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.

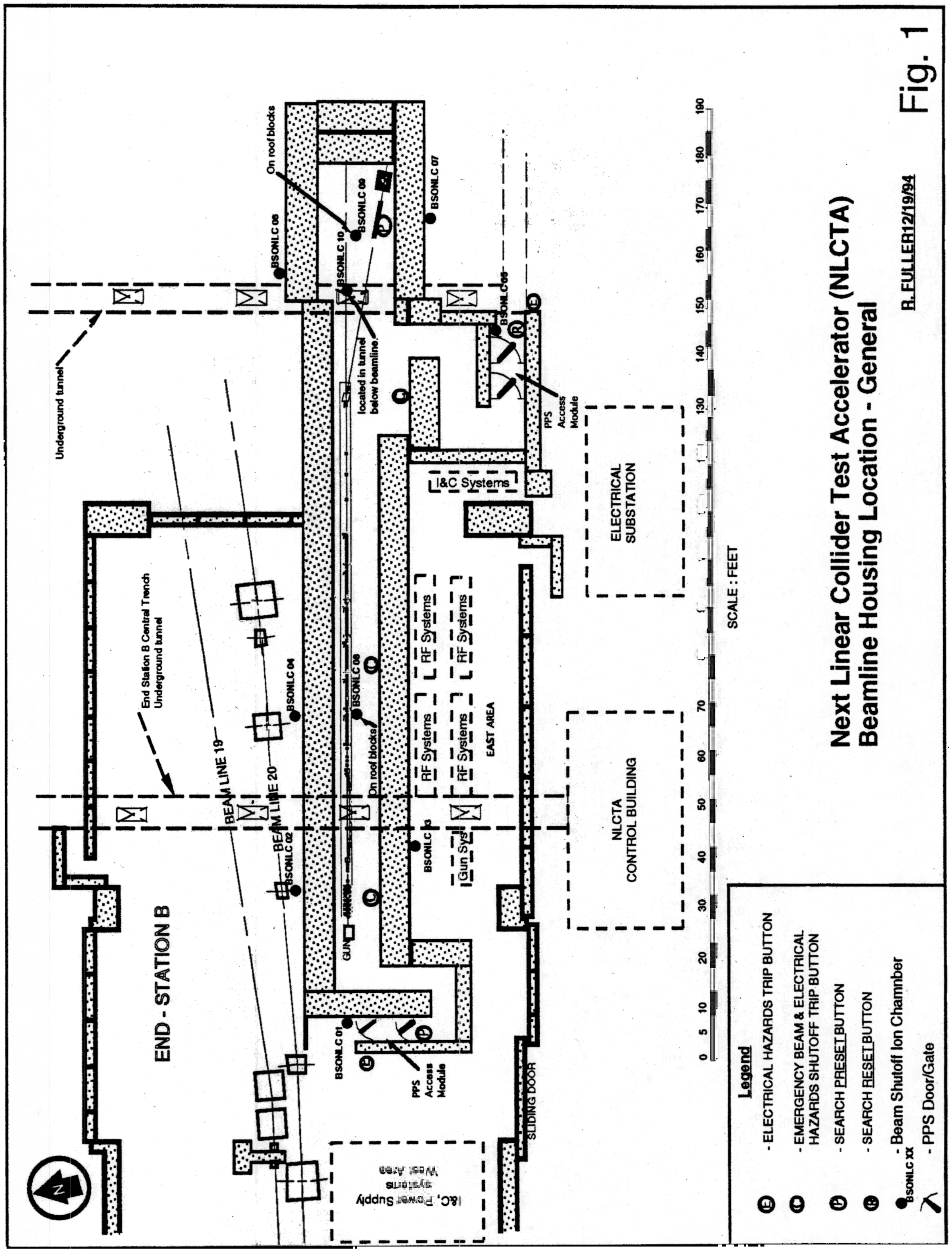
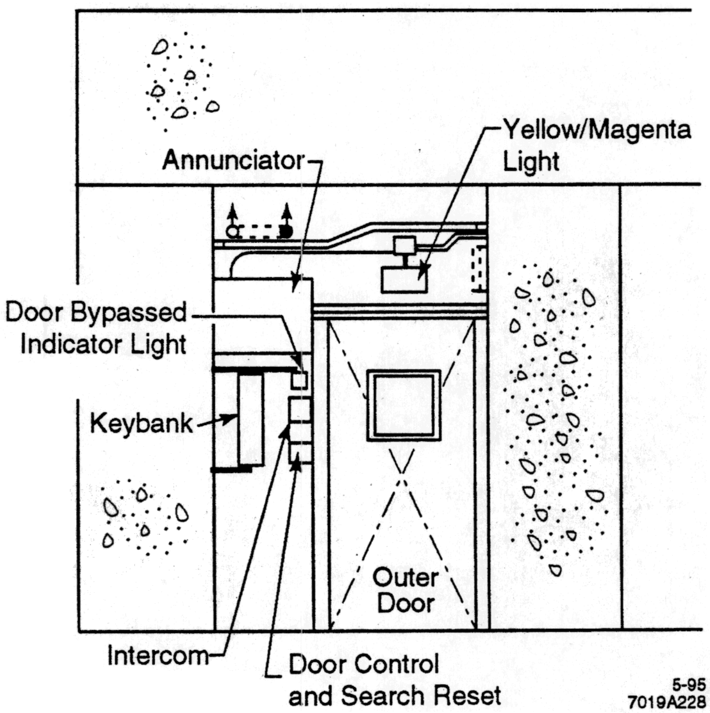


Figure 7.1: NLCTA PPS General Layout



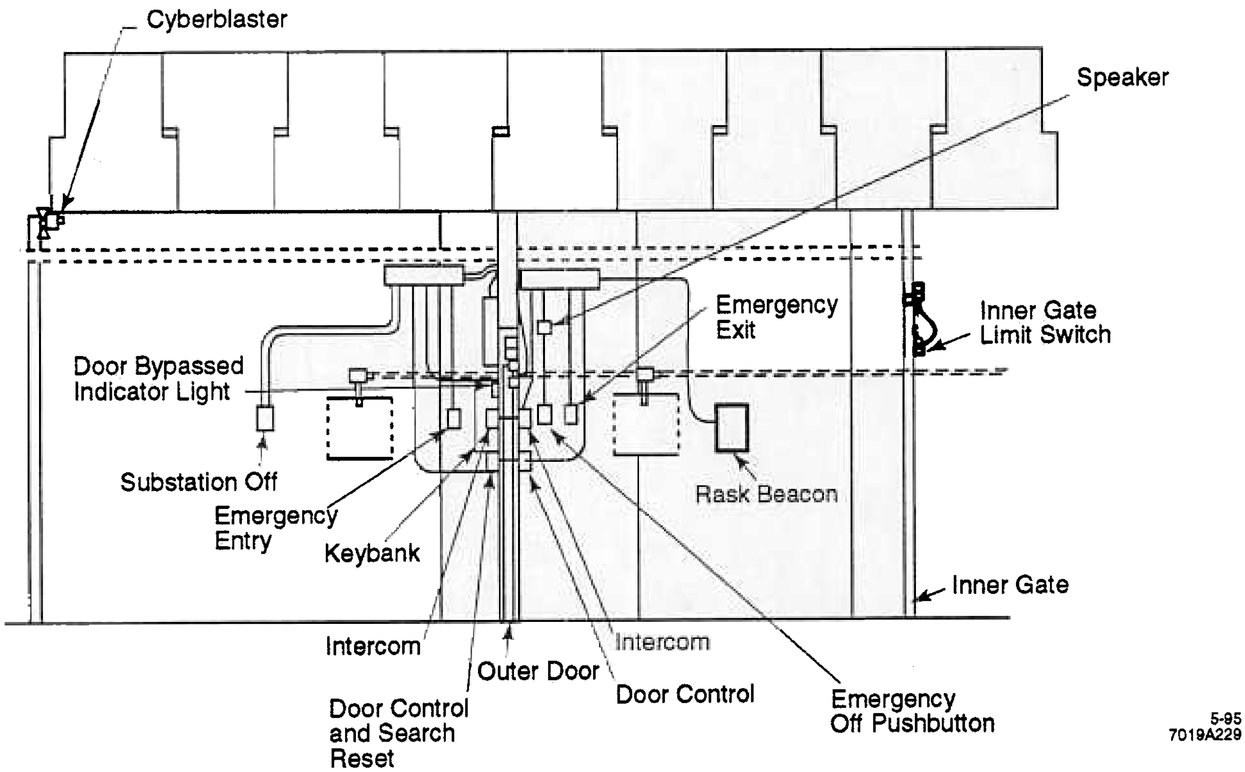


Figure 7.2: NLCTA PPS Door Configuration

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, page 7-2 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 [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 [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.

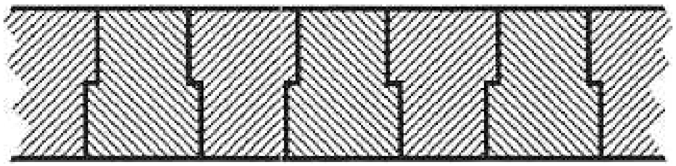


Figure 7.3: Longitudinal Elevation View of the Roof Blocks

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

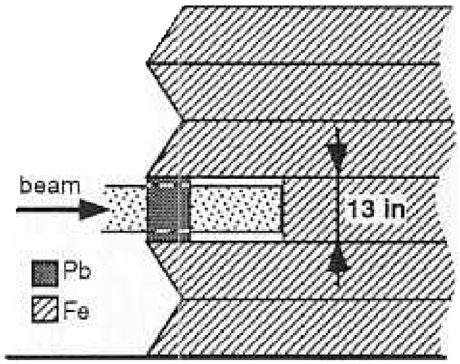


Figure 7.4: Vertical Section of the Front Face of the Beam Dump

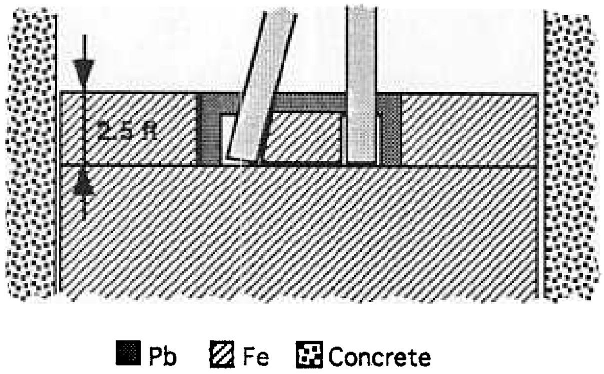


Figure 7.5: Horizontal Section of the Front Face of the Beam Dump at Beam-Line Elevation

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 [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 [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 [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 [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 pos-

[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.

sible trajectories were traced through the mazes in order to find the maximum radiation level at the entrance.

West Maze

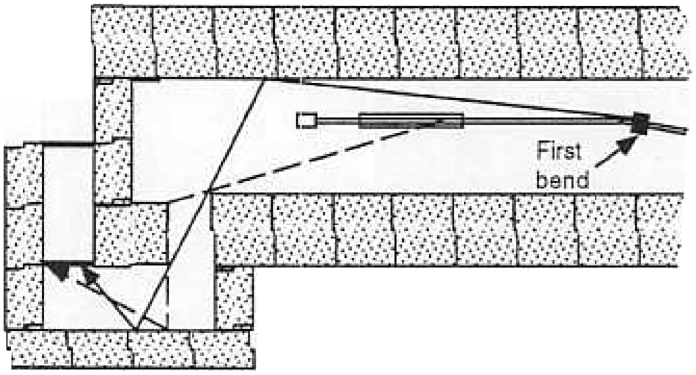


Figure 7.6: Plan View of the West Maze and the Beam Line Up to the Chicane Area

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.

East Maze

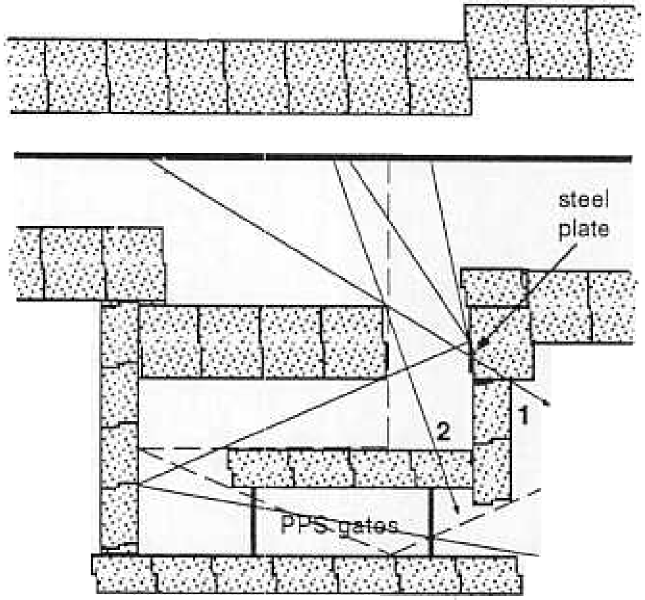


Figure 7.7: Plan View of the East Maze

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.

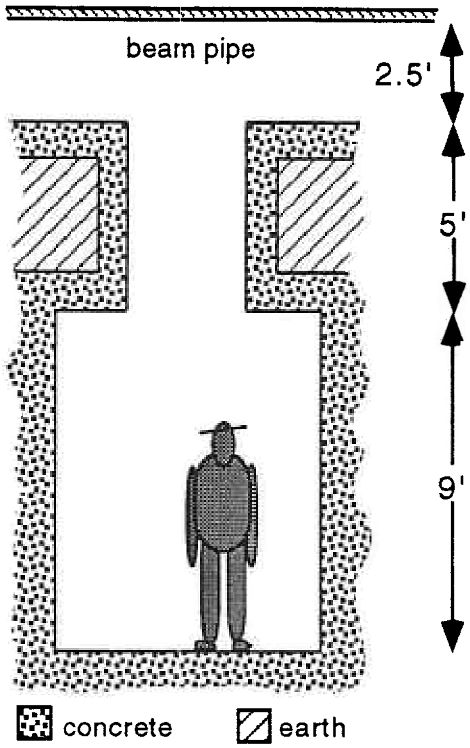


Figure 7.8: Cross-Sectional View of a Utility Tunnel and Manhole

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.

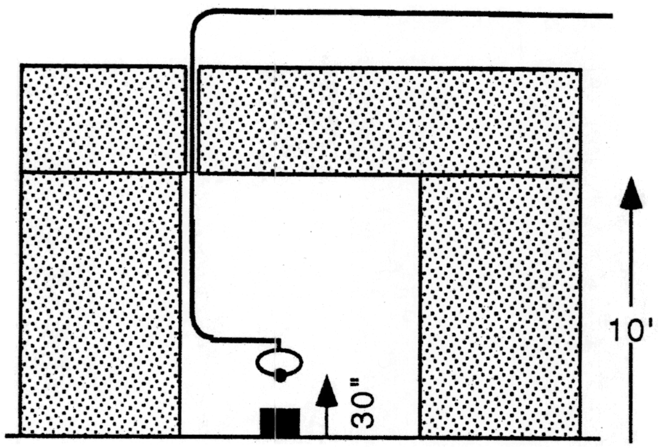


Figure 7.9: Schematic View of the rf Waveguide Passing Through a Roof Penetration

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 [9]. Photon and neutron ducting factors were then calculated using the computer program DUCT [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.

Table 7.1: Expected Dose Rates on the Roof Above the Faraday Cup After Upgrades

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 7.1 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 7.1 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 7.1 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.

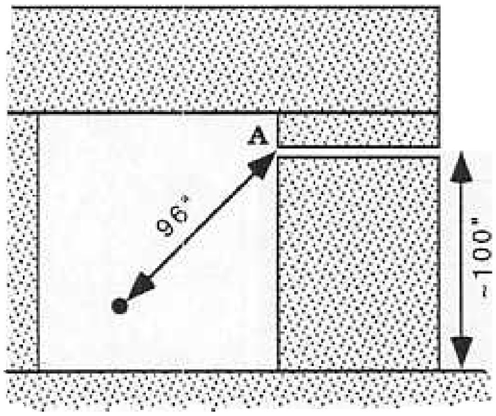


Figure 7.10: Geometry Considered for the Penetrations in the 6-Foot-Thick Side Concrete Walls

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 7.2.

Table 7.2: Estimated Dose Rates at the Exit of Side Wall Penetrations of Various Sizes

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 ([1], [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 7.3 contains a list of potential activation products in air, predicted concentrations at saturation, and Derived Air Concentration (DAC) limits from DOE Order 5480.11 [4]. The values for saturation activity were taken from Swanson [1], with the exception of N-13 and O-15, where more recent values from Ferrari et al. [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[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.

Table 7.3: Potential Activity Induced in Air

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)*	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

Spallation reaction.

The saturation activities reported in literature and used in Table 7.3 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 [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 [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 7.3.

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 [12], under conservative assumptions similar to those taken by Jenkins [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 [14] for compliance with the Environmental Protection Agency's National Emissions Standards for Hazardous Air Pollutants ("NESHAPs") [15], using the computer program "CAP88-PC" [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

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7.2.9 Section Bibliography

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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.

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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.