# NLCTA
# Safety Assessment Document

**Document Approved by (signature/date)**

NLCTA Operations Manager:__________________________________________________

NLCTA Facility Head:______________________________________________________

Director Particle and Particle Astrophysics:________________________________________

Chief Operating Officer:_____________________________________________________

Chairman ES&H Coordinating Council:__________________________________________

## Revision Record

| Revision Number | Revision Date | Section(s) Affected | Description of Change |
|---|---|---|---|
| R001 | December 13, 2006 | All | Revised content. |
| R000 | April 24, 1996 | All | Original release. |

## Table of Contents

# 1. Introduction

## 1.1 Facility Description

The NLCTA facility consists of a 630 MeV X-band electron accelerator and its associated equipment which is used for accelerator R&D primarily related to future linear colliders. The current R&D program entails advanced accelerator research. The facility is housed inside End Station B (ESB) in SLAC's research yard. The facility is not connected to the SLAC Linac and B-Factory complex. The facility operations schedule is independent of that of the B-Factory complex.

## 1.2 Facility Purpose

The NLCTA facility is an experimental facility designed to test and integrate new technologies of accelerator structures, rf systems and instrumentation being developed at SLAC and elsewhere in the world for the International Linear Collider (ILC) and other advanced accelerator systems. The facility also includes a short test beam line for advanced accelerator R&D.

## 1.3 Facility Operations

The NLCTA is used for several applications: 1) as a test bed for the development of rf accelerator structures and power transport systems, 2) as a beam-based testing facility for the testing of new structure designs, 3) for the generation of beams for testing of experimental accelerator diagnostics. Facility operations continue around the clock with breaks in the operations schedule as required to install new devices under test. The shielding analysis is based upon the expectation that the facility will be operated in beam operations mode for not more than 1,000 hours per year. The maximum[1] power capabilities are expected to be as follows:

| **Configuration** | Max. Credible Power | Nominal Beam Power |
|---|---|---|
| **Injector only** | **15.7 Watts (at 130 MeV)** | **0.7 Watts (at 70 MeV)** |
| **Linac** | **76.2 Watts (at 630 MeV[2])** | **6.3 Watts (at 630 MeV)** |

---

[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 5, "Accelerator Safety Envelope," for further discussion of maximum credible power.

[2] Maximum credible energy value established and approved in 1996 NLCTA SAD, SLAC document number 01-13-09-00, dated 24-April-1996, signed by Richter (4/29/96).

## 2. Summary/Conclusions

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 4 and 5 of this document. The hazards addressed are Ionizing Radiation, Fire Hazards, Electrical Hazards, Nonionizing Radiation and Seismic Hazards. The summary results of the safety analysis are shown in the attached

Table 2-1, which lists the applicable hazards and their mitigations for the NLCTA.

**Table 2-1: Hazard Identification and Risk Determination Summary**

| Doc Section | Hazard | Causes | Prevention/Mitigation Means | Potential Impact | Consequence | Probability |
|---|---|---|---|---|---|---|
| 4.1.1 | Ionizing radiation exposure from beam, outside shielding enclosure | 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 | Extremely Low | Extremely Low |
| 4.1.2 | Ionizing radiation exposure from waveguides outside shielding enclosure | 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 | Extremely Low | Extremely Low |
| 4.1.3 | Prompt ionizing radiation exposure, inside shielding enclosure | 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 | Medium | Extremely Low |
| 4.1.4 | Exposure to residual ionizing radiation exposure inside shielding enclosure | Procedural error, personnel error | SLAC Guidelines for Operations, training, Radiation Work Permits | Personnel injury | Extremely Low | Medium |
| 4.2.1 | Fire in accelerator housing, equipment and control areas | Equipment failure | Sprinklers, fire alarms, exit routes, training, on-site fire department, high sensitivity smoke detection, power interlocks. | Personnel injury, property loss | Low | Low |
| 4.4.1 | Electric Shock | Personnel error, interlock failure | NEC compliance, interlocks, training, lock and tag | Personnel injury, fatality | Extremely Low to Medium | Low |
| 4.4.2 | Electric Arc Flash | Equipment Failure | Training, posting of hazards and required protective equipment, PPE | Personnel injury, fatality | Extremely Low to Medium | Low |
| 4.5.1 | Nonionizing radiation exposure – microwave | Personnel error, interlock failure | Safety procedures, design of interlock systems, training | Personnel injury | Low | Low |
| 4.5.2 | Nonionizing radiation exposure – optical | Personnel error, interlock failure | Safety procedures, design of interlock systems, training | Personnel injury | Low | Low |
| 4.8.1 | Seismic Hazards | Earthquake | Building and structural codes and standards, field inspection | Personnel injury, property loss | Low | Low |

## 2.1 Hazard Consequence Rating

The hazards have been rated based on the criteria listed in Tables 2.2 and 2.3.

**Table 2-2 Risk Probability Rating Levels**

| Category | Category Estimated Range of Occurrence Probability (per year) | Description |
|---|---|---|
| High | $>10^{-1}$ | Event is likely to occur several times in a year. |
| Medium | $10^{-2}$ to $10^{-1}$ | Event is likely to occur annually. |
| Low | $10^{-4}$ to $10^{-2}$ | Event is likely to occur, during the life of the facility or operation. |
| Extremely Low | $10^{-6}$ to $10^{-4}$ | Occurrence is unlikely or the event is not expected to occur during the life of the facility or operation. |
| Incredible | $<10^{-6}$ | Probability of occurrence is so small that a reasonable scenario is inconceivable. These events are not considered in the design or SAD analysis. |

**Table 2-3 Risk consequence Rating Levels**

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

# 3. Site, Facility, and Operations Description

## *3.1 Site Description*

A detailed overview of the SLAC site including geology, hydrology, seismicity, and climate is available in *SLAC Annual Site Environmental Report, January-December 2001*.

The geology and hydrogeology of SLAC is further described in *The Geology of the Eastern Part of Stanford Linear Accelerator Center*.

Detailed seismicity information is also available in *Specification for Seismic Design of Buildings, Structures, Equipment and Systems at the Stanford Linear Accelerator Center*.

## *3.2 Functional Description of the Facility*

### 3.2.1 Injector

The injector contains a laser-driven rf gun (“photoinjector”) and two X-band accelerator sections. The laser system is described in the *Authorization to Operate the E-163 Laser System and Standard Operating Procedure*[3]. The bunch charge is 50 pC nominal (1 nC maximum), accelerated by S-band rf to 5 MeV. The pulse-repetition rate is limited by hardware to a maximum of 10 Hz. The photoinjector is capable of delivering a maximum beam power of 15.7 watts into the experimental enclosure. The NLCTA shielding was originally designed for a thermionic injector with much higher average current output as described in Appendix A.

If the laser is severely overfocussed on the cathode, surface plasma can form, and the gun can produce much higher beam charges (~1 μC) that are characterized by large energy spread and emittances. Tracking studies have been completed that establish that most of the beam power (a few watts) in this circumstance is lost in the first few meters of the NLCTA accelerator. The maximum beam power of the photoinjector-equipped accelerator is thus a factor of a few hundred less than was achievable with the original thermionic injector gun.

Under normal operating circumstances, the electron source produces dark current as well as the nominal beam. The dark current is rapidly lost in the first injector X-band accelerator section, as is described in Section B.2.1. Experience with similar injectors shows that taking 29 nA as the average dark current is very conservative, and results in 0.25 W of power deposition at the upstream end of the X-band accelerator section.

### 3.2.2 Injector Spectrometer

Directly following the gun is a capture section and a series of diagnostic devices. The spectrometer bends the low-energy (<7 MeV) electron beam up towards the ceiling of the NLCTA at a 72 degree angle. The beam is stopped in a stainless steel Faraday cup mounted at the end of the short energy analyzing beamline. This case was analyzed for maximum credible beam power entering the spectrometer of 76.2 W (at an average energy of 4 MeV), and the dose rate immediately above the spectrometer, outside the shielding, was found to be within dose limits. See the memos on new injector installation and approval in sections B.1.3 and B.1.4.

---

[3] http://www-project.slac.stanford.edu/lc/local/Projects/NLCTA/Supporting-documentation/E163Laser_SOP.pdf

### 3.2.3 Chicane

A magnetic chicane downstream from the injector 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 0.7 W. Dark current entering the chicane under normal circumstances is 1.8 mW.

### 3.2.4 Linac

The linac contains 8 experimental regions, each approximately 2 meters long. rf power, available from the klystrons described below, may be fed to accelerator sections. The power distribution and configuration of accelerator structures varies in response to the experimental program. Accelerating gradients of 80 MeV/m can be achieved for short accelerator sections, with continued operation at 50 MeV/m.

### 3.2.5 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 absorbs the full beam power. The iron target is cooled by conduction and natural convection.

### 3.2.6 Test Beam Line (“E-163”)

Beams at the nominal energy of 70 MeV may be diverted from the NLCTA injector into a test beam line by means of a dipole. The beams then leave the NLCTA shielding enclosure and enter a separate radiation shielding enclosure, the experimental hall, located immediately north and parallel to the NLCTA. The test beam line is approximately 55 feet total length and is composed of 11 quadrupoles, 2 dogleg dipoles, a 90 degree spectrometer, and an experimental test vacuum chamber. Small test accelerators providing up to a few MeV of energy gain may be tested in the chamber.

Low-current beams of 10 nA and 70 MeV may be transported into the experimental hall for advanced accelerator R&D experiments. The shielding has been designed to be inherently safe for the maximum credible accident at 130 MeV without the need for additional beam containment devices. The beam dump is designed to absorb the full nominal beam power of 0.7 W nominal.

### 3.2.7 High-Power Radiofrequency System

RF power for the NLCTA accelerator sections is provided by 7 X-band klystrons, one S-band klystron, and one L-band klystron. The X-band klystrons power the existing X-band accelerator structures, the S-band klystron powers the new rf photoinjector, and the L-band klystron will power the positron capture cavity, to be installed some time in 2007.

The klystron peak power is combined and/or compressed by rf transmission systems. These klystrons and pulse compressors represent a new microwave technology being developed at SLAC. The klystrons individually produce up to 75 MW in 1.5-2.5 μs-long pulses. The pulse compressors compress the rf pulse length from 1.5 μs to 0.25 μs to boost the peak power. Peak power levels of around 600 MW can be produced.

The NLCTA's X-band klystrons present no new hazards relative to SLAC's S-Band klystrons. As compared to the S-band klystrons, the X-band klystrons 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 is lower than in a SLAC S-band klystron.

The X-band sources are experimental in nature (as compared to the relatively well understood S-band klystrons used in the main linac at SLAC). Since the total beam voltage, beam energy and rf output power are similar, the klystrons do not present any unique electrical or microwave hazards. The increased peak powers of the X-band system lead to higher waveguide voltages and generated X-ray radiation on rf breakdown. Consequently, lead shielding for the X-band waveguide distribution system has been installed per RSC-00-001 (Section A.1.4).

The present electron source is a photoinjector powered by a dedicated S-band klystron. This "5045" type klystron can operate at up to 50 MW and is identical to the klystrons used throughout the main accelerator facility at SLAC. The operation of this type of klystron is well understood and presents no unusual hazards.

The L-band test stand klystron can operate at up to 5 MW. The pulse width is up to 1.6 ms. The klystron operating voltage is up to 128 kV. It runs at 19 kJ per pulse at 5 Hz. The electrical connections are in a standard oil klystron tank, and thus inaccessible. The ionizing radiation emitted from the klystron is appropriately shielded with lead. The whole klystron is in a lead box whose only opening is for the waveguide, which has auxiliary shielding.

The operations staff, with oversight from the ES&H Radiation Protection Group, conducts radiation hazard surveys periodically to ensure that the klystrons and other high-power rf components are appropriately shielded for X-rays. The Radiation Protection Group (formerly OHP) conducts residual radioactivity surveys of beamlines after accelerator operations cease and participates in "run-up" measurements of new rf sources.

The NLCTA Beam Authorization Sheet[4] (BAS) defines the required conditions for the running of beam or rf power sources. The BAS permits the NLCTA to be run in rf-only unattended operation mode, per RSC-00-001 (Section A.1.4). During this time the X-band and the L-band systems are run continuously. The Personnel Protection System (PPS) can disable the rf systems if there is a security fault in the NLCTA housing, including Beam Shut-off Ion Chamber (BSOIC) faults.

### 3.2.8 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 2.5-MW electrical substation, and two control buildings. Figure 3-1 shows the layout of the NLCTA buildings.

---

[4] See Section A.1.4 for a more thorough description and the Radiological Control Manual, Appendix 3E.

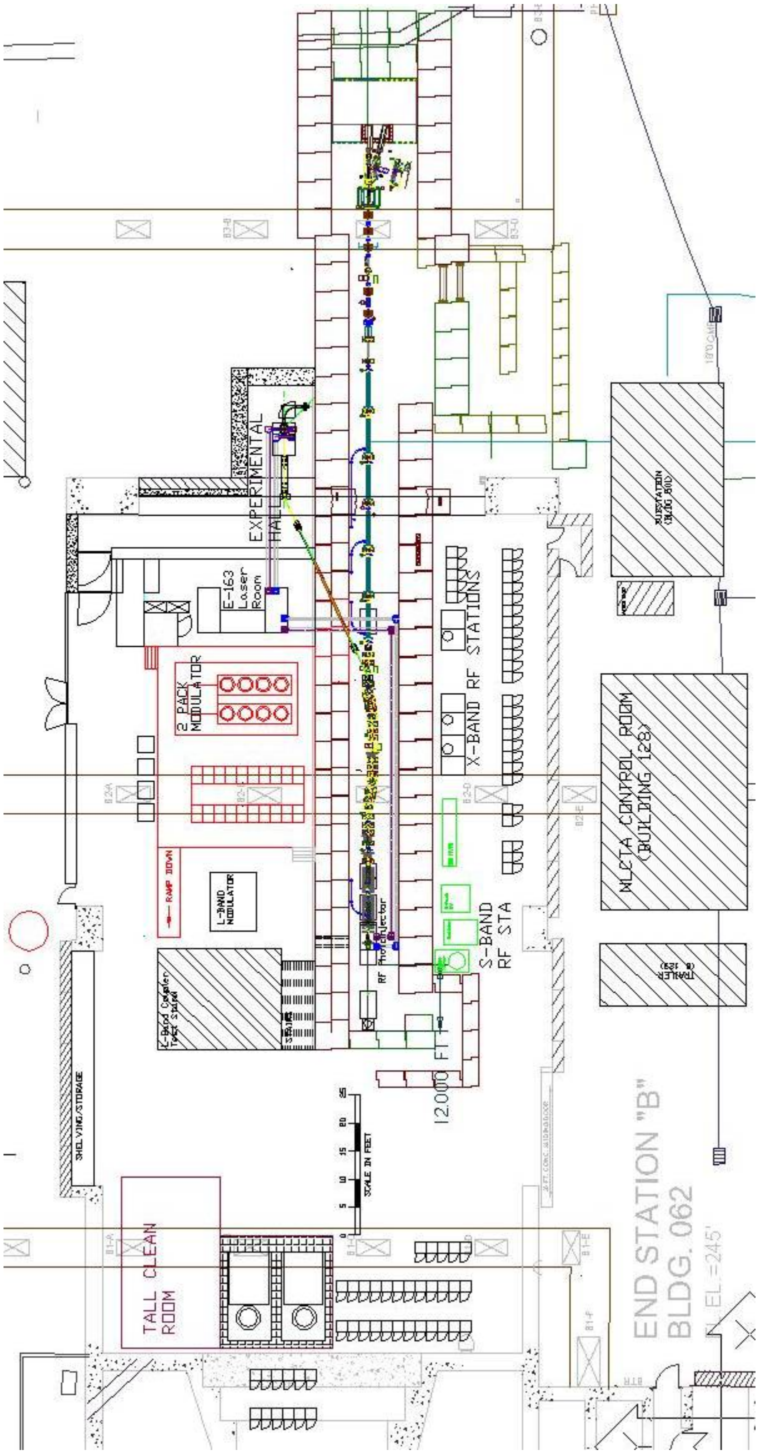

Figure 3-1 Plan View of the NLCTA

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 by 70 feet wide, and are covered with 2-foot-thick portable concrete blocks. The roof and all walls 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 for the NLCTA was 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 consists of iron, lead, and concrete, is at the east end of the accelerator housing. 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 is assisted by using electric fans, when desired. Telephones are spaced approximately 50 feet apart inside the enclosure. Figure 3-2 shows a cross-sectional view of the NLCTA beam line housing.

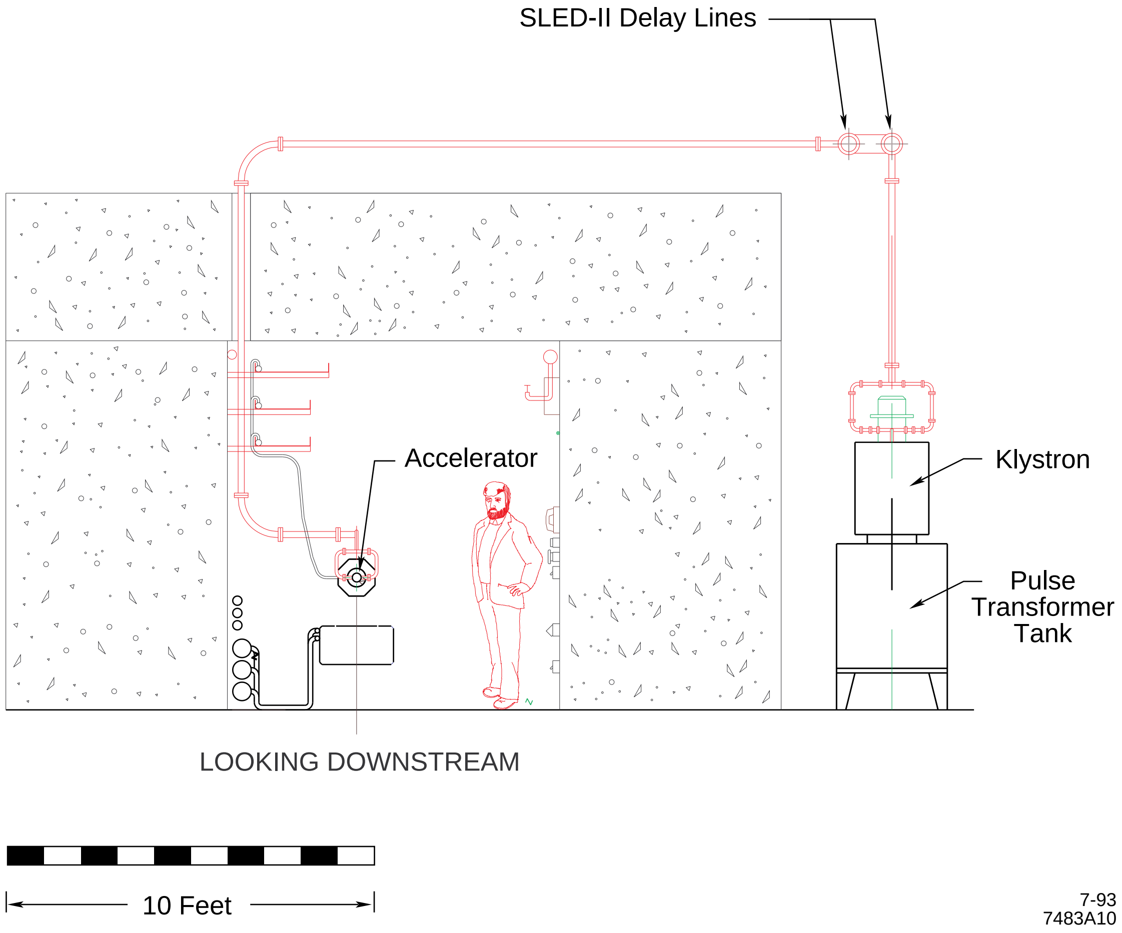

**Figure 3-2 Cross-sectional View of the NLCTA Linac**

The experimental hall, a secondary above-ground seismically reinforced beam line enclosure, was constructed in 2002 from reinforced concrete blocks and steel plates. The walls and roof are 2 feet thick. The interior measures 8 feet high by 16 feet wide by 34 long. Approximately half the enclosure is contained inside End Station B; the rest extends beyond the end station by about 24 feet. The beam dumps, which consist of either a tungsten or lead core surrounded by iron, are located at the east end of the enclosure. Access and egress is provided through a radiation maze that connects the enclosure to the interior of End Station B. Cross-ventilation is provided by an exhaust fan at the east end of the enclosure. Telephones are located throughout the enclosure.

The roof of the experimental hall supports 7 electronic equipment racks for instrumentation and beam line components within the experimental hall. The racks are seismically anchored to the roof of the enclosure. Grounded cable trays carry cable from the racks to the experimental hall, entering though the radiation maze.

Approximately 100 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 2.5-MW substation (Building 501) provides power to the NLCTA, End Station B, and 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 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

The experiment control building (Building 225) contains a secondary control room for the experimental hall. This single-story steel-frame structure measures 20 feet by 40 feet.

The control room annex (Building 129) contains additional work area. This single-story wood structure measures 9 feet by 17 feet.

### 3.2.9 Cooling Water

NLCTA components are cooled by an existing Research Yard Low Conductivity Water (LCW) circuit (at 275 psi pressure). An 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 is transferred by heat exchanger into the Research Yard LCW circuit.

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

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

Components in the experimental hall are cooled from the existing Research Yard LCW circuit, pressure regulated to 120 psi. The beam dumps are not water cooled, and no significant radioactivation of LCW is expected.

### 3.2.10 Power Supplies

The beam line magnets in the NLCTA include approximately[5] 34 air-core solenoids, one steel-core solenoid, and one steel-core dipole in the injector; four steel-core dipoles that make a chicane for manipulating the longitudinal phase space of the beam; 33 iron-core quadrupoles 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[6] and a kicker-compensating dipole. The low-voltage, high-current power supplies for these magnets are interlocked through the Personnel Protection System such that the power supplies must be turned off for unrestricted access to the accelerator housing. The exception is for "Restricted Area Safety Key" (RASK) mode, which permits authorized personnel to occupy areas adjacent to energized hazardous magnets. 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 supplies when pushed. Note: RASK mode has not been reevaluated since the October 11, 2004 accident, and no operator is currently trained to enter under RASK mode.

An additional 20 air-core steering correction 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 are not controlled by the PPS. Vacuum in the NLCTA beam line and high-power microwave systems is maintained by ion pumps. These pumps are powered by high-voltage, low-current power supplies located in racks inside End Station B.

Power supplies for the test beam line in the experiment hall are housed in 7 racks on the experiment hall roof. The supplies power two dipoles, 11 quadrupoles, a spectrometer magnet, and 32 corrector magnets. All magnet leads are insulated, rendering the magnets safe even when powered, thus no RASK mode is provided for the experiment hall, and no PPS electrical hazard control is required. Magnet cables are low-smoke non-halogenated cable, treated with intumescent paint at regular intervals to limit flame propagation.

### 3.2.11 Instrumentation and Control

Beam instrumentation in the NLCTA includes strip-line beam position monitors, beam profile monitors that image the beam on fluorescent screens, wire scanners, toroids, insertable Faraday cups, and adjustable collimators.

The control system for the NLCTA is an extension of the SLAC control system that is currently used to operate PEP-II, ESA, 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 the actual hardware control.

---

[5] The magnet configuration varies slightly depending on the gun configuration and the experimental program requirements.

[6] Not currently installed.

## *3.3 Operating Organizations*

The International Linear Collider (ILC) department is responsible for the operation of the NLCTA.

### 3.3.1 Personnel and Responsibilities

The personnel involved in accelerator operations include the NLCTA Operations Manager, the NLCTA Safety Officer, the NLCTA Engineering Operator in Charge (EOIC), the NLCTA Area Manager, other qualified operators, accelerator physicists, collaborators, and other control room staff who are assigned to the NLCTA. The organization chart is found in Appendix C.

Any accelerator system capable of producing a beam, including high-power rf, may be operated only when there is a valid BAS. The operation of the beam is subject to the conditions of the BAS.

The *NLCTA Operations Directives* (02-02-02) describes how SLAC's Integrated Safety and Environmental Management System (ISEMS) is incorporated into daily NLCTA activities. ISEMS is part of all employees' activities, but those involved in accelerator operations have special responsibilities for activities in NLCTA and End Station B.

The *Directives* also describe the personnel and their responsibilities for program control, operations, safety, and maintenance of the NLCTA facility. The organizational structure of these personnel is also included.

### 3.3.2 Training

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* and the *NLCTA Operator Safety Training Reference Manual* (02-04 Series).

### 3.3.3 SLAC Guidelines for Operations

The NLCTA, like all accelerator facilities at SLAC, is governed by *SLAC Guidelines for Operations* (01-01-01). These documents specify methods and procedures by which accelerator and detector operations are conducted in conformance with DOE 420.2B 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 this document and to operate the facility in a manner consistent with the principles of ISEMS.

# 4. Safety Analysis

## 4.1 Ionizing Radiation

### 4.1.1 Hazard event: Exposure to beam-based ionizing radiation outside of the shielding enclosure as a result of radiation safety system failure during operations

#### 4.1.1.1 Description of Occurrence

Personnel within the Radiological Control Area (namely End Station B, the NLCTA accelerator housing, the experimental hall, and trailers 486 and 4104) may be exposed to low levels of ionizing radiation during normal operations. The source of radiation is accelerated beam that is accidentally lost in the accelerator housing and ionizing radiation emitted by the klystrons. In the case of system failure of one or more of the radiation safety systems and maximum credible beam power, the dose rate external to the shielding enclosure can reach up to 25 rem/h.

#### 4.1.1.2 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 5 mrem/h. See Appendices A and B. 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 or be escorted.

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

The BSOIC system (Section A.1.3) will detect dose rates in excess of 10 mrem/h and shut down the accelerator. The BSOICs outside of the enclosure near the dump and in the utility tunnel are set to trip at 100 mrem/h. All people in the Radiological Control Area are required to wear dosimeters.

#### 4.1.1.3 Consequence

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

#### 4.1.1.4 Probability

The probability of such an occurrence is Extremely Low.

### 4.1.2 Hazard event: Exposure to rf-based ionizing radiation outside of the shielding enclosure as a result of radiation safety system failure during operations

#### 4.1.2.1 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 rf breakdowns in the transport waveguide.

#### 4.1.2.2 Prevention/Mitigation

Shielding integrity is assured by administrative means. The local shielding is designed to maintain the dose rate at the shielding boundary to below 5 mrem/h. Areas which may exceed this are required to be roped and signed.

A system failure which permits the creation of an excessive dose rate requires the failure of the BSOIC system and repeated rf breakdowns in the waveguide.

#### 4.1.2.3 Consequence

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

#### 4.1.2.4 Probability

The probability of such an occurrence is Extremely Low.

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

#### 4.1.3.1 Description of Occurrence

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

#### 4.1.3.2 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 within 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.

#### 4.1.3.3 Consequence

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

#### 4.1.3.4 Probability

The probability of such an occurrence is Extremely Low.

### 4.1.4 Hazard event: Exposure to ionizing radiation inside the shielding enclosure deriving from residual activity, exceeding administrative dose limits

#### 4.1.4.1 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.

#### 4.1.4.2 Prevention/mitigation

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

#### 4.1.4.3 Consequence

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

#### 4.1.4.4 Probability

The probability of inadvertent exposure to activated material is Medium.

## *4.2 Fire Hazards*

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

#### 4.2.1.1 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.

#### 4.2.1.2 Prevention/Mitigation

The fire-protection systems currently installed in the NLCTA housing, control building, experimental hall, laser room, and substation were 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 NLCTA beam line housing, several klystron modulators, and many equipment racks are additionally protected by a high-sensitivity smoke-detection system. The experimental hall and laser room are protected by FP-11 ionization detectors, which power down key energy sources when the fire alarm is activated. End Station B, the substation, and the control building are protected by ionization-type smoke detectors. The modulators for the X-band klystrons have additional fire protection. When the high sensitivity smoke detection system alarms, a carbon dioxide ($CO_2$) fire suppression discharges an entire bottle of $CO_2$ into all three modulators.

SLAC subcontracts with the Palo Alto Fire Department (PAFD) to operate an onsite 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.

#### 4.2.1.3 Consequence

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

#### 4.2.1.4 Probability

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

## *4.3 Hazardous Materials*

Articles fabricated from lead are used in the facility. Fabrication of lead articles is guided by the provisions of Chapter 20 of the SLAC Environment, Safety, and Health Manual.

Trace amounts of beryllium are used in electrical contacts inside the 2-pack and S-band modulators. The contacts are in fully enclosed cabinets. These modulators are serviced only by personnel specifically trained in beryllium hazards and mitigation; handling of beryllium-contaminated articles is closely monitored by both the NLCTA Safety Officer and the SLAC Industrial Hygienist. Swab sampling is performed whenever transfer of beryllium contamination to other surfaces or equipment is possible.

## *4.4 Electrical Hazards*

### 4.4.1 Hazard Event: Electric shock due to a worker contacting energized conductor of a magnet, etc.

#### 4.4.1.1 Description of Occurrence

Personnel enter the shielding enclosure from time to time for maintenance purposes. Electrical loads within the enclosure (magnets) may sometimes be un-insulated, especially for testing. Workers are involved in maintenance of magnet power supplies, klystron modulators, and other equipment capable of causing serious electroshock.

#### 4.4.1.2 Prevention/Mitigation

It is SLAC policy that every necessary precaution should be taken in the performance of work to protect all people 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 and required 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, employ high voltages. The controls and work procedures necessary to ensure safe work on these systems are documented with procedures specific to the equipment. The provisions for the lockout of these systems utilize SLAC’s established procedures for lock out and tag out 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. A special procedure to permit authorized personnel to occupy areas adjacent to energized hazardous magnets is called RASK mode; see Section 3.2.10.

All electrical installations are in accordance with the National Electric Code (NEC).

The SLAC Electrical Safety Committee 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 de-energized 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[7].

Standard lock and tag practice will be applied for electrical hazards within the experimental hall.

#### 4.4.1.3 Consequence

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

#### 4.4.1.4 Probability

The probability of such an occurrence is Low.

### 4.4.2 Hazard Event: Electric arc flash due to a worker contacting an energized conductor of premises wiring, etc.

#### 4.4.2.1 Description of Occurrence

Personnel working on premises wiring systems may be exposed to short circuit conditions resulting in an arc flash.

#### 4.4.2.2 Prevention/Mitigation

Premises wiring has been evaluated for arc flash classification per NFPA 70E and labels affixed to panel boards as appropriate.

The controls and work procedures necessary to ensure safe work on these systems are well understood. The provisions for the lockout of these systems utilize SLAC's established procedures for lock out and tag out as described in *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. Personnel Protection Equipment (PPE) must be worn in accordance with NFPA 70E requirements.

#### 4.4.2.3 Consequence

The consequence level of an arc flash event may range from Extremely Low to Medium.

#### 4.4.2.4 Probability

The probability of such an occurrence is Low.

## *4.5 Nonionizing Radiation*

### 4.5.1 Hazard Event: Workers may be exposed to nonionizing radiation in the microwave spectrum.

#### 4.5.1.1 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.

---

[7] See SLAC *Guidelines for Operations*, Guideline 17, "Electrical Safety," (01-01-17-01)

#### 4.5.1.2 Prevention/Mitigation

All high-power microwave sources are interlocked with the PPS 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.

#### 4.5.1.3 Consequence

The consequence level of an exposure to one of these sources of nonionizing radiation sources is Low.

#### 4.5.1.4 Probability

The probability of such an occurrence is Low.

### 4.5.2 Hazard Event: Workers may be exposed to nonionizing radiation in the optical spectrum.

#### 4.5.2.1 Description of Occurrence

Personnel enter the laser room and are blinded by the laser light. Various class IIIb and class IV lasers operate with output in the visible and invisible portions of the spectrum. Laser radiation can also be sent to the NLCTA enclosure and experimental hall.

#### 4.5.2.2 Prevention/Mitigation

The lasers are enclosed in a light-tight room with interlocked doors. Engineering controls close safety stoppers that block laser radiation if a door is opened by unauthorized personnel. Doors leading into a laser area are locked when laser radiation is present, and door switches monitor the security of the area. Illuminated signs at area entry points state whether a laser hazard is present. Administrative procedures require laser operators to have specific training and to verify that no unauthorized personnel are present in the area when the laser hazard is enabled. Authorized personnel in the laser room must wear PPE, i.e. laser goggles, at all times when the lasers are powered. Emergency Off buttons in each laser zone allow the operator to rapidly disable the laser hazard.

#### 4.5.2.3 Consequence

The consequence level of an exposure to one of these sources of nonionizing radiation sources is Low.

#### 4.5.2.4 Probability

The probability of such an occurrence is Low.

## *4.6 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 and experimental hall are poorly 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.

## *4.7 Flammable Gases or Fluids*

No flammable gases or fluids are planned to be used in the course of operations of this facility. Combustible insulating oil is used in the high voltage transformers and modulator tanks. This has been included in the Fire Hazard Analysis filed on May 11, 1995.

## *4.8 Seismic Hazards*

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

#### 4.8.1.1 Description of Occurrence

The SLAC site is located close to a number of active earthquake faults. 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.

#### 4.8.1.2 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 *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 easily fits 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. Other identified hazards exist and are in the process of remediation.

The experimental hall (built in 2002) and laser room (built in 2004) were constructed to meet UBC 1997 standards of 0.8 g horizontal acceleration, 100% greater than that required by the 1994 UBC. The designs were reviewed and approved by the SLAC Earthquake Safety Committee in 2002 and 2004, respectively.

#### 4.8.1.3 Consequence

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

#### 4.8.1.4 Probability

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

# 5. Accelerator Safety Envelope

## 5.1 Safety Envelope — Ionizing Radiation

The NLCTA Facility has the capability of delivering particle beams which may vary from a few particles per pulse to an equivalent power of 76.2 Watts at 30 pulses per second with the present rf injector. Given these parameters, no operator action can cause the facility to exceed the beam power limits of the Safety Envelope. The shielding was designed and constructed to protect against beams of up to 1.45 kW, so there is significant safety margin.

Shielding design for the NLCTA 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[8] which is required to be less than 25 rem in any one hour period.[9]

The facility is also protected by a BSOIC system which turn off the beam should radiation dose rates external to the shielding exceed a pre-set value (usually 10 mrem/hr).

The experimental hall receives beams from the injector portion of the NLCTA only, and as such no operator action can cause the beam parameters in the experimental hall to exceed 120 MeV, 150 nA, 30 pps, and 15.7 W, the maximum credible beam power. The concrete and steel shielding for the hall has been designed to provide passive protection for this worst-case scenario. As a consequence, Beam Containment System (BCS) devices such as energy or current limiters are not required. Three BSOICs are positioned at the most likely high-dose locations outside the experimental hall and are connected to the NLCTA PPS, shutting off the beam should dose rates exceed 100 mrem/h.

In addition, the PPS for the experimental hall is designed to permit access to the hall when the NLCTA is running. Three beam stoppers in the NLCTA prevent beam from being diverted into the hall, and any breach of security in the hall or loss of status of the beam stoppers immediately disables the NLCTA accelerator through the PPS.

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/y.[10]

---

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

[9] *Accelerator Safety Order*, DOE 5480.25, Guidance, page 10, September 1, 1993 (replaced by Accelerator Safety Order DOE 420.2b and Guidance Document DOE G 420.2-1. Specific reference to this limit needs to be updated.)

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

## 5.2 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 the Gun Trigger Transmitter module which prevents a pulse being delivered less than 0.1 second after a preceding pulse. Should the trigger rate be set above 10 Hz, the modulator trigger rate will drop to less than 1 Hz.
- The maximum average current which can be accelerated, which is determined by the amount of stored energy in the rf gun, the maximum power output of the HV charging supply for the gun modulator, and by the acceptance of the magnet lattice. Tracking simulations have demonstrated the transmitted current to be limited to about 40 nA at 10 Hz, or 120 nA at 30 Hz if the BCS trigger-limiting devices are also defeated.
- The maximum energy capability of the accelerator, which is set by the number of klystrons installed and available for acceleration, the total length of accelerator structures, 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 MeV/m. There is a total length of accelerator structure of 12.6 meters in the injector plus linac. Thus the maximum no-load energy is 630 MeV.[11]

| **Configuration** | Max. Credible Power | Nominal Beam Power |
|---|---|---|
| **Injector only** | **15.7 Watts (at 130 MeV)** | **0.7 Watts (at 70 MeV)** |
| **Linac** | **76.2 Watts (at 630 MeV[12])** | **6.3 Watts (at 630 MeV)** |

The maximum power capability is restrained by redundant methods. Although the trigger hardware has the capability of delivering a repetition rate of 120 pps, the actual rate reaching the gun is limited by an interlock circuit which prevents rates in excess of 10 pulses per second. Should this circuit fail, the average current from the gun is limited both by the available power from the rf system and by the amount of charge that can be transported through the linac.

For the purposes of maximum power calculation the second limit (average gun current = 120 nA at 30 Hz) is used. The resultant maximum credible power capability is 76.2 W.

The highest credible dose rates external to the shielding are calculated to occur in the utility tunnel under the accelerator. If missteering 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[13] 0.16 rem/h. (At full power under normal operating conditions, the dose rates in this location are in the range of 0.1 mrem/h.)

---

[11] Presently installed active length of the accelerator is 6.6 m for which the maximum energy is 330 MeV.

[12] Maximum credible energy value established and approved in 1996 NLCTA SAD, SLAC document number 01-13-09-00, dated 24-April-1996, signed by Richter (4/29/96).

[13] These dose rates will cause the beam to be turned off by the Beam Shut Off Ion Chamber system. See V. Vylet and T. Lavice, “Radiation Protection in the NLCTA,” NLCTA #46.2, December 5, 1995, and Section 4.1above

These then constitute the physical limits of the Accelerator Safety Envelope for prompt ionizing radiation at this facility, which are summarized in Table 5-1. The various administrative and engineered systems involved in assuring that the safety envelope will not be exceeded are summarized in Table 5-2 Means of Assurance of Accelerator Safety Envelope; Ionizing Radiation below. The administrative systems are described in more detail in Chapter 3.3, “Operating Organizations” and in Section 4.1, “Safety Analysis, Ionizing Radiation.”

**Table 5-1 Summary of Design Parameters**

| | **Original Design** | **NLCTA Enclosure** | **Experimental Hall** | **DOE Requirements** |
|---|---|---|---|---|
| **Nominal** | 1.45 kW | 6.3 W | 0.7 W | <5 mrem/h |
| **Missteering** | 1.45 kW | 6.3 W | 0.7 W | <400 mrem/h |
| **Max. Accident** | 5.75 kW | 76.2 W | 15.7 W | <25 rem/h and<br><3 rem/incident |

Operations are constrained to levels which may be significantly below the maximum power level by the BAS[14]. The limits set from time to time by the BAS 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 Experimental Authorization similarly provides authorization for operating rf devices (klystrons) without the possibility of accelerating beam.

The means of assurance employed to control the Operations Envelope are shown in Table 5-2 below.

**Table 5-2 Means of Assurance of Accelerator Safety Envelope; Ionizing Radiation**

| **Restraint** | **Means of Assurance Beam Operation** | **Means of Assurance rf-only Operation** |
|---|---|---|
| **Beam Power** | Intrinsic capability of linear accelerator. Repetition rate limiting circuit required to be periodically checked by the BAS. | **No beam operation allowed.** |
| **Radiation Shielding Design** | 1. Beam line design and shielding arrangement by the Radiation Physicist, in accordance with the Radiological Protection Guidelines.<br>2. Review by the Radiation Safety Committee.<br>3. Field Inspection(s) by the Radiation Physicist and the operations staff.<br>4. Radiation measurements | Same as operation with beam. |

---

[14] See Section 4.1 above

| Restraint | Means of Assurance Beam Operation | Means of Assurance rf-only Operation |
|---|---|---|
| | during commissioning to validate the design. | |
| **Configuration Control** | 1. Beam Authorization Sheet (BAS) or Experimental Authorization (EA) require inspection of moveable shielding, and other safety-related items on start up.<br>2. Configuration control via the Radiation Safety Work Control Form (RSWCF). | Same as operation with beam. |
| **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.<br>2. Design changes are initially reviewed by the Radiation Safety Officer, who is authorized to approve minor changes. If the proposed changes are major modifications, the proposal is reviewed by the Radiation Safety Committee.<br>3. Configuration control via the RSWCF. | Same as operation with beam. |
| **Operations** | 1. Control room is required to be staffed by specified complement of qualified operators[a]<br>2. Operators are required to be qualified in accordance with the training plan[b] | **No operators need be present during rf-only operation.** |

[a] See NLCTA Operations Directives, (02-02-02).

[b] See Section 3.3.2 above.

Table 5-3 Typical Means of Assurance of Operations Envelope; Ionizing Radiation

| **Restraint** | **Means of Assurance Beam Operation** | **Means of Assurance rf-only Operation** |
|---|---|---|
| **Beam Power** | 1. Specification in BAS<br>2. Specified BCS devices (Protection Ion Chambers, etc.)<br>3. Operator surveillance and sign off of BAS<br>4. Verification of calibrations and configuration control | No beam operation allowed. |
| **Path Allocation** | 1. Legitimate beam path specified in BAS. | No beam operation allowed. |

# 6. Quality Assurance

The NLCTA has been constructed and is operated in accordance with the *SLAC Institutional Quality Assurance Program Plan* (SLAC-I-770-0A17M-001, current revision).

# 7. 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.