STANFORD LINEAR ACCELERATOR CENTER

SAFETY ANALYSIS DOCUMENT — NEXT LINEAR COLLIDER TEST ACCELERATOR

Volume 01-13

TECHNICAL DIVISION

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Table of Contents

1 Introduction

2 Site Description

3 Functional Description of the Facility

4 Operating Organizations

5 Research Organization

6 Safety Analysis Methodology

7 Safety Analysis — Ionizing Radiation

8 Safety Analysis — Other

9 Accelerator Safety Envelope

10 Quality Assurance

11 Decommissioning

A Personnel Protection Systems

B Beam Containment System

C Beam Shut-off Ion Chamber System

1 Introduction

1.1 Facility Description

The Next Linear Collider Test Area (NLCTA) is a room-temperature, X-band linear accelerator with a design no-load energy of 630 MeV, which may be increased to 1,096 MeV after future upgrades. Electrons are provided by a thermionic gun with a design maximum current of 3.0 A which may be increased to 4.5 A after upgrade. The maximum pulse length available from the rf system is 225 ns. The maximum gun repetition rate is 10 pps, while the klystrons and modulators are designed to run at 180 pps for the purposes of engineering development. The facility is constructed in the End Station B area of the SLAC Research Yard.

1.2 Facility Purpose

SLAC is the site of the first linear collider facility, the SLAC Linear Collider (SLC).

The NLCTA project is an experimental assembly designed to integrate the new technologies of X-band accelerator structures and rf systems being developed at SLAC and elsewhere in the world for the Next Linear Collider (NLC).

The goals of the project include technology integration, measurement of the “dark current” generated by rf field emission in a high-gradient accelerator, demonstration of multi-bunch beam-loading compensation, suppression of higher-order deflecting modes, and measurement of any transverse components of the accelerating field.

1.3 Facility Operations

The NLCTA will not be used as a production machine; that is, it is not likely that it will ever be used as a source of charged particles. It will, rather, be used as a developmental tool and will operate for relatively short periods of time to study properties of various new technologies incorporated into the design. The shielding analysis is based upon the expectation that the facility will be operated for not more than 1,000 hours per year.

It is planned to be operated in a staged manner, with the injector being commissioned first in 1995, and the accelerator commissioned in 1996. An upgrade is planned at a future date which will increase the accelerating gradient, and hence the maximum power capability. The maximum[1] power capabilities are expected to be as follows:

Configuration	Date	Max. Credible Power
Injector only	8/1/95	669 Watts
Linac	8/1/96	3,233 Watts
Upgrade	Future	5,745 Watts

1.4 Hazard Classification and Safety Analysis

A proposal to classify the NLCTA as a Low Hazard Facility was filed with the DOE on March 23, 1995.

The Director of the Office of Energy Research approved the classification of the NLCTA as a Low Hazard Radiological Facility on June 16, 1995.

A safety analysis is presented in Chapters 7 and 8 of this document. The summary results of the safety analysis are shown in the attached Table 1.1.

Table 1.1: Hazard Identification and Risk Determination Summary

Note: *The hazards reviewed and listed here are only those which arise as a consequence of the operation of the facility concerned. Hazards which arise in the course of production of parts of the facility, or involving on-site transportation of materials or personnel, are not considered here. Normal and customary hazards typical of light industrial operations are not considered.*

Hazard	Causes	Prevention/Mitigation Means	Potential Impact	Consequence	Prob
Ionizing radiation exposure, outside housing	Personnel error, interlock failure	Formality of design, maintenance, and functional testing of radiation safety systems, formal procedures for system use and to assure configuration control, training of operations staff and users	Personnel injury	3 — Low	A — E ly Low
Ionizing radiation exposure, inside housing	Personnel error, interlock failure	Formality of design, maintenance, and functional testing of radiation safety systems, formal procedures for system use and to assure configuration control, training of operations staff and users	Personnel injury	2 — Medium	A — E ly Low

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[1] This assumes that a system failure allows a higher than normal repetition rate transmitted to the gun, such that the average gun current is limited by the charging rate of the gun pulser circuits. See Section 9, “Accelerator Safety Envelope,” for further discussion of maximum credible power.

7.3.3	Exposure to residual activity inside housing	Procedural error, personnel error	*SLAC Guidelines for Operations*, training, Radiation Work Permits	Personnel injury	1 — Extremely Low	A — Extremely Low
8.1	Fire; accelerator housing, equipment and control areas	Equipment failure	Sprinklers, fire alarms, exit routes, training, on-site fire department	Personnel injury, property loss	3 — Low	B — Low
8.3	Electric Shock	Personnel error, interlock failure	NEC compliance, interlocks, training, lock and tag	Personnel injury, fatality	2 — Medium	B — Low
8.4	Non-ionizing radiation exposure	Personnel error, interlock failure	Safety procedures, design of interlock systems, training	Personnel injury	3 — Low	B — Low
8.7	Seismic Hazards	Earthquake	Building and structural codes and standards, field inspection	Personnel injury, property loss	3 — Low	B — Low

2

Site Description

2.1 Site Location

The Stanford Linear Accelerator Center (SLAC) is a national facility operated by Stanford University under contract to the Department of Energy (DOE). The site, at 2575 Sand Hill Road, Menlo Park, California, is in a belt of low foothills between the alluvial plain bordering San Francisco Bay and the Santa Cruz Mountains to the west. The site elevation varies between 175 to 375 feet above sea level, whereas the mountains to the west rise abruptly from the western boundary to an elevation of almost 3,000 feet some seven miles from the site. The neighboring land is largely open space, except for office buildings on the parcel immediately to the west of the entrance gate, and a housing development at the northeast corner of the site. The site is bordered on the north side by a four-lane expressway.

The site is home to four currently operating accelerator facilities:

- The Linear Accelerator Facility, which includes the SLAC Linear Collider
- The Stanford Synchrotron Radiation Laboratory (SSRL), comprised of the SPEAR storage ring and associated linac, booster, and experimental areas
- The Accelerator Structure Test Area (ASTA)
- The Injector Test Facility (ITF)

Under construction at the site are the NLCTA and the PEP-II / *B*-Factory facilities.

The site has two major groups of buildings:

- The campus area, which includes offices, laboratories, and production facilities grouped around a grassy area close to the site entrance, and
- The major accelerator and detector facilities which are situated within a radiological control area some two and one half miles long and a half mile wide at its widest point. The NLCTA is located near the east end of this area, in the Research Yard constructed to serve the fixed-target physics program of the Linear Accelerator Facility.

2.2 Geology

The linear accelerator facility is located in formations of Eocene and Miocene sandstone, the former predominating in the west and the latter in the east. The Eocene formations are in a somewhat chaotic condition in parts of the length of the accelerator, requiring careful attention to engineering geology during design and construction. The Miocene formation is largely undisturbed and exhibits superior characteristics of uniformity and load-bearing characteristics.

2.3 Seismicity

The San Andreas fault passes within a quarter mile of the western boundary of the site, and the line of the linac is traversed by some minor and possibly inactive secondary fault traces. The San

Andreas fault is, at this latitude, considered to be a probable source of a major (> Richter Magnitude 7) earthquake within the next few decades. Other related faults, such as the Hayward fault 15 miles east of the site, and the Calaveras fault a similar distance to the southeast, are also considered active and likely to be the source of major earthquakes.

These proximities make it probable that, if there is a major earthquake on one or more of these faults, there will be some damage to structures at SLAC.[1] The laboratory has, from the beginning, designed its structures to criteria which are more conservative than the Uniform Building Code. In the 1989 Loma Prieta earthquake (Magnitude 7.1, 30 miles away), there was only superficial damage to structures on site, although Stanford University, which is two miles away, suffered $200 million damage. Structural design standards at SLAC are intended to prevent loss of life and to minimize equipment and building damage.

2.4 Hydrology

The SLAC site lies within the eastern half of a 40 square mile area of the Santa Cruz mountains drained by San Francisquito Creek, which flows east along the southern boundary of the site before flowing across the western plain of the San Francisco Bay.

At the site, groundwater flows in a generally southeasterly direction from a topographic high which lies to the north of the facility. Recharge of the groundwater into the Tertiary bedrock from surface infiltration is very small, with only about 10% of rainwater reaching the water table. The southeasterly flowing groundwater, at the higher levels, discharges locally into San Francisquito Creek. Groundwater flows beneath SLAC have been described as being dominated by fractures and porous beds of limited lateral extent, leading to a complex system of perched water zones and multiple, poorly connected, groundwater bearing zones.[2]

2.5 Climatic Factors

The SLAC site experiences a climate which is primarily influenced by the presence of the Pacific Ocean and the cold Humboldt current some 20 miles to the west, and by the intervening ridge of low mountains of the Coast Range. The oceanic influence produces a climate at the Pacific coast itself which is remarkable for the narrow seasonal temperature range (<10°F between summer and winter). The SLAC site is, however, in the rain shadow of the coast range, which counteracts this maritime effect. During the summer months, the prevailing westerlies, crossing the waters of the Humboldt current, cause heavy fog to form over the ocean, and this is pushed up and over the coast range. Much of the moisture is deposited in the form of drizzle in the mountains, and the air mass then increases in temperature (as much as 15°F) as it follows the eastern downslope.

The consequence is that summer temperatures at SLAC may rise to 90–100°F during the daytime, with average daily highs being closer to 70–80°F. The diurnal variation is remarkably large and nighttime temperatures in the summer may fall as low as 50°F.

The winter temperatures will normally be above freezing most of the time, but may occasionally fall below freezing for several days at a time. The diurnal variation is less marked. The frequency of snowfall is of the order of once in 20 years.

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[1] However, it has been shown that soil conditions are sometimes more strongly predictive of structural damage than is proximity to the epicenter of an earthquake, particularly when the distance to the epicenter is less than 30 miles.

[2] *Stanford Linear Accelerator Center*; *Hydrogeologic Review*, ESA Consultants, Mountain View, California, February 1994.

Rainfall is almost entirely restricted to the period between November and April. Thunderstorms are rare, but winter oceanic storms can produce copious rainfall and high winds for limited periods in the winter. Tropical storms from the Southern Pacific regions have usually largely dissipated as they cross the Humboldt current before coming ashore in this latitude. There are no recorded instances of tornadoes.

The temperate climate at the site allows technical systems to be installed in buildings which have only limited provision for heating and cooling. The laboratory has experienced one instance of widespread damage caused by unusually low temperatures at a time when water systems were shut down. Circulation is now maintained in cooling water systems at all times during the winter.

3 Functional Description of the Facility

3.1 Injector

The injector contains a thermionic-cathode gun and two X-band accelerator sections. The gun current is 1.5-A nominal (3-A maximum), accelerated electrostatically to 0.15 MeV. The gun pulse has 0.125-microsecond duration which is set by a fixed network. The pulse-repetition rate is limited by hardware to a maximum of 10 Hz. A pair of 0.9-m-long X-band accelerator sections, powered by a single 50-MW klystron with a dedicated pulse modulator, boost the beam energy by 70 MeV. (The zero-current accelerating gradient is 50 MV/m.) Detailed modeling of the injector indicates that the net current loss in the injector will be approximately 30%.

3.2 Chicane

A magnetic chicane downstream from the injector, Figure 3.1, contains a pair of bends that offset the beam axis by 9 inches, and a second pair of bends that restore the beam to its original axis. Two fixed collimators and one adjustable collimator are positioned between the two pairs of bends. The nominal beam power entering the chicane is 100 W.

3.3 Faraday Cup

An insertable Faraday cup downstream from the chicane, when inserted into the beam line, will absorb the full beam power in a re-entrant block of tungsten.

3.4 Linac

The linac contains three pairs of 1.8-m-long X-band accelerator sections. Each pair is powered by a single 50-MW klystron with a dedicated pulse modulator. Each pair boosts the energy of the nominal-current beam by 135 MeV, for a total energy gain of 405 MeV. (The zero-current accelerating gradient is 50 MV/m.) The dominant source of radiation in the linac is expected to be small, distributed beam losses. The net loss is expected to be much less than 0.5%, consistent with experience in the SLAC linac and Final Focus Test Beam. However, for the purpose of estimating the radiation doses, a net loss of 0.5% at the highest energy, concentrated at a single point, is assumed.

3.5 Spectrometer and Beam Dump

A 12-degree spectrometer line, and a straight-ahead line, both terminate in an iron and concrete beam dump. The dump will absorb the full beam power. The iron target will be cooled by natural convection and thermal radiation. Water cooling will not be necessary, nor will it be provided.

3.6 High-Power Radiofrequency System

Radiofrequency (rf) power for the NLCTA will be provided by four 50-MW X-band klystrons. The klystron peak power will be quadrupled by SLED II rf pulse compressors. These klystrons and pulse compressors represent a new microwave technology being developed at SLAC, which is the *raison d'être* for the NLCTA. The klystrons will produce 50 MW of microwave power at 11.424 GHz in 1.5-microsecond-long pulses. The pulse compressors will compress the rf pulse length from 1.5 microseconds to 0.25 microsecond, and boost the peak power by a factor of 4. The resulting 200-MW microwave pulse, split between a pair of accelerator sections, will boost the energy of the linac beam by 130–180 MeV, depending on the current loading the accelerator.

The NLCTA's X-band klystrons present no new hazards relative to the SLC's S-Band klystrons. Relative to the S-band klystrons, the X-band klystrons will operate at somewhat higher voltage (440 kV versus 350 kV), but at lower perveance (1.2 $\mu A / V^{3/2}$ versus 1.8 $\mu A / V^{3/2}$), and at shorter pulse-length (1.5 µs versus 3.5 µs). Consequently, the total beam energy in an NLCTA X-band klystron will be lower than in an SLC S-band klystron.

The operations staff will conduct radiation hazard surveys periodically to ensure that the klystrons and other high-power rf components are appropriately shielded for both x-rays and microwaves.

3.7 Upgrade Plans

A future upgrade of the rf system is planned in which the rf power will be tripled by replacing each 50-MW klystron with a pair of 75-MW klystrons, which will increase the accelerating gradient in the injector and in the linac by a factor of $\sqrt{3}$. A future upgrade of the injector, which would increase the peak current and change the micropulse structure, may be desirable to advance NLC accelerator-development studies. The injector upgrade as planned would increase the pulse current to 3-A nominal and 4.5-A maximum.

3.8 Conventional Structures

The NLCTA facility, which is partially contained inside End Station B, consists of an above-ground beam-line enclosure, banks of instrumentation, controls, and power supply racks, a 3.33-MW electrical substation, and a control building. Figure 3.2 shows the layout of the NLCTA buildings.

End Station B (Building 62) is a reinforced poured-concrete structure completed in 1966. Interior dimensions at floor level are 150 feet (east-west) by 75 feet (north-south) by 50 feet high. The north and south walls have large openings for moving equipment in and out. A 20 feet by 20 feet portion of the south opening has a motorized 2-foot-thick concrete door. Other openings in the north, south, and east walls are approximately 12 feet high × 70 feet wide, and are covered with 2-foot-thick portable concrete blocks. All walls and the roof are concrete, with minimum thicknesses of 2 feet, varying as required by structural considerations. The roof slabs are supported on steel girders. The floor slab is made of 6-inch thick, un-reinforced concrete on a 6-inch untreated base of coarse graded aggregate. The building is a large single-story concrete structure designed as a rigid frame. There are large sections of uninterrupted walls designed to carry large earthquake-induced shear forces into the sandstone foundation. End Station B is ventilated by nine roof-mounted 25,000-cfm exhaust fans.

The above-ground beam-line enclosure was recently constructed from poured, reinforced concrete blocks. The walls are 6 feet thick. The roof is 4 feet thick. The interior measures 10 feet high by 9 feet wide by 170 feet long. Approximately half of the enclosure is contained inside End Station B;

the rest extends beyond the end station by about 80 feet, to the east. The beam dump, which will consist of iron, lead, and concrete, will be at the east end of the accelerator housing. The interior walls of the enclosure are painted white. The concrete floor is sealed. Access and egress is provided through two radiation mazes: one at the west end, which connects to End Station B; and one on the south side, which connects to the outside. Cross-ventilation is provided by the two mazes, and can be assisted by using portable electric fans, when necessary. Telephones are spaced approximately 50 feet apart inside the enclosure. Figure 3.3 shows a cross-sectional view of the NLCTA beam-line housing.

Approximately 70 racks of instrumentation, controls, and power supplies for the NLCTA are contained inside End Station B. Cables run in overhead trays that enter the beam-line housing through the west maze.

The new 3.33-MW substation (Building 501) provides power to the NLCTA, to End Station B, and to the southern part of the Research Yard. This single-story structure, which measures 20 feet by 39 feet, is made of steel-reinforced masonry-block walls, with a sheet-metal roof, on a 4-inch-thick concrete slab foundation.

The new control building (Building 128) contains the NLCTA operations control room, a conference room, an office, and a toilet. This single-story, sheet-metal, steel-frame structure measures 26 feet by 42 feet

3.9 Cooling Water

NLCTA components will be cooled by an existing Research Yard LCW circuit (at 275 psi pressure). A new Low Conductivity Water (LCW) closed circuit has been constructed for cooling the NLCTA accelerator sections. This accelerator LCW circuit operates at 45 psi and is temperature-stabilized to 45° ± 0.1°C. Heat from the accelerator LCW circuit will be transferred by heat exchanger into the Research Yard LCW circuit.

For operational support and maintenance purposes, the LCW circuits used for the NLCTA project will be part of the SLAC’s overall LCW system, which is tested routinely for tritium and hazardous constituents.

The NLCTA beam dump will not be water-cooled. Significant radioactivation of LCW is not expected to be a problem.

3.10 Power Supplies

The beam line magnets in the NLCTA will include 34 air-core solenoids in the injector; four steel-core dipoles that make a chicane for manipulating the longitudinal phase space of the beam; 33 iron-core quads with trim windings for steering correction throughout the chicane, linac, and spectrometer; and an iron-core (horizontal) dipole for momentum analysis in the spectrometer, used in conjunction with a ferrite-loaded (vertical) kicker and a kicker-compensator dipole. The low-voltage, high-current power supplies for these magnets will be interlocked through the Personnel Protection System such that the power supplies must be turned off for unrestricted access to the accelerator housing. A special restricted-access mode called RASK (“restricted access with safety key”) will be supported, in which qualified persons may work inside the housing while the power supplies are turned on under administrative control.

An additional 20 air-core steering-corrector magnets are distributed throughout the injector and spectrometer. The low-voltage, low-current power supplies for these magnets do not constitute an electrical hazard, and will not be controlled by the Personnel Protection System.

Vacuum in the NLCTA beam line and high-power microwave systems will be produced and maintained by ion pumps. These pumps will be powered by high-voltage, low-current power supplies located in racks inside End Station B. The ion-pump high voltage is insulated by safe connectors.

3.11 Instrumentation and Control

Beam instrumentation in the NLCTA will include strip-line beam position monitors, beam-profile monitors that image the beam on phosphor screen, wire scanners, toroids, an insertable Faraday Cup, and adjustable collimators.

The control system for the NLCTA will be an extension of the SLAC control system that is currently used to operate the SLC, the Final Focus Test Beam, and the Polarized Gun Test Lab. The SLAC control system distributes control functions among a supervisory mainframe, remote workstation consoles for human interface, and remote microcomputers for actual hardware control.

The primary interface to instrumentation at SLAC and in the NLCTA is Computer-Automated Measurement and Control (CAMAC). However, parts of the NLCTA rf system may be controlled by instrumentation of a new open industry standard (IEEE-488 and VXI-bus). Such new modular electronics may be chosen for their superior capabilities in remote data processing, and will be interfaced to the SLAC control system via ethernet.

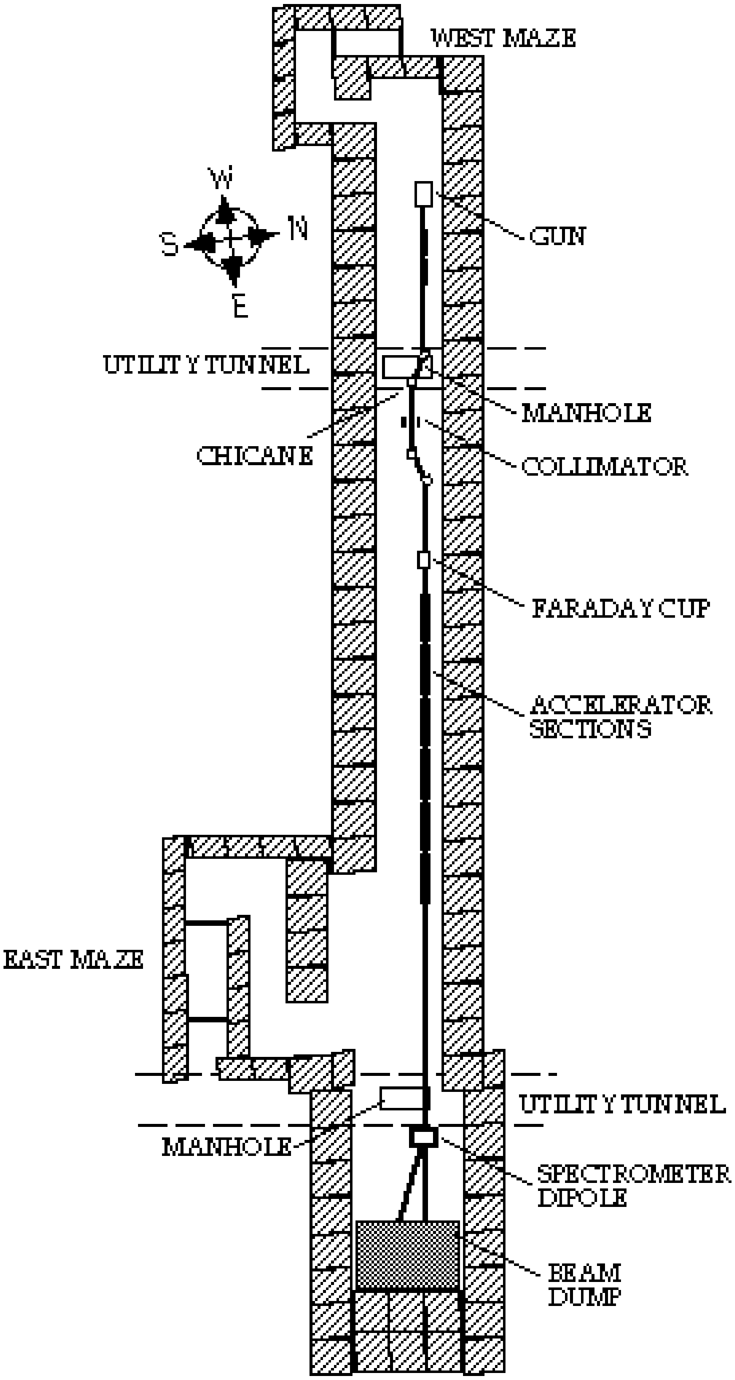

Figure 3-1. Plan View of the NLCTA

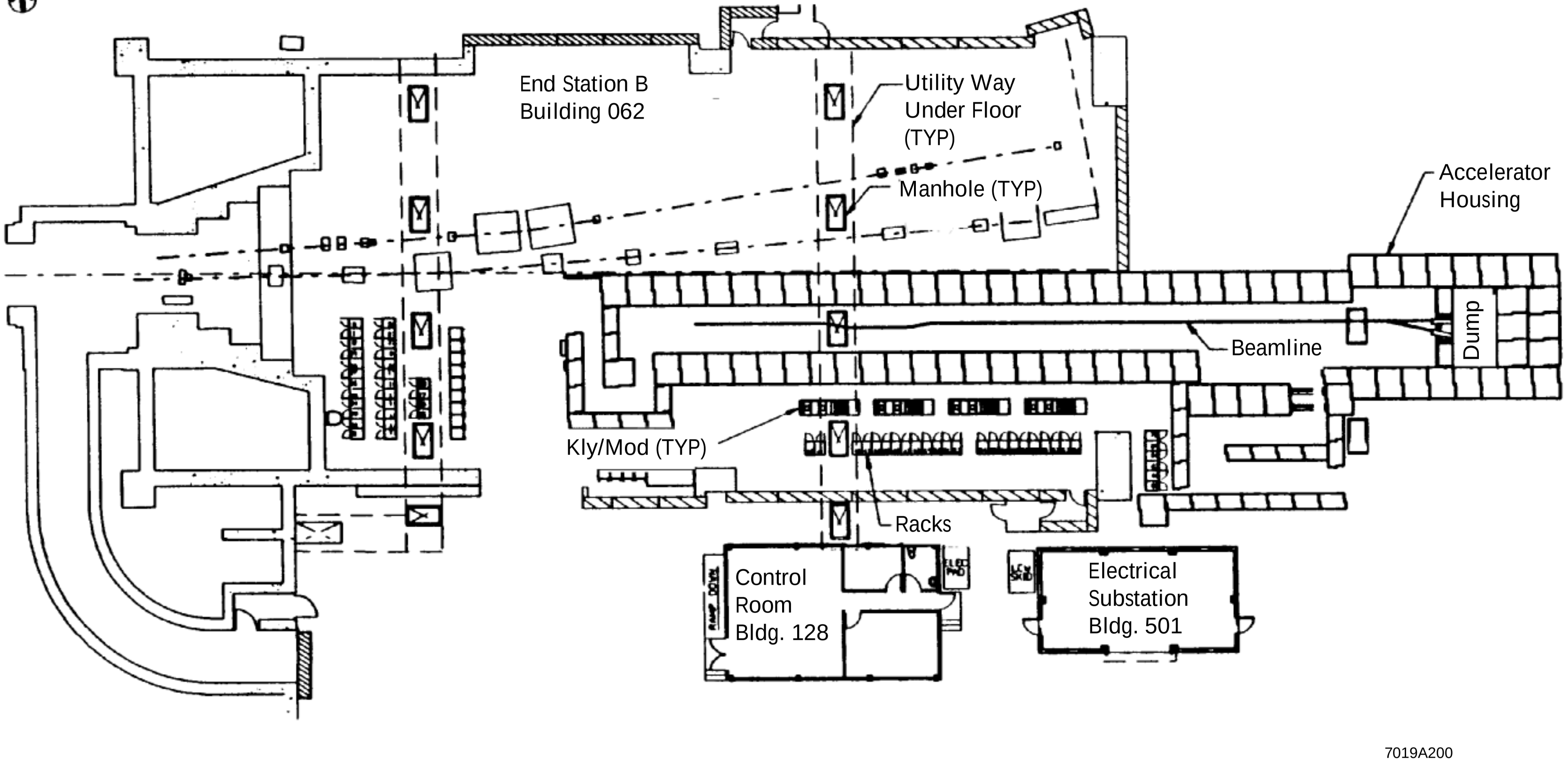

Figure 3-2. NLCTA Site Plan

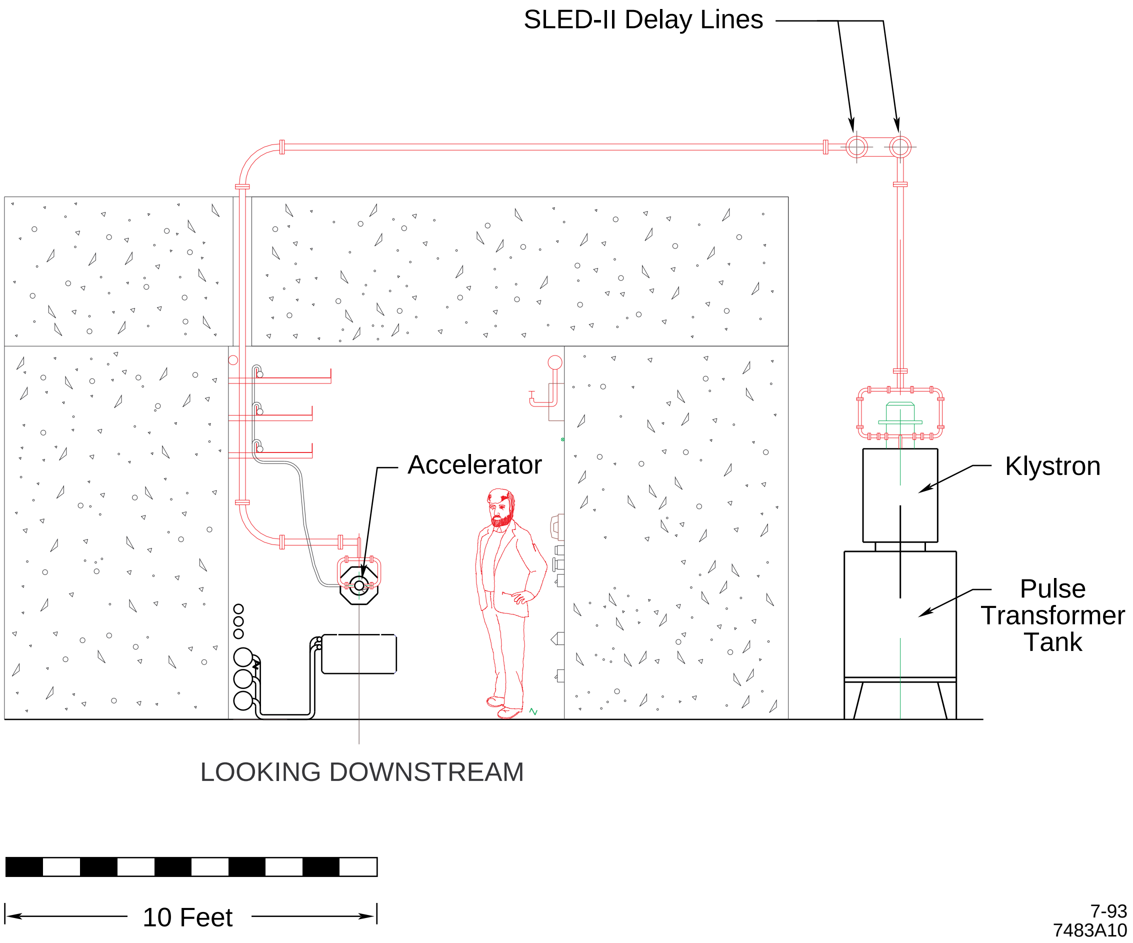

Figure 3-3. Cross-sectional View of the NLCTA Linac

4

Operating Organizations

4.1 Personnel and Responsibilities

The personnel involved in accelerator operations include the NLCTA Operations Manager, the NLCTA Operations Engineer, the NLCTA Operator in Charge (OIC), other control room operators, the NLCTA Program Deputy, other accelerator physicists, and other control room staff who are assigned to the NLCTA.

Any accelerator system capable of producing a beam, including high-power rf, may be operated only when there is a valid Beam Authorization Sheet (BAS) and when a qualified OIC is on duty.

The OIC is the qualified operator designated, in the Operations Log, to be in charge of operations at that time.

OIC qualification consists of learning to operate the NLCTA in a safe and efficient manner through a specified set of training classes, some of which apply to all SLAC operations, and some of which are specific to the NLCTA. In addition to the specified training, competency must be certified by the NLCTA Operations Manager.

The Operations Engineer supervises operator training and maintains records that indicate the training and qualifications of the control room operators.

The control room staff may also include accelerator physicists, engineers, experimenters, and others who operate the accelerator controls to commission new hardware or software, diagnose problems, or perform specific experiments.

The responsibilities of the different participants are described in detail in *NLCTA Operations Directives*, Section 2 (02-02-01, draft dated May 22, 1995). The list of contents of *NLCTA Operations Directives* is attached as Attachment 1.

4.2 Training

Table 4.1 shows the required training for personnel engaged in maintenance or operations at the NLCTA. For the most part, the courses listed are standardized courses presented by the ES&H Division; however, qualified operators of NLCTA are required to receive special training in control room procedures and in use of the Radiation Safety Systems (see *NLCTA Operations Directives*, Section 2 and Section 3, draft dated May 22, 1995).

Table 4.1: Safety Training Matrix for Operations and Maintenance Personnel

Training Requirements	Job Descriptions																		
	Ops	Klystr Techs	Fire Dept	P.E. Labor	P.E. Plumb	P.E. Rigger	P.E. Instr	P.E. M Util	P.E. Electr	P.E. M Fab	Contr Techs	Facil Janitor	Facil HVAC	Mech Vac	Mech Techs	OHP Techs	Cryo Techs	Power Techs	Align Techs
Search Procedures	✓																		
Entry Requirements & HV Safety	✓																		
Radiation Training for NLCTA	✓																		
Emergency Responder Trng			✓																
Overhead Crane						✓													
Cryo Storage & Handling																	✓		
Fork Lift				✓		✓		✓	✓	✓									
ES&H Mach Guard (#198)										✓			✓						
ES&H Gen. Safety (#219)		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ES&H Haz Comm.(G) (#103)				✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
ES&H Haz Comm (S) (#101)																			
ES&H Intro to Haz W (#177)		✓		✓	✓		✓	✓	✓	✓			✓			✓			
ES&H Rad Cont Tech (#237)																✓			
ES&H Gen Rad Trng (#115)			✓									✓	✓						
ES&H Rad Wkr Trng (#116)	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓
ES&H Elec. Safety (B) (#135)		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ES&H Elec Safety (LV) (#243)							✓		✓										
ES&H Nat Elec Code (#260)									✓										
ES&H CPR (#138)		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ES&H Elec Safety HV (#112)									✓										
ES&H Fire Extinguisher (#108)		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ES&H Lock & Tag (#157)		✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓
ES&H Lead Safety (#240)																✓			
ES&H Hearing Cons (#222)		✓																	
ES&H Respir. Safety (#241)					✓			S	S	✓		✓	✓			✓	✓		

4.3 SLAC Guidelines for Operations

The NLCTA, like all accelerator facilities at SLAC, is governed by *SLAC Guidelines for Operations*. These documents specify methods and procedures by which accelerator and detector operations are conducted in conformance with DOE 5480.25 Safety of Accelerator Facilities. The *Guidelines* stipulate the responsibility for operations management, responsibilities of various key positions, the requirement for formality and documentation of various activities, and describe mandatory procedures for configuration control of safety systems. Personnel engaged in accelerator operations or maintenance are required to be familiar with these *Guidelines*. A listing of Guideline titles is attached as Attachment 2.

Attachment 1: NLCTA Operations Directives — Contents List[1]

1. Program Control
    1.1. Personnel and Responsibilities
        1.1.1. Management
        1.1.2. Operations Manager
        1.1.3. Operations Engineer
        1.1.4. Operator in Charge
        1.1.5. Program Deputy
        1.1.6. Accelerator Physicists
    1.2. Directives
        1.2.1. Program Schedule
        1.2.2. Alternate Program
2. Accelerator Operations
    2.1. Personnel and Responsibilities
        2.1.1. Operator in Charge
        2.1.2. Operations Manager
        2.1.3. Program Deputy and Accelerator Physicists
        2.1.4. Control Room Watch
    2.2. Directives
        2.2.1. Shift Protocol
        2.2.2. Operating Procedures
        2.2.3. Accelerator Operations Equipment
        2.2.4. Record Keeping
3. Safety
    3.1. Personnel and Responsibilities
        3.1.1. Operator in Charge and Control Room Staff
        3.1.2. Operations Engineer
        3.1.3. Operations Manager
        3.1.4. Accelerator Department Safety Office
        3.1.5. Radiation Physics Department
    3.2. Directives
        3.2.1. Safety Rules and Procedures
        3.2.2. Key Control
        3.2.3. Safety Communications
        3.2.4. Safety Record Keeping
4. Maintenance
    4.1. Personnel and Responsibilities
        4.1.1. Area Manager
        4.1.2. System Physicists and Engineers

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[1] Draft dated May 22, 1995.

Attachment 2: List of Titles in *SLAC Guidelines for Operations*

Guideline 1	Operations Organization and Administration
Guideline 2	Management of Work in Accelerator Facilities
Guideline 3	Accelerator Maintenance Management
Guideline 4	Operations Procedures
Guideline 5	Safety Organization
Guideline 6	Shift Routines
Guideline 7	Incident Reports
Guideline 8	Emergency, Incident, and Alarm Response
Guideline 9	Control Room Activities
Guideline 10	Communications
Guideline 11	Operator Training
Guideline 12	Safety in the Accelerator Housings
Guideline 13	Radiation Safety
Guideline 14	Configuration Control of Radiation Safety Systems
Guideline 15	Control Over Activated Material
Guideline 16	Radiological Work Controls
Guideline 17	Electrical Safety
Guideline 18	Control of Work on Electrical Devices in Beam Housings
Guideline 19	Use of Software-based Control Systems
Guideline 20	Configuration Control of Atmospheric Safety Systems
Guideline 21	Equipment Identification
Guideline 22	Standards for Alarms, Warnings, and Advisories
Guideline 23	Safety Deficiency Reviews and Continued Operations
Guideline 24	Safety Review of Major Modifications
Guideline 25	Preparation of Safety Assessment Documents
Guideline 26	Safe Use of Liquefied Nitrogen

5 Research Organization

5.1 Program Management[1]

The personnel involved in defining and scheduling the accelerator program include the Associate Director of the Technical Division, the NLCTA Facility Head, the NLCTA Operations Manager, the NLCTA Operations Engineer, the NLCTA Program Deputy and accelerator physicists, and the NLCTA Facility Engineer and Area Manager.

In general, the aspects of the program concerning experimental accelerator physics are the responsibility of the Program Deputy (assisted by other accelerator physicists); the aspects of the program concerning accelerator maintenance and improvements are the responsibility of the Facility Engineer (assisted by the Area Manager); and coordination of accelerator operations with accelerator physics experiments, maintenance, and improvements is the responsibility of the Operations Manager (assisted by the Operations Engineer).

Carrying out the short-term schedule at all times will be the responsibility of an Operator in Charge (OIC). The OIC title is transient, and is passed among a group of qualified people that includes, but is not limited to, the Program Deputy or another accelerator physicist, or the Operations Engineer. The OIC assumes OIC responsibilities typically for the duration of one shift (six to eight hours). The name of the person holding the OIC title will be indicated in the Operations Log at all times when the NLCTA is operating.

Management involved in program control includes the Associate Director, Technical Division, and the NLCTA Facility Head. Together with the NLCTA Operations Manager, they specify the long-term and short-term schedules for the accelerator program. The NLCTA Facility Head publishes the long-term schedule, in consultation with the Associate Director, Technical Division. The NLCTA Operations Manager translates the long-term schedule into a short-term schedule.

The short-term schedule is reviewed at accelerator management meetings and is updated as needed in response to problems or delays. The accelerator management meeting is usually attended by the NLCTA Facility Head, the Operations Manager, the Program Deputy, the Facility Engineer, and the Operations Engineer.

5.1.1 Operations Manager

The program control responsibilities of the Operations Manager (OM) are as follows:

- Develop and manage the short-term schedule so as to ensure safe and effective utilization of the NLCTA facility. This responsibility may be delegated to the Operations Engineer.
- Monitor the activities of the Operations Engineer and the Operator in Charge and provide assistance where needed.
- Conduct operations meetings as necessary to review progress, announce schedule modifications, and dispatch resources.
- Review all maintenance activities that could affect machine operation.

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[1] See also: *NLCTA Operations Directives*, Section 1, Program Control, draft May 22, 1995.

- Review the performance of the Operations Engineer and the qualified operators with regard to operational safety, and make recommendations to the NLCTA Facility Head as to their fitness for accepting operational responsibility.
- Give a summary report of accelerator operations in accelerator management meetings.

The OM may be an accelerator physicist and may participate in accelerator physics experiments.

5.1.2 Operations Engineer

The Operations Engineer (OE) position is filled by an experienced accelerator operator, usually trained by the SLAC Accelerator Department as an EOIC. The OE usually assumes the OE responsibilities for an indefinite period of time. The OE is expected to frequently assume the role of “Operator in Charge” when operations are in progress, and is on call for all operations. The OE may participate in accelerator physics experiments. The OE attends the daily Operations Meeting and is encouraged to attend the shift change meetings.

The program control responsibilities of the OE are as follows:

- Assume the responsibilities of Operator in Charge frequently when operations are in progress, whenever doing so does not conflict with the other responsibilities of the OE.
- Monitor the activities of the Operator in Charge and provide assistance where needed.
- Provide an alternate program when it becomes impossible to carry out the scheduled accelerator program.
- Change the program to make optimal use of the accelerator when neither the primary program nor the alternate programs can be carried out.
- Give a summary report of operations in Operations Meetings.
- Qualify operators in safety, operations, procedures, and in the various accelerator subsystems.
- Develop improvements and upgrades to accelerator tuning procedures and equipment.

6

Safety Analysis Methodology

The methodology used is based upon the guidance given in SAN Management Directive 5481.1A of September 1989.

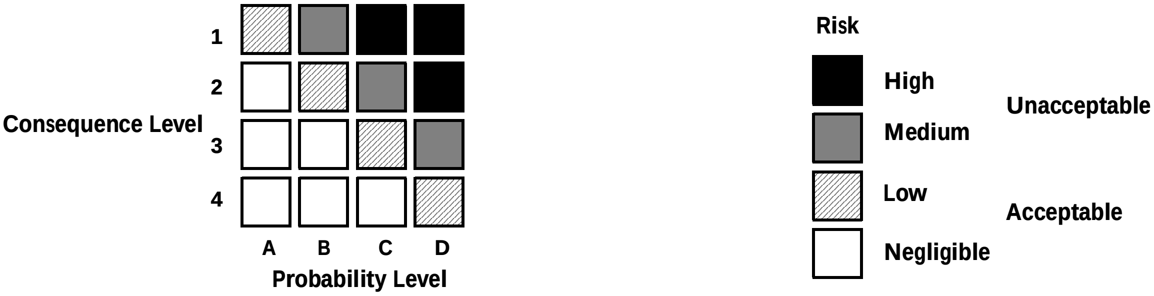
Table 6-1: Probability Rating Levels

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

Table 6-2: Consequence Rating Levels

Consequence Level	Description Words	Maximum Consequence
1	High	Serious impact on site or off site. May cause deaths or loss of the facility/ operation. Major impact on the environment.
2	Medium	Major impact on site or minor impact off site. May cause death, severe injury, or severe occupational illness to personnel or major damage to a facility/operation or minor impact on the environment. Capable of returning to operation.
3	Low	Minor 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.

Figure 6-1:Risk Matrix



Consequence Level	A	B	C	D
1	▨	▓	■	■
2	□	▨	▓	■
3	□	□	▨	▓
4	□	□	□	▨

Probability Level

Risk

■ High
▓ Medium
Unacceptable

▨ Low
□ Negligible
Acceptable

7 Safety Analysis — Ionizing Radiation

7.1 Radiation Safety Systems

Radiation safety is ensured by a number of engineered safety systems and by the administrative measures associated with those systems. The engineered systems are:

- The shielding envelope, which functions as an attenuator of the radiation produced by the accelerated particle beams, such that radiation levels outside the shielding envelope are consistent with worker occupancy, and boundary doses are consistent with permitted off-site levels. The shielding envelope also serves as an access control barrier to prevent personnel from entering high-level radiation areas.
- The Personnel Protection System (PPS), which controls personnel access to the accelerator systems within the shielding envelope in such a manner that personnel access is not permitted when radiation hazards are present.
- The Beam Containment System (BCS), which ensures that the beam remains within the channel which was envisaged for the shielding design, and acts to terminate operations through independent shut-off channels if there is evidence that the channel has been breached.
- The Beam Shut-Off Ion Chamber (BSOIC) system, which acts as a secondary backup system to detect when radiation levels outside the shielding enclosure exceed preset levels (nominally 100mrem / hr). If such is the case, the system terminates operations through the PPS shut-off channels.

Administrative measures include:

- The Beam Authorization Sheet (BAS), which is a document that is required to be completed prior to operation of the beam into any of the possible channels for a particular accelerator. It serves as a detailed prescription of the measures required to ensure that operations remain within the Accelerator Safety Envelope. Signatures are required initially by the Radiation Physicist responsible for the particular beam channel, and from the Accelerator Department Safety Officer, and thereafter signatures are required by operations supervisors on a shift-by-basis. The document is the responsibility of the Radiation Physicist assigned to the area concerned and is approved by the Accelerator Department Safety Office (or the SSRL Safety Office).

Each BAS is divided into the following sections:

- Pre-Running Conditions: Provides for the sign off and approval of inspections or check out of radiation safety items including shielding inspection, PPS and BCS items, and BSOICs.
- Initial checkout: Provides for the sign off and approval of any tests to be conducted requiring beam on, such as radiation surveys or ion chamber response calibration.
- Running Conditions: Itemizes all radiation safety items required to be in place or active throughout the period of beam operation. Also included are allowable beam power limits and beam destinations for the area under consideration.

- Changes or additions: During a running period changes or additions to any part of the BAS may be made with the joint approval of the Radiation Physicist and the Accelerator Department Safety Office (ADSO) or SSRL Safety Office representative.
- Operator Sign-Off Sheets: The Operator in Charge is responsible for ensuring that the Running Conditions are complied with during beam operation and signs at the beginning of the shift to acknowledge any changes or additions that have been made.

Configuration control of radiation safety systems is assured by:

- Design and construction of radiation safety systems are carried out in accordance with the *Quality Implementing Procedure for the NLCTA*, and in conformance with the general design features described in Appendices A, B and C of this document. Testing and periodic functional testing of the systems is done in accordance with formal procedures approved by the Department Head, Controls Department, Technical Division.
- *SLAC Guidelines for Operations*, Guideline 14, which requires written authorization before any work is carried out on any of the radiation safety systems above, and specifies requirements for post-work testing.
- Formality in initial check out, periodic component checks, and semiannual safety system tests which are required to be in accordance with written procedures.

Sections 7.1.1, 7.1.2, and 7.1.3 provide detailed descriptions of the engineered radiation safety systems as implemented at the NLCTA. (Appendices A, B, and C describe the general design of these systems at SLAC.) Section 7.2 describes the shielding design. A hazard analysis follows in Sections 7.3.1 and 7.3.2.

7.1.1 The Personnel Protection System at the NLCTA

The Next Linear Collider Test Accelerator (NLCTA) PPS Access Control System is a four-state access system:

- **Permitted Access**
- **Controlled Access**
- **Restricted Access**
- **No Access**

Entry into the NLCTA beam line housing will require verification that all electrical and radiation hazards are off. If the status of any radiation hazard is lost when the housing is in **Permitted**, **Controlled**, or **Restricted Access**, then the PPS Access Control System will not allow transfer to other access states. In addition, an audible alarm will be sounded at the PPS control console, requiring intervention by the NLCTA operator to investigate. If the “off” status of any radiation hazard is lost while the housing is in the Controlled Access state, all keybank releases will be disabled.

The NLCTA beam line housing has two entrance points (Figure 7.1). Both are standard access modules. One is located at the west end of the beam line housing, and the other is approximately 3/5 of the way down the housing from the west end. Each access module contains an Outer Door, Inner Gate, Keybank, Access Annunciator panel, Door Control boxes, Emergency Entry/Exit buttons, Search circuit boxes, Telephone, Yellow/Magenta warning lights, Door Bypass strobe, and a TV camera (Figure 7-2). The Outer door will use a magnetic lock (magnalock). This device is an electromagnet which secures the door in the closed position. A circuit will monitor this device to ensure its contact with its door stop and monitor its magnet current to ensure proper operation.

The PPS Access Control System will be operated from the PPS control console located in the NLCTA Control Room, Building 128. A second panel will be located in the PPS back up rack, B062 Rk. 01, and will be used by the PPS crew for maintenance and certification purposes only. The logic will be designed using fail-safe and redundant relay circuit techniques. All hardware will be housed in locked cabinets and racks. Wires and cables will be protected in conduit, armored cable, or trays.

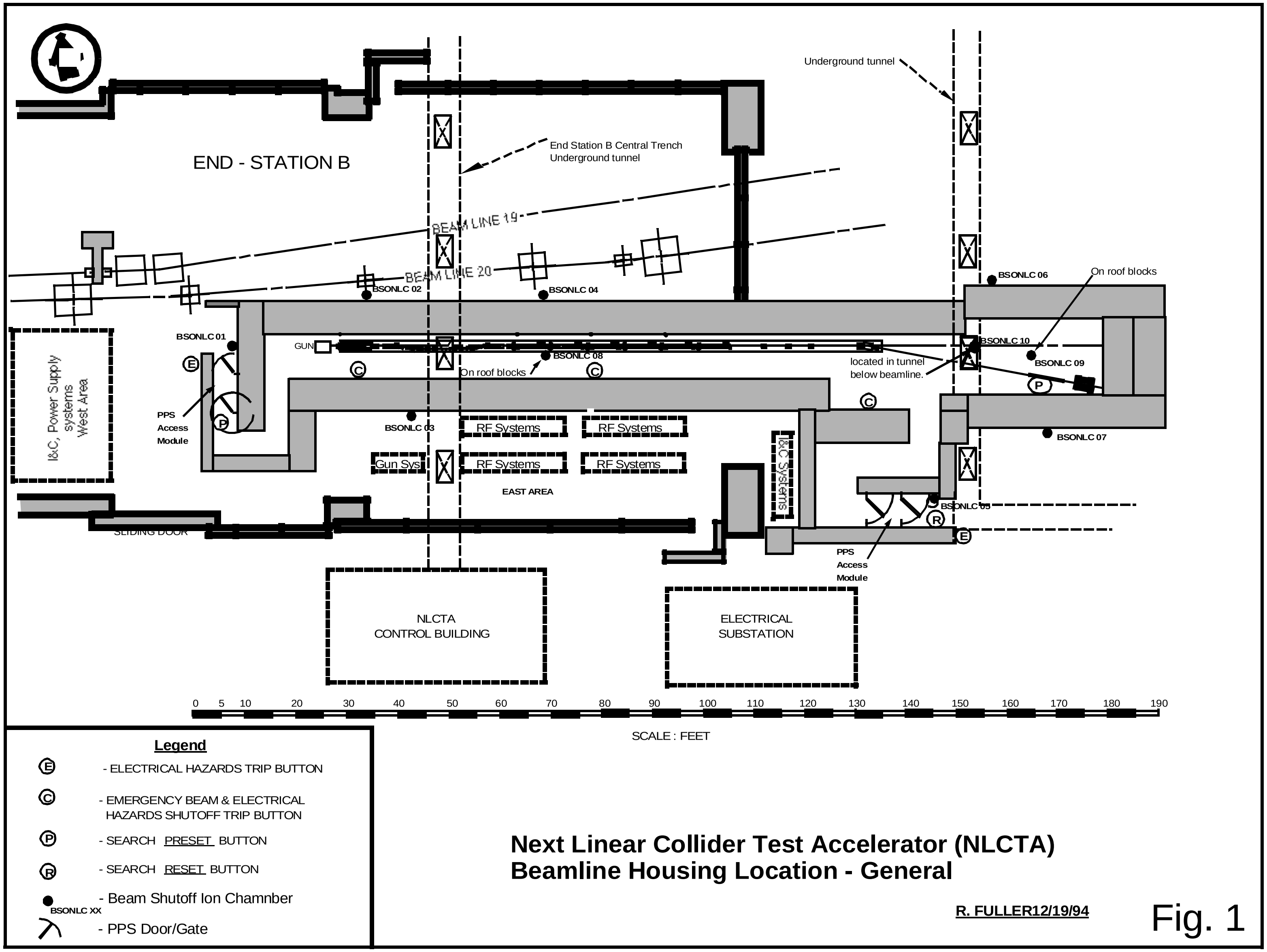


Figure 7.1: NLCTA PPS General Layout

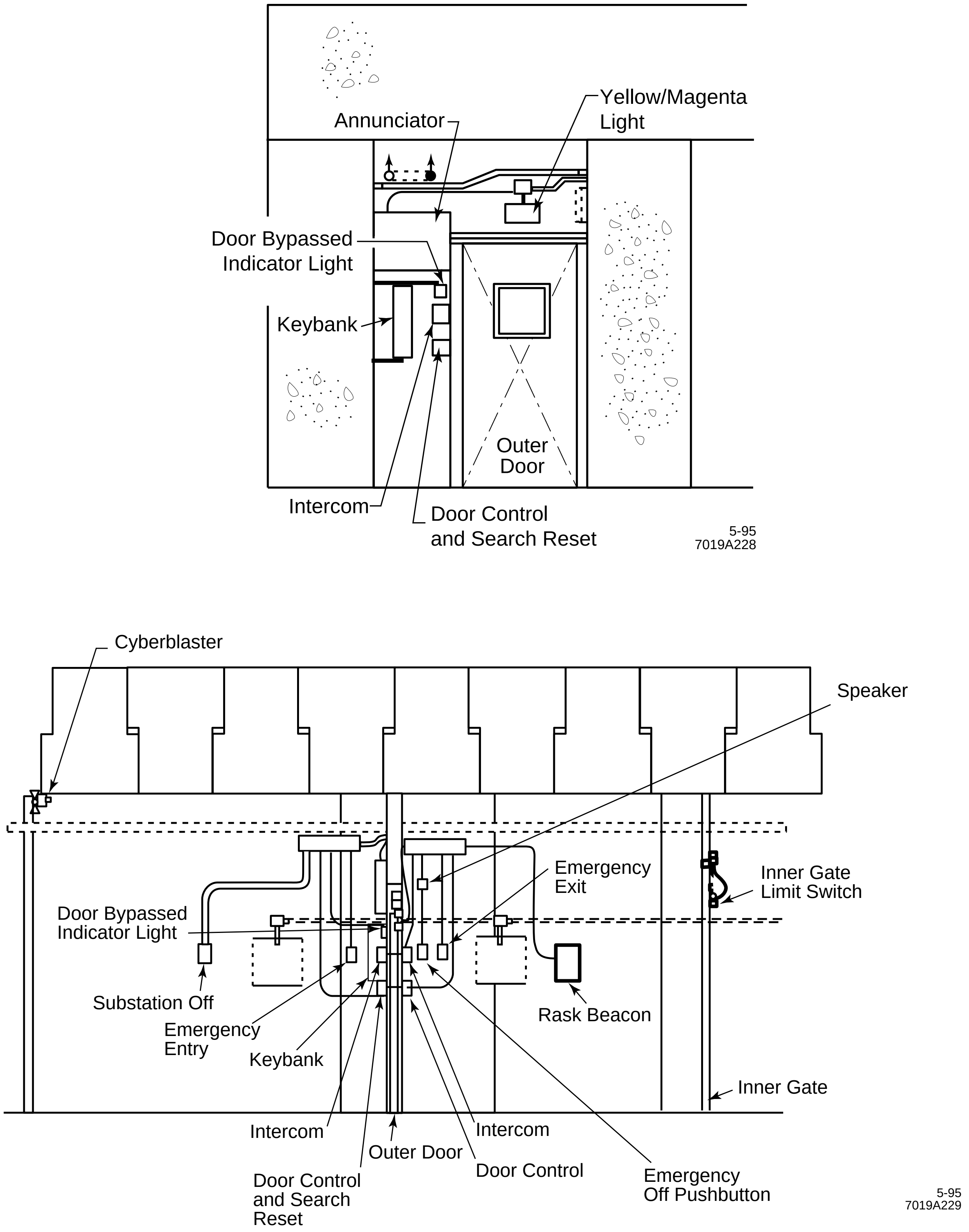


Figure 7-2. NLCTA PPS Door Configuration

7.1.1.1 Normal Entry and Exit Procedure for Controlled Access

Assuming that the NLCTA facility is in the No Access state, the following procedural steps will be followed to enter the housing under Controlled Access:

1. All beam stoppers and electrical hazards will be set to their on / off state by the NLCTA operator. The specific stoppers are:
    a. Thermionic Gun HV Power Supply, Injector Section
    b. RF station No. 1 Modulator HV Power Supply
    c. RF station No. 2 Modulator HV Power Supply
    d. RF station No. 3 Modulator HV Power Supply
    e. RF station No. 4 Modulator HV Power Supply
2. The NLCTA operator will set the access state of the facility to Controlled Access.
3. A radiation survey of the beam line housing components will be made by Operational Health Physics (OHP) technicians as arranged by the NLCTA operator.

At this point, access to the beam line housing is controlled by the NLCTA operator as follows:

a. OHP individuals requesting access to the beam line housing will be identified and logged in by the NLCTA operator via visual and audio communication at the point of entry.

b. Once logged in by the operator, a key release push button will be pressed by the operator at the PPS control console. While the push button is held down, one key by each individual will be removed from the keybank. This key is to be kept in the personal possession of the individual throughout his / her stay in the housing.

c. Once a key has been released to each individual, one individual of the group will insert his / her key into the Door Control box, rotate the key clockwise, and hold. In concert with this action, the NLCTA operator will press and hold down the door-release push button. The outer door can then be opened and the individual can remove and retain his / her key. Those individuals with keys are monitored and allowed to pass through the outer door. Once all individuals have passed through the outer door, and the last individual entering has closed the outer door, the NLCTA operator can then release the door-release push button.

Note:*If, for any reason, the door release push button is released prior to the closure of the outer door, the search circuit will be faulted, requiring a re-search of the housing by qualified operators.*

d. Individuals can immediately pass through the inner gate following the outer door. The inner gate is to be left in the open position for the duration of the access.

e. To exit the housing, an individual must contact the NLCTA operator, request to exit, and insert and rotate the key in the control box. In concert with this action, the NLCTA operator will depress and hold down the door-release push button while the individual exits through and closes the outer door.

The NLCTA operator may now release the door release push button.

Note:*If, for any reason, the door-release push button is released prior to the closure of the outer door, the search circuit will be faulted, requiring a re-search of the beam line housing by qualified operators.*

4. After the radiation survey is completed and OHP has approved occupancy, the NLCTA operator will control access to the housing through either the east or west access modules, by the release of keybank keys as outlined in Step 3 above.

7.1.1.2 Normal Entry and Exit Procedures for Permitted Access

Assuming that the NLCTA facility is in the No Access state, the following procedural steps will be followed to enter the beam line housing under Permitted Access:

1. All beam stoppers and electrical hazards will be set to their on / off state by the NLCTA operator.
2. The NLCTA operator will set the access state of the facility to Controlled Access.
3. A radiation survey of the beam line housing components will be made by Operational Health Physics (OHP) technicians as arranged for by the NLCTA operator, just as in Step 3.
4. After the radiation survey is completed and OHP has approved occupancy, the NLCTA operator will set the access state to Permitted Access. Setting this state automatically releases the Search Reset status.
5. At this point, any individual can enter or exit through either gate into the housing.

7.1.1.3 PPS Security Fault Violations

A Security Fault violation can only occur in the No Access, Restricted Access, or Controlled Access states.

A Security Fault violation in the No Access and Restricted Access states is defined as:

1. Operating the Emergency entry / exit button at the outer doors located at the Access Modules.
2. The act of opening the inner gate at either of the NLCTA Access Modules. Security Faults for this action occur in No Access and Restricted Access only.
3. Operation of any Emergency Beam Shut-Off push button (five each) along the aisle way inside the NLCTA beam line housing and access mazes.
4. Loss of keybank “complete” status.

Any of these Security Fault violations will remove the PPS permits to all radiation and electrical hazards. All of the above Security Fault violations will result in a loss of the Search status, thus requiring a re-search of the NLCTA beam line housing. The loss of Search status does not change the access state.

A Security Fault violation in the Controlled Access state is defined as an Emergency entry or exit through the outer door located in the Access Modules. A Security Fault violation will result in a loss of the Search status, thus requiring a re-search of the NLCTA beam line housing.

There are no Security Fault scenarios for the Permitted Access mode.

7.1.1.4 Search Circuit — NLCTA Beam Line Housing

The Search circuit for the NLCTA beam line housing is comprised of two Search Preset boxes located at the west and east ends of the housing. A Search Reset box is mounted outside the housing at the east Access Module entry. All preset and reset boxes will require a key for actuation. The search logic requires that the NLCTA be set to Controlled Access prior to any search activities. The locations of the Search Reset and Preset boxes are shown in Figure 7.1, page 7-3.

The Search Reset is complete when:

1. The Search Presets for the housing are set.
2. All gates and doors are closed.
3. The Emergency Off buttons are reset.
4. Both Access Module keybanks are “complete.”
5. The searcher outside the housing at the east Access Module and the NLCTA PPS operator at the control room console push their respective Search Reset button simultaneously to set the Search Reset.

After the Search Reset is set, setting the NLCTA back to Permitted Access or having a Security Fault will trip the Search Reset circuit.

7.1.1.5 Visual and Audio Warnings

Both visual and audio warnings will be activated when the access state of the NLCTA beam line housing is set to Restricted Access and No Access. When the housing is set to Restricted Access, the housing lights and Emergency Off pilot lights will flash and a recorded warning message will be played for approximately 2 minutes. The message will be:

> *“Attention. The Electrical Hazards are about to come on. Press the nearest Emergency Beam Shutoff button and call extension 5481 immediately.”*

When the housing is set to No Access the housing lighting will flash and a recorded warning message will be:

> *“Attention. The beam is about to come on. Press the nearest Emergency Beam Shutoff button and call extension 5481 immediately.”*

The flashing lights and message will continue for 2 minutes. No permits to radiation hazards will be issued by the PPS until this message has timed out without the activation of an Emergency Beam Shutoff button or opening a housing gate. Should an Emergency Beam Shutoff button be pushed during the warning cycle, the warning message will be terminated and the Search circuit will be faulted. If either inner gate is opened, the warning message will be terminated, the Search circuit will be faulted, and the housing lights will come on full bright.

7.1.1.6 PPS Keybanks

There are two keybanks, one at the entrance of each Access Module. Both keybanks are required to be complete in order to transfer from Controlled Access to Permitted Access.

7.1.1.7 PPS Emergency Beam Shutoff

The Emergency Beam Shutoff circuit is comprised of five push button boxes located along the aisle way of the housing and in the access mazes. The five boxes inside the housing will be identified with signs "Emergency Beam Shutoff."

With the housing in the Restricted Access or No Access modes, pushing any of these buttons will create a Security Fault. With the NLCTA in Controlled Access the buttons are not active. Each push button station will be tested by the search team for trip status. The reset function of the Emergency Beam Shutoff circuit can only be done in the Controlled Access mode.

7.1.1.8 PPS Emergency Entry/Exit

The Emergency Entry/Exit device for the outer door of each NLCTA Access Module is made up of two 4" × 4" × 6" boxes, one located on each side of the outer door. They have red shrouded push buttons located behind clear pull-away covers. Pushing these buttons will release the door magnalock, allowing egress. An audio alarm will sound at the entry/exit point and in the NLCTA control room. The alarm can be silenced by pushing a button on the NLCTA control room PPS control panel. With the NLCTA in No Access, Restricted Access, or Controlled Access states, making an emergency entry or exit will create a Security Fault.

7.1.1.9 Burn Through Monitors (BTM)

There are no Burn Through Monitors (BTMs) required for the NLCTA at this time.

7.1.1.10 Beam Shutoff Ion Chamber (BSOIC)

There are plans to incorporate 12 channels for BSOICs. There are presently 10 BSOICs assigned to various locations around the housing (see Figure 7.1, page 7-3). If radiation levels exceed their preset threshold, the units will shut off all radiation hazards. Analog readout and reset function will be on the Control Computer (VAX). BSOIC analog levels will also be in the VAX history buffer.

7.1.1.11 Correct functionality of the PPS is assured by the following administrative systems:

- Whenever an area is searched, specific tests of door switches and emergency-off buttons are required to be performed by the members of the search team. These tests are described in the NLCTA PPS Interlock Checklists.
- Semi-annual validation is performed on the entire PPS system in accordance with formal procedures published by the Controls Department and approved by the Accelerator Department Safety Office.
- Formal procedures (*SLAC Guidelines for Operations*, Section 14) which mandate that no work be performed on the system without a Radiation Work Control Form.

7.1.2 NLCTA Beam Containment System

7.1.2.1 Introduction

Beam containment for the NLCTA Facility is achieved by a combination of mechanical and electronic devices.

7.1.2.2 Equipment Description

The simplicity of the NLCTA configuration means that beam containment can be assured by a combination of air cooled dumps, collimators, and discrete ion-chambers.

Protection Collimators

Protection collimators will be installed downstream of the horizontal bend locations (chicane and spectrometer) to prevent an errant beam from targeting in the shielding wall.

Discrete Ionization chambers

Typically, these are argon-filled cylinders about 15 inches long and 4 inches in diameter. High voltage is applied to one of the internal electrodes. The output signal developed on the other electrode is transmitted on coaxial cable to an electronic processing module in MCC or one of the support buildings.

Burn-Through Monitors

These detect the onset of damage to mechanical devices, and turn off the beam through the PPS shut off paths.

Note: *No BTMs are considered necessary in the initial configuration, but may be required in the upgraded configuration.*

7.1.2.3 Administrative Procedures

Beam Authorization Sheet

The Beam Authorization Sheet (BAS) (see Section 7.1 above) specifies the beam containment devices that must be active or present for each beam line during a running cycle. The BAS is prepared by the Responsible Radiation Physicist and approved by the Accelerator Department Safety Office.

Before each beam running cycle, the electronic devices that are required for each beam line, as defined in the Beam Authorization Sheet (BAS), are validated using written procedures.

Daily/Weekly Test Procedures

Even though all of the sensors, modules, and their connecting cable plant use self-test signals to ensure system integrity, daily or weekly checks are carried out on all of the BCS equipment that is required to be active by the Beam Authorization Sheet. This includes verification of trip point settings and confirmation that all shut-off paths are operating normally.

Configuration Control

Procedures that control the modification and retesting of Beam Containment system are described in the *SLAC Guidelines for Operations*. All changes must be carefully reviewed and approved, and retesting must be done in accordance with an approved procedure.

7.1.3 NLCTA Beam Shut-off Ion Chamber (BSOIC) System

The NLCTA is located in a 170-foot-long concrete tunnel originating in End Station B. The beam produces negligible radiation along the accelerator except when beam missteering or equipment failure causes significant beam loss. If the beam is not properly contained in its beam channel (by the Beam Containment System), elevated radiation levels may exist in occupied areas. To prevent these elevated levels from remaining unnoticed for any length of time, a number of interlocked BSOICs have been installed around the shielding perimeter. The BSOICs are connected to the NLCTA Control Room and provide the following output signals:

- An analog signal that gives the actual radiation level at the BSOIC
- A beam interlock signal which acts to shut off the beam when the upper set point is exceeded

7.1.3.1 Locations

The specific location for each BSOIC is determined by a Radiation Physicist and is based on considerations such as the thickness of shielding and the likelihood of beam missteering or loss at a point in a beam line. Initial locations are shown in section 7.1.1 on page 2 and Figure 7.1, page 7-3. Current locations for all BSOICs are recorded on the “SLAC Site Plan, Radiation Monitor Locations,” drawing number GP 885-125-02, prepared and maintained by the Operational Health Physics Department.

This drawing also lists:

- The trip level for each BSOIC.
- The precise location.
- The instrument serial number.
- The height at which the BSOIC is mounted.
- The Responsible Radiation Physicist for each area.

7.1.3.2 Administrative Procedures

Configuration Control

In accordance with the requirements of the *SLAC Guidelines for Operations*, all work on the BSOIC system is performed using Radiation Safety Work Control Forms. Personnel who work on these systems are specifically assigned and authorized to do this work.

7.2 Shielding Design

7.2.1 Design Criteria

The shielding for the NLCTA was designed to limit to 1 rem / y the integrated dose near the surface of the shield around the NLCTA. This goal was taken to correspond to limiting the continuous dose rate at the surface of the shield in occupied areas to 2 mrem / h, assuming the maximum credible average beam power after upgrade, the nominal beam-loss fractions, operation for 1,000 hours per year, and an occupancy factor of one half. The occupancy factor is extremely conservative, since there is no office or other full-time work space immediately adjacent to the NLCTA shielding.

The above design goal implicitly satisfies the DOE requirement for a low-hazard facility: that individual exposures must never be able to exceed 25 rem in any one hour of operation with maximum credible losses at the maximum credible beam power, in the event that the Beam Containment System fails. Here, “maximum credible losses” means 100% loss in either the chicane or the linac.

A SLAC design guideline [Appendix 10] further limits, to 3 rem, the total integrated dose permitted in the event of a failure of beam containment. (Beam containment issues are discussed in detail in Appendix B.)

By achieving acceptable dose rates in the areas adjacent to the NLCTA, the shielding design results in negligible doses at the site boundary. See section 7.2.7 below.

The shielding-design calculations indicate the potential, under normal operating conditions for some unoccupied areas such as the roof of the enclosure and the beam dump, to experience doses greater than 5 mrem / h, (in large part because the concrete roof is 4 feet thick, in contrast to the walls which are 6 feet thick). However, some of these calculations are complicated by the presence of vertical penetrations for waveguides and cables. If a radiation survey verifies that these unoccupied areas do indeed experience doses in excess of 5 mrem / h, then they will be designated “radiation areas,” and will be identified by warning signs, barriers, and other methods, as appropriate, in accordance with SLAC policies. No areas outside the NLCTA shielding are expected to be “high-radiation areas,” where continuous doses exceed 100 mrem / h.

7.2.2 Calculation Methods

Most of the shielding calculations for the NLCTA were performed using the computer program SHIELD11. The original algorithm was developed by T. M. Jenkins, based on his empirical measurements [Appendix 7] and on additional calculations using the electromagnetic shower simulation code, EGS4. SHIELD11 is suitable for calculations of radiation levels behind slab shields resulting from beam losses on thick targets. SHIELD11 calculates total dose (per electron or per kW) and its five separate components:

- **GamD** — The direct photon component resulting from the electromagnetic shower. It has a sharp maximum in the forward direction and decreases steeply with angle up to approximately 5°, followed by a much milder decrease with angles above that value.
- **GRN** — Photo-neutrons produced in the Giant Resonance region, mostly by photons with energies below 30 MeV.
- **MID** — Photo-neutrons resulting from the pseudo-deuteron reactions induced by photons with energies above 30 MeV and up to approximately 300 MeV.
- **HEN** — High energy neutrons resulting from photo-pion production above the threshold of 140 MeV. This component is the most penetrating and therefore becomes dominant at high energies for thick shields, such as the walls of the NLCTA enclosure.
- **CamI** — The indirect photon component, generated by nuclear de-excitation and by neutron capture.

Most radiation levels were calculated assuming a “standard” target in SHIELD11: a 12-inch long iron cylinder with a 2-inch radius. Neutron attenuation in the target was neglected. Only for a few special cases, such as the Faraday cup and the beam dump, were different target materials or target sizes used.

When it was necessary to use additional methods and “rules of thumb,” the source terms often were calculated using SHIELD11. Only photon and neutron doses were of concern in the shielding calculations, except for the beam dump, where the potential for a muon dose in the forward direction was examined.

A summary of the beam parameters, expected beam losses, and resulting radiation levels in various areas of NLCTA is presented in the Appendix (Table A) of Reference [11].

7.2.3 Beam Line Enclosure

7.2.3.1 General Considerations

When the magnitude of expected beam losses is considered, it is practical to divide the beam line (excluding the dump) into two regions. The first region is the upstream one-third of the beam line — the injector, chicane, and Faraday cup —

where a large fraction of the beam power will be lost. The second region is the downstream two-thirds of the beam line — the linac and the spectrometer — where power losses will be less than 0.5%.

The thickness of the concrete shielding is the same in both regions: 6 feet for the walls, and 4 feet for the roof. Parts of the two entrance mazes have walls 3 feet thick. The 3-foot and 6-foot lateral walls, and the 4-foot roof all are constructed from specially-designed concrete blocks that interlock in order to prevent direct streaming of radiation. The contact surfaces of the wall blocks have interleaving 4-inch steps (see Figure 7-3). The roof blocks are wedge-shaped so as to permit them to interlock in alternating “up” and “down” orientations, as illustrated in Figure 7-3.

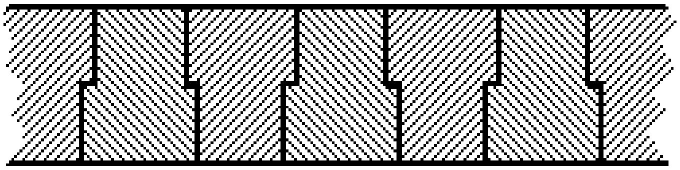


Figure 7-3. Longitudinal Elevation View of the Roof Blocks

In some corners of the beam line enclosure and the mazes, the wall blocks do not interlock as perfectly as was intended. The resulting gaps in these locations have been filled with concrete so as to avoid thin spots in the shield.

7.2.3.2 The Upstream Beam Line (Chicane and Faraday Cup)

Net beam loss of 30% is expected in the chicane bends and collimators. The full beam power will be dumped into the insertable Faraday cup approximately 30% of the running time. The maximum beam energy in this area will be approximately 75 MeV, upgradable to approximately 125 MeV. At these energies, the largest contribution to the dose rates at the side walls and on the roof will come from the photon component. The bend magnets and collimators were modeled in SHIELD11 as standard iron targets, 12-inch deep with a 2-inch radius. The Faraday cup was modeled as a tungsten cylinder, 3.75-inch deep with a 1.625-inch radius. Even though more beam power will be deposited in the Faraday Cup than in the chicane bends and collimators, radiation levels near the Faraday cup will be lower than in the chicane area because of the substantially higher photon attenuation in the Faraday cup.

After the planned upgrades, the continuous dose outside the lateral walls is estimated to be 0.7 mrem / h near the chicane and 0.4 mrem / h near the Faraday cup; the continuous dose on the roof, away from any penetration, is estimated to be 15 mrem / h above the chicane and 8 mrem / h above the Faraday cup. Local shielding around a roof penetration may be necessary to bring the continuous dose in the immediate vicinity of the penetration below 100 mrem / h. The roof will be posted as a radiation area if the roof dose is verified to exceed 5 mrem / h.

Inside the shielding enclosure, local shielding of collimators and bend magnets might be necessary in order to prevent tripping the Protection Ionization Chambers (PICs) located in the enclosure, downstream from the chicane. Such local shielding near the beam line additionally will reduce radiation levels on the roof.

The west end of the shielding enclosure, near the outer PPS gate, consists of only 3 feet of concrete perpendicular to the beam axis. If no additional shielding were present, radiation levels near the entrance to the West Maze resulting from expected losses in the chicane could reach 1.4 mrem / h. However, the very small solid angle subtended by this short wall, as seen from the chicane, is completely shadowed by magnets and other beam-line components. Consequently, the radiation level expected will be significantly less than 1 mrem / h. Depending on the results of preliminary radiation surveys, a small piece of lead might be installed immediately behind the gun to shield radiation streaming backwards through the beam pipe.

7.2.3.3 The Downstream Beam Line (Linac and Spectrometer)

Losses in the linac and spectrometer are not expected to exceed 0.5% of beam power under normal running conditions. The highest dose rates under normal conditions are expected near or beyond the end of the linac, where the energy of the beam is greatest. The continuous dose rate — after upgrades — is estimated to be 0.9 mrem / h in the occupied areas outside the walls, and 3 mrem / h on the roof. The roof will be posted as a radiation area if the roof dose is verified to exceed 5 mrem / h.

7.2.3.4 Beam Dump

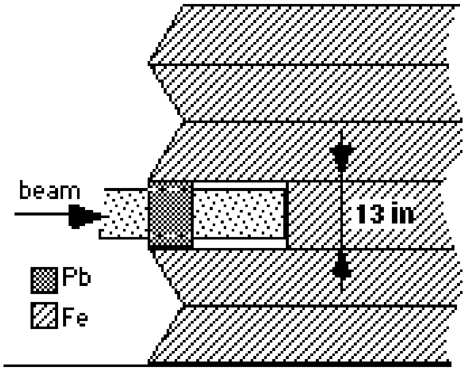


Figure 7-4. Vertical Section of the Front Face of the Beam Dump

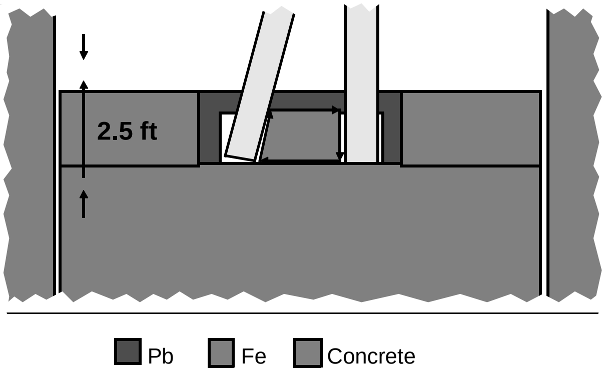


Figure 7-5. Horizontal Section of the Front Face of the Beam Dump at Beam-Line Elevation

Configuration

The NLCTA dump is a large block of iron (approximately $10 \times 15 \times 6$ ft^3) consisting of 6 superimposed iron slabs. The slab on which the beam will be centered is 13 inches thick, and all other five slabs have a thickness of 11.75 inches. The beam will be dumped in two possible locations: either straight ahead or at 12° with respect to the accelerator axis, depending on whether the spectrometer magnet is off or on, respectively. Details of the frontal part of the dump are shown in Figure 7-5.

External Shielding

In addition to the neutron and gamma radiation, the potential for a muon dose in the forward direction behind the dump was evaluated. After examining the muon energy-range tables in the computer program MUON89, it was concluded that the muons will not be an issue, since they will range out in the material of the dump. A similar conclusion was reached independently by Lavine [Appendix 8].

In the forward direction, there is approximately 8 feet of iron followed by 12 feet of concrete. The radiation levels outside the enclosure during normal operation will be negligible both before and after the upgrades. The maximum achievable dose rate at 0° is estimated to be 0.01 mrem / h. Lateral shielding for forward angles (less than 90° with respect to the beam direction) consists of at least 5.5 feet of steel and 6 feet of concrete for both dump lines and will ensure negligible radiation levels. The space created by the recess of the central slab will be filled with solid steel, which will be adjacent to the 8-inch lead shielding immediately surrounding the beam pipes, as shown in Figure 7-5. For angles greater than approximately 120° (that is, backwards) with respect to the beam direction, the rays are no longer fully contained by the steel. However, their path length through the concrete side walls increases with increasing angle. The maximum dose rates — which are expected at angles between 130° and 135° — are estimated to be 0.01 mrem / h before the upgrades, and 0.2 mrem / h after the upgrades. The maximum dose rates expected on the unoccupied 4-foot-thick concrete roof are 0.3 mrem / h before the upgrades, and 2 mrem / h after the upgrades.

A minor addition to the dump design was performed after its construction was completed. Since some steel plates were not perfectly flat, slight gaps between the plates were found on the front face of the dump. A 3 / 4-inch gap between the central plate and the one immediately above was filled with grout, filling from the central cavities towards the sides. The efficiency of this modification will be verified during the initial radiation surveys. Depending on the survey results, vertical steel plates could be inserted, if necessary, into the few inches of space remaining between the steel stack and lateral walls.

Shielding Against Activation Products

Since the dump will absorb most of the beam power produced by the facility, it will be the single most activated component and potentially the most important radiation hazard when the enclosure is opened for access after a beam running period. Using Swanson’s data for saturation activities induced by high-energy electrons in iron (see Reference [Appendix 1], p. 110, Tables XXIIa and XXIIb), we can deduce that the nuclides needed to be considered in shielding against the photons from the activated dump are Sc-46, V-48, Cr-51, and Mn-54. Their half-lives are between 16 and 303 days, so a waiting period before entering the enclosure would not be a viable alternative to shielding. Most of the photons emitted by these nuclides lie in the energy interval of 0.8–1.3 MeV. Although the saturation activities from two additional nuclides, Fe-53 and Fe-55, are fairly high, their photon energies (378 keV and 5.9 keV, respectively) are lower and will be subject to a much stronger self-absorption in iron itself.

The sum of the saturation dose rates from the four nuclides above is estimated to be approximately 2.0 rad-m^2 / kWh, neglecting self-attenuation. De Staebler [Appendix 2] calculated self-attenuation factors in iron for photons resulting from activation by a high-energy electron beam. For photon energies around 1 MeV, a factor of 0.1 is appropriate. Assuming beam power of 1,500 W after upgrade, with self-absorption taken into account, the estimated dose rate at 50 cm from the surface of the dump (from the point of beam impact) will be 1.2 rad / h.

In order to simplify shielding against photons from activation products while taking advantage of the available mass of iron, the front face of the 13-inch-thick slab will be recessed by approximately 70 cm. The photon shielding will then consist of an 8-inch (20.3-cm) layer of lead filling the front face opening, as shown in Figure 7-5. This thickness is more than enough to reduce the photon dose rate below 1 mrem / h outside the beam pipe. The Tenth Value Layer (TVL) in lead for Co-60, which has photon energies similar to our case, is 4.0 cm [Appendix 3]. Three TVLs (12 cm) will reduce the dose rate by a factor of 103.

7.2.3.5 Mazes

The entrance mazes were configured so that radiation from any potential source streaming through the maze will be attenuated by a sufficient number of wall reflections and the total length of the radiation path. The source terms were calculated using SHIELD11 at various locations and followed by simple calculations using the inverse-square variation with distance and a “rule of thumb” for wall reflections. It was assumed that the dose is attenuated for each reflection by a factor of 10 for neutrons and 100 for photons.[1] Since a minimum of two reflections is needed in both mazes, the neutron component will strongly dominate. Many possible trajectories were traced through the mazes in order to find the maximum radiation level at the entrance.

West Maze

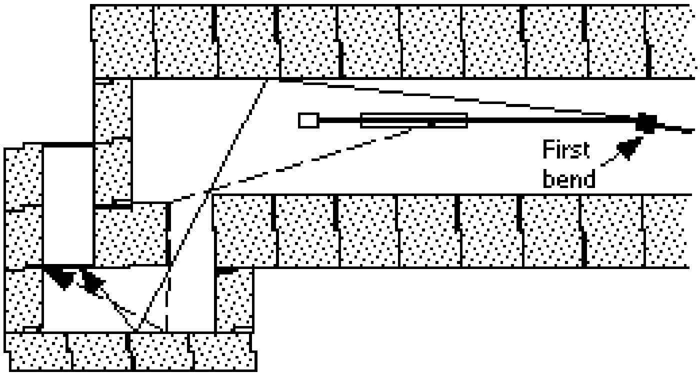


Figure 7-6. Plan View of the West Maze and the Beam Line Up to the Chicane Area

The layout of the West Maze is shown in Figure 7-6. The main radiation sources in the West Maze will be the first chicane bend or the collimator in the middle of the chicane, where 30% of beam power may be lost continuously. Losses in the injector could constitute another source, although these are not expected to be as high. Considering many possible trajectories, the estimated dose rates at the inner PPS gate resulting from 100% losses in the first chicane bend will be below 1 mrem/h and therefore even lower at the outer PPS gate, which is the point of interest. Total loss of the beam in the injector would result in neutron-dominated doses just below 2 mrem/h at the inner PPS gate, and doses less than 0.5 mrem/h at the outer PPS gate.

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[1] The factor is the ratio of the dose rate at the point of impact to the dose rate due only to reflected radiation at a distance of 1 m from the point of impact in any direction.

East Maze

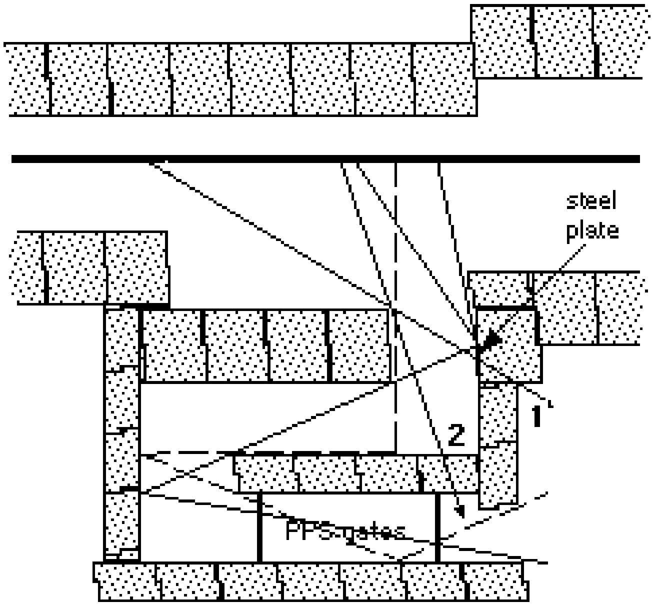

Figure 7-7. Plan View of the East Maze

The layout of the East Maze is shown in Figure 7-7. Due to relatively lower beam power losses and larger distances involved (relative to the West Maze), the radiation streaming through the maze will lead to negligible dose rates at the inner PPS gate. Only the radiation transmitted directly through the shielding is of concern here. A corner between a large and small concrete block (labeled “1” in Figure 7-7) constitutes a potentially weak spot for radiation exiting under an angle of approximately 35°. Without additional shielding, dose rates of 1.6 mrem / h outside the maze could be expected from normal beam losses. An additional steel plate 2 inches thick and 2 feet wide was fixed to the concrete block in the critical area inside the maze, reducing expected dose rates below 1 mrem / h. Radiation transmitted through the 3-feet-thick concrete wall in front of the outer PPS gate (see label “2” in Figure 7-7) will generate dose rates below 0.9 mrem / h.

7.2.3.6 Utility Tunnels

The NLCTA enclosure was built above two existing underground utility tunnels. (See Figure 7.1, page 7-3.) Each of these tunnels originally communicated with the NLCTA enclosure by a manhole 6×3 ft^2, as pictured in Figure 7-8. The tunnels are perpendicular to the beam line. One of them is located under the chicane area and the second under the spectrometer area.

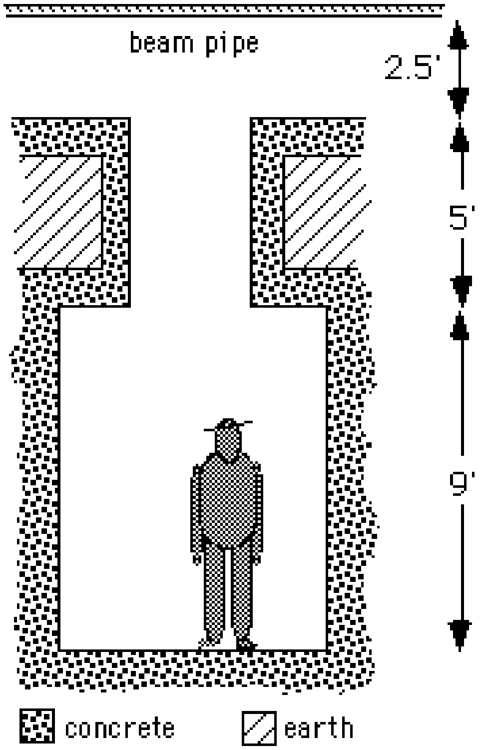

Figure 7-8. Cross-Sectional View of a Utility Tunnel and Manhole

Since access to the tunnels will be possible during NLCTA operation, it was necessary to fill both manholes with shielding material. The radiation safety considerations are somewhat different in each case.

7.2.3.7 Chicane Manhole

The manhole in the chicane area is located under the collimator, where continuous losses of 30% of the beam power are expected. The full 5-foot depth of the manhole is filled with concrete, supported from the bottom by a 1-inch-thick steel plate. Four penetrations were created on the far edge (away from the beam line) of the manhole: two 6-inch diameter penetrations each contain a 2-inch diameter water pipe and its thermal insulation; and two 4-inch diameter penetrations are unused at this time and available for future use. The unused penetrations will be filled with sand.

Without these penetrations, the expected dose rates in the tunnel below the filled manhole would be around 3 mrem/h at a height of 7 feet. Due to potential for radiation streaming and ducting through the penetrations, in particular through the very low-density thermal insulation, dose rates above 5 mrem/h are not unlikely. The tunnel will be therefore posted as a Radiation Area at the existing PPS gates of End Station B, which will be neither locked nor interlocked during

NLCTA operation. Although radiation workers might occasionally access this tunnel when the beam is on, installation of a BSOIC (Beam-Shut-Off Ion Chamber) is not planned. Unlike in most other areas, substantial and continuous beam losses are expected, and 100% beam loss in the chicane will only triple the normally expected dose rates. As a consequence, if higher than expected dose rates are found during radiation surveys, installation of local shielding might be preferable from the operational point of view and also in limiting potential radiation exposure.

7.2.3.8 Spectrometer Manhole

The manhole under the spectrometer area is filled with 3.5-foot-thick concrete shielding. (It was not possible to fill the whole manhole depth of 5 feet because of interference with LCW valves.) Two 4-inch LCW pipes penetrate the shield at its eastern edge. Since the LCW pipes have no insulation layer and will be filled at all times with water, serious radiation ducting is not expected. If the expected 0.5% beam loss occurs after upgrades (7.5 W at 800 MeV) at a single point immediately upstream of the manhole, then dose rates up to 15 mrem / h could be anticipated at a height of 7 feet in the tunnel, qualifying the tunnel as a Radiation Area. (The simultaneous dose rate anticipated outside the lateral shielding walls is 0.9 mrem / h.) The tunnel has been posted with standard signs as a Radiation Area. Swinging barriers, which will not interfere with emergency egress in the event of a fire, have been installed in the tunnel on both sides of the manhole, at least 2 meters from its edges.

In the event of vertical missteering (by the pulsed kicker or the DC kicker-compensator magnet) causing 100% loss of the upgraded nominal beam power (1,450 W, 800 MeV) at a quad near the spectrometer manhole, dose rates up to 2.9 rem / h at a height of 7 feet in the utility tunnel could be expected. To prevent extended duration of such dose rates a BSOIC with a 100-mrem / h trip threshold will be installed in the tunnel under the manhole. The BSOIC in the tunnel will shut off the nominal beam when losses exceed 3.4% (equivalent to 100-mrem / h tunnel dose).

7.2.3.9 Penetrations

Roof Penetrations

Four penetrations 6 inches in diameter will be made in the roof blocks to accommodate waveguides. The waveguides themselves are 3 inches in diameter. Another four or five penetrations 6 inches in diameter might be needed for electrical cables. Radiation streaming through these penetrations will lead to higher radiation levels on the roof. This effect can be substantially reduced in the case of electrical cables by dense packing and by filling the remaining free space with additional shielding material. However, such techniques obviously are not applicable for evacuated waveguides. All penetrations will be situated near the lateral wall, to avoid direct view of the beam line from the roof through the ducts, which would lead to Extremely High Radiation levels.

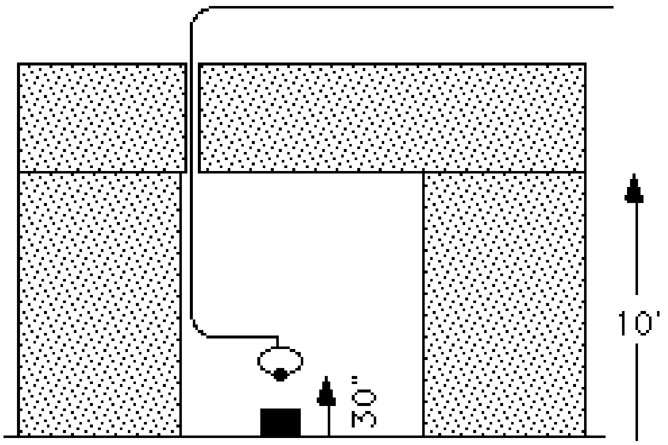

Figure 7-9. **Schematic View of the rf Waveguide Passing Through a Roof Penetration**

In order to estimate the radiation levels above an empty penetration, the source term at the entrance of the penetration was calculated using SHIELD11. Two separate cases were considered. The first estimate assumed the maximum energy achieved at the end of the accelerator was 800 MeV (after upgrade) with nominal beam losses (0.5%). The second estimate was done for the region in the vicinity of the Faraday cup, where the energy after upgrade will be 120 MeV, and assumed 100% beam loss. The loss was assumed to occur at a single point near the penetration. The neutron source term was doubled in order to account for the contribution of scattering off the interior walls of the enclosure [Appendix 9]. Photon and neutron ducting factors were then calculated using the computer program DUCT [Appendix 9], and applied to obtain the dose rate at the exit of the duct. The geometry of the problem is represented in Figure 7-10.

Diameter of Duct	**6"**	**2.93"**	**2.93"**	**2.93"**
Iron shielding local to Faraday Cup	—	—	2"	4"
Dose rate [mrem/h]				
4-ft long duct	305	92	26	11
5-ft long duct	180	53	15	7

Table 1.1 contains the results calculated for the penetration above the Faraday Cup for various shielding configurations. The first column assumes a 6-inch diameter cylindrical void, while the three remaining columns assume that the space around the waveguide is completely filled with shielding material such as sand. In case this filling does not reduce the dose rate to an acceptable level, two additional measures could be considered: locally shielding the Faraday cup with 2 to 4 inches of iron, or increasing the aspect ratio (length / diameter) of the duct by stacking slabs of polyethylene around the waveguide to a height of 1 foot

above the concrete roof. (A stack of slabs 40 × 40 cm^2 with 3-inch holes in their centers could be used to extend the length of the duct.) The dose rates in Table 1.1 were calculated for the upgraded power. Values before upgrade can be estimated by scaling with power, that is, by a factor of 0.3.

It should be noted that the doses in Table 1.1 are subject to a large uncertainty. Furthermore, the location of the waveguide penetration, which for the calculations was assumed to be directly above the Faraday Cup, has not yet been decided and may end up being farther away, which would result in lower dose rates than estimated above. With that in mind, one measure that should be implemented initially is filling the free space around the waveguide with sand or similar material. This configuration should lead to a dose rate of 35 mrem / h or less before any upgrades. Depending on the results of radiation surveys, a decision could be made whether or not to implement additional shielding options. Dose rates due to radiation penetrating the 4-foot concrete roof will be less than 10 mrem / h. Radiation penetrating through the roof from point losses will cover a much larger area of the roof than radiation ducting through the opening of a waveguide. It follows that the relative contribution of a penetration to skyshine at the site boundary will be small and that dose rates of 10–100 mrem / h at the penetration exit can be tolerated, so long as the roof is posted as a Radiation Area.

In the case of a penetration at the high-energy end of the linac, levels of 7 mrem / h are expected after upgrades for a penetration containing a waveguide surrounded by sand fill.

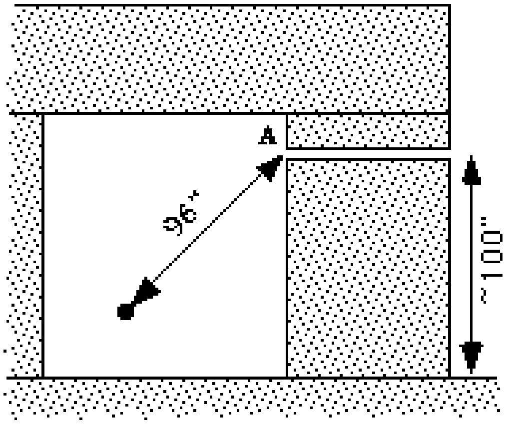

Figure 7-10. Geometry Considered for the Penetrations in the 6-Foot-Thick Side Concrete Walls

7.2.3.10 Wall Penetrations

No penetrations through the 6-foot-thick side walls of the beam line enclosure are planned. However, a study was performed to determine the feasibility of wall penetrations for light from beam profile monitor screens. Figure 7-10 illustrates the geometry considered in the study. The height of a wall penetration was arbitrarily assumed to be 100 inches. The source term at the entrance (Point A) was calculated using the same algorithm and the same assumptions as used in the previous section for the roof penetrations at the end of the linac. The results are summarized in Table 1.2.

Diameter [inch]	Dose rate [mrem/h]	
	100% loss	0.5% loss
6	983	49
4	355	18
3	176	9

Although the exit point is assumed to be at a height of 100 inches, the horizontal penetration substantially increases the dose rate in the occupied area immediately below. Additional local shielding could reduce the dose to a tolerable level, but using roof penetrations seems to be a more practical alternative. In this case, radiation levels above a 3-inch penetration would be very similar to those calculated for the 3-inch waveguide.

7.2.4 Air Activation

When the bremsstrahlung, which results from beam losses along the beam line, is not absorbed in the beam line components, it escapes into the surrounding air volume and causes air activation. The average room concentration can be calculated using the following equation:

$$(\text{Average Room Concentration}) = (\text{Saturation Activity}) \times \left(\frac{\text{Bremsstrahlung Pathlength}}{\text{Room Volume}}\right),$$

where the saturation activity values in units of Bq / m / kW or mCi / m / kW are available from the literature, see ([Appendix 1], [Appendix 5]). The beam loss scenario adopted in this case assumes that 0.5% (that is, 7.5 W out of 1,500 W) of the total beam power after upgrade is being lost in one discrete point at the end of the accelerator structure. The pathlength of the bremsstrahlung that barely misses Quad 1760 is approximately 11 m, before it hits the enclosure wall. This scenario is more conservative than considering 0.5% losses distributed along the beam line, which would lead to lower energy losses and shorter photon paths. The total volume of the beam line enclosure is 500 m^3.

Table 1.3 contains a list of potential activation products in air, predicted concentrations at saturation, and Derived Air Concentration (DAC) limits from DOE Order 5480.11 [Appendix 4]. The values for saturation activity were taken from Swanson [Appendix 1], with the exception of N-13 and O-15, where more recent values from Ferrari et al. [Appendix 5] were used. According to Swanson, even without forced ventilation, a complete air change occurs several times per hour. Due to their long half-lives, it is not possible to accumulate a sizable fraction of the saturated activities of H-3 and Be-7. The most important nuclides to be considered here are N-13 and O-15. It is clear from the above results that predicted levels will be lower than the DOE limits by at least an order of magnitude.

The allowed DAC limits specified in Table 7.3 are taken from DOE Order 5480.11[Appendix 4]. These limits are identical to the limits specified in 10 CFR 835, except for the isotopes C1-38 and C1-39, for which the DOE limits are the more restrictive.

It should be noted that there are several levels of conservatism embedded in both the calculations and the used DAC values. The DOE-imposed DAC values are based on external whole-body exposure of radiation workers from immersion in a semi-infinite hemispherical cloud for 40 hours per week. Since the air volume inside the NLCTA enclosure is substantially limited in comparison with a semi-infinite hemispherical cloud, higher DAC values could be used. Also, since the enclosure can be accessed only when the beam is off, the saturation concentrations will quickly diminish due to decay and ventilation, preventing any continuous exposure of workers to the levels at saturation.

Nuclide	Half Life	Reaction Type	Saturation Activity [MBq/kWm]	Concentration [Bq/cm^3]	Concentration [mCi/cm^3]	DAC [mCi/cm^3]
H-3	12.2 y	(γ,H-3)	5	7.03E–4	1.90E–8	2.00E-6
Be-7	53.6 d	(γ,sp)[a]	1	1.41E–4	3.80E–9	9.00E-6
C-11	20.3 m	(γ,sp)*	10	1.41E–3	3.80E–8	4.00E–6
N-13	10 m	(γ,n)	200	2.81E–2	7.60E–7	4.00E–6
O-15	123 s	(γ,n)	130	1.83E–2	4.94E–7	4.00E–6
N-16	7.14 s	(γ,np)	0.02	2.81E–6	7.60E–11	7.00E–7
Cl-38	37.3 m	(γ,p)	0.22	3.09E–5	8.36E–10	3.00E–6
Cl-39	55.5 m	(γ,p)	1.5	2.11E–4	5.70E–9	3.00E-6
Ar-41	1.8 h	(n,γ)	—	4.94E–3	1.42E–7	3.00E–6

[a] Spallation reaction.

The saturation activities reported in literature and used in Table 1.3 are usually calculated for target composition and geometry that maximize bremsstrahlung production. On the other hand, beam losses in the NLCTA beam line are likely to happen in beam line components that are substantially thicker than the optimum target, leading to relatively lower bremsstrahlung leakage and air activation. Furthermore, a major part of the energy carried away by bremsstrahlung is confined to narrow forward angles, which will be considerably shielded by the presence of the accelerator structure and / or beam line components downstream from the point of beam loss.

One potential source of activated air would be the insertable Faraday cup, where 230 W will be continuously absorbed after the upgrade. Use of saturation activities for optimum targets would yield concentrations of N-13 and O-15, well above the DOE DAC values. In order to take into account bremsstrahlung attenuation, EGS4 was used to compare the energy leakage from the optimum target used by Ferrari et al. and the NLCTA Faraday cup. Only particles with energies above 10.55 MeV, the threshold for N-14 (γ,n) N-13, were scored. Assuming that air activation is proportional to the energy leaking from the target, the above calculations were used to correct the published saturation activity values for attenuation in the thick target. In first approximation, this correction can be also applied to the data for O-15 and other nuclides. The Faraday cup was represented by a 9.53-cm-long tungsten cylinder with a 4.13-cm radius, while the optimum target used by Ferrari et al.

was a 2-cm-long iron cylinder with a 0.5-cm radius. The energy leakage from these two targets was found to be 0.059% and 63.1%, respectively. As a result, the activities at saturation produced around the Faraday cup (assuming an equal photon pathlength) would be lower by a factor of 40 in comparison with the values from the previous scenario.

The only case where a higher activation could be obtained around the Faraday cup in comparison with the first scenario is that of Ar-41, created by the (n,γ) reaction on Ar-40. The cross section is highest for thermal neutrons. Using neutron yields from Swanson [Appendix 1] for thick targets struck by 100-MeV electrons, the source term for fast neutrons was estimated. The thermal neutron fluence (Φ) was then estimated using the rule of thumb of Paterson and Wallace [Appendix 6 to be $\Phi = 1.25Q/S$, where Q is the fast neutron emission rate and S is the surface of the vault. The saturation activity was then calculated as the product of Φ and the macroscopic cross section, and is reported in Table 1.3.

7.2.5 Ozone Production

Ionizing radiation interacting with the air inside the NLCTA enclosure is a likely source of ozone, an industrial-hygiene hazard. Potential ozone concentrations were estimated using a method described by Swanson [Appendix 12], under conservative assumptions similar to those taken by Jenkins [Appendix 13].

As in the case of air activation, the sources of radiation considered were 100% beam loss in the Faraday cup and 0.5% loss at the high-energy end of the linac. Assuming that the beam-line enclosure is unventillated, a saturated ozone concentration will arise due to the equilibrium between the production rate (p) per minute and the decay rate which is characterized by a half life (T) of 50 minutes. The saturated ozone concentration will be $C_s = pT / V$.

The volume (V) of the enclosure was estimated to 500 m^3. To estimate the production rate at the end of the linac, it was assumed that 5% of the lost power, that is , 0.375 W, escapes from the beamline components into the air, which is conservative for thick targets. It was furthermore assumed, again quite conservatively, that all this escaping power is carried by 10-MeV electrons with $dE/\rho dx$ = 2 MeV g^{-1} cm^2, and that the average electron path through the air will be 5 meters. It follows from the above that 13% of the escaping energy will be absorbed in the air, at a rate of 2.03×10^{17} eV / s. Using a conservative “G-value” of 10 molecules generated per 100 eV absorbed, and assuming instantaneous air mixing within the enclosure, the calculated production rate of ozone molecules is 4.12×10^{7} cm^{-3} s^{-1}, resulting in a saturated concentration of 1.24×10^{11} molecules / cm^3, which represents a fraction of 4.61×10^{-9} of the air molecules. Since the Threshold Limit Value (TLV) for ozone is 10^{-7}, our very conservative estimate of concentrations due to losses at the end of the linac will be less than 5% of TLV.

We have previously determined using EGS4 calculations that only 0.06%, that is, 0.137 W, of the power lost in the Faraday cup will escape into the surrounding air, although this calculation neglected absorption in the Faraday cup housing. All other assumptions being the same as above, there will be 4.9×10^{15} eV / s absorbed in the air, about a factor of 50 less than from losses in the linac. The expected ozone concentrations therefore will be lower by the same factor.

When the beam in NLCTA is stopped to permit personnel access, ozone concentrations will decrease exponentially with the characteristic half life of 50 minutes. Opening a PPS door will further accelerate this decrease due to venting of ozone through the doorway.

The above estimates indicate a negligible ozone hazard to personnel entering the NLCTA housing after beam operation. Nevertheless, actual ozone levels will be verified by empirical sampling as higher and higher beam power levels are achieved. In the unlikely event that unsafe ozone levels are ever encountered, the health hazard will be mitigated by requiring a “waiting period” of sufficient duration for the ozone to disintegrate before entry into the NLCTA housing is permitted after beam operation.

7.2.6 Ionizing Radiation from Klystrons

The X-band klystrons used to generate the microwave power which is fed to the accelerator structure can be sources of ionizing radiation, since they operate at 440 kV. The waveguide network which is used for pulse shaping can also be a source of ionizing radiation. The dose rate from these sources varies among individual klystrons, but is in the range of 0–25 mrem / h at 30 cm from the envelope of the tube. Local lead shielding may be applied to mitigate the hazard, and areas which have dose rates in excess of 5 mrem / h will be roped off and signed as Radiation Areas. An x-ray dose in excess of 50 mrem / hr at 30 cm will be mitigated by applying local lead shielding directly to the offending klystron.

7.2.7 Site Boundary Dose

The predominant component of the boundary dose is secondary radiation from the primary beam, in the form of “skyshine” neutrons. Other, much smaller components are airborne activation products (radioactive gases) and klystron x-rays. These sources and their respective attenuations are discussed below. The site boundary monitoring system is also discussed.

7.2.7.1 Prompt Radiation

The distance from the NLCTA to the closest point of the SLAC boundary is approximately 400 meters. The dose at this point will be caused by “skyshine” neutrons leaking through the roof and scattering in the air. Calculations of the boundary dose were performed using the computer program SKYSHINE, written by T. M. Jenkins. Only upgraded beam parameters were considered. Three source terms were taken into account:

A. 0.5% beam loss in the accelerator structure 70% of the running time (1.4×10^{17} e– / y),
B. 100% beam loss in the Faraday cup 30% of the running time (1.2×10^{19} e– / y) without local shielding considered,
C. 100% beam loss in the beam dump 70% of the running time (2.8×10^{19} e– / y).

The boundary dose from all three source terms was found to be negligible:

A. 0.02 mrem / y for the accelerator structure,
B. 0.009 mrem / y for the Faraday cup, and
C. 0.0001 mrem / y for the dump.

Furthermore, the algorithm in SKYSHINE is certain to yield conservative results for narrow and elongated geometries such as the NLCTA roof. Consequently, the boundary dose will be no greater than the sum of sources a–c: 0.03 mrem / y.

7.2.7.2 Airborne Activation Products

The dose at the site boundary due to airborne transmission of air-activation products from the NLCTA enclosure was analyzed [Appendix 14] for compliance with the Environmental Protection Agency’s National Emissions Standards for Hazardous Air Pollutants (“NESHAPs”) [Appendix 15], using the computer program “CAP88-PC” [Appendix 16]. Based on the radioactive source concentrations discussed in Section 7.2.4 (“Air Activation”), the effective dose equivalent to the maximally exposed individual of the general public was found to be 1.5×10^{-4} mrem / y. This is considered acceptable, as it is well below the 10-mrem / y dose permitted by NESHAPs.

7.2.7.3 Klystron x-rays

Ionizing radiation from the NLCTA klystrons was discussed in Section 7.2.6. The dose at the site boundary due to the NLCTA klystrons is reduced to a negligible level by several significant factors:* The NLCTA klystrons are located inside End Station B. The 2-ft-thick concrete walls of the End Station attenuate the X-ray dose by approximately 10^{-6}. The 400-m distance to the site boundary provides a further reduction by approximately 10^{-6}, relative to the 30-cm dose, due the inverse distance-squared factor. Still further reduction of the boundary dose is provided by large earth berms shielding the line of sight from the End Station to the site boundary.

7.2.7.4 Monitoring the Boundary Dose

The SLAC boundary is continuously monitored by an existing system of detectors, both active and passive, which are sensitive to neutrons and gamma-rays. The active detectors (moderated BF_3 tubes for neutrons and Geiger-Muller tubes for photons) are read out and logged every 6 minutes. They are positioned at seven locations which are forward-directed relative to the primary radiation sources of the SLC (Stanford Linear Collider). Since the NLCTA's beam line is nearly parallel to the SLC's 50-GeV linac, the NLCTA is well served by this existing, active monitoring system. In addition to the active monitors, neutron and photon TLDs (thermo-luminescent dosimeters) are located at 35 monitoring stations distributed roughly uniformly along the site boundary. The cumulative doses in these passive monitors are read every three months.

7.2.8 Section Endnotes

[1] Swanson, W. P., “Radiological Safety Aspects of the Operation of Electron Linear Accelerators,” Technical Report Series No.188, IAEA, Vienna, 1979.

[2] De Staebler, H., “Photon-Induced Residual Activity,” SLAC TN-63-92.

[3] *The Health Physics and Radiological Health Handbook,* edited by B. Shleien, Scinta, 1992.

[4] DOE Order 5480.11, “Radiation Protection for Occupational Workers,” US Department of Energy, Washington, DC, 1988.

[5] Ferrari, A., Pelliccioni, M., and Salla, P. R., “Bremsstrahlung Source Terms for Intermediate Energy Electron Accelerators,” Nuclear Instruments and Methods in Physics Research B 82, 1993, pp. 32–38.

[6] Paterson, H. W. and Wallace, R., “A Method of Calibrating Slow Neutron Detectors”, UCRL-8359, 1958.

[7] Jenkins, T. M., “Neutron and Photon Measurements Through Concrete from a 15 GeV Electron Beam on a Target — Comparison with Models and Calculations,” Nuclear Instruments and Methods in Physics Research 159, 1979, pp. 265–268.

[8] Lavine, T. L., Memorandum to N. Ipe and the SLAC Safety Overview Committee, October 8, 1993.

[9] Jenkins, T. M., private communication. This estimate of the contribution of scattered neutrons is based on Jenkins' unpublished calculations based on the MORSE neutron-photon transport code and DESY measurements.

[10] Nelson, G., "Beam Containment Policy and Implementation," SLAC Memo to the Radiation Safety Committee, May 18, 1994.

[11] Browne, M.J., "Average Current Limit of the NLCTA Thermionic Gun," NLCTA Note #48, May 30, 1995.

[12] Reference [Appendix 1], pp. 149–155.

[13] Jenkins, T. M., "Radioactive Air and Ozone Concentrations in the Cooling Vault," Single Pass Collider Memo CN-51 (SLAC internal report), April 30, 1981.

[14] R. Sit, "NESHAPs Compliance Assessment for NLCTA Operations," memo to V. Vylet, dated August 10, 1995.

[15] 40 CFR 61, Subpart H.

[16] CAP88-PC, "Clean Air Assessment Package," 1988.

7.2.9 Section Bibliography

Browne, M. J., "Analysis of Failure Modes of the Average Current Limit for the NLCTA Thermionic Gun," NLCTA Note #51, September 26, 1995.

Independent confirmation of the results found in Browne, M. J., "Analysis of Failure Modes of the Average Current Limit for the NLCTA Thermionic Gun," NLCTA Note #51, September 26, 1995, was requested by the SLAC Radiation Safety Committee on June 6, 1995. This confirmation was provided by Len Genova, in two Memoranda addressed to Ted Lavine, dated July 23, 1995 and July 27, 1995. Copies of these memoranda have been filed with the SLAC Radiation Safety Committee.

Kase, K. R., "Design of Accelerator and Experimental Facilities — Failures, Accidents, and Redundancy," internal SLAC document, March 16, 1994.

Kase, K. R., "Radiological Protection Guidelines for Primary and Secondary Beamlines in the Research Yard," internal SLAC document, January 21, 1994.

SLAC Radiological Control Manual, SLAC-I-720-0A05Z-001, March 1993.

Smith, H., Fuller, R., and Bong, P., "Proposed PPS Access Control System for the NLCTA," NLCTA Note #45, March 30, 1995.

Walz, D. memoranda to T. Lavine: "NLCTA Beam Dump (October 6, 1993) and "NLCTA Beam Dump — Revisited" (May 12, 1995).

7.3 Safety Analysis — Ionizing Radiation

7.3.1 Hazard event: Exposure to ionizing radiation outside shielding enclosure as a result of radiation safety system failure during operations

7.3.1.1 Description of Occurrence

Personnel within the Radiological Control Area may be exposed to low levels of ionizing radiation during normal operations. The source of radiation is the accelerated beams, targeting inside the shielding. In the case of system failure of one or more of the radiation safety systems, the dose rate external to the shielding enclosure can range up to 25rem / h.

7.3.1.2 Prevention/Mitigation

Shielding integrity is assured by administrative means. The shielding enclosure is designed to maintain the dose rate at the shielding boundary to below 5mrem/h. Areas which may exceed this are required to be roped and signed. All personnel entering the Radiological Control Area are required to have either General Employee Radiation Training or Radiation Worker Training.

A system failure which permits this occurrence, creating an excessive dose rate, requires the simultaneous failure of several limiting mechanisms, with redundant shut-off paths.

The Beam Shut-Off Ion Chamber (BSOIC) system will detect dose rates in excess of 100 mrem/h and shut down the accelerator. All persons in the Radiological Control Area are required to wear dosimeters.

7.3.1.3 Consequences

Exposure to these levels of radiation is of Extremely Low consequence.

7.3.1.4 Probability

The probability of such an occurrence is Extremely Low.

7.3.2 Hazard event: Exposure to ionizing radiation inside shielding enclosure as a result of radiation safety system failure during operations

7.3.2.1 Description of Occurrence

Personnel are from time to time admitted to the secured area, within the shielding enclosure, for maintenance purposes. If a combined system failure and administrative failure occurs, one or more personnel may be exposed to unshielded radiation from the accelerated beam.

7.3.2.2 Prevention/Mitigation

Such a failure requires the failure of several fail-safe hardware systems with redundant shut-off paths and/or the failure of administrative methods (search procedures) which involve more than one operator and are supervised through hardware. Change of access state to permit beam acceleration is preceded by audible and visual warnings. Personnel required to work in the secured areas, which are the areas whithin the shielding enclosure to which access is controlled by interlocked access controls, are required to be trained in use of the Personnel Protection System to gain access.

7.3.2.3 Consequences

Exposure to radiation under these circumstances may cause death or severe injury to personnel on site and thus is of Medium Consequence. There is no adverse consequence off site.

7.3.2.4 Probability

The probability of such an occurrence is Extremely Low.

7.3.3 Hazard event: Exposure to ionizing radiation inside shielding deriving from

residual activity, exceeding administrative dose limits

7.3.3.1 Description of Occurrence

Personnel performing maintenance tasks inside the shielding barrier may be exposed to ionizing radiation deriving from parts of the accelerator structures which have been activated by the accelerated beams.

7.3.3.2 Prevention/mitigation

Inadvertent exposure to activated material is controlled by use of radiation survey before entry, real-time dosimetry by self-reading ion chambers, Radiation Work Permits, and by training. All persons requiring unescorted access to the secured areas are required to take Radiation Worker I training.

7.3.3.3 Consequences

The consequence of inadvertent exposure to activated materials is Extremely Low.

7.3.3.4 Probability

The probability of inadvertent exposure to activated material is Medium.

8 Safety Analysis — Other

8.1 Fire Hazards

8.1.1 Hazard Event: Damage or injuries to personnel caused by fire in the accelerator housing or in the equipment areas outside the housing, or in the control room.

8.1.1.1 Description of Occurrence

The possibility exists of fire from overheating of electrical components or other causes which may present a risk to workers. No risk is presented to off-site personnel.

8.1.1.2 Prevention/Mitigation

The fire-protection systems currently installed in the NLCTA housing, control building, and substation were recently installed for the project, under the review of the SLAC Fire Protection Engineer. Heat-sensitive sprinkler systems are installed in End Station B (covering the instrumentation racks, power supplies, cable trays, klystrons, and modulators), in the accelerator housing, and in the control building. The sprinkler protection is hydraulically designed for Ordinary Hazard, Group II protection. The design density is 0.2 gpm per square foot over 1,500 square feet. The beam-line housing is additionally protected by a Fenwal high-sensitivity smoke-detection system. End Station B, the substation, and the control building are protected by ionization-type smoke detectors. All of these fire-protection systems were made operational early in the construction phase of the project.

SLAC subcontracts with the Palo Alto Fire Department (PAFD) to operate an on-site fire station, to provide emergency response services, to conduct ongoing fire safety inspections of SLAC facilities, and to train SLAC personnel on fire safety. All fire-alarm information from the NLCTA facility is available at the PAFD fire station at SLAC. The distance by road from the fire station to the NLCTA facility is 0.7 miles; driving time is two minutes.

SLAC submitted a Fire Hazards Analysis (FHA) to the DOE Site Office on May 11, 1995.

8.1.1.3 Consequence

The consequence may be minor injuries to on-site personnel, no off-site impact; consequence is Low.

8.1.1.4 Probability

Fire involving injury to personnel is not expected to occur during the life of the facility; probability is Low.

8.2 Hazardous Materials

Articles fabricated from lead are used in the facility. No cutting, welding, or machining of these articles will take place within the housing. Fabrication of lead articles will take place elsewhere on site and is guided by the provisions of Chapter 2 of the SLAC *Environment, Safety, and Health Manual.*

No other hazardous materials are planned to be used in the course of operation of the facility.

8.3 Electrical Hazards

8.3.1 Hazard Event: Electroshock due to worker contacting energized conductor of magnet, etc., within shielding enclosure.

8.3.1.1 Description of Occurrence

Personnel enter the shielding enclosure from time to time for maintenance purposes. Electrical loads within the enclosure (magnets) are in some cases un-insulated. Workers are involved in maintenance upon magnet power supplies, Klystron modulators, and other equipment capable of causing serious electroshock.

8.3.1.2 Prevention/Mitigation

It is SLAC policy that every necessary precaution should be taken in the performance of work to protect all persons on the site from the risk of electrical shock and to minimize the probability of damage to property due to electrical accidents. This policy is implemented by assigning responsibility and adhering to basic safety principles, as stated in the SLAC *Environment, Safety, and Health Manual*, Chapter 8, “Electrical Safety,” and by complying with regulations and procedures appropriate to each operation. Appropriate electrical safety training courses are provided by the Laboratory for those workers who are likely to be exposed to high-voltage hazards. Several NLCTA subsystems, such as the Klystron pulse modulators, will employ high voltages. The controls and work procedures necessary to ensure safe work on these systems are well understood. The provisions for locking of these systems will utilize SLAC’s established procedures for lockout and tagout as described in SLAC’s document, *Lock and Tag Program for the Control of Hazardous Energy* (SLAC-I-730-0A10Z-001, current revision). Energized equipment will be worked on only under very limited and controlled conditions, and only qualified employees will perform such work. All work will be performed in accordance with safe work practices and in accordance with OSHA 1910, Subpart S. Special procedures are in place to permit authorized personnel to occupy areas adjacent to energized hazardous magnets. These procedures are called RASK, for “Restricted Access Safety Key.” Under these procedures, a special RASK authorization form must be filled out to obtain a key that enables the hazardous supply under test. Testing is done in accordance with written procedures. The emergency-off buttons remain active and will turn off the power supply when pushed.

Ground Fault Circuit Interrupters (GFCIs) have been installed on all 110-V circuits inside the NLCTA housing, and in the control building, where appropriate. All new electrical installations are in accordance with the National Electric Code (NEC).

The SLAC Electrical Safety Committee has reviewed and approved the electrical safety design of the NLCTA housing, the electrical power distribution system, the control building, and the substation (memo Garg-Lavine, July 12, 1994).

All un-insulated electrical conductors (above 50 volts) within the shielding enclosure are automatically de-energized by the Personnel Protection System before access to the relevant zone of the shielding enclosure is allowed. In cases where work on or near a particular load is intended, the power source must also be isolated by means of lock and tag.[1]

8.3.1.3 Consequence

The consequence level of an inadvertent contact with an energized conductor may range from Extremely Low to Medium.

8.3.1.4 Probability

The probability of such an occurrence is Low.

8.4 Non-ionizing Radiation

8.4.1 Hazard Event: Workers may be exposed to non-ionizing radiation in the microwave spectrum.

8.4.1.1 Description of Occurrence

Personnel enter the shielding enclosure from time to time for maintenance purposes. Various pulsed high-power rf sources are used in the acceleration of particle beams.

8.4.1.2 Prevention/Mitigation

All high-power microwave sources are interlocked with the Personnel Protection System such that they are required to be de-energized before access is allowed in the relevant zone. In addition, the energy is fully contained within the envelope of the waveguides or vacuum chambers. If the vacuum chambers or waveguides are opened, separate interlocks prevent the source from being energized. In cases where work on or near a particular load is intended, the power source must also be isolated by means of lock and tag. Certain low power microwave sources are not enclosed in a vacuum envelope. In these cases (the Travelling Wave Tube (TWT) associated with each modulator) the bolts securing the assembly are secured with locking wire.[2]

8.4.1.3 Consequence

The consequence level of an exposure to one of these sources of non-ionizing radiation sources is Low.

8.4.1.4 Probability

The probability of such an occurrence is Low.

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[1] See *SLAC Guidelines for Operations*, Guideline 17, “Electrical Safety,” (01-01-17-01) and Guideline 18, “Control of Work on Electrical Devices in Beam Housings“ (01-01-18-01).

[2] See NLCTA Note #58, Wilson, Z. “Non-ionizing Radiation Leakage Protection,” March 1, 1996.

8.5 Cryogenic Hazards

No cryogenic materials are planned to be used in the course of operations of this facility except for liquid nitrogen, in quantities consistent with light industrial practice. Since the NLCTA enclosure is not ventilated, a hazard could exist if more than 200 liters of liquid nitrogen is permitted to vent into the closed housing. Portable dewars exceeding this volume are not permitted inside the housing. A failure sequence which is capable of causing personnel injury due to oxygen deficiency is considered non-credible.

8.6 Flammable Gases or Fluids

No flammable gases or fluids are planned to be used in the course of operations of this facility, other than insulating oil used in the high voltage transformers which feed the klystrons. This has been included in the Fire Hazard Analysis filed on May 11, 1995.

8.7 Seismic Hazards

8.7.1 Hazard Event: Damage or injuries to personnel caused by collapse of structures consequent upon a major earthquake with an epicenter close to the site.

8.7.1.1 Description of Occurrence

The SLAC site is located close to a number of active earthquake faults (see Section 2.3, above). In the event of a major earthquake the possibility exists of structural damage to buildings or overturning of equipment, which may present a risk to workers. No risk is presented to off-site personnel.

8.7.1.2 Prevention/Mitigation

All NLCTA structures and equipment are subject to the seismic safety guidelines put forth by the SLAC Earthquake Safety Committee and stated in the SLAC document *Building Manager Manual* (SLAC-I-720-0A03Z-001), Section B, “Seismic Safety Guidelines.” Consequently, all structures and non-structural equipment are designed and restrained so as to protect life, minimize injuries, prevent environmental damage, and maintain the basic mission of the laboratory in the event of an earthquake. The NLCTA project does not present any unique earthquake hazards for SLAC. The project will easily fit within ongoing site-wide earthquake safety practices.

Since the NLCTA lies in close proximity to known earthquake faults, a conservative seismic design was required from the beginning. For structures and equipment, the basis for seismic design was DOE-STD-1020-94 for Performance Category 2 buildings. Specifically, all new structures built for the NLCTA project (the accelerator housing, control building, and substation) are designed to withstand horizontal accelerations up to 0.6 g (50% greater than that required by the 1994 Uniform Building Code, Paragraph 1628), and vertical accelerations up to 0.4 g. Consequently, a portion of the south shielding wall of End Station B was seismically upgraded by the NLCTA project to meet the same base-shear requirements as the new structures.

The SLAC Earthquake Safety Committee has reviewed and approved (memo Youngman to Lavine, July 13, 1994) the seismic design of the NLCTA shielding, the overhead utilities and cable tray support system, the substation, the control building, and the structural modification to the south shielding wall of End Station B.

8.7.1.3 Consequence

The consequence may be minor injuries to on-site personnel, no off-site impact; consequence is Low.

8.7.1.4 Probability

Damage to the facility involving injury to personnel is not expected to occur during the life of the facility; probability is Low.

9 Accelerator Safety Envelope

9.1 Safety Envelope — Ionizing Radiation

The NLCTA Facility has the capability of delivering particle beams which may vary from a few particles per pulse to a current equivalent to a power of 1.45 kW at 10 pulses per second (after planned upgrades). SLAC has chosen to consider that the maximum credible power capability of the accelerator after upgrades is the Safety Envelope boundary for all applications. This being so, no operator action can cause the facility to exceed the beam power limits of the Safety Envelope.

Shielding design has been chosen such that in the case of the maximal credible accident, where only passive devices are considered, the effective dose equivalent that can be experienced by a person outside the secured areas will not exceed the limit specified for a Low Hazard facility,[1] which is required to be less than 25 rem in any 1 hour.[2]

Beam stoppers, collimators, and dumps are designed such that an inadvertent excess power situation which may exceed the power absorbing capability of the device results in a failure mode, whereby the failure itself triggers a shutdown process, either destructively by spoiling the vacuum in the main accelerator structure, or by sensing burn through and turning off the beam through the Personnel Protection System.[3]

The facility is also protected by a Beam Shut-Off Ion Chamber system which will turn off the beam should radiation dose rates external to the shielding exceed a pre-set value (usually 100 mrem / hr).

It is also required that the annual dose outside shielded or secured areas not exceed 1 rem per year, and no person be permitted to exceed the Administrative Control Level of 1.5 rem per year.[4]

9.2 Maximum Power Capabilities of the NLCTA

Maximum beam power is limited by the following factors:

- **The maximum repetition rate delivered by the gun**, which is limited by three independent one shot circuits in the gun, each of which prevents a pulse being delivered less than 0.1 second after a preceding pulse.
- **The maximum average current which can be accelerated**, which is set by the design of the pulser circuit in the thermionic gun. The design is such that if all three of the above circuits fail, and the nominal pulse rate of 10 pps is exceeded, the pulse current from the gun begins to be reduced such that the average current does not exceed 11 microamps.[5] The integrity and functionality of this circuit are a check-off item on

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[1] Radiological Protection Guidelines, 20 May 1994, Ken Kase.

[2] *Accelerator Safety Order, DOE 5480.25,* Guidance, page 10, September 1, 1993.

[3] See Section 7.1.2, “Beam Containment System.”

[4] *SLAC Radiological Control Manual* (SLAC-I-720-0A05Z-001), Article 211.

[5] For further information see: Browne, M. J., “Average Current Limit for the NLCTA Thermionic Gun,” NLCTA Note #48, May 25 1995, and Brown, M. J., “Analysis of Failure modes of the Average Current Limits for the NLCTA Thermionic Gun”, NLCTA note #61, September 26, 1995.

the Beam Authorization Sheet, and the circuit enclosure is locked with a controlled key.

- **The maximum energy capability of the accelerator**, which is set by the number of klystrons installed and available for acceleration, the length of accelerating structure, and the power delivered by each klystron, as modified by beam loading. The initial design provides four 50 MW Klystrons, providing a no-load accelerating gradient of 50 MV/m. The planned upgrade would provide eight 75 MW Klystrons, providing a no-load accelerating gradient of 87 MV/m. In both cases, there is a total length of accelerator structure of 12.6 meters in the injector plus linac. Thus the maximum no-load energy in the initial configuration is 630 MeV, and after upgrade is 1096 MeV.

To summarize: The maximum power capability is restrained by redundant methods. Although the trigger hardware has the capability of delivering a repetition rate of 180 pps, the actual rate reaching the gun is limited by three separate one-shot circuits which prevent rates in excess of 10 pulses per second from reaching the gun. The circuits are independently powered and not subject to common mode failures. Should all three of these circuits fail, the average current from the gun is independently limited (see above: maximum average current). It is judged that the possibility of all three one-shot circuits plus the average current limiter failing at the same time is a non-credible scenario.

For the purposes of maximum power calculation the second limit (average gun current = 11 microamps) is used.

The resultant maximum power capability is:[1]

Initial	Upgrade
3,230 W	**5,750 W**

The highest credible dose rates external to the shielding are calculated to occur in the utility tunnel under the accelerator. If misteering causes the full beam to target close to this location, and the shut off mechanisms of the Beam Containment System and the Beam Shut Off Ion Chamber System fail to work (Maximum Credible Accident), then the dose rates are:[2]

Initial	Upgrade
5.4 rem/hour	**9.6 rem/hour**

(At full power under normal operating conditions, the dose rates in this location are in the range of 15 mrem/hour.)

These then constitute the physical limits of the Accelerator Safety Envelope for prompt ionizing radiation at this facility. The various administrative and engineered systems involved in assurance that the safety envelope will not be exceeded are summarized in Table 9.1 below. The administrative systems are described in more detail in Chapter 4, “Operating Organization” and in Chapter 7, “Safety Analysis — Ionizing Radiation.”

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[1] Two different numbers are derived; the first being the initial configuration as of Fall 1996 with 50 MW klystrons, and the second being that appropriate to the later upgrade with with pairs of 75 MW klystrons replacing the initial complement of 50 MW klystrons.

[2] These dose rates will cause the beam to be turned off by the Beam Shut Off Ion Camber system. See V. Vylet and T. Lavine “Radiation Protection in the NLCTA,” NLCTA # 46.2, December 5, 1995, and Section 7.1.3 above.

Table 9.1: Means of Assurance of Accelerator Safety Envelope; Ionizing Radiation

Restraint	Means of Assurance
Beam Power	Intrinsic capability of linear accelerator. Average current limiting circuit required to be periodically checked by BAS.
Radiation Shielding Design	1. Beam line design and shielding arrangement by the Radiation Physicist, in accordance with the Radiological Protection Guidelines. 2. Review by the Radiation Safety Committee. 3. Field Inspection(s) by the Radiation Physicist and the operations staff. 4. Radiation measurements during commissioning to validate the design.
Configuration Control	1. Beam Authorization Sheet (BAS) requires inspection of moveable shielding, and other safety-related items on start up. 2. Configuration control via Guideline 14.
Radiation Safety Systems	1. Personnel Protection System (PPS), Beam Containment System (BCS) and Beam Shut Off Ion Chamber (BSOIC) system design, maintenance and periodic inspection controlled by formal procedures. 2. Design changes are initially reviewed by the Radiation Safety Officer, who is authorized to approve minor changes. If proposed changes are major modifications, proposal is reviewed by the Radiation Safety Committee. 3. Operation of PPS and BCS and BSOIC system controlled by formal procedures. 4. Configuration control via Guideline 14.
Significant Modification	1. Modifications which may impact Safety Envelope require review by the Safety Overview Committee.[a]
Operations	1. Control room is required to be staffed by specified complement of qualified operators.[b] 2. Operators are required to be qualified in accordance with the training plan.[c]

[a] See *SLAC Guidelines for Operations*, Guideline 24, “Safety Review of Major Modifications*.”*

[b] See NLCTA Operations Directives, (in preparation).

[c] See Section 5.2 above.

Operations may be constrained to levels which are significantly below the maximum power level by administrative and technical means specified in the Beam Authorization Sheet.[1] The limits set from time to time by the Beam Authorization Sheet then constitute the Operations Envelope for the facility. The Operations Envelope will be chosen such as to restrain power to conform to annual radiation dose limits and / or to avoid damage to system hardware. The means of assurance employed to control the Operations Envelope are shown in Table 9.2 below.

Table 9.2: Typical Means of Assurance of Operations Envelope; Ionizing Radiation

Restraint	Means of Assurance
Beam Power	1. Specification in BAS 2. Specified BCS devices (Average Current Monitors, etc.) 3. Operator Surveillance and sign off of BAS 4. Verification of calibrations and configuration control
Path Allocation	1. Legitimate beam path specified in BAS

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[1] See Section 7.1 above.

10

Quality Assurance

The NLCTA has been constructed, and will be operated, in accordance with the SLAC Institutional Quality Assurance Program Plan (SLAC-I-770-0A17M-001, current revision), and with the *Quality Implementing Procedure for the NLCTA Project* (draft, May 5 1995).

11

Decommissioning

The NLCTA, by reason of its low power and limited expected hours of operation, will generate only a small quantity of radioactive material. This will be comprised of parts of the accelerator structure, the beam dump, and possibly some parts of the concrete shielding adjacent to the dump.

The NLCTA is not expected to generate any hazardous wastes in the course of its operation.

SLAC has a procedures manual for the management of radioactive material, and a policy for the assignment of responsibility for the management of decommissioning of both conventional and technical facilities. The facility will not present any special problems in the execution of these policies and procedures.

A Personnel Protection Systems

A.1 Introduction

A Personnel Protection System (PPS) consists of electrical interlocks and mechanical barriers that prevent personnel from entering Radiation Safety Enclosures when particle beams may be operating. The interlocks also serve to shut off the radiation source if any of the gates into an enclosure are opened when beams are on. The interlock system must be operated and maintained in accordance with an extensive set of administrative procedures. These ensure that activities such as setting access states, searching an exclusion area, and testing the interlocks are carried out safely and thoroughly.

At SLAC, the Personnel Protection Systems serve primarily as Access Control Systems. This term is favored by the National Council on Radiation Protection. The DOE uses the name Beam Interlock Safety System. In the following description, PPS will be used because of its widespread and long-standing use at SLAC, and because the system does perform safety functions other than control of access. It provides the logic and the hardwired connections to beam shut-off devices that operate in response to signals from Burn-through Monitors (BTMs) and Beam Shut-Off Ion Chambers (BSOICs). These devices are described in separate documents under the titles “Beam Containment System” and the “Beam Shut-Off Ion Chamber System.” In addition, the PPS limits the potential radiation exposure to persons inside the beam housing when access is permitted, by ensuring that beam-blocking stoppers are in place. The stoppers are designed so that the dose rate in the occupied areas remains below that which could result in a dose of 1 rem a year under normal conditions and less than 25 rem in one hour in the event of a system failure.

While the main function of the PPS is to prevent entry to radiation enclosures when beams are operating, and to turn off the beams when a security violation is detected, there are several other important functions that the logic circuits must accomplish. These include:

1. The provision of interlocks for orderly searching of an area before beam turn-on;
2. Interlocks for setting up the various entry states, such as Controlled and Restricted Access;
3. Provision for emergency shut-off;
4. The operation of annunciator signs and audio warning systems; and
5. Control of electrical hazards in tunnel areas — specifically, uncovered magnet terminals operating at 50 V and above.

It should be noted that the PPS is not designed to protect people against residual radiation when the beam is off, although it does present a somewhat formidable barrier against casual entry to tunnel areas when in the Controlled, Restricted, or No Access states. The reason for its relative ineffectiveness in protecting against residual radiation is because every entry door has an emergency entry (and exit) mechanism, and a determined or untrained person could easily gain access. During long shut-down periods, the Control Room is not manned, and an alarm signal indicating a forced entry would not be noticed. The emergency entry / exit devices are fitted with microswitch interlocks such that if beams were operating, the accelerator would be shut off immediately by the emergency entry interlock, and also by the interlocks associated with the door microswitches.

At SLAC, the PPS is implemented using relay logic. Fail-safe circuits are used wherever possible. For relay systems, this means that for the beam-on condition, all relays in the safety logic circuits are in the operated or energized state. Dual, redundant paths or chains are used to reduce the likelihood that a single unsafe failure would completely disable the protection system. An example of an unsafe failure would be a sticking contact on a relay or switch that failed to open when the relay was deenergized or the switch operated. The dual redundancy is carried from the input devices, such as door microswitches, through duplicate wiring to the dual chains in the logic. The logic output connects to redundant shut-off devices. At least two independent devices are used to ensure positive shut down of beams, but typically three and sometimes four devices are used.

A.2 Design Features

The PPS has been designed in accordance with guidelines that are in common usage in other accelerators, and at similar facilities where a life-threatening situation might arise if inadvertent entry were made to a restricted area. The guidelines have been heavily influenced by publications such as The American National Standard N43.1 [1] and the National Council on Radiation Protection and Measurements Report, NCRP 88 [2]. Many of the principles listed below are described in SLAC-327 [3] and are now incorporated in the guidance section of the DOE Accelerator Safety Order [4].

A.2.1 High Quality Components

Materials and components are of high quality for dependability and long life. Materials that resist radiation are used for components located in areas where radiation levels are high enough to cause radiation damage.

A.2.2 Fail-safe Circuits

Fail-safe circuits and components are used whenever practicable. Fail-safe design includes consideration of the effects of open-circuited or short-circuited cables, the failure of primary AC or DC power, and the loss of pressurized air that feeds air-actuated solenoids. In each case, the safety interlock system reacts to render the area safe. To achieve fail-safe operation, the logic has been implemented using relays that are maintained in the energized state for the normal running (beam on) condition. Thus, all normally open contacts are in the closed condition. Abnormal conditions such as a power loss, cable disconnection, or a conductor short or open circuit, will cause the relay to de-energize and the logic to go to the fault (safe) state. The relays operate at 24 V DC.

A.2.3 Redundancy

Duplicate circuits or redundant components are used in critical applications where the failure of a single circuit or device could lead to a hazardous condition. Most tunnel entrances have two doors, and doors used for routine entry have two microswitches. Double or triple redundancy is used for beam absorbers or magnets that serve as beam stoppers when entry is required into a downbeam area. In the case of logic wiring and circuits, two independent chains, or circuit paths, are used. The failure or activation of any one or both chains results in a beam shut-off and the removal of power to tunnel magnets operating at 50 V or above.

A.2.4 Protection of Equipment

Circuits, equipment, and connecting cables are protected against inadvertent modification, disconnection, or tampering. Logic equipment is located in locked racks or cabinets.

All cables have been protected by armor covering or conduit, except for long cable runs where tray cable has been used in metal trays. When the cable leaves the tray, protective conduit has been installed.

A.2.5 Test Features

To the maximum extent possible, “press-to-test” switches and status indicators have been incorporated into the equipment to permit efficient testing and certification. Thus, the use of clip leads and bypass boxes for testing individual chains has been reduced significantly.

A.2.6 Location of Control Panels

Wherever feasible, control and status of the PPS logic for a specific enclosure are available both at the radiation enclosure itself and at the operations control room. This is to permit maximum flexibility for operational efficiency.

A.2.7 Use of Computers

In some instances, the general purpose control system computer that is used to monitor and control the accelerator may be used for monitoring the status of a remote PPS logic chassis. However, if an operator response is necessary to maintain safety, status signals that are defined as alarms and warnings are also communicated by audible or visual indicators that are not generated by software (*SLAC Guidelines for Operations,* [5]). Control signals to a remote PPS logic chassis may operate through the general-purpose control computer, provided an additional hardwired permissive signal is also transmitted in parallel (logic AND). The control computer is not permitted to perform any PPS logic function because there is not adequate configuration control over hardware or software.

A.2.8 Interlocks for Safe Entry

Interlocks, such as door microswitches, are not used to shut off the beam for routine entries. Beams must be shut down, or stoppers inserted, in an orderly sequence. Entry to a beam housing is prevented (except in an emergency) until the PPS logic circuitry confirms that all machine-generated radiation sources and electrical hazards are turned off, or that the required beam stoppers are inserted or off. Only then is it possible to release a key, operate the electric door latch, and gain entry.

A.2.9 Stopper Integrity

When entry is permitted in an area that is protected by beam stoppers, beams in the up-beam area must be shut off immediately if there is any indication that a stopper is not properly positioned or if it is damaged.

A.2.10 Reset Requirement

If an interlock trips during normal beam operation, the accelerator cannot be restarted until the operator has reset the interlock at the PPS panel in the control area. In the situation where the security of an enclosure has been lost, or when an Emergency Off button has been pushed, a complete search of the area is required before the interlocks can be reset.

A.2.11 Search and Warning Provisions

Interlocks have been provided to ensure complete and effective searching of an enclosure. The interlocks consist of push button or key switches for:

1. Search Preset (search start),
2. Search In Progress, and
3. Search Complete.

The interlock circuits prevent beams from being turned on until the search has been completed and the audio and visual warnings are finished.

The audio warning is a voice recording that instructs persons who may have been overlooked in the search that they must push the nearest emergency-off button and exit immediately. In some areas, a siren is used as the audible warning. The visual warning is given by the flashing of the overhead lights. At the end of two minutes, the lights are left in the dim condition.

A.2.12 Emergency-off Switches

Emergency shut-off switches have been installed in all tunnel enclosures. The switches are large, clearly labeled, and easily accessible. A large red light is mounted on each switch assembly.

A.2.13 Radiation Warnings

Radiation signs and lights, or large annunciators have been installed outside all entrance doors.

A.2.14 Emergency Entry/Exit Provisions

Most doors have emergency exit and entrance mechanisms. These may consist of a crash-bar, a key kept in an adjacent key-box, or a pull-ring.

A.2.15 Access State

In addition to No Access and Permitted Access, many enclosures have Controlled Access and Restricted Access states. These are described in the following section.

A.3 System Description

A block diagram of a typical personnel protection system is shown in Figure A.1. The PPS logic circuits receive information from the accelerator about the status of doors, key banks, emergency-off switches, and other devices. Depending on the safe (or unsafe) state of these components, “permissive” or “enable” signals are generated (or withdrawn) to allow control of safety devices such as beam stoppers. The logic also issues control signals to release keys at remote doors, and to operate warning systems at entrance doors and in accelerator tunnels.

The operator interface to the logic circuits of the PPS may be achieved through a hardware or software control panel. Frequently, both types of panels are provided — a hardware panel near the entrance to the enclosure and a computer touch screen in a central control room area.

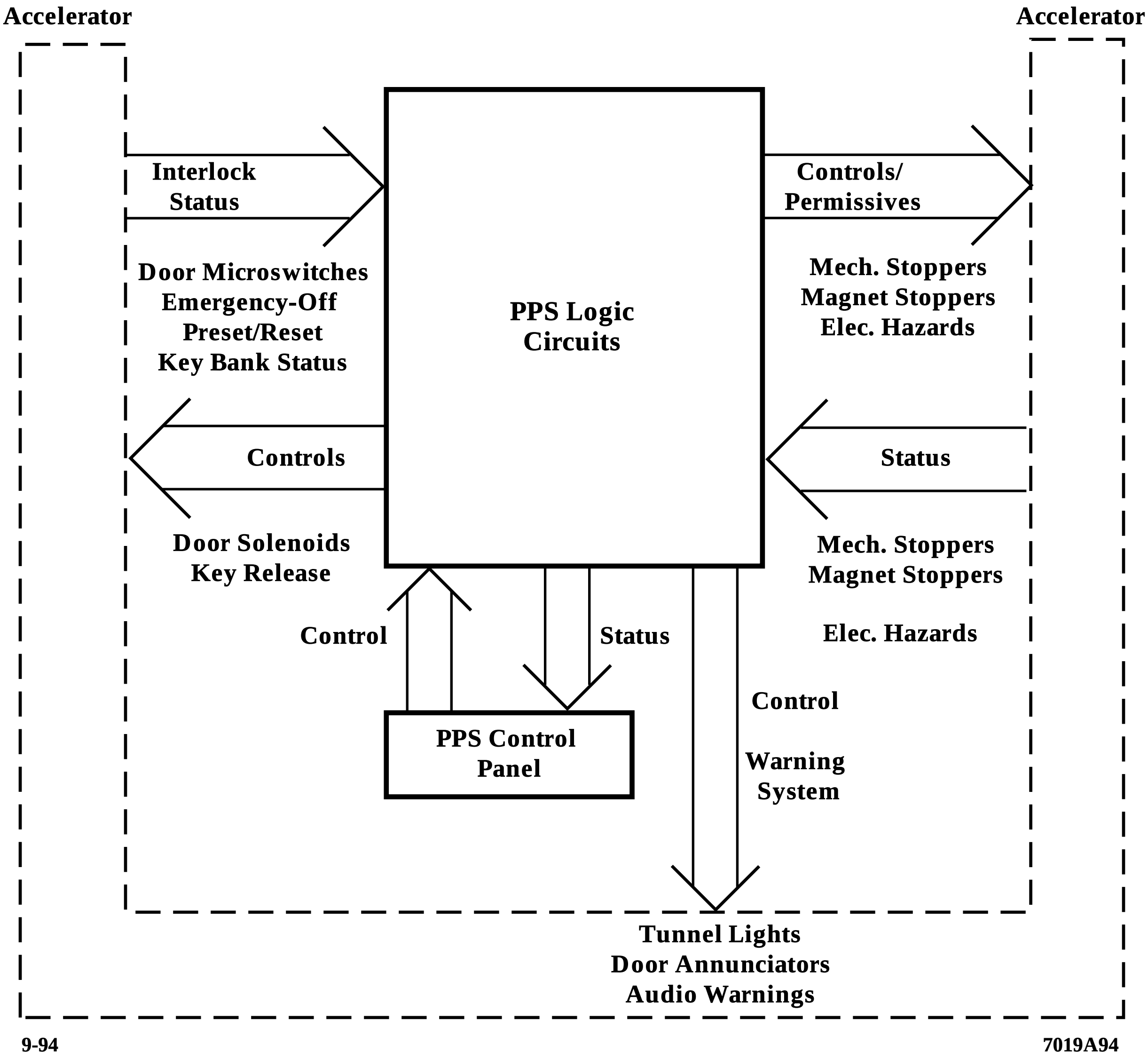


Figure A.1: Block Diagram of Typical PPS System

A.3.1 Stoppers

The term “stopper” refers to any device used to block the beam or prevent it from reaching occupied areas. Thus a stopper could be a mechanical assembly, a deflecting magnet, or the modulators that drive the klystron tubes. SLAC policy requires at least two beam stoppers for protection of personnel, but typically three, and sometimes four, are used. The specific requirements for stoppers are contained in the *SLAC Beam Containment Policy and Implementation* document, available from the Radiation Physics Department. In summary, the current requirements are:

a. If the beam line is designed to permit the beam to be incident on the first stopper when access is permitted to the beam line downbeam of the stoppers, two additional PPS stoppers (for a total of three) are normally required. If fewer stoppers are used, the design must be justified on the basis of adequate safety.

b. If the beam line is designed so that the beam cannot be incident on the first PPS stopper unless a prior failure occurs, then at least one additional PPS stopper (for a total of two) is normally required. If fewer stoppers are used, the design must be justified on the basis of adequate safety.

c. One or more magnets can function as one of the stoppers.

A.3.1.1 Entry Requirements

Stoppers must be inserted in a beam line before entry is allowed to a downbeam area. The PPS logic requires two status signals from each stopper confirming the “in” status before the area can be set to an entry state. In the case of mechanical stoppers, such as slits, collimators, dumps or scatterers, two microswitches are used to determine the “in” position. For magnets used as stoppers, the magnet power supply provides two independent status signals to the PPS logic to confirm that the supply is off. In the case of the linac, the Variable Voltage Substations (VVSs) that power the klystron modulators serve as stoppers. Each VVS provides two “off” status signals to the PPS logic.

A.3.1.2 Security Violation

A security violation of any zone must immediately shut off all machine-produced radiation and electrical hazards in the area. The internal PPS logic circuits respond within about 10 to 100 milliseconds to the opening of any gate or the pushing of an emergency-off button. This delay is due to the drop-out characteristics of the relays that constitute the logic elements in the PPS. Beyond this internal delay, there is an additional delay due to the time taken for mechanical devices to drop into the beam line or for large electromechanical contactors on power supplies or VVSs to release. This second delay could add as much as one or two seconds to the internal delay of 10 to 100 milliseconds.

Note that the logic circuits generate two permissives for each stopper and that both permissives are removed when there is a security violation.

A.3.1.3 Damage to Stoppers

Mechanical stoppers are protected from overheating and damage from accelerator beams by Protection Ion Chambers and Temperature Sensors. Burn-Through Monitors (BTMs) are also used to give an early warning of potential damage to stoppers. The BTM is a pressurized chamber placed in the beam line that ruptures when struck by a beam or beam shower. A pressure switch on the chamber acts through the PPS logic to shut down all beams. The protection of stoppers is covered in more detail in a companion report describing the Beam Containment System, and in the SLAC *Beam Containment Policy and Implementation* document.

A.3.2 PPS Access States

The PPS design provides for up to four access states — No Access, Restricted Access, Controlled Access, and Permitted Access. In some locations, such as the linac, only two states are available — No Access and Permitted Access.

A.3.2.1 No Access

Allows operation of the beam in that area and electrical hazards to be on. No personnel are allowed in the area.

A.3.2.2 Restricted Access

Allows electrical hazards to be on but no beam. No personnel are allowed in area except under RASK. (See below.)

A.3.2.3 Controlled Access

No beam and no uncovered electrical hazards may be on. Personnel access is allowed by contacting the control room. Each person entering must be logged-in by an operator, take a key from a keybank, and be in possession of the key at all times while in the radiation enclosure. In Controlled Access, searching of the area is not required before establishing the No Access state, and resuming of beam operation.

A.3.2.4 Permitted Access

No beam and no uncovered electrical hazards may be on. Personnel access can be made without restriction. Keys are not required. The area must be searched by operators before beams or electrical hazards can be turned on.

A.3.2.5 Restricted Access Safety Key (RASK)

This is a special operating mode that permits personnel to occupy a radiation enclosure with electrical hazards on. Beam operation is prevented by ensuring, through the PPS logic circuits, that the upbeam stoppers are inserted (or off) and that they cannot be removed (or turned on). This special operating mode is used when voltage or polarity measurements must be made on beam line magnets, or when it is necessary to check the integrity of bus and terminal connections on magnets. In this case, temperature probes are used to detect hot spots at connection points.

RASK mode testing is done in the Restricted Access state of the PPS (except for the linac). In this state, beam operation is prevented by the insertion of stoppers as noted above, housing lights are on at full brightness, and key release at entrance door key banks is prevented once the test team has entered the enclosure.

Testing is done in strict conformance with approved procedures. The procedures are somewhat different for each area, depending on the nature of the electrical hazards, and the particular design of the PPS logic, which in the recently constructed systems, provides more interlocked safety features than the earlier designs. For example, because there is no Restricted Access state available for the linac, RASK testing is done in the “Sector Secure” condition, with each team member required to carry an ODD-sector key. Sector Secure is the logic state for the linac PPS that is reached when the sector has been searched and reset; the gates, door, and hatch closed; and the light timer has completed its two-minute timeout.

A.3.3 Warning Lights and Signs

Each entry point to a beam enclosure has a warning light, or annunciator, and a radiation sign. In the klystron gallery, large yellow and magenta warning lights are mounted above the manway door. When the yellow light is on continuously, the linac is off, but there may be residual radiation in the tunnel. A steady magenta light means that the area has been searched and is ready for the beam. A flashing magenta light means that dark current may exist or that the beam is actually running in the accelerator tunnel. In other areas, each entry point has a large annunciator which indicates the access state for that area (No Access, Restricted Access, Controlled Access, Permitted Access).

A.3.4 PPS Control Panels

PPS controls and status are available to operators as either a software-generated display with a touch screen overlay, or as a conventional hardware panel with lamps and switches. For many areas, both hardware and software panels are available.

A.3.4.1 Hardware Panels

A typical hardware panel includes the following features:

- A key switch to enable the panel; the key is kept in the control room key safe.
- Stopper status and controls
- Electrical hazards status and controls
- Access state status and controls
- Door/gate status
- Warning tape status and control
- Interlock status and reset control for Emergency-Off Circuits, doors, and Beam shutoff Ion Chambers (BSOICs), where applicable
- Search preset status
- Search reset status and control
- TV monitor for remote monitoring of the zone entry doors
- Intercom or phone to communicate with persons entering or leaving an enclosure
- Control for release of key bank key
- Key bank status
- Control for release of door solenoid

A.3.4.2 Software Panels

Software-generated panels emulate all of the control and status functions provided by hardware panels, with the exception that no control function to a remote PPS logic chassis is active unless a hardware enable button is also pushed simultaneously with the computer software command.

This additional safeguard, the use of a hardware enable in conjunction with a computer-generated control function, is mandated by the Radiation Safety Committee and by the requirements of the *SLAC Guidelines for Operations.* The reason is that the computer control system is an open system, with no configuration control and no redundancy. Programming errors or software bugs introduced into a beam control program might inadvertently affect safety control programs. Hence the requirement for a hardware backup circuit whenever a safety control function is being exercised through a computer path. Remote key release and door solenoid control are examples of safety control signals requiring hardware backup.

A.3.5 Typical PPS Enclosure

Following is a description of a typical PPS enclosure at SLAC. Figure A.2 shows such an enclosure. It consists of a shielded beam area with a main entrance module and another gate leading to an adjacent beam enclosure.

Its features include:

- An interlocked outer door, with electric strike or magnetic lock, and an emergency exit/entry mechanism
- An interlocked and unlocked inner gate. In some locations, the inner barrier is a movable concrete shielding block or hatch.
- Key bank with 8 or 16 keys
- Door release key switch and push button
- Search preset button inside the enclosure
- Search reset button outside the enclosure
- Emergency-off buttons
- TV camera
- Intercom or telephone
- PPS annunciator sign
- Loud speakers for audio warning
- Flashing lights

A.3.6 Searching and Securing an Enclosure

Entry and exit procedures, and procedures for searching and securing a PPS area are fully documented for each of the SLAC facilities. Operators are required to be familiar with the procedures and to follow them meticulously.

A general description of the steps necessary to bring an area such as the one shown in Figure 2 from Permitted Access to beam operation is as follows. (For a specific enclosure, searchers would follow the documented procedures for that area.)

1. The PPS operator in the control room makes an announcement over the paging system that the area is about to be searched and that personnel should prepare to leave.
2. The operator sets the area to the Controlled Access state, and releases a key from the local key bank to each member of the search team after logging the entry in the control room security logbook for the specific area. In simple enclosures such as the one shown, it would be possible for one operator to safely search the area.
3. One member of the search team inserts the key into the door release box, and turns it clockwise, while the control room operator releases the electric door latch.
4. The searchers enter the enclosure, closing the outer door behind them but leaving the inner gate open. (The microswitches on the open gate serve as an additional pair of interlocks that prevent the beam from being turned on when an enclosure is occupied). The control room operator checks on the remote TV that each person entering has a key. One searcher goes to the far end of the enclosure, checks that the gate is closed and that the emergency entry mechanism is not faulted, and then pushes the Search Preset switch. Pushing the Search Preset sets a latch in the logic circuit, and in some areas, starts a timer that sets the maximum time allowed for the search.
5. The searcher starts the search at the area adjacent to the Search Preset button and walks back toward the entrance gate, making sure that there is no one on the far side of the beam line. The searchers complete the search, close the inner gate, and contact the control room operator who releases the latch on the outer door. The searchers leave the enclosure, close the outer door, and return all keys to the key bank.

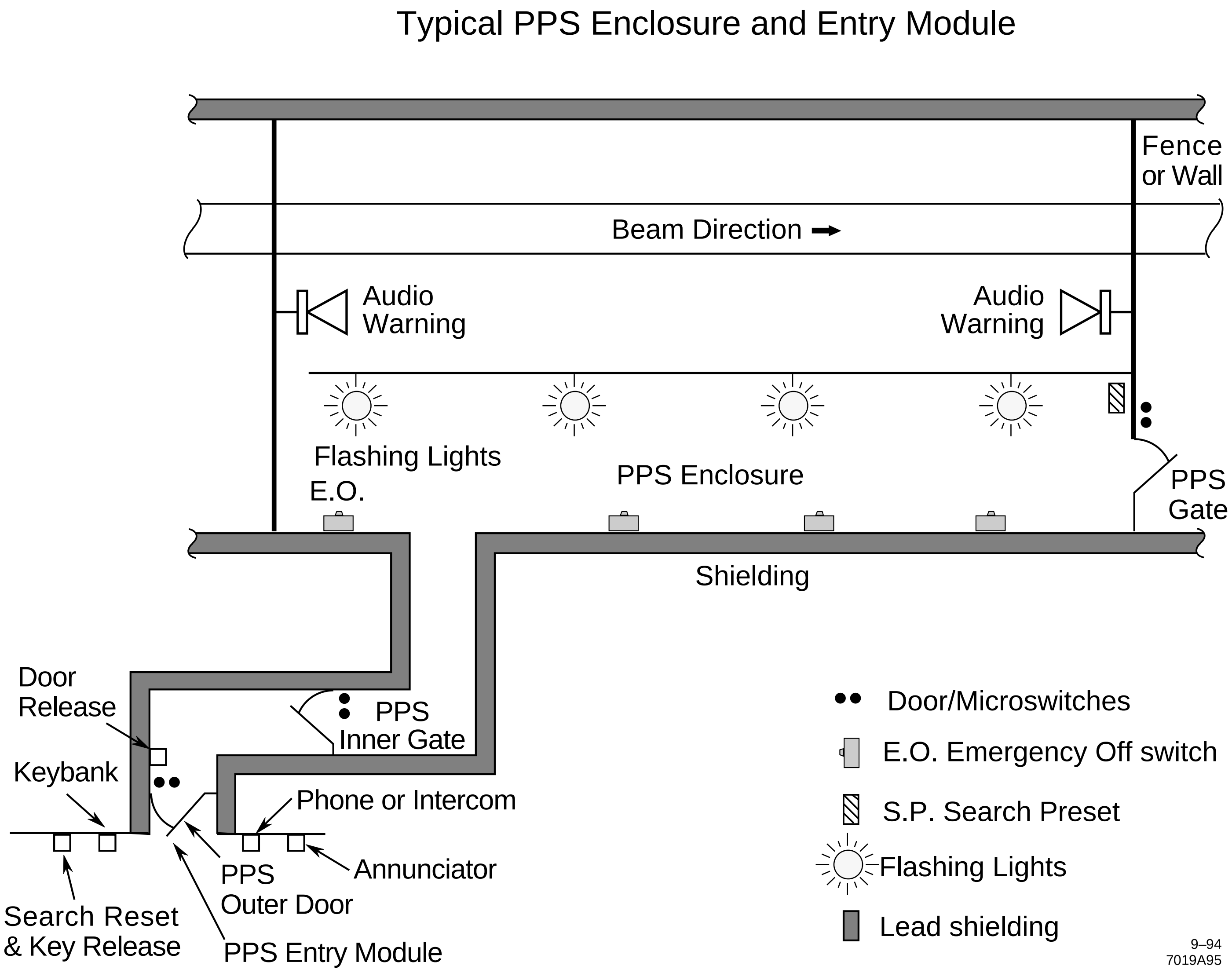


Figure A.2: Typical PPS Enclosure at SLAC

6. The control room operator may now reset the interlocks. Alternatively, in many locations, this may be done at the local control panel outside the enclosure. Resetting interlocks sets latches, or memory circuits on all momentary contacts that connect to the PPS logic circuitry. Momentary contacts are associated with door microswitches, emergency shut-off buttons, and emergency entry / exit mechanisms. Providing memory circuits for these contacts ensures that all interlock trips must be acknowledged and reset by an operator. Also, troubleshooting is much easier because momentary failures can be easily detected even if the transient fault disappears.
7. To complete and confirm the search, one of the searchers pushes the Search Reset button outside the door, simultaneously with the control room operator who pushes the Search Reset button for that area. This sets the state called “Search Reset Complete,” assuming that all emergency-off switches and emergency entry / exit circuits are in the normal state. Simultaneous operation of the Search Reset function is to ensure that the control room operator remains fully aware that an area has been searched.
8. When Search Reset has been set, the area may now be raised to the Restricted Access or No Access state.
9. Once in the NO-ACCESS or RESTRICTED ACCESS state, the operator acivates an audio warning system which provides a siren sound alternating with a voice warning to the effect that either radiation hazards or electrical hazards may be coming on in the zone concerned. There is also an instruction to push the nearest emergency-off button and to call the operations control room. In addition to the audio warning, the housing lights are flashed from bright to dim for two minutes. They remain in the dim state until the area is set to one of the access states, or until an interlock trip causes loss of security.
10. When the visual and audio warnings are complete, the area is ready for the beam, and permissives are generated by the PPS logic to allow the beam stoppers to be removed or the electrical loads to be energized.

A.3.7 Circuit Logic Description

There are several major logic blocks that make up a typical personnel interlock system.

These include the:

- Search and secure logic
- Stopper permissive logic
- Electrical hazard logic
- Access state change logic
- Key and door release logic
- Annunciator and warning system logic
- RASK logic

Formal circuit schematics show the detailed interconnections of relay coils and contacts that comprise each logic block and that join logic blocks together. These circuit schematics and wiring diagrams are essential for the construction and maintenance of the system. They are not so useful if only a quick overview of the logic is required. It is often difficult to locate a specific switch or contact on one of the five or six large circuit schematics that describe the logic of a typical zone. For this reason, shorthand methods are often used to describe PPS logic functions. One common method is to use AND/OR logic symbols.

Figure A.3 is an AND/OR diagram that shows the Search and Secure functions (Search Preset and Reset) for the enclosure described above. It illustrates the level of complexity contained in a typical logic block. Other functions such as electrical hazard and stopper permissive circuits, key bank key release, door release, and access state change circuits (so-called bailing circuits) can be described on similar logic diagrams.

Operation of the search logic circuit is as follows:

The Search Preset is made up by pushing the preset button which sets an electrical latch or holding circuit shown on the bottom of Figure A.3. The latch is set when the signal labeled “Search Preset Cmd, S / Pc” is “high” or “true.” The momentary command signal is held at the output of OR Gate 12 if the output of OR Gate 11 is “true.” This signal is “true” when the output of AND Gate 10 is “true.” This AND Gate is satisfied when the key bank is incomplete, which it must be because the searcher has a key, and when the inner PPS Gate is open. This gate would be open for a Controlled Access entry. Note that there is a timer at the output of AND Gate 10. The timer output is initially “true,” and remains “true” for about two minutes after the inner gate is closed. If the Search Reset has not been made up before this time, the Preset drops out.

To make up the Search Reset, the searcher closes the inner gate and outer door, returns all keys to the key bank, resets the interlocks, and pushes the Search Reset button (S/R C{L}) simultaneously with the control room reset button (S/R C{R}). At this time, all inputs to AND gates 5 and 7 are “true,” and the Search Reset state is “true” at the output of OR Gate 8. This state is held by the latch formed by AND Gate 6.

The loss of any of the input signals such as emergency-off, key bank complete, etc., will drop the latch and cause the reset to be lost. This, in turn, unlatches the preset circuit which remains in the “false” state until the search process is repeated.

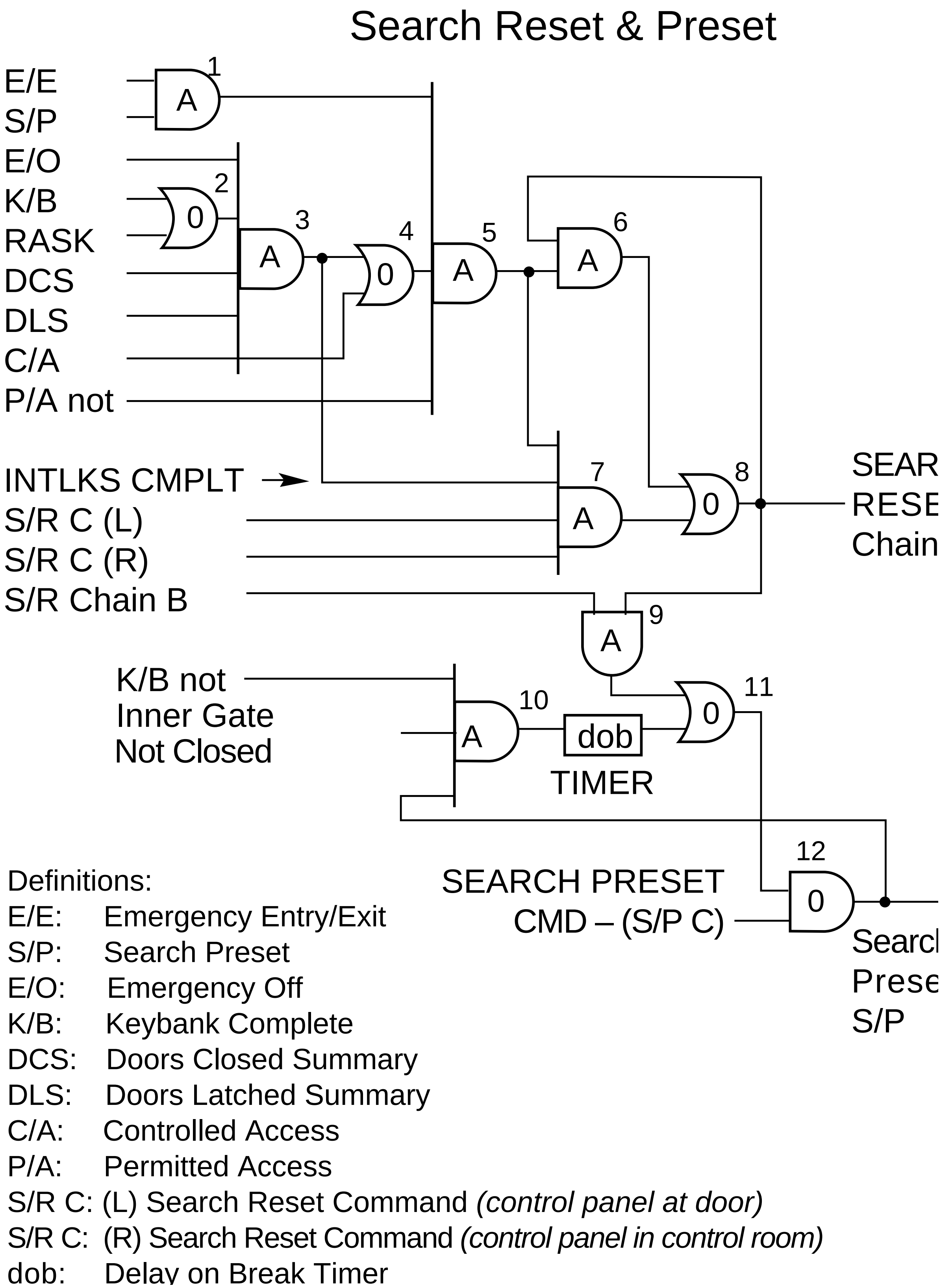
If a beam had been operating in the enclosure when security was lost, the PPS logic would withdraw permissive signals from the radiation stoppers. Loss of these signals causes the mechanical stoppers to drop into the beam line, the electrical stoppers (magnets) to turn off, and other radiation sources, such as klystrons, to be shut down. Electrical hazards would also be turned off.

A.3.8 Zone Entry Requirements

A planned entry into a zone may be made in the Permitted Access state or in Controlled Access, depending on the number of people requiring entry and the time that the area is expected to be open. In either case, the stoppers required for entry to the area must be in place before the PPS logic can generate permissives to release keys and to operate door latches. In addition to the requirement that stoppers be inserted, all electrical hazards in the area must be turned off before door latch and key permissives are given.

A.3.9 Security Violation

A security violation in any zone that is receiving or is ready to receive the beam, must immediately turn off electrical hazards and remove beam-related radiation by inserting the upbeam stoppers and turning off the klystron modulator power sources (VVSs). Thus while normal entry to an area requires only that the appropriate beam line stoppers be inserted and electrical hazards be off, a security violation turns off the electrical hazards, inserts stoppers, and turns off VVSs.



Definitions:

E/E: Emergency Entry/Exit

S/P: Search Preset

E/O: Emergency Off

K/B: Keybank Complete

DCS: Doors Closed Summary

DLS: Doors Latched Summary

C/A: Controlled Access

P/A: Permitted Access

S/R C: (L) Search Reset Command *(control panel at door)*

S/R C: (R) Search Reset Command *(control panel in control room)*

dob: Delay on Break Timer

Figure A.3: Search and Preset Functions

A.4 Administrative Procedures

Even the most carefully engineered interlock system can fail to provide protection if not augmented by administrative rules and procedures covering operation, testing, and modifications. These are summarized below.

A.4.1 Training

Operators and other users of the PPS are trained by the ES&H Division in the Radiation Worker Training course. Further guidance and reference material is provided in the SLAC Radiological Control Manual and the *SLAC Guidelines for Operations.* Operators receive advanced training in the use of the PPS by senior personnel, and the progress and status of their training is carefully monitored and recorded in PPS Certification Workbooks for each area.

A.4.2 Search Procedures

These are formal documents that must be rigidly followed. All unusual or unsafe conditions must be reported to the Accelerator Department Safety Office and these must be corrected or mitigated before beam operation.

A.4.3 Validation

Validation of the PPS is done semiannually, following detailed procedures and checklists prepared by the Controls Department and approved by the Accelerator Department Safety Office. The procedures include radiation interlock tests, electrical hazard tests, and system tests.

A.4.4 Testing

Whenever an area is searched, specific tests must be done on door microswitches and emergency-off buttons by members of the search team. These tests are described in the Accelerator Department PPS Interlock Checklists. Also, whenever an area is open for more than two hours, a safety inspection of the radiation protection devices must be made in accordance with written procedures. These are described in the Safety Inspection Checklists issued by the Accelerator Department.

A.4.5 Configuration Control

Procedures that control the modification and retesting of PPS systems are described in the *SLAC Guidelines for Operations.* All changes must be carefully reviewed and approved, and retesting must be done in accordance with an approved procedure.

A.4.6 Beam Authorization Sheets

For each beam running cycle, specific safety instructions on beam parameters, the operational safety envelope, and required safety devices, including any special requirements for the PPS operation, are given in the Beam Authorization Sheet (BAS). This is a formal document prepared by the Radiation Physics Department and approved by the Accelerator Department Safety Office. It specifies the operational requirements for a particular beam cycle as authorized by the Radiation Safety Officer. Operations are constrained to levels which may be significantly below the Accelerator Safety Envelope.

A.4.7 Electrical Hazard Testing

Procedures for testing energized magnets in tunnel areas are issued by the Accelerator Department. All personnel involved in high voltage testing must adhere to these procedures.

A.5 References

[1] "Radiological Safety in the Design and Operation of Particle Accelerators." American National Standard N43.1 1978.

[2] National Council on Radiation Protection and Measurements. Radiation Alarms and Access Control Systems, NCRP Report No. 88, December 1986.

[3] *Health Physics Manual of Good Practices for Accelerator Facilities*. SLAC-327 R. C. McCall, April 1988.

[4] "Safety of Accelerator Facilities," US Department of Energy, DOE 5480.25, November 3, 1992.

[5] *SLAC Guidelines for Operations*, Chapter 19, "Use of Software-Based Control Systems."

[6] *SLAC Guidelines for Operations*, Chapter 14, "Configuration Control of Radiation Safety Systems."

B Beam Containment System

B.1 Introduction

Radiation safety at an accelerator requires that beams deposit their energy at preselected locations. If beams diverge from their proper channels, high radiation levels can occur in unprotected areas. The Beam Containment System prevents accelerated beams from diverging from the desired channel, and detects excessive beam energy or intensity that could cause unacceptable radiation levels in occupied areas.

Containment of beams is usually accomplished by a combination of passive devices such as collimators, that are designed to absorb errant beams, and active devices, such as electronic monitors, that shut off beams when out-of-tolerance conditions are detected. The combination of these mechanical and electronic devices is called the Beam Containment System.

Beam containment may be lost for a number of reasons. In one instance, a magnet was connected backwards in a new beamline. This was discovered during the initial radiation survey. In another case, a beamline component was significantly damaged by the beam. Following the discovery of this damage, tests were conducted on 13 different devices. These were irradiated at various beam power levels, and the time for burn-through was recorded. As an example, a copper cylinder, 15 cm in diameter and 38 cm long, burned through its length in 22 seconds when struck by a 360 kW beam (Reference 1).

Given the destructive power of SLAC beams and the possibility of excessive radiation in occupied areas as illustrated above, formal guidelines and procedures have been adopted to ensure that appropriate protective devices are installed to contain beams. These guidelines, and the devices that are used to provide protection, are described in the following sections.

It should be noted that the Beam Containment System (BCS) is distinct and separate from the Machine Protection System (MPS). The BCS protects personnel against elevated radiation levels in occupied areas. One of the means by which this protection is achieved is to prevent damage to beamline devices that have been designated as having a safety function. The MPS also protects beamline components from damage due to high power beams, but in this case, the components being protected do not have a personnel safety function. Thus even if there were to be significant damage to an MPS device, there would be no increase in radiation levels in occupied areas. The MPS uses many of the same protection techniques and instruments as the BCS, but there is less redundancy and less rigid administrative control compared to the BCS.

B.2 Beam Containment Principles

We can define a *properly contained beam* as one that terminates on a device that can absorb either

1. The *maximum credible beam* or
2. The *allowed beam power* indefinitely.

In this latter case, the device must be protected by appropriate means. (See Glossary, page B-10, for definition of the terms in italics.)

For example, the maximum credible beam that could be delivered to a particular beamline might be as high as 100 kW if all the beam power-limiting interlocks failed. If the dump at the end of the line could absorb 100 kW indefinitely, then the beam would be safely contained at the dump. If, however, the dump had a rating of 50 kW, then it would have to be equipped with a *burn-through monitor* (BTM) and protected by devices such as *ion chambers* or *temperature detectors* that would shut off the beam when the power exceeded 50 kW. (A BTM is a pressurized container that ruptures when excessive beam power causes damage to a mechanical beam containment device.)

Now take the situation where a 50 kW beam is targeted on a 50 kW dump, and the beam is diverted from its proper trajectory in the beamline by either a steering misadjustment or a magnet failure. If the beam hits a safety collimator that is rated for 50 kW, no additional protection is needed. If the collimator is rated for less than 50 kW, it must be protected by BCS devices in a similar manner to the dump protection.

These two examples illustrate the need for an electronic protection system in addition to the mechanical devices. The electronic system serves three basic functions:

1. To monitor and limit the beam power in a beamline to the allowed value,
2. To limit the losses along a beamline that is operating at its allowed power, and
3. To protect safety-related beamline components from damage.

Thus we can arrive at a definition of beam containment as follows:

> The Beam Containment System (BCS) is a combination of mechanical devices (e.g., collimators and beam dumps) and associated protection devices (e.g., current toroids or ionization chambers) that assure that a beam is confined to an approved beam channel at an approved allowed beam power.

B.3 BCS Policy and Implementation

The SLAC Beam Containment Policy is given in Appendix I and the Implementation Guidelines are given in Appendix II. These are formal documents that are used by the Radiation Safety Officer and the Radiation Safety Committee to ensure that all safety requirements are incorporated into the design of new or modified beamlines.

B.4 Mechanical Beam Containment Devices

B.4.1 Failure Mechanisms

Mechanical devices that are used to contain beams are subject to damage or destruction from either loss of coolant or when design specifications are exceeded. (See Reference [1] for a detailed discussion of this topic.)

B.4.2 Loss of Coolant

Most SLAC power absorbers that are designed to dissipate more than a few hundred watts of beam power on a regular basis are water-cooled. Their safe operation depends heavily on the proper functioning of the cooling system. Malfunctions in this system such as loss of coolant due to a leak, loss of flow due to pump failure, or excessive inlet water temperature due to loss of heat exchanger capacity can have disastrous consequences for the heat dissipating areas of the power absorbers, even though the beam power may be within the rating of the absorber. Failure is generally due to melting in the areas of high beam power deposition, but other mechanisms, such as plastic deformation and / or fracture due to thermal stresses exceeding the yield and tensile properties of the material, may also contribute. The latter may occur in combination with thermal fatigue due to the pulsed nature of the beam.

B.4.3 Design Limits Exceeded

Since not all power-absorbing devices are called upon to dissipate the maximum allowed beam power for indefinite periods of time, there are a wide range of design limitations for the devices in each beam line. For example, there are protection collimators with an average power absorption limit of 5 kW in beam lines that are operated at power levels up to maximum machine output. These collimators are protected against excessive power deposition by means of ionization chambers and temperature detectors in the water system, and are equipped with BTMs that shut off the beam if the collimator is damaged.

B.4.4 Device Descriptions

The specific mechanical devices used for containment are:

B.4.4.1 Protection Collimators

These are placed in strategic locations to intercept a missteered beam and prevent it from entering another beam port or from striking a shielding barrier. These devices are either cooled or uncooled, depending on whether they intercept the beam on a regular basis. They are typically at least 20 X_0 (radiation lengths) long. They offer good protection, except where a high-power beam impinges at grazing angles along the aperture. Typically they are equipped with a BTM and protected by devices such as ionization chambers, temperature sensors, and flow switches. If the electronic protective devices fail to shut off the beam, collimator burn-through could occur within a few seconds at power levels of 100 kilowatts. In this event, the BTM would turn the beam off within one to two seconds after the detection of damage to the collimator.

B.4.4.2 Beam Dumps and Beam Stoppers

These are designed to absorb a beam of specific power for an indefinite period. If they are designed to absorb the maximum credible beam, no protection devices are needed.

B.4.4.3 Burn-Through Monitors

Burn-Through Monitors (BTMs) are used to detect the onset of damage to collimators, dumps, and stoppers. BTMs are pressurized cavities, usually located at or near shower maximum, that are designed to rupture when the device being protected absorbs greater than its allowed beam power. A pressure switch connected to the cavity turns off the beam through the Personnel Protection System. The switch acts through energized relays that de-energize on either a BTM fault, the loss of power, or a short or open circuit on any connecting cable.

B.4.4.4 Blow-Out Fuses

These fuses are an integral part of the stopper assembly. When excess power is absorbed by the stopper, the fuse melts, allowing air to enter the beamline vacuum pipe, resulting in the beam scattering.

B.5 Electrical Beam Containment Devices

B.5.1 Bending Magnets

These are frequently used as protective devices in the containment system. Typically the magnet polarity, the magnet current, and the on / off status of the power supply are monitored and interlocked, such that when an out-of-tolerance condition is detected, the beam is deflected into a safe location, or is prevented from entering a beamline that has an inadequate power rating.

B.6 Electronic Beam Containment Devices

If mechanical containment devices could be designed to absorb the maximum credible beam power, there would be no need for additional electronic protection or for the installation of BTMs. However, cost and physical space limitations preclude such an approach in most beamline designs. The alternative is to provide fast electronic protection for devices and beamlines. The electronic devices in the BCS provide this protection. (As noted earlier, the BTMs do not act through the electronic shut-off circuits of the BCS. They operate directly through the Personnel Protection System to shut-off beams.)

B.6.1 BCS Electronics

Each electronic protection path or system, from the sensor (ion chamber, flow switch, etc.) to the processing electronics, is designed to be as fail-safe as possible, with self-checking signals that serve to confirm the correct operation of the sensor and electronic module. This continuous self-checking coupled with formal administrative procedures, provides a protection system that has both high reliability and high availability. (See Reference [4] for more information.)

B.6.2 Design Philosophy

- All systems incorporate continuous self-checking features to ensure integrity of the transducer, the cabling, and the electronic processing unit.
- All pulsed equipment, with the exception of ion chamber electronics, utilizes narrow window gating (5-10 μs) at beam and test time to reduce the effects of noise that may be introduced into the electronic modules via the cable plant.
- The protection devices in each beam line are independent of each other and are different whenever possible. For example, one protection channel might monitor the average beam current while another monitors the beam repetition rate. Type diversity such as this reduces the chances that a common mode failure would disable both channels simultaneously. In practice, three or more independent devices are used for protection in most beamlines.
- Beam power is monitored by measuring beam current. Beam energy is known because the number of klystrons accelerating the beam is known, or the field strength of bending magnets (or the magnet currents) can be measured. Beam current is typically measured by beam line current transformers (toroids).
- The requirement for verification that a beam has reached its proper destination without significant beam loss is met by using toroid comparators that measure and compare beam current on a pulse-to-pulse basis at two locations in a beam line.

- Beam loss in a beamline may also be measured by discrete ionization chambers placed near mechanical devices or by long ion chambers that protect a section of the beamline or the whole beamline.
- When a fault is detected, beams are shut off by three independent methods.
- Equipment and cabling is protected in locked racks.
- Operation of the equipment is checked daily using formal procedures.

B.6.3 Beamline Sensors

Typical sensors, or transducers, used in the BCS include ionization chambers, beam current toroids, flow switches, and temperature detectors.

B.6.4 Processing Electronics

Signals from transducers are processed in electronic modules that shut off the beam when out-of tolerance conditions are detected.

Processing modules measure:

- Average current
- Charge per pulse
- Beam repetition rate
- Beam loss between two beamline sensors (toroid comparator)
- Beam loss along a beamline (long ion chamber)
- Beam loss at a point (discrete ion chamber)
- Temperature of devices or water systems
- Position of stoppers and other mechanical devices

B.6.5 Beam Shut-off Paths

Beam shut-off for a BCS fault has the following characteristics:

- High speed — within a few beam pulses
- Redundant — three shut-off methods are used
- Diversity — each shut-off method is different

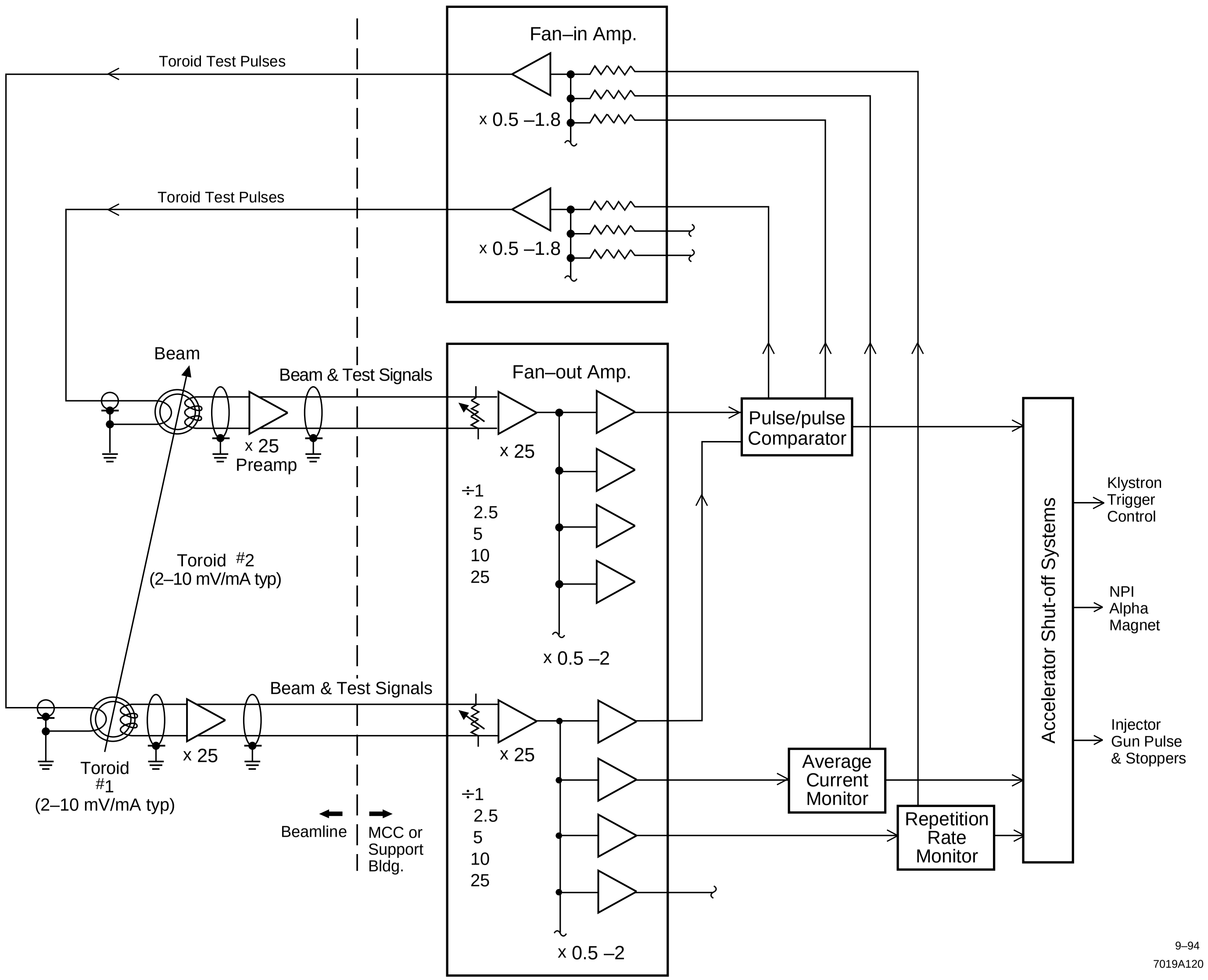


Figure B.1: Typical BCS Signal Distribution

B.7 Beam Containment Policy[1]

The SLAC policy for containing beams requires all three of the following to be met:

1. Primary beams must be prevented from escaping Beam Containment.
   Secondary beams must also be confined if they are of sufficient power to exceed SLAC radiation design limits.
2. Primary and secondary beams must be prevented from striking beamline components or the shielding enclosing the Radiation Containment Area if this results in radiation levels in occupied areas that exceed SLAC radiation design limits.
3. Primary and secondary beams must be turned off if excessive radiation levels occur in occupied areas or if the beam power striking a device, which is designated to contain the beam, exceeds the power limit of the device.

B.8 Implementation Guidelines

To achieve the goals stated in the policy, the following guidelines have been adopted.[1]

B.8.1 Beamline Design

Beamlines are designed by beamline engineers or physicists:

- With advice from Radiation Physics;
- Using these Beam Containment guidelines;
- With consultation from the Radiation Safety Officer for variances;
- With the advice from Radiation Safety Committee before construction starts.

Design of beamline includes an estimate of the maximum credible beam power that can be delivered, and the specification of the locations of mechanical containment devices with their power absorption capabilities. Ray traces should be included that demonstrate the normal beam path and the consequences of beam missteering. Shielding calculations must be made for potential beam losses.

In the description below, unless otherwise stated, the radiation levels in occupied areas must not exceed the allowable levels for normal beam operation.

B.8.1.1 Equipment Requirements

1. The beam power in a beamline must be limited to the allowed beam power by each of three independent protection devices if the allowed power is less than the maximum credible beam power.

   Beam losses in Radiation Containment Areas may need to be limited by two protection devices to prevent radiation levels in occupied areas from exceeding those given in Section B.8.1.3 on page B-9 for normal beam operation.
2. Mechanical Beam Containment devices, such as dumps, collimators, and stoppers must either
   a. Be capable of intercepting the maximum credible beam power for an indefinite time period, or
   b. If not able to absorb the maximum credible beam power, must be protected by at least two protection devices.

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[1] Current policy at time of writing. Contact the Radiation Safety Office for latest revision.

These devices must turn off the beam to prevent exceeding the power limit of the mechanical device. If the mechanical beam containment device is capable of intercepting the allowed beam power, the protection devices in Point 1 may serve this function.

If the protection devices mentioned in Points 1 or 2 fail and the maximum credible beam strikes a mechanical device, the radiation levels in occupied areas must not exceed the allowable levels for accident cases given in Section B.8.1.3 on page B-9.

3. Mechanical beam containment devices as described in Point 2 must also be equipped with a Burn-Through Monitor (BTM) over as large an area as the beam can be steered if the device cannot absorb the maximum credible beam indefinitely.
4. Beam containment devices, such as magnets, and mechanical and electronic protection devices, must be designed or implemented to fail in a safe manner.
5. PPS stoppers are considered to be beam containment devices in that their function is to “contain” the beam upstream of a secured area when access is permitted. The required redundancy of PPS stoppers depends on the beamline design.
    a. If the beamline is designed to permit the beam to be incident on the first stopper when access is permitted to the beamline downbeam of the stoppers, two additional PPS stoppers are normally required. If fewer stoppers are used, the design must be justified on the basis of adequate safety.
    b. If the beamline is designed so that the beam cannot be incident on the first PPS stopper unless a prior failure occurs, then at least two PPS stoppers are normally required. If fewer stoppers are used, the design must be justified on the basis of adequate safety.
    c. One or more magnets can replace one of the stoppers.
    d. These stoppers must meet the criteria for beam containment devices as indicated in Points 2, 3, and 4 above.
6. Beam Shut-Off Ion Chambers (BSOIC) should be associated with each beamline unless it is proven that they are not needed. The BSOIC is responsive to radiation levels, and is not considered as one of the electronic protection devices for limiting beam power or losses.
7. Primary beams must be prevented from entering secondary beam channels unless the secondary beam channels are also completely confined. This may be accomplished by one or more of the following:
    a. All bends in the primary beam line must be in different planes than the secondary beam channels.
    b. Failure of magnets or the most radical steering, at all energies, must not send the primary beam into the secondary beam channels.
    c. Secondary beam channels must be plugged or shadowed with a beam containment device meeting the criteria in Points 2, 3, and 4 above.
    d. A redundant system of permanent magnets must prevent the primary beam from entering the secondary beam channels. The permanent magnets must be protected from beam related damage.
    e. Charged particle secondary beams can be controlled by proper secondary transport magnet polarity and / or transport energy. The polarity must be properly controlled and / or interlocked into the Beam Containment Shut-Off System.

B.8.1.2 Administrative Requirements

1. All devices described in Section B.8.1.1 above must be certified to function properly before the beamline is operated.

2. Sufficient scheduled accelerator time must be provided for adequate beam containment checkout as prescribed by the responsible Radiation Physicist and the Accelerator Department Safety Office, or the Stanford Synchrotron Research Laboratory Safety Office. To ensure that this time is allocated, line items may be included on the Beam Authorization Sheet.
3. All protection devices must be protected against unauthorized modification or bypassing. Wherever possible, appropriate fail-safe and self-checking features are to be included in the design.
4. Protection devices should be reviewed by the Radiation Safety Committee.
5. The burden of proof for the safety of the beamline design lies with the designer. It is not the responsibility of the Radiation Safety Committee to prove the safety.

B.8.1.3 Maximum Allowable Radiation Design Levels

The maximum allowable radiation levels in potentially occupied areas are limited to the following:

1. Normal beam operation — The total integrated dose equivalent to an individual outside secured area must not exceed 10 millisievert (1 rem) in a year when running the allowed beam power and the beam is fully contained. This limit shall include radiation levels caused by normal beam losses and occasional missteered beam conditions.
2. System Failures — In the event of a BCS failure, the total integrated whole body dose equivalent to an individual outside secured area shall not exceed 30 millisievert (3 rem) for broad beam exposure. Narrow beam, ð2 inch diameter, exposures shall not exceed 120 millisievert (12 rem). With dose rates on the order of 250 millisievert / hr. (25 rem / hr) under accident conditions, the beam must be turned off in approximately 1 / 10 hour to meet these criteria. Burn-Through Monitors (BTMs) must be used to limit the duration of the accident.

System failures are defined as follows:

   a. All the beamline containment protection devices have failed, thereby permitting the maximum credible beam to enter the beamline. Loss of this maximum credible beam at any point shall not cause radiation dose exposure levels to exceed those stated in Section B.8.1.3, Point 2, above.

   b. If any beam containment device or its associated protection devices fail, such that the beam is no longer properly contained, the resulting radiation levels must be limited as in Section B.8.1.3, Point 2. Since PPS stoppers are categorized as beam containment devices, the above criteria applies in the event of the failure of any stopper. As long as one stopper remains, the above criteria applies.

B.8.1.4 Documentation (For presentation to the Radiation Committee)

1. A documentary description of each beam line should be prepared and circulated to the Radiation Safety Committee. Its preparation should be the responsibility of the beam line engineer and the responsible Radiation Physicist.
2. The documentation should contain the following elements:

   a. A general beam layout drawing showing all elements of the beam and the adjacent equipment.

   b. Ray traces of areas of interest.

   c. A list of all safety components and a quantitative description of their function.

   d. A statement of assumptions.

   e. A description of the accidents envisioned in the design.
   f. A list and description of routine inspections required to ensure integrity of the safety system.
   g. Description of tests or presentation of calculations that support performance claims of safety features or devices.
   h. Description of conditions and limitations of the design analysis, that is, what conditions were not covered in the analysis.

3. All drawings and sketches should contain SLAC drawing numbers and all components should be clearly identified.

Glossary

Allowed Beam Power	The highest primary power permitted for the beamline in question by administrative and/or electronic restraints. The Radiation Physicist responsible for the beamline determines the allowable beam power.
Beam Containment	A beam channel defined by a system of devices, that is, shielding, dumps, collimators, stoppers, magnets, or electronic restraints, designed to “contain” the beam and/or limit the beam power and/or beam losses to prevent excessive radiation in occupied areas.
Beam Containment Shut-off System	This system utilizes two electronic summary modules that shut off the beam by three independent methods.
Beamline Engineer	The engineer responsible for the design of the beamline, including the provision of all safety devices such as collimators, dumps, ion chambers, and other containment devices.
Beam Shut-Off Ion Chamber (BSOIC)	A device wired into the PPS to put in beam stoppers (or turn off gun High Voltage) if radiation is detected above a pre-set level.
Blowout Fuse	A thermal plug that is part of a stopper assembly. It is designed to rupture when the beam power absorbed by the stopper exceeds the design value. Air enters the accelerator vacuum pipe and the beam is scattered.
Burn-Through Monitor (BTM)	A device wired into the PPS to turn off the VVSs if the mechanical beam containment device has melted. Burn-Through Monitors are presently limited to pressure or vacuum release. The BTM must turn off the VVSs in less than 1/10 of the calculated burn-through time of the beam containment device when the device is absorbing greater than the specified beam power.

Controlled Area	Areas that may contain potential radiation hazards. In these areas, a dosimeter badge must be carried at all times. These areas are: • Inside the Controlled Area fence with entrance points at the Sector 30 guard shack, the SSRL / SPEAR gate, and the Alpine road gate. • The high bay area of the Test Lab (Building 44). • Certain areas of the Cryogenics Building (Building 06), Building 08, and Building 24.
Ion Chamber	A beamline device that responds to beam-related ionizing radiation. It consists of a gas-filled chamber with an inner electrode at high voltage. The output signal current is transmitted on coaxial cable to an integrating circuit in one of the support buildings. The integrator output trips a comparator circuit when the ionization level exceeds a preset level.
Maximum Credible Beam	The highest credible beam power the accelerator can deliver to the point in question assuming all protection devices have failed.
Normal Beam Operation	Beamlines operated within the allowed beam power, and with well-steered beams.
Properly Contained Beam	A beam that terminates on a device that can absorb the Maximum Credible Beam indefinitely, or one that can absorb the Allowed Beam indefinitely, provided it is protected by appropriate means such as ionization chambers, and is equipped with a Burn-through Monitor (BTM).
Protection Devices	Electronic circuits or modules connected to beamline transducers such as toroids, flow switches, or ion chambers that prevent the beam rate, beam power, temperature, or beam losses from exceeding specified values. When out-of-tolerance conditions are detected by these electronic modules, beams are shut off by the Beam Containment Shut-Off System.
Radiation Containment Area	An area designed to confine hazardous radiation and prevent personnel access by means of shields, fences, procedures, etc. The adequacy of such enclosures must be approved by the Accelerator Department Safety Office or the SSRL Safety Office and the Radiation Physics Department.
Responsible Radiation Physicist	That member of the Radiation Physics staff assigned to the design and operation of a specific beam line.
Secondary Beam Channels	A beamline in which the incoming beam is the result of an interaction of the primary beam with a target or a synchrotron radiation beamline.

Secured Areas	Radiation containment areas whose doors or gates are locked with strictly controlled keys or are interlocked in the Personnel Protection System.
System Failure	System failure of the BCS occurs when all the beamline containment protection devices have failed, thereby permitting the Maximum Credible Beam to enter the beamline or when any beam containment device or its associated protection devices has failed such that the beam is no longer Properly Contained.

References

[1] "Tests and Description of Beam Containment Devices and Instrumentation — A New Dimension in Safety Problems." D. Walz et al. IEEE Trans. *Nuclear Science*. March 1973. NS-20, 465.

[2] "Safety of Accelerator Facilities." DOE 5480.25, November 1992.

[3] "A Precision Actuator and Shaft Encoder for a High Radiation Environment and Other Beam Component Developments at SLAC." L. R. Lucas and D. R. Walz. SLAC Pub 879, March 1971. IEEE Trans. *Nuclear Science*, June 1971. NS-18 #3, June 71.

[4] "Operational Experience with SLAC's Beam Containment Electronics." T. Constant, K.F. Crook, D. Heggie. SLAC Pub. 1901, March 1977. Particle Accelerator Conference 1977.

C Beam Shut-off Ion Chamber System

C.1 Introduction

Beam Shut-off Ion Chambers (BSOICs) are radiation detectors that have been installed in a number of locations around the SLAC site. Their function is to measure beam-related radiation outside the shielded areas and to turn off the accelerator beams if radiation levels exceed design limits. Typically, the limits are set to either 10 millirem / hr or 100 millirem / hr, depending on the location of the BSOIC.

C.2 BSOIC Description

C.2.1 Ionization Chamber

The ionization chamber and associated electronics are housed in a watertight cylindrical can, 10 inches in diameter by 28 inches high. The ionization detector is a 10-liter aluminum chamber filled with ethane at one atmosphere. Aluminum and ethane are approximately tissue-equivalent for photons in the energy range from 200 KeV to 10 MeV. Ethane was selected to enhance the response to fast neutrons. The chamber response to neutrons is about 20% less than its response to the same dose of photons. Since warning and trip levels are adjustable, this under-response can be calibrated out.

The chamber is designed to produce one pA / mrad / hr at 10-liter-atm with a collecting potential of 500 V. It has been checked for saturation in fields up to 100 rads / hr. The nominal operating range is from one to 1000 mrad / hr.

C.2.2 Electronics

The entire unit is AC-powered and the electronic processing is all solid-state. The collecting potential is provided by a 500 V internal power supply. The log converter consists of two base-to-emitter junctions in series as the major part of a feedback network in an operational amplifier. This amplifier has a dual MOS-FET input and has an open loop gain of the order of 10,000. Primarily because of the temperature dependence of the log converter, the entire circuit is enclosed in an oven operating at approximately 50°C. The proportional controller for the oven uses a thermistor for temperature sensing. Within 1 / 2 hour from a cold start, the oven stabilizes to within ±0.1°C. The entire oven temperature control circuit is also located within the oven housing. The oven housing measures approximately 3 1 / 4 × 3 1 / 4 × 2 1 / 4 inches. The log converter uses two 2N2913 transistors. These exhibit an almost ideal logarithmic characteristic (i.e., base-to-emitter voltage versus base-to-emitter current) over the range of 10^{-5} to 10^{-12}.

Figure 1 is a block diagram of the internal BSOIC circuit. It also shows typical external connections to beam shut-off and monitoring devices. The complete electronic diagram including oven control, is shown on drawing SD-123-823-00, available from SLAC Document Control.

C.2.3 Fail-safe Design

C.2.3.1 Self-Test

To provide fail-safe operation, a 0.4 -µCi90 Sr. source is incorporated within the chamber. The source produces a current corresponding to about 2 mrads/hr. This “housekeeping” current generates a continuous analog voltage at the output of the integrator. When the output signal drops below a preset level, indicating either a deterioration of the source, a fault in the electronics, or an open circuit or short circuit on the wire pair to MCC, an alarm is generated and the BSOIC is replaced or repaired.

C.2.4 Power Disconnection

In addition to the fail-safe operation provided by the internal source, the BSOIC is fail-safe when AC power is disconnected. To prevent inadvertent disconnection, and thus the shutting down of the accelerator, the AC plugs are protected by locking collars.

C.2.5 Cable or Connector Disconnection

When the signal cable that connects the BSOIC to the external safety devices (stoppers) is disconnected or short circuited, the accelerator is immediately shut down.

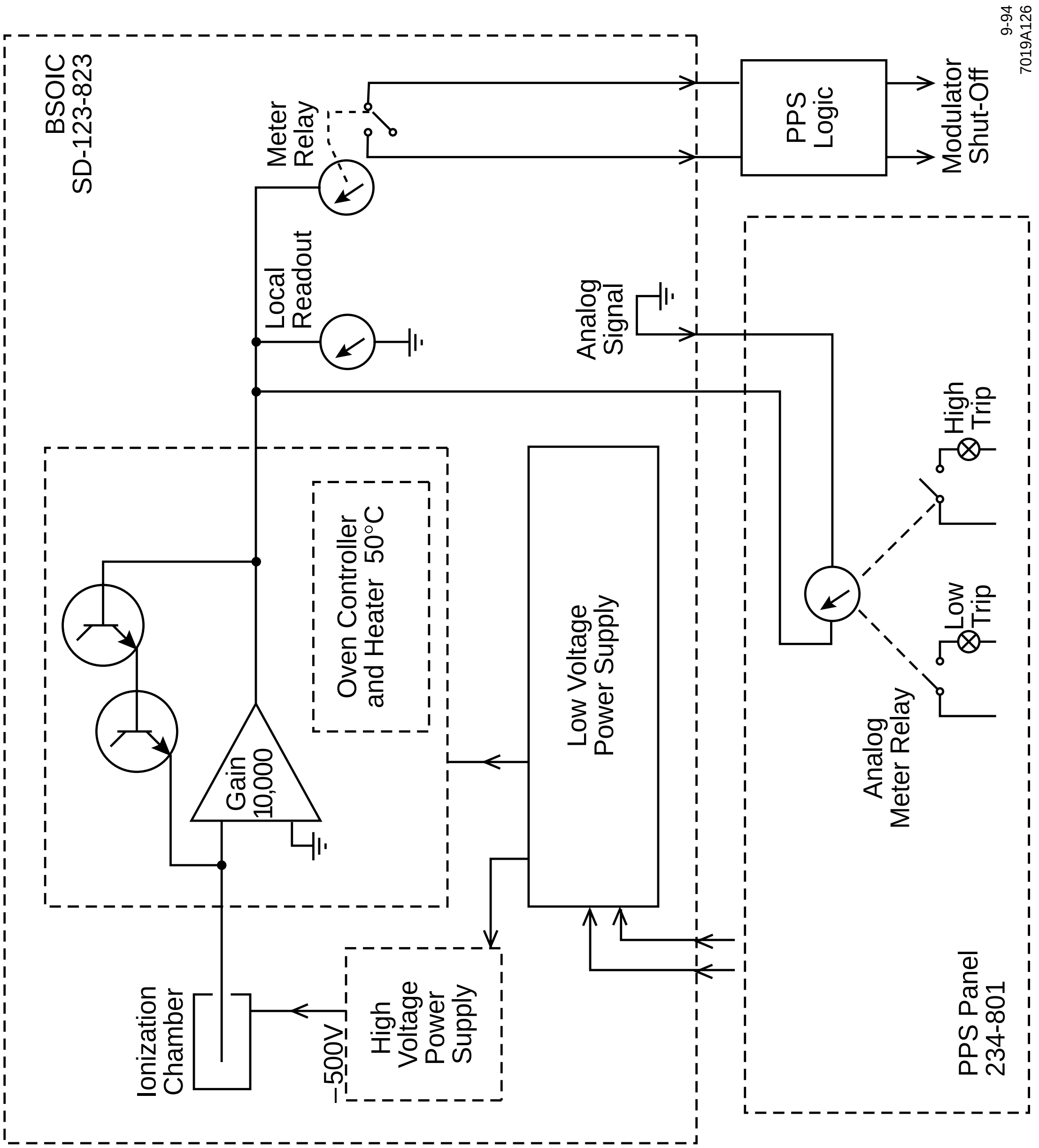

Figure C.1: Simplified BSOIC System Diagram