used to align and qualify the upstream optical components. The instrumentation will vary depending upon the specific experiment requirements. Depending on the needs of the users, experimental areas may contain a number of manually or electrically operated vacuum isolation valves, vacuum delay lines, differential pumping stations (to permit samples to be at higher pressures than allowed in the beamlines), and radiation-transparent solid windows (to isolate the sample chamber from the beamline).

The equipment in the experimental areas will reflect the requirements and interests of both categories of users, members of PRTs and independent investigators who may use PRT experimental chambers or bring their own. Most will involve vacuum chambers with UHV capability, movable specimen stages for positioning and orientation of samples in the synchrotron-radiation beam, electron and photon detectors and spectrometers, and ancillary diagnostic instrumentation. Some areas will have cryogenic equipment. Some areas will be for the investigation of gaseous samples and will have mechanisms for introducing the sample into the chamber without degrading the UHV environment elsewhere in the beamline. Some areas may have the capability to fabricate specimens in-situ by, for example, molecular-beam epitaxy, or to subject them to structure- or behavior-changing treatments, such as changing the characteristics of a solution containing biological-cell structures. Some areas may have associated facilities nearby for sample preparation and hazardous material containment. All experimental areas will have extensive instrument-control and data-acquisition computer systems with links to the ALS computer system.

To a great degree, end stations for VUV and soft x-ray experiments with synchrotron radiation are based on a generic structure, namely, an ultrahigh-vacuum (UHV) chamber, to which numerous instruments for sample preparation, manipulation, and characterization, as well as detectors and spectrometers for electrons, photons, and ions, are appended, as required by the specific experiments to be conducted. For example, low-energy electron diffraction (LEED), reflection high-energy electron diffraction (RHEED), and scanning tunneling microscopy (STM) instruments are important for characterization of solid samples, whereas gas-phase samples require a gas-handling system in the experimental chamber, as well as a differential-pumping system to isolate the sample from the UHV environment of the beamline and the storage ring. For chemical reaction dynamics, end stations are somewhat more specialized. For example, lasers are used to create well-characterized initial conditions before the initiation of chemical reactions in chambers equipped with molecular beam sources.

For hard x-ray experiments, radiation-protection hutches are required for personnel protection, but maintenance of an ultra-high vacuum is not always needed in the sample chamber, a potential advantage for examining materials in near-natural environments. The absence of UHV vacuum chambers also makes it more practical to construct special-purpose experimental stations for specific purposes, such as a fluorescence x-ray microprobe.

3.3.8 Ancillary laboratory, shop and office space

Approximately 19,000 square feet of laboratory and office space has been constructed in the second floor or mezzanine of B6. 8,500 square feet of this is equipped with standard laboratory plumbing, ventilation, and other utilities. Much of this space is used for instrument, detector and laser development, and the rest is used for preparation of chemical and biological samples. The remainder of space in the mezzanine is used for office space.

The basement of B80 is primarily machine and electronics shop space, the main floor is primarily office space and the second floor houses both office and laboratory space.

3.4 Description of Organization

3.4.1 ALS Organization

In over 12 years of operation, the scientific output and capabilities of the ALS have grown dramatically. The organization of the ALS has expanded and evolved alongside that growth. The following paragraphs describe the present position of the ALS facility within the LBNL structure and the operational structure of the ALS organization.

The LBNL organization (see Figure 3-16) vests primary responsibility for all activities in the Laboratory Director.

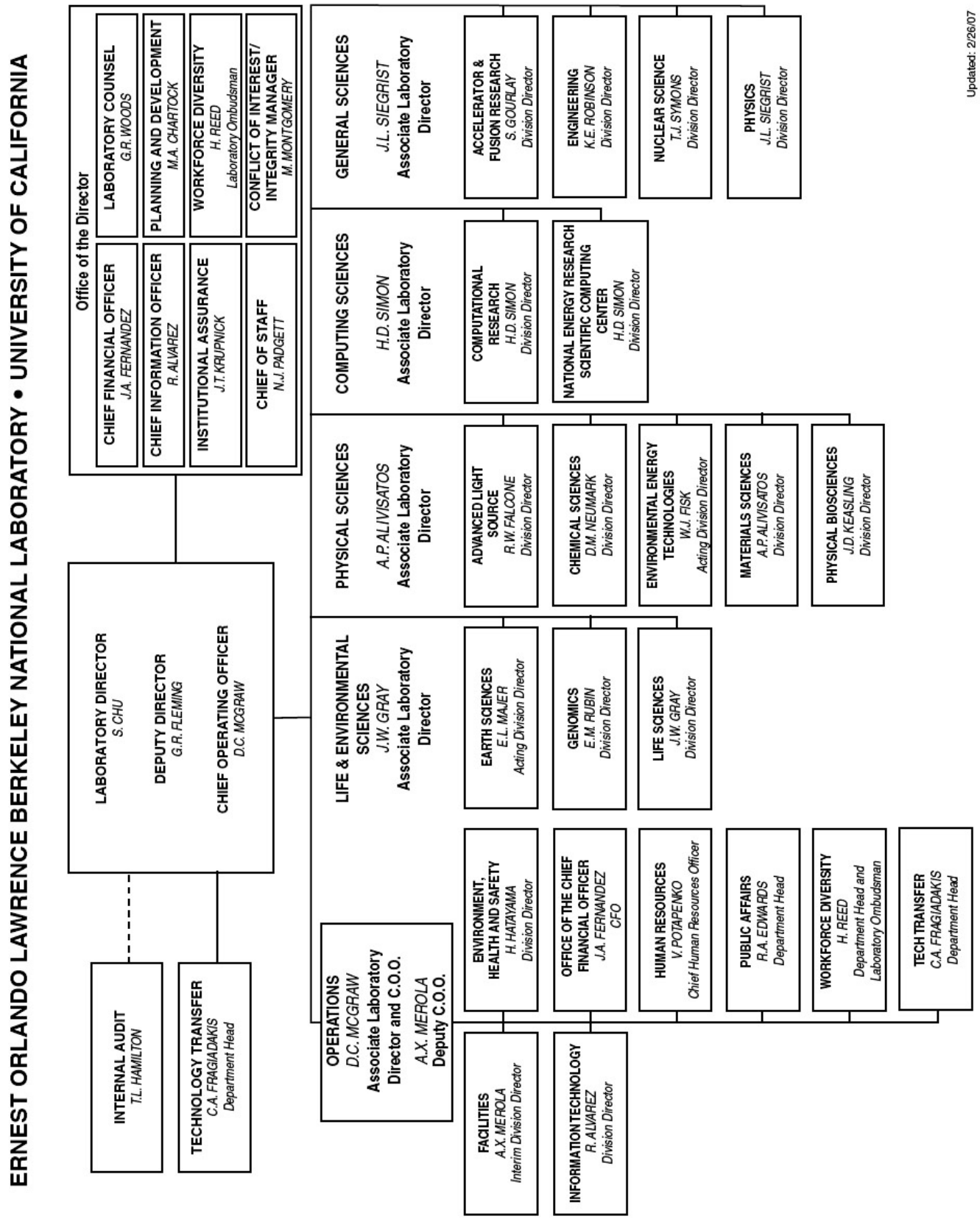


Figure 3-16. Berkeley Lab organization chart

Though the ALS falls under the Physical Sciences Directorate, the ALS Division Director reports directly to the LBNL Laboratory Director.

In the ALS organization, full responsibility for operation of the facility, and development of the scientific program resides with the ALS Division Director (see Figure 3-17). Duties of the Division Director include, evaluating the need for an applying appropriate Quality Assurance policies to all ALS activities, establishing and maintaining an active environment, safety, and health program, setting overall goals for the facility, authorizing new programmatic and major R&D activities, securing and assigning resources within the ALS organization, and development of the scientific program. As the Director of an LBNL Division, the ALS Division Director has direct access to the LBNL management by such means as participation in meetings of the Division Directors.

Reporting to the Division Director are the Deputy Division Director, the Division Deputy for Operations and Accelerator Development, the Scientific Advisor, the Division Deputy for Planning and Administration, the Division Deputy for Scientific Support, the Division Deputy for Experimental Systems, the ALS ES&H Program Manager, the Head of the User Services Group, the Computer Protection Officer, and the Quality Assurance Officer.

The Deputy Division Director is responsible for acting as Director in the absence of the Division Director. The Division Deputy for Operations and Accelerator Development is responsible for all activities related to facility operations, for facility planning and development. Specific duties include providing oversight of operations, allocating resources within the organization, leading overall planning for the ALS operations, and ensuring that the operation of the ALS meets user and scientific goals. For these purposes, the ALS is divided into functional groups, the leaders of which report to the Division Deputy for Operations and Accelerator Development:

(1) The Accelerator Physics Group is responsible for planning R&D and technical development leading to enhanced capabilities of the accelerator complex, for overseeing improvements of accelerator capabilities and operations needed to implement new capabilities, for overseeing the health physics program to ensure that accelerator improvements are appropriately monitored for radiation-field changes, and for scientific support of relevant activities in other departments.

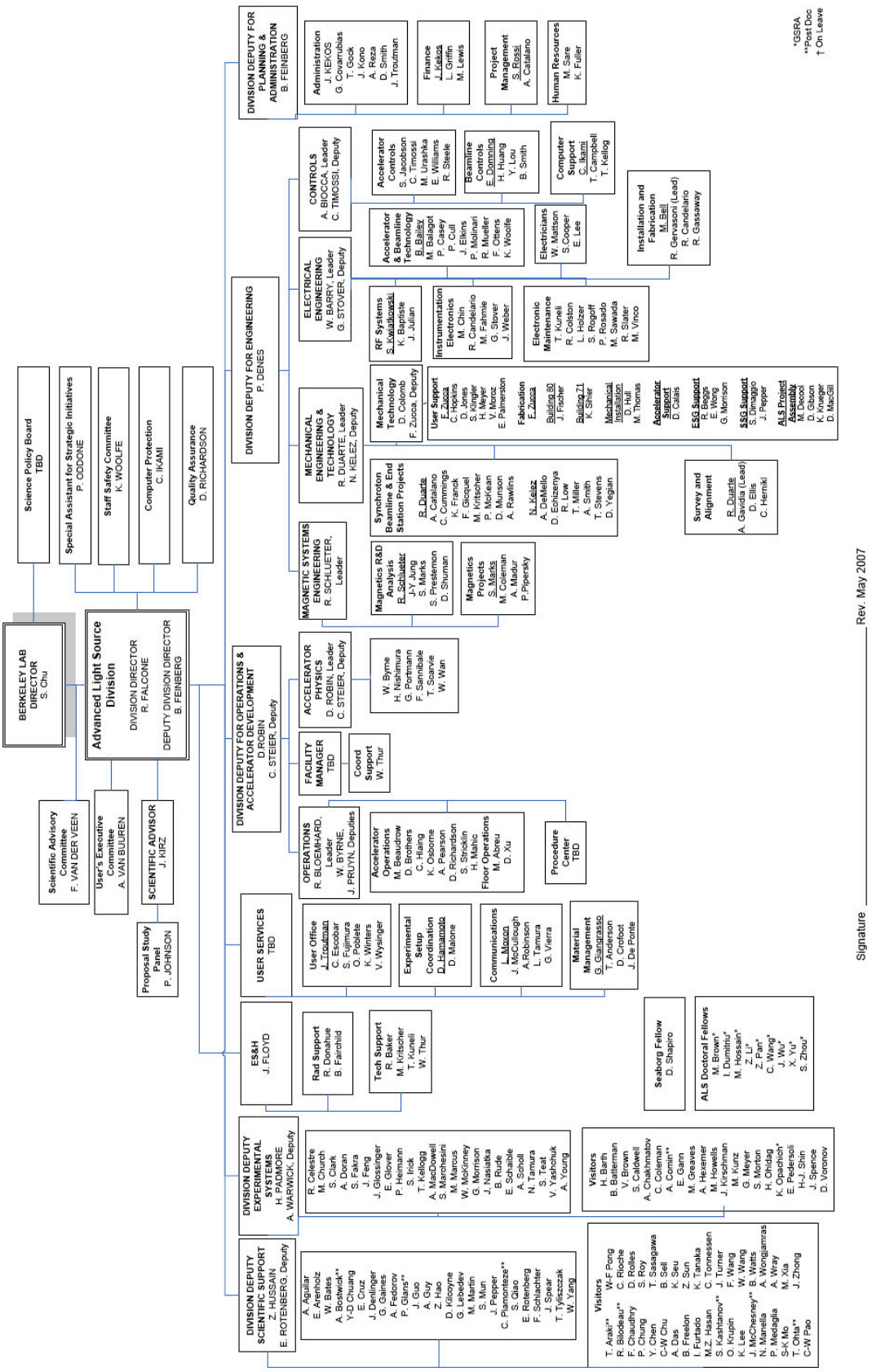


Figure 3-17. Advanced Light Source organizational chart

(2) The Mechanical Engineering and Technology Group is responsible for providing engineering and technical support for R&D and improvement activities of the programmatic groups, providing maintenance of operational systems, and overseeing selected projects needed to implement new capabilities.

(3) The Magnetic Systems Engineering Group is responsible for providing engineering for magnetics and insertion device R&D and improvement activities, including overseeing projects needed to implement new capabilities.

(4) The Electrical Engineering Group is responsible for providing engineering and technical support for R&D and improvement activities of the programmatic groups, providing maintenance of operational systems, and overseeing selected projects needed to implement new capabilities.

(5) The ALS Operations Group is responsible for ensuring safe and efficient facility operations, ensuring safe and efficient technical user support, and for organizing and scheduling required facility maintenance.

(6) The ALS Controls Group is responsible for the remote actuation, automatic control, status reporting, and archiving of the accelerators and beamline systems. It is also responsible for the creation and maintenance of controls software and hardware.

The Scientific Advisor is responsible for the development of the scientific program, which includes promoting the unique ALS capabilities to the user community and to potential new user groups, as well as oversight over user services and administration. Specific duties include supervising the user program, chairing the Program Review Panel, acting as scientific representative of the ALS, and ensuring that the operation of the ALS meets user and scientific goals.

The Division Deputy for Planning and Administration is responsible for overseeing planning of improvement projects needed to implement new capabilities, for overseeing the planning and budget process to ensure optimum use of the budget, and for ensuring required tracking of non-operations projects. The Administration Section oversees all administrative operations, including personnel administration, budgeting, Planning and scheduling, and inventory control, and it represents the ALS in administrative contacts with external organizations.

The User Services Group plans and organizes workshops in areas related to the ALS scientific programs, organizes advisory group meetings, initiates and implements procedures for users (including proposals and user EH&S), represents user concerns and needs to the ALS Division management, and ensures that priorities are communicated to operational support groups. Additional duties include writing and editing (publicity, reports, documentation, manuals, and newsletters) and user administration (site access, experimental floor access, proposal administration, accounts, publicity, meeting organization, annual report preparation, travel, housing counseling, and parking).

The ES&H Program provides overall management of the safety program at the ALS and develops facility-specific hazard control programs to meet both the institutional and regulatory requirements as well as the operational needs of the user facility. It also provides on-going assistance to all staff and supervisors through technical evaluations and monitoring.

The Experimental Systems Group (ESG) is responsible for planning R&D and technical development leading to the enhanced capabilities of the experimental facilities, for overseeing improvements and other projects needed to implement new capabilities, for safe and efficient physics support of user-related activities, and for scientific support of relevant activities in other departments.

The Scientific Support Group (SSG) provides scientific and technical support to ALS users for carrying out their experiments, provides access to state-of-the-art data analysis tools for interpretation of experimental data, and assists users in developing novel and/or better experimental equipment. In addition, the SSG provides suggestions on improvements to beamlines and endstations and helps researchers disseminate scientific results through presentations, papers, reports, and publications in journals.

The Computer Protection Officer maintains a regimen of preventive maintenance, upgrading and continuous monitoring to ensure that all ALS monitoring systems are maximally secure from intentional and unintentional failures and accesses.

The Quality Assurance Officer assists in carrying out the ALS QA effort through preparation and review of the ALS Center's Project and Facility Notebooks prior to their submission for approval, provision of QA guidance to ALS personnel, arrangement of QA program orientation and training, and service as a communications link with the AFRD Quality Assurance Officer.

There are three primary ALS advisory committees:

(1) The ALS Science Policy Board (SPB) is appointed by the LBNL Director to provide advice on major policy issues that bear on effective utilization of the ALS [ALS, 1988a]. The SPB serves two primary functions:

- To serve as a "visiting committee" to advise the Laboratory on policy aspects of ALS operation, development, and plans for the future; and
- To ensure that the ALS operates as a national facility whose development and utilization contribute maximally to scientific and technical productivity.

The SPB is composed of persons who are distinguished by excellence of scientific or technological accomplishment and experienced in the management of scientific organizations. Membership on the SPB is for a three-year term, renewable for no more than one term.

(2) The ALS Scientific Advisory Committee (SAC) is advisory to the LBNL Director and provides, through the ALS Director, specific recommendations on the disposition of all proposals for the development and use of beamlines of all types [ALS, 1989c]. The SAC will review and evaluate proposals from Participating Research Teams (PRTs); it will review PRT performance, both during the beamline-construction phase and afterwards in the operations phase; and it will provide peer review of proposals Approved Program (AP) status by General Users.

The members and chair of the SAC are appointed by the LBNL Director. The ALS Director recommends nominees to the LBNL Director after broad consultation with LBNL management and with the synchrotron-radiation community through the ALS Users' Executive Committee. The SAC has nine members. Membership on the SAC is for a three-year term, renewable for no more than one term. The ALS Scientific Advisor serves as the primary contact to the SAC.

(3) The ALS Users' Executive Committee (UEC) is charged with conducting the day-to-day business of the ALS Users' Association (ALSUA). The purpose of the ALSUA is to provide an organized framework for the interaction between those who use the ALS for their research and the ALS management, as well as to provide a channel for communication with other synchrotron-radiation laboratories and, on suitable occasions, with federal agencies [ALS, 1988b]. The ALSUA, representing the research workers, is in a position to make known to the ALS management the needs and desires of users regarding operating policy, use of the ALS, user support, and other relevant issues of concern to those engaged in research at the facility.

The ALSUA further provides a means for the ALS management to inform users with regard to current and future plans for the facility. Thorough discussion with users of current projects, as well as plans for the future, places ALS management in a better position to evaluate the needs of users and enables users to plan more efficiently their utilization of the facility.

The members of the UEC are elected by mail ballot by the members of the ALSUA. The UEC has 11 members. Membership is for a three-year term. The UEC elects its own officers, who then also serve as the officers of the ALSUA. In partial fulfillment of its function, the ALSUA holds an annual meeting, normally in Berkeley, which serves as a general vehicle for communication between the ALS and the user community. In addition, the UEC meets as often as necessary, which has been approximately quarterly, for direct communication with the ALS management. The UEC also establishes subcommittees as necessary or participates in joint committees to provide advice on specific issues of interest to the user community.

3.4.2 EH&S Organization

LBNL EH&S

EH&S administration at the ALS will take place within the existing LBNL EH&S structure in which all levels of management are delegated the authority necessary to implement LBNL's health, safety, and emergency preparedness policies, as described in Chapter 1 of the LBNL Health and Safety Manual.

It is the policy of the Lawrence Berkeley National Laboratory to provide a safe and healthful working environment for its employees, participating guests, and visitors and to prevent any harm to these individuals, the general public, or to the environment as a result of the Laboratory’s activities. The Laboratory Director exercises the authority to carry out this policy and interpret the requirements for health, safety, and emergency preparedness placed upon the University of California as a consequence of its contract with the U.S. Department of Energy for the operation of the Laboratory.

The Laboratory Director is responsible for ensuring that LBNL’s health, safety, emergency-preparedness policies are carried out. The Director has delegated the responsibility and authority necessary to implement the health, safety, and emergency-preparedness policies of the Laboratory to appropriate members of the Laboratory management and staff. In particular, the Associate Laboratory Director for Operations has been delegated the authority to develop and administer the Laboratory’s Health and Safety Program. Division Directors must ensure that facilities and operations for which they

have responsibility are maintained free of life-safety hazards and that they comply with applicable health and safety requirements. The Director of the Environment, Health, and Safety Division reports to the Chief Operating Officer. The primary functions of the Environment, Health and Safety Division are to ensure that LBNL's scientific programs are carried out in compliance with the applicable orders of the DOE and with the regulations of other agencies having jurisdiction; to provide professional support in various disciplines of the Environment, Health and Safety Division to the Laboratory's scientific programs; to assist in the development of health and safety regulations; and to provide liaison with local, state, and federal agencies and with various organizations in the University of California in the field of Environment, Health, and Safety.

The Safety Review Committee (SRC) performs research for and makes recommendations to the Laboratory Director on the development and implementation of Environment, Health & Safety (EH&S) policy, guidelines, codes, and regulatory interpretation. It conducts reviews of special safety problems and provides recommendations for possible solutions to the Laboratory Director and/or the EH&S Division. The SRC also provides advice and counsel to the Associate Laboratory Director for Operations by reviewing appeals from the Laboratory Divisions when any Division and the EH&S Division do not agree on the interpretation or application of criteria, rules or procedures. Such advice and counsel may include options for a resolution.

In addition, the SRC chair, in cooperation with the Office of Contract Assurance, is responsible for scheduling and conducting the portion of institutional self-assessment known as Management of Environment, Safety & Health (MESH) reviews. These reviews are designed to ensure management systems consistent with Integrated Safety Management (ISM) are in place in all Laboratory Divisions and that these systems are leading to effective implementation of the Laboratory's EH&S program. MESH reviews are normally triennial by Division and are conducted by an SRC sub-committee. Depending on the MESH review results and the Division response, the SRC shall have the option to recommend changing the interval by one year. All members of the SRC are expected to serve on MESH sub-committees.

To properly execute its responsibilities under this charter, the SRC Chair may appoint expert sub-committees to address specific health and safety matters. Such sub-committees may become long standing expert sub-committees, or they may be of short duration, depending upon the technical support requirement.

To aid supervisors and employees in establishing and maintaining a healthy and accident-free working environment, the LBNL Health and Safety Manual (PUB3000) is issued. In addition, the

Environment, Health and Safety Division periodically audits all LBNL activities for compliance with the applicable EH&S rules and standards and provides appropriate technical services.

ALS Safety Committees

Environment, health and safety committees have been established to create and maintain a high level of interest in and awareness of, EH&S among all employees at all levels, to ensure that authority for EH&S is available at all levels, and to provide an EH&S system that encourages every individual to exercise their responsibility to protect themselves, their co-workers, the Laboratory property, and the environment, as described in the Advanced Light Source (ALS) Integrated Safety Management (ISM) Plan. These committees act to eliminate threats to the environment, unsafe conditions, and workplace safety and health hazards through routine inspections, and they identify and provide training, controls, and equipment needed for these tasks. The ALS Safety Committees function at two levels: Division Safety Committee, and Supervisor/Employee Safety Circles.

The ALS Division Safety Committee (leaders of all safety circles plus ALS management) meets every month. At the meeting, the members discuss safety issues and the lessons learned from them. Divisional EH&S managers pass on information about lab-wide EH&S/QA programs and problems that have arisen. All ALS employees, including staff matrixed from Engineering and AFRD divisions, belong to a safety circle that generally meets once a month to pass along safety issues and lessons learned from the ALS Division Safety Committee meeting, and to provide every employee a forum for calling attention to safety issues.

Monthly Supervisor/Employee Safety Circles, as well as routine EH&S inspections of immediate work area, are held. The ALS Division Director may periodically participate in Supervisor/Employee Safety Circles and/or inspections. Responsibilities of the supervisors involved in the safety circles include: 1) conduct safety circles that will provide regularly scheduled time for supervisors and their employees to discuss potentially unsafe acts and hazards, so actions can be taken to control them; 2) conduct and document periodic work area inspections to identify potentially unsafe acts and hazards and to communicate EH&S issues or information from the ALS Director.

ALS Staff Safety Committee

The ALS Staff Safety Committee has been formed by the ALS Division Director specifically to perform multi-disciplinary, detailed analyses of specific safety issues. Its charter is to review identified

safety issues and incidents, make recommendations back to the ALS Division Management, and to track their implementation. Through *ad hoc* technical subcommittees it can investigate a variety of complex issues. Examples of these evaluations include recommendations on hutch interlock designs, beamline shielding endpoint definition, and laser and robotic safety implementation.

Beamline Review Committee

Another important committee with safety responsibilities the ALS is the Beamline Review Committee. Its charter is to assure that all new beamlines and those that are modified significantly receive proper safety review. Its procedures follow project management protocols in evaluating the safety issues at conceptual design, at formal design, and at readiness review. It is composed of staff from all significant technical and safety disciplines.

ALS ES&H Organization

The ALS Division Director has overall EH&S responsibility for the facility and its operations. The Director has established an ALS Integrated Safety Management (ISM) Plan which states that the Advanced Light Source basic EH&S policy is to ensure that all activities are planned and performed in a manner which ensures that every reasonable precaution is taken to protect the health and safety of employees and the public, and to prevent damage to property and the environment. Consistent with the principles of integrated safety management, the ALS holds line managers accountable for safety performance.

The primary source of EH&S expertise within the ALS is the ES&H Program, whose primary responsibility is to assure that all work performed at the ALS is consistent with institutional and regulatory requirements while meeting the operational needs of the facility. The ES&H program manager reports directly to the ALS Division Director. It is the primary conduit for coordination with the LBNL Environment, Health, and Safety Division.

As described in Section 3.4.1, the ES&H Program provides technical input, evaluations, and oversight as needed to support ALS activities. Much of this involves coordinating internal and external expertise, and the overall ALS safety organization consists of staff from all parts of the ALS organization as well as support staff from the LBNL EH&S Division.

Among the functions of the ES&H Program are: audits of the facility; developing hazard communications, chemical training programs, and ES&H training programs for users, conducting inspection and work-place review activities related to both radiological and non-radiological health

protection, EH&S training of ALS operating staff and users, developing facility emergency plans, and administering programs for development of required Documents (AHDs and other formal authorizations) [formerly Operational Safety Procedures (OSP's)]. In addition, the ES&H Program Manager participates in design reviews to verify that EH&S considerations have been adequately addressed and included in the final design of all ALS components and systems.

An important component of the safety program is User safety. This program is coordinated between the EH&S Program and the User Services Group. User Services is responsible for proposal review procedures and pre-experiment coordination with the users. Experiment coordination consists of determining the hazards and proper controls needed for each experiment before the users arrive. This process is encompassed in Experiment Safety Sheets (ESS). The processes for reviewing proposals are described in Sections 3.5.1. The ESS process is described in section 3.5.2. Once experiments are reviewed and approved, on-going support and oversight of the work is performed by the Floor Operations group.

3.5 User Administration

3.5.1 Proposal Process

All proposals for experiments at the ALS undergo a formal review process beginning with the submission of a proposal to the ALS User Services Office. In addition to the EH&S review described in Section 6.4.4, the proposal is reviewed for technical compatibility with the ALS by beamline scientists and is reviewed for scientific merit by the Proposal Study Panel. In the case of proposals from PRTs to establish beamlines, the recommendations of the Program Study Panel, the Science Advisory Committee and the ALS Director are forwarded to the LBNL Director, who makes the final decision. Proposals from General Users are peer reviewed by the Program Study Panel who may delegate review responsibility to sub-panels for additional scientific expertise. The final responsibility for approval lies with the ALS Director. Scheduling beam time for approved experiments is the responsibility of the beamline scientists with oversight by the User Services Office. The proposal and the scheduling processes are described in detail on the ALS web site Users Guide (http://www-als.LBNL.gov/als/quickguide/).

3.5.2 Experiment Safety Sheet

The primary tool for assuring safety on the experimental floor is the Experiment Safety Sheet (ESS), see Procedure US 02-05 at http://alsintra.lbl.gov/procedures/index.htm. For each new experiment at the ALS, the General User in charge of a particular experiment completes the on-line General User Proposal and Request for Beamtime Form requesting beam time to conduct an experiment, http://www-als.lbl.gov/als/quickguide/independinvest.html. If the proposal is allocated beam time, an Experiment Safety Sheet is automatically generated from the Proposal Form and this sheet is used during the on-the-floor safety inspection. This inspection is coordinated by the ALS Experiment Setup Coordination Section. For PRT members, an Experiment Safety Sheet is filled out directly at http://alsusweb.lbl.gov/. When several experiments are to be conducted on the same beamline, a separate form is required for each experiment. The Experiment Safety Sheet has a lifetime of one year if no changes are made to the experiment, after which it either expires or is updated. Final approval for an experiment consists of a signed Experiment Safety Sheet posted at the beamline. No experimenter is allowed to participate in an experiment on the ALS floor without being listed on the Experiment Safety Sheet.

The first page of the Proposal asks for basic administrative information about the proposed experiment and the experimenter in charge and for a brief description of the experiment (Abstract). The following page contains space for listing all participating experimenters. The next page lists the classes of potential hazards, which are to be checked if they apply to the proposed experiment. Each category checked takes the user to a new safety section requesting further details of the potential hazard. Each of the sections provides the experimenter with the basic requirements pertaining to the hazard (e.g., training, rules for handling, protective measures, safety advisories) and provides space for describing the hazard (e.g., listing hazardous materials and their quantities). In some safety sections, the experimenter is warned that it may be necessary to generate an AHD or other formal authorization for the hazards before the experiment can be performed.

This information is reviewed by Experiment Setup Coordination before users arrive so that issues can be resolved early. Also, training requirements are passed on to the users at this point. Based on the information on potential hazards for the experiment, various technical and EH&S experts must sign off on the Experiment Safety Sheet indicating the potential hazard has been mitigated to a safe level. Finally, the Beamline Scientist and ALS EH&S Program Manager sign the ESS to indicate that the experiment is safe to run.

3.5.3 Institutional User Agreement

Before beginning research, an Institutional User Agreement **(**http://www-als.LBNL.gov/als/quickguide/useragreement.html) must be executed by each User Institution sending experimenters to the ALS. Agreements are required both for members of PRTs and for General Users, The Institutional User Agreement is an umbrella agreement that can cover all ALS projects and all user experimenters for up to a five-year period. It covers issues such as intellectual property rights, liability, safety and health, and payment of expenses. A separate User Agreement exists for proprietary research.

By signing the Institutional User Agreement, the institution agrees that the institution's employees are responsible for and shall take reasonable precautions in the performance of their work to protect the environment and the safety and health of employees and members of the public and shall comply with all applicable LBNL EH&S regulations and requirements. The agreement also states that employees of the institution shall obtain EH&S training at the earliest possible time upon arrival at LBNL and in all cases before they work unsupervised or are exposed to any special potential hazards.

3.5.4 Memorandum of Understanding

For each Participating Research Team, a legally non-binding Memorandum of Understanding (MOU) between the spokesperson of the PRT and the ALS Director is generated that covers activities that the PRT is carrying out in collaboration with the ALS towards the construction and operation of an insertion-device or bend-magnet beamline, including experimental chambers. The MOU asserts that the highest priority will be given to assuring the health and safety of LBNL employees and guests and visitors, as well as to protecting the environment. The MOU specifically assigns responsibility to the PRT spokesperson to assure that all members of the PRT are made aware of, and comply with, all applicable safety and health regulations of LBNL, the University of California, and the DOE. This is an especially important responsibility because the MOU also assigns to the PRT responsibility to support operation of its beamline during the time that General Users are conducting experiments.

3.5.5 Site Access

Access to LBNL by visitors, including those who come as Participating Guests for the purpose of conducting research at user facilities, such as the ALS, is governed by Section 1.06 LBNL Site Access of the LBNL Regulations and Procedures Manual. In the past, visitors to LBNL had to interact with several different and separate administrative offices. To avoid wasted time and duplication of effort, on

the part of both the visitor and LBNL staff, LBNL has established an ALS badging and registration center at the Users' Office where most requirements can be satisfied in a one-stop shopping mode.

Any LBNL employee may request site access for a prospective visitor upon approval of the employee's supervisor and/or with knowledge of the employee's Division Administrator/Director. An employee who extends an invitation to a prospective visitor becomes the LBNL host for that visitor. In the case of the ALS, the invitation comes in the form of acceptance of a proposal to conduct research and the ALS beamline scientist is the host.

The host advises the visitor of LBNL site access policies and procedures. Specifically, the host is responsible for ensuring that the visitor is directed to the User Office to initiate the ALS visit and that the visitor is aware of and complies with applicable LBNL EH&S policies. The host receives significant support from the User Services Office in performing these duties. The User Services Office provides the information and is responsible for ensuring that the visitor understands pertinent access procedures. The visitor is responsible for compliance with scientific and administrative requirements as identified by the User Services office and for taking reasonable precautions in the performance of work at LBNL to protect the environment and the safety and health of other personnel. Responsibility for compliance with all applicable EH&S regulations and requirements of the DOE and LBNL extends from the host and host division to the visitor.

The process for obtaining and terminating guest status at the ALS meets the requirements as stated in RPM Section 1.06). An outline of this process is as follows:

(1) An application for approval of Participating Guest status is made to the LBNL Office. The ALS User Services Office works with the visitor to facilitate administrative procedures needed in advance of arrival at LBNL. Typically, an experimenter with an approved proposal to conduct research at the ALS will execute an Institutional User Agreement as described in Section 3.5.3, in advance of arrival at LBNL. These agreements provide for the establishment of accounts for use of LBNL computers, telephones, stores, photocopier, and shop services.

(2) The ALS User Services Office confers approval of visitor status based on several criteria, including documented receipt of the above-mentioned contractual agreements.

(3) The ALS User Services Office issues visitor identification in the form of a badge indicating the appropriate category of Participating Guest (User, Scientific Collaborator, Student, etc.), as well as a

parking permit and account numbers, as applicable. Information about the visitor is entered into a database whose contents are accessible to the ALS and LBNL.

(4) The ALS User Services Office issues appropriate EH&S publications to the visitor. General training requirements that can be satisfied at the ALS User Services Office are also provided and include a video presentation on general safety, LBNL General Employee Radiation Training (GERT) and a facility-specific radiation safety course. ALS-specific training that is dependent on the anticipated need of the visitor to enter laboratories, shops, and exposure to hazardous activity will be discussed in Section 3.5.6. The User Services Office maintains user records and training records for users, which are kept in the Users Services Office 4D database.

(5) At the end of a project or experiment, the visitor stops at the Users' Office reception area as part of the departure procedure to surrender any parking permit and other appropriate administrative material. In the event that no notification of departure is made, visitor status terminates automatically on the expiration date indicated on the visitor's record.

3.5.6 User Responsibilities and Training

The ALS Proposal and Request for Beamtime Form and the Experiment Form safety information are used to create an Experiment Safety Sheet, which provides the basic guidance for assurance of user safety. The Experiment Safety Sheet was developed in consultation with the ALS user community, spokespersons for PRTs and LBNL EH&S personnel and is formally approved by LBNL for implementation of user safety at the ALS. Through this process, each experiment P.I. identifies the work and the hazards and accepts responsibility to ensure that all controls required by the ALS will be implemented. Each lead experimenter, typically the P.I., must sign a form acknowledging these responsibilities.

RPM Section 1.07, the Institutional User Agreement, the Individual User Authorization, and, in the case of PRTs, the Memorandum of Understanding all require that each Participating Guest who works at the ALS be responsible for his/her safety and health, which includes acting in a prudent and responsible way when dealing with hazards and seeking help when unsure of proper procedures. Each person is responsible for ensuring that his/her actions do not endanger others and for reporting unsafe conditions and activities. Users are responsible for the safe conduct of their experiments and for having the knowledge and plans necessary for dealing with potential hazards in their experimental areas. Each user signs an orientation form acknowledging these responsibilities.

Since the ALS is a multiple-user facility with many types of operations and experiments under way simultaneously, there are significant differences between the EH&S aspects of activities performed at the ALS and at laboratories dedicated to a single use by a small number of experimenters. In addition to the training discussed below, information about EH&S at the ALS is available from the following documents:

- LBNL Health and Safety Manual provides a comprehensive guide to EH&S issues and defines the EH&S rules at LBNL.
- ALS Beamline Design Guide (http://www-als.lbl.gov/als/bdguide/) interprets EH&S issues as they apply to the facility and will provide ready answers for specific questions on radiation shielding mechanical, seismic, and electrical safety.
- Conduct of Operations Procedures provide specific guidance for operating equipment and systems during normal and postulated abnormal and emergency conditions (see Section 6.1).

User EH&S training falls into several categories: (1) general EH&S training required by LBNL, (2) facility training required by the ALS and (3) training specific to the beamline and experiment at which the visitor. Conduct of Operations Procedure US02-01 User Safety Training delineates the applicable site-specific EH&S training, radiation-safety training, and additional EH&S training required of ALS users.

The ALS ES&H Program, the EH&S Division, and ALS User Services cooperate to provide the general LBNL and ALS facility training to all Users. All first-time ALS users view a user EH&S orientation video.. The video is available from the ALS User Services Group during business hours or at other times through the Control Room group. The orientation includes ALS EH&S procedures, radiation hazards, protective interlock systems, hutch access (if applicable), and procedures to follow in case of emergencies (earthquakes, fires, etc.). The user must sign a form indicating completion of viewing the video.

The ALS experimental floor is a controlled area. Access to the floor is controlled by posted and locked doors. Users are required to take the institutional General Employee Radiation Training (GERT), EH&S405. The ALS has developed an additional radiation safety orientation for all users, ALS5001, that provides facility-specific information. These are both provided concurrently with the ALS EH&S orientation video. These training records are maintained by the User Services Office. Users are required to certify that they have received and read the EH&S material, that they have received EH&S instruction by ALS staff, that they understand the procedures, and that they will comply with them.

The initial stimulus for determining what beamline and experiment-specific training a user will 0need comes from the information provided on the Proposal Form. No experimenter will be permitted to work on the ALS floor without being listed on one or more of these forms and without having the required training. This training may consist of LBNL EH&S Division prepared courses such as Laser Safety, EH&S280, or Chemical Hygiene and Safety Training, EH&S346/EH&S348. In addition, the ALS ES&H Program works with the Beamline Scientists to provide beamline-specific training. Documentation of standard EH&S safety courses utilizes the institutional databases. Documentation of beamline-specific training is flexible and is done in cooperatively between the Experiment Setup Coordination Section and the beamline scientists.

SECTION 4. SAFETY ANALYSIS—IONIZING RADIATION

The ALS safety analysis was prepared in accordance with the guidance provided in DOE Order 5481.1B, Safety Analysis and Review System [DOE, 1986a] and in DOE Order 420.2B Safety of Accelerator Facilities, including attachments. A description of the methodology used in identifying hazards, analyzing credible accident scenarios, and assessing risks is presented in Section 4.1. Ionizing-radiation hazards are identified in Section 4.2. Hazards other than ionizing radiation are analyzed in Section 5. Sections 4.3 and 4.4 discuss the radiation shielding and radiation safety system, respectively. Section 4.5 is a summary of the safety analyses of radiation hazards. Conclusions and an assessment of the overall risk associated with ionizing radiation in ALS operations, including the Beam Test Facility (BTF), are discussed in Section 4.6.

4.1 Safety Analysis Methodology

The methodology used to perform the ALS safety analysis is shown in Figure 4-1. The hazards analysis process began with a review of proposed ALS commissioning, operations, and research activities. Information concerning operations and research at similar facilities at other laboratories was also reviewed. Using the information obtained, a hazard analysis of proposed ALS activities was prepared. Potential hazards associated with the use of radiation sources were studied.

Credible hazards with potential on-site or off-site consequences were then analyzed to assess associated risk. The analyses were based on a bounding event approach, where the most severe of each particular category of credible accident was analyzed to obtain worst-case results. Each event analysis included determining the initiating occurrence, possible detection methods, the safety features that might have prevented or mitigated the event, the possible consequences, and the probability of the event occurring.

The probability estimates were originally made by a Technical Safety Subcommittee on the basis of the best professional judgment of the members of the subcommittee, by statistics on occurrences at DOE accelerator facilities for the period September 1990 to December 1992 obtained through the DOE Occurrence Reporting and Processing System (ORPS) [DOE, 1993] and by data accumulated on actual instances of exposure to radiation at LBNL over the period 1981-1986 [EH&S, 1987]. In addition, site-specific design criteria for earthquakes were used in determining the probability of these events [UCRL, 1989]. These were reevaluated in 2007 by an independent team of EH&S Division subject matter experts against current risk analysis practices and judgments on contemporary Facility projects.

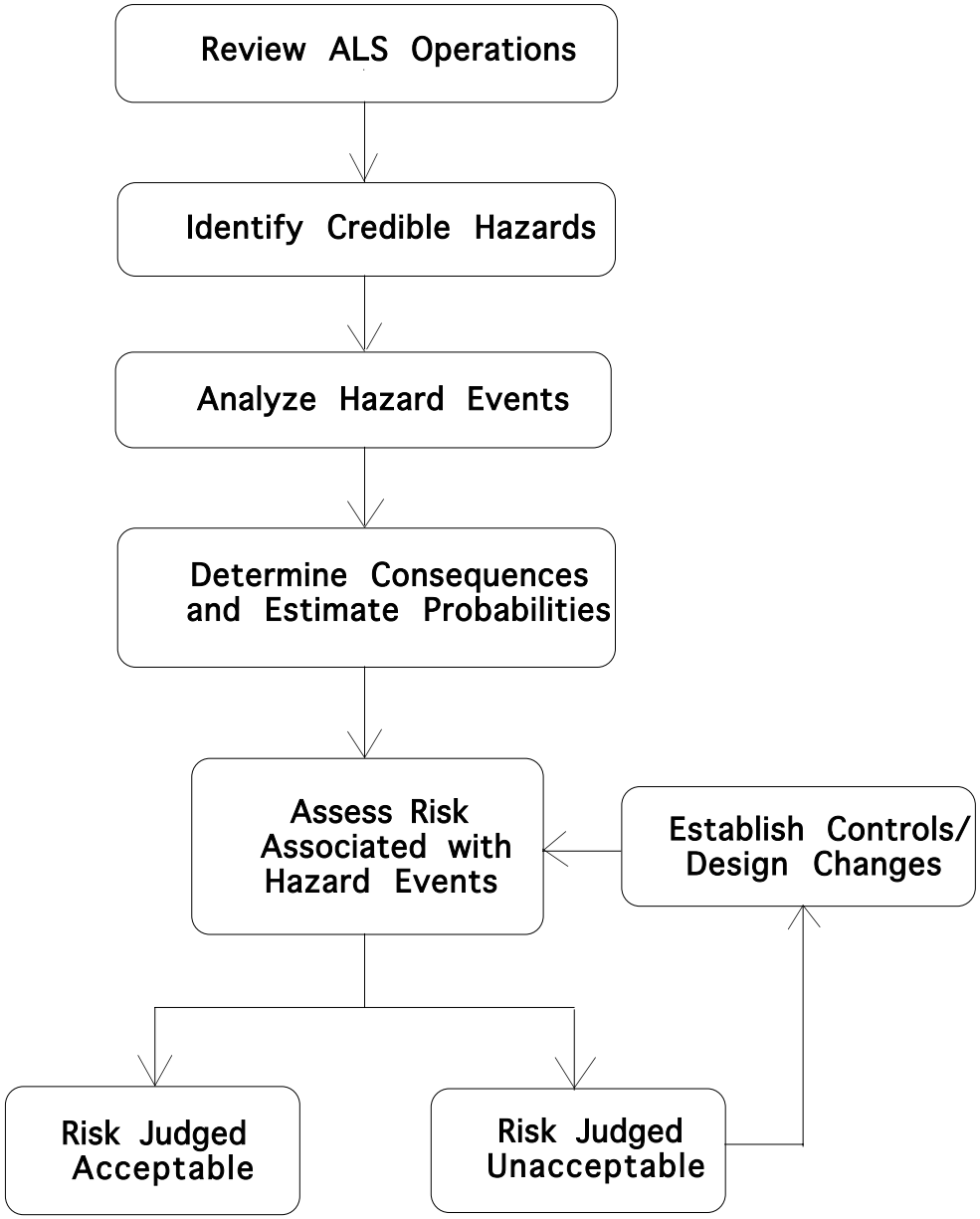


Figure 4-1. ALS Safety Analysis Methodology.

The Implementation Guide (DOE G420.2-1) for the Accelerator Safety Order, DOE O420.2B, provides a reference for conducting safety analyses, which is DOE O5480.25, Guidance for an Accelerator Facility Safety Program [1993]. This Order provides guidance for rating the consequences and probability of each hazard and assigning levels to each, and then the overall risk associated with each specific hazard, and then for the facility as a whole, is determined using a risk matrix. This Safety Analysis follows this guidance, and a summary of this approach is given in Tables 4.4 through 4.6.

4.2 Ionizing Radiation Hazards

The general procedures to be followed for radiation safety are defined in Chapter 21 Radiation Safety of the LBNL Health and Safety Manual.

Ionizing-radiation hazards at the ALS are due to loss of electrons at various stages of the beam acceleration and storage process and to the synchrotron radiation emerging from the insertion devices and bend magnets in the storage ring. Ionizing radiation is also produced by accelerator-related equipment, such as the klystrons that generate rf power.

Credible hazards fall into two primary categories. The first category is exposure to ionizing radiation resulting from operation of the machine. Exposures can result from normal operation of the accelerators or from accidental loss of beam. Exposures of either type are limited by shielding in the accelerator, beamline, and experimental areas and by exclusion areas in the beamline and experimental areas. Administrative procedures, including Radiological Work Authorizations (RWAs) and various approved and published ALS procedures covering personnel training, testing, radiation monitoring, and record keeping, are also used to limit exposure to radiation (see Sections 6.1 and 6.2.5). The second category is exposure of personnel inside the accelerator shielding or exclusion areas. Exposures of this type are limited by a combination of means, including interlock systems, personnel training, and administrative procedures, such as search and secure. In addition, the EH&S Division Radiation Protection Group has assigned a Radiation Control Technician (RCT) to monitor operations and radiation levels and to ensure system integrity.

The following sections describe and analyze the safety systems for ionizing-radiation hazards. Section 4.3 analyzes the production of bremsstrahlung and neutron radiation and the shielding required to protect against it. Hazards due to radiation exposure will be different for those working in the ALS facility and those outside the building in the general area; hazards are analyzed for both types of personnel. The protective interlock (radiation safety) system that shuts down radiation-producing systems when an interlock chain is broken is described and its operation analyzed in Section 4.4.

Administrative procedures are referred to where appropriate. Section 4.5 summarizes the analysis in the framework of the methodology outlined in Section 4.1.

4.3 Shielding Policy

Goal

In order to ensure minimum risk to the general public and to facility personnel from operation of the ALS, it is LBNL policy to implement the Department of Energy regulatory radiation-safety limits, as currently expressed in10 CFR 835. Accordingly, the radiation shielding design is based on the dual design goals of limiting the radiation exposure to the general public to less than 10 mrem/year (0.1 mSv/year) and limiting occupational exposure to laboratory workers to less than 250 mrem/2000-hour worker year (2.5 mSv/year) and to 1 rem/9000-hour worker year (10 mSv/year). The design goal for continuous occupancy is 0.5 mrem/hour (5 μSv/hour). These goals meet the DOE radiation-dose limit to the general public of 10 mrem/year and are far below the maximum allowable occupational dose limit of 5 rem/year.

Design

The ALS accelerator shielding configuration required to meet these design goals evolved, as described in the following sections. In brief, a basic concrete shielding design was developed. The design was based on conservative assumptions about accelerator operations and about beam losses, which were estimated from experience at other accelerator facilities. Additional calculations that were used to analyze specific shielding issues, such as the storage-ring ratchet wall, led to detailed designs. In accordance with the process adopted for approval of ALS project technical designs [Paterson and Lancaster, 1987], reviews were held to analyze the proposed shielding design, with pertinent recommendations from the reviews being incorporated into the final design. The shielding design for the injector complex (and by implication for the storage ring, as well) has been validated by radiation monitoring and personal dosimetry during commissioning in 1992. Monitoring data has shown that beam losses are lower than expected. In addition, commissioning experience with the injector has shown that some assumptions about accelerator operations are more conservative than necessary.

Beamlines are shielded in various ways. Bremsstrahlung shielding requirements are given in the ALS Beamline Design Guide and must consist of at least 10” lead in the longitudinal path and at least 2” lead beyond the extreme ray in the transverse direction. Anamorphic drawings documenting this are required and are reviewed and approved by the Beamline Review Committee when a new beamline is

designed and whenever there are significant changes. Areas of synchrotron scatter are shielded as necessary with lead sheeting or other high-Z materials. Guidance for this has been developed for the hard x-ray beamlines. All shielding is reviewed and approved by EH&S Division Radiation Physics.

In sum, the ALS shielding is properly designed to limit occupational exposure to ALS staff and visiting scientists, as well as to the general public at the site boundary, under both normal and abnormal operating conditions.

Operation

Worker dose is monitored and a variety of real-time and integrated area dose measurements are taken to verify that design goals are being met. When elevated levels are found, the causes are investigated and mitigations instituted to assure that doses remain ALARA.

Strict configuration controls are in place to assure that all required shielding remains in place. These include: maintenance of controlled documentation for all shielding, design and review of any proposed changes to the configuration, independent verification of configuration before operation of beamlines, and on-going assessments of the effectiveness of shielding. These controls are all implemented through conduct of operation procedures.

4.3.1 Generation of Ionizing Radiation

For synchrotron-radiation facilities, bremsstrahlung (photons) and neutrons are the dominant ionizing radiation. Electrons lost from the accelerator beam generate bremsstrahlung when colliding with residual gas molecules in the accelerator vacuum chambers, with the chamber walls, or with other objects. Neutrons are generated, primarily by the giant photo-nuclear resonance, when the bremsstrahlung is absorbed by shielding.

Different levels of photon and neutron radiation are produced during different stages of operation. For example, in the case of the storage ring, the first stage of interest is the injection cycle. The efficiency of the injection process determines the average level of radiation. However, mis-steering the beam into the storage-ring or booster-to-storage ring transfer line will produce the most significant levels of radiation, so that special consideration must be applied in designing the shielding for the injection region. The next stage of operation after injection is stored beam in the storage ring.

Under normal conditions when beam is gradually lost over several hours, one would be concerned with the radiation produced by the interaction of electrons with atoms distributed in the storage-ring vacuum chamber (gas bremsstrahlung) and the radiation produced by the collision of electrons that are slowly lost from stable orbit with the vacuum chamber. Under accident conditions, one must evaluate the radiation produced when the entire electron beam is lost at a single point in the storage ring. The final stage of operation is dumping the electron beam when it has decayed and needs to be replenished. Similar scenarios exist for the booster synchrotron and the linear accelerator.

In general, shielding consists of concrete supplemented with lead and polyethylene. As a hydrogenous material, concrete is an effective material for neutron shielding. Polyethylene, another hydrogenous material, is used to provide additional neutron shielding. Concrete also protects against bremsstrahlung, but the required thickness is so large that it is not always practical to rely exclusively on concrete. Lead, which is a more effective bremsstrahlung shield material than concrete, is therefore used to provide additional protection.

The bremsstrahlung dose equivalent far exceeds the average neutron dose equivalent and will dominate the shielding [Swanson, 1985]. Hence, it is very probable that an adequate shield for bremsstrahlung would be more than adequate for neutrons, if concrete were used. However, if bremsstrahlung were shielded primarily by non-hydrogenous materials, such as lead or iron, the neutrons may not be adequately attenuated. The combination of concrete and lead is optimized to provide maximum shielding. Additional lead and polyethylene are used for local shielding in critical locations where space or geometrical constraints are an important consideration.

4.3.2 Conservative Initial Assumptions

The design values of the occupational and site-boundary exposures determined the thicknesses of the concrete shielding around the linear accelerator and linac-to-booster transfer line, the booster synchrotron, the booster-to-storage ring transfer line, and the storage ring for protection against both bremsstrahlung and neutrons [McCaslin, 1986; ALS, 1986; Swanson, 1987]. To protect against worst-case radiation exposures, pessimistic assumptions were made concerning the accelerator operating parameters and schedule. In addition, estimates of the number of electrons that would be lost from the beam during commissioning and during routine operation under these pessimistic assumptions were made based on experience at other accelerator facilities.

The conservative assumptions about accelerator operations include:

- The injection system would have to operate at 4 Hz, rather than the nominal 1 Hz, to fill the storage ring. This is the maximum frequency at which the injection system could be made to operate without major modifications to the hardware. However, the 4-Hz option would require a major upgrade of the magnet power-supply system.
- Injection would be carried out twice per eight-hour shift, rather than once. Depending on the lifetime of the beam after installation shutdowns, this assumption is not unrealistic.
- Injection would be to an accumulated current of 800 mA, rather than the nominal 400 mA.
- The ALS would be operational for 1095 eight-hour shifts per year. Typical actual operations (including Accelerator Physics and startup/tuning runs) are closer to 900 eight-hour shifts per year.
- Losses from the storage ring would occur at the maximum possible energy of 1.9 GeV, which has become the energy at which the storage ring operates most of the time.
- The injection system would be routinely "tuned-up" prior to an injection period. This operation was envisaged as one hour at one-fourth of the maximum intensity, followed by 15 minutes at full intensity. Experience has shown, however, that the injector complex can be brought into operation in five to 15 minutes.

Radiation hazards in the accelerator system result from capture losses in the linac, the booster, and the storage ring, from normal loss of the stored electron beam between fills, and from beam losses due to equipment malfunctions. The electron losses during injection repeat at the cycle rate of the system. Based on beam losses common at similar accelerator facilities, normal operational losses for each acceleration cycle were estimated to occur at the following places for a linac beam current of 8×10^{10} electrons per cycle:

- 4×10^{10} electrons per cycle are lost at the collimator in the linac-to-booster transfer line at 50 MeV.
- 0.8×10^{10} electrons per cycle are lost in the collimator and at the injection septum magnet at the booster at 50 MeV.

- 0.6 x 10^{10} electrons per cycle are lost around the booster at an average energy of less than 150 MeV during acceleration.
- 0.325 x 10^{10} electrons per cycle are recirculated and lost around the booster at 1.5 GeV after acceleration and extraction.
- 0.325 x 10^{10} electrons are lost per cycle in the booster-to-storage ring transfer line at an energy of 1.5 GeV.
- 0.325 x 10^{10} electrons are lost per cycle at the storage-ring injection point.
- 0.325 x 10^{10} electrons per cycle are lost around the storage-ring during injection at 1.5 GeV.
- The 3.3 x 10^{12} stored electrons per fill are eventually lost at 1.9 GeV.

4.3.3 Shielding Design

By means of empirical formulae, radiation exposures were calculated as a function of concrete thickness for these operating scenarios and estimated beam losses [McCaslin, 1986]. These calculations took into account the contributions of both uniform losses during normal operation and point losses during machine malfunctions. Shielding thicknesses were then found such that the general-public and laboratory-worker dose equivalents were acceptable. Figure 4-2 shows the design values for radiation exposure at various locations around the ALS for both uniform and point losses during machine malfunctions. Figures 4-3 and 4-4 show representative results for the booster synchrotron and the storage ring, respectively, and illustrate how the shielding thicknesses required to meet the design exposure specifications were determined. In all cases, the radiation shielding has been designed to be at least as thick as the minimum calculated requirements. Even with these safety factors, radiation monitoring constitutes an ongoing activity at the ALS, with extra shielding being employed where it is deemed necessary.

The ALS radiation shielding enclosures are constructed using both cast-in-place concrete structures and precast (removable) roof panels and wall blocks. Linac-vault walls are a minimum of 4 feet thick, as is the roof. Booster-synchrotron shielding is cast in place; the tunnel walls are a minimum of 2.5 feet thick; the roof is also 2.5 feet thick. Removable roof blocks are provided in three locations around the booster for access to equipment and for maintenance. The storage ring has a fixed (cast-in-place) inner wall and a removable (precast) outer wall section and roof section around its entire circumference to facilitate beamline egress from the tunnel. Storage-ring tunnel walls are nominally 1.5 feet thick; the roof is 1 foot thick. Figures 4-5, 4-6, 4-7, and 4-8 diagram the ALS shielding configuration for the ALS accelerators. In some locations,

the storage-ring shield-wall and -roof thicknesses differ from the nominal values, and in some locations lead shielding is added (see Section 4.3.4).

To verify the performance of the ALS shielding, the Oak Ridge National Laboratory code MORSE was used to calculate the neutron dose equivalents in the facility and at the site boundary [Sun, 1989, 1991]. Use of the code required the construction of a geometrical model of the ALS facility that lends itself to numerical analysis on a computer. The model generated used circular approximations of the polygonal accelerators and included representative materials for the parts of the model. The code accounts for both direct neutrons penetrating the shielding and for "skyshine" neutrons scattered in the air [Swanson, 1988]. Additional contributions from intermediate- and high-energy neutrons were added as fixed percentages (25% and 2.5%, respectively) of that calculated with the code.

Output from MORSE gives the neutron dose equivalent as a function of position coordinates. Analysis of the output showed that two representative positions adequately describe the radiation hazard. A location 39 m from the ALS center along the line connecting the centers of the booster and storage ring and 6 m above the floor (i.e.. in the second floor) is the nearest to both the booster and storage ring and is representative of the location where the maximum occupational dose would be received. A second location 125 m from the ALS center on the south side and a height of 2.4 m represents the LBNL boundary where the maximum exposure of the general public would be received.

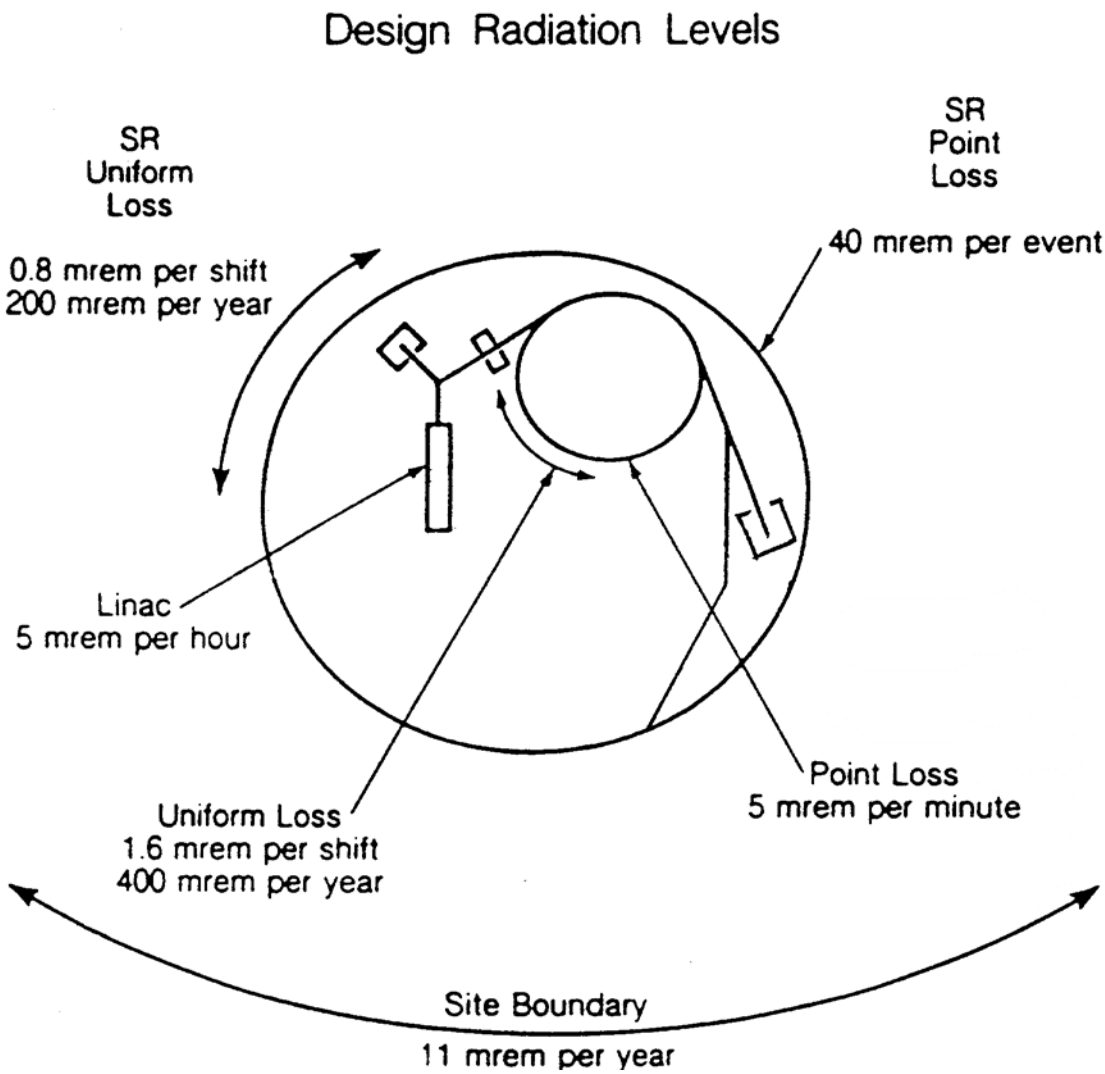


Figure 4-2. Schematic diagram the ALS accelerator area showing the design radiation levels for uniform and point losses at the storage ring, booster synchrotron, linear accelerator, and the LBNL site boundary.

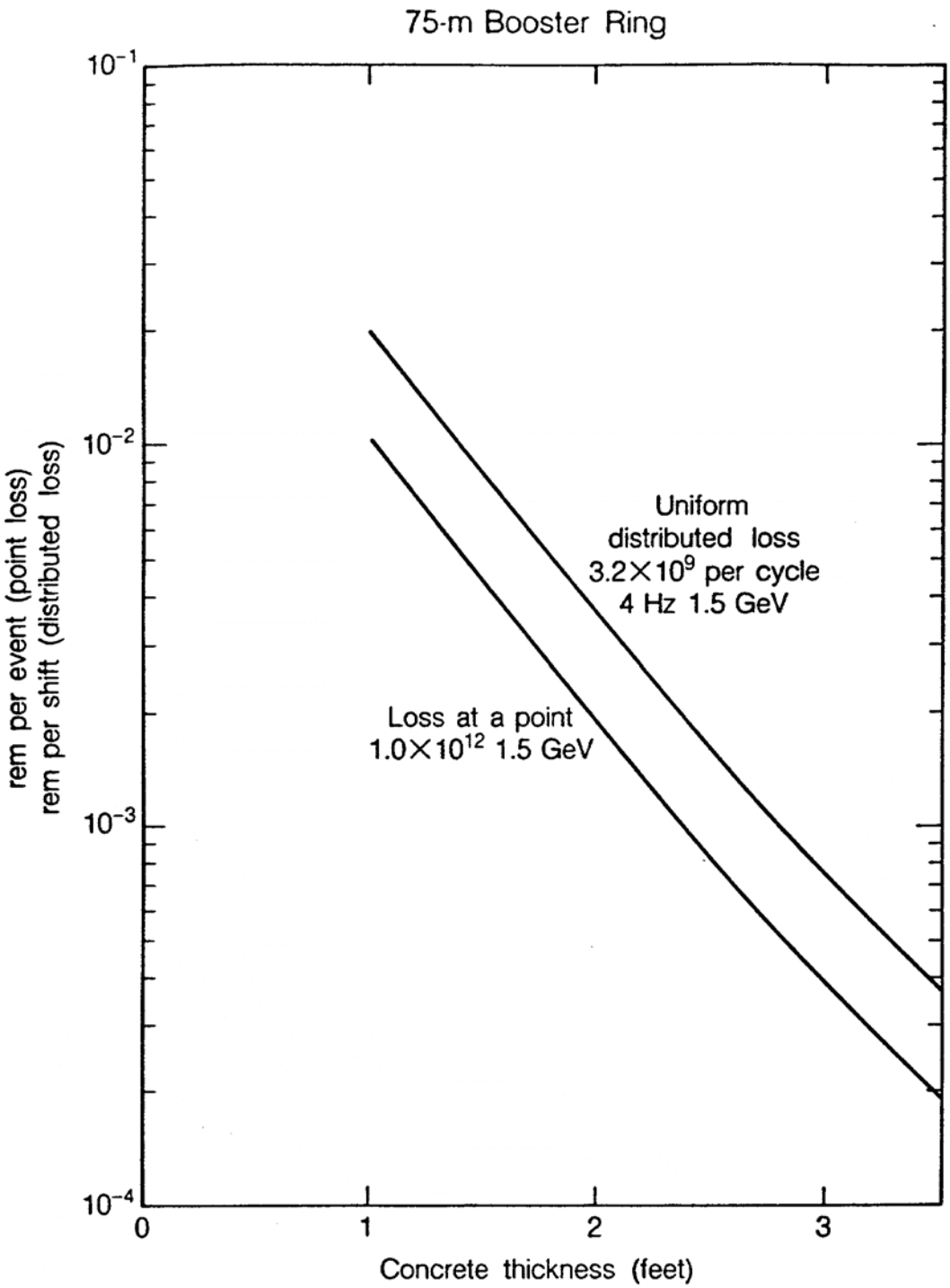


Figure 4-3. ALS booster-synchrotron occupational dose equivalent.

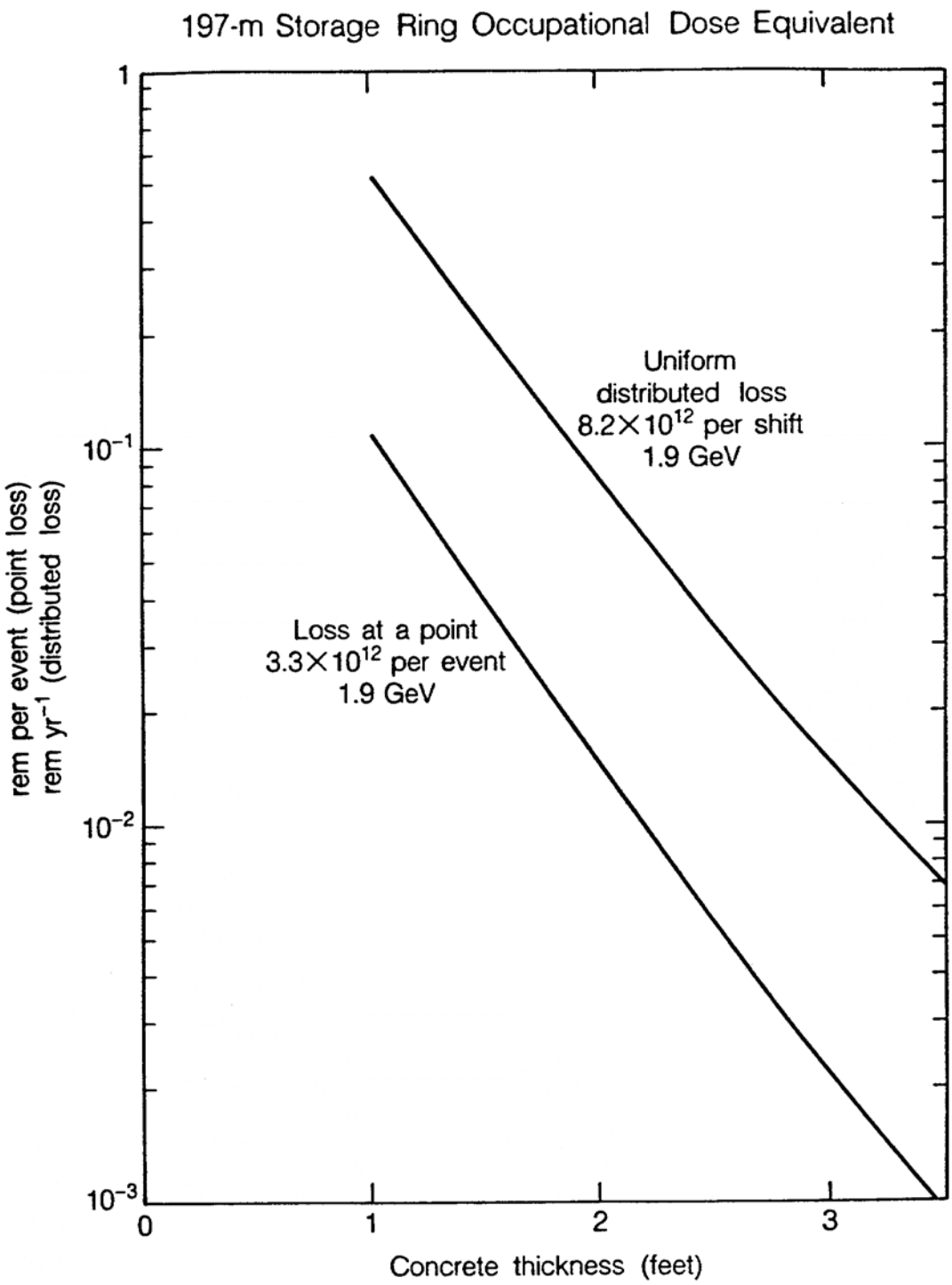


Figure 4-4. ALS storage-ring occupational dose equivalent.

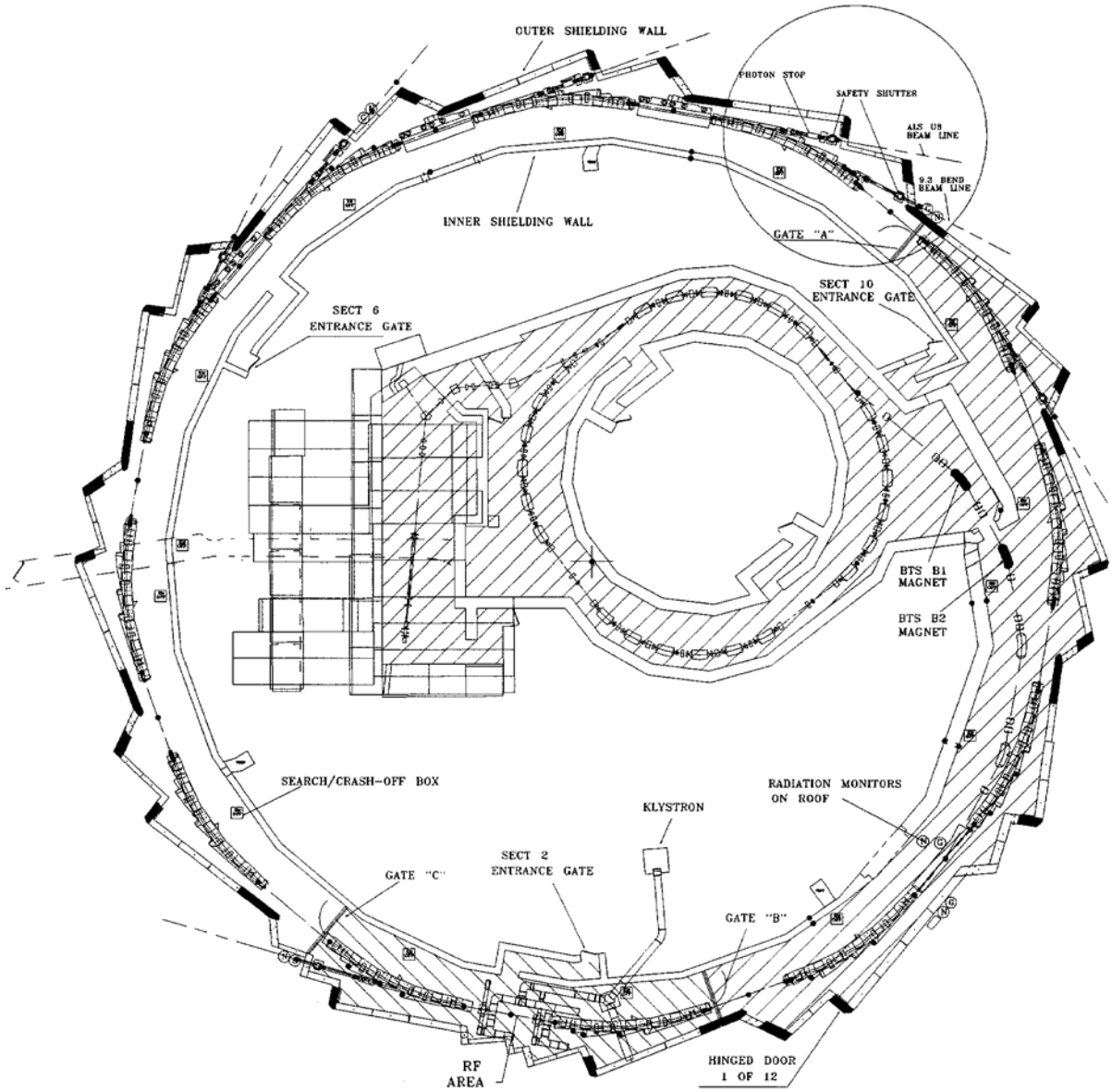


Figure 4-5. Schematic diagram of the ALS accelerator area showing the radiation shielding for the storage ring, booster synchrotron, and linear accelerator and the approximate locations of the neutron and photon detectors.

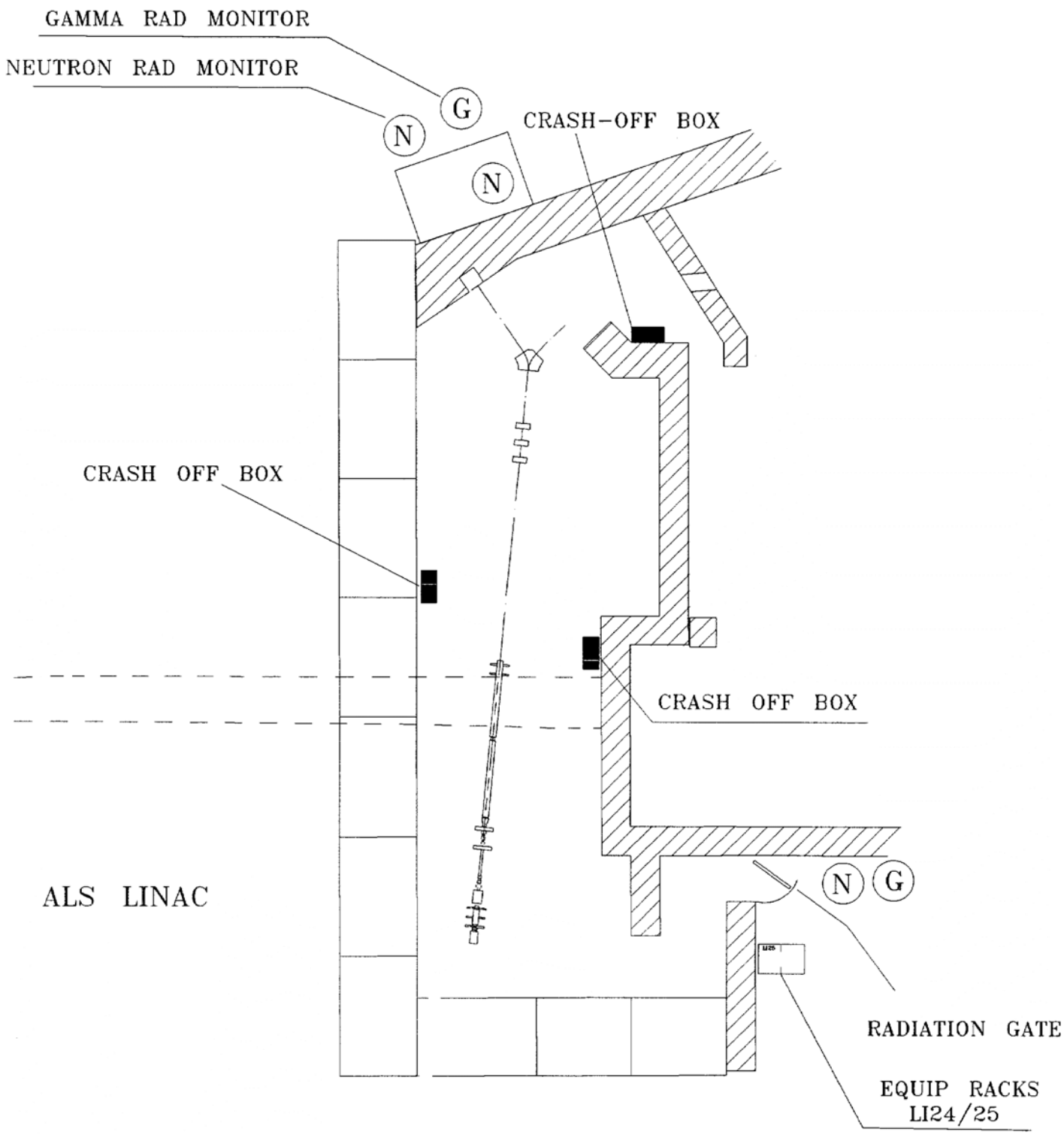


Figure 4-6. Detailed schematic diagram of the ALS linac area showing the radiation shielding and the locations of the radiation gate, the crash-off boxes, and the neutron (N) and photon (G) detectors.

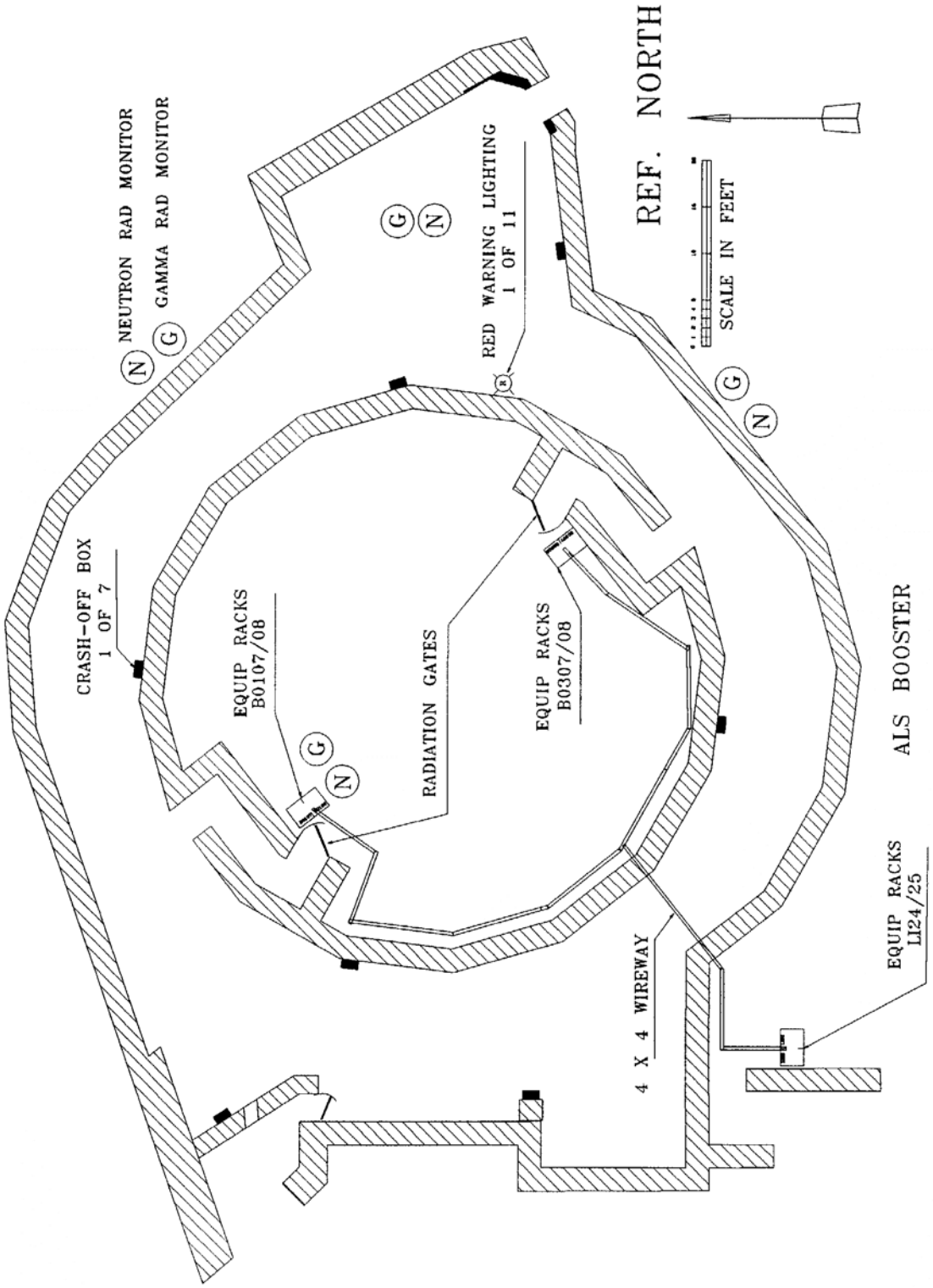


Figure 4-7. Detailed schematic diagram of the ALS booster-synchrotron area showing the radiation shielding and the locations of the radiation gates, the crash-off boxes, and the neutron (N) and photon (G) detectors.

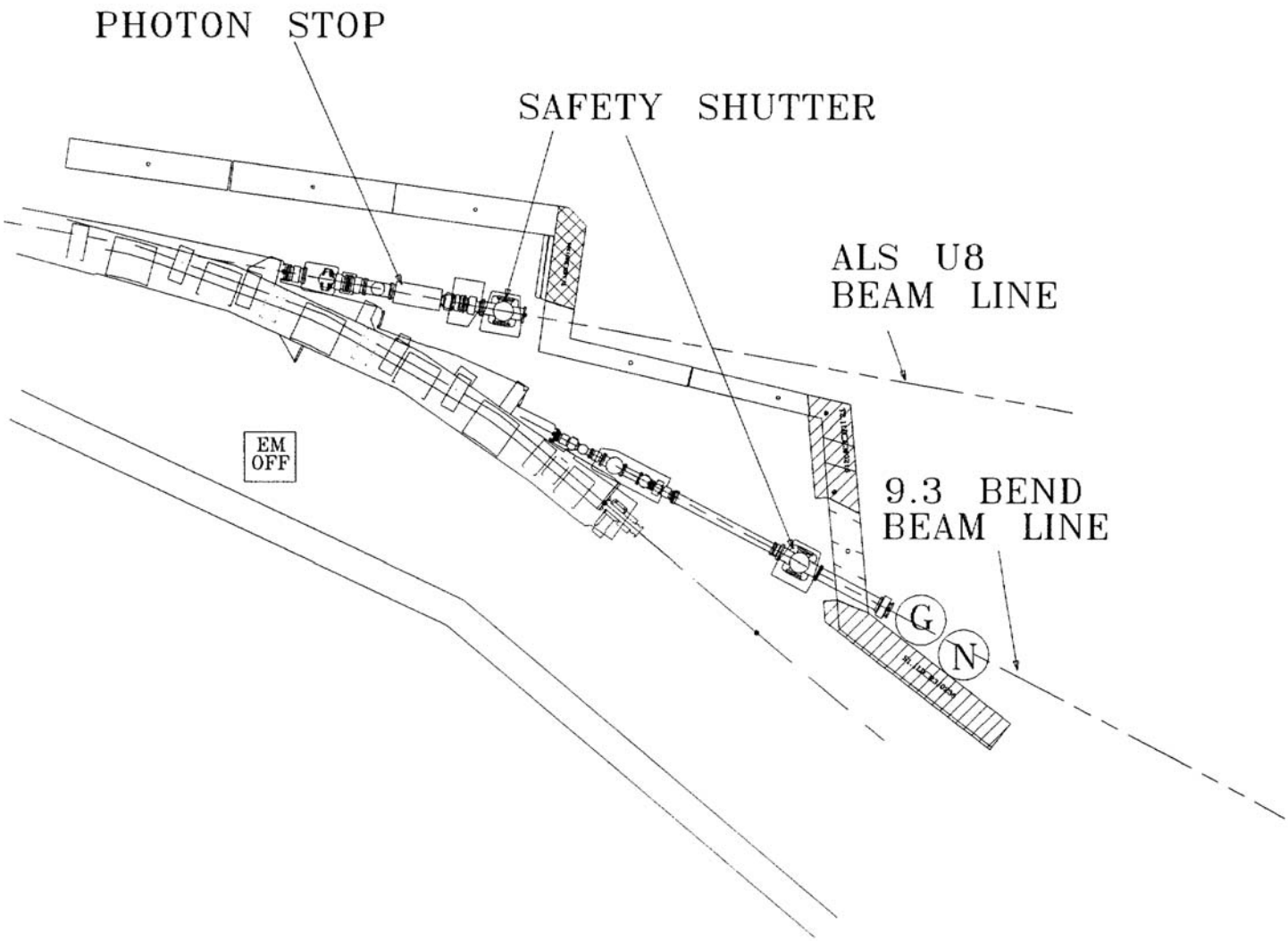


Figure 4-8. Detailed schematic diagram of one sector of the ALS storage-ring area showing the radiation shielding and the locations of the search/crash-off boxes (EM) and the neutron (N) and photon (G) detectors.

Table 4-1a summarizes the calculated maximum neutron dose equivalents at these two locations separately for radiation from each section of the accelerator complex and gives the total annual neutron dose equivalent at these locations from all the sections. The maximum annual neutron dose equivalents are calculated to be 114 mrem/year (1.14 mSv/year) on the second floor for the 2000-hour occupational year and 30.2 mrem/year (0.30 mSv/year) to the general public at the site boundary.

The consequences of the conservative assumptions about accelerator operations are most noticeable in the accumulated dose at the site boundary. The site-boundary value exceeds the design goal and required administrative reporting level of 10 mrem/year. In light of this result, the MORSE calculations were repeated [Sun, 1991] using the expected operating parameters of the ALS of 400 mA storage-ring current (rather than 800 mA), injection pulse rate of 1 Hz (rather than 4 Hz), and 8760 annual hours of operation (rather than 8760 hours). These changes result in a reduction factor of 0.086 that can be applied directly to the dose equivalents in Table 4-1a, as shown in Table 4-1b, giving a maximum environmental dose equivalent at the site boundary of 2.65 mrem/year (26.5 μSv/year), well below the current administrative reporting level (and design goal) of 10 mrem/year. In addition, some local shielding near the linac, collimators, and other components, and the shielding effect of equipment, furniture, partitions, etc. inside the ALS building were not considered. Consequently, the calculated dose equivalents are higher than those expected to be observed. It can therefore be concluded that the ALS shielding was adequately designed and complies both with radiological protection and environmental dose limits.

A potential additional factor to consider is that interaction of bremsstrahlung radiation with molecules in the air can generate radioactive isotopes by means of photonuclear reactions. The principal products are nitrogen-13 and oxygen-15 from nitrogen-14 and oxygen-16, respectively [McCaslin, 1990a; Donahue, 1991a]. However, the ALS building, which is equipped with air conditioning in the storage ring tunnel and the experimental areas, affords sufficient mixing, dilution, and time delay to reduce exposure levels from these short-lived isotopes to less than 0.1 mrem/year in the building and less at the site boundary.

Table 4-1a. Maximum annual dose-equivalent rates for the ALS for the most conservative operating conditions

Maximum occupational dose equivalent (D.E.) on the second floor (39 m from ALS center and 6 m above ground floor, 2000-hour/year)

Quantities	Linac +LTB	Booster ring	BTS	Storage ring	Units
D.E. from MORSE	4.30×10^{-5}	1.04×10^{-5}	1.33×10^{-6}	3.22×10^{-8}	mrem joule^{-1}
Annual energy loss	1.39×10^{6}	2.88×10^{6}	1.95×10^{5}	6.23×10^{5}	joule year^{-1}
Calculated D.E. rate	59.8	29.9	0.259	0.0200	mrem year^{-1}
Modified[a] annual D.E.	76.2	38.2	0.33	0.0255	mrem year^{-1}
Total annual D.E.			114		mrem year^{-1}

Maximum environmental dose equivalent (D.E.) (125 m from ALS center and 2.4 m above ground floor, 8760 hour/year)

Quantities	Linac +LTB	Booster ring	BTS	Storage ring	Units
D.E. from MORSE	2.74×10^{-6}	5.46×10^{-7}	1.24×10^{-8}	2.08×10^{-8}	mrem joule^{-1}
Annual energy loss	6.09×10^{6}	1.26×10^{7}	8.57×10^{5}	2.72×10^{6}	joule year^{-1}
Calculated D.E. rate	16.7	6.88	0.106	0.0566	mrem year^{-1}
Modified[a] annual D.E.	21.3	8.78	0.135	0.0722	mrem year^{-1}
Total annual D.E.			30.02		mrem year^{-1}

[a]Including 25% for intermediate-energy neutrons and 2.5% for high-energy neutrons.

Table 4-1b. Maximum annual dose-equivalent rates for the ALS for realistic operating conditions

Maximum occupational dose equivalent (D.E.) on the second floor (39 m from ALS center and 6 m above ground floor, 2000-hour/year)

Quantities	Linac +LTB	Booster ring	BTS	Storage ring	Units
D.E. from MORSE	4.30×10^{-5}	1.04×10^{-5}	1.33×10^{-6}	3.22×10^{-8}	mrem joule^{-1}
Annual energy loss	1.22×10^{5}	2.52×10^{5}	1.07×10^{4}	5.44×10^{4}	joule year^{-1}
Calculated D.E. rate	5.15	2.62	0.0277	0.00175	mrem year^{-1}
Modified[a] annual D.E.	6.67	3.34	0.029	0.0223	mrem year^{-1}
Total annual D.E.			10.0		mrem year^{-1}

Maximum environmental dose equivalent (D.E.) (125 m from ALS center and 2.4 m above ground floor, 6000 hour/year)

Quantities	Linac +LTB	Booster ring	BTS	Storage ring	Units
D.E. from MORSE	2.74×10^{-6}	5.46×10^{-7}	1.24×10^{-8}	2.08×10^{-8}	mrem joule^{-1}
Annual[a] energy loss	5.33×10^{5}	1.10×10^{6}	7.50×10^{4}	2.38×10^{5}	joule year^{-1}
Calculated D.E. rate	1.46	0.602	0.00927	0.00495	mrem year^{-1}
Modified[b] annual D.E.	1.86	0.768	0.0118	0.00631	mrem year^{-1}
Total annual D.E.			2.65		mrem year^{-1}

[a]Calculation with storage-ring current 400 mA, injection rate 1 Hz, and use factor 0.7.
[b]Including 25% for intermediate-energy neutrons and 2.5% for high-energy neutrons.

4.3.4 Present Shielding Configuration

Linac

Calculation of the dose rates expected during linac commissioning [McCaslin, 1990b] verified that the shielding was adequate, except for a region behind the linac beam dump, where rates were potentially significantly higher. To protect against the additional radiation, shielding blocks with total dimensions 10-feet wide by 10-feet high by 4 feet thick were placed outside the existing shielding wall behind the beam-dump area.

Storage Ring

The storage-ring shielding is ratcheted with side walls approximately tangential to the storage ring and transition walls perpendicular to the beamlines, which radiate tangentially from the storage ring. In addition, there are special shielding requirements in the injection area. In some locations, the storage-ring shield-wall and -roof thicknesses differ from the nominal values enumerated in Section 4.3.1, and in some locations lead shielding is added. The design goals for radiation exposure are 250 mrem/2000-hour work year (0.13 mrem/hour) for normal operation and 40 mrem/event for accidental loss of beam. It should be noted that the details of the storage-ring ratchet wall are not an issue for exposure to the general public at the site boundary, since the linac dominates the dose equivalent at this location.

The details of the present configuration of radiation shielding have evolved, but the design remains based on the calculations described in Sections 4.3.2 and 4.3.3. The evolution reflects in-depth examination of specific radiation issues, the outcomes of design and safety reviews, and the results of radiation monitoring during commissioning of the linac and booster synchrotron.

During the course of the ALS construction project, several internal and external reviews were held that included the shielding design, including formal DOE Safety Reviews in November 1989 [ALS, 1989d] and September 1991 [ALS, 1991b]. A major Conceptual Design Review was held in July 1990 [Melczer, 1990a], with a follow-up review in September 1990 [Melczer, 1990a]. The outcomes of these reviews led to the specific shielding configuration shown in Figure 4-9 [Matuk, 1991]. In addition, calculations were used to investigate specific radiation issues and to validate shielding-design features, as indicated by the references in the following paragraphs:

(1) The transition walls are designed for the worst-case scenario of a zero-degree beam perpendicularly penetrating the transition wall [Swanson, 1986; Melczer, 1991a; Donahue, 1992a; Donahue 1993]. Outside the injection region, the storage-ring transition wall comprises 1.5 feet of concrete, a floor-to-ceiling lead shield 3 inches thick, and a 9.2-inch band of lead, also 3 inches thick, centered at the orbit plane of the electron beam. The transition walls at insertion-device ports comprise monolithic, interlocked, hinged shielding blocks.

(2) To provide clearance for the insertion-device beamlines, the thickness of the side walls between the transition walls facing insertion-device and bend-magnet ports was reduced to 1 foot [Swanson, 1987; Melczer, 1991a; Melczer, 1991b]. All storage ring side walls have provision for 1 inch of lead shielding at a future date, should radiation surveys indicate a requirement for additional shielding against photons.

(3) To provide additional protection against injection loss, additional storage-ring wall and roof shielding is provided downstream of the region where electrons are injected from the booster synchrotron into the storage ring [Donahue, 1991b]. The thickness of the storage-ring shielding roof blocks is increased to 1.5 feet near the booster-to-storage ring transfer line, and the thickness of outside walls normally 1.5 feet and 1 foot, respectively, are increased to 2 feet and 1.5 feet, respectively, in much of this area. Inside walls are 3.3 feet thick in the injection area. Side walls in the storage-ring injection area have 2 inches of lead shielding, and transition walls have a floor-to-ceiling lead wall 4 inches thick and a 3-inch thick band of lead 9 inches high centered on the electron orbit plane.

(4) There are penetrations in the storage-ring walls for ventilation (HVAC) [Sun, 1990; Donahue, 1991c]. There is already sufficient shielding provided by the storage-ring components (such as the magnets) outside the injection area. Monitoring will be used to determine if additional lead shielding is needed in the injection area.

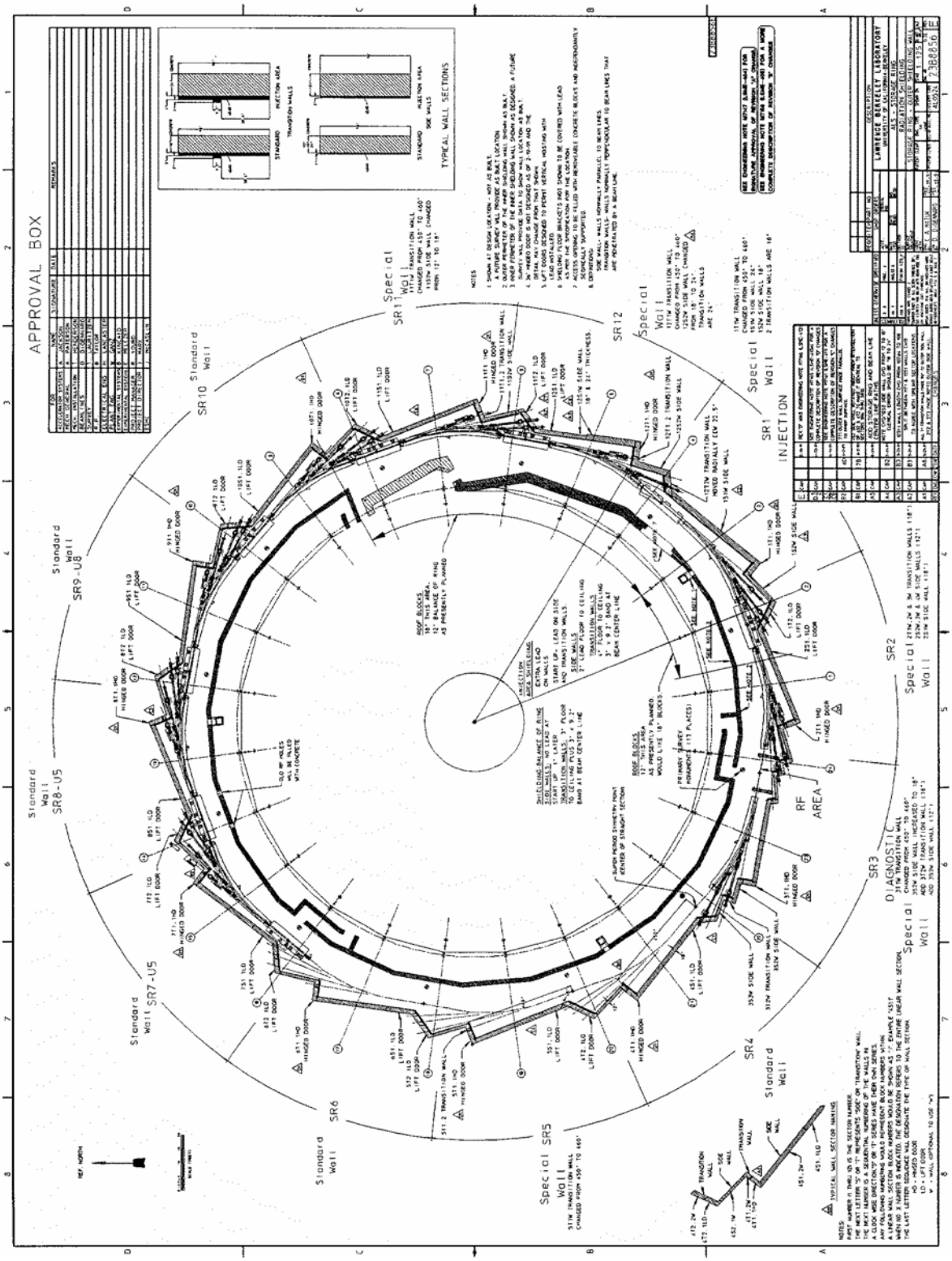


Figure 4-9. ALS Storage-ring shielding configuration.

4.3.5 Validation of the ALS Shielding Design by Injector-Commissioning Experience

Commissioning of the accelerator systems started in October 1990 with the linac. Commissioning of the booster began in May 1991 and commissioning of the entire accelerator complex continued through to April 1993. The initial stages of this activity took place at a time when construction and installation work was ongoing.

Radiation monitoring at the site boundary and in the ALS building, as well as personal dosimetry data, during the injector commissioning show that radiation levels are, in general, lower than expected. This not only confirms the adequacy of the shielding, but suggests that electron beam losses are lower than estimated. Assuming the same pattern holds for the storage ring, the conclusion is that the reduced radiation levels associated with the lower beam losses makes operation of the ALS even less hazardous.

Radiation Monitoring at the Site-Boundary

There is a single radiation-monitoring station at the LBNL site boundary located about 125 m south of the ALS-building center. Both neutrons and photons are detected. There are four site-monitor channels whose pulses from the site-boundary station are logged on a computer at 10-minute intervals. Data from this station has been continuously accumulated since commissioning, thereby including intervals when the ALS injector complex was operational and intervals when there was no accelerator activity. By scanning the data to search for intervals with counts above a minimum representing the time-dependent background, the presence or absence of radiation above background is verified. As part of the LBNL Site Environmental Reports, these data are summarized and evaluated on an annual basis. Observed annual dose at this station has never been distinguishable from background. This is confirmed by supplementary TLD data from various perimeter stations around the LBNL site boundary.

These findings confirm that the operation of the ALS has no measurable effect on the radiation level at the site boundary.

Radiation Monitoring in the ALS Building

During commissioning of the injector complex, radiation surveys and monitoring were carried out in accordance with LSP-023 Accelerator Initial-Operation Radiation Safety Check List [Massoletti, 1992a], as described in Section 6.5.1. Measurements during the period of linac commissioning since February 1991 and during the period of booster commissioning beginning in May 1991 make it possible

to test the adequacy of the shielding and to compare the survey results with the predictions of calculations of the various contributions to prompt radiation fields [McCaslin, 1986].

For the linac, comparison between the predicted dose rate and measurement showed that radiation levels were generally lower than expected. During acceleration of electrons from the electron gun down the linac, electrons are lost along the accelerating structure at energies ranging from 120 keV to 50 MeV. The radiation shielding was designed to reduce the levels immediately outside the shielding to less than 5 mrem/hour. In most areas, the measured radiation levels were well below this value. On the linac roof, typical levels are 0.2 to 1 mrem/hr [Collins, 1992a]. When the beam was mis-steered, however, photon-radiation levels up to 50 mrem/hr were measured above the linac-to-booster (LTB) transfer line.

In localized areas where measurements showed that the radiation levels exceeded 5 mrem/hour, local shielding of lead and concrete was added and easily reduced the dose rate to below the design goal. For example, outside the beam-splitting magnet in the LTB line, fields up to 40 mrem/hr were observed before a lead shield was installed at the vee of the line. Since then, radiation levels have not exceeded 1 mrem/hr outside the shielding. Above the Faraday cup, a thin spot in the shielding created by a conduit gave rise to radiation levels of about 5 mrem/hr when beam was directed to the Faraday cup. Local shielding was added to this location, which reduced the combined photon and neutron radiation level to about 1 mrem/hour.

Booster commissioning involved optimizing the capture of beam from the linac at 50 MeV and ramping the beam energy from 50 MeV to 1.5 GeV. Beam losses at this time were at any or all energies in this interval. The radiation shielding faces its most demanding job when the full beam current has been accelerated to full energy. The shielding around the booster is uniform and sufficient to reduce point-loss doses from the loss of the full beam at 1.5 GeV to less than 75 mrem/hour adjacent to the booster shielding. The design goal for uniform losses is 0.2 mrem/hour.

Once efficiently accelerated and extracted, the 1.5 GeV beam will either be steered into a well-shielded beam dump, as in normal tune-up operation, or directed down the booster-to-storage ring (BTS) transfer line to the storage ring. In the former case, the shielding is sufficient to permit local temporary occupancy and to meet the site-boundary condition. Radiation monitoring in the most sensitive areas is used to determine where extra radiation shielding would be beneficial.

Measured dose rates during injection into the booster were minimal. A 50-MeV point loss in the booster was predicted to give 10 mrem/hour on the booster roof. Measured dose rates were about 0.1

mrem /hour, suggesting that the loss was distributed (as was also predicted) and/or that significant shielding is provided by the magnet structures, for which credit was not taken in the calculations.

During ramping from 50 MeV to 1.5 GeV, uniform losses were measured to be, typically, less than 0.1 mrem/hour or less. Maximum point losses of 200 mrem/hour were measured at a location tangential to the BTS extraction-septum area during a commissioning period when there was incomplete extraction. Individual hot spots were also found with higher radiation levels during abnormal operating conditions, such as mis-steered beam or non-standard tunes and tune resonances. One hot spot of about 5,000 mrem/hr was observed over a measurement time of 1 minute. Since this time, fixed lead shields have been permanently attached to the inner shield walls each time such high loss points are identified, or in areas where they are likely to occur.

Table 4-2 summarizes the comparison between calculated and measured radiation values from operational surveys.

Table 4-2. Calculated and Measured Radiation Doses during Injector Commissioning

Location	**Calculated, mrem/hour**	**Measured, mrem/hour**
Linac	1.25	1 (typical, roof, high-energy end) 50 (roof, small hot spot with beam mis-steered)
Booster, point loss	75	200 (commissioning studies)
Booster, uniform loss	0.05	<0.1

Since commissioning, 20 to 30 stations have been located throughout the ALS floor to monitor radiation with thermoluminscent detectors (TLDs). Neutron and photon dose are monitored at both monthly and quarterly frequencies, and the locations are chosen to monitor the maximum expected dose rates. The data from these TLDs confirm the original conclusions made during commissioning that ambient dose levels on the floor are low enough that no individuals would ever be expected to receive 100 mrem dose in a year.

Personnel Monitoring

The Berkeley Lab Advanced Light Source (ALS) is a state-of-the-art 3rd generation light source which has been operating for about 13 years. Much effort was involved in designing the radiation shielding to meet today's stringent standards and ALARA considerations. The overall design goal was to maintain dose rates to less than about 200 mrem per 2000 hr-year (0.1 mrem/hr) using conservative beam loss assumptions. Operating experience has taught us that actual sustained ambient radiation levels are much lower. These levels are very consistent and predictable since the operation and delivery of beam to users is required to be extremely precise and predictable over long periods of time.

When the accelerator first began operation and a radiation badging policy was to be developed it was decided that, until we had the necessary dosimetry data to decide otherwise, we would badge the entire worker and experimental population. This would provide us with the best statistical data on stray radiation levels around the accelerator. Each person was issued a dosimetry badge that contained 4 TLD elements. Badges were processed on a monthly basis.

The badged population consisted of about 450 people. After three full years of operation, including the commissioning year where beam losses were the highest, the decision was made to remove the restriction that all workers and experimentalists must be issued personnel radiation dosimetry. The evidence was clear. Three years of badging the entire population (total of 65,000 TLD elements) failed to yield a single element exceeding 100 mrem in a year due to stray radiation fields at the ALS. In fact over 98% of the personnel badges have not exceeded 10 mrem per year above normal background using the LBNL DOELAP accredited system and monthly changeout of the badges.

These results can be attributed to several factors:

- Shielding was based on conservative beam loss assumptions.
- No credit was taken in the design for self-shielding by the many accelerator beamline components, particularly the thick aluminum vacuum vessel and massive lattice magnets.
- The linac walls are twice as thick as required (4-6' vs. 2-3') due to the availability of shield blocks from the decommissioning of the cyclotron originally at this site.
- Locations of significant scatter radiation identified during the commissioning phase of a beamline are quickly retrofitted with local shielding to maintain low levels.

10 CFR 835 states: "For the purpose of monitoring individual exposures to external radiation, personnel dosimeters shall be provided to and used by radiological workers who are, under typical conditions, are likely to receive. . . an effective dose equivalent to the whole body of 0.1 rem or more in a year."

10 CFR 20 Subpart F requires personal dosimetry for doses expected to be in excess of 10 percent of the 5 rem occupational exposure limit (five times the DOE limit).

Since, after three years of operation, we had not had a single person exceed 100 mrem in a year due to stray radiation under typical conditions at the ALS, we do not meet the threshold for providing personnel dosimetry. Under abnormal or accident conditions one should rely on detailed measurements under appropriate conditions and time and motion studies to evaluate potential exposures. Personnel dosimetry can be misleading and non-conservative under these conditions. According to the DOE Radiological Control Manual, unnecessary issuance of dosimeters should be avoided.

Consensus Practices

Under the auspices of the Howard Hughes Medical Institute, a set of consensus guidelines for radiation protection practices for academic research institutions were developed. The Health Physics Journal published these guidelines in December 1996, Volume 71, Number 6. The guidelines referring to personal monitoring criteria are as follows:

> Goals: The goals of personal monitoring in a radiation program are (1) to verify the adequacy of radiation control procedures; (2) to help in eliminating unnecessary or unwarranted exposures; (3) to provide data for analysis of the distribution of doses among individuals and groups; and (4) to satisfy regulatory requirements.
>
> Guidelines: Routine monitoring results rarely can be accepted as representative of true doses received by the monitored individuals without supplementary information and analysis by a radiation protection professional.
>
> To achieve the goals stated above, individual radiation users should be monitored for exposures to internal and/or external radiation sources unless they are unlikely to exceed 10% of an occupational dose limit. The likelihood of exceeding 10% of any dose limit may be inferred from monitoring data obtained from groups of workers in other comparable programs or by performing monitoring within defined groups or categories of radiation users.

> Monitoring of individuals who receive negligible doses is discouraged because it may lead to a false sense of protection against both biological and legal risks. In particular, external monitoring devices and data provide no protection to the individual but may actually increase legal liability to the institution unless there are adequate procedures that control the exchange and proper use of the devices and evaluation of the exposure conditions. Exposure conditions can be evaluated by monitoring of randomly selected individuals, by exposure rate measurements, and area monitoring . . .

The Federal occupational dose limit referred to above is 5 rem per year. According to 10 CFR 835.202, the occupational exposure limit to general employees resulting from DOE facilities is also 5 rem.

New Personnel Monitoring Plan and Rationale

We have taken several steps in order to be conservative and further study radiation levels at the ALS. First, we have continued to provide personnel dosimetry to about 10% of the population (70 out of about 700). These individuals comprise that part of the workforce that we think have the greatest potential for any radiation exposure - no matter how small. They include: accelerator operators, beamline coordinators, mechanical and electrical technicians, etc. In addition a small number of beamline users are badged.

New Area Monitoring Plan and Rationale

We have more than doubled the number of area monitors around the experimental area. We currently have about 2 in-close area monitors located on each beamline and about a two dozen area monitors located around the inside periphery of the building. The in-close monitors are exchanged monthly and the peripheral monitors are exchanged quarterly.

Since these area monitors are recording exposure 24 hours per day, 7 days per week we feel that information attained from them will provide the greatest sensitivity. These monitors are usually placed in locations that will give us the maximum integrated exposures based on radiation surveys.

As an example of the area monitor results, we will pick the area monitor labeled as ALS_ENV_14. This is located on beamline 5. This beamline provides for the transport of wiggler radiation for use in protein crystallography. Construction on the beamline outside the storage ring wall started about at the end of 1996. Scatter radiation from several components just inside the storage ring

wall has resulted in what we consider significant levels. In ten months of taking data from December 1996- October of 1997, we have recorded about 106 mrem.

Note that the time interval for which this exposure has been summed over is about 7,200 hrs, i.e. 0.015 mrem/hr average. In spite of such low levels, efforts were recently completed which reduced the scatter dose rates in this area by about a factor of 2. These efforts continue.

In addition to the passive area monitors discussed above we have developed an active real-time area monitoring program. Since operation began we have had interlocked real-time monitoring which dumps the stored beam if a predetermined threshold has been exceeded. These were primarily intended for use during electron beam injection into the storage ring and were positioned around the ring before any synchrotron beamlines had been constructed. The injection process has now been well characterized. In addition to these interlocked monitors, we have installed active monitors in the white light section of each beamline and in new beamlines as they have been developed. These monitors have remote readout to the control room and alarm in the control room at preset levels. In addition, we log the data from these monitors.

The “in close” monitors have a threshold of less than a few mrem and are changed out monthly. The “peripheral” monitors have a threshold of 10-15 mrem and are changed out quarterly. These, combined with the approximately 70 personnel badges (changed out quarterly), the interlocked real time monitors around the shield walls, and the real time beamline monitors provide us with a very complete characterization of the stray radiation fields at the ALS, both in time and location.

In summary, we are adhering to Federal, DOE, and consensus standards by not requiring personnel dosimeters. In addition, our dosimetry program is in the true interest of maintaining personnel exposures ALARA.

4.3.6 Bremsstrahlung Radiation in the Beamline Areas

ALS beamlines require holes to be opened in the storage-ring shielding. In addition to the synchrotron radiation, the holes will allow hard bremsstrahlung to pass through to the experimental floor. Based on safety requirements currently in force at the National Synchrotron Light Source, initial guidelines for designs for beamlines were developed [Warwick, Melczer, Perera, and Heimann, 1990]. Installation of beamlines that satisfy these requirements is now in progress. Radiation shielding designs are subject to design and safety reviews. Typical among the major reviews for LBNL-engineered

beamlines are a Front End Radiation Safety Requirements Review that was held in February 1991 [Johnson, 1991] and a Beamlines Preliminary Design Review that was held in September 1992 [DiGennaro, 1992]. All beamline designs, both LBNL- and user-engineered are subject to review by the Beamlines Review Committee, as described in Section 6.3.4. Calculations were used to investigate specific radiation issues and to determine criteria for shielding designs [Swanson, 1986; Melczer, 1990b; Melczer, 1991c; Donahue, 1992b; Donahue, 1993]. During beamline commissioning, radiation monitoring will be used to determine the need for supplementary shielding.

The shielding design in the beamline area is based on the following factors:

- Apart from the hole in the shielding, the storage-ring shield wall is assumed to give adequate protection against all radiation from the ring.
- A radiation safety shutter that is an integral part of the bremsstrahlung collimation system or bremsstrahlung shield will close the hole during storage-ring injection and when the beamline is not in operation, except that a PSS may be left open during injection under controlled testing conditions with equivalent protection in place. Equivalent protection will include software limits on stored current, additional bremsstrahlung shielding, personnel barriers, off-shift running, and reduced injection frequency. The closed shutter will intercept all lines of sight from inside the storage-ring shield wall through the hole.
- The possibility that the shutter will provide inadequate shielding against neutrons will be dealt with if neutron radiation is observed; it has not been a problem at other facilities.
- All parts of the shutter and any extra shielding associated with it will be inside the shield wall.
- The shutter will be fail-safe and will be positively sensed in the closed position.

When the shutter is open, bremsstrahlung passes through to the experimental floor, requiring additional shielding at certain locations and the establishment of exclusion areas by means of physical barriers or administrative procedures. In many cases, the physical barrier will be the beamline vacuum chamber itself. Beamline design factors pertaining to the open-shutter condition include:

- Analysis at the National Synchrotron Light Source [NSLS, 1982] indicates that the bremsstrahlung yield down a beamline over one year of normal operation is greater than that from a single worst-case vacuum accident. Protection against normal operation is therefore the basis of the shielding design.

- All lines of sight from the bremsstrahlung source will be collimated or blocked by shielding to contain the bremsstrahlung inside the portion of the beamline to which access is excluded, except that under controlled testing conditions lines of sight where equivalent protection is designed to reduce the maximum potential dose to that of a Radiation Area (> 5mrem/hr, < 100mrem/hr) may be protected by roping and posting. Equivalent protection will include software limits on stored current, personnel barriers, off-shift running, and reduced injection frequency.
- The region of the experimental floor within the collimated direct bremsstrahlung beam will be an exclusion zone. Physical barriers will keep all body parts of personnel from entering this zone. Where the beamline vacuum chamber does not contain the bremsstrahlung, external physical barriers (such as secured lexan exclusion zones) or interlocks will be required, except that under controlled testing conditions lines of sight where equivalent protection is designed to reduce the maximum potential dose to that of a Radiation Area may be protected by roping and posting. Equivalent protection will include software limits on stored current, personnel barriers, off-shift running, and reduced injection frequency
- Bremsstrahlung can be scattered outside the collimation zone by massive objects (mirrors, flanges, etc.). Scattered radiation will be dealt with as required during commissioning the beamline.

4.3.7 Validation of Personnel Safety Shutter

A personnel safety shutter includes an 8-inch block of tungsten, which is designed to provide bremsstrahlung attenuation equivalent to the transition wall shielding. The shielding performance of the personnel safety shutter in Beamline 8.0 was tested by closing vacuum valves in the storage ring and observing the resulting radiation at the end of representative location at the end of a beamline and outside the shielding [Collins, 1993a]. This scenario simulates the worst case accident, a thin-target source directly irradiating a beamline.

In the first part of the test, a vacuum valve at the upstream end of the straight section in Sector 8 of the storage ring was closed during injection of 7 mA of current from the booster synchrotron. The valve created a thin-target source of bremsstrahlung that was most intense in the straight section of Sector 8 and hence illuminated Beamline 8.0. The personnel safety shutter attenuated the radiation to less than 1 mrad/hour photons and less than 0.1 mrem/hour neutrons at the end of the beamline.

In the second part of the test, a vacuum valve in Sector 3 of the storage ring was closed, again creating an intense source of bremsstrahlung in the Sector 3 straight section. At 0.8 mrad/hour photons

and less than 0.1 mrem/hour neutrons, the results of measurements outside the Sector 3 shielding (there is no Beamline 3.0) were comparable to those made for Sector 8.

The acceptance criterion for the personnel safety shutter is that it provide bremsstrahlung attenuation equivalent to the shielding. These test results satisfy this criterion, indicating that the performance of the personnel safety shutter is acceptable.

4.3.8 Shielding for the Beam Test Facility

Shielding materials and thicknesses required for the BTF, which have been calculated assuming very aggressive operation of the linac, are adequate to limit occupational worker exposure to l00 mrem/year [Donahue, 1992d]. For a normal operating schedule of 1000 hours/year, this corresponds to an hourly dose limit of 0.1 mrem/hour. The shielding comprises concrete walls 7 feet thick in most locations and concrete roof blocks 4 feet thick supplemented with lead and polyethylene where necessary. The concrete shielding is 8.25 feet thick in front of the BTF beamline, where a beam dump is located. Locations of the lead and polyethylene include 4 inches of lead on the roof above collimators and scrapers, 7 inches of lead and 21 inches of polyethylene on the roof above the beam dump, 3.2 inches of lead and 14 inches of polyethylene between the beam dump and the entrance labyrinth, 4 inches of lead by the first bend magnet in the BTF vault, and 3 inches of lead by the bend magnets in the linac cave. Figure 4-10 shows the BTF layout and shielding.

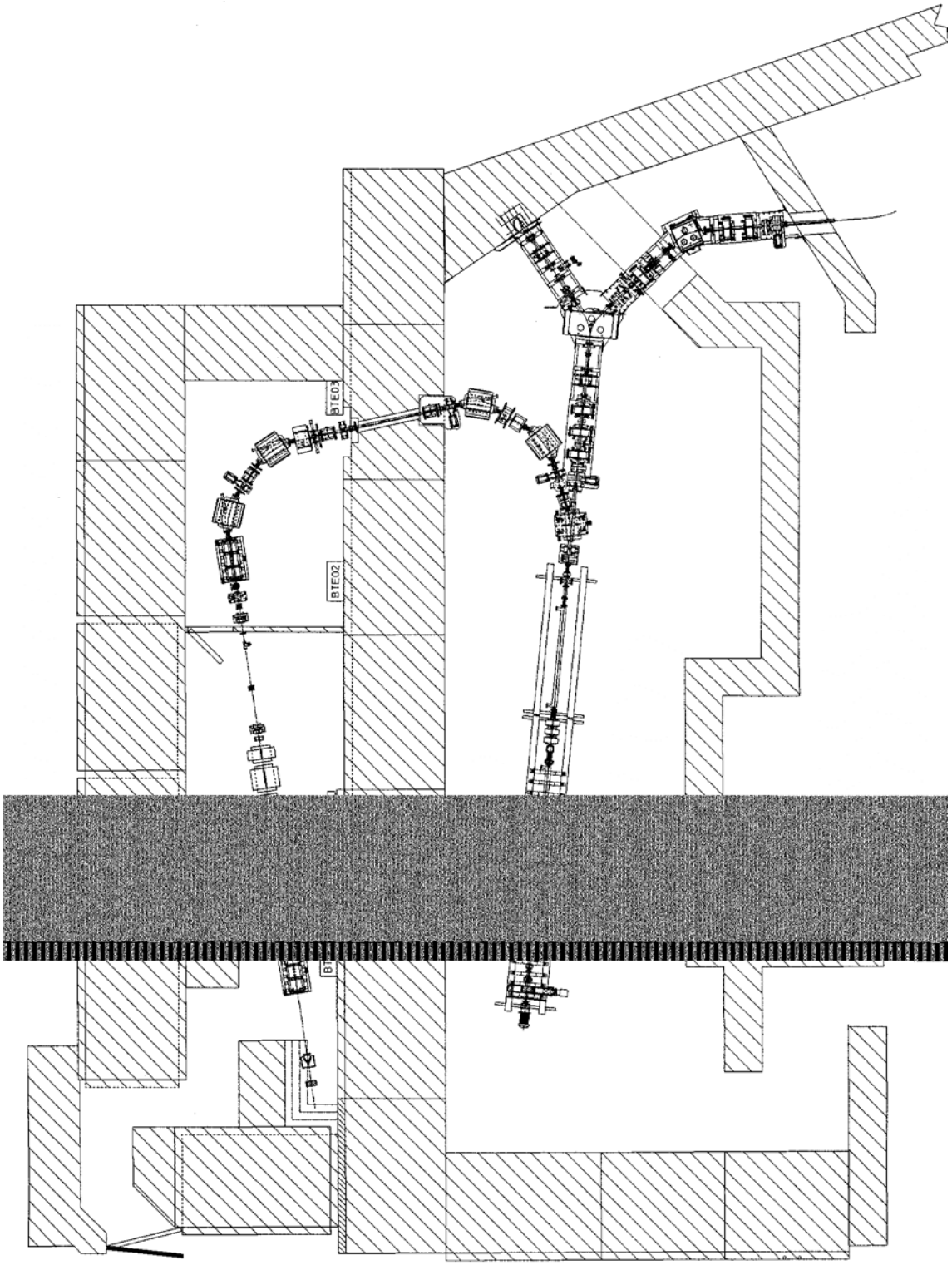


Figure 4-10. Detailed schematic diagram of the Beam Test Facility area showing the radiation shielding and the locations of the radiation gates and the crash-off boxes.

4.4 Radiation Safety System

The radiation safety system is the major control subsystem responsible for the overall personnel radiation safety at the ALS. The elements of this system comprise the interlock logic, operator station, and status displays associated with each component of the overall ALS architecture. All of the major accelerator subsystems are associated with one or more radiation safety system controller(s).

The ALS consists of three major parts: the injection system (electron gun, linac, booster synchrotron and transfer lines), the storage ring, and the beamlines and experimental areas. Each of the major parts of the ALS has three areas of concern regarding radiation safety: access control, area monitoring, and control-room management.

The radiation safety system is designed to allow independent operation of these major parts while providing the required personnel protection. Functionally, each of the three major parts are linked to inhibit operation should a radiation hazard exist in an occupied area as a result of operating an adjacent part. For example, it is desirable to be able to operate the linac and booster and at the same time have access to the storage ring for maintenance. Administrative procedures, radiation monitoring, and training are also considered part of the safety system.

4.4.1 Radiation Safety System Design

The design of the radiation safety system has been subject to an extensive series of internal and external reviews [ALS 1992b and references therein], including DOE Project Safety Reviews in November 1989 [ALS, 1989d] and September 1991 [ALS, 1991b]. The most recent review is the ALS Accelerator Interlock and Safety Systems Operational Review in July 1992 [ALS, 1992d]. Safety-system modifications are governed by EE 02-01 Procedure for Design and Modification of Personnel Safety Systems [Jones, 1993d].

The design philosophy behind the radiation safety system is that it must protect personnel from all plausible hazards related to the operation of the linac, booster, transfer lines, storage ring, beamlines, and experimental areas. The primary hazards addressed are those associated with radiation, high voltage, high-stored-energy devices, and moving mechanical parts or assemblies. To achieve its aim, such a system must be fail-safe, redundant, testable, reliable, and simple.

Features of the radiation safety system design include:

- Totally redundant control of all systems and devices, such as rf, magnets, beam stops, etc. Redundancy requires more than one level of checking and protection. The long history of safe operation at facilities with two levels of redundancy led to the adoption of the same number at the ALS. Redundancy is accomplished by means of independently wired relay systems with parallel functions.
- No solid-state devices in critical personnel protection circuits. A simple hard-wired electromechanical system was selected. Switches of the microswitch type are used to sense position (open or closed). When semiconductors are used in applications where a failure could render the system inoperative or result in a hazardous situation, the system is designed to fail in the safe condition. Improvements have been made to existing "tried and true" components, such as the use of light emitting diodes in place of incandescent lamps.
- Testable. Testable means that any single system error or failure must be detected before other failures occur that might produce a hazardous situation. This requires that all individual circuits and chains be checked to determine whether they are reporting the same status.
- System voltage is 24 V DC. The radiation safety system uses the industry-standard 24-V DC control voltage. Numerous components are therefore available for design.
- Separate routing of wiring. Wiring for non-safety equipment is not allowed in safety-system wireways.
- No wiring in open ladder trays. Wiring is protected by enclosed steel wireways or conduits.
- Tamper resistant. Equipment racks, cross-connection racks, and cable junction boxes are locked and key-controlled.

4.4.2 Operation of the Accelerator Protective Interlock System

Each of the major parts of the ALS has three major areas of concern for radiation safety: access control, area monitoring, and control-room management.

"Controlled access" designates a system of interlocked, physical barriers to prevent personnel from entering hazardous areas. If these barriers are violated, all hazardous equipment is turned off, and all sources of radiation are secured. Controlled access is achieved by locked gates at entrances to the parts of the ALS accelerator complex. All gates are provided with switches to indicate whether they are closed and latched.

Opening of any gate in this area causes the shutdown of appropriate equipment. Each gate also has a key tree and a lighted sign to indicate the accelerator status. Each person entering under controlled access is required to take a key. The action of taking a key prevents operation of the accelerator, which cannot resume until all persons having keys have exited and returned their keys to the tree.

Crash-off/search boxes in the accelerator enclosures are dual-function devices. If any "crash-off" box is activated, all radiation and large magnet power supplies are rendered safe by appropriate equipment shutdowns. Activation of the "search" portion of each box is part of a search-and-clear chain, which demands that a search be made of the area in a prescribed manner (and the boxes reset in a prescribed sequence) before hazardous equipment can be made operational once again.

Active neutron and photon area monitoring of radiation outside the shielding where personnel are allowed to work is continuous. Excessive radiation or monitoring-equipment failure will turn off all sources of radiation under all circumstances.

A brief description of how the protective interlock system addresses these concerns for the major parts of the ALS follows:

Electron Gun/Linac

The radiation safety system for the electron gun and linac (hereafter together called the linac) is designed with one main access and one emergency escape exit gate. The position of each gate is sensed by redundant microswitches. During normal operation, access to the linac via the main gate is controlled by the main control room. A two-way audio communications system, a closed-circuit television system, a "key tree" and a lighted status sign are located adjacent to the gate. Access inside the shielding requires communications with, and surveillance by, the main control room. The following sequence of operations must occur for controlled access to take place:

(1) The main control room disables linac operation by switching it to the safe mode;
(2) The person entering must take a key from the key tree;
(3) The control room must log the access and release the gate for entry.

These actions prevent either local or remote operation of the linac. Inside the shielding are three "crash-off/search" boxes. The main access and emergency exit gates have emergency "crash-off/in" release mechanisms. Activation of a crash-off box or crash-off/in gate release prevents the operation of

the linac. Restarting requires a search of the linac shielding. The search requires a key from the main control room and a search sequence such that the key is used to reset the crash-off/search boxes in a manner ensuring that a complete search has been made. The linac can only be operated after the key returned to its key switch cache in the main control room.

Radiation monitoring outside the shielded linac enclosure consists of x-ray and neutron detectors. Radiation detected above allowable limits in this area prevents operation of the linac.

Figure 4-6 shows locations of the features of the safety system in the linac area; Figure 4-11 is a block diagram of the linac radiation-safety interlock system.

Booster Synchrotron

The booster has two main access gates with access-control systems identical to those described for the linac. The booster has six crash-off/search boxes. After activation of a crash-off box, restarting requires three (3) persons with two keys from the main control room to perform a search-and-secure procedure. The search is done in a controlled sequence as with the linac. Controlled access for testing and maintenance can be granted. The following sequence of events must occur for controlled access to take place:

(1) The main control room disables linac and booster operation by switching it to the safe mode;
(2) The person entering must take a key from the key tree;
(3) The control room must log the access and release the gate for entry.

These actions prevent the operation of the linac and booster.

Radiation monitoring outside the booster shielding consists of x-ray and neutron detectors. Radiation detected above allowable limits in this area prevents operation of the linac and booster.

Figure 4-7 shows locations of the features of the safety system in the booster-synchrotron area; Figure 4-12 is a block diagram of the radiation-safety interlock system for the booster.

Storage Ring

The system is designed to allow operation of the linac and booster while portions of the storage ring are accessible for testing and maintenance.

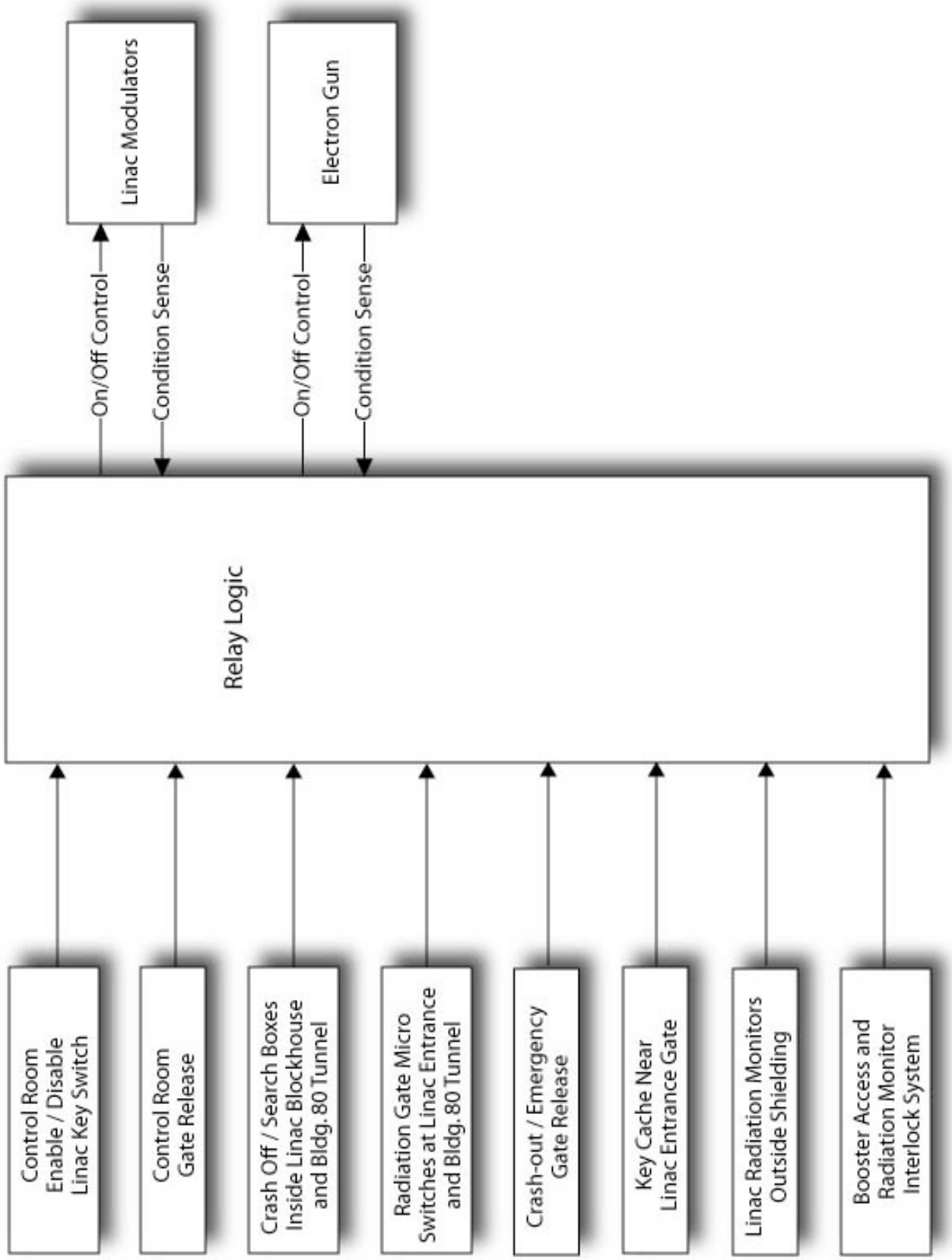


Figure 4-11. ALS radiation-safety interlock system for the linear accelerator.

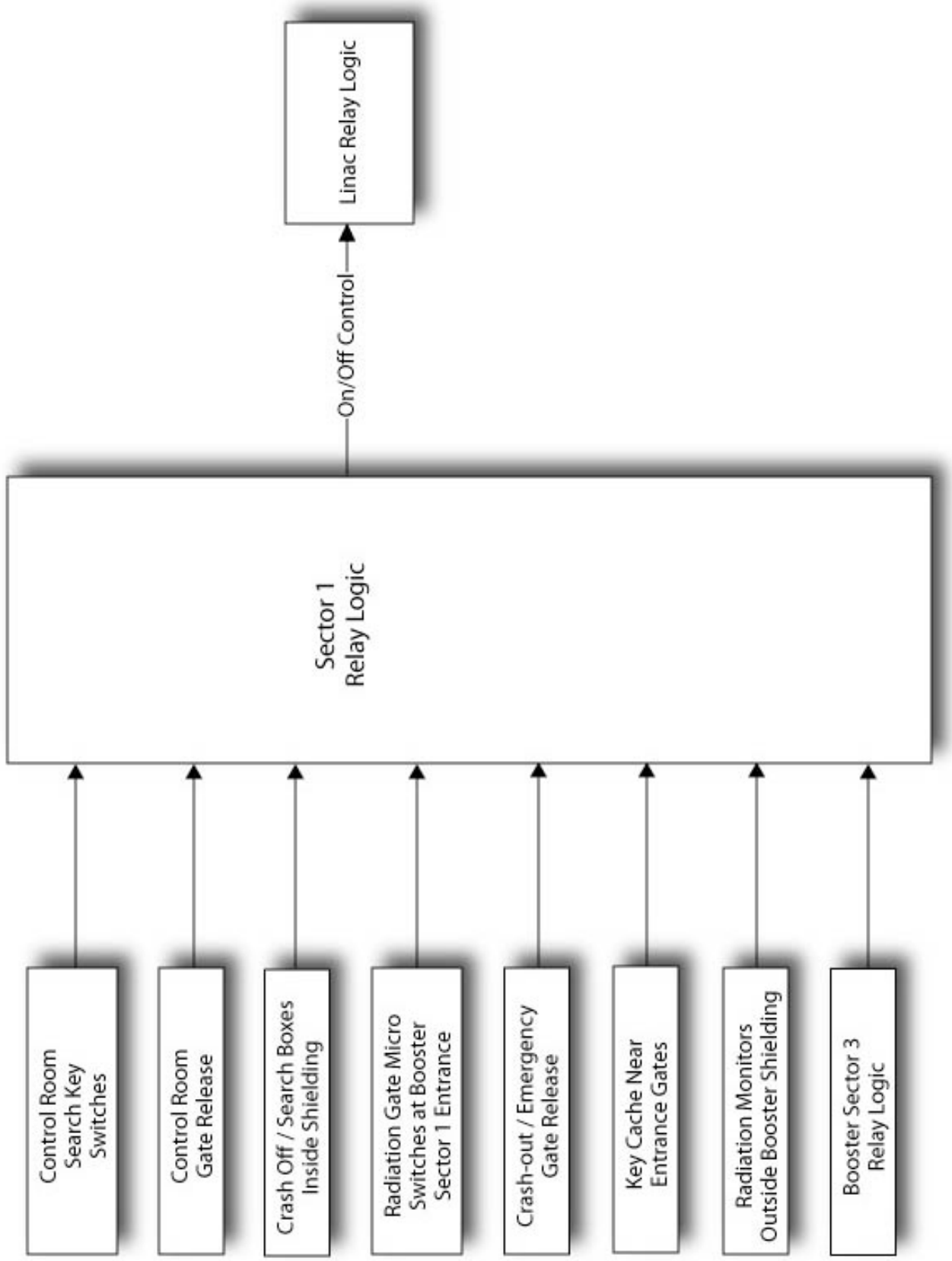


Figure 4-12. ALS radiation-safety interlock system for the booster synchroton.

The storage ring has three main access gates at sectors 10, 2, and 6 with access-control systems identical to those described for the linac and the booster. The entrance gate at sector 10 interlocks the injection systems and the storage-ring RF system during normal operation. The entrance gate at sector 2 interlocks the storage-ring RF systems during low-power tests, high-power tests, and normal operation. The entrance gate at sector 6 interlocks the storage-ring RF system during normal operation. The hinged concrete shielding blocks in the outer shielding wall are interlocked to the zone in which they reside.

The storage ring has three internal gates: one associated with the booster-to-storage ring injection area, one associated with the storage-ring RF system, and one serving both areas. Internal gates A and B prevent access to the storage-ring BTS area while the injection system is being tested and the beam goes to the BTS beam dump. The BTS area then becomes part of the injection interlock system, and the electron gun is inhibited if the area is not secure. Internal gates B and C prevent access to the RF-cavity area during full-power testing and normal operation. The area can be accessed during low-power testing.

There are 12 crash-off/search boxes. Boxes in each of the three storage-ring zones operate independently. After activation of a crash-off box, restarting requires two people with two keys from the main control room to perform a search-and-secure procedure. The search is done in a controlled sequence as with the linac. The following sequence of events must occur for controlled access to take place:

(1) The main control room inhibits operation of the injection system, if appropriate, by switching it to the safe mode;

(2) The person entering must take a key from the key tree;

(3) The control room must log the access and release the gate for entry.

Radiation monitoring outside the storage-ring shielding consists of x-ray and neutron detectors. Radiation detected above allowable limits in this area prevents operation of the storage-ring RF and prevents injection into the storage ring.

Figures 4-5 and 4-8 show locations of the features of the safety system in the storage-ring area; Figure 4-13 is a block diagram of the radiation-safety interlock system for the storage ring.

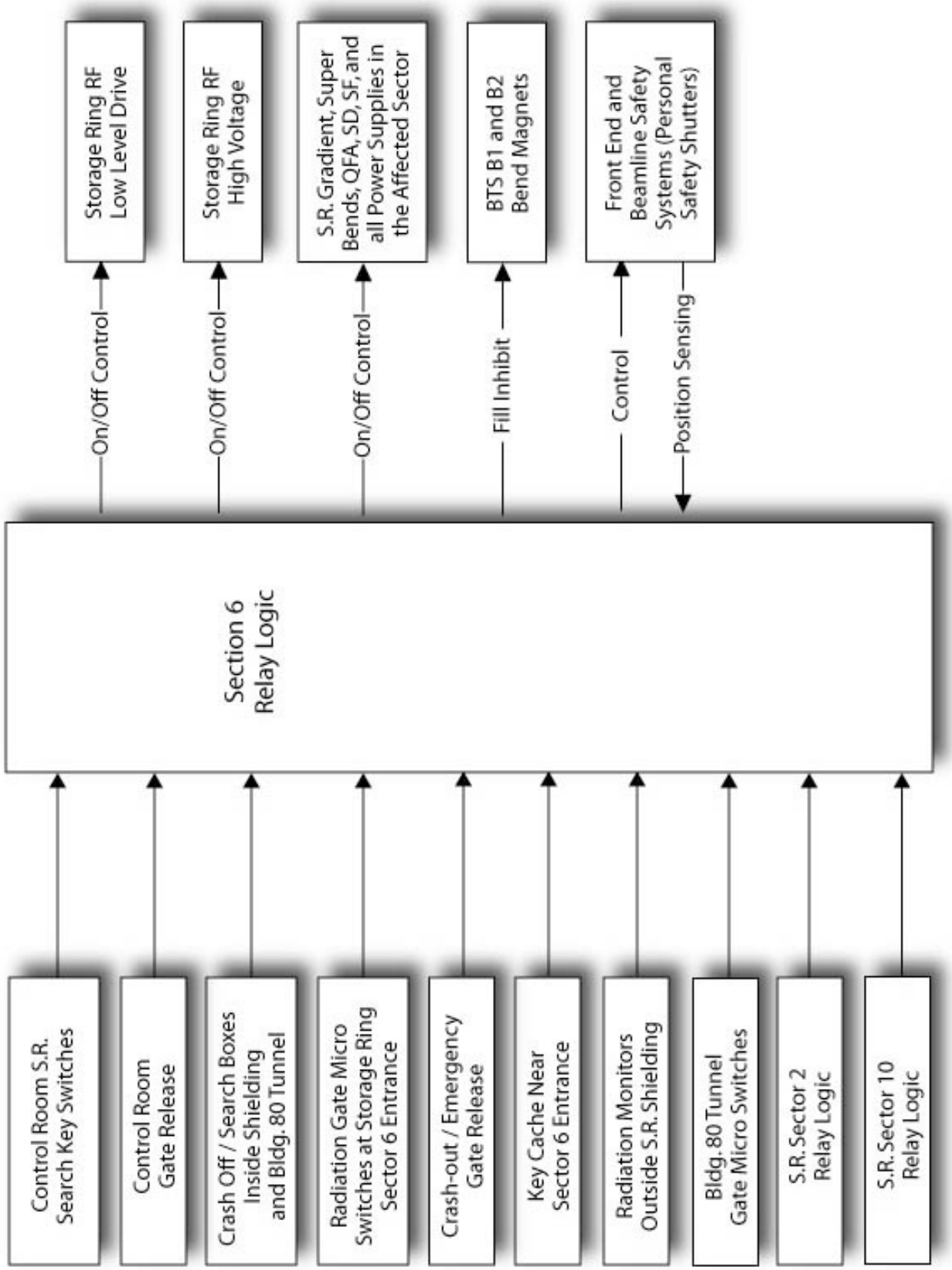


Figure 4-13. ALS radiation-safety interlock system for the storage ring.

4.4.3 Beamline Radiation Safety System

The beamline radiation safety system comprises subsystems for each of the one or more branch lines associated with a beamline and the end stations associated with each branch line. Note that the beamline front-end components are contained within the storage-ring shield wall and are thus controlled by the storage-ring radiation safety system. However, the radiation emanating from the beamline front ends is moderated by the branch-line radiation safety subsystems. Figure 4-14 diagrams the beamline radiation safety system.

Branch-Line Radiation Safety Subsystem: The branch-line radiation safety subsystem is responsible for control of the radiation passing into the branch line and for control of access to areas with potentially elevated radiation levels during normal operation. The personnel safety shutter that is located just inside the storage-ring shield wall controls passage of the radiation. The shutter controller responds principally to commands from the front-end beamline equipment protection system (e.g., to close the shutter during injection or to open/close the shutter in response to operator requests). A personnel safety shutter keyswitch may be used to enable or disable individual branch lines.

During the filling of the storage ring, photon shutters and safety shutters will be inserted in the photon beamlines, except that a PSS may be left open during injection under controlled testing conditions with equivalent protection in place. Equivalent protection will include software limits on stored current, additional bremsstrahlung shielding, personnel barriers, off-shift running, and reduced injection frequency. These devices will be monitored by redundant position-indicating microswitches that prevent filling of the storage ring whenever any improper photon stop, water flow, or safety shutter condition is detected The system is designed so that the safety shutters cannot be closed unless the photon shutters are closed, and the storage ring cannot be filled unless both are closed, except under the above conditions. Self-checking ensures detection of a failure in one of the redundant circuits. A failure will not shut down the machine, but it will prevent further filling of the storage ring.

Access to beamline areas with potentially elevated radiation levels is controlled by enclosures with redundant interlock chains and emergency crash-off boxes.

End Station Radiation Safety Subsystem: In some cases (e.g., when an x-ray hutch is required), a separate end-station radiation safety subsystem, which is functionally identical to the branchline radiation safety subsystem, controls radiation passing into the end-station region. For most beamlines, the safety shutter valve will be controlled by a lock and key. These controls protect the experimenter

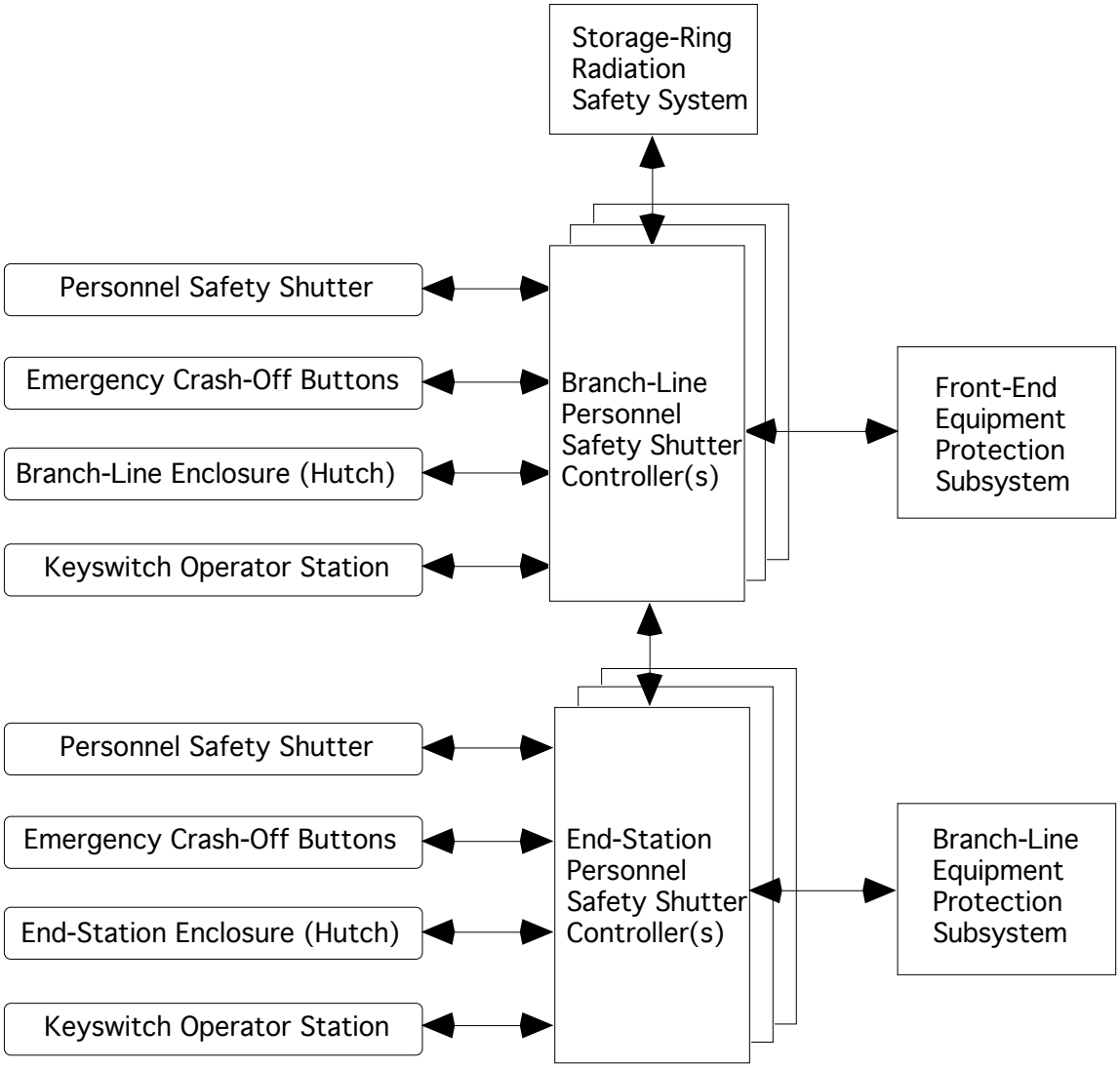


Figure 4-14. Diagram of the beamline radiation safety system showing branch-line and, where applicable, end-station subsystems.

from accidental exposure to synchrotron radiation and provide a control interface for enabling/disabling beam to the experiment.

Access to the beamline and experimental area will be controlled. Administrative procedures will be established for education of users about entry requirements.

Radiation monitoring in the beamline and experimental areas is by means of the same system used to monitor radiation outside the storage-ring shielding and consists of x-ray and neutron detectors. Active radiation monitors with preset trip levels of 10 mrad/hour are part of the interlock chain and prevent operation of the storage-ring rf. Thermoluminescent dosimeters, for backup, are also placed around the building.

4.4.4 Beam Test Facility Radiation Safety System

The BTF radiation safety system follows the principle adopted for the ALS accelerator radiation safety system (see Section 4.4.1). The system is designed to allow access to portions of the BTF vault when the linac is operating as part of the ALS injector system. For this purpose, in addition to the access gate to the BTF vault, a second access gate is installed downstream of the penetration through the wall separating the linac and the BTF line, thereby separating the vault into A and B caves as shown in Figure 4-10. The BTF radiation safety system provides protection against entrance into cave B but permits access to cave A during operation of the linac for ALS storage-ring injection, and it provides protection against entrance into cave A during operation of the linac for the BTF.

To enter the B cave, the control room must shut down the linac. If the B gate is opened while the linac is operating, the linac interlock chain will be broken and the linac turned off. To return the linac to operation, a search of the B cave is required to complete the BTF interlock chain, which in turn allows the linac interlock chain to be completed. The search must be conducted by at least two trained personnel. Search push buttons on two crash-off boxes on opposite walls of the cave must be pushed simultaneously, which requires a two-person search team. The B gate must be closed within 10 seconds of pushing the crash-off box buttons.

To enter the A cave, the power supplies of the bend magnets that divert the beam into the BTF vault must be turned off. To return to BTF operation, the gate must be closed after a two-party search is conducted. Crash-off boxes on opposite walls, one with a push-button and one with a key switch, must be activated simultaneously, and the gate must be closed within 30 seconds. The B key must be

reinserted into the kirk key assembly and the A key returned to the safety rack. Turning the A key activates the red lights in the cave and completes the circuit for the on-off switch. Pushing the switch causes a 60-second alarm to sound before energizing the bend-magnet power supplies.

4.5 Safety Analysis of Radiation Hazard Events

Radiation hazards potentially exist at the LBNL site boundary and within the ALS building. It is assumed that the general public has access to the site boundary. Access to controlled areas within the ALS building is governed by several approved and published ALS procedures. The main floor of the ALS building is considered a Controlled Area for the purposes of radiation protection. All entrances are posted as such.

The methodology described in Section 4.1 was applied to each identified radiation hazard event. Each event analysis included determining the initiating occurrence, possible detection methods, the safety features that might have prevented or mitigated the event, the probability of the event occurring, and the possible consequences.

Based on the discussion in the following sections, a hazard control matrix was constructed (Table 4-3). The matrix shows that ionizing-radiation hazards exist throughout the facility. The matrix also indicates mitigation and control features operative in the various parts of the facility.

The consequences and probability of each hazard were rated by levels, using guidance from DOE O5480.25. Table 4-4 summarizes the consequence levels, and Table 4-5 summarizes the probability rating levels. The overall risk associated with each specific hazard was determined using these rating levels and the risk matrix (Figure 4-15) also provided in DOE O5480.25. Table 4-6, which summarizes the risk assessment for exposure to ionizing radiation according to this methodology, shows that the ALS facility operates within the risk envelope for low-hazard facilities as defined in DOE O5480.25.

4.5.1 Hazard Event: Exposure to Ionizing Radiation at the Site Boundary

<u>Initiating Occurrence</u>

The maximum exposure to a member of the general public occurs at the LBNL site boundary. Prompt radiation relevant to the site boundary from operation of the accelerator systems comprises bremsstrahlung radiation and neutrons, which are produced during both normal and abnormal operating conditions.

Method of Detection

Radiation is monitored by photon and neutron detectors in a station located 125 m south of the ALS building center at the LBNL site boundary.

Table 4-3. Hazard Control Matrix

Hazard Type	**Accelerator Area**	**Experimental Floor**	**Site Boundary**
Exposure to ionizing radiation at the site boundary	NA	NA	13, 14
Exposure to ionizing radiation outside the accelerator enclosures	NA	1, 2, 3, 11, 12, 13, 14	NA
Exposure to ionizing radiation inside the accelerator enclosures	1, 2, 3, 9, 12, 13	NA	NA
Exposure to synchrotron radiation	NA	2, 3, 5, 9, 11, 13, 12, 14	NA
Exposure to air activation products	11, 14, 15	11, 14, 15	14, 15, 17
Exposure to ionizing radiation from sources other than accelerators	2, 3, 5, 9, 11, 12, 13, 14	NA	NA

Preventive and Mitigating Factors:
1. Alarm
2. Automatic Devices
3. Barriers/Isolation
4. Decontamination
5. Equipment Design/Aids
6. Fire Department
7. Insulation
8. Limited Quantities/Load
9. Lockouts/Interlocks
10. Manual Intervention
11. Monitoring
12. Personal Protective Equipment
13. Operational Procedures
14. Shielding
15. Ventilation
16. Emergency Plan
17. Dilution

NA Not Applicable

Preventive/Mitigating Features

All elements of the accelerator are enclosed in concrete shielding supplemented with lead and polyethylene in critical locations. Active radiation monitors in the experimental area with preset trip levels are part of the interlock chain. The administrative reporting level for site-boundary exposure is 10 mrem/year.

Consequences

Exposure at the site boundary to radiation from the shielded accelerators is not potentially lethal. Similarly, operation of the accelerator would have no major impact on the environment. From Table 4-4, it is judged that the consequence level at the site boundary of operating the accelerator is medium.

Table 4-4. Consequence Rating Levels

Consequence Level	Description Words	Maximum Consequences
1	High	Serious impact on-site or off-site. May cause deaths or loss of facility/ operation. Major impact on the environment.
2	Medium	Major impact on-site and/or minor impact off-site. May cause death, severe injury, or severe occupational illness to personnel or major damage to the facility/operation, or minor impact on the environment. Capable of returning to operation.
3	Low	Minor impact on-site with no off-site impact. May cause minor injury or minor occupational illness, or minor impact on the environment.
4	Extremely Low	Will not result in a significant injury or occupational illness, or provide a significant impact on the environment.

Probability

Because the accelerator would neither be operated without shielding nor without the other preventive/mitigating factors enumerated, which are basic ingredients in the design of the ALS, the Technical Safety Subcommittee concluded that the probability of exposure to radiation at the site boundary was extremely low. From Table 4-5, the Technical Safety Subcommittee assigned a probability level of extremely low.

Table 4-5. Probability Rating Levels

Category	Symbol	Description	Estimated Range of Probability of Accident per Year
Incredible		Probability of occurrence is so small that a reasonable scenario is not conceivable. These events are not considered in the design or SAD accident analysis.	$<10^{-6}$
Extremely Low	A	Probability of occurrence is extremely unlikely or event is not expected to occur during the life of the facility or operation. Events are limiting faults considered in design (Design Basis Accidents).	10^{-6} to 10^{-4}
Low	B	Probability of occurrence is unlikely or event is not expected to occur during the life of the facility or operation.	10^{-4} to 10^{-2}
Medium	C	Event may occur during the facility or operation lifetime.	10^{-2} to 10^{-1}
High	D	Event is likely to occur several times during the facility or operation lifetime.	$>10^{-1}$

Risk

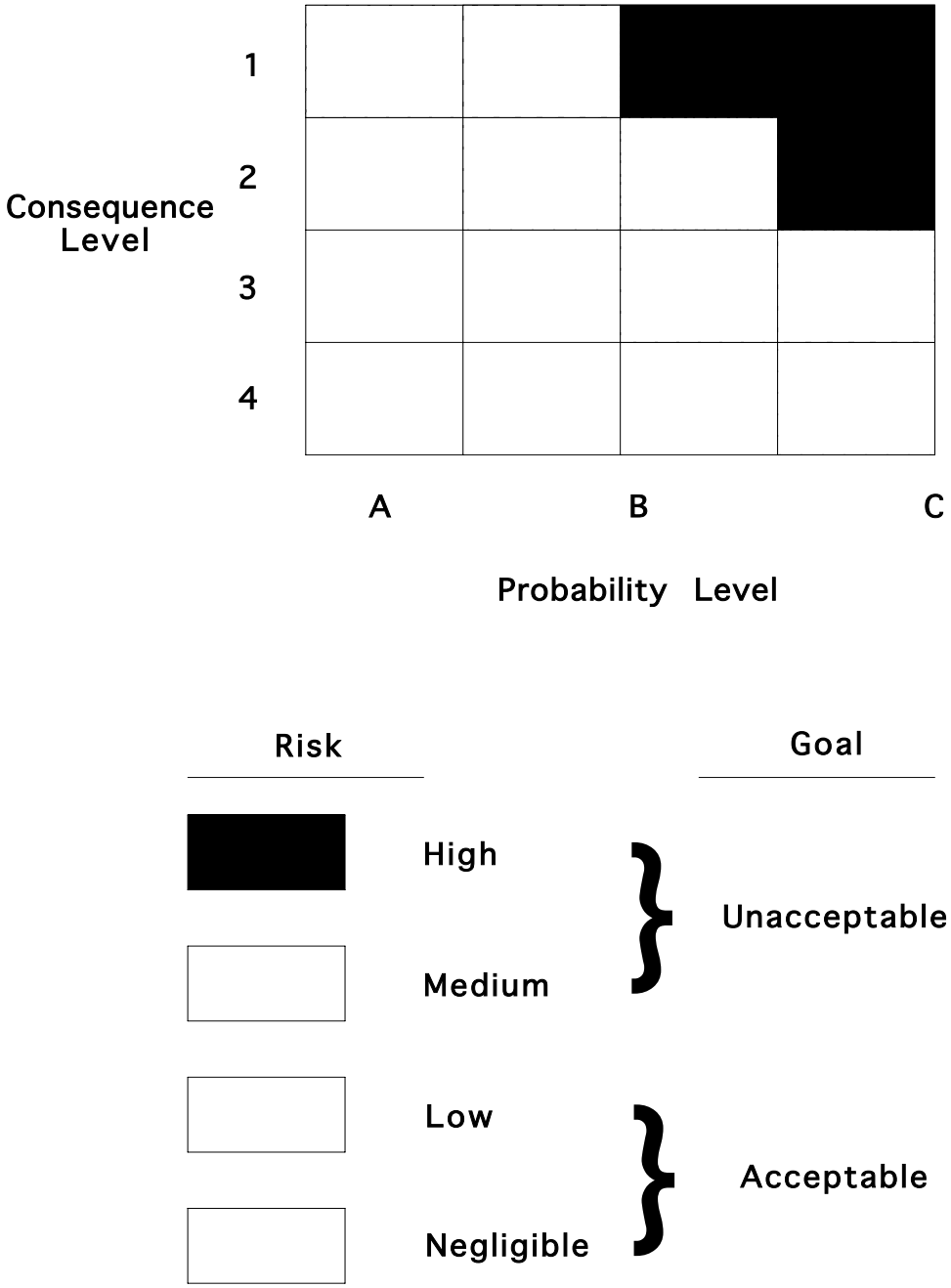
From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of extremely low result in site-boundary exposure risk of negligible for both normal and abnormal operation of the accelerator.

4.5.2 Hazard Event: Exposure to Ionizing Radiation outside Accelerator Enclosures

Initiating Occurrence

Occupational exposure to ionizing radiation may occur to workers in the ALS building under all operating conditions. Prompt radiation from operation of the accelerator systems comprises x-rays from the 120-kV electron gun and from RF power systems on the linac, booster, and storage ring, x-rays from the booster and storage-ring rf cavities, and bremsstrahlung radiation and neutrons from the linac, booster, and storage-ring operation. In addition, when a beamline Personnel Safety Shutter (PSS) is opened during injection, prompt radiation outside the accelerator shielding can result from freshly injected electrons either (i) passing down the beamline and colliding with the beamline optics, or (ii) colliding with the storage ring vacuum chamber near the beamline.

Figure 4-15. Risk Matrix.



Method of Detection

Radiation is continuously monitored by photon and neutron detectors at many locations around the ALS facility. The monitors at fixed locations form part of the radiation safety system and are interlocked to trip the beam if limits are exceeded. Fixed real-time radiation monitors are located near the first optics in the beamline. Their reading is displayed in the control room and in case of an error condition, they also alarm in the control room There are also regular surveys made with portable monitors that are recorded in the radiation survey log book, as well as periodic surveys using thermoluminescent detectors to measure integrated doses over longer periods of time. Surveys are made at prescribed times and intervals.

Preventive/Mitigating Features

All elements of the accelerator are enclosed in concrete shielding supplemented with lead and polyethylene in critical locations. Access to the linac cave and the booster and storage-ring tunnels is prevented by fail-safe, redundant, independent interlocked physical barriers while the beam is on or the linac accelerator guides, the booster cavity, or the storage-ring cavity systems are rf-powered. Photon beamlines are designed to contain bremsstrahlung radiation within the vacuum chamber and are protected by lead shielding in critical locations. Active radiation monitors in the controlled areas with preset trip levels are part of the interlock chain. Interlocks are fail-safe, redundant, and testable. In addition, ALS procedures require that: (1) staff and visiting workers receive radiation safety training, (2) radiation surveys are made at prescribed times and intervals, (3) radiation detectors are calibrated at prescribed intervals, and (4) interlocks are tested as part of a scheduled maintenance program.

Radiation due to a beamline PSS being opened during injection to test top-off operation will be mitigated by six precautions that provide equivalent protection to operating with the PSS open during normal stored beam operation.

(1) Fixed passive shielding will reduce the dose from the worst case beam loss condition, a single shot of injected beam striking the first optic, from several hundred rem to less than a few mrem. This is equivalent to the dose downstream of the PSS if the stored beam intercepts the vacuum chamber (a routine situation) when the PSS is open during normal stored beam operation. The layout of this supplemental shielding will be documented in an approved ray trace drawing which is then used to verify the location of installed shielding prior to operations. Shielding will typically be 6" of Pb to provide this protection.

(2) Roping off the area will reduce the dose from the worst case beam loss condition (above) due to large-angle scattering. This measure will reduce the dose from 15-20 mrem down to less than a few mrem, consistent with the dose if the stored beam intercepts the vacuum chamber (a routine situation) when the PSS is open during normal stored beam operation.

(3) Perform these tests only on "off-shifts" – from 4 pm until 8 am, or on weekends – when most of the ALS staff (and the users, since these tests will be during accelerator physics shifts, not during routine user operations) are not present. This measure reduces the number of people in the vicinity of the tests and thus reduces the potential for personnel exposure.

(4) Monitor the radiation level as part of the test using the fixed active radiation monitors and modify or suspend the tests if the radiation levels are not as predicted.

(5) Provide a software verification which reduces the storage ring injection rate from 1 Hz to 0.033 Hz (one injection every 30 sec.). This measure provides ample time to modify or suspend the tests after each shot if the radiation levels are not as predicted.

(6) Provide a software verification that disables injection if there is no stored beam. This measure serves to minimize the probability of the worst case scenario (see item (i), above), the consequences of which are mitigated by measures 1 through 5, above.

Documentation of the effectiveness of the fixed passive shielding and the roping off of the area is provided in a memorandum from Rick Donahue to Dave Robin, dated 10/4/2004. This memorandum shows that these measures will reduce both gamma and neutron radiation as described in sections (i) and (ii), above.

Consequences

Excess exposure to ionizing radiation may cause death, severe injury, or severe occupational illness to personnel. From Table 4-4, the consequence level is judged to be medium.

Probability

Excess exposure could occur if the shielding were improperly installed or if more than one radiation monitor malfunctioned in the same area. Radiation monitoring during ten years of operation with the ALS has verified the adequacy of the shielding design and installation. For the top-off testing, redundant measures (above) provide assurance that is equivalent to operations with the PSS open during normal stored beam operation. The probability that these redundant measures would fail simultaneously

in the same area of the facility is low. From Table 4-5, the Technical Safety Subcommittee assigned a probability level for exposure to excess ionizing radiation of low.

Risk

From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of low results in risk of low.

4.5.3 Hazard Event: Exposure to Ionizing Radiation inside Accelerator Enclosures

Initiating Occurrence

Exposure to prompt radiation from operation of the accelerator systems could occur if a person were inside the accelerator enclosures while the accelerators were operating.

Method of Detection

Observation of affected personnel in the accelerator enclosures.

Preventive/Mitigating Features

Access to the linac cave and the booster and storage-ring tunnels is prevented by fail-safe, redundant, independent interlocked physical barriers while the beam is on or the linac accelerator guides, the booster cavity, or the storage-ring cavity systems are rf-powered. Before turning on the rf power systems or the accelerator beam, accelerator and controlled-area search and secure procedures are required. Audio and visual monitoring systems are active at all times in the gate areas. Interlocks are fail-safe, redundant, and testable. Warning lights/signs and audible alarms in the accelerator area are activated before these systems are turned on. Crash-off boxes are part of the interlock chain. Interlocks are tested as part of a scheduled maintenance program. Bypassing of interlocks is regulated by LBNL procedures and specifically by an ALS procedure.

Consequences

Exposure to radiation from the unshielded accelerator is potentially lethal, but the consequences would be limited to the individual or few individuals inside the shielding. From Table 4-4, it is judged that the consequence level of exposure to ionizing radiation inside the accelerator enclosures is medium.

Probability

For an individual to be exposed to ionizing radiation inside the accelerator enclosures, several events would have to occur. First, either the search and secure procedure was not executed correctly, so that a person was inside an enclosure when the accelerator was turned on, or the interlock system would have to fail, so that a person could enter while the accelerator was turned on. Second, either the warning signs and lights and audible alarms would have to fail, the individual would have to disregard the signs and lights, or the crash-off boxes that are part of the interlock chain would have to fail. From experience at other accelerator facilities it is judged that the probability of such events occurring is low. From Table 4-5, the Technical Safety Subcommittee assigned a probability level of low for exposure to ionizing radiation inside the accelerator enclosure.

Risk

From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of low results in risk of low.

4.5.4 Hazard Event: Exposure to Synchrotron Radiation

Initiating Occurrence

Exposure to synchrotron radiation can in principle occur for personnel in the beamline and experimental areas during operation of the accelerator.

Method of Detection

The active and passive monitoring systems include a substantial set of radiation monitors in the vicinity of the beamlines and experimental chambers which are designed to detect synchrotron radiation.

Preventive/Mitigating Features

Beamlines are designed to contain the synchrotron radiation within the vacuum chamber. Shielding is also used in certain cases where a significant flux of hard x-rays is present. Access to experimental areas where exposure to synchrotron radiation could occur is prevented by physical barriers that are interlocked or whose method of access precludes a radiation hazard. Interlocks are fail-safe, redundant, and testable. Enclosures on hard x-ray beamlines are required to be constructed with locks or tamper-

proof seals that prevent disassembly. ALS Procedures require that (1) staff and visiting workers receive radiation safety training and (2) interlocks are tested as part of a scheduled maintenance program.

Consequences

Exposure to synchrotron radiation may cause injury or occupational illness to personnel. From Table 4-4, the consequence level is judged to be medium.

Probability

Exposure to synchrotron radiation would be possible on hard x-ray beamlines if the beamline and/or endstation were poorly designed or constructed, disassembled or that the protective interlock system failed when an attempt was made to pass through physical barriers blocking access. The ALS beamline review process ensures that design errors are reviewed by the appropriate personnel, and that construction errors are detected through a thorough, documented commissioning process. If the beamline were not intact, either the photon shutter and the personnel safety shutter in the beamline front end would be shut by the ALS Floor Operator who is required to key off the beamline before providing access to the locks or tamper-proof seals on enclosures, or storage-ring operation would be halted by the protective interlock system. If the end station on hard x-ray beamlines were disassembled, the end-station personnel safety shutter would be shut by the protective interlock system or the ALS Floor Operator who provided the keys to allow disassembly would key off the beamline. Either case would automatically cause the personnel safety shutter to close. Because of the fail-safe, redundant, testable character of the interlock system, the probability of any of these events is low. From Table 4-5, the Technical Safety Subcommittee assigned a probability level of low.

Risk

From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of low results in risk of .low.

4.5.5 Hazard Event: Exposure to Air-Activation Products

Initiating Occurrence

Exposure to ionizing radiation can occur in the ALS building and at the site boundary as a result of the generation of air-activation products, primarily from photonuclear interaction of bremsstrahlung

radiation with nitrogen-14 and oxygen-16 in the air around the accelerator to produce nitrogen-13 and oxygen-15, respectively.

Method of Detection

Regular monitoring for air-activation products will be carried out by the LBNL Environment, Health, and Safety Division during the early operation of the ALS.

Preventive/Mitigating Features

The building enclosure affords mixing, dilution, and time delay, thereby reducing the exposure due to the short-lived isotopes produced at the ALS. In addition, fans and air-conditioning are installed and are required to be on during accelerator operations to minimize the concentration of activated air.

Consequences

Exposure to ionizing radiation from air-activation products may cause death, severe injury, or severe occupational illness to personnel. From Table 4-4, the consequence level is judged to be medium.

Probability

The primary protective mechanism (the building itself) is passive and cannot fail. The secondary protective mechanism (the fans and air conditioning) are required to be operating before the storage ring is turned on. The probability of the hazard event is therefore extremely low, and, from Table 4-5, the Technical Safety Subcommittee assigned a probability level of extremely low.

Risk

From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of extremely low results in risk of negligible.

4.5.6 Hazard Event: Exposure to Ionizing Radiation from ALS Sources other than Accelerators

Initiating Occurrence

Exposure to ionizing radiation can occur due to production of low-energy x-rays in components of the rf power systems, including the klystrons, vacuum switches, and modulator tetrodes.

Method of Detection

X-rays are detected by routine area monitoring and by personnel dosimetry.

Preventive/Mitigating Features

The rf power systems are commercial equipment of the type that has been installed elsewhere for many years at accelerator facilities and such industrial plants as television stations. The klystrons are shielded. The glass vacuum switches are in interlocked enclosures by three separate safety systems. The tetrode modulator is contained with an aluminum deck and the deck is further enclosed by a steel equipment cabinet. ALS procedures cover all aspects of operation, testing, maintenance, and repairs. Physical barriers will prevent access.

Consequences

Exposure to ionizing radiation may cause severe injury, or severe occupational illness to personnel. From Table 4-4, the consequence level is judged to be medium.

Probability

Exposure to x-rays will require failure of interlocked enclosures, failure of x-ray monitors, and/or failure to follow administrative procedures. The probability of the hazard event is low, and, from Table 4-5, the Technical Safety Subcommittee assigned a probability level of low.

Risk

From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of low results in risk of low.

4.6 Conclusions

Operations activities planned for the ALS facility have been analyzed for ionizing-radiation hazard potential, and appropriate mitigation measures have been developed. The hazards analysis identified potentially hazardous conditions that could occur in the ALS during operations. Control measures were incorporated into the facility and systems design to mitigate most of the identified potential hazards. In other cases, administrative procedures were developed to ensure that facility operations could be conducted with a minimum of on-site and off-site consequences.

A risk analysis based on credible ionizing-radiation hazard events, performed using a bounding event/worst-case approach, showed that the ALS facility will be operated within the risk envelope for low-hazard facilities as defined in DOE O5480.25. Table 4-6 summarizes the risk analysis.

Table 4-6. ALS Ionizing Radiation Risk-Determination Summary

No.	Hazard Event	Probability Level	Consequence Level	Risk Level
1	Exposure to Ionizing Radiation at the Site Boundary	Extremely Low	Medium	Negligible
2	Exposure to Ionizing Radiation outside the Accelerator Enclosures	Low	Medium	Low
3	Exposure to Ionizing Radiation inside the Accelerator Enclosures	Low	Medium	Low
4	Exposure to Synchrotron Radiation	Low	Medium	Low
5	Exposure to Air Activation Products	Extremely Low	Medium	Negligible
6	Exposure to Ionizing Radiation from Sources Other than Accelerators	Low	Medium	Low

SECTION 5. SAFETY ANALYSIS—OTHER THAN IONIZING RADIATION

The ALS safety analysis was prepared in accordance with the guidance provided in DOE G 420.2-1, Accelerator Facility Safety Implementation Guide [2005]. A description of the methodology used in identifying hazards, analyzing credible accident scenarios, and assessing risks is presented in Section 5.1. The hazards are identified in Section 5.2, except for ionizing radiation hazards, which are discussed in Section 4. The sections following Section 5.2 contain safety analyses for the hazards. Conclusions and an assessment of the overall risk associated with ALS operations are discussed in Section 5.10.

5.1 Safety Analysis Methodology

The methodology used to perform the ALS safety analysis is shown in Figure 4-1. The hazards analysis process began with a review of proposed ALS commissioning, operations, and research activities. Information concerning operations and research at similar facilities at other laboratories was also reviewed. Using the information obtained, a hazard analysis of proposed ALS activities was prepared. Potential hazards associated with the use of energy sources, hazardous materials, and from natural phenomena were studied.

Credible hazards with potential on-site or off-site consequences were then analyzed to assess associated risk. The analyses were based on a bounding event approach, where the most severe of each particular category of credible accident was analyzed to obtain worst-case results. Each event analysis included determining the initiating occurrence, possible detection methods, the safety features that might have prevented or mitigated the event, the probability of the event occurring, and the possible consequences.

The consequence and probability estimates were reviewed by an independent EH&S Committee composed of subject matter experts from safety engineering, industrial hygiene and fire protection. The methodology used was consistent with guidance provided in DOE Order 5480.25, Guidance for an Accelerator Facility Safety Program [1993] as referenced in G420.2-1. The consequence levels are summarized in Table 4-4 and the probability levels are summarized in Table 4-5. The overall risk associated with each specific hazard, and then for the facility as a whole, was determined using these rating levels and the risk matrix (Figure 4-15).

The estimates were also evaluated against several criteria including: current criteria used by EH&S staff when developing Preliminary Hazard Assessments for facilities projects; ALS operating experience; and benchmarking against other, similar facilities within DOE.

5.2 Hazard Control Matrix

Credible hazards were identified in 19 categories, as summarized in the hazards control matrix below (Table 5-1), which correlates the hazard category with locations in the ALS facility where that hazard exists.

Table 5-1. Hazard Control Matrix

Hazard Type	Accelerator Area	Experimental Floor	Site Boundary
Room fire	1, 2, 3, 6, 8, 10, 11, 13, 15	1, 2, 3, 6, 8, 10, 11, 13, 15	16
Room fire with radioactive or toxic materials	1, 2, 3, 6, 8, 10, 11, 13, 15	1, 2, 3, 6, 8, 10, 11, 13, 15	11, 16
Equipment fire	1, 2, 3, 6, 8, 10, 11, 13, 15	1, 2, 3, 6, 8, 10, 11, 13, 15	NA
Uncontrolled chemical reactions	1, 5, 6, 8, 10, 11, 12, 13, 15	1, 5, 6, 8, 10, 11, 12, 13, 15	NA
Chemical exposure	1, 5, 6, 8, 10, 11, 12, 13, 15	1, 5, 6, 8, 10, 11, 12, 13, 15	NA
Cryogenic temperature exposure	5, 8, 10, 12, 13	5, 8, 10, 12, 13	NA
Compressed-gas explosion	1, 5, 6, 8, 10, 11, 12, 13, 15	1, 2, 5, 6, 8, 10, 11, 12, 13, 15	NA
Gas explosion (hydrogen, oxygen, acetylene)	5, 6, 8, 10, 12, 13, 15	5, 6, 8, 10, 12, 13, 15	NA
Inhalation, ingestion, or dermal exposure to toxic or carcinogenic material	5, 6, 8, 10, 12, 13, 15	5, 6, 8, 10, 12, 13, 15	11, 16, 17
Oxygen-deficient atmosphere	1, 11, 13, 15	1, 11, 13, 15	NA
Electrical shock	2, 3, 5, 7, 9, 10, 11, 13	2, 3, 5, 7, 9, 10, 11, 13	NA
High magnetic forces	3, 9, 11, 13, 14	3, 9, 11, 13, 14	NA
Nonionizing-radiation	2, 3, 5, 9, 10, 11, 13	2, 3, 5, 9, 10, 11, 13	NA
Laser-light energy transfer	NA	3, 5, 9, 10, 11, 12, 13	NA
Exposure to visible or near-UV light	NA	3, 5, 10, 13	NA
Ozone	3, 11, 13, 15	3, 11, 13, 15	NA
Earthquake	5, 13, 16	5, 13, 16	16

Table 5-1. Hazard Control Matrix (cont'd.)

Hazard Type	Accelerator Area	Experimental Floor	Site Boundary
Beamline vacuum vessel implosion or explosion	NA	5, 13	NA
Rotating machinery and falling objects	3, 5, 9, 13	3, 5, 9, 13	NA

Preventive and Mitigating Factors:
1. Alarm
2. Automatic Devices
3. Barriers/Isolation
4. Decontamination
5. Equipment Design/Aids
6. Fire Department
7. Insulation
8. Limited Quantities/Load
9. Lockouts/Interlocks
10. Manual Intervention
11. Monitoring
12. Personal Protective Equipment
13. Operational Procedures
14. Shielding
15. Ventilation
16. Emergency Plan
17. Dilution

NA Not Applicable

The following sections comprise the safety analyses for hazards other than ionizing-radiation, according to the methodology outlined in Section 5.1. Ionizing-radiation hazards are analyzed in Section 4.

5.3 Fire Safety

The ALS building was designed and contracted for under the 1985 editions of the Uniform Building Code [UBC, 1985] and the Life Safety Code [NFPA, 1985]. DOE Orders 5480.7, Fire Protection [DOE, 1987b], and 6430.1A, General Design Criteria [DOE, 1987a], were also enforced. Other observed guides and standards come from the Factory Mutual Engineering Corporation, Underwriters Laboratories, and the Office of the State Fire Marshal.

5.3.1 Building Construction

The ALS building is a two-story building with a total floor area of 116,000 gross square feet (gsf). The building consists of:

- The original one-story 184-Inch Cyclotron building (which will be referred to as the original building), a 24-sided, essentially circular structure about 163 feet in diameter with a domed roof 65 feet high at the apex. The original building floor area is 20,800 gsf.
- A two-story addition approximately concentric to the original building was added in 1989 to house the ALS. The addition has a flat roof 87 feet wide and 30 feet high. The total floor area of the ALS addition is 93,200 gsf, of which 60,200 gsf is on the first floor and 33,000 gsf is on the partial second floor.
- Two small expansions of the ground floor area were constructed in 2002 and 2003 which added another 2,000 gross square feet for a total building area of 116,100 gsf.

The allowable floor area for a Type II 1-Hour rated structure that is fully sprinkled, two stories and with separation on three sides is 111,600 gsf per the 2001 CBC. In a ruling memo dated September 9, 1996, the acting building official at LBNL (Facilities Department Head), authorized a waiver for an excess of 4,700 gsf over the 1985 Uniform Building Code mandated maximum area based on the following considerations:

(1) Close proximity (less than 100 yards) of building 6 to the LBNL Fire Department fire fighting apparatus at the building 48 Fire House.

(2) Direct alarm to the LBNL FD by the building 6 fire alarm system.

The current total area of building 6 is 4,500 gsf over the code mandated amount and is within the limits of the Building Officials allowable waiver.

The original building was completed in 1942. It received a substantial addition in 1961, which has since been removed as part of the ALS project. The original drum-shaped sides are about 49 feet high, thereby extending 19 feet above the new addition. The structural steel frame consists of columns and curved trusses that support the domed roof, which is sheathed with heavy-timber tongue-and-groove decking.

Modifications to the original building include the removal of all existing utilities, services, and combustible materials and replacement with systems and materials conforming to applicable codes. Light-wood framing, which formed the circumferential parapet was removed and replaced with steel framing. The heavy-timber roof decking that forms the dome remains. The magnet yoke also remains.

The new addition is constructed of structural steel with one-hour fireproofing. To maintain a seismic flexible separation, the building is not structurally attached to any adjacent buildings. The partial second floor, located completely within the new addition is separated from the first floor by one-hour fire-resistive construction. There is no separation at the first-floor level between the original building and the new addition.

The addition is built on new concrete footings, along with a heavy-duty concrete floor slab. The roof consists of ribbed metal decking on a steel frame, supported by steel beams and columns, and finished with a single-ply roof over rigid thermal insulation. Exterior walls are sheathed with vertically-ribbed, thermally insulated metal siding and cementitious panels extending from the concrete floor to the top of the parapet, to replicate and replace the corrugated transite panels of the original building. Roll-up doors are provided for vehicle access to the experimental areas and the support facilities. The floor contains no drains and is coated with an epoxy sealer, both features helping to prevent environmental contamination.

The structural steel support columns of the new addition were located so that the 30-ton bridge crane (with 5-ton auxiliary) that was in an annex of Building 6 could be reinstalled. The reinstalled bridge crane services the full circumference of the ALS storage ring. The linear accelerator and booster synchrotron are serviced by the original 30-ton polar crane operating in the domed area of the original building.

Building 80 immediately adjacent to the ALS has been modified only to the extent of window and door removals and their replacement with matching fire-rated wall materials where they are common with the new-addition walls. There is a seismic gap between the ALS and Building 80. Dedicated to support of ALS activities, it is included in this SAD. At the time of ALS construction, Building 10 was also immediately adjacent. This building was subsequently demolished in preparation of a new User Support Building.

The Building 6 area is surrounded on three sides by roadways and service-vehicle parking. Roadways around the site have been improved and some close-in parking has been provided.

5.3.2 Fire Protection Systems

Fire protection in the ALS is governed by applicable codes and standards, including chapter 12 of the LBNL Health and Safety Manual [Publication 3000, revised 9/98]. The LBNL Fire Department reviewed and approved the fire-protection systems for the ALS. Locations of fire-protection systems are specified in the ALS Pre-Fire Plan prepared by the Fire Department [Fire Department, 1992] and in the Building 6 Complex Emergency Plan [EH&S, 1992]. The Emergency Plan includes both the ALS building (Building 6) and Building 80.

Fire protection features include:

- LBNL Fire Department

  The Fire Department is located within 200 feet of the ALS building, is staffed continuously, normally by four paid career firefighters and should provide on-scene response within four minutes of any alarm Normal first-alarm response is with one pumper engine and one ladder truck. There is also a four-wheel drive brush patrol unit and a Hazardous Material Emergency Response vehicle available. Additional engine and ladder service and fire fighters are available on call from the Berkeley Fire Department and the Oakland Fire Department, Berkeley and Oakland border LBNL.

- Water supply for fire protection

  The fire hydrants, automatic sprinkler systems, and inside fire-hose stations in the ALS building are supplied by an 8-inch water-main loop around the building. Water is supplied by the LBNL site-wide, looped and gridded distribution system of mainly 8-inch and 12-inch mains. The 8-inch loop around the ALS building is fed at three points by the site-wide system.

  The public utility reservoirs that feed the site-wide system are supplemented by three widely separate on-site storage tanks, each of 200,000 gallons capacity. Two of these tanks supply two separate sets of automatic-starting diesel-engine-driven fire pumps.

  Flow tests show that the available water quantities and pressures are adequate for automatic sprinkler systems and inside hose stations. [Plant Engr, 1992, Appendix A-11].

- A wet-pipe, automatic fire-sprinkler system throughout the building

  All of the ALS facilities are protected by wet-pipe sprinkler systems meeting DOE standards and all related regulations. There are nine sprinkler zones, including the second-floor area,

accelerator tunnels, and underground cable vaults. The first zone covers the original building beneath the dome roof, which earlier had a pre-action dry system, and now has a wet sprinkler system providing Ordinary Hazard, Group 2 protection. The building addition with new structural steel protected to 1 hour is sprinklered throughout and consists of three zones each on the first floor and second floor, providing Ordinary Hazard, Group 3 protection. The accelerator tunnels are protected to the equivalent of Ordinary Hazard, Group 2. Experimental stations in the experimental hall are, and will continue to be, individually sprinklered.

The 12-kV electrical substation is located 25 feet from the ALS building. Pit and tunnel areas are protected with sprinklers to Ordinary Hazard, Group 2. This protection level exceeds Pacific Gas & Electric standards and meets Factory Mutual Engineering Corporation criteria for Improved Risk.

- Smoke detection systems

  An ionization-type smoke detector system is installed throughout the ALS building. The main floor comprises three smoke detection zones corresponding to the areas served by the three 50,000 cfm roof exhaust fans. Ionization-type detectors are also located in the shielding-tunnel exhaust-fan ducts and ventilation-system ducts. In addition, a fourth zone in the southwest sector with a 20,000 cfm dedicated smoke purge fan will utilize space-type ionization smoke detectors.

  - A seven zone highly sensitive smoke detection system (HSSD) has been provided for early fire warning for the experimental floor, storage ring and booster ring.
  - A smoke-purging system designed to actuate automatically upon detector activation.

  The smoke-purge system includes automatic and manual activation of the four major exhaust fans on the main floor. These fans will exhaust the affected area(s) and pressurize surrounding areas. There are separate smoke-control systems for the linac cave, the booster synchrotron, and the storage ring.

  Twelve barometric dampers, each 42 square feet in area, are installed around the base of the dome and rise above the roof of the new addition. These dampers open out with building positive pressure caused by fire and will assist in venting of smoke.

- Isolation of the second-floor HVAC system

  The HVAC system for the second floor is completely isolated from that of the main floor and automatic shutdown of second-floor supply air takes place if ionization-type smoke detectors in second-floor supply ducts activate.

- Audible local alarm systems in the entire building

  The alarms are activated from both suppression and detection systems. The nine sprinkler zones will be monitored by sprinkler water-flow detection and control valve supervisory switches throughout the building. There are 14 manual pull fire alarm stations at exit points on the main floor. Laboratory areas of the second floor (when completed) will be equipped with space-type smoke detectors.

  The alarm system will be fully addressable, allowing for documentation and rapid location of specific initiating devices. Zone alarm signals are transmitted directly to the LBNL Fire Dispatch Office located at LLNL, thus minimizing response time.

- Fire hydrants, fire hose and fire extinguishers

  Four fire hydrants on the south, east, west, and north sides of the ALS building are available. There is a sprinkler connection at the location of the south fire hydrant.

  Fire extinguishers are installed through the main floor of the building in accordance with NFPA Standard No. 10. Experimental stations in the experimental hall are similarly equipped. Fire extinguishers are also provided per NFPA on the second floor.

- Dry standpipes

  Three dry standpipes conforming to NFPA Standard No. 14 are provided with duplex connections on the main floor, the second floor, and on the roof with Fire Department hose connections at strategic locations outside the building to expedite fire attack. The system water is supplied by Fire Department pumpers from the site fire hydrants. Dry standpipes are located at the building lobby between sectors 12 and 13 (north side) and the roll-up doors between bays 3 and 4 (southeast corner) 19 and 20 (southwest corner) and to maximize their accessibility to nearby fire hydrants.

  Figures 5-1 and 5-2 show the locations of the fire-hose stations, fire extinguishers, dry standpipes and other emergency equipment in and around the ALS building.

5.3.3 UBC Building Occupancy Classification and Maximum Allowable Area

The UBC occupancy and construction-type designation for the ALS building is B-2 Occupancy and Type II one-hour construction. Determination of this designation was based on UBC provisions for historical buildings and on the requirements established by the University of California Board of Regents for preservation of internal and external architectural features of the original building [Plant Engr, 1992]. The mitigation measures incorporated to preserve the historical and architectural significance of the original building constitute legal requirements for design and construction of the ALS, thereby providing a firm basis for application of the UBC provisions for historic buildings. In particular, not fireproofing the structural steel members in the original building and retention of the heavy-timber roof decking in the dome of the original building were necessary to meet the requirements for preservation of the internal architectural features.

The building area is based on the designation of B-2, Type II one-hour and on credits for having (1) two stories, (2) fully sprinklered fire protection system, and (3) side-yard separations sufficient to permit an area increase of 1.6. Under these conditions, the allowable total area for the two-story ALS building is 115,200 square feet, as compared to the design area of 114,000 square feet, and the allowable area for any one floor is 86,400 square feet, as compared to the design area of 81,000 square feet. Two determinations made by the LBNL Building Official support this maximum allowable area:

(1) Determination of the construction type as one-hour even though the structural steel members in the original building are not fireproofed and the roof decking in the dome is heavy timber.

(2) Determination that the side-yard separation is 1.6 minimum.

Both determinations are based on meeting the <u>intent</u> of the code rather than its prescriptive requirements. The UBC gives the Building Official site authority to use intent as a basis for additions, alterations, or repairs of existing buildings without complying with all prescriptive provisions of the code, as long as the new work will not make the exiting building more hazardous than it was. In particular, Section 106 [UBC, 1988] permits the Building Official to modify the requirements of the code if strict application is impractical and the modifications are in conformance with the intent and purpose of the code.

The LBNL Plant Engineering Department has analyzed both determinations in the light of these considerations [Plant Engr., 1992]. The conclusions are that (a) the designation Type II one-hour constructions is reasonable and fulfills the intent of the code and (b) the ALS building has separations

equivalent to a rectangular building with side yards on three sides of at least 50 feet, providing an allowable area increase factor greater than 1.6.

The DOE Office of Assessment and Support has also reviewed these issues and concurs that fireproofing the structural steel in the original building is not required and that there is adequate side-yard separation to allow personnel egress and fire-department access [Maher, 1992].

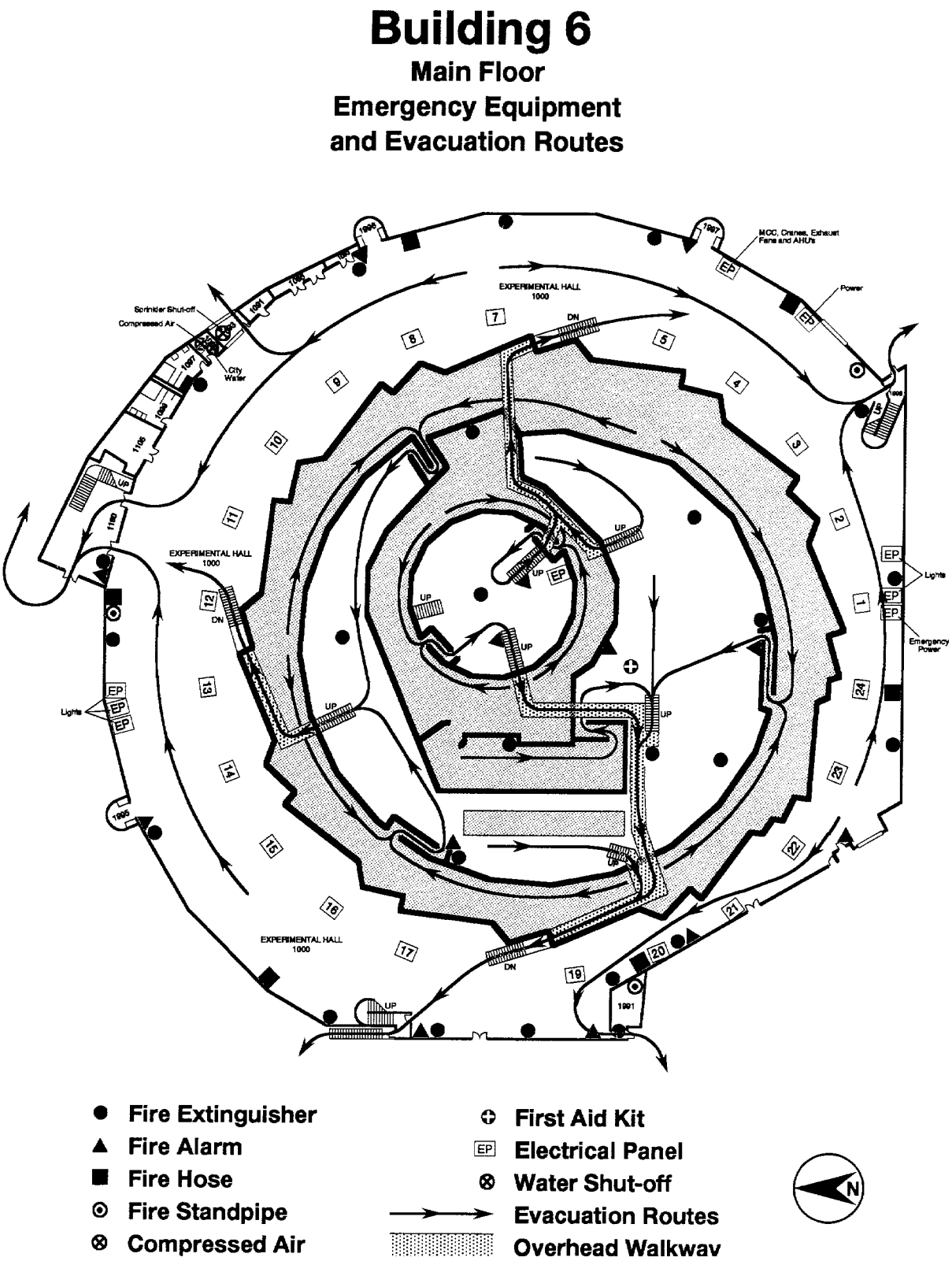


Figure 5-1. Location of emergency equipment and evacuation routes in the ALS building.

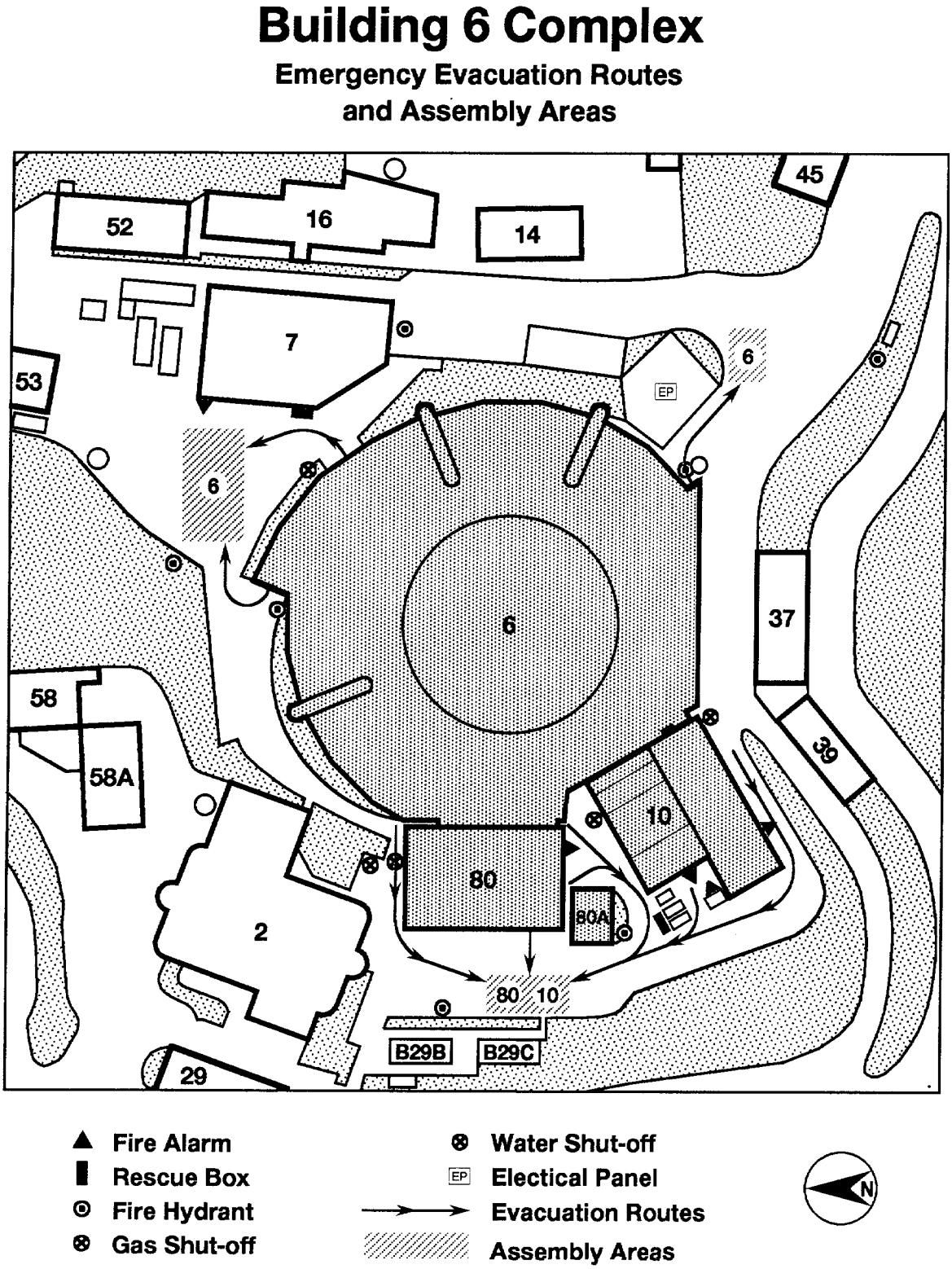


Figure 5-2. Location of emergency equipment, evacuation routes, and assembly areas in the ALS building area.

5.3.4 Life Safety Analysis

Life Safety requirements of the ALS building were based on NFPA Standard No. 101 Life Safety Code for an industrial facility primarily occupied by equipment with a relatively low density of people and low to ordinary hazard. A life safety code analysis has been carried out by the LBNL Plant Engineering Department [Plant Engr., 1992, Appendix A-1].

For purposes of the life safety analysis, the main floor of the ALS building comprises two areas. The first is the 40,000-square foot accelerator area, which extends from the center of the original building to the storage-ring outer shielding wall in the new addition. The second is the remainder of the new addition, which includes the beamline and experimental areas outside the storage-ring shielding. It should be noted that the smoke-removal system, which is provided in the ALS building to enhance life safety for occupant egress and fire-fighting capability, is not required for low-to-ordinary hazard special-purpose industrial occupancies to meet the exiting provisions of the Life Safety Code. There are also emergency lighting and emergency notification (PA) systems.

The accelerator area consists of the storage-ring tunnel, the north and south open areas bounded by the storage ring, the booster-ring tunnel, the linac cave, and the open area bounded by the booster ring.

When the accelerator is in operation, access to the area bounded by the booster ring is controlled. On rare occasions, a small group not to exceed 10 persons will be in this area for a guided tour. The probable maximum occupant load will not exceed 30 persons at any time.

Exiting arrangements are shown in Figure 5-1. There are at least two exits provided from each area except the linac cave, which has only one approved means of egress.

The exiting passageways are 36-inch wide areas bounded by stripes painted on the floor. Directional arrows are also painted on the floor within the striped paths. There is also signage indicating the direction to the nearest exit at intersections where more than one direction of travel are available. The directional arrows on the floor and the nearest exit directional signage are in addition to the exit signage as required by the Life Safety Code.

Two sets of stairs are provided for access to the roof of the booster-ring tunnel and the storage-ring tunnel from each open area. Three sets of stairs are provided from the roof of the storage-ring tunnel to the experimental hall for exiting the building. All stairs are 36 inches wide. Two of the stairs are fire-

escape stairs and are located inside the open spaces bounded by the storage-ring tunnel, one in the north open space and one in the south open space. Each of these open spaces has another stair as the primary means of egress.

In the experimental hall, it is anticipated that usage and equipment arrangement will vary greatly over the years. An occupant load factor of 100 square feet per person was used in the life safety code analysis. The probable maximum occupant load is 410 persons.

Total occupant load for the main floor is 440 persons maximum (410 in the experimental hall and 30 in the accelerator area.

The area of the ALS second floor is over 34,000 square feet. The usage is primarily offices for visiting researchers, light laboratories, two mechanical rooms, and a boiler room. For the life safety code analysis, an occupant load factor of 100 square feet per person is used, giving a calculated occupant load of 340 persons. Three enclosed stairwells are provided and located at least 192 feet apart.

Table 5-2 shows the exiting requirements and the actual conditions for the main floor [Plant Engr., 1992]. The maximum travel distance from any point on the main floor to an exit is 400 feet, in conformance with the Life Safety Code. The floor exiting arrangement conforms to the Life Safety Code with two exceptions:

- The linac cave has one approved exit, thereby creating a common path of travel of 120 feet. The life safety code analysis concludes that, considering the low hazard level and the fire-protection features in the cave, the 120-foot maximum common path of travel will not jeopardize the life-safety aspects of the building.
- The fire-escape stairs are located in areas congested with equipment and building structural components. The life safety code analysis concludes that, based on the maximum occupant load of 30, use of the fire-escape stairs provides adequate exiting and does not pose a life-safety hazard to the occupants.

Table 5-2. Life Safety Code Analysis of the ALS Building.

MAIN FLOOR		
Occupancy Classification	Special Purpose Industrial	
Hazard	Ordinary	
Accelerator Area	.	
Area	40,000 sq. ft	
Occupant Load Factor	Maximum Probable Employees and Occasional Guests	
Occupant Load		
Inside Storage-Ring Tunnel	Total of 30 Persons Maximum in All Five Areas	
Open Area within Storage Ring		
Inside Booster Tunnel		
Open Area within Booster Ring		
Inside Linac Cave		
Number of Exits Required/Provided		
Inside Storage-Ring Tunnel	2/2	
Open Area within Storage Ring	2/3	
Inside Booster Tunnel	2/2	
Open Area within Booster Ring	2/2	
Inside Linac Cave	2/1	**See Justification**
Exit Width		
Inside Storage-Ring Tunnel	2 @ 36 Inches Each	
Open Area within Storage Ring	2 @ 36 Inches Each	
Inside Booster Tunnel	2 @ 36 Inches Each	
Open Area within Booster Ring	2 @ 36 Inches Each	
Inside Linac Cave	2 @ 36 Inches Each	
Allowable Exit Travel Distance to Exterior or Horizontal Exit in Sprinklered Building	400 Feet Maximum	
Actual Exit Travel Distance		
Inside Storage-Ring Tunnel		
From Point I to Exit E	392 Feet	
From Point I to Exit C	400 Feet	
From Point II to Exit E	394 Feet	
From Point II to Exit C	362 Feet	
Open Area within Storage Ring/Southern Sector		
From Point III to Exit E	299 Feet	
From Point III to Exit B	251 Feet	
Open Area within Storage Ring/Northern Sector		
From Point IV to Exit E	218 Feet	
From Point IV to Exit C	204 Feet	
Inside Booster Tunnel		
From Point VI to Exit E	398 Feet	
From Point VI to Exit B	393 Feet	
Open Area with Booster Ring		
From Point VII to Exit B	337 Feet	
From Point VII to Exit E	325 Feet	
Inside Linac Cave		
From Point V to Exit E via Linac	312 Feet	
Common Path of Travel	120 Feet > 50 Feet Allowed	**See Justification**
Existing Dead End Pocket	120 Feet > 50 Feet Allowed	**See Justification**

Table 5-2. Life Safety Code Analysis of the ALS Building (cont'd.)

Experimental Hall	
Area	43,00 Square Feet
Occupant Load Factor	100 Square Feet per Person
Occupant Load	30AAccelerator Area & 430 in Experimental Hall
Number of Required Exits	2 for Occupant Load of 460 (430+30)
Number of Exits Provided	5
Exit Width Required	92 Inches (0.2 Inches X46
Exit Width Provided	252 Inches with 36-Inch Minimum Width
Travel Distance Allowed	400 Feet
Travel Distance Provided	374 Feet Maximum (Booster Ring to Sector 4 exit)
Exit Separation Required	142 Feet (Half the Diagonal Distance)
Exit Separation Provided	192 Feet Minimum
SECOND FLOOR	
Occupancy Classification	Business
Hazard	Ordinary
Area	33,000 Square Feet
Occupant Load Factor	100 Square Feet per Person
Occupant Load	330 Persons
Number of Required Exits	2 for Occupant Load of 330
Number of Exits Provided	3
Exit Width Required (Level Components)	66 Inches (0.2 Inches X 330)))
Exit Width Provided (Level Components)	144 Inches with Three at 36 Inches Minimum Width
Exit Width Required (Stairs)	99 Inches (0.3 Inches X330) =
Exit Width Provided (Stairs	144 Inches with Three at 48 Inches Wide Each
Travel Distance Allowed	400 Feet
Travel Distance Provided	270 Feet Maximum
Exit Separation Required	142 Feet (Half the Diagonal Distance)
Exit Separation Provided	192 Feet Minimum

5.3.5 Fire Loss Potential

The initial value of the completed ALS facility at the beginning of operations in 1993 was approximately $80 million (1990 dollars). The value has increased as more beamlines and experimental stations are added. After twelve years of operation, the value well exceeds $120 million (1990 dollars). The maximum possible property loss in the event of a fire on the main floor is estimated to be in excess of $75 million [Plant Engr., 1992, Appendix A-11]. The main floor comprises an open area of some 84,000 square feet.

DOE Order 5480.7 Fire Protection states that when the maximum possible property loss exceeds $50 million, redundant fire-protection systems are to be provided and that, to limit the maximum

property loss to $75 million, a failure-proof fire-protection system, such as blank walls or physical separation, is to be provided.

To meet the literal requirements of DOE Order 5480.7 would require the installation of four-hour fire-separation walls, thereby subdividing the ALS building into isolated zones. However, installation of such walls is not practical. The areas interior to the storage ring must remain open to accommodate the use of the polar crane in the original building and the bridge crane in the new addition. In addition, fire walls could not be built around or through shielding tunnels. To build around a shielding wall would severely compromise the integrity of the fire wall, while to build through a tunnel would disable the accelerator. These areas alone contain equipment with a replacement value in excess of $60 million.

The only area on the main floor subject to subdivision by fire walls would be the area of the experimental hall directly below the second floor. This area could be subdivided by free-standing four-hour fire walls. The fire walls would be required to extend from floor to parapet, three feet above the roof. Installation of such fire walls could reduce the maximum possible loss to less than $75 million. Such a subdivision would not protect the full length of the synchrotron-radiation beamlines, and each beamline would have to penetrate a fire wall, compromising fire-wall integrity. Fire walls would also make installation, operation, and servicing of beamlines difficult and costly and would introduce substantial emergency egress difficulties.

Because four-hour firewall separations are not feasible, a waiver of the $75 million fire-loss requirement was requested to allow the construction of the ALS facility with the open configuration described in Section 5.3.1. The waiver request was also based in part on the many fire-protection features described in Section 5.3.2, such as redundant water reservoirs, conservative wet-sprinkler system design, smoke detection and alarm systems, standpipes, additional fire-hose stations, and fire department location within 200 feet of the ALS building. The DOE has approved the waiver request [Ziemer, 1990].

5.3.6 Description of Fire Hazard

The primary fire hazard is in the original building because of the heavy-timber roof deck in the dome and the unfireproofed structural steel members. However, even in this area, the fuel loading is minimal. Dry-type transformers and electrical panels are located next to the unprotected steel columns. In addition, UL-listed power and control cables with low flame-spread characteristic jackets are laid in trays that are attached to the columns and control panels. All of these will burn only if constant ignition

and heat sources are available. If not, they will not sustain burning, owing to the limited quantity of combustible contents in the equipment and components.

The potential fuel sources for fire are (1) the two 100-gallon-capacity transformers located outside the booster ring, (2) the five-gallon-capacity oil-filled transformer located next to two of the steel columns, and (3) wooden pallets for equipment delivery.

The oil used in the 100-gallon-capacity transformers has a flash point of 148°C. The operating characteristic of this transformer dissipates 1250 watts, which is very low in comparison to typical transformers of 30 kilowatts and above. Each transformer is installed over a drip pan that has a containment capacity of approximately 20 gallons with a 1-inch gravity drain line for transporting any leakage into a 120-gallon-capacity steel tank located in a below-grade trench. The fire hazard potential of these units is very low since the unit will shut down automatically if there is a loss of six gallons or more, and the spill will be confined to the drip pan and the below-grade holding tank.

The 5-gallon-capacity transformers pose very little threat to the steel columns [Plant Engr., 1992, Appendix A-2]. In the event of a transformer rupture (assuming the liquid spilled over an area approximately 6 feet in diameter with a liquid depth of 1/4 inch), the total heat release will be approximately 630,000 Btu in two minutes. Considering the present location of the transformer, it is unlikely that a liquid spill would completely surround the column on all sides. The amount of heat absorbed is only a fraction of the total heat released by the fire. Neither the heat release nor the duration is near the limit that can raise the temperature of the steel to its critical point. The available fuel load would be spent before the temperature of the column could rise to a damaging level.

It is possible for equipment to be delivered with wood pallets or crating inside the area surrounded by the storage ring. The chance of having any of the pallets located next to the unprotected steel columns is remote. Through administrative control, the storage of pallets in this area can be eliminated with all pallets being removed once the equipment is off-loaded.

The most serious fire hazard in the experimental area, which is fully fireproofed and sprinklered, is likely to come from flammable liquids and gases brought by ALS users. Due to the extreme variability of experiments, it is not possible to list specific materials. Very strict administrative controls are in place to limit the quantities of flammable materials at the beamlines. Each experiment undergoes a thorough evaluation and specific chemicals and quantities are a part of this evaluation. A list of current flammable (and toxic) gases at the beamlines is maintained in the Control Room to assure that the total

quantity is far below allowable limits. Because of the limited quantities of these materials, the fire potential is low. Further discussion of hazardous materials is found in Section 5.4.

5.3.7 Exposure Fire Potential

Exposure is the potential for heat to be transmitted from one building to another, with radiation as the primary means of heat transfer. Uniform Building Code provisions are based on the assumption that the owner can have no control over the type of construction and fuel loading that exists on adjacent property nor over what activities occur there. Consequently, the locations of buildings must be regulated relative to their distance from adjacent buildings and property lines. This concept provides a convenient and prescriptive means of protecting one building from another, insofar as fire exposure is concerned.

The space between the periphery of the ALS building and other nearby buildings provides protections against exposure by thermal radiation. The building has no significant exposure from other buildings less than 50 feet away over approximately 85% of its circumference. Buildings 80, which is included in this 85%, abuts the ALS building, is separated by two-hour fire-resistive construction. Building 7, which is separated from the ALS building by approximately 20 feet, occupies 11% of the circumference. Building 7 was scheduled for removal in FY 1993. When Building 7 is removed, there will be no significant fire exposure to the ALS building from other buildings less than 50 feet away over 96% of its circumference. Only the switch-gear house remains. Operational plans for fire fighting include considerations for the temporary existence of Building 7.

5.3.8 Administrative Controls

A host of administrative controls are described elsewhere in this SAD, primarily in Section 4, that bear on fire safety. Adherence to Chapter 12 Fire Safety of the LBNL Health and Safety Manual is strictly required. Operational Procedures govern beamline activities. There will be a companion set of AHDs and other formal authorizations. ALS procedures for the experimental areas, as needed. The ALS Beamline Review Committee and Experiment Safety Sheet processes assure that all beamlines are constructed and all experiments are conducted only after rigorous safety analysis according to detailed procedures. Fire-safety training, inspections, and drills are conducted. A fire evacuation plan is included in the LBNL Emergency Plan that defines escape routes and personnel responsibilities and actions and annual drills are conducted.

5.3.9 Fire Safety Analysis Summary

(1) Hazard Event: Room Fire

Initiating Occurrence

A room fire could be initiated by ignition of combustible materials (such as solvent, machining oils, flammable liquids, and flammable gases) resulting from welding operations, equipment failure, improper equipment maintenance, personnel failure, and earthquakes.

Method of Detection

Fire is detected by means of smoke detectors and personnel observation. Activation of smoke detectors and sprinkler flow automatically trigger an audible alarm. Personnel can trigger manual alarms.

Preventive/Mitigating Features

Building construction is according to standards contained in the 1985 Uniform Building Code and is designed according to standards of the 1985 Life Safety Code. Electrical installation is according to standards in the National Electric Code [NFPA, 1990]. There is an automatic, wet-pipe sprinkler system. There are three standpipes, six hose cabinets, and 25 fire extinguishers throughout the building. There is an automatic HSSD smoke purge system. Flammable liquids and gases and reactive chemicals, if any, will be stored in UL and/or FMEC approved metal fire-resistant storage cabinets. Samples of flammable liquids will be limited according to the 1988 Uniform Fire Code. There will be gas detection devices in areas containing flammable gases. The ALS fire alarm system is directly connected to the LBNL Fire Dispatcher, and the fire station is located less than 200 feet from the ALS building. The automatic alarm is backed up by telephone communication. There is a fire evacuation plan and annual drills. Administrative controls include ALS Procedures, formal authorizations such as Radiological Work Authorizations (RWAs), Activity Hazard Documents (AHDs), adherence to Chapter 12 Fire Safety of the LBNL Health and Safety Manual (PUB 3000), mandatory safety analysis of all experiments, employee and visitor training, and no smoking in the ALS building. Medical treatment is available at LBNL.

Consequences

Possible consequences of a room fire include loss of the affected area, smoke and water damage to the building and equipment, shutdown of operations, and injury to personnel from smoke inhalation and burns. From Table 4-4, the consequence level is judged to be low.

Probability

From the discussion in Section 5.3.7, the fire load in the ALS building is minimal. From Table 4-5, the EH&S Review Committee assigned a probability level of low.

Risk

From the risk matrix in Figure 4-15, a consequence level of low and a probability level of low results in a risk of negligible.

(2) Hazard Event: Room Fire Involving Radioactive or Hazardous Materials

Initiating Occurrence

A room fire could be initiated by ignition of combustible materials (such as solvent, machining oils, flammable liquids, and flammable gases) resulting from equipment failure, improper equipment maintenance, personnel failure, and earthquakes.

Method of Detection

Fire is detected by means of smoke detectors and personnel observation. Activation of smoke detectors and sprinkler flow automatically trigger an audible alarm. Personnel can trigger manual alarms.

Preventive/Mitigating Features

Building construction is according to standards contained in the 1985 Uniform Building Code and is designed according to standards of the 1985 Life Safety Code. Electrical installation is according to standards in the 1990 National Electric Code. There is an automatic, wet-pipe sprinkler system. There are three standpipes, six hose cabinets, and 25 fire extinguishers throughout the building. There is an automatic smoke control system. Flammable liquids and gases, toxic materials, and radioactive materials, if any, will be stored in UL and/or FMEC approved metal fire-resistant storage cabinets.

Samples of flammable liquids and gases and toxic materials will be limited according to the 1988 Uniform Fire Code. There will be gas detection devices in areas containing flammable gases. The LBNL alarm system is directly connected to the Fire Dispatcher and the fire station is located less than 200 feet from the ALS building. The automatic alarm is backed up by telephone communication. There is a fire evacuation plan and annual drills. Administrative controls include formal authorizations, LSPs, ALS Operational Procedures, adherence to Chapter 12 Fire Safety of the LBNL Health and Safety Manual, mandatory safety analysis of all experiments, employee and visitor training, and no smoking in the ALS building. Medical treatment is available at LBNL.

Consequences

Possible consequences of a room fire involving radioactive or toxic materials include loss of the affected area, smoke and water damage to the building and equipment, shutdown of operations, release of radioactive or toxic materials and injury to personnel from smoke inhalation, inhalation of toxic or radioactive materials, and burns. From Table 4-4, the consequence level is judged to be medium.

Probability

Administrative controls on the storage and use of radioactive or toxic materials and strict adherence to limits on quantities make significant releases of material unlikely (see Section 5.4). From Table 4-5, the EH&S Review Committee assigned a probability level of low.

Risk

From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of low results in a risk of low.

(3) Hazard Event: Equipment Fire

Initiating Occurrence

An equipment fire could be initiated by an electrical short, component failure, operator error, or improper maintenance.

Method of Detection

Fire is detected by means of smoke detectors and personnel observation. Activation of smoke detectors and sprinkler flow automatically trigger an audible alarm. Personnel can trigger manual alarms.

Preventive/Mitigating Features

Building design is according to standards contained in the 1985 Life Safety Code. Electrical installation is according to standards in the 1990 National Electric Code. There is an automatic, wet-pipe sprinkler system. There are three standpipes, six hose cabinets, and 25 fire extinguishers throughout the building. There is an automatic smoke control system. The LBNL alarm system is directly connected to the Fire Dispatcher and fire station is located less than 200 feet from the ALS building. The automatic alarm is backed up by telephone communication. There is a fire evacuation plan and annual drills. Administrative controls include formal authorizations, ALS Operational Procedures, adherence to Chapter 12 Fire Safety of the LBNL Health and Safety Manual, mandatory safety analysis of all experiments, employee and visitor training, and no smoking in the ALS building. Medical treatment is available at LBNL.

Consequences

Possible consequences of an electrical fire include loss of the affected equipment, water damage to the building, shutdown of operations, and injury to personnel from smoke inhalation and burns. From Table 4-4, the consequence level is judged to be low.

Probability

Generally, the history of electrical fires at LBNL has demonstrated that the probability of electrical fires is small. The EH&S Review Committee noted that ALS recently experienced two small fires (2005 and 2006) due to failure of the facility lighting fixtures. This is being mitigated by a replacement project, currently in the engineering design/feasibility phase. From Table 4-5, the Committee assigned a probability level of medium.

Risk

From the risk matrix in Figure 4-15, a consequence level of low and a probability level of medium results in a risk of low.

5.4 Hazardous Materials

The ALS has been designed and will be operated as a Group B, Division 2 facility pursuant to the 1985 Uniform Building Code. The Group B occupancy designation permits the handling of limited quantities of hazardous materials consistent with the facility design. Hazardous materials are classified according to the guidelines in Title 29 of the Code of Federal Regulations [OSHA, 1988]. DOE Order 3790.1A Federal Employee Occupational Safety and Health Program [DOE, 1984] is also applicable. Administrative procedures developed limit the quantity of hazardous materials in use at the ALS to those permitted by provisions of the current California Building Code for Group B occupancy. Hazardous material safety requirements included in the code will be incorporated where appropriate. Operations involving hazardous materials in excess of the allowable limits will not be authorized.

Facility maintenance and user research activities may involve the preparation, storage, transport, and handling of hazardous, toxic, carcinogenic, biologically active, and radioactive materials. These operations will follow federal and LBNL standards, building and fire codes, and procedures, as described above. An updated inventory of hazardous materials will be maintained by the ALS EH&S Group. Equipment using hazardous materials will be reviewed as part of the experimental approval process described in Sections 3.5 and 6.4.4 and, if appropriate, beamline review process described in Section 6.3.4. All equipment will be inspected on arrival at the ALS by appropriate subject matter experts coordinated by the ES&H Program for compliance with applicable EH&S regulations. All ALS users are required to provide on the Experimental Form a list of materials involved in their experiment for review by the ALS EH&S Group before approval for their experiments will be given. All hazardous equipment and materials will be reviewed by the ALS EH&S Group to determine if an AHD or other formal authorization is required, in accordance with the requirements given in Chapter 6 of the LBNL Health and Safety Manual. If required, an AHD will be prepared as described in Appendix D.

5.4.1 Hazardous Materials Quantities

The California Building Code sets limits for a control zone in a Group B, Division2 occupancy building. The ALS building will be one control zone. Establishing additional control zones within the ALS building would require construction of enclosures with one-hour fire walls, appropriate exits, and other steps, which are not now anticipated. Examples of materials and their maximum quantities allowed in one control zone for B-2 occupancy include:

combustible liquid	120 gallons
flammable liquid	15 gallons
flammable gas	750 cubic feet (STP).

The aggregate quantities can be doubled for a sprinklered building, such as the ALS building. The aggregate quantities can be doubled again if specified storage procedures are followed. The maximum quantities allowed in the ALS building then become:

combustible liquid	480 gallons
flammable liquid	60 gallons (250 liters)
flammable gas	3000 cubic feet (STP).

These are relatively large quantities, which are easy to avoid exceeding in ALS operations. In addition, it is likely that the largest quantities of chemicals will be stored and/or used in laboratories and work areas outside of the ALS building. Volumes of hazardous materials will not exceed applicable building and fire code limits, and required venting and containment systems will be provided.

5.4.2 Hazardous Materials Control

An Operational Procedure has been developed to control handling of hazardous materials by users in the ALS building. All chemicals and potentially flammable, explosive, and other hazardous materials will be listed by users on the Experiment Safety Sheet (ESS). As a part of the ESS authorization, guidance will be provided for the receipt, storage, use, and disposal of hazardous materials.

Records of all hazardous materials will be maintained in the LBNL chemical inventory system. Records to be maintained include arrival data, quantity, and location of each hazardous material. Chemicals will be stored in the special storage areas created in the ALS under the supervision of the Head of the Experiment Setup Coordination Section. Smaller quantities will be allowed onto the ALS floor. Table 5-3 lists categories of hazardous materials, with examples typical of a materials science laboratory for research on semiconductors, catalysts and superconductors and shows the quantities permitted per control area for B-2 occupancy.

Table 5-3. Categories of Hazardous Materials.

Category and Examples	Threshold Limit Value for Chemical Substances in the Work Environment [ACGIH, 1988-89]	1988 UBC/UFC B-2 Exempt Aggregate Quantity per Control Area
TOXIC GAS		1300 ft^3 in vented enclosure
Boron trifluoride	1 ppm	
Hydrogen chloride	5 ppm	
HIGHLY TOXIC GAS		40 ft^3 in vented enclosure
Arsenic pentafluroide	not listed	
Arsine	0.05 ppm	
Diborane	0.1 ppm	
Germane	0.2 ppm	
Nitric oxide	25 ppm	
Phosphine	0.3 ppm	
Phosphorous pentafluoride	0.1 ppm	
FLAMMABLE GAS		1500 ft^3
Acetylene	not listed	
Arsenic pentafluoride	not listed	
Arsine	0.05 ppm	
Carbon monoxide	50 ppm	
Diborane	0.1 ppm	
Ethylene	not listed	
Germane	0.2 ppm	
Hydrogen	not listed	
Methane	not listed	
Phosphine	0.3 ppm	
FLAMMABLE GAS, LIQUEFIED		30 gallons
Propane	not listed	
PYROPHORIC GAS		20 ft^3
Phosphine	0.3 ppm	
Diborane	0.1 ppm	
Silane (5% hydrogen)	5 ppm	
OXIDIZING GAS		3000 ft^3
Oxygen	not listed	
PYROPHORIC LIQUID		2 pounds
Trimethylaluminum	not listed	
Trimethylgallium	not listed	
OXIDIZING LIQUID		20 gallons
Hydrogen peroxide	1 ppm	

Table 5-3. Categories of Hazardous Materials (cont.).

Category and Examples	Threshold Limit Value for Chemical Substances in the Work Environment [ACGIH, 1988-89]	1988 UBC/UFC B-2 Exempt Aggregate Quantity per Control Area
CORROSIVE LIQUID		200 gallons
Acetic acid	10 ppm	
Ammonium hydroxide	not listed	
Bromine	0.1 ppm	
Formic acid	5 ppm	
Hydrochloric acid	5 ppm	
Hydrofluoric acid	3 ppm	
Nitric acid	2 ppm	
Potassium hydroxide	2 mg/m^3	
Sodium hydroxide	2 mg/m^3	
Sulfuric acid	1 mg/m^3	
FLAMMABLE LIQUID		20 gallons
Acetone	750 ppm	
Ether (ethyl)	400 ppm	
Ethyl alcohol	1000 ppm	
Hexane (isomers)	500 ppm	
Isopropyl alcohol	400 ppm	
Methyl alcohol	200 ppm	
Methyl ethyl ketone	200 ppm	
TOXIC LIQUID		200 gallons
Carbon tetrachloride	5 ppm	
Trichloroethane (1,1,2)	10 ppm	
HIGHLY TOXIC LIQUID		2 pounds
Bromine trifluoride		
TOXIC SOLID		2000 pounds
Arsenic	10 μg/m^3	
Barium carbonate	0.5 ml/m^3	
Barium hydroxide		
Barium oxide	0.5 mg/m^3	
Beryllium	2 μg/m^3	
Gallium arsenide	not listed	
Mercury	0.05 mg/m^3	
Phosphorous oxide	not listed	
Selenium	0.2 mg/m^3	
Thallium	not listed	
OTHER SOLID		
Chromic acid	0.05 mg/m^3	
Lithium fluoride	not listed	
Lithium hydroxide	0.025 mg/m^3	

The Head of the Experiment Setup Coordination Section will be responsible for ensuring that the quantities do not exceed the building limits described in the Section 5.4.1.

Users will be informed about the safe handling, storage, ventilation, and disposal through, EH&S training, the Experiment Safety Sheets and specific procedure training, if necessary. The ES&H Program Manager is responsible for (i) developing emergency plans, where needed in addition to the procedures specified in the Building 6 Complex Emergency Plan; (ii) ensuring that potential personnel and environmental exposures are analyzed; and (iii) recommending appropriate control measures.

5.4.3 Handling Gases

Dedicated gas cabinets are provided for health hazard gases. Gas cylinders for toxic gases reside in gas cabinets at all times, except during the exchange (loading and unloading process). The gas is fed from the gas cabinet directly to the equipment. Con Ops procedures are maintained to ensure proper operation, maintenance, and use of these cabinets.

The gas cabinets have brackets to restrain the gas cylinders and valves that can be operated from outside the cabinet. A vent duct connects the gas cabinets to the ALS building exhaust blowers for hazardous gases.

Hazardous gas cylinders are handled according to LBNL hazardous gas receiving, storage, and transportation procedures in accordance with the LBNL Chemical Hygiene and Safety Plan.

5.4.4 Toxic Gases

To determine the level of risk involved in the handling of highly toxic gases, reference was made to a dispersion-modeling and risk-assessment study that was conducted on the use of arsine [Dames & Moore, 1990]. This gas was chosen for analysis because it has the highest toxicity rating of gases that could conceivably be used in the ALS building. Arsine gas is a potent toxic agent that produces fulminating hemolysis with subsequent renal failure following acute high-dose exposure. Human-exposure data and studies in laboratory rats and mice have shown a very steep dose-response relationship, which results in a very sharp threshold between tolerated and toxic does of arsine. A human health criteria of 1 ± 0.5 ppm is an appropriate extrapolation of the toxicological database for arsine.

Results for several accidental release scenarios were modeled to estimate potential impacts to nearby individuals for a release of arsine from a laboratory roof vent and release of arsine during handling of a compressed gas cylinder outdoors next to the laboratory. The study found that, depending on the prevailing wind direction at the time of a release, airborne concentrations above the estimated no-effect level in humans may occur on the premises of LBNL. However, in any case, because of its narrow width and limited areal extent, potential exposures are likely to be transient. Adverse effects that potentially could be associated with a plume on the LBNL premises should not produce significant observable symptoms. It is unlikely that exposure at these levels will result in significant or irreversible adverse effects in potentially exposed individuals on or off the LBNL site.

The effects of an accidental arsine leak caused by a single-point failure (gas-line rupture) in a laboratory room have also been calculated [Buerer, 1990]. Several assumptions were made: (1) gas cylinders are stored in gas cabinets resulting in a maximum length for any single gas line of 50 feet and an OD. of 0.25 inch; (2) single-point failure consists of a section of the stainless steel gas line rupturing or breaking ; (3) the toxic gas monitor senses arsine in the room at the Threshold Limit Value of 0.05 ppm and immediately shuts off the cylinder and isolates the leak to the longest length of tubing; (4) the room exhaust ventilation continues to function at its design rate, thereby causing the air in the room to mix; and (5) the arsine pressure in the gas line is regulated to 5 psi (the maximum that researchers would require). The resulting concentration of arsine gas in the room following such a failure was found to be below one-half the Immediately Dangerous to Life or Health (IDLH) level of 6 ppm. The IDLH level is that concentration determined by NIOSH that would not cause escape-impairing symptoms or irreversible health effects for a 30-minute exposure

5.4.5 Administrative Controls

A host of administrative controls are described elsewhere in this SAD, primarily in Section 4, that bear on hazardous materials safety. Adherence to PUB 3000, the LBNL Health and Safety Manual is strictly required. The LBNL Chemical Hygiene and Safety Plan governs all operations involving hazardous chemicals and provides a framework for a comprehensive chemical hygiene program. Guidelines for Generators of Hazardous Chemical Waste at LBNL and Guidelines for Generators of Radioactive and Mixed Waste at LBNL {LBNL, 1991b] govern handling and disposal of hazardous wastes. ALS Procedures provides that no beamline will be constructed nor will any experiment be approved without a rigorous safety analysis according to detailed procedures, as described in Sections 6.3.4 and 6.4.4. The ALS User Plan also provides for a hazardous-material control program, as outlined

in Section 5.4.2. Safety training is required for all staff and visiting scientists, as described in Sections 3.5.6 and 6.5.1.

5.4.6 Hazardous Materials Safety Analysis Summary

(1) Hazard Event: Uncontrolled Chemical Reaction

Initiating Occurrence

Uncontrolled chemical reactions can occur when incompatible chemicals are mixed as a result of personnel error, improper maintenance, or earthquakes.

Method of Detection

Uncontrolled chemical reactions are detected by means of gas detectors, smoke detectors, and observation by personnel.

Preventive/Mitigating Features

When not in use for experiments, flammable liquids and gases and reactive chemicals will be stored in UL and/or FMEC approved metal fire-resistant storage cabinets. Samples of flammable liquids will be limited according to the 1988 Uniform Fire Code. Use of chemicals will be limited to ventilated fume hoods. Incompatible chemicals will be segregated. Shelving is seismically restrained. There is an automatic, wet-pipe sprinkler system. There are three standpipes, six hose cabinets, and 25 fire extinguishers throughout the building. There is an automatic smoke control system. The ALS alarm system is directly connected to the LBNL Fire Department, which is located less than 200 feet from the ALS building. The automatic alarm is backed up by telephone communication. Administrative controls include formal authorizations such as AHDs, ALS Operational Procedures, adherence to the LBNL Chemical Hygiene and Safety and the LBNL Health and Safety Manual. EH&S analysis of all experiments, employee and visitor training, and no smoking in the ALS building. Design reviews of piping, exhaust, and alarm systems for beamlines are mandatory. Medical treatment is available at LBNL.

Consequences

Arsine is the most toxic chemical expected at the ALS. Release scenarios show no significant or irreversible adverse effects to individuals on or off the LBNL site. In addition, owing to the limited quantities of the less toxic materials in use at the ALS, uncontrolled chemical reactions would not result in a significant injury or occupational illness, nor would the have a significant impact on the environment. From Table 4-4, the consequence level is judged to be low.

Probability

Segregation of chemicals and adherence to administrative procedures make the probability of an uncontrolled chemical reaction low. From Table 4-5, the EH&S Review Committee assigned a probability level of low.

Risk

From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of low results in a risk of low.

(2) Hazard Event: Chemical Exposure

Initiating Occurrence

Exposure to chemicals can occur when toxic material, acids, or caustic materials are spilled as a result of personnel error or earthquake.

Method of Detection

Exposure is detected by the affected personnel.

Preventive/Mitigating Features

When not in use for experiments, flammable liquids and reactive chemicals are stored in UL and/or FMEC approved metal fire-resistant storage cabinets. Samples of flammable liquids are limited according to the 2001 California Fire Code. Use of chemicals is limited to ventilated fume hoods. Incompatible chemicals are segregated. Shelving is seismically restrained. The ALS is provided with an automatic fire sprinkler system that operates based on heat and a Highly Sensitive Smoke Detection

system in high risk areas. These systems provide for early detection of fires and are monitored by LBNL's fire alarm system. The system is monitored by the Dispatch Office that is responsible for dispatching LBNL's Fire Department located at Station 19. This fire station is located less than 200 feet from the ALS building. The automatic alarm is backed up by telephone communication. Administrative controls include AHDs and ALS Operational Procedures, adherence to the LBNL Chemical Hygiene and Safety Plan, mandatory EH&S analysis of all experiments, employee and visitor training, and no smoking in the ALS building. Design reviews of piping, exhaust, and alarm systems for beamlines are mandatory. Medical treatment is available at LBNL.

Consequences

The consequence of exposure to chemicals is personnel injury, including inhalation of toxic material. From Table 4-4, the consequence level is judged to be low.

Probability

Proper storage of chemicals, use of ventilated fume hoods, and adherence to administrative procedures reduce the probability of a chemical exposure, but the routine use of chemicals causes the probability to remain medium. From Table 4-5, the Technical Safety Subcommittee assigned a probability level of medium.

Risk

From the risk matrix in Figure 4-15, a consequence level of low and a probability level of medium results in a risk of low.

(3) Hazard Event: Exposure to Cryogenic Temperature

Initiating Occurrence

Exposure to cryogenic temperature can occur as a result of cryogenic fluid leakage or personnel error.

Method of Detection

Exposure is detected by the personnel affected.

Preventive/Mitigating Features

Cryogenic systems are designed according to ASME pressure-vessel codes [ASME, 1986]. Piping is designed according to applicable codes. Administrative controls include AHDs and ALS Operational Procedure, adherence to the LBNL Health and Safety Manual, mandatory EH&S analysis of all experiments, and employee and visitor training. Design reviews of piping, exhaust, and alarm systems for beamlines are mandatory. Medical treatment is available at LBNL.

Consequences

The consequence of exposure to cryogenic temperature is injury to the affected personnel. From Table 4-4, the consequence level is judged to be low.

Probability

Proper design of cryogenic systems and adherence to administrative procedures reduce the probability of exposure to cryogenic temperature, but the routine use of cryogens causes the probability to remain medium. From Table 4-5, the Technical Safety Subcommittee assigned a probability level of medium.

Risk

From the risk matrix in Figure 4-15, a consequence level of low and a probability level of medium results in a risk of low.

(4) Hazard Event: Pressurized Gas Explosion

Initiating Occurrence

Compressed gas explosion can occur as a result of damage to gas cylinders, valves, or gas lines due to personnel error or earthquake.

Method of Detection

Detection of a compressed gas explosion is by observation of personnel in the area.

Preventive/Mitigating Features

When not in use for experiments, gases will be stored in UL and/or FMEC approved metal fire-resistant storage cabinets. Gas cylinders are designed to ASME pressure-vessel codes. Pressure regulators and relief valves are installed on gas lines. Confinement of an explosion is provided by walls of the building. The ALS is provided with an automatic fire sprinkler system that operates based on heat and a Highly Sensitive Smoke Detection system in high risk areas. These systems provide for early detection of fires and are monitored by LBNL's fire alarm system. The system is monitored by the Dispatch Office that is responsible for dispatching LBNL's Fire Department located at Station 19. The fire station is located less than 200 feet from the ALS building. The automatic alarm is backed up by telephone communication. Administrative controls include AHDs, LSPs, ALS Operational Procedures, adherence to Chapter 13 Gases, Flammable and/or Compressed of the LBNL Health and Safety Manual, mandatory EH&S analysis of all experiments, employee and visitor training, and no smoking in the ALS building. Design reviews of piping, exhaust, and alarm systems for beamlines are mandatory. Medical treatment is available at LBNL.

Consequences

Consequences of a compressed gas explosion include injury to personnel, damage to equipment, and shutdown of operations. From Table 4-4, the consequence level is judged to be medium.

Probability

Proper storage of compressed gases, properly designed gas cylinders, and adherence to administrative procedures reduce the probability of compressed-gas explosions to low. From Table 4-5, the Technical Safety Subcommittee assigned a probability level of low.

Risk

From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of low results in a risk of low.

(5) Hazard Event: Gas Explosion (Hydrogen, Oxygen, Acetylene)

Initiating Occurrence

A gas explosion involving hydrogen, oxygen, or acetylene can occur as a result of damage to gas cylinders or leakage in gas lines, from operator error, or from an electrical spark.

Method of Detection

A gas explosion is detected by personnel in the affected area.

Preventive/Mitigating Features

When not in use for experiments, flammable gases will be stored in UL and/or FMEC approved metal fire-resistant storage cabinets. Gas systems will exhaust to the atmosphere. There is an automatic, wet-pipe sprinkler system. There are three standpipes, six hose cabinets, and 25 fire extinguishers throughout the building The ALS is provided with an automatic fire sprinkler system that operates based on heat and a Highly Sensitive Smoke Detection system in high risk areas. These systems provide for early detection of fires and are monitored by LBNL's fire alarm system. The system is monitored by the Dispatch Office that is responsible for dispatching LBNL's Fire Department located at Station 19. The fire station is located less than 200 feet from the ALS building. The automatic alarm is backed up by telephone communication. Administrative controls include AHDs, LSPs, ALS Operational Procedures, adherence to Chapter 13 Gases, Flammable and/or Compressed of the LBNL Health and Safety Manual, mandatory EH&S analysis of all experiments, employee and visitor training, and no smoking in the ALS building. Design reviews of piping, exhaust, and alarm systems for beamlines are mandatory. Medical treatment is available at LBNL.

Consequences

An explosion can cause a fire, damage to equipment, injury to personnel, and shutdown of operations. From Table 4-4, the consequence level is judged to be medium.

Probability

Proper storage of flammable gases in fire-resistant cabinets, the use of atmospheric exhausts on gas systems, and adherence to administrative procedures reduce the probability of a gas explosion involving hydrogen, oxygen, or acetylene to low. From Table 4-5, the Technical Safety Subcommittee assigned a probability level of low.

Risk

From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of low results in risk of low.

(6) Hazard Event: Inhalation, Ingestion, or Dermal Exposure to Toxic or Carcinogenic Material

Initiating Occurrence

Inhalation, ingestion, or dermal exposure to toxic or carcinogenic material can occur as a result of personnel error, including improper material handling.

Method of Detection

Inhalation, ingestion, or exposure is detected by the affected personnel and by bioassay.

Preventive/Mitigating Features

When not in use for experiments, toxic or carcinogenic chemicals will be stored in UL and/or FMEC approved metal fire-resistant storage cabinets. Samples of chemicals will be limited according to the 2001 California Fire Code. Use of chemicals will be limited to ventilated fume hoods or other ventilated structures that are designed to applicable codes. There are emergency showers. The ALS is provided with an automatic fire sprinkler system that operates based on heat and a Highly Sensitive Smoke Detection system in high risk areas. These systems provide for early detection of fires and are monitored by LBNL's fire alarm system. The system is monitored by the Dispatch Office that is responsible for dispatching LBNL's Fire Department located at Station 19. The fire station is located less than 200 feet from the ALS building. The automatic alarm is backed up by telephone communication. Administrative controls include ALS Operational Procedures, adherence to the LBNL Chemical Hygiene and Safety Plan, mandatory EH&S analysis of all experiments, and employee and visitor training. Protective clothing and self-contained breathing apparatus are available. Medical treatment is available at LBNL.

Consequences

The consequence of inhalation, ingestion, or dermal exposure to toxic, or carcinogenic material is personnel injury. From Table 4-4, the consequence level is judged to be medium.

Probability

Proper storage of toxic or carcinogenic materials in fire-resistant cabinets, the use of limited quantities of materials, the use of ventilated systems, and adherence to administrative procedures significantly reduces the probability of inhalation, ingestion, or dermal exposure to toxic, or carcinogenic material. From Table 4-5, the Technical Safety Subcommittee assigned a probability level of low, which is comparable to that of the chemical exposure scenario above.

Risk

From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of low results in a risk of low.

(7) Hazard Event: Oxygen-Deficient Atmosphere

Initiating Occurrence

Oxygen-deficient atmospheres can be generated in enclosed spaces, such as the accelerator tunnel, by a significant spill of liquid nitrogen. For example, a rapid release of a full 160-liter liquid nitrogen dewar in an accelerator cave during liquid-nitrogen boil-off used to bring portions of the vacuum system to atmospheric pressure for installation, modifications, maintenance, and repairs. Hardware and operator error are potential causes of such events.

Method of Detection

Detectable by highly visible vapor cloud.

Preventive/Mitigating Features

Nitrogen dewars are only inside accelerator caves while in use; exhaust blowers and/or air-conditioning systems are continuously running in these areas.

Consequences

The consequence of oxygen deficiency is personnel injury due to asphyxiation. From Table 4-4, the consequence level is judged to be medium.

Probability

Forced-air ventilation, the limited supply of nitrogen, and obvious warnings signs of a large spill reduce the probability of exposure to an oxygen deficiency atmosphere to extremely low. From Table 4-5, the EH&S Review Committee assigned a probability level of low.

Risk

From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of low results in a risk of low.

5.5 Electrical Safety

5.5.1 Electrical Safety Systems

Electrical protection is achieved by scrupulous adherence to applicable standards, codes, and directives governing design, operation, and maintenance of electrical equipment, including the National Electric Code (NFPA 70), the Standard for Electrical Safety in the Workplace (NFPA 70E), and the National Electrical Safety Code (NESC). All installation and maintenance of electrical equipment is checked by LBNL Technical Services supervisory personnel or ALS electronic-maintenance-shop personnel. In addition, all installations and operations must be in accordance with the latest edition of Chapter 8 Electrical Safety of the LBNL Health and Safety Manual PUB 3000, which defines responsibilities of personnel, principles of implementation of safety procedures, requirements for design and construction of equipment, means of accident prevention, and Chapter 18 Lockout/Tagout & Verification, which details lockout/tagout (LOTO) procedures. Cabinet doors to high-voltage equipment are interlocked to turn off circuits when doors are opened. Enclosures with equipment of more than 600 volts are marked in accordance with National Electric Code "Danger High Voltage Keep Out." Enclosures containing equipment with less than 600 volts will have appropriate warning.. Stored-energy devices, such as capacitors, will have automatic discharging devices. Grounding and bonding of electrical equipment cabinets, electromechanical devices, including magnet iron, and girder support assemblies are in accordance with the National Electric Code. Special equipment is reviewed by the LBNL Electrical Safety Subcommittee for operational safety. Interlocks for electrical equipment are tested as described in Section 6.5.2 and as specified in ALS Operations Procedure EC 02-02 ALS Radiation Interlock System Testing Procedure. Bypassing equipment interlocks not associated with the personnel safety system is governed by EE 01-01 Equipment Interlock Bypass Procedure.

5.5.2 Electrical System Operations

Activities will involve operation and maintenance of power supplies, RF equipment, high-field magnets, vacuum apparatus, and scientific instrumentation.

Injection System

The electrical power to operate the ALS is distributed to most of the equipment at 480 V AC, 3 phase, with a grounded WYE system. Other power equipment and control equipment is operated from a 120/208 volt system. The installation of this distribution equipment is according to standard industrial practice for equipment of this type and conforms to applicable codes. All sources of exposed voltages above 50 volts are isolated by covers and enclosures. Access to all voltages above 50 volts rms is by means of screw-on panels, each of which contains no less than four screws or bolts, or by means of interlocked, hinged doors or covers. The frames and chasses of all electrical enclosures or cabinets are connected to rated electrical grounds with a conductor capable of handling any potential fault current. Automatic-discharge devices are used on equipment with stored energy of 10 joules or more. Suitable manual grounding devices that are readily visible are provided to short to ground all dangerous equipment while work is being performed.

Cabinets housing high-voltage equipment in the linac vault and the booster-synchrotron area are the gun modulator, the klystron modulator, and the booster RF-system power supplies and associated equipment. All entry doors to these cabinets are electrically interlocked so that the high voltage is turned off when the door is opened. In addition, grounding sticks are provided within these high-voltage areas. High pulsed voltages are also present in the fast-kicker power-supply enclosures that provide the power for the injection and extraction kickers, the septa, and the bend magnets of the booster. Removal of the access panels to this equipment automatically interrupts the high-voltage power supply to that unit.

The magnet power supplies necessary for booster operation are located inside the booster area. When beam is being injected into the booster, this becomes an exclusion area and access is controlled.

Storage Ring

The general EH&S requirements detailed for the injection system also apply to the storage ring. Hazards peculiar to the storage ring are as follows. The magnet power supplies and RF power equipment necessary for storage-ring operation are situated inside the ring area. When beam is being injected into the

storage ring, this becomes an exclusion area and access is controlled. However, both the magnet power supplies and the RF power equipment may be operated without beam while this inner area is occupied by ALS personnel. The power supplies for the linac-to-booster transfer line are automatically turned off, thereby shutting down the electron beam whenever the area inside the storage ring tunnel is entered. As with the injection-system hardware, the individual cabinets of high-voltage equipment are all interlocked so that the power is turned off automatically when the door is opened. In addition, the high-current dipole, quadrupole, and sextupole magnet bus systems are covered or protected by lexan barriers.

Beamlines

The general EH&S requirements detailed for the injection system also apply to the beamlines. Electronics racks and cable trays will conform to applicable codes.

5.5.3 Lockout/Tagout Procedures

All lockout/tagout procedures are done in accordance with CFR 1910.147 and with Chapter 8 Electrical Safety of the LBNL Safety and Health Manual (PUB3000) and Chapter 18 Lockout/Tagout & Verification which describes the lockout and tagout procedures used to secure mechanical and electrical systems for the purposes of performing work on them. This procedure mandates strict conformance when it is necessary to work on systems that may contain stored energy. This procedure covers the servicing, maintenance, and modification of machines and equipment in which the unexpected energizing, start-up, or release of stored energy in the machines or equipment could cause injury to an employee or damage to the machine or equipment. Specific LOTO instructions applicable to the ALS are contained in ALS 09-01 Electrical Logout/Tagout (LOTO) Supplemental Procedure for the ALS

PUB 3000 Chapter 18 further provides that LOTO of machines and equipment shall only be performed by authorized employees. Typically, LOTO authorization is assigned to the cognizant project or lead engineer, mechanical designer, electronic coordinator, plant maintenance technician, mechanical technician, electronic technician, plant electrician, or construction and maintenance technician. Written procedures must be approved by line management and included in the ALS Procedures.

5.5.4 Non-Ionizing Radiation Safety

ALS Procedure RF01-01, RF Authorized Persons List and Training Documentation outline the people who have the authorization to make or approve changes in the high power RF systems.

Additionally, this procedure describes the supervisor's responsibility to identify the hazards and to provide training to the employees whom are designated to work on these RF systems. ALS Procedure RF02-01, Injector S-Band Modulator Startup and Shutdown, describes how to operate the high power 2997.9 MHz Linac RF systems. ALS Procedures RF02-63 and RF02-64, Startup of the Booster High Power RF Amplifier and Shutdown of the Booster High Power RF Amplifier, respectively describe how to operate the high power 499.65 MHz Booster RF systems. ALS Procedure RF02-73 and RF02-74, Startup of the SR High Power RF Amplifier and Shutdown of the SR High Power RF Amplifier, respectively describe how to operate the high power 499.65 MHz SR RF systems.

Injection System

The Rf systems for the sub-harmonic bunchers (24kW peak) operate at frequencies of 124.91 MHz and 499.65 MHz and at an average power of <10W. All high power Rf is contained in coax cable and buncher cavities. The RF system for the Linac uses two high-power (25 MW peak) klystrons operating at a frequency of 2997.9 MHz and an average power level of < 250W each. All high-power RF is contained within the interlocked vacuum waveguide or accelerator cavities and poses no health hazard since high power RF operation is inhibited without high vacuum. The RF system for the Booster synchrotron (15 kW peak) operates at a frequency of 499.65 MHz and an average power of 10.9 kW. All high power RF is contained in the transmission system and accelerating cavity. The RF power amplifiers and transmission line systems were manufactured to a specification [ANSI] which required that RF leakage level, for near field exposure from the source, from these units be below 1 mW/cm^2, 5 mW/cm^2 and 1.67 mW/cm^2 for 124.91 MHZ, 2997.9 MHz and 499.65 MHZ respectively. Leakage measurements are made by an EH&S radiation safety technician or by a member from the RF Group after every transmission system modification or disassemble/reassemble process to ensure continued conformance with the specification.

Magnetic fields of the order of 1 kG developed by large electromagnets are used for focusing the electron beam in the klystrons. Exclusion zones have been constructed around accessible areas and signs warning of this hazard are posted near the magnets.

Storage Ring

The RF system for the storage ring (300 kW max) operates at a frequency of 499.65 MHz and at an average power level of 214 kW. The power from the klystron is divided equally between two RF cavities by a "Magic Tee" in a power-dividing system with standard transmission line components. Each

flange joint in the transmission-line system is a potential source for non-ionizing radiation. All high power RF is contained in the transmission system and accelerating cavities. The RF power amplifier and transmission line systems were manufactured to a specification [ANSI], which required that RF leakage levels, for near field exposure from the source, from these units be below 1.67 mW/cm^2 for 499.65 MHz. Leakage measurements are made by the EH&S radiation safety technician or by a member from the RF Group after every transmission system modification or disassemble/reassemble process in order to ensure continued conformance with the specification. During operation, RF power levels are interlocked at strategic points in the transmission line to ensure proper operation and RF power levels are computer monitored for access by operations staff.

5.5.5 Electrical Safety Analysis Summary

(1) Hazard Event: Electrical Shock

Initiating Occurrence

Electrical shock can occur as the result of an electrical short-circuit, improper maintenance of equipment, interlock failure on high-voltage equipment, or failure to follow lockout-tagout procedures.

Method of Detection

The primary means of detection is observation by personnel in the affected area. Loss of electrical power may also occur.

Preventive/Mitigating Features

Installation of equipment is according to National Electric Code standards. All hazardous power supplies are enclosed in grounded enclosures. Equipment fed by high-voltage power supplies, above 5 kV, are fully enclosed. High-voltage equipment is interlocked. Interlocks are fail-safe, redundant, and testable. Provision is made for grounding wands. Circuit breakers have lockout tabs. Equipment has current-limiting circuits. Administrative controls include, AHDs, ALS Operational Procedures, adherence to Chapter 8 Electrical Safety of PUB 3000 , the LBNL Health and Safety Manual, mandatory EH&S analysis of all experiments, and employee and visitor training. Enclosures may only be opened when two authorized persons are present and published procedures must be followed. Interlock bypass operations must follow prescribed procedures. Warning signs are posted. Medical treatment is available at LBNL.

Consequences

The consequences of electrical shock include injury to personnel and damage to equipment. From Table 4-4, the consequence level is judged to be medium.

Probability

The use of interlocks and grounding and adherence to the National Electric Code and ALS administrative procedures reduces the probability of electrical shock to low. From Table 4-5, the Technical Safety Subcommittee assigned a probability level of low.

Risk

From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of low results in a risk of low.

(2) Hazard Event: Exposure to non-ionizing radiation

Initiating Occurrence

High-power RF systems associated with the accelerator pose a burn hazard through exposure to non-ionizing radiation. Exposure can occur as a result of equipment or interlock failure, operator error, or leaky transmission line joints and interfaces.

Method of Detection

Non-ionizing radiation is detected by means of area monitoring with hand-held radiation detectors and by visual inspection of transmission systems looking for damaged or burnt flanges and connectors.

Preventive/Mitigating Features

All hazardous power supplies are enclosed in grounded transmission lines of types coax and waveguide. Accelerating cavities fed by high power RF amplifiers are fully enclosed, evacuated chambers and access, which is interlocked to the high power RF, is controlled by electrical interlocked and electro-magnetically locked tunnel access gates (with the exception of the sub-harmonic bunchers and Booster RF cavity). The gates are controlled by operations staff during operational periods. The sub harmonic amplifier and transmission line components are visually inspected as part of its periodic

maintenance. The Linac high-power RF is contained within the interlocked vacuum waveguide or accelerator cavities and poses no health hazard since high power RF operation is inhibited without high vacuum. In this system, a vacuum leak would correspond to an RF leak and poor vacuum inhibits high power RF operation. The Booster RF amplifier and transmission line components are visually inspected as part of its periodic maintenance. The Storage Ring RF amplifier and transmission line components are protected by arc detectors, so any ambient light that leaks into the wave guide will trip off the high power RF. In this system a light leak would correspond to an RF leak. Additionally, the RF amplifier and transmission line components are visually inspected as part of their periodic maintenance. All interlocks are fail-safe and testable. Leakage measurements are made after every transmission system modification or disassemble/reassemble process in order to ensure RF tightness and its safety integrity

Consequences

The consequence of exposure to non-ionizing radiation is injury to personnel. From Table 4-4, the consequence level is judged to be medium.

Probability

For an individual to be exposed to non-ionizing radiation one or more events would have to occur: failure of the Personnel Safety System Controlled Access interlock system (failure of the interlock system would include an interlock bypass), transmission line equipment failure, leaky transmission line joint or interface, or operator error. During our greater than 10 years of operational experience we have only experienced occurrences of leaky transmission line joints which resulted in very low RF fields. The occurrences were discovered by a required survey with a hand-held detector while the system was operated at very low power after a transmission line disassemble/reassemble process. Based on this experience it is judged that the probability of having one or more events as outline above is low. From Table 4-5, the Technical Safety Subcommittee assigned a probability level of extremely low.

Risk

From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of extremely low results in a risk of negligible.

(3) Hazard Event: Exposure to High Magnetic Forces

Initiating Occurrence

Strong pulsed and DC magnetic fields may be created near the accelerator and transport magnets. The continuous magnetic fields near the beam-transport magnets can locally exceed 5 Gauss. Exposure to high magnetic forces of the order of 1 T can also occur during fabrication, testing, maintenance, or installation activities on permanent-magnet insertion devices.

Method of Detection

High magnetic forces are detected by observation of personnel in the affected area.

Preventive/Mitigating Features

During normal operation, magnetic fields are generated within the accelerator enclosures and are not accessible by personnel. During commissioning and periods of testing, signs are posted warning of the magnetic-field hazard, including a specific warning concerning pacemakers. Access to high-field magnets that are operated for testing while personnel are present are posted with signs and lights during testing. Access to insertion devices during fabrication and testing is restricted by physical barriers, enclosures, and signs. Assembly equipment is semi-automated. Non-magnetic tools are used. Small quantities of magnetic material are handled.

Consequences

Consequences to exposure to high-magnetic forces include injury to personnel and damage to magnetic material and/or equipment. Steady-state magnet-field intensities above approximately 30 Gauss may affect cardiac pacemakers and metallic implants. From Table 4-4, the consequence level is judged to be low.

Probability

Blocking access to equipment generating high magnetic fields by accelerator enclosures during operation and warning lights and signs during testing reduce the probability of exposure to high magnetic forces to medium. From Table 4-5, the EH&S Review Committee assigned a probability level of medium.

Risk

From the risk matrix in Figure 4-15, a consequence level of low and a probability level of medium results in a risk of low.

5.6 Laser Safety

Guidance for the safe use of lasers and laser systems is provided by Chapter 16 Laser Safety of the LBNL Health and Safety Manual. It, in turn, is derived from Standard for the Safe Use of Lasers [ANSI, 136.1].

5.6.1. Laser Safety Officer

The Laser Safety Officer of the LBNL Environment, Health and Safety Division will review the initial use of lasers with researchers at the facility. The following is a partial list of responsibilities of the Laser Safety Officer:

- Reviews and approves all laser AHDs at new facilities and modifications at existing facilities that change the laser safety-control parameters.
- Provides consulting services for laser users and for EH&S and training programs.
- Conducts a required safety class for all Class 3b and Class 4 laser and laser-system users.
- Maintains the necessary records required by applicable government regulations.
- Accompanies DOE inspectors and documents any discrepancies noted; ensures that corrective action is taken where required.
- Aids in investigating any known or suspected accident resulting from a laser operation.
- Has the authority to suspend, restrict, or terminate the operation of a laser or laser system if the laser-hazard controls are considered inadequate.

5.6.2. Laser Classification and Control

The ANSI standard establishes a hazard classification scheme based on the ability of the laser beam to cause biological damage to the eye or skin. This scheme is used to place each laser into one of four classes; each laser must meet the EH&S requirements specified for its class.

Lasers or laser systems certified for a specific class by a manufacturer in accordance with the Federal Laser Product Performance Standard may be considered as fulfilling all classification requirements of this regulation. In cases where the laser or laser-system classification is not provided, or where the class level may change because of a change from the use intended by the manufacturer or because of the addition or deletion of engineering control measures, the laser or laser system shall be classified by the Laser Safety Officer.

Control measures will be applied after the laser has been properly classified. Control measures are divided into two categories:

- Engineering (protective housings, area posting, beam stops, control areas, interlocks, beam path, etc.)
- Administrative procedures (AHDs, training, eye protection, alignment procedures, etc.)

AHDs are required for all Class-3b and Class-4 laser systems. Engineering measures are almost always the preferred method for controlling access to laser radiation.

As proposals for experiments are received and before laser operation is permitted, appropriate control measures, including physical barriers, protective equipment, warning devices, and administrative procedures, will be in place for all laser and laser-system installations at the ALS, along with employee and researcher orientation and training concerning laser hazards and control and applicable EH&S standards.

5.6.3 Laser Safety Analysis Summary

(1) Hazard Event: Laser Light Energy Transfer

<u>Initiating Occurrence</u>

Exposure to laser light can occur as a result of laser-beam misalignment, laser-beam scattering, laser-beam reflection, operator error, or interlock failure,

<u>Method of Detection</u>

Exposure to laser light is detected by means of its effect on personnel in the affected area.

Preventive/Mitigating Features

Protection (protective housings, interlocks, beam stops, eye protection, protective clothing, and warning devices) appropriate to classification of laser under laser-safety classification code is provided. Administrative controls include AHDs and ALS Operational Procedures, adherence to Chapter 16 Laser Safety of the LBNL Health and Safety Manual, and employee training. Warning signs are posted. Medical treatment is available at LBNL.

Consequences

The consequence of exposure to laser light can be severe injury to personnel. From Table 4-4, the consequence level is judged to be medium.

Probability

Protective devices and adherence to administrative procedures reduce the probability of exposure to laser light to low. From Table 4-5, the EH&S Review Committee assigned a probability level of low.

Risk

From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of low results in a risk of medium

5.7 Visible and Near-UV Light

Visible and near-UV light is produced by synchrotron-radiation sources, particularly bend magnets and wigglers, which generate a broad, continuous spectrum of radiation that extends to long wavelengths. Long-period undulators operating at high K values may also produce near-UV light. The optical properties of visible and near-UV light, such as the reflectivity from surfaces and transmission through windows, differ from those of x-ray and VUV radiation.

5.7.1 Visible and Near-UV Light Safety Analysis Summary

(1) Hazard Event: Exposure to Visible and Near UV Light

Initiating Occurrence

Visible light or near-UV that is produced by synchrotron-radiation sources could be transported by the beamline optical system to a window or viewport where exposure could damage an observer's vision.

Method of Detection

Exposure to visible and near-UV light is detected by observation by of personnel in the affected area.

Preventive/Mitigating Features

Viewports and windows through which visible or near-UV could be transmitted will be covered by an opaque cover with a warning of the hazard. Administrative controls include review by the Beamline Review Committee, an ALS Operational Procedure that describes the process for removing the cover, and employee training. Verification that the cover is in place is included in the operations checklist for the beamline. Medical treatment is available at LBNL.

Consequences

The consequence of exposure to visible or near-UV light can be minor to severe injury to personnel. From Table 4-4, the consequence level is judged to be low.

Probability

Protective devices and adherence to administrative procedures reduce the probability of exposure to visible or near-UV light to low. From Table 4-5, the EH&S Review Committee assigned a probability level of low.

Risk

From the risk matrix in Figure 4-15, a consequence level of low and a probability level of low results in risk of negligible.

5.8 Environmental Safety

5.8.1 Ozone Production

Ozone is produced when short-wavelength x-rays pass through air. This is potentially a problem in those ALS experimental areas in which x-rays exit the beamline through a thin beryllium or other type window and enter the atmosphere. Forced exhaust systems control this potential hazard. For a beamline where high-intensity x-ray beams are allowed to pass through the atmosphere, a calculation of the ozone level will reviewed by the ALS Beamline Review Committee.

Ozone is also produced in the accelerator enclosures by ionization of atmospheric components by the photoelectric shower produced when energetic electrons are lost to the vacuum chamber wall. The dominant reactions are:

$$O_2 + h\nu \rightarrow O_2^*$$
$$O_2^* + O_2 \rightarrow O_3 + O$$
$$NO_2 + h\nu \rightarrow NO + O$$
$$O_2 + O + (M) \rightarrow O_3 + (M).$$

Under the conditions pertaining at the ALS (and confirmed by experience at similar facilities), the maximum production rate occurs where the maximum power is lost from the beam. In the ALS, maximum production occurs when all of the linac beam is stopped in a region where the electromagnetic shower emerges into the atmosphere, for example at the beam collimator immediately after the first bend magnet. This situation has been reviewed by the LBNL EH&S Division [McCaslin, 1990c]. It was assumed that all the radiation yield from the interruption of 5 W (average power) of beam at 50 MeV is absorbed in the air, rather than in surrounding support structures. With the additional assumption of no decomposition or ventilation, it is calculated that the permissible exposure limit (or PEL) of 0.1 ppm [OSHA, 1989] is reached in about 37 minutes. When normal ventilation (3000 cu. ft./ min) and ozone recombination [George, 1965] are taken into account, the steady-state concentration is calculated to be one-tenth of PEL. In practice, Ozone has not been a problem in the ALS Accelerator enclosures.

5.8.2 Ozone Safety Analysis Summary

(1) Hazard Event: Ozone Exposure

Initiating Occurrence

Ozone is produced during normal operation of the linac, the booster, and the storage ring from high-voltage corona and from the passage of short-wavelength x-rays through the air.

Method of Detection

Ozone is detected by sensing equipment and by observation of personnel in the affected area.

Preventive/Mitigating Features

The linac, booster, and storage-ring tunnels are ventilated to reduce the concentration of ozone. The electron-gun enclosure has a closed-circuit air-conditioning system to dehumidify the air to reduce corona. The door to the enclosure is opened for 10 minutes to allow adequate venting before entry. The ozone odor is noticeable. Open air paths for x-rays will be minimized in the photon beamlines.

Consequences

The consequence of ozone exposure is personnel injury. From Table 4-4, the consequence level is judged to be low.

Probability

Forced-air ventilation and administrative procedures reduce the probability of exposure to ozone to low. From Table 4-5, the EH&S Review Committee assigned a probability level of low.

Risk

From the risk matrix in Figure 4-15, a consequence level of low and a probability level of low results in a risk of negligible.

5.9 Seismic Safety and Emergency Preparedness

5.9.1 Seismic Safety

Seismic safety is designed into the ALS technical components through the application of standard LBNL design criteria or approved criteria for special structures. The seismic design criteria and installation procedures are documented in Chapter 23 Seismic Safety of the LBNL Health and Safety Manual. The intent of the design criteria is to result in structures that can resist, without collapse, earthquakes of Richter magnitude 7.0 on the Hayward fault and 8.3 on the San Andreas Fault. Seismic safety is designed into components by means of static or dynamic analyses. Design criteria for the accelerator support components were developed from DOE and LBNL guidelines, were reviewed by the LBNL Seismic Safety Subcommittee, and are consistent with DOE Order 6430.1A. Other references include Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards [UCRL, 1989], Strong Seismic Ground Motion for Design Purposes at the Lawrence Berkeley National Laboratory [Bolt, 1979], Fundamentals of Earthquake Engineering [Newmark and Rosenbluth, 1971], and Seismic Analyses of Structures and Equipment for Nuclear Power Plants [Bechtel, 1974].

Dynamic analysis was performed on the accelerator support components, which were engineered to be in compliance with the design criteria. All accelerator concrete shielding structures were engineered to be in compliance with the seismic design criteria and were reviewed by a qualified consulting engineer retained for this purpose by LBNL.

The building has been designed to meet structural criteria required by the 1988 Uniform Building Code and to meet the July 1, 1985 LBNL Lateral Force (Wind and Earthquake) Design Criteria. The LBNL criteria for lateral loads are wind: 20 psf and earthquake: base shear equal to 0.2 W, where W = total dead load of structure plus equipment weight, as specified in Chapter 23 of the LBNL Health and Safety Manual.

In FY2004, the University of California performed a comprehensive seismic reevaluation of all Berkeley Lab's buildings under the LBNL Facility Division's Seismic Evaluation and Hazard Communication Plan. The purpose of this reevaluation was to assure that the original designations were still valid in light of new information gained from the actual experience of buildings in major earthquakes, and to develop funding prioritization for mitigation. The result of this for the ALS was

that the annex portion of Building 6, the experimental hall, was still rated ‘good’, but the original domed part of the building was downgraded to ‘poor’.

This meant that the consequences of a major earthquake were anticipated to result in significant structural and nonstructural damage and/or falling hazards that would represent appreciable life hazards. This therefore became a high priority and a Facilities Division project was funded to mitigate this. Over the course of four years, the structural cross braces that support the dome will be retrofitted bringing the designation of the entire building back to “good” again. The first phase of this project has now been completed, and the project is on schedule to complete the retrofit over the course of the next three major shutdowns.

Earthquake-safety measures have been developed to provide safety for personnel in the event of a seismic disturbance. It is required that protection be provided to allow adequate time for personnel to exit an endangered area with a minimum of injuries. All sizable equipment and hardware inside and outside of buildings are adequately restrained and/or anchored from toppling, sliding, rolling, walking, or falling so that equipment and hardware will not block egress paths and exit doors during seismic ground motion.

5.9.2 Emergency Preparedness

The LBNL Master Emergency Plan (MEP) [LBNL, 1980] developed in accordance with DOE Order 5500.3A [DOE, 1991a], addresses site-wide disasters including earthquakes. The MEP defines the elements of the emergency response organization and their capabilities. Organization and functions of the Emergency Command Center and Command Center Team are discussed. Annual emergency drills and training are required in accordance with the MEP.

The Building 6 Complex Emergency Plan is consistent with the MEP . The Building Manager, who serves as the building-emergency team leader, is responsible for planning and coordinating emergency actions for the ALS. The ALS Building Manager works closely with the Laboratory Emergency Preparedness Coordinator to ensure emergency plans are coordinated and are consistent with lab wide plans. Emergency team members are required to participate in emergency team training, building manager orientation and must be first aid and CPR qualified.

Evacuation maps located throughout the ALS complex show routes of egress and assembly areas outside the complex. Evacuation maps also designate the location of emergency equipment (see Figures 5-1

and 5-2 Op 02-08, Accelerator Emergency Shutdown Procedure]. This procedure gives the appropriate actions when the decision has been made to shut down the accelerator system in the event of an emergency.

5.9.3 Seismic Safety Analysis Summary

(1) Hazard Event: Earthquake

Initiating Occurrence

Earthquakes are a natural phenomenon. The most serious event would be a large earthquake of Richter magnitude 7 or larger on the Hayward fault.

Method of Detection

Noticeable ground movement is the primary means of detection.

Preventive/Mitigating Features

The building structure and equipment meet earthquake design criteria and applicable codes. All significant equipment, hardware, and objects inside and outside of buildings are restrained and/or anchored. In accordance with LBNL earthquake design criteria, the accelerator is bolted to withstand a 0.7 g lateral acceleration. The design allowable stress during a seismic event for structural steel members, fasteners, and anchor bolts is limited to 75% of the material ultimate strength; the stress for welds is limited to 50% of the material ultimate strength. There is an emergency power generator. The Building 6 Complex Emergency Plan is integrated into the LBNL Master Emergency Plan. Administrative controls include AHDs, ALS Operational Procedures, adherence to Chapter 23 Seismic Safety of the LBNL Health and Safety Manual, and employee training. Medical treatment is available at LBNL.

Consequences

Possible consequences of an earthquake occurrence are personnel injury, damage to equipment, and shutdown of the facility. Currently the domed part of the ALS is rated “poor” which translates to a consequence rating in the DOE O5480.25 guidance of “medium”. The B6 seismic retrofit project is being implemented to reduce the consequence rating to low.

Probability

The frequency of large earthquakes on either the Hayward or the San Andreas faults is not well known. The last large earthquake on the Hayward fault occurred more than 100 years ago. The U.S. Geological Survey predicts a major earthquake on this fault system will occur in the next 30 years with less than a 50% probability. From Table 4-5, the EH&S Review Committee assigned a probability level of low.

Risk

From the risk matrix in Figure 4-15, a consequence level of low and a probability level of medium results in a risk of low.

5.10 Beamline Vacuum System Safety Analysis Summary

(1) Hazard Event: Beamline Vacuum Vessel Implosion and Explosion

Initiating Occurrence

Beamline vacuum vessels potentially can implode under vacuum (if improperly designed) or explode during venting (if overpressured). Failure of the containment wall or window of a vacuum vessel could result in injury to personnel or equipment from flying debris.

Method of Detection

Observation by personnel in the affected area is the primary means of detection of a beamline vacuum vessel implosion or explosion.

Preventive/Mitigating Features

Beamline vacuum vessels and windows on vacuum systems are designed and tested following the guidelines contained in Chapter 7 of the LBNL Health and Safety Manual. Pressure relief devices and heavy glass viewport safety covers mitigate explosion danger. Administrative controls include review by the Beamline Review Committee, the Experimental Systems AHD, an ALS Operational Procedure for beamline venting, and employee training. Medical treatment is available at LBNL.

Consequences

Possible consequence of accidents involving implosion or explosion of beamline vacuum vessels are severe personnel injury or damage to equipment. From Table 4-4, the consequence level is judged to be medium.

Probability

Proper design and testing of vacuum vessels and windows and use of pressure relief devices reduce the probability of accidents involving implosion or explosion of vacuum vessels to extremely low. From Table 4-5, the EH&S Review Committee assigned a probability level of extremely low.

Risk

From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of extremely low results in a risk of negligible.

5.11 Industrial Accident Safety Analysis Summary

(1) Hazard Event: Industrial Accident Involving Rotating Machinery or Falling Objects

Initiating Occurrence

Pumps, blowers, and fans are examples of automatic rotating machinery that are part of normal operations in the ALS building. The cavity water systems of the storage-ring rf system have high-speed, motor-driven pumps and remotely operated motorized valves for the cavity water systems; the rf-cavity-tuner drives have a high-torque, semi-open mechanism, which is servo-operated and can move without warning; the variable-voltage transformer on the exterior pad has a powerful chain-driven linear motion system with the confined VVT cabinet; and the high-voltage switches and door lock within the crowbar cabinet have powerful solenoid-operated mechanisms. The insertion-device gaps are varied by moving the backing beams, which is accomplished in turn by rotating 2-mm-pitch Transrol roller screws that are mounted to the horizontal beams and support the backing beams. Valve and shutter actuators are high-force compressed-air devices. The overhead crane hook and/or its burden can move in the ALS building, and the burden could drop to the floor.

Method of Detection

Observation by personnel in the affected area is the primary means of detection.

Preventive/Mitigating Features

During operation, guards must be in place on fans and pump-motor shafts, and signs warning of automatic equipment startup are posted. Before beginning work on a pump, it will be switched off and locked out at the exterior pump breaker in accordance with lockout-tagout procedures as Chapter 18 Electrical Safety of the LBNL Health and Safety Manual and ALS 09-01 Electrical Logout/Tagout (LOTO) Supplemental Procedure for the ALS. Before operating the cavity-tuner drives, they must be checked to assure that the guard plates are in position and that no cables become entangled in the mechanism. During crane operation, the active area is designated as a hard-hat area and non-essential personnel are moved away. Crane operation is in accordance with Chapter 27 Cranes, Hoisting and Rigging, of the LBNL Health and Safety Manual. Crane operators are trained and certified. Medical treatment is available on-site.

Consequences

Consequences of accidents involving rotating machinery or falling objects include personnel injury and potential equipment loss. From Table 4-4, the consequence level is judged to be low.

Probability

Use of guards on rotating machinery, adherence to lockout/tagout procedures, and use of hardhats reduces the probability of accidents involving rotating machinery or falling objects to medium. From Table 4-5, the EH&S Review Committee assigned a probability level of medium.

Risk

From the risk matrix in Figure 4-15, a consequence level of medium and a probability level of low results in a risk of low.

5.12 Conclusions

Operational activities planned for the ALS facility have been analyzed for hazard potential, and appropriate mitigation measures have been developed. The hazards analysis identified potentially hazardous conditions that could occur in the ALS during operations. Control measures were incorporated into the facility and systems design to mitigate most of the identified potential hazards. In other cases, administrative procedures were developed to ensure that facility operations could be conducted with a minimum of on-site and off-site consequences.

A risk analysis on 19 categories of credible hazard events for hazards other than ionizing radiation, was performed using a bounding event/worst-case approach. Table 5-4 summarizes the results of the risk analysis. Combined with the risk analysis for ionizing-radiation hazards summarized in Table 4-6, these results show that the ALS facility will be operated within the risk envelope for low-hazard facilities as defined in SAN Management Directive 5481.1A.

Table 5-4. Summary on ALS Risk-Determination, other than Ionizing Radiation

No.	Hazard Event	Probability Level	Consequence Level	Risk Level
Fire Hazards				
1	Room Fire	Low	Low	Negligible
2	Room Fire Involving Radioactive or Toxic Materials	Low	Medium	Low
3	Equipment Fire	Medium	Low	Low
Hazardous Materials				
1	Uncontrolled Chemical Reactions	Low	Medium	Low
2	Chemical Exposure	Medium	Low	Low
3	Cryogenic Temperature Exposure	Medium	Low	Low
4	Pressurized Gas Explosion	Low	Medium	Low
5	Gas Explosion (Hydrogen, Oxygen, Acetylene)	Low	Medium	Low
6	Inhalation, Ingestion, or Dermal Exposure to Toxic or Carcinogenic Material	Medium	Low	Low
7	Oxygen Deficient Atmosphere	Low	Medium	Low
Electrical Hazards				
1	Electrical Shock	Low	Medium	Low
2	Nonionizing Radiation Exposure	Extremely Low	Medium	Negligible
3	Exposure to High Magnetic Forces	Medium	Low	Low
Laser Hazard				
1	Laser Light Energy Transfer	Low	Medium	Low
Visible and Near-UV Light Hazard				
1	Exposure to Visible and Near-UV Light	Low	Medium	Low
Ozone Hazard				
1	Ozone Exposure	Low	Low	Negligible
Seismic Hazard				
1	Earthquake	Low	Medium	Low
Vacuum Vessel Hazard				
1	Beamline Vacuum Vessel Implosion or Explosion	Extremely Low	Medium	Negligible

Table 5-4. Summary on ALS Risk-Determination, other than Ionizing Radiation (cont'd.)

No.	Hazard Event	Probability Level	Consequence Level	Risk Level
Industrial Accident				
1	Industrial Accident Involving Rotating Machinery or Falling Objects	Medium	Low	Low

SECTION 6. SAFETY ENVELOPE

The Safety Envelope is a set of physical and administrative conditions based on environment, health, and safety (EH&S) considerations that are contained in DOE Order 420.2B Safety of Accelerator Facilities and that establish and define the boundaries within which an accelerator and its experiments may be operated. If all operations are performed within the boundaries of the Safety Envelope, the facility staff, the facility users, the general public, and the environment will be protected. Variations in operating conditions are permitted if and only if their extent, duration, and consequences do not exceed the bounds imposed by the Safety Envelope. Within its Safety Envelope, for example, an accelerator facility can experience unplanned events, such as an unscheduled power outage, that may interrupt its operation but do not compromise the safety of the facility. The Safety Envelope should not be violated by the effects of such unscheduled, but anticipated, events of no EH&S consequence. Variations beyond the boundaries of the Safety Envelope are treated as reportable occurrences, as defined by DOE Order 231.1A Occurrence Reporting and Processing of Operations Information [DOE, 1991b].

The basis of the Safety Envelope presented here is the safety analysis described in Sections 4 and 5. The Safety Envelope is documented to define physical conditions and administrative controls that ensure safe operation of the ALS accelerator complex and the beamline and experimental areas within the envelope of the accident scenarios identified for the facility. The requirements specified in the Safety Envelope are binding for operation of the ALS. Significant revisions of these requirements, changes in operating conditions, or any facility and/or equipment modifications that involve an unreviewed EH&S issue will require a revision or supplement to this SAD. The Safety Envelope covers both technical and administrative matters. Requirements in the Safety Envelope related to technical matters address those facility features of controlling importance to EH&S. Requirements in the Safety Envelope related to administrative matters include those that are important to establishing safe operating conditions in the facility. Nothing in the Safety Envelope will restrict changes in organizational titles or organizational assignments within these requirements if equivalent functions are provided.

Facility operations routinely takes place with variability in the numerous parameters characterizing its performance. Accordingly, an Operations Envelope is used to provide assurance that the Safety Envelope is not exceeded as the operating parameters change. By defining the limits beyond which the operating parameters would require corrective actions to be taken, the Operations Envelope serves as a form of administrative control to provide assurance that the Safety Envelope is not exceeded. Variations of operating parameters within the Operations Envelope are normal. Variation of operating parameters

outside the Operations Envelope but within the Safety Envelope are not treated as an occurrence requiring reporting under DOE Order 231.1A but can cause administrative actions to be taken by the facility management.

Maintenance, inspection, and surveillance of all facility EH&S systems are assured by appropriate formal authorizations (AHDs, RWAs, etc.) and procedures, as provided for in Section 6.5.

Operations and Safety Envelopes for accelerators, beamlines, and experiments are discussed separately in Sections 6.2, 6.3, and 6.4, respectively. The separate requirements of the accelerators, beamlines, and experiments Safety Envelopes are integrated in Table 6-1 and comprise the ALS Safety Envelope:

Table 6-1. Safety Envelope for ALS Accelerators, Beamlines, and Experiments

(1)	Linac beam power: any combination of beam current, energy, and cycle rate that gives a beam power of 0.85 W (e.g., for the nominal operating parameters of 2 x 10^{10} electrons/cycle, 50-MeV electron energy, and 1-Hz cycle rate, the beam power is 0.16 W).
(2)	Booster synchrotron beam power: any combination of beam current, electron energy, and cycle rate that gives a beam power of 8.25 W (e.g., for the nominal operating parameters of 0. 16 mA or 2.6 x 10^{10} electrons accelerated and extracted/cycle, 1.5-GeV extracted beam energy, and 1-Hz cycle rate, the beam power is 6.2 W).
(3)	Energy in storage-ring beam: any combination of stored current and electron energy that gives a total energy of 1000 J (e.g., for the nominal operating parameters of 400-mA stored current or 1.65 x 10^{12} electrons and 1.5-GeV electron energy, the energy in the beam is 395 J).
(4)	A search-and-secure is carried out for each High Radiation Area (in which there is the potential for a whole body dose of 1 rem in any one hour) in the ALS building to assure that all personnel are excluded.
(5)	At least one accelerator operator is on shift during accelerator operation.
(6)	The personnel safety shutters that are an integral part of the bremsstrahlung collimation system or bremsstrahlung shield are closed during injection of beam into the storage ring, except that a PSS may be left open during injection under controlled testing conditions with equivalent protection in place. Equivalent protection will include software limits on stored current, additional bremsstrahlung shielding, personnel barriers, off-shift running, and reduced injection frequency.

Table 6-1. Safety Envelope for ALS Accelerators, Beamlines, and Experiments (cont'd.)

(7)	The bremsstrahlung shielding and exclusion zones are in place.
(8)	In beamline areas, the VUV and x-ray radiation is contained within vacuum tubes and chambers.
(9)	In experimental areas, the VUV and x-ray radiation is contained within vacuum chambers, within an interlocked hutch, or an enclosure whose method of access precludes a radiation hazard
(10)	Quantities of hazardous chemicals and materials in the ALS building do not exceed the 1988 UBC/UFC B-2 Exempt Aggregate Quantity per Control Area listed in Table 5-3.

6.1 Operational Procedures

The ALS is committed to the highest level of quality in all its activities. In this context, quality encompasses successful achievement of operational goals, environmentally responsible operation, and, above all, safety. Facility operations are specifically intended to be in compliance with DOE Order 420.2B, Safety of Accelerator Facilities and DOE Standards.

Assurance of safe conduct of operations within the boundaries of the Safety Envelope relies in part on ALS Operations Procedures, which are written documents providing specific direction for operating systems and equipment during normal and postulated abnormal and emergency conditions. All current ALS procedures can be located at http://alsintra.lbl.gov/procedures/procedures.html. Further information on Operational Procedures, including steps for generating and approving the procedures can be found in section 6.2.4.

Formal authorizations are required by the LBL Health and Safety Manual, PUB-3000 for all operations where a significant potential health, safety, or environmental hazard can be identified. Examples at the ALS include AHDs for Class 3B/4 lasers and Radiological Work Authorizations (RWAs) for the accelerator and various x-ray devices. During the preparation of these documents, potential hazards are identified, mitigation measures developed, and specific controls established for the conduct of the proposed operations. These documents receive independent review by the subject matter experts in the EH&S Division and formal authorization before work can begin.

6.2 Accelerators

6.2.1 Accelerator Systems

For the purposes of this SAD, the ALS accelerator systems include the injector complex (50-MeV electron linear accelerator; 1.5-GeV, 1-Hz booster synchrotron; and transfer lines), and the electron storage ring (operating range from 1.0 to 1.9 GeV), but not the insertion-device synchrotron radiation sources in the straight sections of the storage ring (maximum of 20 insertion devices) or the bend-magnet synchrotron-radiation sources in the curved arcs of the storage ring (maximum of 48 bend-magnet ports) which are included in the Beamlines, Section 6.3.

6.2.2 Accelerator Operations Envelope

Operation within the Operations Envelope for accelerators is guaranteed primarily by Operational Procedures, by the safety systems designed into the ALS accelerator systems, and by the administrative procedures that regulate operations of the accelerator systems.

The accelerator systems are designed to operate safely and without harming the environment, not only under the standard set of operating conditions, but also under unusual operating conditions that might be encountered during the commissioning of new and novel facility enhancements. The parameters that specify these operating conditions are the injection scenarios, the beam energy, the beam current, and the beam duration. Table 6-2 summarizes the values of these parameters and operating ranges that are permitted within the Operations Envelope.

Table 6-2. Operations Envelope for the ALS Accelerator systems

(1)	Linac beam power: any combination of beam current, energy, and cycle rate that gives a beam power of 0.30 W.
(2)	Booster energy will not exceed the limits of 50 to 1500 MeV (ramped).
(3)	Booster current will not exceed 16 mA.
(4)	Storage ring energy will be from 1000 to 1900 MeV (1500 MeV nominal).
(5)	Storage ring current will not exceed 500 mA.
(6)	Magnetic-field and rf/microwave-radiation intensities comply with Threshold Limit Values (TLVs) established by the American Conference of Government Industrial Hygienists.
(7)	Operations is guided by the ALS Accelerator Conduct of Operations Procedures and references therein.
(8)	All entrances to the ALS experimental-area floor are locked and posted as a Controlled Area; access is restricted to authorized personnel.
(9)	The integrity of the accelerator and safety systems is verified by inspection tours and by adherence to maintenance schedules, as specified in Operational Procedures.
(10)	The requirements of the Beamlines Operations Envelope and the Experiments Operations Envelope are met.

Additional discussion of Operational Procedures for accelerators appears below throughout Section 6.2. Maintenance, inspection, and surveillance of safety systems and staff EH&S training are discussed in Sections 6.5 and 6.6, respectively. Reference to procedures is also made in Sections 4 and 5.

6.2.3 Accelerator Safety Envelope

The Safety Envelope for accelerator operations emphasizes, but is not limited to, the primary accelerator operating parameters, which directly affect the production of and exposure to ionizing radiation. The values of the operating parameters are chosen to meet the design goals of limiting the radiation exposure to the general public to less than 10 mrem/year (0.1 mSv/year) and limiting occupational exposure to laboratory workers to less than 250 mrem/2000-hour worker year (2.5 mSv/year) and to 1 rem/9000-hour worker year (10 mSv/year), as well as the design goals for continuous occupancy of 0.5 mrem/hour (5 μSv/hour) and for a single event of 40 mrem.

Day-to-day accelerator operations will be guided by the requirements contained in the Operations Envelope described in the previous section and by the documents referenced in the Operations Envelope. Deviations from these requirements will cause administrative action by ALS management but will not be automatically considered as reportable occurrences under DOE Order 231.1A until further investigation in accordance with the order indicates that the deviations are reportable. Deviations that violate the Safety Envelope will be reported as occurrences in accordance with DOE Order 231.1A.

The Safety Envelope for accelerator operations therefore comprises the following maximum allowed values of the primary accelerator operating parameters:

- Linac beam power: any combination of beam current, energy, and cycle rate that gives a beam power of 0.85 W (e.g., for the nominal operating parameters of 2×10^{10} electrons/cycle, 50 MeV electron energy, and 1 Hz cycle rate, the beam power is 0.16 W).
- Booster synchrotron beam power: any combination of beam current, electron energy, and cycle rate that gives a beam power of 8.25 W (e.g., for the nominal operating parameters of 16 mA or 2.6×10^{10} electrons accelerated and extracted/cycle, 1.5 GeV extracted beam energy, and 1 Hz cycle rate, the beam power is 6.2 W).
- Energy in storage-ring beam: any combination of stored current and electron energy that gives a total energy of 1000 J (e.g., for the nominal operating parameters of 400-mA stored current or 1.65×10^{12} electrons and 1.5-GeV electron energy, the energy in the beam is 395 J).

and the following operating requirements:

- A search-and-secure is carried out for each of the interlocked areas in the ALS building (in which there is the potential for a whole body dose of 1 rem in any one hour) to assure that all personnel are excluded.
- At least one accelerator operator is on shift during accelerator operation.

6.2.4 Operational Procedures

Accelerator operations are guided by the ALS accelerator Conduct of Operations procedures. The ALS accelerator Conduct of Operations procedures apply the DOE Order 420.2B and DOE Guidance 420.2-1 to the specific situations encountered in ALS accelerator operations.

DOE 420.2B emphasizes the importance of Operational Procedures for accelerator operations. The formal requirements for preparation of ALS Procedures are themselves the subject of an ALS procedure, ALS 16-01. The purpose of this procedure is to ensure that only the most current documentation is used in the workplace. The procedure describes rigorous standards regarding identification, layout, page numbering, review, approval, distribution, changes, and cancellation for all ALS procedures. The basic steps in generating an approved procedure are (1) the draft procedure is completed by the originator; (2) the approving official designates three knowledgeable reviewers; and (3) the procedure is approved by the line manager with knowledge the day-to-day operations regarding the activities described in the procedure. The procedure center manager determines the review schedule, which is not to exceed three years from the initial approval or most recent review. However, all procedures are seen as living documents that are to be revised and updated as the need arises, including changes, additions, or deletions to the procedure.

6.2.5 Accelerator Operational Safety Procedures

The ALS Procedures describe the controls and procedures necessary for safe commissioning, operation, maintenance, and trouble-shooting of the ALS injector complex, the storage ring, and their subsystems. The ALS procedures identify the hazards associated with the components of the facility and the controls that have been implemented to assure that all operations are conducted in a manner consistent with the safety of environment, personnel, and equipment in accordance with the provisions of the LBNL Health and Safety Manual. Both the general policies and specific procedures referred to in the ALS procedures have been devised with these goals in mind. In addition, the existence of detailed and documented procedures does not remove the responsibility of any individual recognizing a hazardous situation to take immediate corrective action and/or to notify the appropriate responsible person and his/her immediate supervisor.

6.2.6 Operations Log

In accordance with the requirements of DOE Order 420.2B, the purpose of keeping an ALS Operations Log is to maintain a complete record of events concerning the operation of the facility. Entries are made in the Operations Log for those activities that occur in or about the facility, both routine operational events and data and any abnormal occurrences. In addition, all significant events affecting operations are recorded in a timely manner.

ALS procedure OP 11-01 Accelerator Operations Log Keeping regulates operations log-keeping. Topics include:

- Format of entries
- Required entries
- Use of highlighting
- Log archive
- Required reading and verification
- Fault reporting
- Procedure performance verification (startup and shutdown).
- Control Room key locker entries and maintenance

The log consists of two parts: the electronic, or online (Olog), and the paper log.

To facilitate the recording of sign-off requirements and compliance with the procedures for standard operations OP 11-01 provides for the use of start-up and shut-down check lists that cover (in the case of startup) startup preparation, procedures performed prior to turn-on, turn-on, and shift-manager verification and (in the case of shutdown) shutdown procedures performed, removal of access barriers, facility tour, and shift-manager verification (see Figures 6-1 and 6-2).

6.3 Beamlines

6.3.1 Types of Beamlines

For the purpose of this section, a beamline comprises the radiation source (insertion device or bend magnet), the front end, and one or more branch lines up to the experimental chamber. Beamlines can be categorized in several ways. First, beamlines can be illuminated by undulators, wigglers, or bend magnets, the radiation source affecting the details of the beamline design. Second, beamlines can be designed and constructed by the ALS staff; beamlines can be designed and constructed by participating research teams (PRTs); or beamlines can be joint ALS-PRT undertakings with separate responsibility for different beamline systems (e.g., front end or branch line) or for different aspects (e.g., design, construction, or funding). Finally, beamlines differ according to the photon-energy range they service, the principal division coming between beamlines with grating monochromators at lower photon energies and those with crystal monochromators at higher photon energies.

Shift Manager _____

On-Shift _____

_____

Startup Preparation (Initial)

Vacuum status in log [ ] Ln fan/BR fans on. [ ]

Access panels, Linac/Booster roof barriers/plugs and BTS area barriers in position as required. [ ]

BTS Block positioned on the template. [ ] Verified [ ]

All Radiation Safety Interlock racks/panels closed and locked. [ ] Verified [ ]

Procedures performed (Initial)

Electron Gun Enclosure Securing [ ]

Booster Magnet Turn On [ ]

Booster RF Power Systems Operation [ ]

Injector Administrative Search & Secure [ ] [ ] [ ]

Linac/Booster Gates Functional [ ]

SearchSecure of Bldg 6 Controlled Area [ ] [ ] [ ]

Booster Kicker Magnet Operation [ ]

Turn On (Initial)

Verified EG HV setting is at 120 KV. [ ]

Ready for beam. _____ (Signature)

Beam On [ ]

EG HV drain current at the power supply. [ ] milli-amps.

Shift Manager Verification (Initial) [ ]

LSP-030

Figure 6-1. Signature block in Operations Log for accelerator startup.

Shutdown (Initial) LSP-030

ACL Save file name, if any, recorded in log. ☐

Linac key and Booster keys switched off. ☐

Procedures performed

Booster Kicker Magnet Operating Procedure ☐

Booster Magnet Turn On, Turn Off Procedure ☐

Booster RF Power Systems Operating Procedure ☐

Barriers to free access of tunnels and restricted areas removed. ☐

Toured facilities. check for abnormal conditions. ☐

Vacuum system checked and print-out of vacuum system status inserted in Log. ☐

Shift Manager Verification (Initial) ☐

Figure 6-2. Signature block in Operations Log for accelerator shutdown.

The EH&S considerations for the various types of beamlines are essentially identical, and, for the purposes of this SAD, a single Safety Envelope is sufficient to establish and define the boundaries within which all beamlines may be operated. The Safety Envelope for experimental chambers is discussed separately in Section 6.4. In the event that future beamlines with special requirements are proposed that result in an unresolved EH&S issue, modifications or addenda to this SAD will be required.

6.3.2 Beamlines Operations Envelope

Operation within the Operations Envelope for beamlines is guaranteed primarily by Operational Procedures, by the EH&S systems designed into the beamlines, and by the administrative procedures that constitute the proposal submission and approval process and that regulate operations of the ALS beamlines. The ALS User Guides provide the basic guidance to users for beamline EH&S. These guides have been developed and updated as needed in consultation with the ALS user community, principally through the ALS Users' Executive Committee and spokespersons for Participating Research Teams.

The Operations Envelope for ALS beamlines is defined by the following set of requirements:

- Beamline design, construction, and installation has passed Beamline Design and Operational Readiness Reviews. Annual Beamline Readiness Reviews have been passed.
- Experiment Safety Sheets for all experiments on a beamline are approved and posted at the beamline.
- The integrity of the beamline and safety systems is verified by inspection tours and by adherence to maintenance schedules, as specified in Operational Procedures.
- The branch-line personnel safety shutters are in place and are operable, and during injection are closed, except that a PSS may be left open during injection under controlled testing conditions with equivalent protection in place. Equivalent protection will include software limits on stored current, additional bremsstrahlung shielding, personnel barriers, off-shift running, and reduced injection frequency.
- Required key enable procedures specific to each beamline are complete.
- The LBNL Health and Safety Manual and the Conduct of Operations Procedures applicable to the beamlines are adhered to in all normal, abnormal, and emergency situations.
- The requirements of the Accelerator Operations Envelope and Experiments Operations Envelope are met.

- Viewports and windows through which hazardous levels of visible or near-UV could be transmitted are covered by an opaque cover.

Additional discussion of elements of the Beamline Operations Envelope appears below throughout Section 6.3. Control of hazardous materials is discussed in Section 6.5.

6.3.3 Beamlines Safety Envelope

The Safety Envelope for beamline operations is deliberately confined to the production of and exposure to ionizing radiation. Radiation levels must not exceed the design goals of limiting the radiation exposure to the general public to less than 10 mrem/year (0.1 mSv/year) and limiting occupational exposure to laboratory workers to less than 250 mrem/2000-hour worker year (2.5 mSv/year) and to 1 rem/9000-hour worker year (10 mSv/year), as well as the design goals for continuous occupancy of 0.5 mrem/hour (5 μSv/hour) and for a single worst-case event of 40 mrem.

Day-to-day beamline operations will be guided by the requirements contained in the Operations Envelope described in the previous section and by the documents referenced in the Operations Envelope. Deviations from these requirements will cause administrative action by ALS management but will not be automatically considered as reportable occurrences under DOE Order 231.1A until further investigation in accordance with the order indicates that the deviations are reportable. Deviations that violate the Safety Envelope will be reported as occurrences in accordance with DOE Order 231.1A.

The Safety Envelope for Beamline Operations therefore comprises the following:

- The personnel safety shutters that are an integral part of the bremsstrahlung collimation system or bremsstrahlung shield are closed during injection of beam into the storage ring, except that a PSS may be left open during injection under controlled testing conditions with equivalent protection in place. Equivalent protection will include software limits on stored current, additional bremsstrahlung shielding, personnel barriers, off-shift running, and reduced injection frequency.
- The bremsstrahlung shielding and exclusion zones are in place.
- The VUV and x-ray radiation is contained within vacuum tubes and chambers.

6.3.4 Beamline Design and Operational Readiness Reviews

As provided by the ALS User Guide, beamlines to be constructed will be subject to a Beamline Design Review by the Beamline Review Committee following the latest Beamline Design Review Procedure BL08-16 and appendices. For the purposes of the review, the beamline includes, as appropriate, front ends, branch lines, and any other permanently installed optics. (In this SAD, the specific characteristics of the synchrotron radiation sources, including insertion devices, are used by the Beamline Review Committee in reviewing the design of the beamline.) The beamline designer will provide such information about the beamline as is required to evaluate its design, expected performance, and EH&S features, as outlined in the ALS Beamline Design Guide. Appendix A of this document describes criteria for beamline bremsstrahlung shielding [Donahue, 1996]. The information provided by the beamline designer could include, but is not limited to, drawings, radiation and shielding calculations, descriptions of interlocks, and operational procedures.

A Beamline Review Committee [ALS Procedure BL 08-16] has been appointed that will be responsible for reviewing proposed beamlines for all relevant considerations, including general safety, radiation shielding, interlocks, vacuum systems, and space requirements. The committee comprises a Chair, Chair-Select and Chair-Past, representatives from the Division Planning Office, Experimental Systems Group, Mechanical Engineering, Operations, Scientific Support Group, and User Services, along with technical experts covering Accelerator Operations, ALS ES&H Program, Floor Operations, Beamline Engineering, Electrical Safety, Equipment Protection Systems, Health Physics, Mechanical Safety, Radiation Safety Systems, Radiological Control, Survey and Alignment, and Vacuum Technology. In addition to these permanent members, there are *ad hoc* members for laser safety and fire safety.

The review process will proceed in four parts. First, the beamline designer submits conceptual design documentation to the Beamline Review Committee. The committee conducts a Conceptual Design Review (CDR) based on the principles enumerated in the ALS Beamlines Design Guide and evaluates overall safety and floor space considerations. If the conceptual design is approved, the beamline designers continue with a complete design and submit the full design documentation to the Beamline Review Committee. The Committee conducts a Beamline Design Review (BDR) based on the principles in the ALS Beamlines Design Guide and all relevant ALS Procedures. If the design is approved, the beamline is installed and documentation is prepared. The Committee then conducts a Beamline operational Readiness Review BRR) followed by a Beamline Readiness Review Walk-through (BRRW) to physically inspect that the beamline is installed as designed. The BRRW triggers

the final operational test of all beamline components and a radiation survey. At each review stage, the beamline designer can rework the design or installation and submit the revised work for another review. Upon passing all review stages, the beamline is authorized for operation.

Completion of the review provides the start of the beamline's permanent, formal file. Thereafter, the beamline will be re-reviewed annually, or in cases of substantive change or actual revision of the beamline. A beamline is essentially a permanent structure that can serve many experiments by, for example, exchanging the experimental chamber(s) at the end of the beamline. Exchanging experimental chambers will have minimal impact on radiation shielding, interlocks, and other permanent or semi-permanent installations. Therefore, BRC reviews of beamlines are relatively infrequent.

Actual user research at the beamlines is controlled through the Experiment Safety Sheet (ESS) process and an ESS is generated for each experiment on a given beamline.

6.3.5 Vacuum Policy

The storage ring and most of the beamlines share a common vacuum and are operated under ultra-high-vacuum (UHV) conditions. To maintain an adequate electron-beam lifetime and to prevent contamination of the optical components in the beamlines, the UHV systems must remain free of hydrocarbons. The storage-ring vacuum system, consisting entirely of metal, chemically cleaned, and bakeable components, will operate at a nitrogen-equivalent pressure of 2×10^{-10} Torr without beam. The ALS goal is to operate the storage ring at a maximum pressure of 2×10^{-9} Torr with beam.

To assure the maintenance of comparable UHV conditions in the beamlines and experimental chambers and to protect the storage-ring vacuum, the document Advanced Light Source Vacuum Policy and Vacuum Guidelines for Beam Lines and Experimental Endstations, Appendix B of the Beamline Design Guide, outlines the vacuum practices that will be permitted at the ALS. The main features of the ALS Vacuum Policy are:

- Vacuum Interlocks: Fast valve sensors are located in the beamlines to protect the storage ring in the event of a beamline-vacuum failure by closing when the pressure exceeds a threshold value of 1×10^{-5} Torr. Slower-moving isolation valves follow the fast valves in closing off the affected sector. Once closed, the interlocked isolation valves can be reopened only when the pressure is below 2×10^{-9} Torr. The front end isolation valve can be reopened only by an authorized ALS staff person.

- Beamline Vacuum Systems: ALS beamlines are required to have all-metal, hydrocarbon-free components in the front end and satisfy UHV design criteria downstream of the front end if there is a common vacuum. Components must be inspected and leak tested after fabrication. Oil-sealed pumps are not permitted, except in experimental chambers under prescribed safeguarded conditions.
- Vacuum Design Review: Proposed Beamline Projects are required to submit beamline assembly drawings, a list of construction materials, and a vacuum pump layout for review as part of the Beamline Design Review process before ordering non-standard equipment and before fabrication of beamline components.
- Performance Tests: Conditions to be met before opening the front end isolation valve and requirements to be satisfied before an experiment can begin are prescribed.
- Experimental Chambers: End stations generally operate under UHV conditions similar to those in the beamline and the storage ring and follow similar vacuum requirements and interlock procedures. In the event that the experimental chamber is not to be maintained in UHV conditions, a window capable of withstanding at least 1 ATM pressure or a thin window with appropriate interlocks must isolate the storage-ring vacuum or differential pumping must be used. The ALS Beamline Review Committee must approve whichever strategy is adopted.

6.4 Experiments

6.4.1 Types of Experiments

Experiments at the ALS involve the use of VUV and x-ray radiation from beamlines to illuminate samples in experimental chambers or hutches. The experiments described in Section 3 and covered by the Safety Analysis in Sections 4 and 5 fall roughly into two general categories: (1) those in which there is no solid window between the beamline and the experimental chamber, so that radiation is entirely contained at all times within the stainless-steel walls of the beamline and experimental chamber, and (2) those in which there is a window between the beamline and the experimental chamber, so that in some experiments the radiation may pass through air and is not entirely contained within the walls of the beamline and the experimental chamber.

Experiments may also be conceptually categorized as PRT experiments and general user experiments. PRT experiments involve the construction and operation of beamlines, as well as

experimental chambers. The beamline and experimental chamber are quasi-permanent in nature, but the experimental investigations change with time. General user experiments may involve bringing experimental chambers to the ALS from other locations or they may involve use of chambers provided by the ALS facility or by PRTs and they are transient in nature with a typical experiment lasting two weeks. Detailed discussion of ALS user types may be found in "User Policy at the ALS" on the ALS web site under User Guide.

The EH&S considerations for the various types of experiments differ somewhat. For example, a beamline delivering high-photon-energy x-rays to an experimental chamber in which the x-rays pass through air for some distance would have an interlocked hutch that would prevent access to the experimental chamber when the beam was on. For the purposes of this SAD, however, a single Safety Envelope is sufficient to establish and define the boundaries within which all experiments may be operated. The Safety Envelope for beamlines is discussed separately in Section 6.3.

6.4.2 Experiments Operations Envelope

Chapter 6 of the LBNL Health and Safety Manual (PUB 3000), “Safe Work Authorizations” provides the basic guidance for assurance of experimental EH&S. That chapter defines thresholds for evaluating and controlling the EH&S hazards for work. Work below these thresholds can be reviewed and authorized by the ALS. Work above these thresholds requires formal authorization and must also be reviewed and approved by the EH&S Division subject matter experts and then formally authorized by the ALS Division Director. An example is work with lasers; lasers below Class 3b can be reviewed and authorized internally while Class 3b and 4 lasers must also be reviewed by the LBNL Laser Safety Officer. ALS has written operational procedures to implement these reviews of experimental work. These have been developed in consultation with the ALS user community, principally through the ALS Users’ Executive Committee and spokespersons for Participating Research Teams.

The Operations Envelope for ALS experiments is defined by the following set of requirements:

- Approved final Experiment Safety Sheet forms and applicable formal authorizations (AHDs, etc.) for all active experiments at an experimental station are posted.
- Each experimenter has received applicable ALS EH&S training.

- The integrity of the experimental, vacuum, and safety systems is verified by inspection tours at the beginning of each new experiment and before the beamline is brought from off-line to on-line.
- All required radiation safety protective interlock systems are tested according to the approved schedule and are operating to prevent access to excluded areas by experimenters.
- Hazardous chemicals are stored in approved cabinets or are used in limited, controlled quantities appropriate for a B occupancy and for the approved purpose.
- Viewports and windows through which hazardous levels of visible or near-UV could be transmitted are covered by an opaque cover.
- The LBNL Health and Safety Manual and the ALS Operations Procedures applicable to the experiments are adhered to in all normal, abnormal, and emergency situations.
- The requirements of the Accelerator Operations Envelope and Beamlines Operations Envelope are met.

Additional discussion of elements of the Experiments Operations Envelope appears below throughout Section 6.4. Control of hazardous materials is discussed in Section 6.5.

6.4.3 Experiment Safety Envelope

The Safety Envelope for experiment operations is deliberately confined to the production of and exposure to ionizing radiation and to use of and exposure to hazardous chemicals and materials. Radiation levels must not exceed the design goals of limiting the radiation exposure to the general public to less than 10 mrem/year (0.1 mSv/year) and limiting occupational exposure to laboratory workers to less than 250 mrem/2000-hour worker year (2.5 mSv/year) and to 1 rem/9000-hour worker year (10 mSv/year), as well as the design goals for continuous occupancy of 0.5 mrem/hour (5 μSv/hour) and for a single worst-case event of 40 mrem.

Day-to-day experiment operations will be guided by the requirements contained in the Operations Envelope described in the previous section and by the documents referenced in the Operations Envelope. Deviations from these requirements will cause administrative action by ALS management but will not be automatically considered as reportable occurrences under DOE Order 231.1A until further investigation in accordance with the order indicates that the deviations are reportable. Deviations that violate the Safety Envelope will be reported as occurrences in accordance with DOE Order 231.1A.

The Safety Envelope for Experiments therefore comprises the following:

- The VUV and x-ray radiation is contained within vacuum chambers, within an interlocked hutch, or an enclosure whose method of access precludes a radiation hazard.
- Quantities of hazardous chemicals and materials in the ALS building do not exceed the 1988 UBC/UFC B Exempt Aggregate Quantity per Control Area listed in Table 5-3 of the SAD.

6.4.4 Experiment Safety Review

As provided for in the ALS User Guide and ALS Operations Procedures an Experiment Safety Sheet is generated for each new experiment and no experiment will be approved until it is compliance with applicable ALS, LBNL, DOE, or other federal or state environmental, safety, and health regulations. For example, experimental chambers must have chemical hazard safeguards, such as exhaust ventilation and containment systems. For experiments that do not pass the Safety Review, the information necessary to bring the experiment into conformance, if that is possible, will be provided to the experimenter.

When an experiment has passed the review, the Head of the Experiment Setup Coordination Section will coordinate with the experimenter-in-charge concerning shipping/receiving and storage of equipment and materials. All equipment and materials brought to the ALS as part of an experiment will be subject to inspection by the ALS ES&H Program and the Experiment Setup Coordination Section with cognizant engineers brought in as needed.

A one-page Experimental Modification Form will be used to describe minor modifications to an already-approved Experiment safety sheet, as described by ALS Operations Procedures.

The information on an approved Experiment Safety Sheet will also be used to help determine the types of training required for experimenters. The ALS ES&H Program and the Training Department of the Environment, Health, and Safety Division will be responsible for establishing the need for training and for providing the training (see Section 3.5.6).

Where the information on an Experiment Safety Sheet indicates there is a significant potential health, safety, or environmental hazard, a formal authorization such as AHD will be required before approval is granted. In some cases, already existing AHDs will be applicable and a new one will not be

necessary. In cases where no existing AHD is applicable, an AHD will be generated as described in Section 6.1.

No experiment will be permitted to begin until copies of an approved Experiment Safety Sheet and applicable AHDs are posted at the experimental station, as required by ALS Operations Procedures.

6.4.5 Vacuum Policy

The ALS Vacuum Policy discussed in Section 6.3.5 applies to experimental chambers as well as to beamlines. In particular, before beginning an experiment, the user must demonstrate that all vacuum interlocks in the experimental chamber(s) perform satisfactorily, that pumps are properly vented and equipped with appropriate interlock isolation valves to protect against pressure and/or power failures, and that adequate measures have been provided to protect the storage-ring vacuum from an accidental break in the experimental-chamber vacuum system. The experimental chamber and its contents should be manufactured in conformance with guidelines presented in the ALS Vacuum Policy. In the event that the beamline and experimental chamber are not to be maintained in UHV conditions, a window capable of withstanding at least 1 ATM pressure or a thin window with appropriate interlocks must isolate the storage-ring vacuum or differential pumping must be used. The ALS Beamline Review Committee must approve whichever strategy is adopted.

6.4.6 Experiment Safety Responsibilities

Consistent with Integrated Safety Management (ISM), ultimate responsibility for safety of the experiments rests with the users. Their review and signatures on the ESS forms constitutes an agreement between them and the ALS for implementation of the required safety controls. Beamline Scientists retain ultimate responsibility and authority for safety on their beamlines and their approvals on the ESS allow the experiments to proceed.

Consistent with the mission of a DOE User Facility, several different sections have responsibilities to support the users in meeting those safety responsibilities. The Experiment Setup Coordination section maintains the ESS forms and assures their accuracy and completeness. The ALS ES&H Program reviews each ESS form and assures that proper technical review is performed on each ESS. Floor Operations provides on-going support and oversight to the users. Each of these sections interact closely to assure that user safety is integrated and effective.

6.5. Maintenance, Inspection, and Surveillance of Safety Systems

Maintenance, inspection, and surveillance of accelerator EH&S systems is assured by appropriate ALS operations procedures. Maintenance, inspection, and surveillance of EH&S systems for beamlines and experiments will be assured by the ALS operations procedures and by additional formal authorizations as they are required by PUB 3000.

6.5.1 Radiation Monitoring

Since the accelerator beam is an intense source of secondary radiation (electromagnetic showers and neutrons), the accelerator is housed in concrete shielding with extensive interlocked radiation monitoring in the immediate vicinity. The purpose of the area-radiation-monitoring system is to provide radiation-level measurements, to generate audible and visual alarms when elevated radiation levels are measured, and to shut-down the accelerator when excessive levels occur. There is also a site-boundary radiation monitoring station (neutrons and photons) located 125 m south of the ALS building. Approved ALS Procedures dealing with radiation monitor testing and calibration, response to detector trips, radiation training requirements, conducting and documenting radiation surveys, and the archiving of appropriate personnel records are published on the ALS Procedure Center web page (www-als.lbl.gov/procedures).

Radiation surveys are conducted whenever changes in ALS design or operation could change radiation levels, such as would occur with the passage of a milestone represented by the beginning of a new phase of testing. ALS Procedures specifically require and describe measurements to be made at the time of the first tests in order to verify the EH&S adequacy of the shielding that has been positioned around the accelerator and to characterize the new conditions. Also specified are the placement of the radiation detectors and measurement intervals for monitoring during routine operation.

The fixed and portable radiation monitoring instrumentation for the ALS were selected from those commercially available and of reliable design known to be suitable to expected intensities and duty cycles at the ALS. Placement of the fixed radiation detectors was determined by consultation with Accelerator Physicists and EH&S Division Radiation Physicists. Two main criteria were used:

(1) <u>Probable areas of loss.</u> These locations help with machine tuning since minimum loss also means minimum radiation intensity.

(2) Locations of personnel. These locations monitor fields close to the accelerator that could affect personnel located at areas in and around the facility.

Fixed instruments are installed according to this placement plan and the manufacturer's recommendations. Since these instruments are also part of the accelerator interlock chain, they must be operational before the area they are intended to monitor can be occupied.

During the one-year commissioning period and following the first three years of normal operation, it was the ALS policy that everyone working on the experimental floor be assigned personal dosimeters. The results of this four-year period indicated that not a single worker approached the 100 mrem/yr threshold for requiring dosimetry per 10CFR835. Based on these results, dosimetry badging policy has changed to require only a subset of permanent staff, those who were likely to spend more than 10% of their time working on the storage ring roof or inside the inner walkway while the ALS is operating, should wear dosimeters. This policy was reviewed by a DOE-led independent review team from October 20-22, 1997, who concurred with the policy change. Together with this policy change we have greatly increased the number of fixed-area monitors, both passive and active.

6.5.2 Interlock Testing

Section 4.4 discusses the radiation-safety interlock protective system. For radiation and fire safety, the interlock system consists of radiation safety chains and includes "crash-off" boxes and "crash-in" and "crash-out" release mechanisms on doors. The entire personnel-safety interlock system must be inspected and tested at least once annually.

6.5.3 Interlock Bypass

Section 4.4 discusses the personnel protection (interlock) system. For radiation and fire safety, the interlock system consists of radiation safety chains and includes "crash-off" boxes and "crash-in" and "crash-out" release mechanisms on doors. Testing and operation of a system may require the installation of circuit bypasses for equipment or radiation interlocks.

Authorized temporary bypasses of the personnel protection systems during operation of the ALS shall be installed in accordance with ALS 01-02 Procedure for Temporary Bypass of Personnel Protection Systems and with the provision of Chapter 8, Electrical Safety, of the LBNL Health and Safety Manual. ALS 01-02 covers roles and responsibilities of affected personnel, installation of a personnel safety system bypass,

and removal of a bypass. (Bypassing equipment interlocks not associated with the personnel safety system is governed by ALS 01-05 Equipment Interlock Bypass Procedure.)

ALS 01-02 applies to all systems involved with personnel safety. Bypasses shall be installed only if measures implemented to insure personnel safety are not compromised and only if documented in the manner described in ALS 01-02. Authority to bypass systems may be granted only after every other effort has been made to clear the problem.

6.5.4 Controlled Access

Access to controlled areas is governed by ALS OP 03-01.

For normal operation, a search-and-secure procedure is carried out for each area to assure that all personnel are out of the interlocked area before startup or before resuming operation after a shut-down period when uncontrolled access has been permitted in accordance with OP 02-07 Accelerator Search and Secure Procedure. For testing and commissioning, controlled access to the area inside the shielding is permitted in accordance with OP 03-01, Accelerator Controlled-Access Procedure.

The purpose of OP 02-07 is to prescribe the requirements and provide step-by-step procedures for the search-and-secure of the Linac, booster synchrotron, and storage-ring in preparation for operation. The search-and-secure will result in checking equipment and clearing all personnel from the interlocked areas before starting the accelerators. The specified number of authorized persons must perform the search-and-secure for each area. The procedure is written to provide for a total accelerator search-and-secure; specific areas are searched and secured using the section of OP 02-07 written for that area. Log entries required in OP 02-07 are made in accordance with OP11-01. Only qualified personnel listed in ALS 02-01 Accelerator Authorized Persons List are permitted to secure the shielded areas.

Access to the accelerator enclosures during testing, commissioning, and normal operation is regulated by OP 03-01. Such restricted access requires shut-down of specific accelerator power systems, visual surveillance of the accelerator entrances during entrance and egress, and appropriate log entries. Additional restrictions on booster rf and storage-ring operation for access must comply with the requirements given in this procedure. With proper performance of this procedure, operations may resume without performing an additional search-and-secure procedure.

6.6 Staff Training

LBNL policy and federal law require that LBNL staff, participating guests, and visitors receive appropriate EH&S training. LBNL management is responsible, through supervisors, for ensuring that employees and guests under their supervision receive this training and are thereby fully informed about possible occupational health hazards and have the information needed to work safely. It is also the responsibility of ALS management, through supervisors to identify training needs for job classifications for which they are responsible, as specified in the LBNL Health and Safety Manual and as provided for in the Conduct of Operations Procedures

6.6.1 ALS Training

The training for ALS staff will include LBNL EH&S training, job-specific EH&S training, and task-specific EH&S training. Here “staff” includes operators, accelerator and experimental physicists, and others who perform tasks that are directly related to the operation of the ALS accelerators and/or experimental equipment including those matrixed from other divisions. The training goals are to provide the trainee with the necessary skills, knowledge, and background to carry out tasks safely, correctly, and expeditiously without the presence of a supervisor.

The ALS staff is required to complete the Job Hazard Questionnaire (JHQ) to identify pertinent training requirements. The JHQ is a tool to help managers and supervisors identify which EH&S training requirements their employees must satisfy. The answers on the questionnaire lead to a series of training requirements / recommendations (known as a training profile) based on the work environment and hazards that may be encountered by an employee. The training profile is web based and provides a record of when retraining is necessary.

The ALS Procedures Center provides a method to create and document training in the ALS Operations Procedures and for other areas or topics where training documentation is required. This training is also documented and managed in a web based system very similar to the JHQ tool.

6.6.2 Operations Training

Training programs within the ALS vary widely in content, format and forum, from individual instruction about specific pieces of equipment at the job site to general presentations to large numbers of staff in a conference room or auditorium. For this reason, a graded approach to training practice and

documentation is appropriate. In each category of training, an auditable set of records is maintained, including entries in the training database as described in Section 6.6.1, file copies of the training programs, and, when appropriate, training certification forms. For some task-specific training, written examinations are required. Some training programs, particularly those involving safety equipment, require independent verification that the training has been completed successfully, usually by a second authorized instructor monitoring the trainee in the course of performing the assigned tasks.

6.7 ALARA

It is the policy of the Lawrence Berkeley National Laboratory that exposure to ionizing radiation associated with LBNL operations be As Low As Reasonably Achievable (ALARA) [LBNL EH&S, PUB: 3000, LBNL Health and Safety Manual, Chapter 21]. The elements of the policy, which also forms the basis of the ALS ALARA policy, include:

- ALARA consists of those actions that are taken to keep individual and collective exposures to ionizing radiation, as well as radiation levels at the perimeter fence, below regulatory limits in any case and as far below regulatory limits and administrative control levels as possible consistent with satisfactory job completion.
- In all activities, there should be no exposure to radiation without commensurate benefits.
- Line management at all levels should emphasize to their subordinates that the basic philosophy of ALARA should be incorporated into all work practices. Written procedures should incorporate notes and suggestions to minimize radiation exposure when performing activities in which there is an opportunity for radiation exposure.
- Every employee is expected to demonstrate responsibility and accountability through an informed, disciplined and cautious attitude toward radiation and radioactivity.
- All workers should apply the basic principles of ALARA—time, distance, and shielding—to minimizing radiation exposure during their work activities.

The policy requires that each operation involving radioactive material or the production of radiation be evaluated individually to ensure that the resultant exposure is as low as is reasonably achievable. The relevant average risk to radiation workers should be no greater than the corresponding risk to workers in other industries generally considered to be safe.

ALS operations are subject to the principles of the LBNL ALARA policy defined in Chapter 21 on Radiation Safety of the LBNL Health and Safety Manual and applied throughout the chapter. The chapter contains sections on Protection Guides for Ionizing Radiation, Personal Radiation Monitoring, Monitoring of the Working Environment, Requirements for Off-Site Control, Exposure to Radiation in an Emergency, Accelerator Health Physics, Radioactive Materials, Documentation of ALARA Program, Emergency Procedures for Radioactive Spills, Radiation Safety Training, X-Ray Safety Policy, X-Ray Machines Classifications and Specific Supplemental Requirements, and X-Ray Equipment Systems Safety Analysis Policy.

Documentation of the ALARA program is provided as follows:

- Personal dosimetry exposure reports are issued monthly to individuals receiving a measurable dose. These reports include both whole body and extremity dosimeter results. Doses exceeding 50 mrem whole body or 1000 mrem extremity are investigated by the LBNL Radiation Protection Group.
- Area monitoring reports. Areas around accelerators are monitored using TLDs and film packs. These data are studied by health physicists and operations personnel at the accelerators. Results above action levels are investigated, and steps are taken to correct any problems. All such investigations must be documented, and a copy of the investigation report must be sent to the LBNL Radiation Safety Subcommittee.
- Real Time Monitoring: Areas around the first optics of insertion device beamlines are monitored in real time for scattered radiation. Alarms indicate the presence of elevated levels. Results are routinely studied for trends by safety staff and operations.
- Radiation Surveys: The ALS Radiological Control Technician (RTC) conducts and documents a number of required radiation surveys including periodic injection surveys, beamline and shield wall surveys, and, annual beamline commissioning surveys.

SECTION 7. QUALITY ASSURANCE

All LBNL activities that contribute to the scientific and operational objectives of the Laboratory are carried out in accordance with the requirements of the LBNL Operating and Assurance Plan [LBNL, 1993]. Conduct of operations and research activities at the ALS are subject to the provisions of the LBNL program. In addition, the ALS has developed a facility quality-assurance program that specifically applies to the conduct of its accelerator operations and research activities [ALS, 1993b].

7.1 LBNL Operating and Assurance Plan

The LBNL Operating and Assurance Plan (OAP) is administered by the Office of Contract Assurance, which reports to the Chief Operating Officer of the Laboratory. The OAP is a management system and set of activities designed to

- Maintain the level of performance necessary to achieve LBNL's programmatic and administrative objectives effectively and safely through the application of quality-assurance and related conduct-of-operations and maintenance-management principles.
- Implement an LBNL management philosophy that supports and encourages continual improvement in performance and quality at the Laboratory.
- Provide a management system that permits an integrated approach to compliance with applicable related regulatory requirements and DOE orders.

The requirements specified by the OAP are intended to meet the requirements of DOE Order 414.1C Quality Assurance [DOE, 2004c]. The OAP also contains management-system elements of DOE Orders 5480.19 Conduct of Operations Requirements for DOE Facilities [DOE, 2001b] and 433.1 Maintenance Management Program for DOE Nuclear Facilities [DOE, 2001c], where appropriate, and is meant to integrate these elements into the overall LBNL approach to Laboratory management.

The requirements of the OAP apply to LBNL employees and organizations and to contractors and facility users as managed by their LBNL sponsors. The requirements are also applicable to external vendors and suppliers as specified in procurement documents and contracts. It is line management's responsibility to plan for and achieve compliance with the requirements and to provide sufficient resources to accomplish the OAP objectives.

7.2 ALS Quality Assurance Program

The ALS Quality Assurance Program (QAP) reflects the LBNL philosophy for meeting the requirements of DOE Orders 414.1C Quality Assurance and 5480.19 Conduct of Operations Requirements for DOE Facilities. Under the QAP, the ALS goals are to (1) apply resources efficiently to activities, (2) ensure that ALS facilities are operated in a manner that protects the environment and assures the health and safety of both the public and LBNL employees, and (3) eliminate unproductive activities that are costly or unnecessarily burdensome. The Quality Assurance Officer (QAO) assists ALS staff in implementing the requirements of the QAP.

The QAP comprises five elements. These elements reflect a "plan-do-check-act" logic to quality assurance as suggested by the following table:

	Element
Plan	1. Organization
Do	2. Staff selection, proficiency and training
	3. Work processes
	4. Document management
Check/act	5. Performance assessment and improvement

Not all activities have the same effect on health and safety, environmental protection, or programmatic objectives. For this reason, the ALS uses a graded approach to determine the applicability of QAP requirements to each activity and the degree to which the requirements should be enforced. The objective of the ALS graded approach is to ensure that activities with quality-assurance implications are managed through adequate systems that are commensurate with the scale, cost, complexity, and hazards of the work being performed. Considerations in making these determinations include:

- public health and safety
- researcher health and safety
- environmental protection
- compliance with regulations
- ALS mission and programmatic goals
- protection of LBNL cost/investment
- impact on scientific results

Cognizant ALS engineers and line managers are responsible for identifying activities that are subject to the QAP requirements and for carrying out the analyses to justify the degree to which requirements should be enforced. The role of the QAO is to consult with cognizant personnel concerning quality-assurance issues and to assess adherence to quality-assurance principles.

SECTION 8. ENVIRONMENTAL MONITORING PROGRAM

8.1 Environmental Compliance

ALS operations adhere to DOE orders and to federal, state, and local regulations applicable to environmental protection. DOE orders applicable to activities with potential environmental consequences include 450.1 Environmental Protection Program [DOE, 2003a] 5400.5 Radiation Protection of the Public and the Environment, 435.1 Radioactive Waste Management [DOE, 2001a], 231.1A Environment, Safety and Health Reporting [DOE, 2004a], and 420.2B Safety of Accelerator Facilities [DOE, 2004b].

8.1.1 National Environmental Policy Act Compliance Program

ALS activities are subject to the requirements of the National Environmental Policy Act in accordance with DOE Order 451.1B National Environmental Policy Act Compliance Program. Environmental studies and documentation for the ALS are complete. The principal environmental documents are the Environmental Assessment [DOE, 1989] and the Findings of No Significant Impact.

The original ALS project scope assumed that significant portions of the then existing 184-Inch Cyclotron and its shielding would be reused. LBNL prepared an environmental evaluation of the original project, which resulted in a June 1987 DOE-SF Memorandum to File [Neely 1987] stating that the project has “clearly insignificant impact.”

In October 1987, decommissioning and removal of the 184-Inch Cyclotron was authorized. In an April 1988 memorandum, DOE/EH-1 requested that an environmental assessment (EA) be prepared for the project. The EH-1 memorandum cited the increased project scope and a lack of depth in the earlier LBNL environmental evaluation as the bases for the request. An EA was prepared and received S-1 concurrence and EH-1 approval. A Finding of No Significant Impact was issued in August 1989 [Brush, 1989].

A subsequent minor project change added a cooling tower, chiller plant, and associated piping to the project scope. This modification was found to have insignificant impact, and Memorandum to File on the change was issued in September 1990 [Decker, 1990].

8.1.2 Prevention of Significant Deterioration (PSD)

The ALS is located in the San Francisco Bay Area Air Basin, which is considered by the U.S. Environmental Protection Agency (EPA) to be an attainment area for nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). The EPA has not yet classified the air basin with respect to suspended particulate matter less than 10 microns in diameter (PM10). Emissions of NO_2 and SO_2 from the ALS would be generated primarily by fuel combustion (e.g., in boiler operation). These emissions would not cause PSD threshold levels established by the Bay Area Air Quality Management District (BAAQMD) to be exceeded and, therefore, would not trigger PSD review requirements by the BAAQMD.

8.1.3 California Clean Air Act

To conform with the California Clean Air Act (CCCA), the BAAQMD has revised its new source-review rules to achieve the goal of “no net increase” in emissions of nonattainment pollutants. The BAAQMD requires: (1) emission offsets if emissions of organic compounds, nitrogen oxides, or PM10 exceed the threshold amounts and (2) the best available control technology (BACT) for sources that emit criteria pollutants in excess of threshold amounts. The ALS will not result in the emission of any criteria pollutants in excess of threshold amounts that would trigger emission-offset or BACT requirements.

8.1.4 National Pollutant Discharge Elimination Systems (NPDES)

In accordance with the Federal Clean Water Act, Berkeley Lab has held a California General Industrial Storm Water Permit since 1992. This permit applies to the entire site and includes requirements that address plans and documents, monitoring inspections, employee training, an annual report, and best management practices to protect the quality and minimize the quantity of stormwater released from the Lab site.

8.1.5 National Emission Standard of Hazardous Air Pollutants (NESHAP)

Radionuclides released to the atmosphere for ALS research activities must adhere to NESAHP regulations. The ALS handles a variety of radionuclides and can generate a number of radioactive air-activation products due to accelerator activities. Potential environmental releases are evaluated and reported annually to the Environmental Protection Agency. Copies of historical reports can be found at the following website: http://www.lbl.gov/EH&S/esg/tableforreports/tableforreports.htm

8.1.6 DOE Environmental Orders 450.1, 435.1, and 5400.5

DOE Order 450.1, Environmental Protection Program, established a requirement that LBNL must implement an Environmental Management System (EMS) and that the EMS must be integrated with existing Integrated Safety Management (ISM) systems. The EMS focuses on improving environmental performance in 3 general areas: 1) preventing pollution, 2) minimizing waste and 3) conserving resources. This goal has been incorporated into the EH&S Self-Assessment process.

DOE Orders 450.1, 5400.5 and external regulations (above), contain requirements for environmental monitoring programs, including: (1) sampling of workplace and effluent air in all areas where significant quantities of radionuclides are handled, (2) continuous monitoring of penetrating radiation at three perimeter stations, one offsite station and in each major accelerator complex, (3) sampling of wastewater discharges at 2 perimeter stations for radionuclides, organic chemicals and metals, (4) on-site and off-site ambient air sampling for radionuclides, (5) sampling of rainfall for tritium, and (6) groundwater sampling for organic chemicals, metals and tritium.

DOE Order 435.1 contains the requirement for preparing an annual Site Environmental Report. Copies of past reports may be obtained at the following website:
http://www.lbl.gov/EH&S/esg/tableforreports/tableforreports.htm

8.2 Existing Permits

Copies of environmental permits are available at the following website:
http://www.lbl.gov/EH&S/esg/permitfortable/operatingpermitstable.html.

8.2.1 Air Emissions

Generally, the Bay Area Air Quality Management District exempts research activities, such as laboratory hoods and vacuum systems, from needing operating permits authorizing the activity. But any activity, research or support, may require an operating permit if the chemical-specific threshold quantities are emitted into the air during a set period of time. The BAAQMD has issued permits to Berkeley Lab for such activities such as wipe cleaning using solvents, spray paint booths, emergency generators, fuel dispensing and soil vapor extraction systems. The wipe cleaning permit is issued for activities across the entire site. The ALS support operation is one of the groups that tracks monthly

solvent usage for wipe cleaning activities. One or more of Berkeley Lab's permitted emergency generators serves the ALS buildings.

Above and beyond operating permits, all activities are expected to adhere to standards of operations that are found in BAAQMD's Rules and Regulations (http://www.baaqmd.gov/dst/regulations/index.asp).

8.2.2 Water Consumption

The State of California currently does not require permits for water consumption.

8.2.3 Wastewater Discharge

The East May Municipal Utility District (EBMUD) has issued a site-wide wastewater discharge permit that would also cover the ALS. The ALS will not generate wastewater streams that would require additional pretreatment and, consequently, associated pretreatment permits from EBMUD.

8.2.4 Storm Water Discharge

Berkeley Lab's stormwater releases are permitted under the California-wide Industrial Activities Storm Water General Permit. As required by this permit, the Laboratory has implemented a Storm Water Pollution Prevention Plan that includes measures to prevent the release of contaminants into the storm water system.

8.2.5 Hazardous Waste Generation and Discharge

Hazardous waste generated at the ALS will be handled and disposed of in accordance with California EPA hazardous waste regulations and with LBNL procedures for hazardous waste, as described in the Guidelines for Generators of Hazardous Chemical Waste at LBNL and Guidelines for Generators of Radioactive and Mixed Waste at LBNL Small quantities of hazardous wastes will be stored at satellite accumulation areas at the ALS at the various points of waste generation. Storage quantities at the ALS satellite waste-accumulation areas will not exceed LBNL (and regulatory) limits. Following LBNL procedures, waste will periodically be transferred from satellite accumulation areas to the LBNL Hazardous Waste Handling Facility (HWHF). Permits are not required by the state or the

EPA for satellite accumulation areas. LBNL is in the process of renewing its permit from the California EPA to operate the HWHF.

8.2.6 Underground Tanks

There will be no underground tanks constructed as part of the ALS.

SECTION 9. DECOMMISSIONING AND DECONTAMINATION PLAN

The life of the ALS will be 20 years or longer. Chemicals and other hazardous materials will be similar to those of other general laboratory facilities. Operation of the ALS will produce small quantities of long-lived radioactive products over its lifetime. The ALS is primarily a soft X-ray/EUV storage ring and produces very small amounts of induced activity in components chronologically impacted by the beam. A detailed D&D plan will be written when the facility is declared excess.

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SECTION 11. APPENDICES

Appendix 1: Operational Procedures

Appendix 2: Conduct of Operations Procedures

Appendix 1: Operational Procedures

The controlled versions of all ALS operational procedures are maintained on a website. To find the current version, go to the following URL:

http://alsintra.lbl.gov/procedures/index.htm

Appendix 2: Conduct of Operations Procedures

Safety Envelope for ALS Accelerators, Beamlines, and Experiments

- Linac beam power: any combination of beam current, energy, and cycle rate that gives a beam power of 0.85 W (e.g., for the nominal operating parameters of 2×10^{10} electrons/cycle, 50-MeV electron energy, and 1-Hz cycle rate, the beam power is 0.16 W).
- Booster synchrotron beam power: any combination of beam current, electron energy, and cycle rate that gives a beam power of 8.25 W (e.g., for the nominal operating parameters of 16 mA or 2.6×10^{10} electrons accelerated and extracted/cycle, 1.5-GeV extracted beam energy, and 1-Hz cycle rate, the beam power is 6.2 W).
- Energy in storage-ring beam: any combination of stored current and electron energy that gives a total energy of 1000 J (e.g., for the nominal operating parameters of 400-mA stored current or 1.65×10^{12} electrons and 1.5-GeV electron energy, the energy in the beam is 395 J).
- A search-and-secure is carried out for each High Radiation Area (in which there is the potential for a whole body dose of 1 rem in any one hour) in the ALS building to assure that all personnel are excluded.
- At least one accelerator operator is on shift during accelerator operation.
- The personnel safety shutters that are an integral part of the bremsstrahlung collimation system or bremsstrahlung shield are closed during injection of beam into the storage ring.
- The bremsstrahlung shielding and exclusion zones are in place.
- In beamline areas, the VUV and soft x-ray radiation is contained within vacuum tubes and chambers.
- In experimental areas, the VUV and soft x-ray radiation is contained within vacuum chambers, within an interlocked hutch, or an enclosure whose method of access precludes a radiation hazard.
- Quantities of hazardous chemicals and materials in the ALS building do not exceed the 1988 UBC/UFC B-2 Exempt Aggregate Quantity.

Operations Envelope for ALS Accelerator Systems

- Linac beam power: any combination of beam current, energy, and cycle rate that gives a beam poser of 0.30 W.
- Booster energy will not exceed the limits of 50 to 1500 MeV (ramped).
- Booster current will not exceed 16 mA.

- Storage ring energy will be from 1000 to 1900 MeV (1500 MeV nominal).
- Storage ring current will not exceed 500 mA.
- Operation is guided by the ALS Accelerator System Activity Hazard Document and references therein.
- Magnetic-field and rf/microwave-radiation intensities comply with Threshold Limit Values (TLVs) established by the American Conference of Government Industrial Hygienists.
- Operations is guided by the ALS Accelerator Conduct of Operations and references therein.
- All entrances to the ALS experimental-area floor are locked and posted as a Controlled Area; access is restricted to authorized personnel.
- The integrity of the accelerator and safety systems is verified by inspection tours and by adherence to maintenance schedules, as specified in Operational Procedures.
- The requirements of the Beamlines Operations Envelope and the Experiments Operations Envelope are met.

Operations Envelope for ALS Beamlines

- Beamline design, construction, and installation has passed Beamline Design and Operational Readiness Reviews.
- Approved Experiment Forms for all experiments on a beamline are posted at the beamline.
- The integrity of the beamline and safety systems is verified by inspection tours and by adherence to maintenance schedules, as specified in Operational Procedures.
- The branch-line personnel safety shutters are in place, are operable, and during injection are closed.
- An Operational Procedure specific to each beamline is complete.
- The LBNL Health and Safety Manual, the Light Source Procedures, and the Conduct of Operations Procedures applicable to the beamlines are adhered to in all normal, abnormal, and emergency situations.
- The requirements of the Accelerator Operations Envelope and Experiments Operations Envelope are met.
- Viewports and windows through which visible or near-UV could be transmitted are covered by an opaque cover with a warning of the hazard.

Operations Envelope for ALS Experiments

- Approved Final Experiment Safety Review forms and applicable OSPs for all active experiments at an experimental station are posted.
- Each experimenter has received ALS EH&S training
- The integrity of the experimental, vacuum, and safety systems is verified by inspection tours at the beginning of each unit of beamtime and before the beamline is brought from off-line to on-line.
- All required radiation safety protective interlock systems are tested according to the approved schedule and are operating to prevent access to excluded areas by experimenters.
- Hazardous chemicals are stored in approved cabinets or are used in limited, controlled quantities appropriate for a B-2 occupancy and for the approved purpose.
- Viewports and windows through which visible or near-UV could be transmitted are covered by an opaque cover with a warning of the hazard.
- The LBNL Health and Safety Manual, the Light Source Procedures, and the Conduct of Operations Procedures applicable to the experiments are adhered to in all normal, abnormal, and emergency situations.
- The requirements of the Accelerator Operations Envelope and Beamlines Operations Envelope are met.

Safety Envelope for ALS Accelerators, Beamlines, and Experiments

- Linac beam power: any combination of beam current, energy, and cycle rate that gives a beam power of 0.85 W (e.g., for the nominal operating parameters of 2×10^{10} electrons/cycle, 50-MeV electron energy, and 1-Hz cycle rate, the beam power is 0.16 W).
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