STANFORD LINEAR ACCELERATOR CENTER
Operated by Stanford University for the U.S. Dept. of Energy*

SAFETY ANALYSIS DOCUMENT – NEXT LINEAR COLLIDER TEST FACILITY

ILC DEPARTMENT
PARTICLE & PARTICLE ASTROPHYSICS DIVISION

*Work supported by Department of Energy contract DE-AC03-76SF00515.

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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.

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1.2 Facility Purpose

The NLCTA facility is an experimental assembly 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:

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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)	6.3 Watts (at 630 MeV)

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[1] This assumes that a system failure allows a higher than normal repetition rate transmitted to the gun, such that the average gun current is limited by the charging rate of the gun pulser circuits. See Section 7, "Accelerator Safety Envelope," for further discussion of maximum credible power.

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 6 and 7 of this document. The hazards addressed are Ionizing Radiation, Fire Hazards, Electrical Hazards, Non-ionizing 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
6.1.1	Ionizing radiation expo-sure 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	1 — Extremely Low	A — Extremely Low
6.1.2	Ionizing radiation expo-sure 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	1 — Extremely Low	A — Extremely Low
6.1.3	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	2 — Medium	A — Extremely Low
6.1.4	Exposure to residual ionizing radiation exposure inside shielding enclosure	Procedural error, personnel error	*SLAC Guidelines for Operations*, training, Radiation Work Permits	Personnel injury	1 — Extremely Low	C — Medium
6.2.1	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	3 — Low	B — Low
6.4.1	Electric Shock	Personnel error, interlock failure	NEC compliance, interlocks, training, lock and tag	Personnel injury, fatality	1 — Extremely Low to 2 — Medium	B — Low
6.4.2	Electric Arc Flash	Equipment Failure	Training, posting of hazards and required protective equipment, PPE	Personnel injury, fatality	2 – Medium	B – Low

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6.5.1	Non-ionizing radiation exposure – microwave	Personnel error, interlock failure	Safety procedures, design of interlock systems, training	Personnel injury	3 — Low	B — Low
6.5.2	Non-ionizing radiation exposure – optical	Personnel error, interlock failure	Safety procedures, design of interlock systems, training	Personnel injury	3 — Low	B — Low
6.8.1	Seismic Hazards	Earthquake	Building and structural codes and standards, field inspection	Personnel injury, property loss	3 — Low	B — Low

3. Site, Facility, and Operations Description

3.1 Site Location

The Stanford Linear Accelerator Center (SLAC) is a national facility operated by Stanford University under contract with the Department of Energy (DOE). SLAC is located on the San Francisco Peninsula, about halfway between San Francisco and San Jose, California (see Figure 3-1).

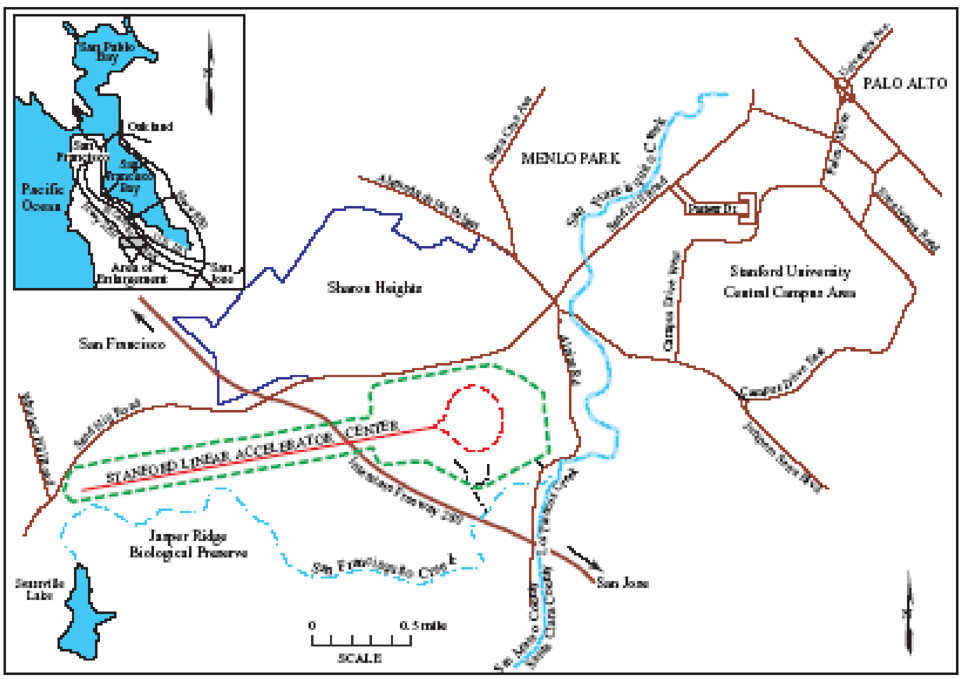

Figure 3-1 : SLAC Site Location

The site area is in a belt of low, rolling foothills lying between the alluvial plain bordering San Francisco Bay on the east and the Santa Cruz Mountains on the west. The accelerator site varies in elevation from 53 to 114 meters (m) above sea level. The alluvial plain to the east around the Bay lies less than 46 m above sea level; the mountains to the west rise abruptly to over 610 m (see Figure 3-2).

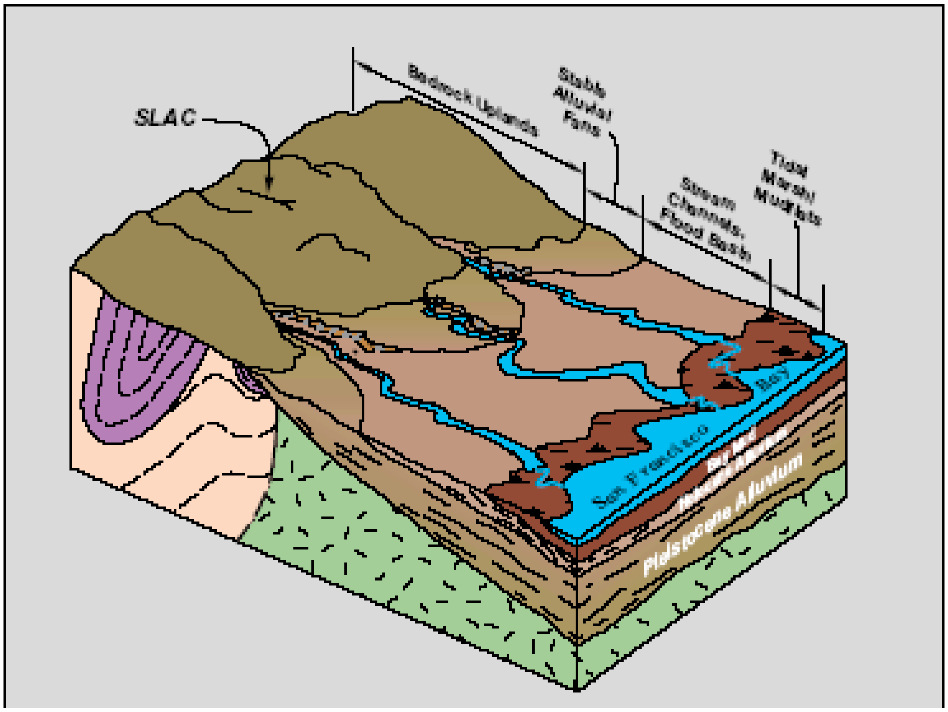

Figure 3-2 : Geographic Site Area

The SLAC site occupies 170 hectares of land owned by Stanford University. The property was leased in 1962 for purposes of research in the basic properties of matter. The original lease to the Atomic Energy Commission (AEC), now DOE, was for fifty years. The land is part of Stanford's "academic reserve," and is located west of the University and the City of Palo Alto in an unincorporated portion of San Mateo County.

The site is bordered on the north by Sand Hill Road and on the south by San Francisquito Creek. The laboratory is located on an elongated parcel roughly 3.2 kilometers (km) long, running in an east-west direction. The parcel widens to about 910 m at the target (east) end to allow space for buildings and experimental facilities.

The SLAC population currently numbers about 1,350 people, of which about 150 are Ph.D. physicists. Approximately 800 staff members are professional, composed of physicists, engineers, programmers, and other scientific-related personnel. The balance of the staff is composed of support personnel, including technicians, crafts personnel, laboratory assistants, and administrative associates. In addition to the regular population, at any given time SLAC hosts between 900 and 1,000 visiting scientists.

3.2 Program Description

The SLAC program presently centers around experimental and theoretical research in elementary particle physics using accelerated electron beams as well as a broad program of research in atomic and solid-state physics, chemistry, and biology using synchrotron radiation from accelerated electron beams. Scientists from all parts of the United States and from throughout the world participate in the experimental programs at SLAC.

The main instrument of research is the 3.2-km linear accelerator (linac), which generates high intensity beams of electrons and positrons up to 50 GeV. The linac is also used for injecting electrons and positrons into colliding-beam storage rings for particle physics research.

The Positron-Electron Project (PEP) storage ring is about 800 meters in diameter. While the original PEP program was completed in 1990, the storage ring has since been upgraded to serve as an Asymmetric B Factory (known as PEP-II) to study the B meson. Current plans involve running PEP-II through 2008.

A smaller storage ring, the Stanford Positron-Electron Asymmetric Ring (SPEAR3), contains a separate, shorter linac and a booster ring for injecting accelerated beams of electrons. SPEAR3 is fully dedicated to synchrotron radiation research. The synchrotron light generated by the SPEAR3 storage ring is used by the Stanford Synchrotron Radiation Laboratory (SSRL) to perform experiments.

SLAC is also host of the International Linear Collider (ILC) test facilities, including the Next Linear Collider Test Accelerator (NLCTA) and ESA.

The site has two major groups of buildings:

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

3.3 Geology

The SLAC site is underlain by sandstone, with some basalt at the far eastern end of the site boundary. In general, the bedrock on which the western half of the SLAC linac rests is the Whiskey Hill Formation (Eocene age), and the bedrock under the eastern half is the Ladera Formation (Miocene age). On top of this bedrock at various places along the accelerator alignment is the Santa Clara Formation (Pleistocene age), where alluvial deposits of sand and gravel are found. At the surface is a soil overburden of non-consolidated earth material averaging from 0.1 to 1.5 m in depth.

The San Andreas Fault passes within a quarter mile of the western boundary of the site, and the line of the linac is traversed by some minor and possibly inactive secondary fault traces. The San Andreas Fault is, at this latitude, considered to be a probable source of a major (> Richter Magnitude 7) earthquake within the next few decades. Other related faults, such as the Hayward fault 15 miles east of the site and the Calaveras fault a similar distance to the southeast, are also considered active and likely to be the source of major earthquakes.

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

3.4 Hydrology

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

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

3.5 Climatic Factors

The climate in the SLAC area is Mediterranean. Winters are cool and moist, and summers are mostly warm and dry. Long-term weather data describing conditions in the area have been assembled from official and unofficial weather records at Palo Alto Fire Station Number 3, which is 4.8 km east of SLAC. The SLAC site is 60 to 120 m higher than the Palo Alto Station and is free of the moderating influence of the city; temperatures therefore average about two degrees lower than those in Palo Alto. Daily mean temperatures are seldom below zero degrees Centigrade or above 30 degrees Centigrade. Rainfall averages about 560 millimeters (mm) per year. The distribution of precipitation is highly seasonal. About 75% of the precipitation, including most of the major storms, occurs during the four-month period from December through March. Most winter storm periods are from two days to a week in duration. The storm centers are usually characterized by relatively heavy rainfall and high winds. The combination of topography and air movement produces substantial fluctuations in intensity, which can best be characterized as a series of storm cells following one another so as to produce heavy precipitation for periods of five to fifteen minutes with lulls in between.

The temperate climate at the site allows technical systems to be installed in buildings which have only limited provision for heating and cooling. The laboratory has

[1] However, it has been shown that soil conditions are sometimes more strongly predictive of structural damage than is proximity to the epicenter of an earthquake, particularly when the distance to the epicenter is less than 30 miles.
[2] *Stanford Linear Accelerator Center, Hydrogeologic Review*, ESA Consultants, Mountain View, California, February 1994.

experienced one instance of widespread damage caused by unusually low temperatures at a time when water systems were shut down. Circulation is now maintained in cooling water systems at all times during the winter.

4. Functional Description of the Facility

4.1 Injector

The injector contains a laser-driven rf gun (“photoinjector”) and two X-band accelerator sections. 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 is described in Appendix 10.

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 11.2.1. 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.

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4.2 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 11.1.3 and 11.1.4.

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4.3 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.

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4.4 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.

4.5 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.

4.6 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.

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4.7 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 next year.

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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 µA/V3/2 versus 1.8 µA/V3/2), 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

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breakdown. Consequently, lead shielding for the X-band waveguide distribution system has been installed per RSC-00-001 (Section 10.1.4).

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[1] (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 10.1.4). 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.

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[1] See section 10.1.4 below for a more thorough description and the Radiological Control Manual, Appendix 3E.

4.8 Conventional Structures

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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 4-1 shows the layout of the NLCTA buildings.

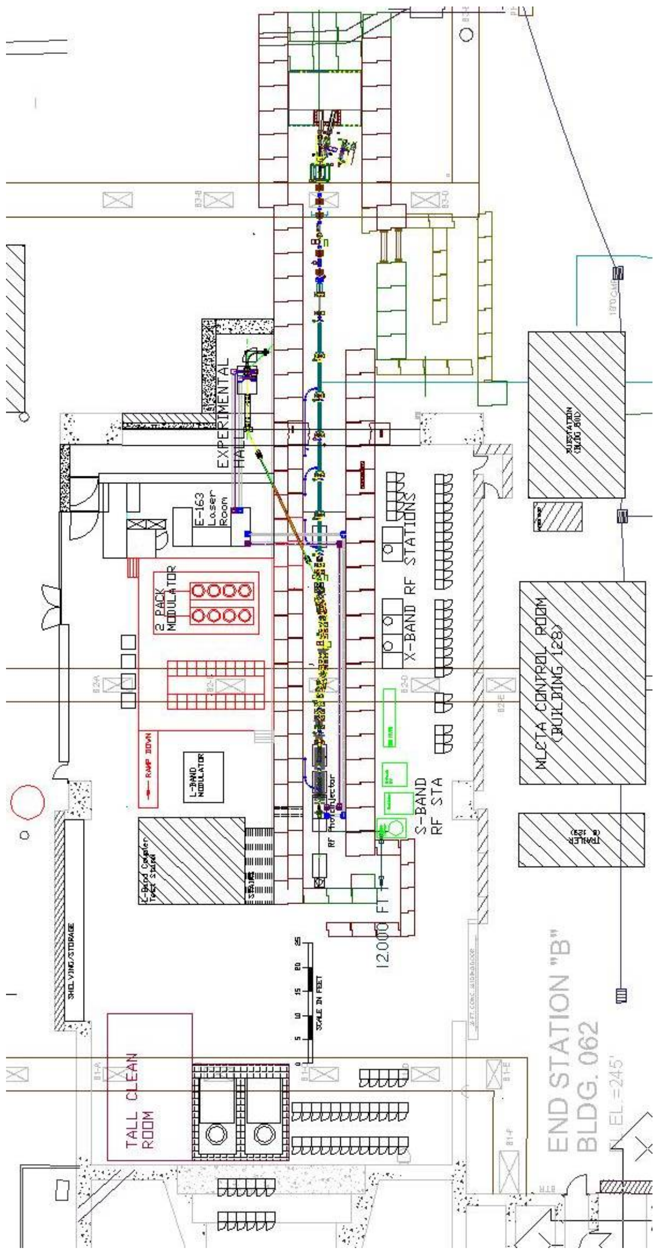

Figure 4-1: Plan View of the NLCTA

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,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 4-2 shows a cross-sectional view of the NLCTA beam line housing.

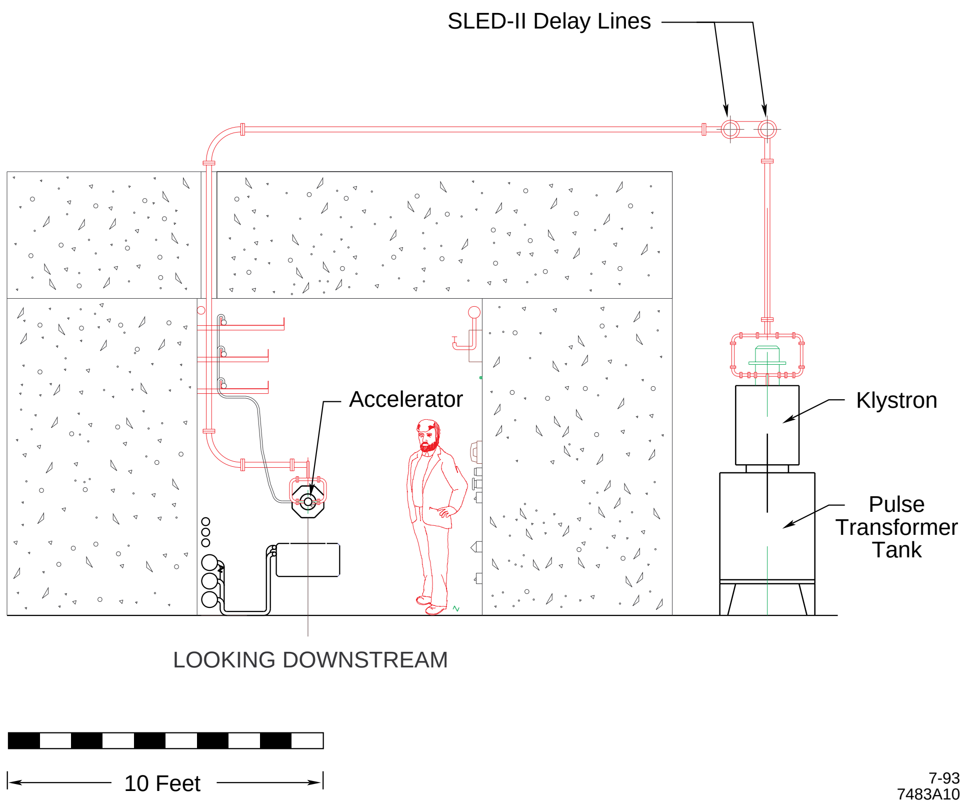

Figure 4-2. Cross-sectional View of the NLCTA Linac

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 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.

4.9 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.

4.10 Power Supplies

The beam line magnets in the NLCTA include approximately[1] 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[2] and a kicker-compensator 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

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[1] The magnet configuration varies slightly depending on the gun configuration and the experimental program requirements.
[2] Not currently installed.

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 re-evaluated since the October 11, 2004 accident, and no operator is currently trained to enter under RASK mode.

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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 2 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.

4.11 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. Operating Organizations

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

5.1 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.

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.

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The *NLCTA Operations Directives* (02-02-02) describes the responsibilities of the different participants as well as 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.

5.2 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).

5.3 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 5480.25 Safety of Accelerator Facilities. The Guidelines stipulate the responsibility for operations management, responsibilities of various key positions, the requirement for formality and documentation of various activities, and describe mandatory procedures for configuration control of safety systems. Personnel engaged in accelerator operations or maintenance are required to be familiar with this document and to operate the facility in a manner consistent with the principles of ISEMS.

6. Safety Analysis

6.1 Ionizing Radiation

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

6.1.1.1 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.

6.1.1.2 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 10 and 11. 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.

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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 10.1.3) 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.

6.1.1.3 Consequence

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

6.1.1.4 Probability

The probability of such an occurrence is Extremely Low.

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

6.1.2.1 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.

6.1.2.2 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.

6.1.2.3 Consequence

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

6.1.2.4 Probability

The probability of such an occurrence is Extremely Low.

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

6.1.3.1 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.

6.1.3.2 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.

6.1.3.3 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

6.1.3.4 Probability

The probability of such an occurrence is Extremely Low.

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

6.1.4.1 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.

6.1.4.2 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.

6.1.4.3 Consequence

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

6.1.4.4 Probability

The probability of inadvertent exposure to activated material is Medium.

6.2 Fire Hazards

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

6.2.1.1 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.

6.2.1.2 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.

6.2.1.3 Consequence

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

6.2.1.4 Probability

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

6.3 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.

6.4 Electrical Hazards

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

6.4.1.1 Description of Occurrence

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

6.4.1.2 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 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 well understood. 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. Special procedures are in place to permit authorized personnel to occupy areas adjacent to energized hazardous magnets (RASK mode, see Section 4.10).

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

The SLAC Electrical Safety Committee has reviewed and approved the electrical safety design of the NLCTA housing, the electrical power distribution system, the control building, and the substation (memo Garg-Lavine, July 12, 1994). All un-insulated electrical conductors (above 50 volts) within the shielding enclosure are automatically de-energized by the Personnel Protection System before access to the relevant zone of the shielding enclosure is allowed. In cases where work on or near a particular load is intended, the power source must also be isolated by means of lock and tag[1].

Electrical hazards within the experimental hall are insulated, alleviating the need for PPS control. If the insulating coverings must be removed for any reason, standard lock and tag practice will be applied to render the affected device safe.

6.4.1.3 Consequence

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

6.4.1.4 Probability

The probability of such an occurrence is Low.

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

6.4.2.1 Description of Occurrence

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

6.4.2.2 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.

6.4.2.3 Consequence

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

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

6.4.2.4 Probability

The probability of such an occurrence is Low.

6.5 Non-ionizing Radiation

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

6.5.1.1 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.

6.5.1.2 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.

6.5.1.3 Consequence

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

6.5.1.4 Probability

The probability of such an occurrence is Low.

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

6.5.2.1 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.

6.5.2.2 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.

6.5.2.3 Consequence

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

6.5.2.4 Probability

The probability of such an occurrence is Low.

6.6 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.

6.7 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.

6.8 Seismic Hazards

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

6.8.1.1 Description of Occurrence

The SLAC site is located close to a number of active earthquake faults (see Section 3.3 above). In the event of a major earthquake the possibility exists of structural damage to buildings or overturning of equipment, which may present a risk to workers. No risk is presented to off-site personnel.

6.8.1.2 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.

6.8.1.3 Consequence

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

6.8.1.4 Probability

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

7. Accelerator Safety Envelope

7.1 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 94.5 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[1] which is required to be less than 25 rem in any one hour period[2].

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[3].

7.2 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.

[1] Radiological Protection Guidelines, 20 May 1994, Ken Kase.
[2] *Accelerator Safety Order*, DOE 5480.25, Guidance, page 10, September 1, 1993.
[3] *SLAC Radiological Control Manual* (SLAC-I-720-0A05Z-001), Article 211.

- 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.

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- 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.[1]

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.

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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[2] 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.)

These then constitute the physical limits of the Accelerator Safety Envelope for prompt ionizing radiation at this facility, which are summarized in Table 7-1. The various administrative and engineered systems involved in assuring that the safety envelope will not be exceeded are summarized in Table 7-2: Means of Assurance of Accelerator Safety Envelope; Ionizing Radiation below. The administrative systems are described in more detail in Chapter 5, "Operating Organizations" and in Section 6.1, "Safety Analysis, Ionizing Radiation."

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Table 7-1: 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

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[1] Presently installed active length of the accelerator is 6.6 m for which the maximum energy is 330 MeV.
[2] 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 6.1above

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 <3 rem/incident

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Operations are constrained to levels which may be significantly below the maximum power level by the BAS[1]. 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.

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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 7-2 below.

Table 7-2: 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. 2. Review by the Radiation Safety Committee. 3. Field Inspection(s) by the Radiation Physicist and the operations staff. 4. Radiation measurements during commissioning to validate the design.	Same as operation with beam.
Configuration Control	1. Beam Authorization Sheet (BAS) or Experimental Authorization (EA) require inspection of moveable shielding, and other safety-related items on start up.	Same as operation with beam.

[1] See Section 6.1 above

	2. Configuration control via the Radiation Safety Work Control Form (RSWCF).	
Radiation Safety Systems	1. Personnel Protection System (PPS), Beam Containment System (BCS) and Beam Shut Off Ion Chamber (BSOIC) system design, maintenance, and periodic inspection controlled by formal procedures. 2. Design changes are initially reviewed by the Radiation Safety Officer, who is authorized to approve minor changes. If the proposed changes are major modifications, the proposal is reviewed by the Radiation Safety Committee. 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] 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 5.2 above.

Table 7-3: 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 2. Specified BCS devices (Protection Ion Chambers, etc.) 3. Operator surveillance and sign off of BAS 4. Verification of calibrations and configuration control	No beam operation allowed.

Path Allocation	1. Legitimate beam path specified in BAS.	No beam operation allowed.

8. 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).

9. 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.

10. NLCTA Radiation Safety

10.1 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 beam path 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 radiation levels outside the shielding enclosure exceed preset levels (nominally 10 mrem/h). 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 NLCTA, and from the NLCTA Safety Officer, and thereafter signatures are required by operations supervisors on a shift-by-shift basis. The document is the responsibility of the Radiation Physicist assigned to the area concerned and is approved by the Accelerator Department 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).
- 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:

- *SLAC Guidelines for Operations*, 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.

10.1.1 The Personnel Protection System at the NLCTA

The 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 requires 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 does not allow transfer to other access states. In addition, an audible alarm sounds 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 are disabled.

The NLCTA beam line housing has two entrance points (Figure 10-1). 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, and a TV camera (Figure 10-2). The outer door uses a magnetic lock (magnalock). This device is an electromagnet which secures the door in the closed position. A circuit monitors this device to ensure its contact with its door stop and monitors its magnet current to ensure proper operation.

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

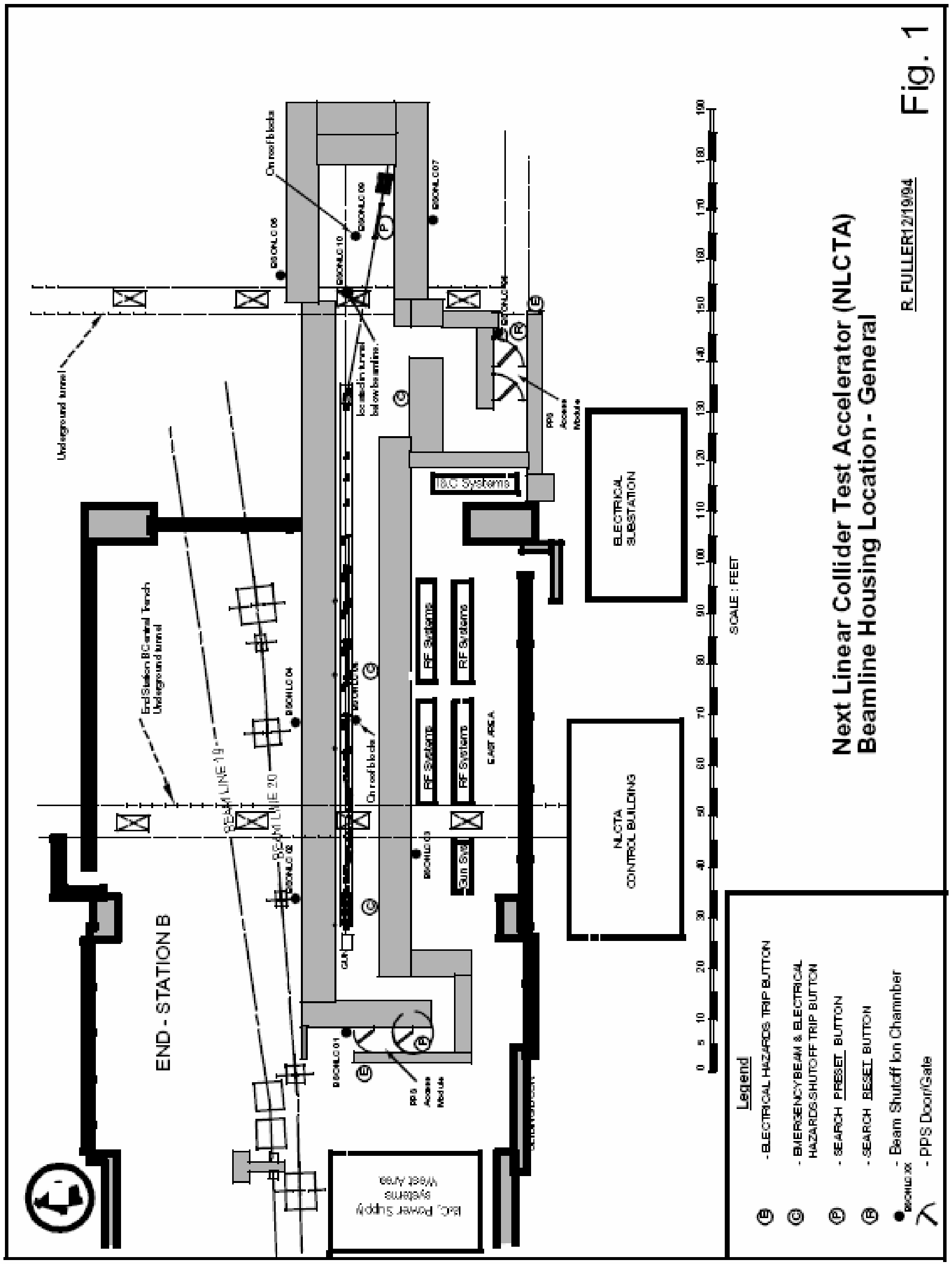

Figure 10-1: NLCTA PPS General Layout

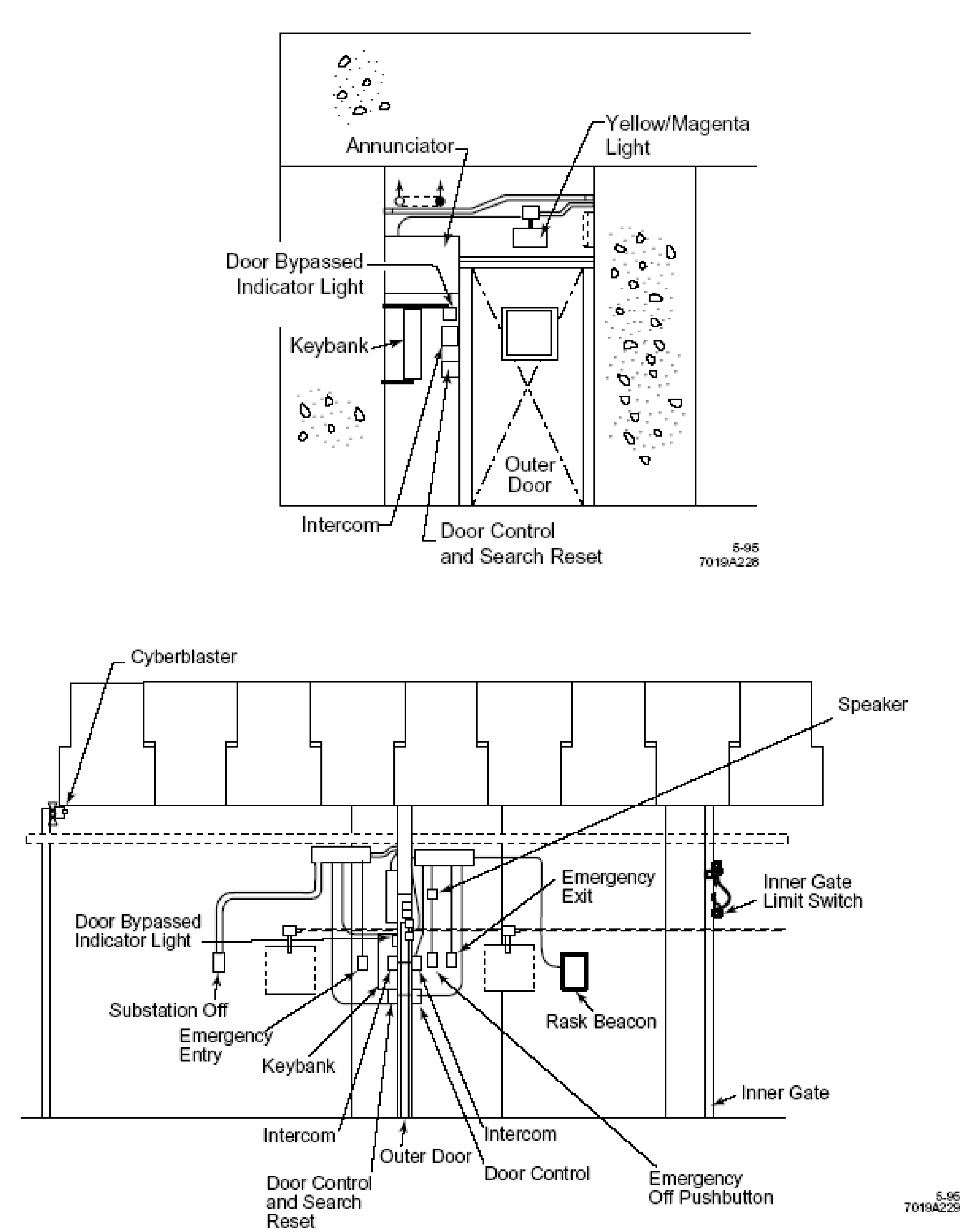

Figure 10-2: NLCTA PPS Door Configuration

10.1.1.1 Normal Entry and Exit Procedure for Controlled Access

Assuming that the NLCTA facility is in the No Access state, the following procedure is followed to enter the housing under Controlled Access:

- All beam stoppers and electrical hazards are set to their on/off state by the NLCTA operator. The specific stoppers are:
  - S-band rf gun modulator HV charging supply
  - All main power supplies for klystron systems configured to power accelerator structures
- The NLCTA operator sets the access state of the facility to Controlled Access.
- A radiation survey of the beam line housing components is made by a qualified person following long pulse electron beam operation[1].
- At this point, access to the beam line housing is controlled by the NLCTA operator as follows:
  - OHP individuals requesting access to the beam line housing are identified and logged in by the NLCTA operator via visual and audio communication at the point of entry.
  - Once logged in by the operator, a key release push button is pressed by the operator at the PPS control console. While the push button is held down, each individual removes one key from the keybank. This key is to be kept in the personal possession of the individual throughout his/her stay in the housing.
  - Once a key has been released to each individual, one individual of the group inserts his/her key into the Door Control box, rotates the key clockwise, and holds. In concert with this action, the NLCTA operator presses and holds 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 is faulted, requiring a re-search of the housing by qualified operators.
  - 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.
  - 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 depresses and holds 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.

[1] The long pulse operation is only possible with the thermionic gun, which is currently not installed. The Radiation Posting of the enclosure is updated as the configuration changes.

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

- After the radiation survey is completed and OHP has approved occupancy, the NLCTA operator controls access to the housing through either the east or west access modules by the release of keybank keys as outlined in the fourth step above.

10.1.1.2 Normal Entry and Exit Procedures for Permitted Access

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

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

10.1.1.3 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:
- Operating the Emergency entry/exit button at the outer doors located at the Access Modules.
- The act of opening the inner gate at either of the NLCTA Access Modules.
- Operation of any Emergency Off push button (five each) along the aisle way inside the NLCTA beam line housing and access mazes.
- Loss of keybank "complete" status.

Any of these Security Fault violations remove the PPS permits to all radiation and electrical hazards.

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.

All of the above Security Fault violations 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. There are no Security Fault scenarios for the Permitted Access mode.

10.1.1.4 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 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 10-1.

The Search Reset is complete when:

- The Search Presets for the housing are set.
- All gates and doors are closed.
- The Emergency Off buttons are reset.
- Both Access Module keybanks are "complete."
- 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.

10.1.1.5 Visual and Audio Warnings

Both visual and audio warnings are 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 flash and a recorded warning message is played for approximately 2 minutes. The message is:

> *"Attention. The Electrical Hazards are about to come on. Press the nearest Emergency Off button and call extension 5481 immediately."*

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

> *"Attention. The beam is about to come on. Press the nearest Emergency Off button and call extension 5481 immediately."*

The flashing lights and message 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 Off button or the opening of a housing gate. Should an Emergency Off button be pushed during the warning cycle, the warning message is terminated, and the Search circuit is faulted. If either inner gate is opened, the warning message is terminated, the Search circuit is faulted, and the housing lights come on full bright.

10.1.1.6 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.

10.1.1.7 PPS Emergency Off

The Emergency Off 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 are identified with signs "Beam Emergency Shut Off."

With the housing in the Restricted Access or No Access modes, pushing any of these buttons creates 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 Off circuit can only be done in Controlled Access.

10.1.1.8 PPS Emergency Entry/Exit

The Emergency Entry/Exit device for the outer door of each NLCTA Access Module is made up of two 4 inch by 4 inch by 6 inch 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 releases the door magnalock, allowing egress. An audio alarm sounds at the entry/exit point and in the NLCTA control room.

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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 creates a Security Fault.

10.1.1.9 Burn Through Monitors (BTM)

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

10.1.1.10 Beam Shut-Off Ion Chamber (BSOIC)

There are presently 10 BSOICs assigned to various locations around the NLCTA enclosure with an additional three assigned to the experimental hall. If radiation levels exceed their preset threshold, the units shut off all radiation hazards. Analog readout and reset function are on the Control Computer. BSOIC analog levels are also be in the control system history buffer.

10.1.1.11 PPS Functionality

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

- As required by SLAC policy, specific tests of door switches and emergency off buttons are 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*) which mandate that no work be performed on the system without a Radiation Safety Work Control Form.

10.1.2 NLCTA Beam Containment System

10.1.2.1 Introduction

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

10.1.2.2 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 are installed downstream of the horizontal bend locations (chicane and spectrometer) to prevent an errant beam from targeting 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.

Note: No BTMs are considered necessary.

Deleted: <#>Air-cooled dumps: These absorb the beam power.¶

10.1.2.3 Administrative Procedures

- Beam Authorization Sheet: The Beam Authorization Sheet (BAS) 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 BAS, are validated using written procedures.

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- 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 BAS. This includes verification of trip point settings and confirmation that all shut-off paths are operating normally.

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- 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.

10.1.3 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 path (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, ten 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

10.1.3.1 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. These locations are specified in the BAS.

10.1.3.2 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.

10.1.4 Radiation Safety Committee Approval for Unattended Operation

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SLAC MEMORANDUM **RSC-00-001**

TO: Distribution 02/15/00

FROM: G. Nelson

SUBJECT: Radiation Safety Committee Meeting February 7, 2000
Unattended Operation of NLCTA

Attendees:
Members: N. Ipe, H. Lynch, G. Nelson, M. Ross*, J. Sheppard, R. Sit
Others: C. Adolphson, W. Baumgartner, K. Jobe, J. Liu, W. R. Nelson

Marc Ross requested permission to operate Klystrons and modulators at the NLCTA for the purpose of processing test accelerator structures when an operator is not in attendance.[1] The gun will be locked off to prevent beam operation when an authorized operator is not present. With the gun locked off there may still be dark current in the accelerating structure but radiation levels are not expected to be a problem.

Even though an operator may not be present in the control room, there will be a designated EOIC (Engineering Operator in Charge) responsible for the processing operation at all times. The EOIC will perform daily inspections and complete a daily inspection check sheet. A call in list will be prominently posted identifying back up staff as well as the responsible EOIC. In addition the SLAC security guards will provide surveillance of the NLCTA area three times per shift.

It was noted that even when an operator is present in the control room monitoring of the structural facility, access to the roof and Klystron area for example, is not presently a routine requirement.

Radiation Sources on the NLCTA roof have been identified and will be shielded (nine locations, typically at bends in the waveguide structures, will be covered by 1/8" thick Pb lined plywood boxes). In addition a gate at the roof access stairs will be posted indicating the roof is a radiation area. There is also a BSOIC (BSONIC08) located on the roof; if the BSOIC exceeds 10 mr/hr the RF is turned off. The level of hazard in the Klystron area is similar to the 2 mile Linac Klystron gallery. OHP will follow standard practices including radiation surveys every other week.

Two modifications will be made to the hardware PPS panel in the NLCTA Control room:

1) The "Stopper enable" key switch will be changed to be captive in the enable position. This will allow "anyone" to disable the stoppers, i.e. turn off the RF, in an emergency.

2) The PPS panel "local/remote" key switch will be captive in the local position so that when switched to remote and the key is locked up no one can operate the panel controls except for the above mentioned stopper enable key switch.

* Though Marc is a member of the RSC he is also the presenter and proponent of this NLCTA proposal so he did not wear his "RSC hat".

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Also, additional Yellow/Magenta lights and new signage will be installed outside the NLCTA housing.

These PPs modifications have been reviewed internally by the Controls Department Safety Systems Review Office.[2]

The Radiation Safety Committee approved the proposal with two requests:

1) Report on the integrated dose for RF processing

2) Inform Ken Moffeit (SOC) to make sure other safety issues are addressed. (Marc and Keith are addressing other issues (References 3, 4 & 5) but these were not of concern to the RSC.)

References:

1. A proposal to operate the NLCTA for the purpose of RF Processing accelerator structures without an Operator in Attendance – M. Ross – Jan. 18, 2000

2. NLCTA proposed PPS changes – W. Kroutil – Dec 15, 1999

3. Environmental safety of proposed NLCTA operating schedule change – Joe Kenny – Dec. 1, 1999

4. Unattended 24-hour operation of the NLCTA – Robert Reek – Dec. 2, 1999

5. Unattended 24-hour operation of the NLCTA – Rick Yeager – Nov. 30, 1999

10.2 Shielding Design

10.2.1 Design Criteria

The shielding for the NLCTA was designed to limit to 1 rem/y the integrated dose near the surface of the shielding 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 a maximum credible average beam power of 5.75 kW, the nominal beam-loss fractions, beam 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's 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 11.)

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 10.2.7 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.

10.2.2 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 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].

10.2.3 Beam Line Enclosure

10.2.3.1 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, and chicane, where a large fraction of the beam power is lost. The second region is the downstream two-thirds of the beam line, the linac and the spectrometer, where power losses is less than 7.25W. 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 10-3). The roof blocks are wedge-shaped so as to permit them to interlock in alternating “up” and “down” orientations, as illustrated in Figure 10-3.

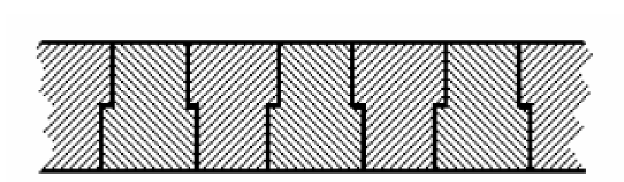

Figure 10-3: Longitudinal Elevation View of the Roof Blocks

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.

10.2.3.2 The Upstream Beam Line (Chicane)

Net beam loss of 37.5 W is expected in the chicane bends and collimators. The maximum beam energy in this area is approximately 60 MeV. At these energies, the largest contribution to the dose rates at the side walls and on the roof comes 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. Inside the shielding enclosure, local shielding of bend magnets has been installed 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.—ASK SAYED IF MEASUREMETS WERE MADE? CHANGE STATEMENT.

10.2.3.3 The Downstream Beam Line (Linac and Spectrometer)

Losses in the linac and spectrometer are not expected to exceed 7.25W 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 roof will be posted as a radiation area if the roof dose is measured to exceed 5 mrem/h.

10.2.3.4 Beam Dump

Configuration: The NLCTA dump is a large block of iron (approximately 10 feet by 15 feet by 6 feet) 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 front part of the dump are shown in Figure 10-4.

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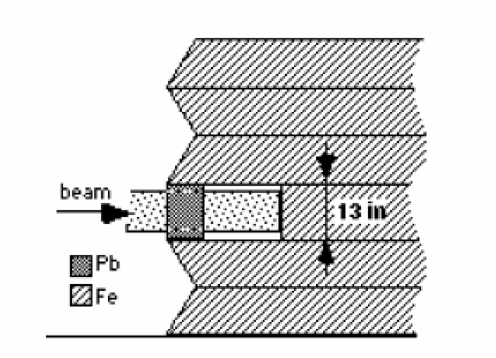

Figure 10-4: Vertical Section of the Front Face of the Beam Dump

- 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. 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 10-5. 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. The maximum dose rates expected on the unoccupied 4-foot-thick concrete roof are 0.3 mrem/h.

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.

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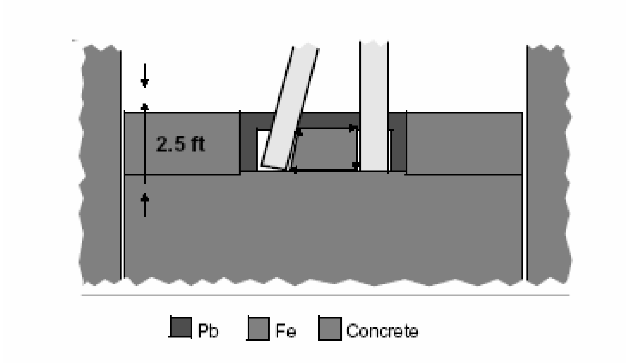

Figure 10-5: Horizontal Section of the Front Face of the Beam Dump at Beam Line Elevation

- Shielding Against Activation Products: Since the dump absorbs 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, 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.

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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 10-5. 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.

10.2.3.5 Mazes

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

10.2.3.6 West Maze:

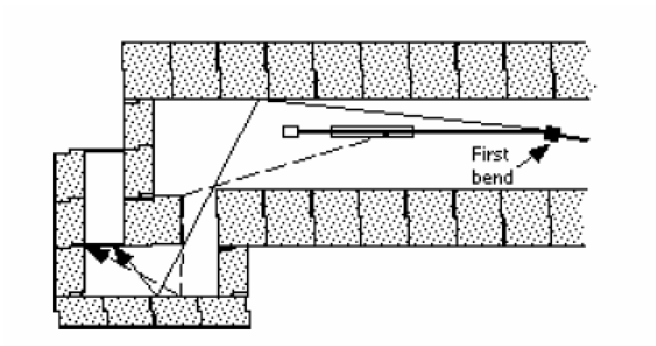

Figure 10-6: Plan View of the West Maze and the Beam Line Up to the Chicane Area

The layout of the west maze is shown in Figure 10-6. The main radiation sources in the west maze will be the first chicane bend or the collimator in the middle of the chicane, where 75W 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 250W 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.

[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.

10.2.3.7 East Maze:

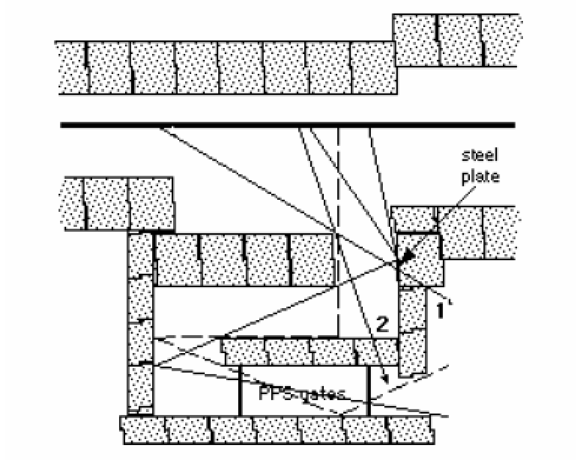

Figure 10-7: Plan View of the East Maze

The layout of the east maze is shown in Figure 10-7. 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 10-7) 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 10-7) will generate dose rates below 0.9 mrem/h.

10.2.3.8 Utility Tunnels

The NLCTA enclosure was built above two existing underground utility tunnels. (See Figure 10-1.) Each of these tunnels originally communicated with the NLCTA enclosure by a manhole 6 feet by 3 feet, as pictured in Figure 10-8. The tunnels are perpendicular to the beam line. One of them is located under the chicane area and the other under the spectrometer area.

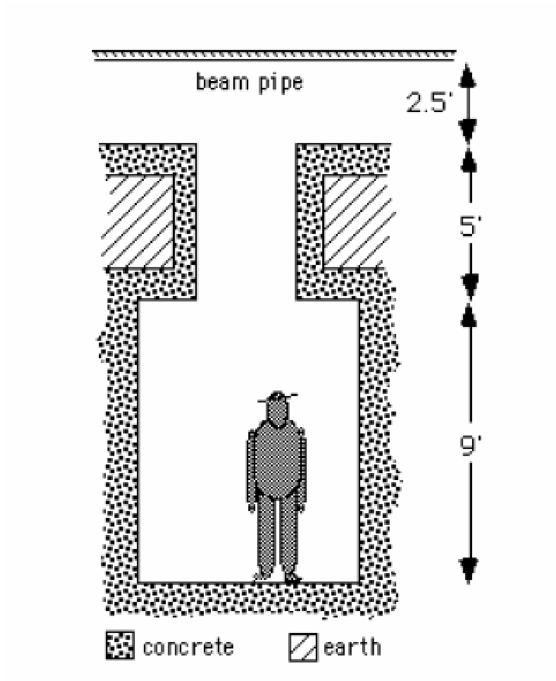

Figure 10-8: Cross-Sectional View of a Utility Tunnel and Manhole

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.

10.2.3.9 Chicane Manhole

The manhole in the chicane area is located under the collimator, where continuous losses of 75 W 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 its existing PPS gates, 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 250 W beam loss in the chicane will only triple the normally expected dose rates. As a consequence, if higher than expected dose rates are found

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during radiation surveys, installation of local shielding might be preferable from the operational point of view and also in limiting potential radiation exposure.

10.2.3.10 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 0.6 W beam loss at 800 MeV at a single point immediately upstream of the manhole, then dose rates up to 1.2 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 0.1 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.

To prevent extended duration of elevated dose rates a BSOIC with a 100 mrem/h trip threshold is installed in the tunnel under the manhole. The BSOIC in the tunnel will shut off the nominal beam when dose rates exceed 100 mrem/h.

10.2.3.11 Penetrations

- Roof Penetrations: Four penetrations 6 inches in diameter were made through the roof blocks to accommodate waveguides. The waveguides themselves are 3 inches in diameter. 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 are 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.
- Additional penetrations through the concrete shielding were made as follows:
    a. Four penetrations were added to the roof and north wall in 2003 for the E163 experiment. The geometry and radiation impact of these penetrations is described in the April 10, 2003 memo from H. Y. Khater and H. Vincke to S. Rokni, Section 10.2.11.1.

    b. Five penetrations were added to the roof in 2004 to accommodate the 8-pack experiment. The geometry and radiation impact is described in the January 8, 2004 memo from H. Khater to S. Rokni, Section 10.2.11.2.

    c. One more penetration will be added to the roof in 2006 to accommodate an L-band waveguide. The geometry and radiation impact is described in the June 1, 2005 memo from H. Khater to S. Rokni, Section 10.2.11.3.

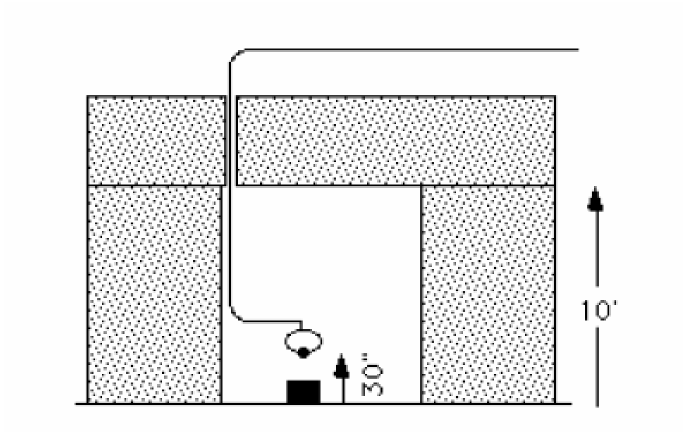

Figure 10-9: Schematic View of the rf Waveguide Passing Through a Roof Penetration

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 with nominal beam losses (0.5%). The second estimate was done for the region around the waveguide penetration for station 1, where the energy was assumed to 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. This was calculated to be 305 mrem/h. The geometry of the problem is represented in Figure 10-9.

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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.

10.2.4 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:

$$(AverageRoomConcentration) = (SaturationActivity) \times \left(\frac{BremsstrahlungPathlength}{RoomVolume} \right)$$

where the saturation activity in units of Bq/m/kW or mCi/m/kW are available from the literature [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 is being lost in one discrete point at the end of the accelerator structure. The path length of the bremsstrahlung that barely misses

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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 10-1 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 10-1 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 10-1: Potential Activity Induced in Air

Nuclide	Half Life	Reaction Type	Saturation Activity [MBq/kWm]	Concentration [Bq/cm3]	Concentration [mCi/cm3]	DAC [mCi/cm3]
H-3	12.2 y	(γ,H-3)	5	7.03E–4	1.90E–8	2.00E-6
Be-7	53.6 d	(γ,sp)a	1	1.41E–4	3.80E–9	9.00E-6
C-11	20.3 m	(γ,sp)*	10	1.41E–3	3.80E–8	4.00E–6
N-13	10 m	(γ,n)	200	2.81E–2	7.60E–7	4.00E–6
O-15	123 s	(γ,n)	130	1.83E–2	4.94E–7	4.00E–6
N-16	7.14 s	(γ,np)	0.02	2.81E–6	7.60E–11	7.00E–7
Cl-38	37.3 m	(γ,p)	0.22	3.09E–5	8.36E–10	3.00E–6
Cl-39	55.5 m	(γ,p)	1.5	2.11E–4	5.70E–9	3.00E-6
Ar-41	1.8 h	(n,γ)	—	4.94E–3	1.42E–7	3.00E–6

The saturation activities reported in literature and used in Table 10-1 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.

10.2.5 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 source of radiation considered was 0.5% loss at the high-energy end of the linac. Assuming that the beam line enclosure is unventilated, 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 $Cs = pT / V$.

The volume (V) of the enclosure was estimated to be 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 75 W, escapes from the beam line 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 m. It follows from the above that 13% of the escaping energy will be absorbed in the air, at a rate of $2.03 \cdot 10^{17}$ 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 $4.12 \cdot 10^7$ cm^{-3} s^{-1}, resulting in a saturated concentration of $1.24 \cdot 10^{11}$ molecules/cm^3, which represents a fraction of $4.61 \cdot 10^{-9}$ 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.

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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.

10.2.6 Ionizing Radiation from Klystrons

The X-band klystrons, the S-band klystron, and the L-band klystron used to generate microwave power can be sources of ionizing radiation. 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 has been 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.

10.2.7 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.

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10.2.8 Prompt Radiation

The distance from the NLCTA to the closest point of the SLAC boundary is approximately 400 m. 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. Two source terms were taken into account:

- 0.5% beam loss in the accelerator structure 70% of the running time ($1.4 \cdot 10^{17}$ e–/y),
- 100% beam loss in the beam dump 70% of the running time ($2.8 \cdot 10^{19}$ e–/y).

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

- 0.02 mrem/y for the accelerator structure,
- 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 the sources, 0.02 mrem/y.

10.2.8.1 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 $1.5 \cdot 10^{-4}$ mrem/y. This is considered acceptable, as it is well below the 10 mrem/y dose permitted by NESHAPs.

10.2.8.2 Klystron X-rays

Ionizing radiation from the NLCTA klystrons was discussed in Section 6.5. 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-foot-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.

10.2.8.3 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 linac. Since the NLCTA's beam line is nearly parallel, the NLCTA is well served by the existing, active monitoring system. In addition to the active monitors, neutron and photon thermo-luminescent dosimeters, TLDS, 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.

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

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

[12] Reference [1], pp. 149–155.

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

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

[15] 40 CFR 61, Subpart H.

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

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

10.2.11 Penetration References

10.2.11.1 April 10, 2003 Memo describing Penetrations added for E-163

SLAC Memorandum **Date:** April 10, 2003

To: Sayed Rokni

From: H. Y. Khater and Heinz Vincke

Subject: Shielding Calculations for the Proposed E163 Penetrations

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INTRODUCTION

Plans for the E163 experiment include drilling a one 6"-diameter penetration (#1) in the 6'-thick concrete sidewall of the NLCTA shielding enclosure. The beam passes through the NLCTA shielding wall into the future E163 enclosure. Under normal experimental circumstances (for future E163 operation), a current of 10 pC @ 60 MeV, 10 Hz beam will exit the NLCTA enclosure via a 25.5^o bend dipole originating from the position of the NLCTA Faraday Cup FARC1140. In the meantime, the current long-pulse operation of the NLCTA allows for a maximum credible beam of 126 W (1.5 A, 140 ns, 60 MeV, and 10 Hz). Since this penetration will need to be blocked during the construction of the E163 enclosure, an analysis of radiation streaming through the penetration was performed to calculate the required shielding. In addition, the plan calls for drilling two 4"-diameter laser and diagnostic penetrations (#2 and #3) in the sidewall of NLCTA (the 8-pack side). The center of each penetration is 72" above beam line. A third 4"-diameter penetration (#4) is drilled vertically through the roof to allow for rf waveguide to enter the NLCTA shielding enclosure. This penetration is located in the roof of the west entrance labyrinth (no direct exposure to the beam line).

SHIELDING CALCULATIONS

The SHIELD11 code was utilized to calculate the neutron and gamma dose rates at the penetration (#1) exit (outside the NLCTA wall). The SHIELD11 calculations were performed for a maximum credible beam loss of 126 W. Since a beam loss may be produced by beam interactions with thin target (e.g., beam pipe), the SHIELD11 results (thick-target) need to be adjusted. To take into account the thin target effect, gamma and neutron dose rate results from SHIELD11 (with thick target) were compared to dose rates calculated by using the photon and neutron source terms from thin targets generated using a separate FLUKA simulation [1]. In this simulation, a 3-GeV electron beam was assumed to hit a 1^o-tilted, 0.7-cm-thick Cu plate (10 cm high and 200 cm long), as a simulation of a beam hitting a thin beam pipe. At an angle of 25.5^o with respect to the beam pipe, the FLUKA photon and neutron thin target results were a factor of 22 and 1.4 higher than the SHIELD11 results, respectively.

Based on discussions with the NLCTA physicists, the normal loss at the Faraday Cup location (with a disabled Faraday Cup) is about of 1% of the total beam. In case of radiation streaming through the E163 penetration (#1) during a normal beam loss (1.26 W) from a 126 W beam, results of the analysis showed the need for using a (15" iron + 6" poly) plug to reduce the dose rate outside the NLCTA wall to less than 1 mrem/h. This dose rate is based on the assumption that the integrated dose rate is limited to less than 1 rem during 1000 hours of operation. The plug reduced the dose rate due to the loss of 1.26 W (1 % of the beam) to a 0.3 mrem/h. The same plug size reduced the dose rates outside the NLCTA wall due to a mis-steering beam loss to a 30 mrem/h. This value is lower than the mis-steering limit of a 400 mrem/h. Finally, to take into account that the plug might not fully fill up (radially) the penetration and hence allowing for radiations streaming through the cracks, an additional shielding of 4" of iron and 2" of poly should fully cover the exit of the penetration on the E163 enclosure side. The shield reduces the dose rate behind the shield to a 5 mrem/h. These shielding requirements are calculated under the assumption that the maximum dose rate to an organ is about a factor of four higher than the dose limit to the whole body.

In order to evaluate the two laser penetrations (#2 and #3) in the NLCTA sidewall, the SHIELD11 code was utilized to calculate the neutron and gamma doses at the entrance of the penetration. The SHIELD11 calculations assumed either a 1.26 W (normal loss), or a 126 W (mis-steering loss) beams hitting a thick target at a 90° angle with respect to the penetrations. Dose rate values at the exit of each penetration were calculated by using the conservative reflection coefficients for monoenergetic x-rays ($\alpha_\gamma = 0.03$) and neutrons ($\alpha_n = 0.06$) given in Appendices E.15 and F.12 of the NCRP Report No. 51 [2]. Equal angles of incidence and reflection were assumed while choosing the reflection coefficients from the NCRP report. In addition all calculations assumed that the streaming radiation undergo a single reflection (bounce) within each penetration.

Table I. Summary of dose rate results (at the exit) for radiation streaming through the two laser penetrations (#2 and #3).

Loss Type	SHIELD11	SHIELD11 with Thin Target Correction
Normal (1.26 W)	80 mrem/1000h	300 mrem/1000h
Mis-steering (126 W)	8 mrem/h	30 mrem/h

Results in Table I show the dose rates outside the two laser and diagnostic penetrations. The results in the table assume that the penetrations are not filled. As shown in the table, at the exit of each penetration, the dose rates during 1000 hours of exposure due to normal loss of a 1% of a 126 W beam is 300 mrem. In the meantime, a mis-steering beam of 126 W would result in a dose rate at the penetration exit of a 30 mrem/h. The accumulative SHIELD11 dose rate (photon + neutron) is about a factor of four lower than the thin target dose rate. The table also shows that mis-steering dose rates caused by radiation streaming through the penetrations are below the limit of a 400 mrem/h. Since the penetrations are located at more than 8’ from the floor of End Station B, personnel working inside the building would be exposed to lower level of radiation (larger distance form the penetration exit). The actual dose rates are proportional to the inverse of distance square (in meters) between each penetration and the nearest personnel on the floor. Finally, since the rf penetration (#4) in the roof of the west entrance labyrinth is not directly exposed to the beam line and located down beam from the low energy part of beam line, the dose rate caused by radiation streaming through this penetration is smaller than the values shown in Table I.

CONCLUSION

We recommend the approval of the penetration drilling request under the following conditions:

1. The 6”-diameter penetration (#1) is plugged with a (15” iron + 6” poly) plug.
2. 4” of iron and 2” of poly should fully cover the exit of the penetration (#1). To reduce the shield weight, the shield could be cut (on the inside) to only cover the cracks along the edge of the penetration. This shield must be also locked in place by an ADSO lock.
3. The entrance to the penetration (on the NLCTA beam line side) is covered (e.g, with a metal plate) and locked with an ADSO lock.
4. The NLCTA Faraday Cup is disabled and locked out with an ADSO lock.
5. The unused laser penetrations (#2, #3) must be filled up as much as possible.
6. The BAS of the NLCTA must be modified to reflect all of the previous requirements.
7. Radiation physics will perform a survey to check the adequacy of the shielding prior to NLCTA operation.

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[1] J. Liu et al., “FLUKA Calculations of Source Terms and Attenuation Profiles for Generic Shielding Design of SPEAR3 Ring,” RP Note 02-20, SLAC, Dec. 2002.

[2] National Council on Radiation Protection and Measurements, “Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities,” NCRP Report No. 51, 1977.

Cc: D. Walz, E. Colby, K. Jobe, M. Saleski

10.2.11.2 January 8, 2004 Memo Describing Penetrations added for the 8-Pack Experiment

SLAC Memorandum **Date:** January 8, 2004

To: Sayed Rokni

From: H. Y. Khater

Subject: Analysis of the New 8-Pack Penetrations in the NLCTA Roof (Revised)

The 8-Pack project requested adding five new penetrations to the roof of the NLCTA [1]. These penetrations will be used for rf waveguide and instrumentation cables. The five additional penetrations are identical to and in the same line with the existing six penetrations in the NLCTA roof. The diameter of each penetration is 7". Figures 1 and 2 show the elevation and top view of the NLCTA roof penetrations, respectively. The six penetrations currently present in the NLCTA roof were analyzed for a beam power of 1.3 kW and beam energy of 1.1 GeV. On the other hand, the NLCTA SAD Shielding Design specifies initial and upgraded power levels of 3.23 and 5.75 kW, respectively. Analysis of radiation streaming through the new penetrations is performed for the three different power levels. In addition to radiation streaming through the penetrations, direct dose rates are also calculated on the top of the 4' concrete.

Dose rates on the roof are calculated by using conservative reflection coefficients that are included in the NCRP Report No. 51 [2], for monoenergetic x-rays ($\alpha_\gamma = 0.03$) and neutrons ($\alpha_n = 0.02$). The SHIELD11 code was utilized to calculate the neutrons and gamma doses at the entrance of each penetration. The SHIELD11 calculations assumed a mis-steering beam hitting a thick target at a 90° angle with respect to the penetrations. Based on the penetrations geometries shown in Figures 1 and 2 [figure 2 damaged/lost], equal angles (60°) of incidence and reflection were assumed while estimating the reflection coefficients from the NCRP report. Since the full body is not exposed to the streaming radiation, the calculated effective dose equivalent values are reduced by a factor of 4. In addition all calculations assumed that the streaming radiation undergo a single reflection (bounce) within each penetration.

Table I. Summary of dose rates (mrem/hr) on top of the NLCTA roof.

Power (kW)	**Radiation Streaming through Penetrations**	**Direct Radiation through the 4' Concrete**

1.3	460	640
3.23	1140	1590
5.75	2035	2830

Table I shows a comparison between the dose rates resulting form radiation streaming through the penetrations and the direct dose rates on top of the 4' concrete roof. As shown in the table, the dose rates caused by radiation streaming through the penetration are less than the direct dose rates on the roof. Similar to the existing penetrations, radiation streaming through the new penetrations results in dose rates of less than 1 rem/h on the NLCTA roof, if the maximum beam power is limited to 1.3 kW. On the other hand, the initial and upgraded power levels specified in the NLCTA SAD Shielding Design result in dose rates on the NLCTA roof that exceeds 1 rem/h.

Summary

Adding the new penetrations to the roof of the NLCTA may proceed under the following conditions:

1. Beam power is limited to 1.3 kW.
2. Unused penetrations are blocked.
3. Proper RSWCF are issued.

References

[1] K. Jobe, "New Penetrations in NLCTA Accelerator Housing," Memo to Radiation Physics, August 27, 2003 (Revised on January 7, 2004).

[2] National Council on Radiation Protection and Measurements, "Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities," NCRP Report No. 51, 1977.

Cc: K. Jobe, M. Ross, D. Schultz, Fred Asiri, RP file.

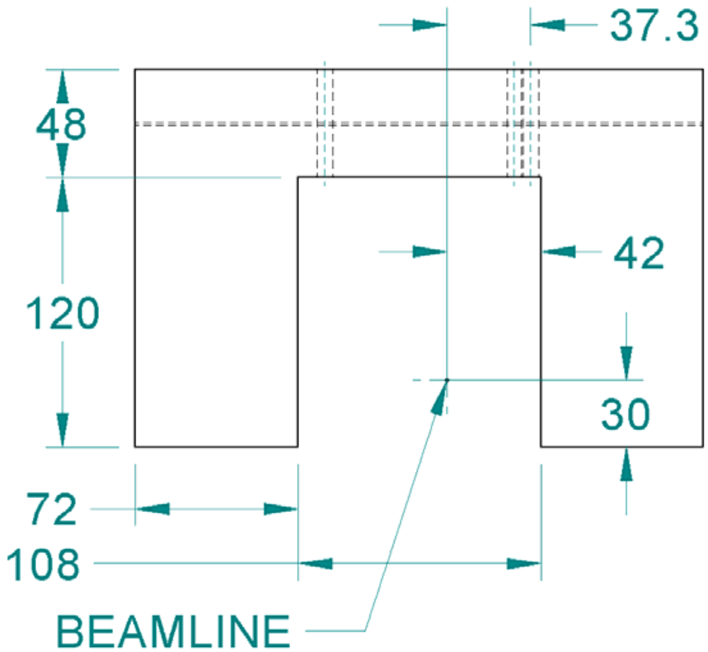

Fig 1. Elevation View of the NLCTA Roof Penetrations

10.2.11.3 June 1, 2005 Memo Describing the L-Band Penetration

SLAC Memorandum **Date:** June 1, 2005

To: Sayed Rokni

From: H. Y. Khater

Subject: Analysis of the New L-band RF Penetration in the NLCTA Roof

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The ILC group requested adding a new penetration to the roof of the NLCTA [1]. The new penetration will be used for L-band RF waveguide. The standard waveguide size is 6.5” x 3.25” but the associated flanges require an 11”-diameter hole. Figure 1 shows an elevation view indicating the position of the new penetration relative to the NLCTA beamline. The waveguide will be connected to L-band structure located in the high energy region of the NLCTA beamline The level of radiation streaming through the penetration was analyzed for the nominal and safety envelop beam powers previously analyzed [2] and included in the NLCTA safety Assessment Document (SAD) [3]. In addition to radiation streaming through the penetrations, direct dose rates are also calculated on the top of the 4’-thick concrete.

In order to calculate the dose rates outside the penetration, a Monte Carlo simulation was performed using the MCNPX code [4]. The MCNPX code was run with incident electron kinetic energy of 1.1 GeV, and with electron cutoff energy of 1 MeV. The kinetic energy represents the highest possible energy included in the NLCTA SAD. The beam was assumed to hit a 12”-long cylindrical copper target which has a 2” radius. Results obtained for the maximum energy and power (5747 W) specified by the SAD (safety envelop for upgraded power level) were scaled for power levels specified for nominal operation (438 and 1451 W) as well as the safety envelop design power level (3233 W). Figure 2 shows the MCNPX model used in the calculation. In this figure, the inside of the NLCTA enclosure is shown in light blue, the enclosure concrete walls in light green, penetration in dark green, scoring region in yellow. In addition, the beam line is shown in dark blue. Finally, the two circles shown in blue are not part of the geometry and only represent DXTRAN spheres (for MCNPX variance reduction).

Calculations were performed for two penetration options. The first option (Option I) represents the requested 11”-diameter hole. On the other hand, the second option (Option II) assumes that the roof hole matches the actual size of the wave guide size (6.5” x 3.25”). Finally, dose rates resulting form radiation streaming through the penetrations were compared to direct dose rates on top of the 4’-thick concrete roof. The direct dose rates were calculated by using the SHIELD11 code [5].

Table I shows a comparison between the dose rates resulting form radiation streaming through the penetrations and the direct dose rates on top of the 4’-thick concrete roof for Option I. Since the full body is not exposed to the streaming radiation through the hole, the calculated effective dose equivalent values are reduced by a factor of 4. As shown in the table, the dose rates caused by radiation streaming through the penetration are higher than the direct dose rates on the roof. The dose rates on the top of the penetration, at nominal power levels, which are caused by normal beam loss (0.5% loss at a point) or mis-steering beam losses (100% loss at a point), exceeds the maximum dose rates on top of the 4’-thick concrete roof by ~ factor of 5 or 6. On the other hand, 100% beam losses of the power levels identified by the safety envelop produced dose rates which are factor of 5 higher for the penetration case. The dose rates caused by neutron streaming through the penetration are more than twice the dose rate caused by photon streaming.

Table II shows a comparison between the dose rates resulting form radiation streaming through the penetrations and the direct dose rates on top of the 4’-thick concrete roof for Option II. As shown in the table, the dose rates caused by radiation streaming through the penetration are somewhat higher than the direct dose rates on the roof for the nominal power levels. On the other hand, the dose rates above the penetration are lower than the direct dose rates above the concrete for the safety envelop power levels. In this case, the dose rates caused by photon streaming through the penetration are twice the dose rate caused by neutron streaming. Comparing dose rates results from Tables I and II shows that using Option II penetration (RF waveguide size) results in a reduction of radiation streaming through the penetration by about factor of 5. The reduction is due to a drop in photon and neutron dose rates by factors of 2 and 10, respectively.

Summary

Adding the new penetration to the roof of the NLCTA may proceed under the following conditions:

4. The space between the 11”-diameter hole and the RF waveguide is filled with gravel (option II).
5. The penetration is blocked when not in use.
6. Proper RSWCF is issued.

References

[1]. S. Doebert, “Evaluation of New Penetration into the NLCTA Housing,” Memo to Hesham Khater, March 23, 2005.

[2]. V. Vylet and T. Lavine, “Radiation Protection in the NLCTA,” NLCTA-Note # 46.2, January 8, 1996.

[3]. SLAC Technical Division, “Safety Assessment Document – Next Linear Collider Test Accelerator,” April 24, 1996.

[4]. L. Walters (Ed.), “Monte Carlo N-Particle Transport Code System for Multiparticle and High Energy Applications, Version 2.5.f, LANL, 2005.

[5]. W. Nelson and T. Jenkins, “The SHIELD11 Computer Code,” SLAC-R-737, February 2005.

Cc: S. Doebert, K. Jobe, M. Ross, T. Raubenheimer, F. Asiri, H. Vincke, RP file.

Table I. Summary of dose rates (mrem/hr) on top of the NLCTA roof (option I).

Parameter	Nominal		Safety Envelop	
	Design	**Upgrade**	**Design**	**Upgrad e**
Power (W)	438	1451	3233	5747
Energy (MeV)	480	796	600	1066
Normal Dose Rate Outside 4'-thick Concrete Roof (mrem/h)[1]	0.6	2.8	1043	2806
Normal Dose Rate on Top of the Roof Penetration (mrem/h)[1,2]	4.6	15.2	6665	11845
Mis-steering Dose Rate Outside 4'-thick Concrete Roof (mrem/h)[3]	114	568	1043	2806
Mis-steering Dose Rate on Top of the Roof Penetration (mrem/h)[2,3]	920	2990	6665	11845

[1] **Normal loss at a point is 0.5% for nominal and 100% for safety envelop.**

[2] **Effective dose equivalent values are reduced by a factor of 4.**

[3] **Mis-steering loss at a point is 100% for nominal and safety envelop.**

Table II. Summary of dose rates (mrem/hr) on top of the NLCTA roof (option II).

Parameter	Nominal		Safety Envelop	
	Design	Upgrade	Design	Upgrade
Power (W)	438	1451	3233	5747
Energy (MeV)	480	796	600	1066
Normal Dose Rate Outside 4'-thick Concrete Roof (mrem/h)[1]	0.6	2.8	1043	2806
Normal Dose Rate on Top of the Roof Penetration (mrem/h)[1,2]	1	3.3	1449	2575
Mis-steering Dose Rate Outside 4'-thick Concrete Roof (mrem/h)[3]	114	568	1043	2806
Mis-steering Dose Rate on Top of the Roof Penetration (mrem/h)[2,3]	200	650	1449	2575

[1] **Normal loss at a point is 0.5% for nominal and 100% for safety envelop.**

[2] **Effective dose equivalent values are reduced by a factor of 4.**

[3] **Mis-steering loss at a point is 100% for nominal and safety envelop.**

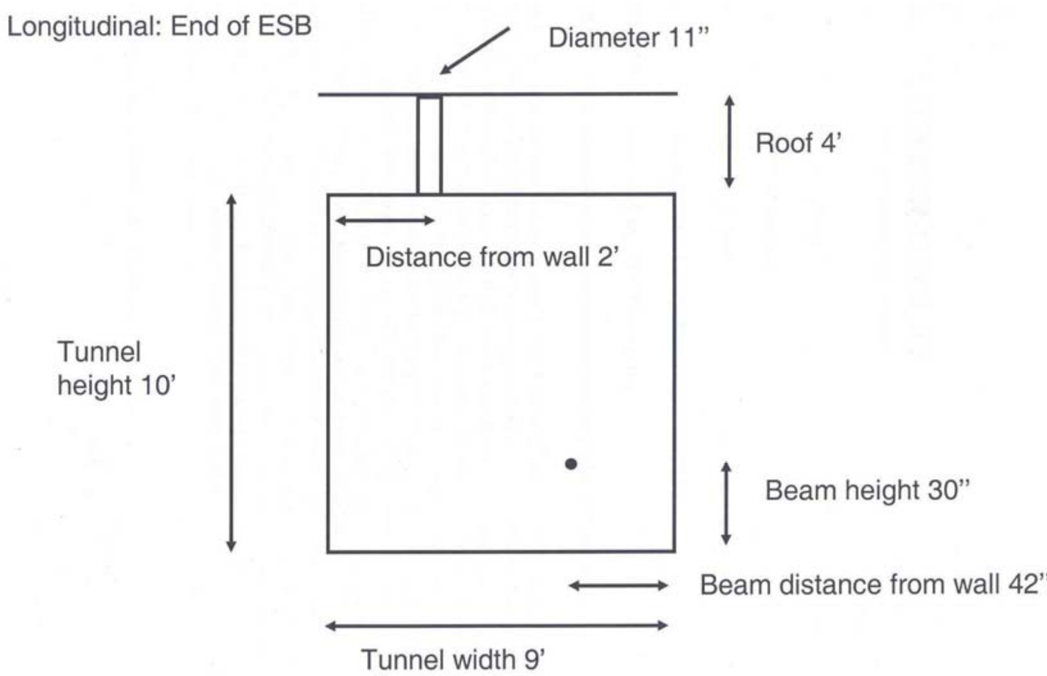

Fig. 1. Elevation view of the NLCTA roof penetrations.

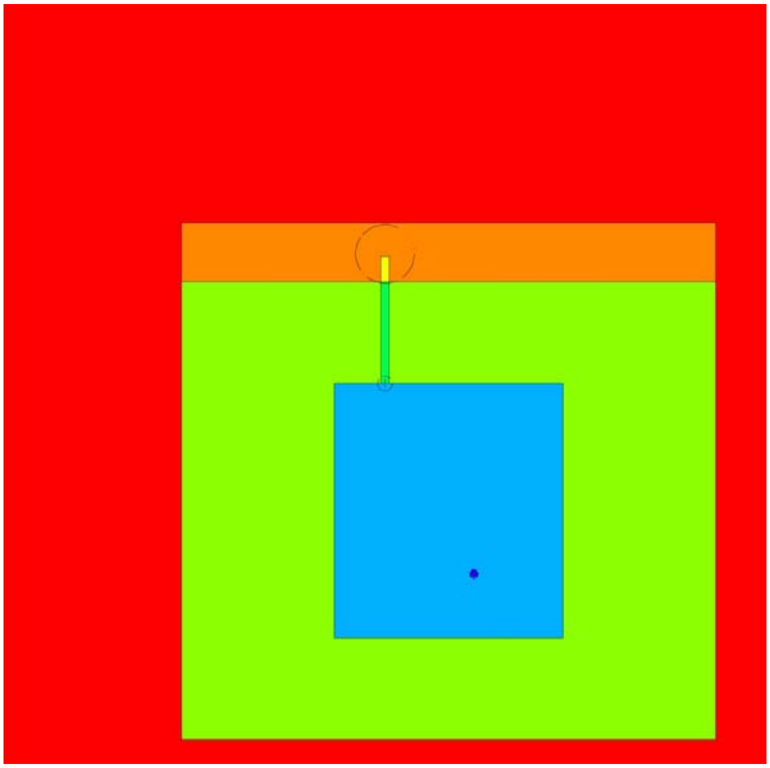

Fig. 2. Elevation view of MCNPX model.

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11. Experimental Hall Radiation Safety

11.1 Maximum Credible Beam Power Calculations for the New Photoinjector

11.1.1 May 27, 2005 Memo describing Explosive Electron Emission (EEE) for E-163

Deleted: April 16, 2006

SLAC MEMORANDUM-E163

DATE: May 27, 2005

Deleted: August 21, 2006

TO: Heinz Vincke

FROM: Eric Colby

SUBJECT: **Explosive Electron Emission (EEE) Loss Calculations for E163**

This memo describes a calculation of beam power losses that result from "Explosive Electron Emission" (EEE) from the photocathode of the ORION/E163 rf gun. EEE can result when a plasma is formed in response to an over-focused laser striking the photocathode. In addition to producing large amount of beam current and radiation, this form of emission generally results in permanent damage to the cathode surface and must be assiduously avoided.

Prior estimates for the LCLS gun apply[1] to the ORION/E163 gun, as the microwave design, maximum gradient and manner of laser illumination are similar. Estimates for the beam transmission through the booster linac, however, differ substantially owing to significant differences between the LCLS and NLCTA accelerator beamlines. We will assume, as in reference [1], that the charge per rf bucket is space-charge limited, which for 120 MV/m gradient in the gun, and the design E163 spot size of 2.5 mm means:

$$q = E_o \pi r_o^2 \varepsilon_o = (120MV/m)\pi(2.5mm)^2(8.854\times10^{-12}F/m) = 20.8nC \qquad (1)$$

is the approximate charge emitted in each rf bucket. At this emission rate, the beam (initially) extracts energy at a rate of 20.8 nC*2.856 GHz*6 MeV~360 MW and the rf stored energy in the gun is depleted very rapidly, causing the electric fields to diminish rapidly to levels that no longer sustain the EEE mode. Experiments show the integrated charge emitted over a single rf pulse from a similar s-band rf gun at Brookhaven approaches 1 μC[2]. Beam is emitted at rapidly diminishing energy (and hence in rapidly diminishing charge bunches) due to the stored energy depletion. For (conservative) estimation purposes here, the entire charge of 1 μC will be assumed to be emitted at full energy (6 MeV) in 20.8 nC bunches, and the beam loss power deposition profile calculated using Parmela (a tracking code that includes rf and space charge effects).

Equation (1) with $E_o \rightarrow E_o \sin(\omega_{rf}t)$ is used to derive the temporal bunch shape. This gives a significantly longer electron bunch (and consequently larger energy spread and emittance) than Fowler-Nordheim emission, the mechanism thought primarily responsible for dark current emission.

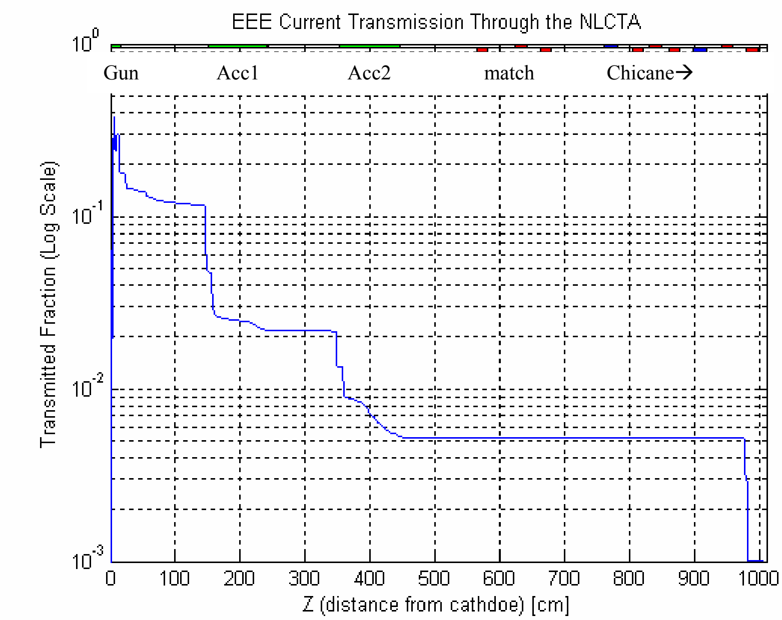


Figure 1. Transmitted fraction of EEE charge on a logarithmic scale.

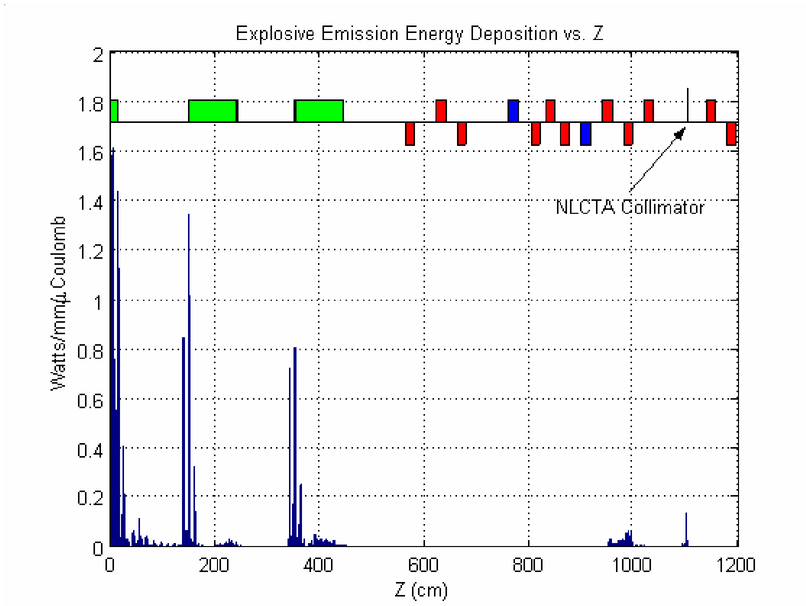


Figure 2. Deposited power along beamline. It is assumed that 1 μC total charge is emitted from the cathode surface each rf pulse at 10 Hz and that all emitted bunches experience the maximum gun field of 120 MV/m.

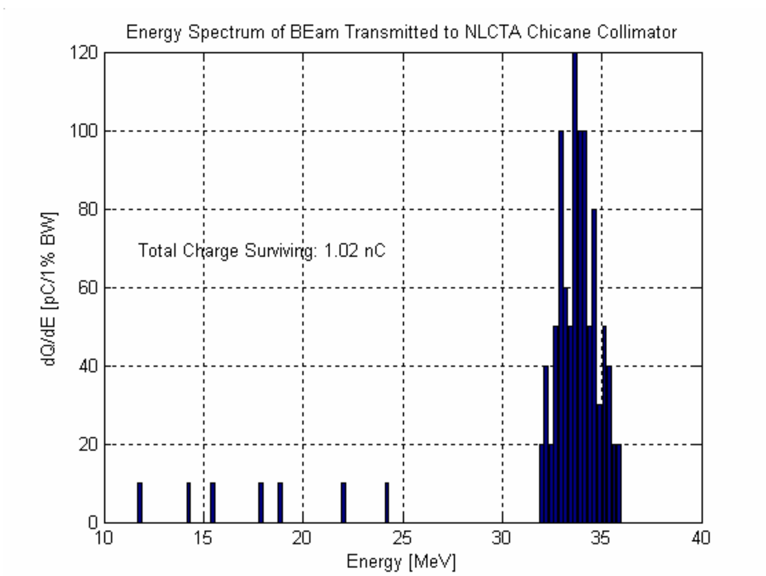


Figure 3. Energy spectrum of surviving EEE charge at the position of the NLCTA chicane collimator. The NLCTA chicane collimator will be set to a fairly narrow slit that passes ~60 MeV particles under both E163 and NLCTA HGRF testing circumstances.

From figure 1 it is clear that more than 99% of all the EEE charge produced will be intercepted in the x-band accelerators of the NLCTA injector. Figure 2 shows where the deposited power falls, with a few watts average intercepted in the first few cells of each rf structure.

From figure 3 it is clear that most of the remaining particles that are not scraped off in the accelerators have energies low enough to be lost in the NLCTA chicane, either after the first bend or two, or at the NLCTA collimator. As the NLCTA chicane and E163 dogleg have regions of substantial dispersion (0.3m and 0.7m, respectively) the large energy deviation of the transmitted bunch (~34 MeV) from the lattice setting of ~60 MeV means that the EEE beam will be far off-orbit and intercept the walls of the chicane beam pipe long before reaching the E163 extraction point.

Conclusion

The EEE process leads to long, large energy spread, large emittance bunches with high charge that are rapidly lost in the injector x-band accelerators and chicane. From the transmission calculations, it is anticipated that negligible EEE beam power (of the same order as the E163 photocurrent, tens of mW) will exit the NLCTA enclosure under any circumstances.

References

[1] J. Clendenin, *et al*, “LCLS Maximum Credible Beam Power”, LCLS-TN-01-2, March (2001).
[2] X.-J. Wang, *et al*, J. Appl. Phys., **72**, p. 888ff, (1992).

11.1.2 November 16, 2006 Memo revisiting Explosive Electron Emission (EEE) for E-163

SLAC MEMORANDUM-E163

DATE: November 16, 2005

TO: Heinz Vincke

FROM: Eric Colby, Robert Noble

SUBJECT: **Maximum Credible Beam Power: revisiting the Explosive Electron Emission (EEE) Loss Calculations for E163**

This memo describes a calculation of the maximum credible beam power that can be delivered to the Experimental Hall. "Explosive Electron Emission" (EEE) from the photocathode of the E163 rf gun was described in a earlier memo[1]. The prior memo calculated transmission of the EEE current with magnets and rf structures set to an otherwise nominal configuration.

This document carries those calculations further, under the following, more conservative assumptions:

1) RF devices are set to the maximum gradient possible with the available klystron power
2) The magnet lattice is reoptimized for best transmission of the EEE current to the Experimental Hall

These are conditions that would arise if a skilled operator deliberately operates the machine in a manner that is destructive to the components (both through frequent rf breakdown and large beam losses) and quite difficult to optimize (since several key groups of diagnostics will be saturated by the high charge). Such operation goes well beyond the scope of accidents that could occur with an unskilled operator, and is possible only with a malicious accelerator operator.

One can immediately bound the maximum beam power possible from the electron gun by observing that (1) the laser pulse (hence the onset of EEE) is always very near the end of the rf pulse, and (2) the total stored EM energy is 6.8J for 115 MV/m, the demonstrated maximum field in the gun. At the highest gun PRF of 10 Hz, this limits the output beam power to 68 Watts, assuming perfect conversion to beam power. (This is the number listed in Table 1 of the memo titled "Installation of New Electron Source" to Sayed Rokni).

A similar argument may be applied to the stored energy in the x-band accelerator sections. With a Q_o=7005[2], and a peak accelerating field of 70 MeV/m for 100 MW forward power[3], the available stored energy is 9.75J per structure. Adding this to the gun energy gives a maximum possible beam power of 263 Watts, assuming again that all the stored energy becomes usable beam power.

When one properly accounts for beam loading effects and beam transmission losses, this number becomes significantly lower. We will now more carefully evaluate this number.

Explosive Electron Emission Model and Beam Loading in the Gun

The explosive emission process results from the formation of plasma on the cathode surface with approximately the same dimensions as the laser pulse that ignited it. The current which may be extracted is presumed to be fully space-charge-limited, that is, the

[1] E. Colby, memo to Heinz Vincke/RP, "EEE Loss Calculations for E163," SLAC Memorandum, (2004).
[2] NLC ZDR, SLAC-474, page. 486.
[3] C. Adolphsen, private communication, 11/11/2005.

Child-Langmuir law may be applied to estimate the current as a function of field strength and time. The total charge extracted in an rf bucket may be estimated as:

$$Q_i = (\pi r^2)\frac{4}{9}\varepsilon_o\sqrt{\frac{2e}{m_e}}E_{cath}^{3/2}d^{1/2}\int_0^{\tau/2}\sin^{3/2}(\omega t)dt$$

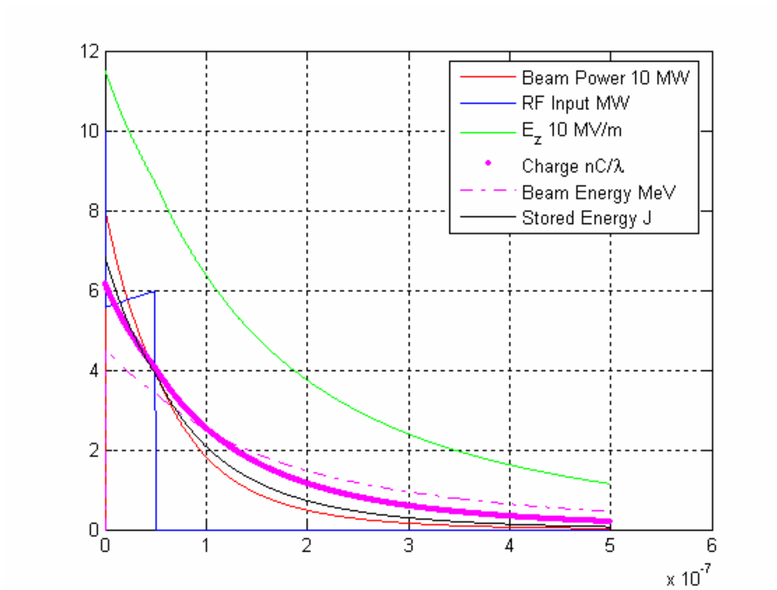
Where the result of the half-cycle integral is $2\int_0^{\pi/2}\sin^{3/2}(\omega t)dt = \frac{1}{3\omega\sqrt{2\pi}}\Gamma(\frac{1}{4})^2$.

Energy balance in the gun cavity provides:

$$\frac{dU(t)}{dt} = P_F(1-\rho^2) - P_{beam} - P_{wall} - P_{rad}$$

With the reflection coefficient ρ included to properly account for the cavity mismatch induced when heavy beam loading modifies the cavity impedance. For a maximum gun gradient of 115 MV/m (on the cathode, corresponding to P_F=*10 MW*), and a 5 mm radius laser spot, and the laser timed to arrive 50 nsec before the end of the rf flat-top (when maximum stored energy is available to make EEE beam), the emitted charge per rf bucket, gun gradient, beam exit energy, and cavity stored energy are shown in figure 1. This small time offset before the end of the rf pulse is typical of normal operation, and does little to change to total stored energy (since 50 nsec is short compared to the fill-time, 307 nsec.)

Note that the RF forward power (i.e. power entering the cavity) drops abruptly from 10 MW to 5.5 MW when EEE commences, and recovers only slightly as the EEE current drops. RF power is terminated at t=0.5x10^{-7} seconds.



Time (s)

FIGURE 1. Gun fields (green), stored energy (black), forward power (blue), emitted charge per rf bucket (pink dots), emitted bunch energy (pink dot-dash), and beam loading power (red), as a function of time. Note scaling factors of x10 in some units. The total emitted charge and beam power are 2.1 μC and 56 Watts, respectively.

Beam Loading in the Injector X-band Accelerator

The model is implemented in a manner analogous to the gun model, but without correction for cavity mismatch due to increased beam loading. As before, the laser pulse is presumed to be timed within 50 nsec of the end of the x-band power pulse, at the time when the stored energy in the accelerator is maximum, and additional power from the klystron can help sustain the fields during the EEE beam passage.

Figure 2 shows the evolution of the linac accelerating voltage, forward rf power, final EEE beam energy, beam loading power, and bunch charge (Calculated transmission losses of 80%, evaluated with Parmela, are included) , zoomed in to cover the initial 75 nsec period when the cavity fields are dropping rapidly. Note the scale is magnified compared with figure 1. Blue dot-dash lines indicate the momentum bandwidth and temporal extent accepted by the magnet lattice for highest EEE beam power which can be transported to the Experimental Hall.

It is clear from Figures 2 that within the first 5 nsec after onset of EEE, the accelerating gradient in the linac has been depleted significantly, causing the exiting EEE beam energy to drop more than 10%. This rapid decline is a direct result of the very large current represented by the first EEE bunches emitted—in this case corresponding to an initial current of over 3.5 Amperes—well above the design loaded value.

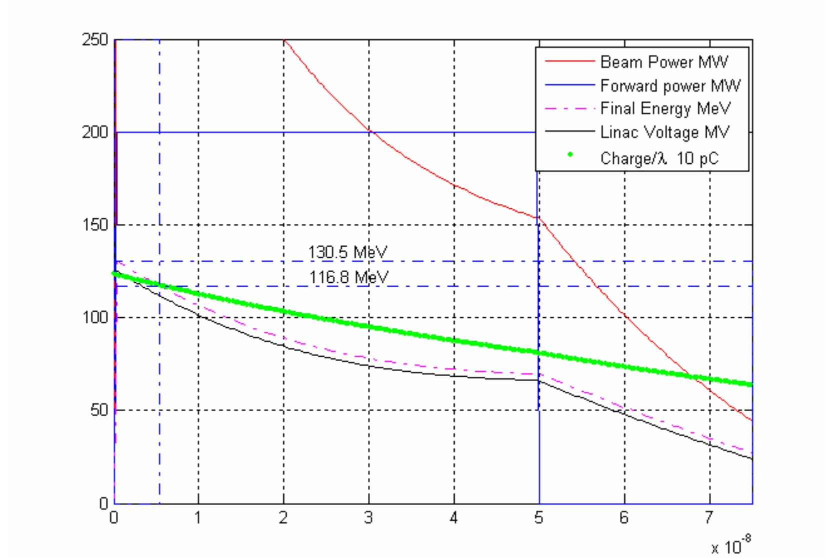


FIGURE 2. Injector Linac total voltage (black), RF total forward power (blue), bunch charge (green), final bunch energy (pink dot-dash), and beam power (red) for the first
Time (s)

75 nsec after onset of EEE. Note scaling factor of x0.1 in charge units. Horizontal blue dot-dash lines indicate the momentum range that actually survives transport through the NLCTA chicane. The vertical blue dot-dash line indicates the last EEE bunch that survives transport, the remaining bunches are lost in the NLCTA chicane.

EEE Beam Transmission to the Experimental Hall

Transmission losses of the EEE beam are calculated and included in the credible beam power estimate as follows. A Parmela simulation from the gun to the exit of the x-band accelerator sections was made to establish the accelerated EEE beam properties. This beam phase space was loaded into Elegant and transported into the experimental hall. The Elegant simulation was repeated for the first 33 bunches (viz. until transmission dropped below 0.5% per bunch) and the transmission fraction for each was evaluated. Figure 3 shows the transmitted fraction and mean energy for the first 33 bunches. The beam phase spaces for each of the subsequent bunches was assumed identical to the highest energy (first) bunch, but with the beam momenta scaled to match the declining bunch energy calculated and displayed in figure 2. The bunch charge is taken directly from the calculated values shown in figure 2.

We note that transmission losses were included in calculating the maximum credible beam power deliverable to End Station A[1].

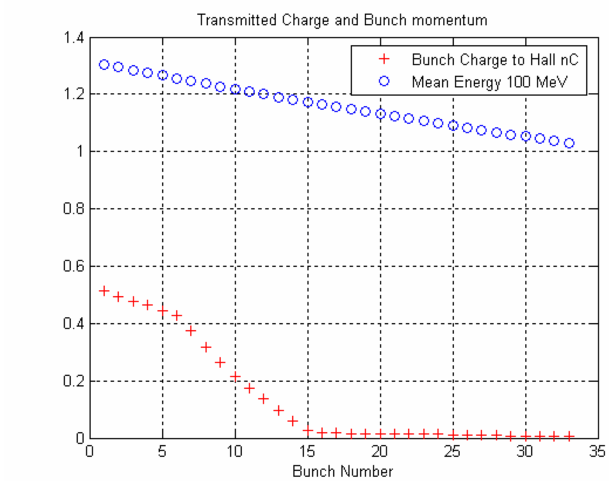


Figure 3. Bunch-by-bunch mean energy in units of 100 MeV (blue circles) and transmitted charge in units of nC reaching the Experimental Hall (red plus signs).

[1] S. Ecklund, SLAC Memo, “Maximum Credible Power to End Station A,” 28 November 2000.

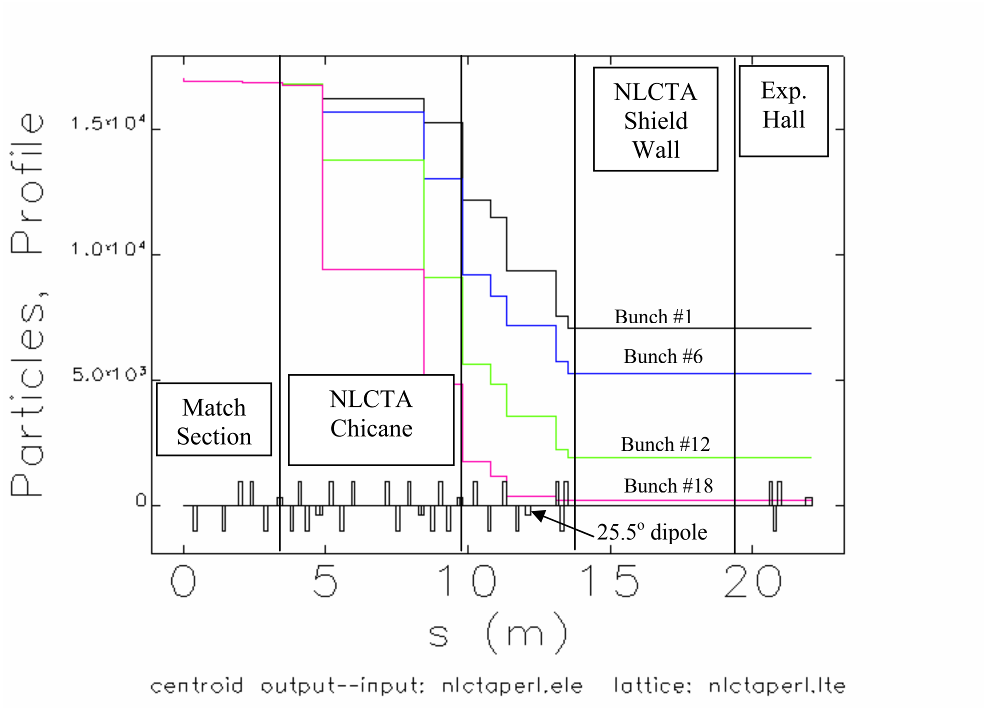


Figure 4. Transmission of charge from the exit of the x-band injector accelerators through to the Experimental Hall. The four traces show the number of particles surviving (out of 17,019 initial macroparticles) for the 1^{st}, 6^{th}, 12^{th}, and 18^{th} bunches. The lattice magnet positions are indicated at the bottom of the graph.

The limited momentum bandwidth significantly reduces the beam power that can be transmitted to the Experimental Hall, with much of the beam power being lost in the NLCTA chicane. Figure 4 shows the scraping losses for four representative bunches. As the energy rapidly slews downward, the lower energy bunches are lost earlier in the NLCTA chicane.

If one sums the beam power transmitted in the first 33 bunches (beyond which bunch transmission is less than 0.5% per bunch and the energy is ever decreasing) the maximum credible beam power is:

$$P_{ave} = PRF \cdot \sum_{0<i<34} Q_i V_i = (10Hz) * 0.524C \cdot V = 5.24 \text{ Watts}$$

And the total transmitted charge per beam pulse is:

$$Q_{tot} = \sum_{0<i<34} Q_i = 4.68 \text{ nC}$$

which is distributed into ~33 rf buckets.

Conclusion

Although deliberate tuning of the beamline to pass a significant fraction of the EEE current is possible, the combined beam loading effects and poor transmission result in the maximum credible beam power which can be delivered to the Experimental Hall of just 5.2 Watts at 130 MeV peak energy.

If one also includes the possibility that an astute operator could (1) modify or bypass the BCS rep-rate limiter and (2) provide new hardware or make appropriate SCP modifications to produce a 30 Hz gun trigger (slightly above the maximum rep rate possible with the present s-band HV charging supply), then the maximum credible beam power is 15.7 Watts at 130 MeV.

This stands in marked contrast to the prior calculations[1] which showed that EEE beam power of ~1 Watt would survive transport to the Experimental Hall if the NLCTA chicane collimator was fully open, and that "tens of mW" would survive transport if the chicane collimator was set to the position used for conducting E163's low-charge experiments. The significant gain in power is traceable to two sources: (1) a doubling of the beam energy, and (2) significantly improved transmission (10% vs. <1%) possible if the magnet lattice is reoptimized to pass the EEE beam. The former case is the most probable accident scenario during otherwise normal operation. The case presented here requires skill and malice (or at least willful neglect of obvious signs the machine is operating abnormally, such as frequent rf breakdown and saturated diagnostics) on the part of the operator.

It should be noted that EEE results in substantial degassing (since the cathode is being aggressively eroded by the emitting plasma), which would result in both the MPS vacuum interlock tripping off the gun (resulting in a significantly lowered repetition rate), and in such poor vacuum conditions that the gun would breakdown on most rf pulses. Long-term operation in EEE mode (hours) would result in substantial physical damage to the cathode, and would be very likely to make the gun prone to voltage breakdown even in the absence of EEE.

It should also be noted that the EEE beam will comprise ~4.7 nC of total charge, almost a factor of 5 above the maximum design charge (1 nC), and roughly two orders of magnitude above the nominal E163 bunch charge (50 pC). This beam will drive many of the beam diagnostics (e.g. profile screens and BPMS) to saturation, providing a readily recognized indication of a problem to the operator, and making the tuning of magnets to optimize EEE beam problematic.

[1] E. Colby, memo to Heinz Vincke/RP, "EEE Loss Calculations for E163," SLAC Memorandum, (2004).

11.1.3 August 21, 2006 Installation of New Electron Source at the NLCTA Memo

SLAC MEMORANDUM

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DATE: August 22, 2006

TO: Sayed Rokni, Radiation Safety Officer

FROM: Eric R. Colby, E-163 Spokesman

SUBJECT: Installation of New Electron Source at the NLCTA

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With this memo I am formally seeking the Radiation Physics Department's evaluation and subsequent approval to install a new RF-powered photoemission electron source at the NLCTA. We would like to install and commission this gun in the June-July 2005 timeframe. This request to install and operate the gun represents a significant step beyond the scope of the currently progressing NLCTA Restart Plan.

Synopsis

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The NLCTA presently has a thermionic gun electron source that produces a pulse train of 2 Amperes[1] at 160 kV[2] with a pulse duration of up to 120 nsec[1]. We will remove this gun, and replace it with an s-band 1.6 cell rf gun. The remainder of the NLCTA will be unchanged (we will seek separate approval for installing the extraction beamline into the E-163 experimental hall in 4-6 months). The new gun can produce beams of significantly greater energy (up to 7 MeV, vs. 160 keV for the old gun), but at significantly reduced average beam current (up to 10 nA vs. 2.4 μA, averaged over 1 second), resulting in significantly reduced beam powers at all downstream locations (see Table 1).

The beam current, energy, and power produced by each electron source are compared in Table 1. The new gun, even in the worst-case failure scenario, will produce significantly less beam power than the old gun at all locations except right out of the gun itself.

Table 1. Comparison of beam parameters for the old (thermionic) and new (photoemission) NLCTA guns

Maximum Values	**Thermionic Gun**	**RF Gun**	
		Nominal case	**Worst case failure**
Charge per bunch	175 pC	1 nC	Varies significantly
Bunches per beam pulse	1371	1	>1000
Total charge per beam pulse	240 nC	1 nC	2.3 μC
Beam pulse repetition rate	10 Hz	10 Hz	10 Hz
Average beam current	2.4 μA	10 nA	23 μA (ave)
Beam Energy	160 keV	7 MeV	7 MeV (max) 4 MeV (ave)
Average beam power	0.38 W	0.07 W	92 W
Beam transmission to chicane	50%	100%	0.5%[3]
Beam energy at chicane	60 MeV	67 MeV	64 MeV (ave)
Beam power at Chicane	71.3 W	0.67 W	7.4 W

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[1] D. Yeremian, *et al*, "NLCTA Injector Experimental Results", in Proc. IEEE Part. Accel. Conf., Vacouver, B.C., p.2852-4, (1997).

[2] D. Yeremian, NLCTA-Note #57, (1996).

[3] E. Colby, "Explosive Electron Emission Loss Calculations for E-163", memo sent to Heinz Vincke, (2004).

Beam transmission to spectrometer	100%	100%	20%
Beam power assuming E=500 MeV	594 W	5 W	11.5 W
Beam power assuming E=1.17 GeV	1390 W	11.7 W	27 W

As shown in Table 1, even the worst-case failure mode (the so-called explosive electron emission[1] (EEE) mode) results in significantly less beam power than for long-pulse operation of the thermionic gun at all locations except right out of the gun. The EEE-produced beam has very large emittances and energy spread and is rapidly lost in the first few meters of transport. It is worth noting that explosive emission is very damaging to the electron source (it results from the formation of a plasma on the cathode surface when too high a laser intensity is used; this plasma erodes the surface of the cathode), and will be actively avoided during operation.

The new gun will be integrated into the PPS system in a manner similar to the old gun. The high voltage charging supply for the modulator is powered through two redundant contactors which will be connected to the NLCTA PPS system. The high voltage supply will only be powered when the NLCTA enclosure is in No Access and all beam stoppers have been removed. Without rf, the gun cannot produce an electron beam or x-rays. [The laser hazard associated with the gun is handled by a separate Laser Safety System]. No changes to the present NLCTA shielding or BSOIC placement will be necessary to install the new gun.

It is expected that the gun will operate for 50-60 hours per week during the commissioning, then at least 1-2 weeks per month (40-50 hrs/week) thereafter, with usage depending on the evolving ILC and E-163 programs, and on the introduction of other experiments and users.

7 MeV Spectrometer Beamline

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A 72^{o} vertical bend dipole and short spur beamline will be installed immediately downstream of the gun, as shown in Figure 1. This spectrometer will direct the full photocurrent (10 nA/0.07W) at a 72 degree angle upwards towards the roof of the NLCTA. The beam will be fully stopped in a Faraday Cup made of 0.75" thick steel, backed by additional steel shielding as RP deems necessary.

[1] E. Colby, "Explosive Electron Emission Loss Calculations for E-163", memo sent to Heinz Vincke, (2004).

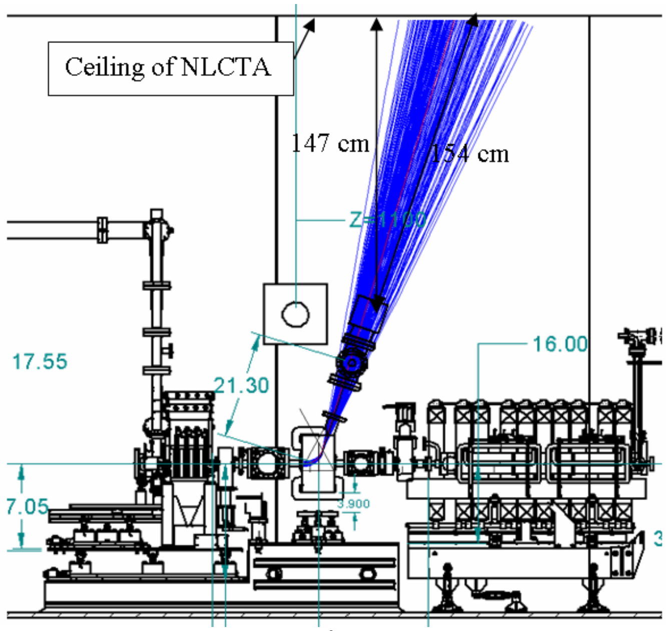

FIGURE 1. Elevation view of photo gun, showing 72° spectrometer and energy analysis beamline. Rays are 200 representative particles showing the EEE beam trajectory in the absence of any materials (e.g. spectrometer iron, dump, flanges, vacuum chamber, etc.)

In the worst-case scenario, the bend dipole is on when the EEE beam is produced (23 μA/92W). Since the EEE beam has a large energy spread, it is lost in a broad fan covering 64°-78° (99% of particles), shown in Figure 2 (left). Working downstream from the bend center of the spectrometer, the outgoing fan is shielded by the following items:

1. Spectrometer yoke: 1.5” thick, covering 77° to 127° above the beam axis
2. Spectrometer chamber exit flanges, 1.5” thick, covering 60° to 69.5° and 74.5° to 84°
3. Faraday cup beam dump, 0.75” thick, covering 69.5° to 74.5°
4. Spectrometer chamber wall, 0.25” thick, covering 51° to 10°
5. Beam tube presents significant material in the remaining angles

Figure 2 (right) shows that 7 MeV electrons range out in iron within 5 mm, meaning that the spectrometer vacuum chamber wall (6.35 mm) already presents sufficient material to stop the electrons.

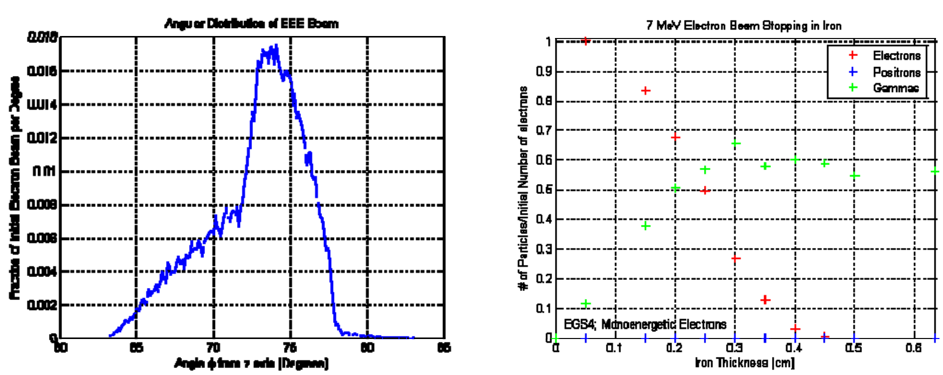

FIGURE 2: Angular distribution (left) of EEE beam at nominal spectrometer bend field, and range out of monoenergetic 7 MeV electrons (right) in elemental iron, from EGS4.

Request

I ask that Radiation Physics review our request to install the RF Gun at the NLCTA and work with us to establish and follow the proper approval procedure.

Cc: Siemann, R. H.
Noble, R. J.
Jobe, R. K.
Ross, M. C.
Khater, H.
Vincke, H.

11.1.4 July 27, 2005 New Electron Source at the NLCTA

SLAC MEMORANDUM **July 27, 2005**

Subject: ***New Electron Source at the NLCTA***

To: ***S. Rokni***

From: ***H. Vincke and H. Khater***

Cc:

We analyzed the request[1] from Eric Colby to replace the thermionic gun in NLCTA with a new photoemission gun. We conclude that the installation of the new gun does not pose any radiological hazard in the End Station B. The Radiation Safety Analysis of the New Electron Source at the NLCTA has been documented in a Radiation Physics Technical Note (RP-TN-05-12, July 15 2005). We recommend approving installation of the new gun.

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[1] SLAC memorandum from E. Colby, Installation of New Electron Source at the NLCTA, May 31, 2005.

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11.2 Experimental Hall Shielding Design

11.2.1 October 17, 2005 Radiation Safety Analysis of E-163 – Laser Acceleration of Electrons in Vacuum

SLAC RADIATION PHYSICS NOTE RP-05-24

October 17, 2005

Radiation Safety Analysis of E-163 - Laser acceleration of electrons in vacuum

H. Vincke and H. Khater

Radiation Protection Department, SLAC, MS 48,
2575 Sand Hill Road, Menlo Park, CA 94025

Abstract

The feasibility of laser based high gradient acceleration of charged particles has been demonstrated in the Laser Electron Acceleration Project ("LEAP") at Stanford Campus. E-163 experiment will continue research in that field by using the same technology installed in End Station B at the Stanford Linear Accelerator Center. In this note, the radiation safety analysis for E-163 is presented.

Radiation Safety Analysis of E-163 - Laser acceleration of electrons in vacuum

H. Vincke and H. Khater

1 Introduction

The E163 experiment will require two major changes to the Next Linear Collider Test Accelerator (NLCTA) from a radiation safety standpoint. First, the thermionic injector will be replaced by a laser-driven radiofrequency electron gun. Second, beam will be kicked out of the NLCTA by an extraction dipole and into a second shielded enclosure running parallel to the NLCTA, within which the E163 experiments will be conducted.

2 Radiation shielding criteria

In the shielding analysis that follows, the following criteria should be satisfied for normal and for mis-steered beam. Note, maximum credible beam power is equal to the mis-steered beam power and does not pose an additional concern.

Normal loss scenario:	< 1.0 mrem/h outside the enclosure but < 1000 mrem/y
	< 3 mrem/hr on the roof
Mis-steering scenario:	< 400 mrem/h outside the enclosure without any BCS devices

3 Description of modifications to the NLCTA facility

A concrete and steel shielding enclosure of approximately 600 square feet has been constructed immediately to the north of and sharing a common wall with the NLCTA enclosure, and will house the E163 experiment. The enclosure geometry is shown in Figure 1.

Four penetrations of 6” or less have been drilled through the NLCTA shielding walls to pass electron beam, rf, laser, and Cerenkov light. The penetration for the beam consists of a 6” diameter hole running 25.5^{o} to the NLCTA beamline, originating at the position of the Faraday Cup FARC1140 will be used for the extraction beamline. Two additional penetrations will connect the E163 shielding enclosure to a laser room. Steel and poly plugs are presently locked in place and marked as radiation protection items in the beamline-height penetration.

The electron source will be replaced by an s-band rf photoinjector, essentially identical to that presently operating at the GTF and planned for operation at the LCLS. The gun is a 1.5 cell microwave structure powered for ~2 μs at 10 Hz to a gradient of 120 MV/m or less. Electrons are generated by striking the rear surface of the gun cavity with UV light, and are then rapidly accelerated to 7 MeV with microwaves.

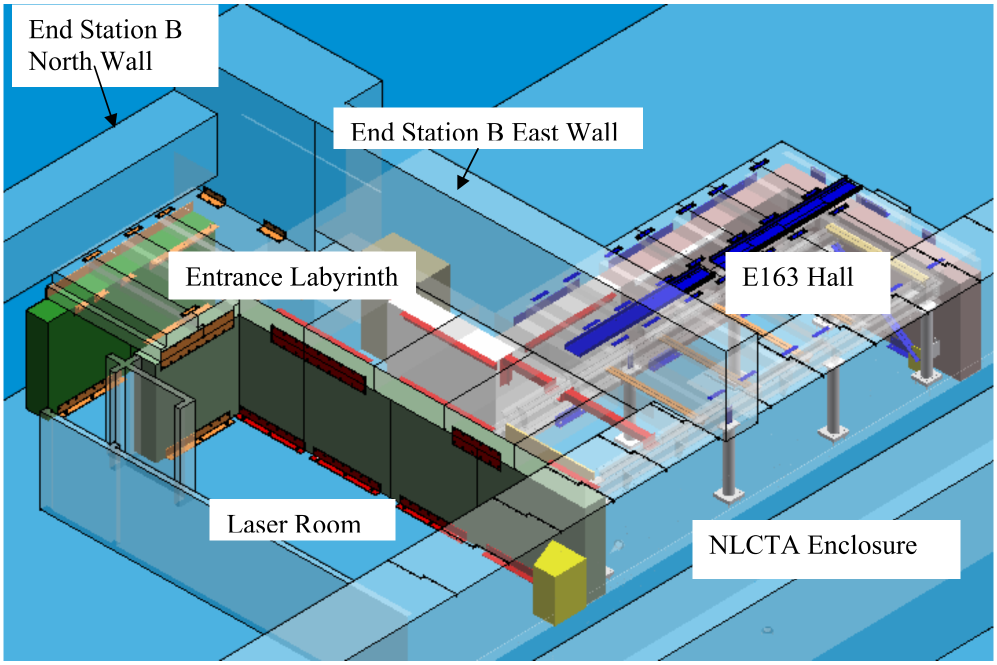

Figure 1: CAD sketch of completed E163 enclosure, viewed looking northeast. All walls and roof blocks are at least 24 inches of concrete. The wall separating the southeast corner of the laser room from the southwest corner of the shielding enclosure has an additional 2" of steel plate shielding.

4 Beam parameters and mode of operations

The facility will be operated either in "Tune-up", as is typical of the commissioning phase and much of the running phase and "Experiment" mode, when the experiment is taking data. Both modes are described below. The beam charge is controlled by a laser intensity striking the photocathode of the E163 gun. Note, that the maximum charge that can be emitted from the E-163–gun under normal running conditions is around 1nC.

4 .1 Description of "Tune up" Mode

For tune-up, the following charge and energy will be used: 60 MeV, 1 nC, 10 Hz (0.6 W). Tuning up usually requires that the beam intercepts with a screen, often for extended periods of time. Six screens are planned for the E163 beamline, see Figure 2.
Screens will be the most frequently used intercepting device during the tune-up. Two types are likely to be used: a phosphor screen, which typically is a metal plate coated with fluorescent material, and a fluorescent crystal. The former was modeled in the simulation simply as a 1 mm thick aluminum plate (X_o=24.01 gm/cc and X_o/ρ=8.9 cm), and the latter was made of a 1 mm thick $Y_3Al_5O_{12}$ for which the computed radiation length is X_o=16.11 gm/cc and X_o/ρ=3.54 cm.

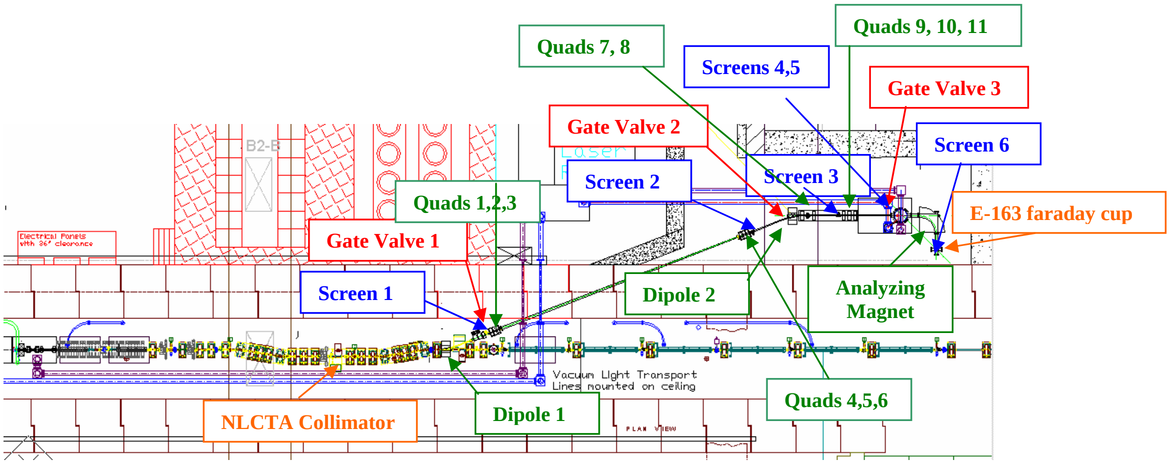

Figure 2: NLCTA and E163 enclosures, showing beamline component locations.

4.2 Description of "Experiment" Operation

Under normal experimental circumstances, ~60 MeV, **~50 pC**, 10 Hz (0.03 Watts) beam will exit the NLCTA enclosure via a +25.5^o bend dipole placed immediately downstream of the NLCTA chicane. The beam passes through the NLCTA shielding wall into the E163 enclosure, is bent –25.5^o, and is focused into the experiment vacuum chamber, where it interacts with the laser fields at the accelerator cell (fused silica X_o=27.05 gm/cc, X_o/ρ=12.3 cm). The beam is then bent –90^o in an energy analyzing spectrometer, strikes a thin (1 mm) Ce:YAG fluorescent screen, and passes on through and into a beam dump.
Finally, E-163 tests "short" laser accelerator structures during the E163 program, with expected energy gains of no more ~1 MeV total for the small group of particles that is successfully trapped in the accelerating mode, of order 10^5 or less. This means the accelerated beam will have a power of 10 Hz*10^5*e*61 MeV ~ 10 μW, and will not produce a significant increase in radiation compared to the unaccelerated case.

4.3 "Mis-steering" Beam Loss Scenarios

Equipment failure and operator error can lead to unintentional radiation production. Failure of the bend magnets and unintended closure of vacuum gate valves is considered here for illustrative purposes. Failure of a screen, causing it to be unintentionally inserted, has the same radiation distribution as for the tune-up cases above. A conservative value of 1 W total beam power has been used for the analysis.

5 Details about the Calculation

The 2003 version of the FLUKA Monte-Carlo code was used to determine the effective dose rates at the E-163 facility for normal and mis-steering condition as discussed later.

Co-ordinate system: The geometry is described in a right-handed orthogonal system with the vertical x-axis perpendicular to the beam axis. The z-axis is pointing in beam direction and the y-axis is horizontal and is pointing towards the right - looking along the beam direction.

Energy thresholds: For the simulation the threshold for particles transport was set to 0.5 MeV for electrons and positrons, Neutrons are followed down to thermal energies and for photons an energy cut-off threshold of 300 keV was used.

Biasing: Leading particle biasing was activated for all photons and all electrons. Further, the inelastic interaction length of photons was reduced by a factor of 0.02 in order to enhance the statistical significance of photonuclear reactions. Importance biasing was used in concrete shielding walls of E-163.

Scoring: The particle fluence was weighted during the scoring procedure by energy- and particle type-dependent conversion factors using the EWTMP option in FLUKA. This uses fits to the data from M. Pellicioni and the concept of the WORST value of effective dose for any body orientation.

6 Shielding requirements

The shielding of E-163 consists of 24 inch of concrete blocks and one 20 ft long 2 inch thick steel plate inside the west wall. Local shielding around beam line components will be added as described in the following paragraphs.

6.1 Tune up and Normal operation

For tune up and normal operation the following criteria had to be satisfied:

- ≤ 1.0 mrem/h outside the enclosure and ≤ 1000 mrem/y
- ≤ 3 mrem/hr on the roof

6.2 Beam loss scenarios

Beam loss scenarios considered in this note are described below (a summary table with dose rate outside the enclosure are given in Table I).

6.2.1 Dark Current

Field emission or “dark current” from the new photoinjector will be generated, and owing to its large energy spread and poor beam quality will be almost entirely lost in the first 2 meters of the NLCTA accelerator. Operational experience with existing guns suggests losses on the order of 1 mA or less. This loss distribution was calculated assuming 2.9 mA of dark current and is shown in Figure 3 (left graph) below, reproduced from reference [1]. The beam power loss distribution (right graph) is also shown, and gives some 83 mW total loss power per milliampere of dark current emitted. Beyond the narrow acceptance NLCTA collimator, there is negligible dark current transmission.

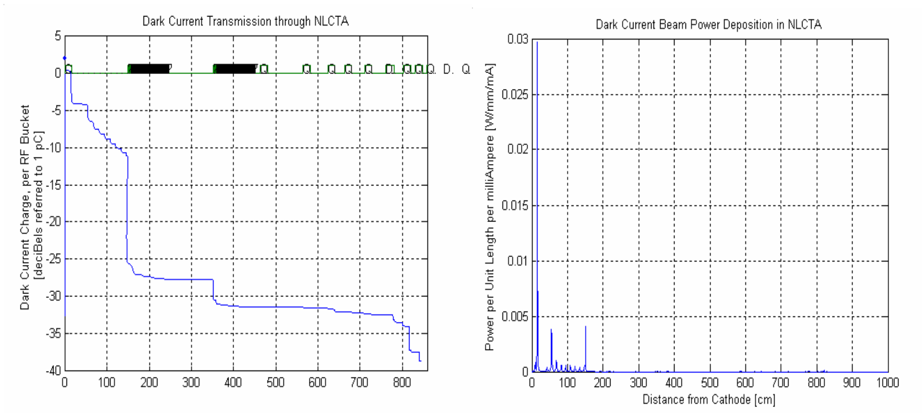

Figure 3: (Left) Dark current transmission through the NLCTA beamline, shown on a logarithmic scale, referenced to 1 pC (=0 dB) per rf bucket. A drop of 10 dB in transmission means that 90% of the current has been lost. (Right) Dark current beam power deposition in Watts per mA per millimeter of beam line. Note, that the extraction point to the E-163 enclosure is located at ~1600 cm.

6.2.2 NLCTA collimator loss

During tune up mode, the whole beam could be lost unintentionally on the NLCTA collimator. Based on SHIELD11 calculations, the existing six feet of concrete shielding of the NLTCA tunnel reduces the dose rate to 5 μrem/hr in the laser room it that case.

6.2.3 Beam intercepting screens

The tune up phase requires frequent insertions of one of the six screens into the beam line. Two different types of screens will be used; a phosphor screen, which typically is an aluminum plate coated with fluorescent material, and a fluorescent crystal Ce:$Y_3Al_5O_{12}$.

Part of the E-163 experimental setup was modeled within FLUKA to calculate the dose rate at the facility when beam intercepts with the screens, see Figure 4.

First calculations indicated that the dose rate outside the E-163 enclosure will considerable exceed the dose limit of 1 mrem/hr when a 70 MeV, 0.7 W electron beam is intercepting with the screen 3. The dose rate outside the enclosure of more was calculated to be 100 mrem/hr, see Figure 5. To reduce the dose rate either shielding along the beam line or a back-up stopper is required immediately downbeam of the screen. The latter one was preferred by E-163 Experimenters. The back-up stopper will be inserted always together with the screen. A sketch of the backup stopper is depicted in Figure 6.

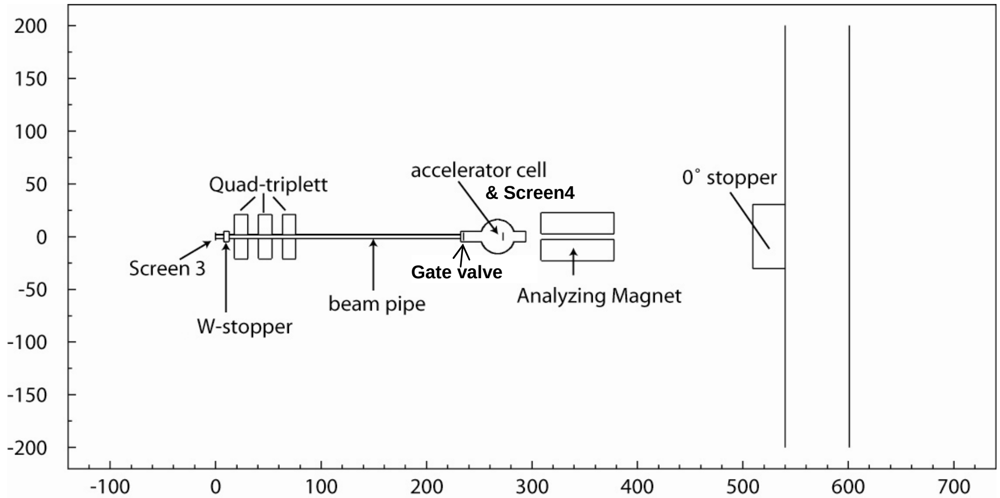

Figure 4: FLUKA geometry of beam components of E-163. Used for calculations when beam intercepts screen 3, 4 and accelerator cell. Units are in cm.

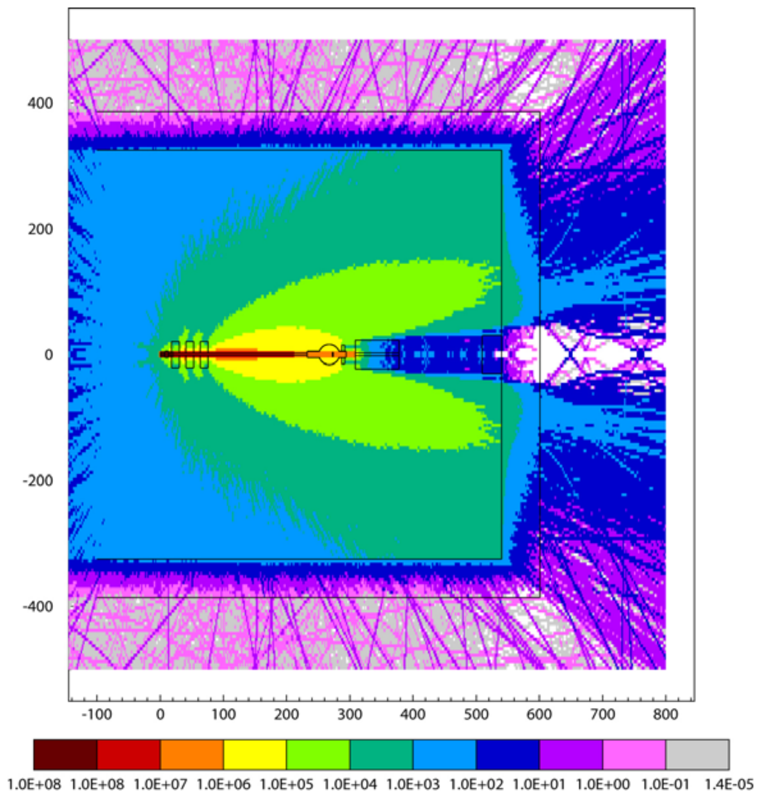

Figure 5: Total dose rate in mrem/hr at the E-163 enclosure when a 70 MeV, 0.7 W e-beam hits screen3 (1 mm $Y_3Al_5O_{12}$).

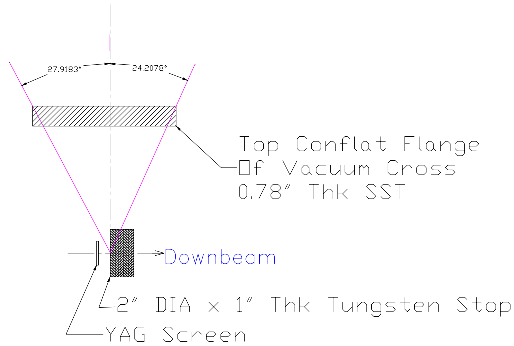

Figure 6: Ce:YAG Screen and Tungsten Stop with an iron shield on top. Backstop shield is required for screens 2 and 3 only.

The backup solution, screen plus tungsten-stopper, reduces the forward dose significantly but also increases the dose rate perpendicular to the beam line from 0.1 mrem/hr to 2.0 mrem on the side (Figure 7). On the roof the dose values goes up to 4.6 mrem/hr (shorter distance) – Figure 8. Nevertheless, as discussed later, mis-steering studies require 2" of steel on the north side which reduces the dose rate below 0.7 mrem/hr. The screens are placed inside a vacuum cross which has a 0.78" thick steel flange on top. This reduces the dose rate on the roof to 3 mrem/hr.

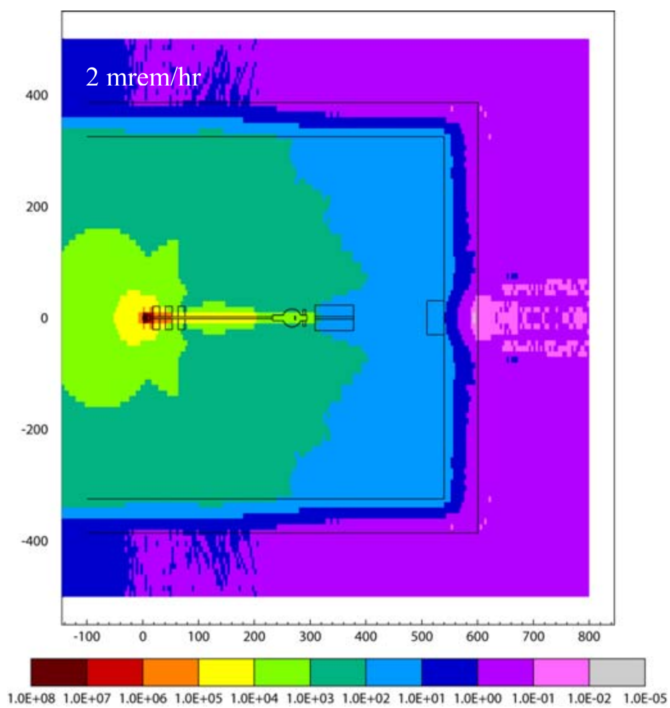

Figure 7: Plan view - Dose rate in mrem/hr at the E-163 enclosure when a 70 MeV, 0.7 W e-beam hits screen 3 (1 mm $Y_3Al_5O_{12}$) with tungsten back shield (2 inch diameter and 1 inch thick).

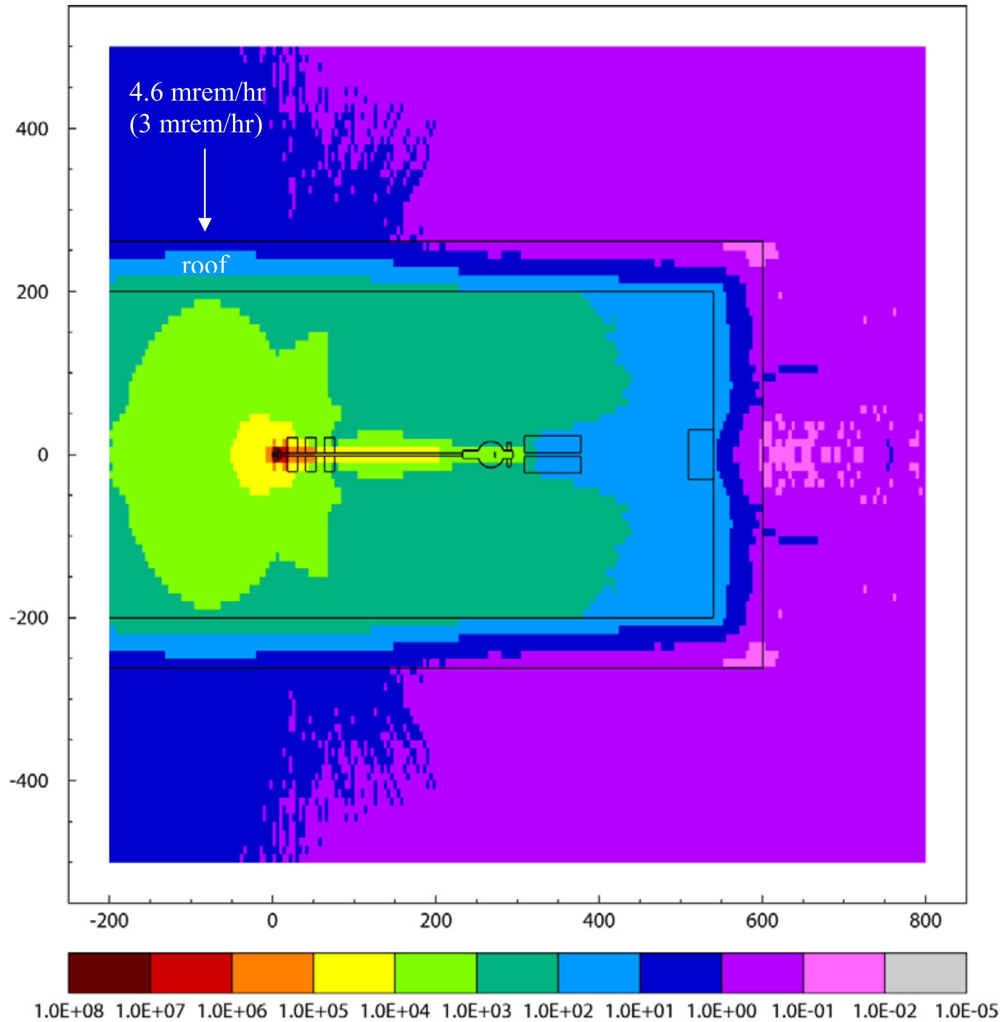

Figure 8: Elevation view - Dose rate in mrem/hr at the E-163 enclosure when a 70 MeV, 0.7 W e-beam hits screen 3 (1 mm $Y_3Al_5O_{12}$) with tungsten back shield (2 inch diameter and 1 inch thick). The value in parenthesis is the dose rate with 0.78" thick steel flange on top of the tungsten shield.

The FLUKA geometry for simulating intercepting of beam with screen 2 is shown in Figure 9. The dose rate distribution at the facility when a 70 MeV 0.6 W e-beam intercepts with screen 2 is shown for all particles, photon and neutron separately in Figure 10 to 12. It can be seen that, the dose rate outside the enclosure is always below the limit of 1 mrem/hr. At the E-163 entrance maze a dose rate was calculated to be much lower than 1 mrem/hr namely 3 only μrem/hr.

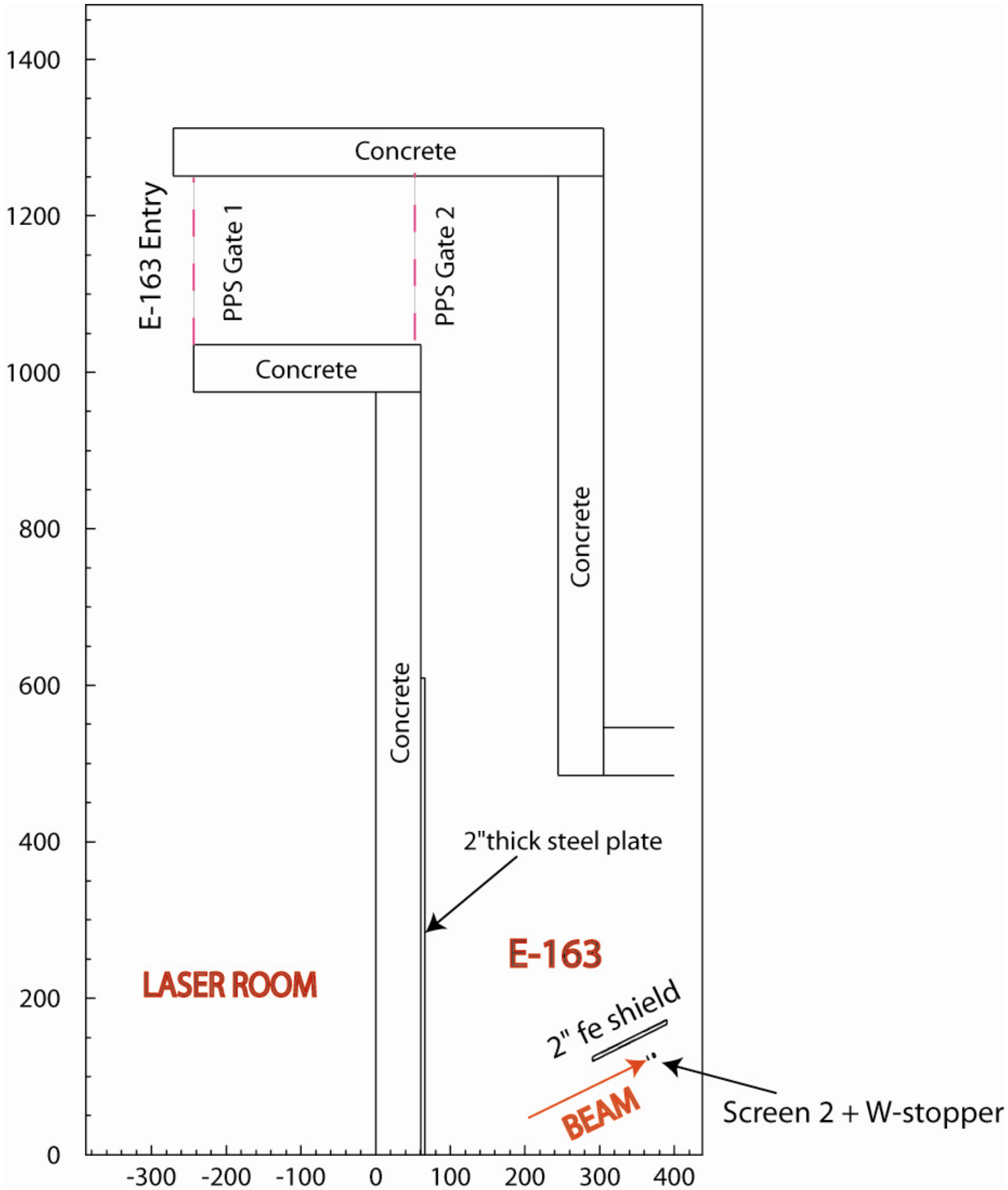

Figure 9: FLUKA geometry used to determine dose rates at the E-163 facility when beam intercepts with screen 2. Units are in cm.

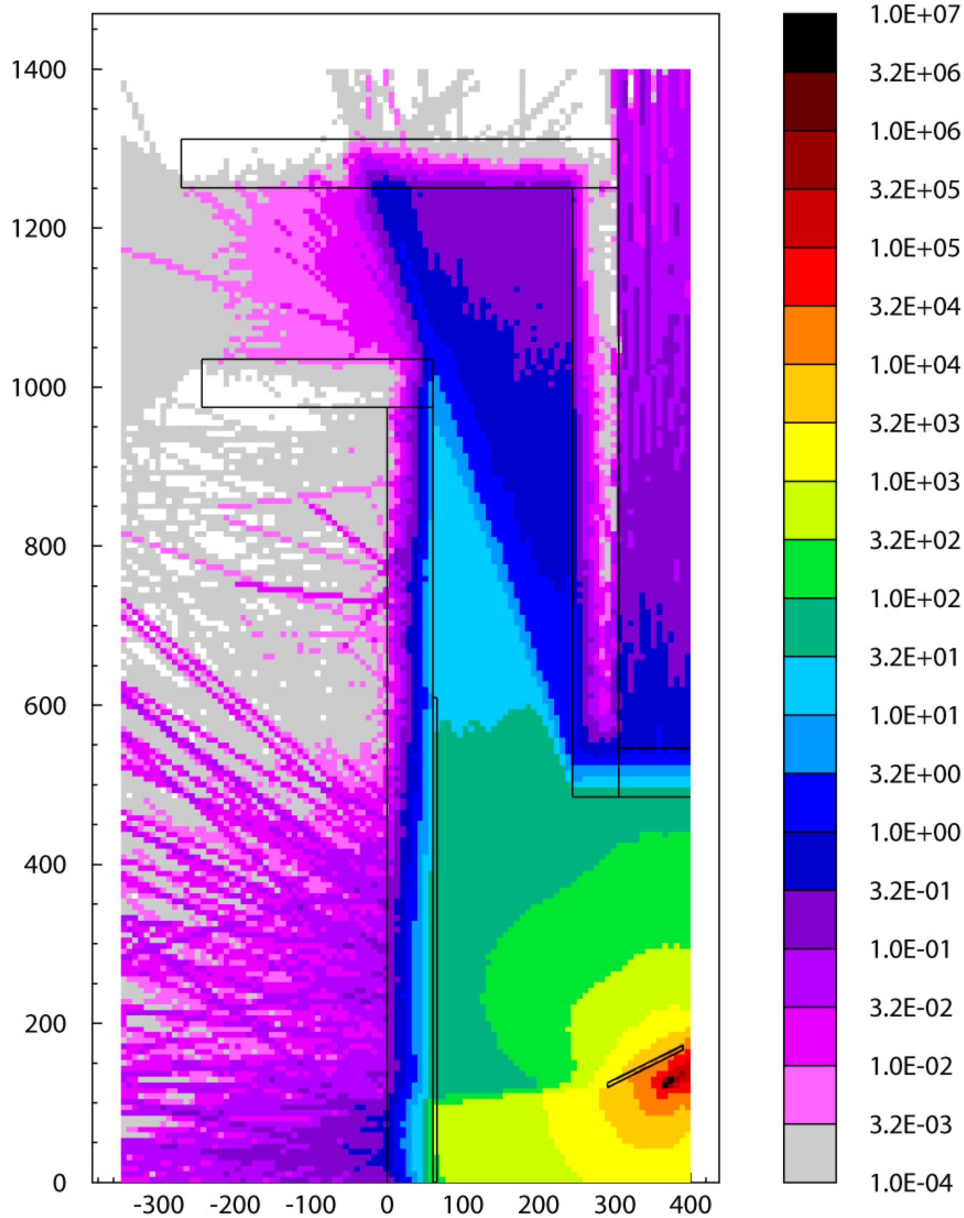

Figure 10: Total dose rate in mrem/hr - Beam intercepting with screen 2. A tungsten back up shielding is located behind the screen.

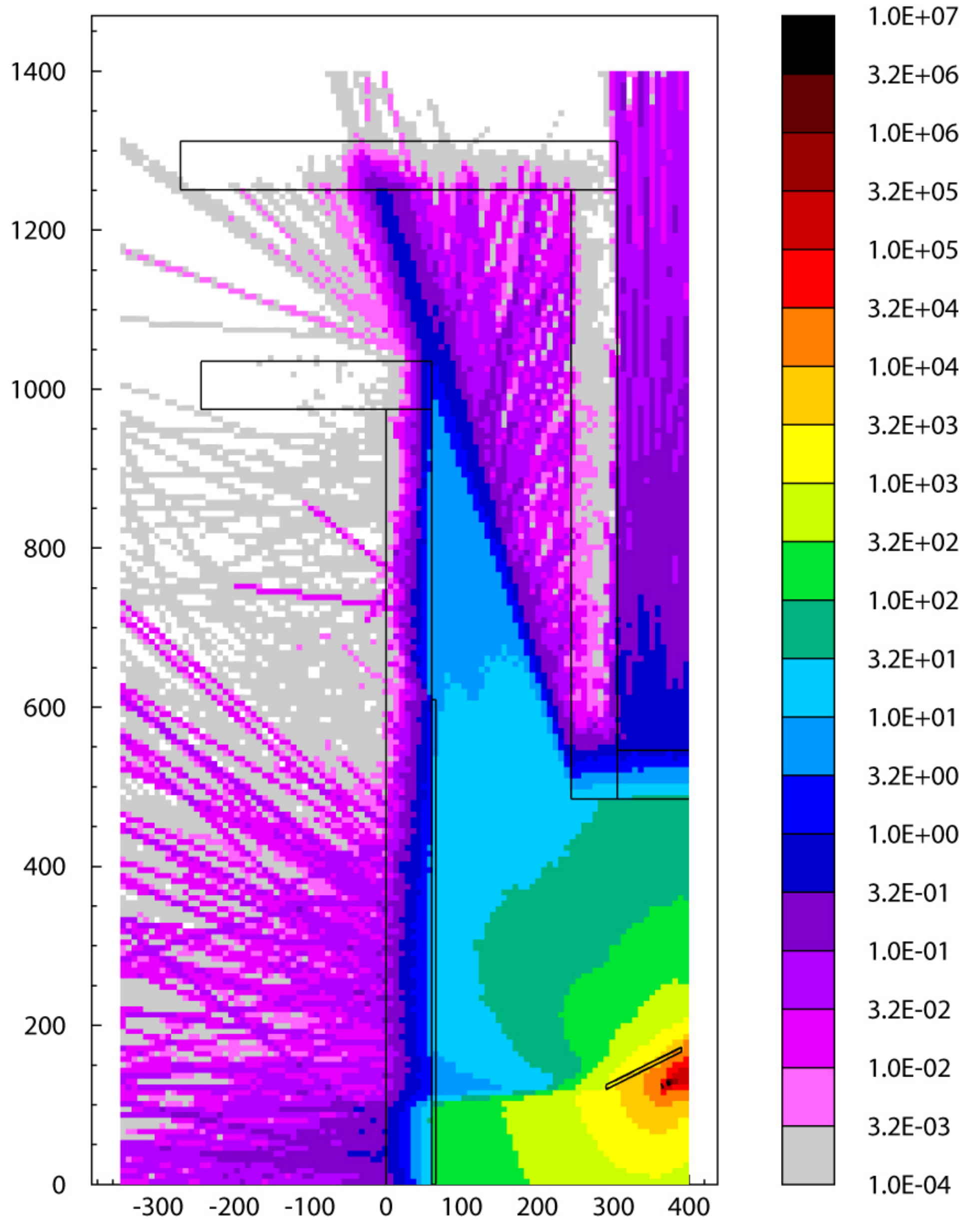

Figure 11: Photon dose rate in mrem/hr - Beam intercepting with screen 2. A tungsten back-up shielding is located behind the screen.

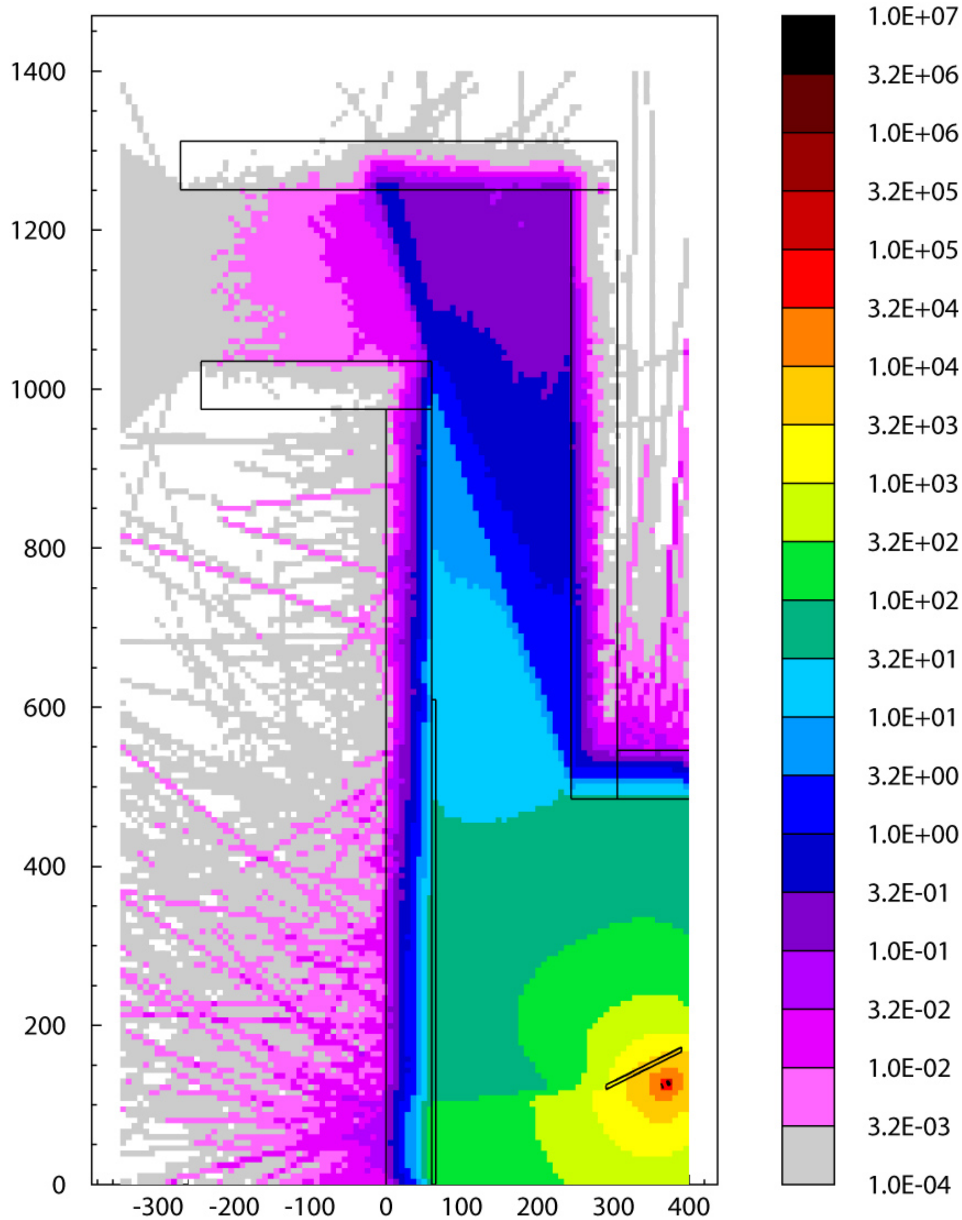

Figure 12: Neutron dose rate in mrem/hr - Beam intercepting with screen 2. A tungsten back-up shielding is located behind the screen.

Interception of a 70 MeV, 0.6 W beam with screen 4 and the accelerator cell was also simulated with FLUKA in details. For screen 4 and 5 a tungsten backup shield is not required. Figure 13 shows the components as implemented into the FLUKA geometry. In a first set of calculations electrons and positrons reaching the analyzing magnet were just discarded. It turned out that detailed transport of charged particles through the magnetic field is necessary to identify the required shielding configuration at 0-degree correctly.
Total equivalent dose rates at the enclosure is shown in Figure 14. Contribution to the dose from electrons, positrons, photons and neutrons are given in Figures 15-18, separately. It can be seen that a bulk part of positrons and neutron are actually generated by interaction with the analyzing magnet and the main dump and not be interaction with the screen it self.

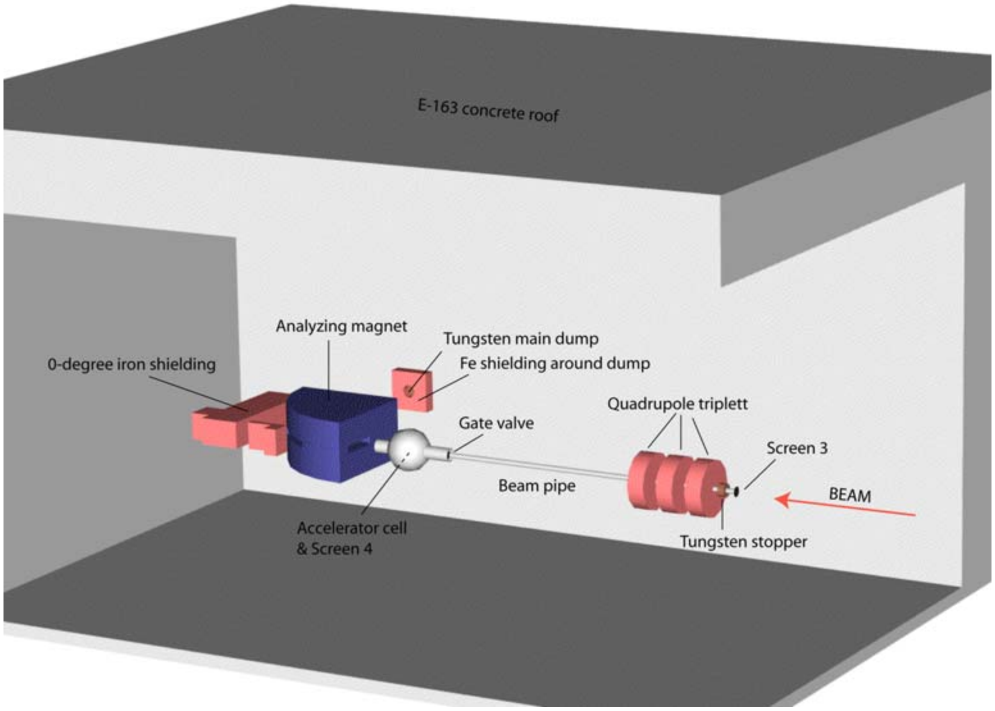

Figure 13: FLUKA geometry

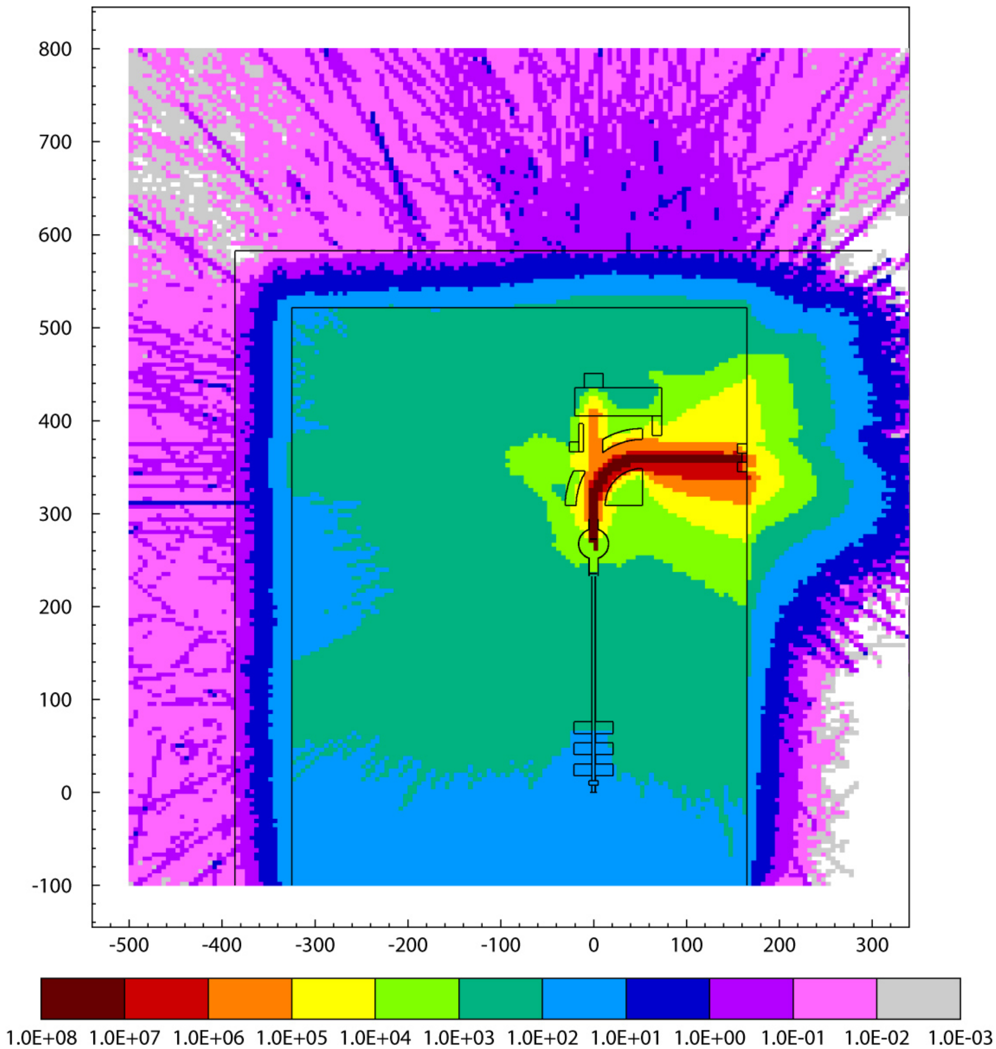

Figure 14: Total dose rate in mrem/hr at the E-163 enclosure when a 70 MeV e-beam (0.6W) intercepts screen 4.

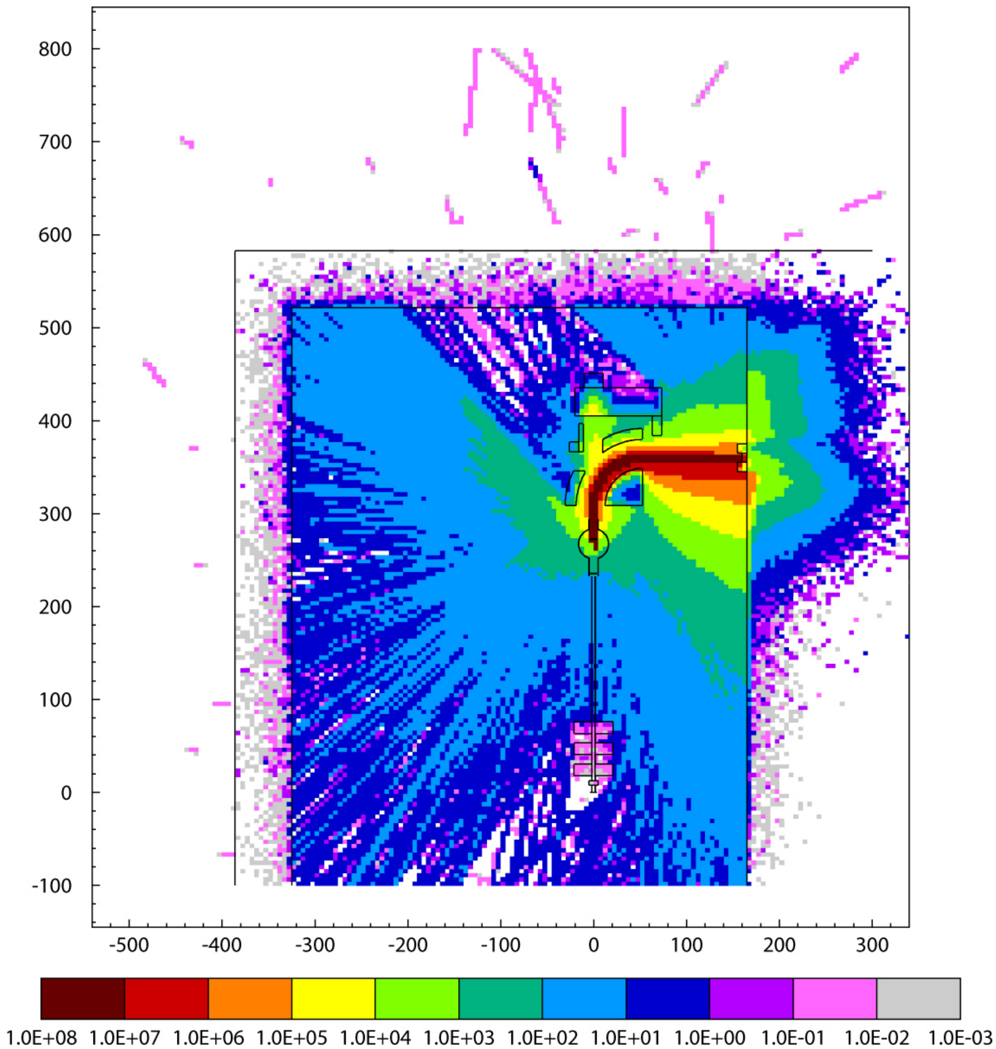

Figure 15: Electron dose rate in mrem/hr at the E-163 enclosure when a 70 MeV e-beam (0.6W) intercepts screen 4.

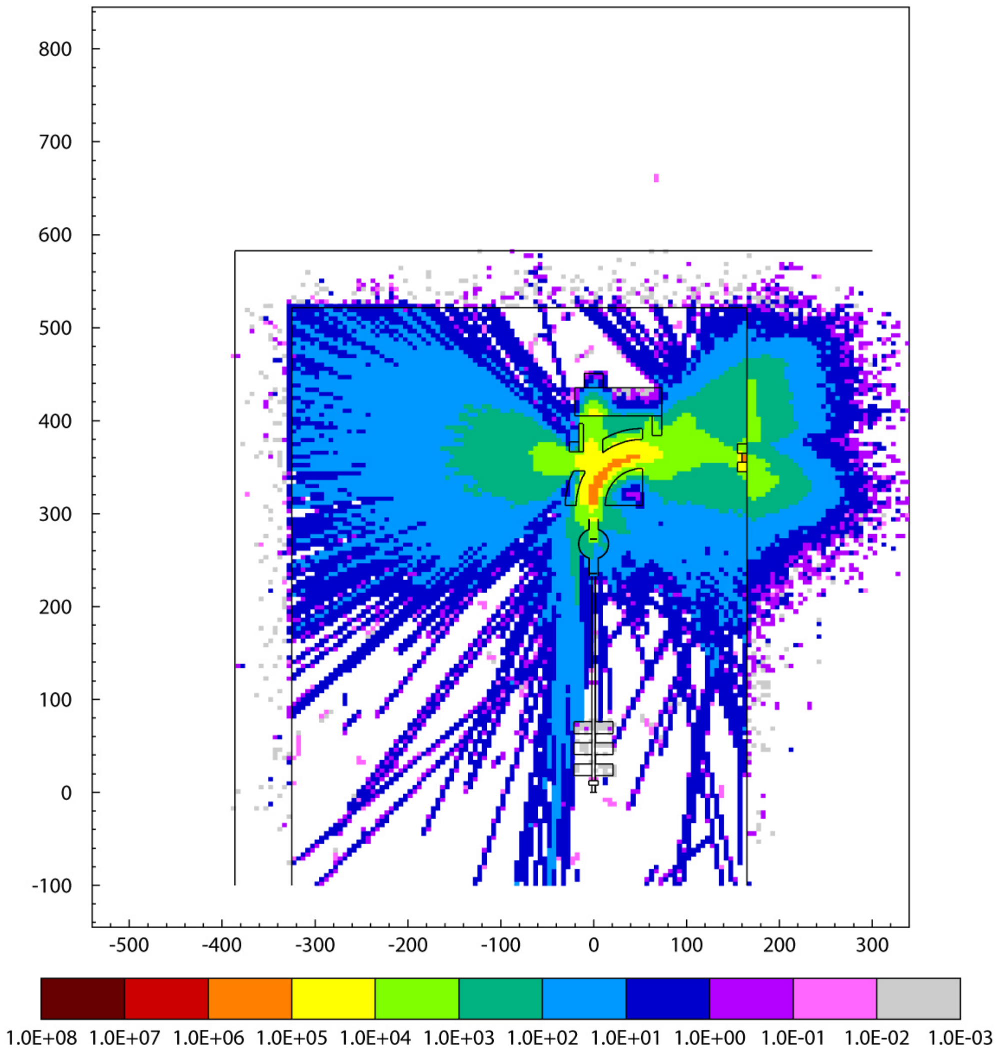

Figure 16: Positron dose rate in mrem/hr at the E-163 enclosure when a 70 MeV e-beam (0.6W) intercepts screen 4.

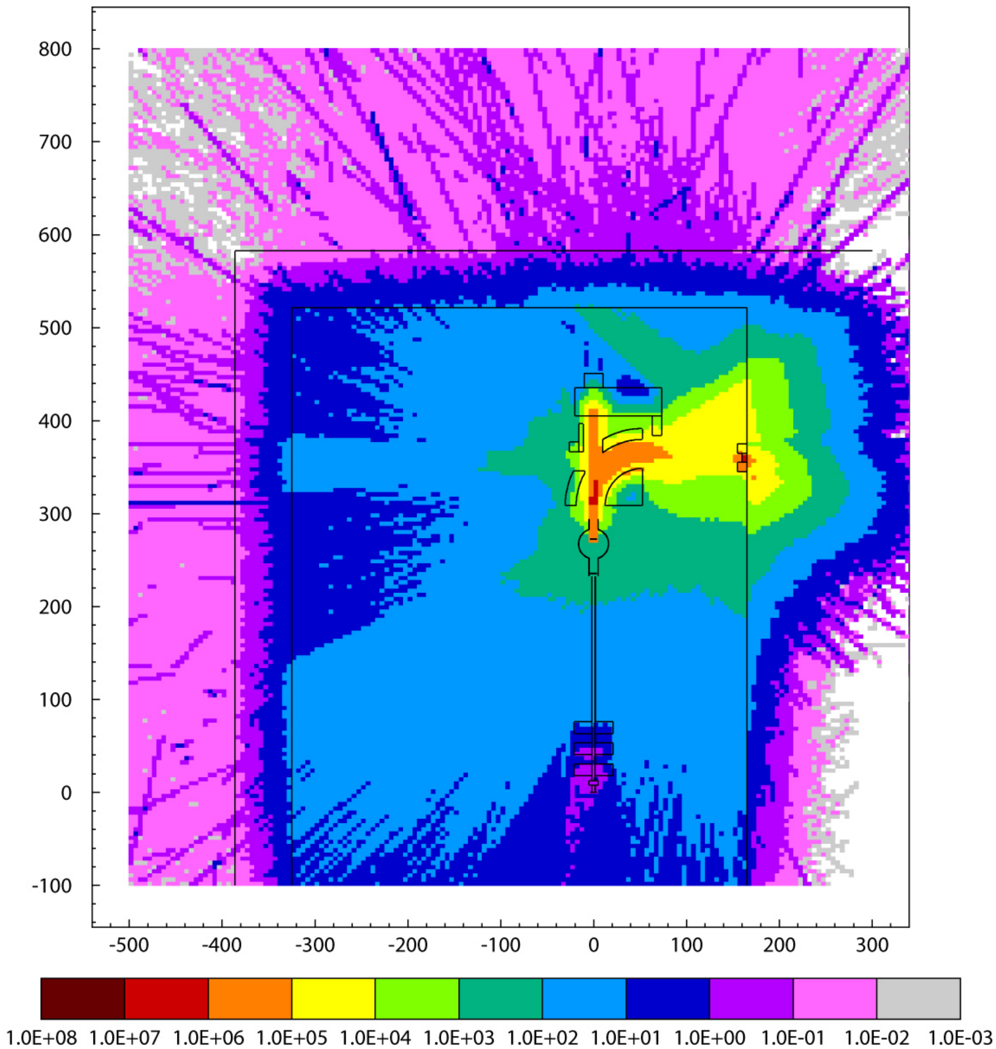

Figure 17: Photon dose rate in mrem/hr at the E-163 enclosure when a 70 MeV e-beam (0.6W) intercepts screen 4.

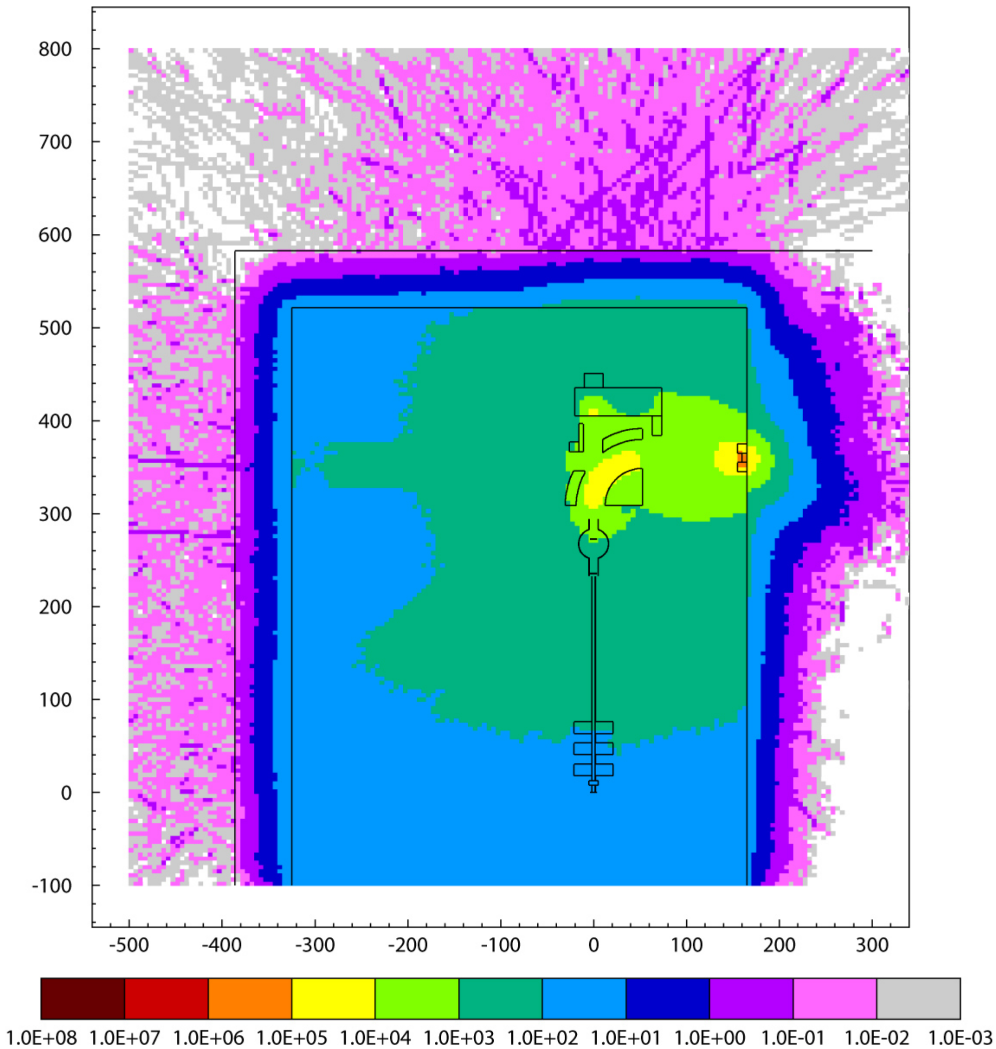

Figure 18: Neutron dose rate in mrem/hr at the E-163 enclosure when a 70 MeV e-beam (0.6W) intercepts screen 4.

6.2.4 Accelerator Cell

During normal operation a 30mW electron beam can intercept with the accelerator cell (fused silica X_o=27.05 gm/cc, X_o/ρ=12.3 cm). As shown in Figure 19, the dose rate outside the facility is below the limit of 1 mrem/hr.

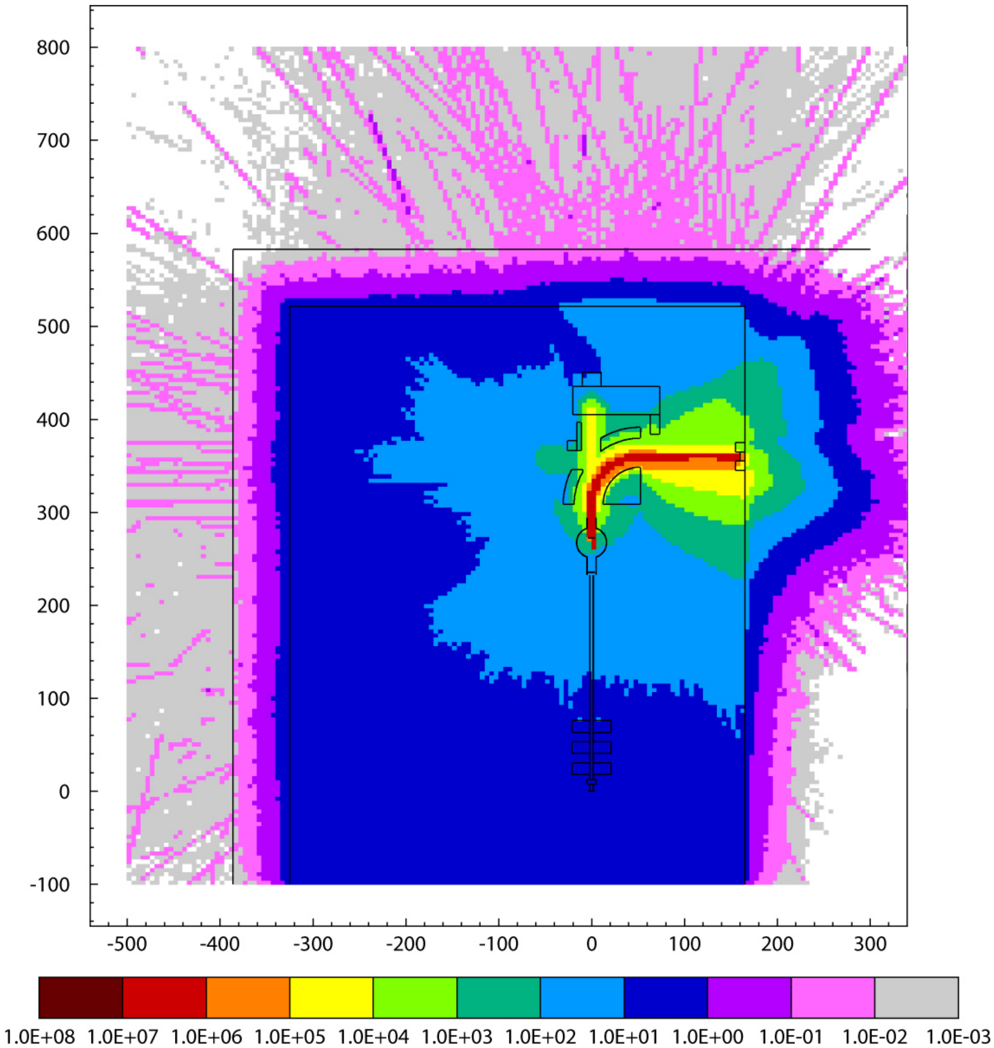

Figure 19: Dose rate in mrem/hr at the E-163 enclosure when a 70 MeV e-beam (0.03W) intercepting with the accelerator cell.

6.2.5 Screen 6 and Faraday cup after screen 6

The faraday cup, a tungsten cylinder 2" thick by 3.8" diameter, can be inserted into the beam line. Calculations indicated that shielding on the right side on the Faraday cup is required in this case to reduce the dose rate to the allowed limit of 1 mrem/hr. The shielding consists of 2 iron shielding blocks as depicted in Figure 20. The FLUKA geometry is shown in Figure 21 and the dose rate distribution at the enclosure in Figure 22.

For screen 6, a tungsten back-up stopper is not required. The dose rate outside the E-163 concrete east wall is below 1 mrem/hr when the beam intercepts with the screen, see Figure 23.

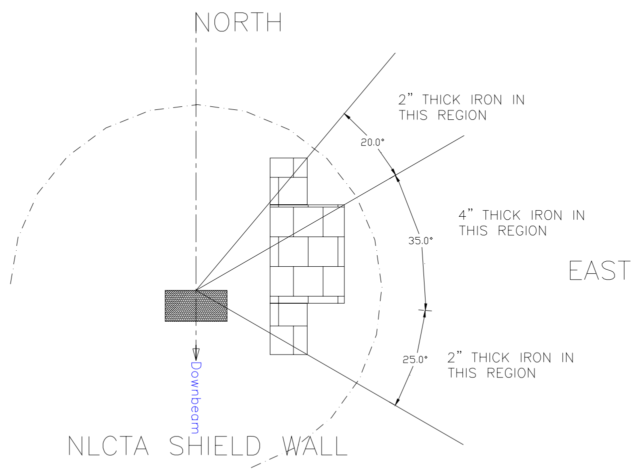

Figure 20: Faraday cup east shielding wall requirements. Wall height coverage 45 degrees up and 25 degrees down (shadows east wall floor to ceiling).

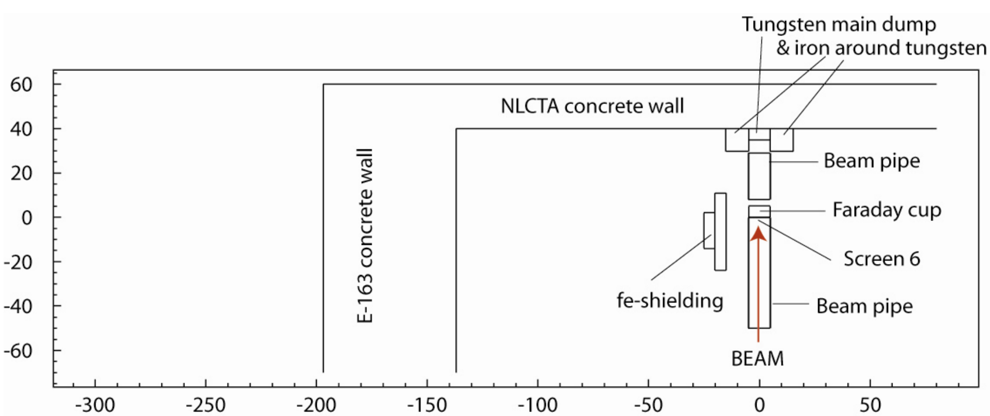

Figure 21: FLUKA geometry

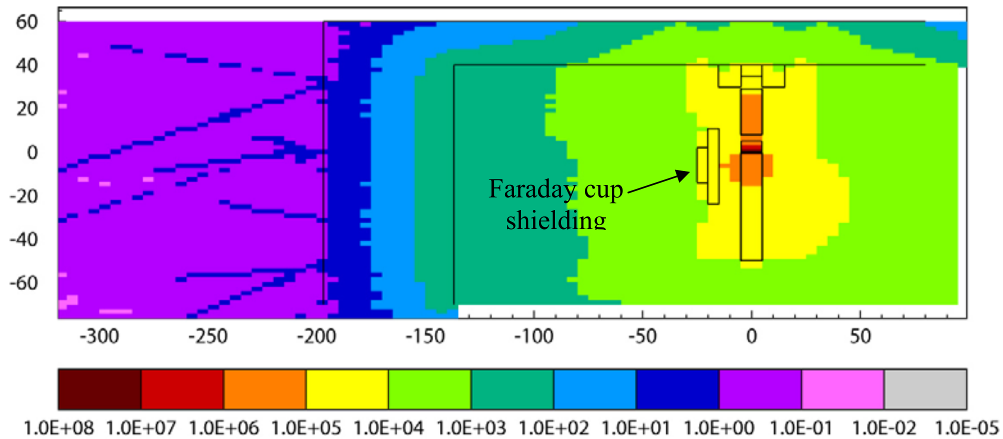

Figure 22: Dose rate in mrem/hr at the E-163 enclosure when a 70 MeV, 0.6 W e-beam hits E-163 Faraday cup

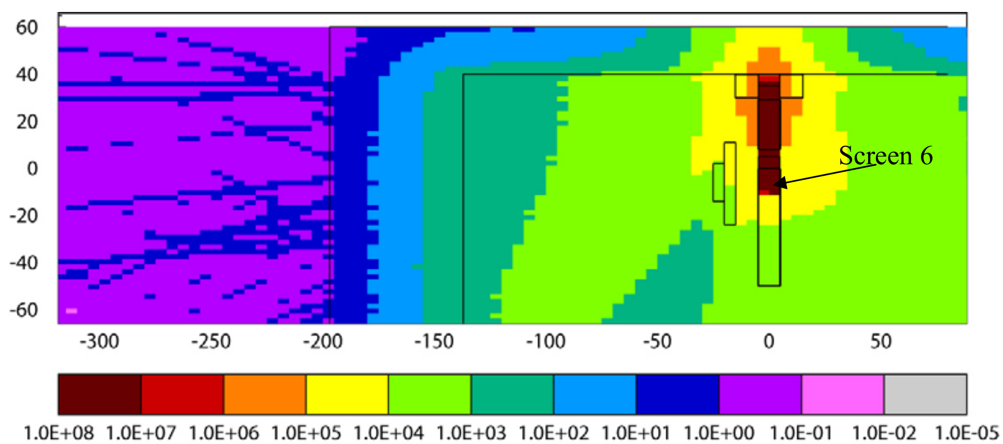

Figure 23: Dose rate in mrem/hr at the E-163 enclosure when a 60 MeV, 0.6 W e-beam intercepts with screen 6

6.2.6 Main dump

The main dump of the E-163 facility consists of a 2” diameter, 2” long tungsten stopper that is surrounded by an iron plate as shown in Figure 24. Dose rate at the enclosure when a 0.6 W 70 MeV electron beam is send to the dump is given in Figure 25.

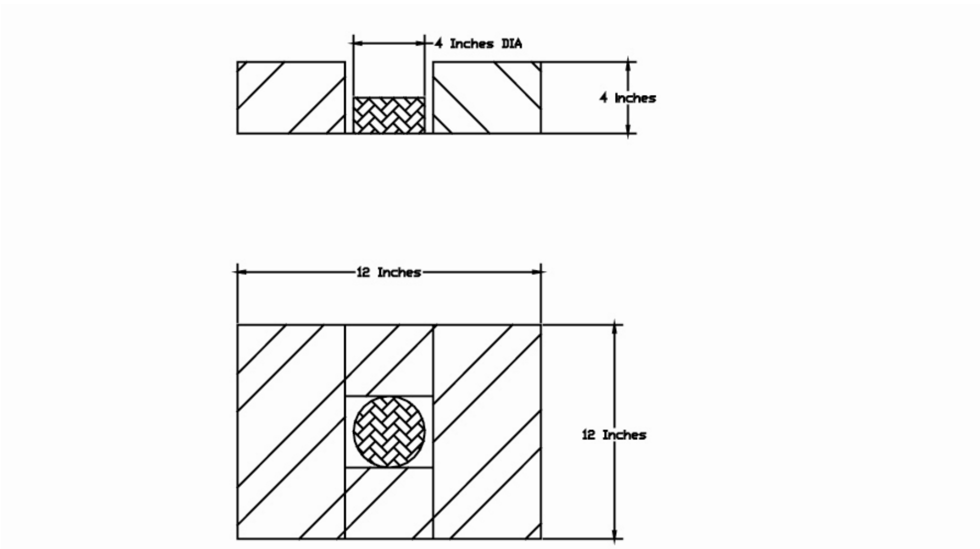

Figure 24: E-163 main dump design: A 4” diameter tungsten dump is surrounded by 12” of steel.

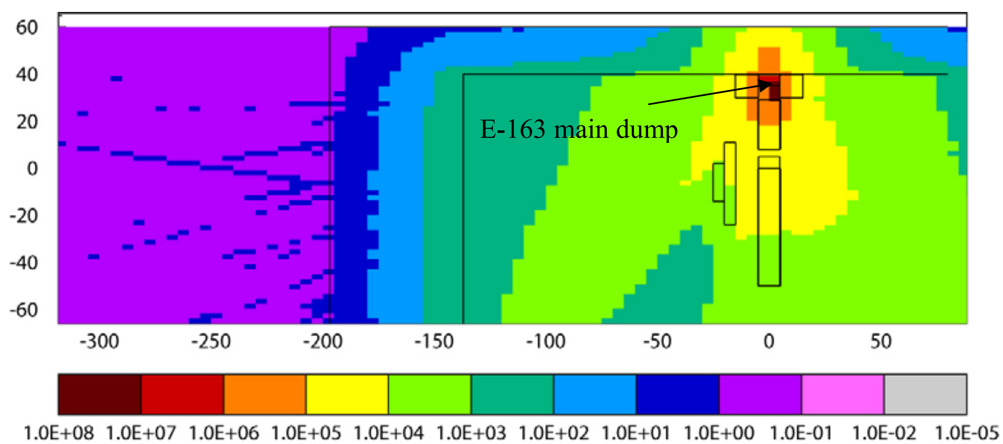

Figure 25: Dose rate in mrem/hr at the E-163 enclosure when a 70 MeV, 0.6 W e-beam is send to the main dump.

6.2.7 Penetrations

Two 4” diameter penetrations will be drilled through the West wall of the E-163 concrete enclosure to the laser room. The holes will be at a height of ~ 2.5m. The dose rate in the laser room at the penetration was calculated as 0.24 mrem/hr - source term at the opening inside the enclosure is 54 mrem/hr calculated with FLUKA and an attenuation factor obtained from [2] of 4.4×10^{-3}.

Two 4” diameter holes drilled near ceiling height and running 90^o to the NLCTA beamline will be used for optical transport vacuum tubes. The expected dose rate in the laser room due to 0.6 W, 60 MeV electrons hitting the NLCTA collimator is <0.03 mrem/hr.

6.2.8 Summary of beam losses during “normal running conditions

Table I: Summary of beam power losses during “normal running conditions

	Experiment Mode **60 MeV, 50 pC, 10 Hz** **30 mW** **Dose rate limit : 1 mrem/hr**	**Tune-up Mode** 60 MeV, 1 nC, 10 Hz 0.6 W *Dose rate limit :* ***1 mrem/hr***	**Dose rate in mrem/hr** [1] outside E-163 enclosure - except roof	**Dose rate in mrem/hr** [1] outside E-163 enclosure - on the roof
Duration	**500 hours/year**	**500 hours total**		
Dark Current Loss	240 mW in first 2 m of NLCTA injector		Negligible	Negligible
NLCTA collimator Loss	30 mW	Up to 0.6 W	0.005*	<0.005*
	Intentional Beam Loss Scenarios			
Screen 2		0.6 W	0.32	3
Screen 3		0.6 W	0.7	3
Screen 4		0.6 W	0.9	0.3
Screen 5		0.6 W	0.9	0.3
Screen 6		0.6 W	0.9	0.5
Accelerator Cell	30 mW		0.05	<0.05
Bend-Line Dump		0.6 W	0.9	0.5

* Shield11

6.3 Mis-steering

Mis-sterring cases have been analyses for the following cases. The dose rate limit is 400 mrem/hr.

6.3.1 Quads short at start of extraction line

A 1 watt beam loss on the beam chamber immediately adjacent the SW corner of the laser room was assumed. Calculations based NCRP-51 give a dose rate of 3 mrem/hr in the laser room.

6.3.2 Dipole 2 fails or is set incorrectly

A 1 watt beam loss on beam chamber near dipole 2 would result in a dose rate outside the concrete wall of 100 rem/hr, see Figure 26, which is 250 times over the limit for mis-steering and accident. A two inch thick shielding parallel to the beam pipe (i.e. actual path length is 4.6 inch) reduces the dose rate to values below the limit of 400 mrem/hr (Figure 27).

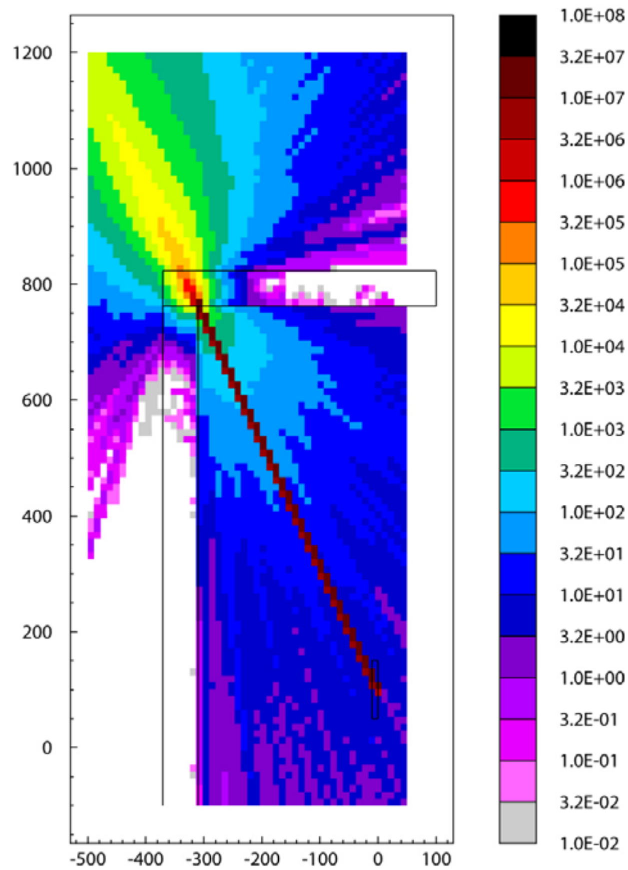

Figure 26: Dose rate in mrem/hr – Dipole 2 fails and beam hits NE corner of E-163 concrete enclosure.

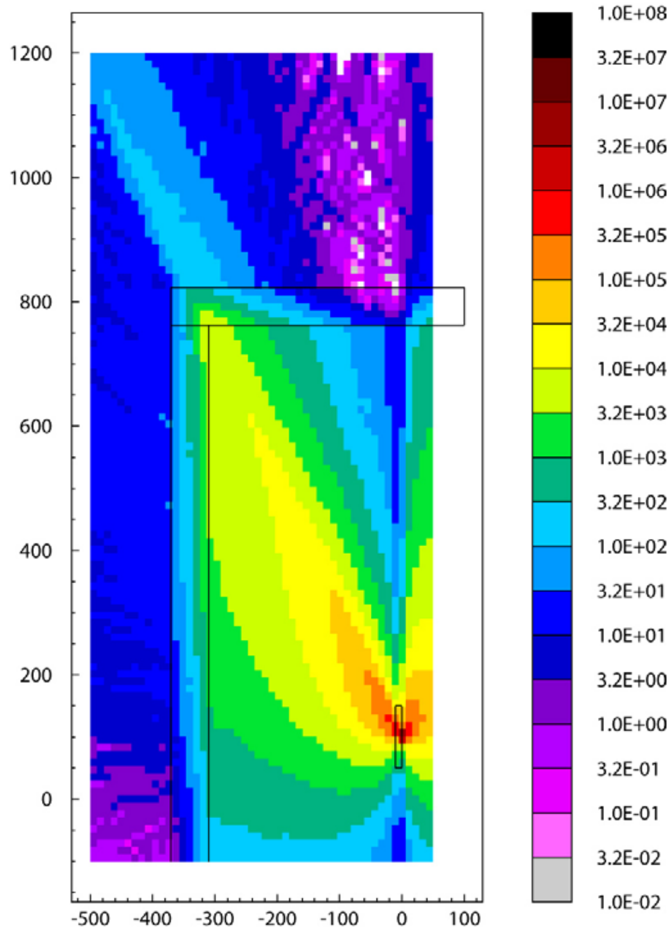

Figure 27: Dose rate in mrem/hr – Dipole 2 fails and beam hits a 2” iron shield (actual path length 4.6 “).

6.3.3 Spectrometer failure
In the case of a spectrometer failure, the beam will be stopped in a thick iron stopper, located at the 0-degree line after the spectrometer. Three different cases were studied.

- A 1 W 70 MeV Beam hits iron shielding behind spectrometer magnet.
- A 1 W 70 MeV beam intercepts with screen 4 or 5 during magnet failure.
- A 1 W 70 MeV beam intercepts with gate valve #3 (7 mm stainless steel) during magnet failure

The dose rate for these cases are depicted in figures 28-30. The case when the beam intercepts with the accelerator cell and the spectrometer magnet fails is similar to the case when screen 4 or 5 is intercepting with beam.

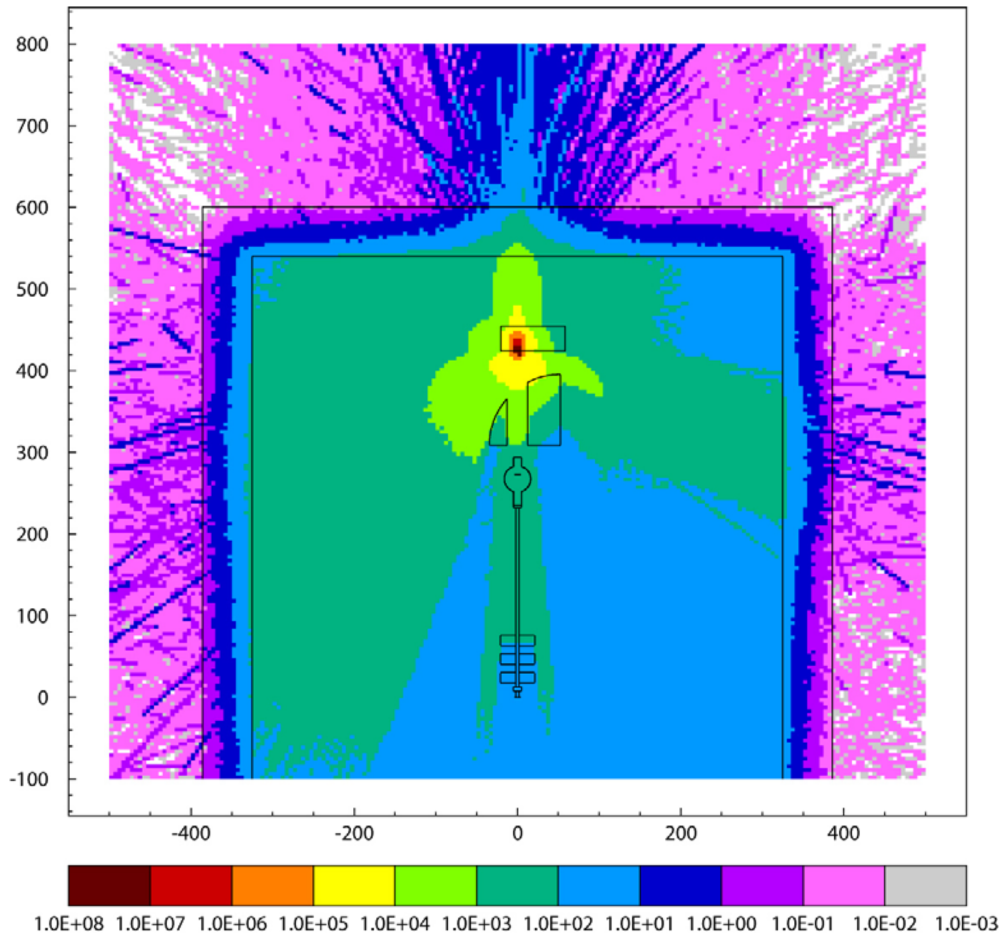

Figure 28: Dose rate in mrem/hr. Spectrometer failure - 1 Watt, 70 MeV beam strikes on a 12" thick iron shielding behind the spectrometer magnet.

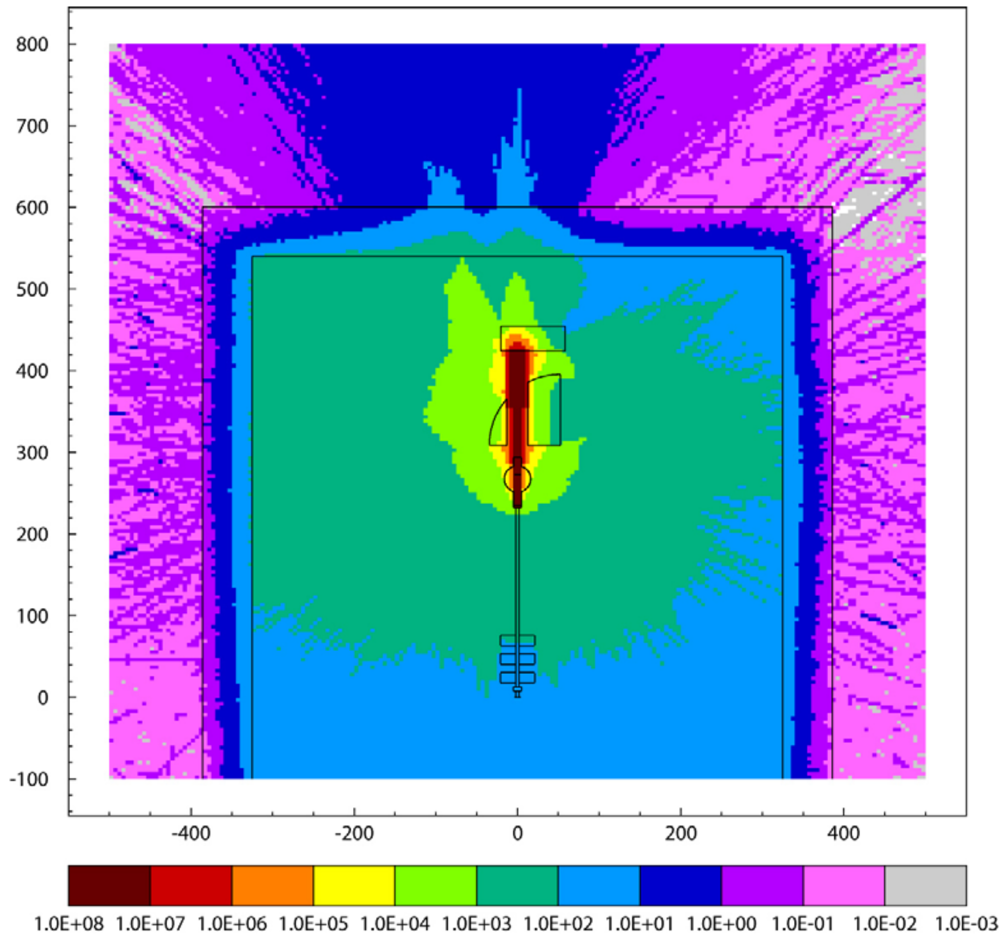

Figure 29: Dose rate in mrem/hr - A 1W, 70 MeV beam intercepts with screen 4 and the spectrometer magnet fails.

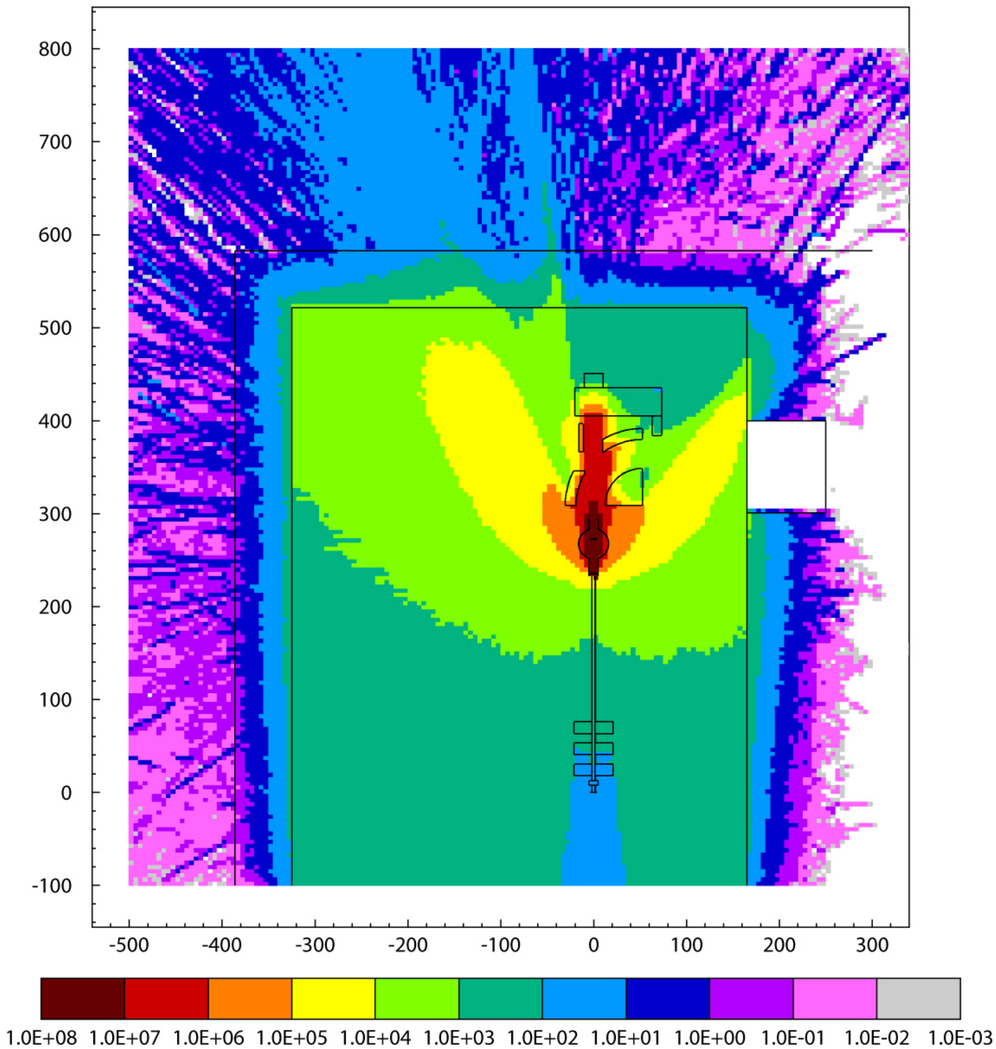

Figure 30: Dose rate in mrem/hr - A 1W, 70 MeV beam intercepts with a 7 mm thick stainless steel gate valve and the spectrometer magnet fails.

6.3.4. Gate Valve

Next, a 1 W 70 MeV beam intercepting with gate valve #3 (7 mm stainless steel) without a magnet failure of the spectrometer was studied. The dose rate outside the enclosure, as shown in Figure 31, is below 100 mrem/hr.

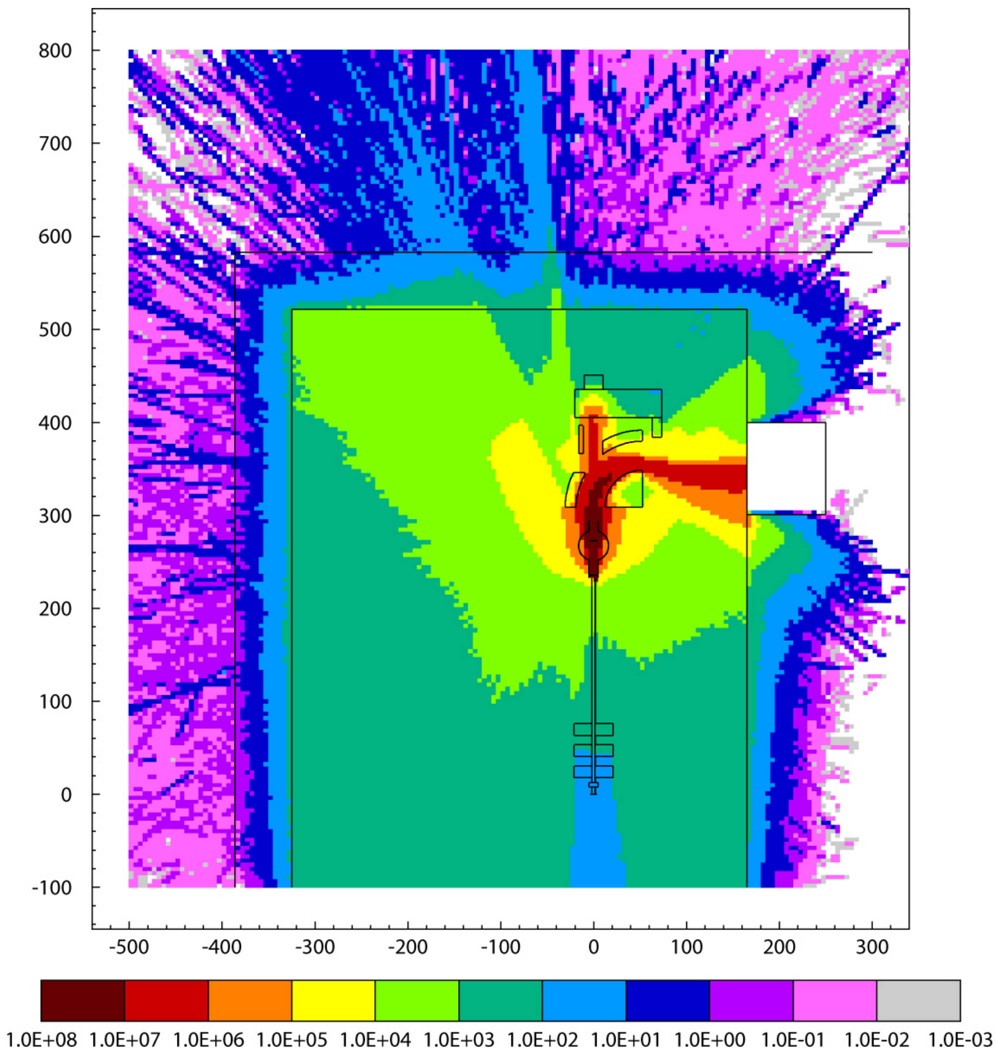

Figure 31: Total dose rate in mrem/hr - A 1W, 70 MeV beam intercepts with a 7 mm thick stainless steel gate valve; magnetic field on. Note, the main dump region was defined as Blackhole.

6.3.5 Beam stoppers in NLCTA

Two 4 inch long Tungsten stoppers will be placed inside the NLCTA tunnel approximately 4 feet away from the extraction point of the NLCTA line, see Figure 32. When the stoppers are inserted the bending magnet in the NLTCA beam line will be disabled and no beam will be kicked out onto the W-stoppers. As it can be seen in Figure 33 and Figure 34, the dose rate inside the E-163 enclosure is still below the 400 mrem/hr limit if the magnets are incidentally extracting beam into the E-163 extraction line.

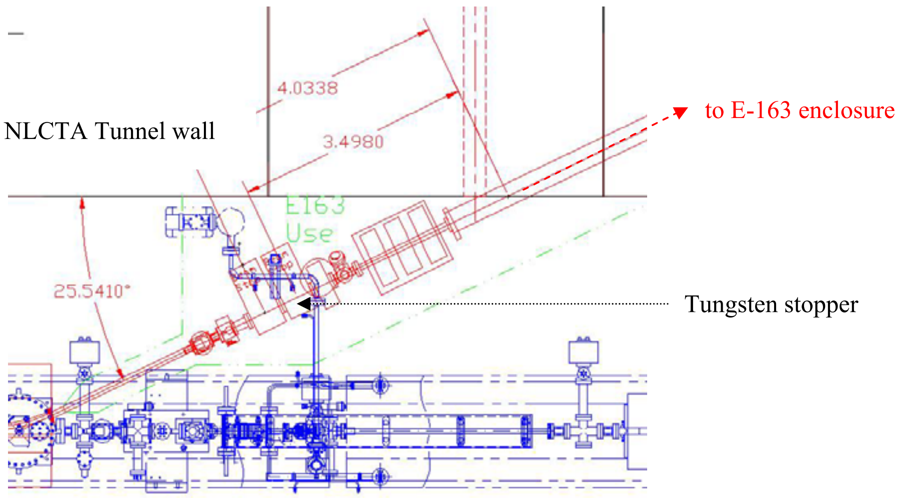

Figure 32: Location of Tungsten Stoppers in the NLCTA tunnel

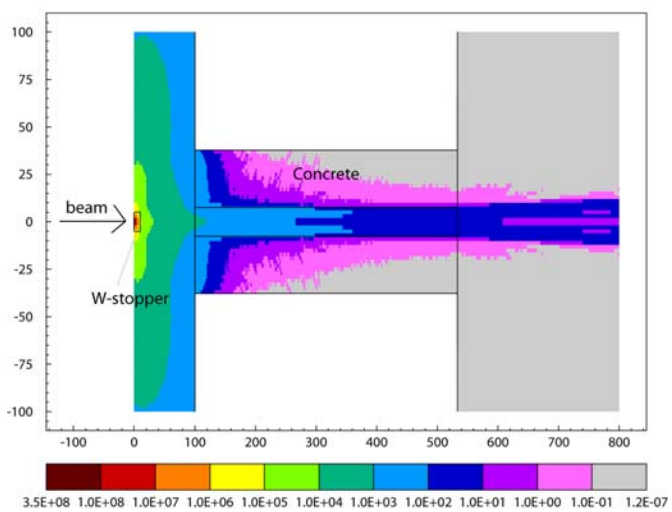

Figure 33: Dose rate in mrem/hr when 0.7 W, 70 MeV e- are hitting a 4 " W-stopper. Note, that E-163 uses two 4" long W-stoppers.

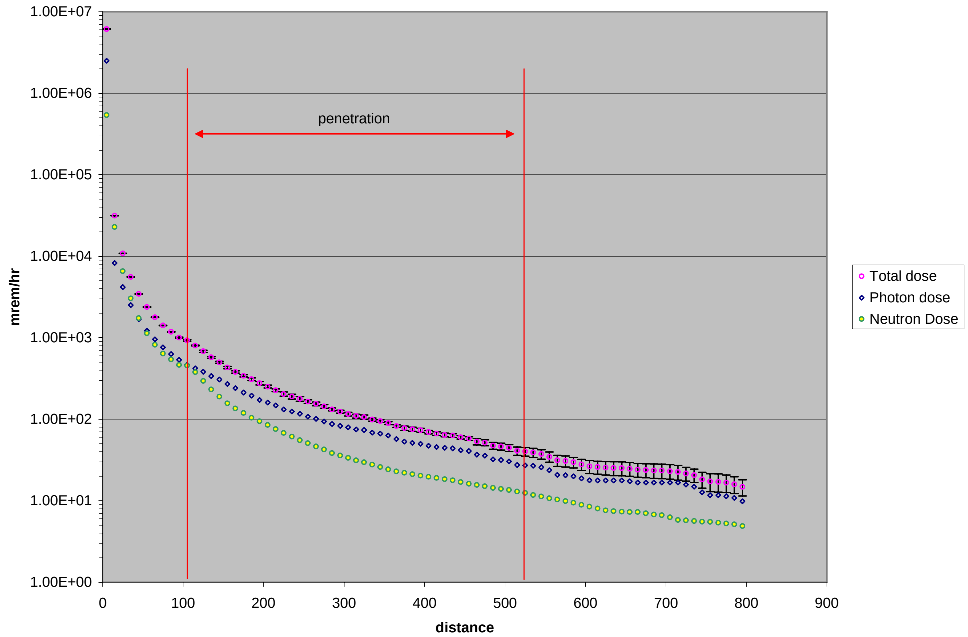

Figure 34: Dose rate behind a 4" tungsten stopper as a function of distance.

6.3.6 Failure of Quadrupoles

Ray tray studies were performed by E. Colby to identify mis-steered beam. FLUKA calculations were performed to determine the minimum thickness of shielding around these quads. The following shielding is required (see also figure 35):

- *Quads 4, 5 & 6* : 4"fe down beam, 2" on north-west, 2" above 2" south-east (to shadow east wall)
- *Quads 7 & 8* : 7" fe down beam, 2" fe north and 2" above
- *Quads 9, 10 & 11* : 8" fe down beam, 2" fe north and 2" above

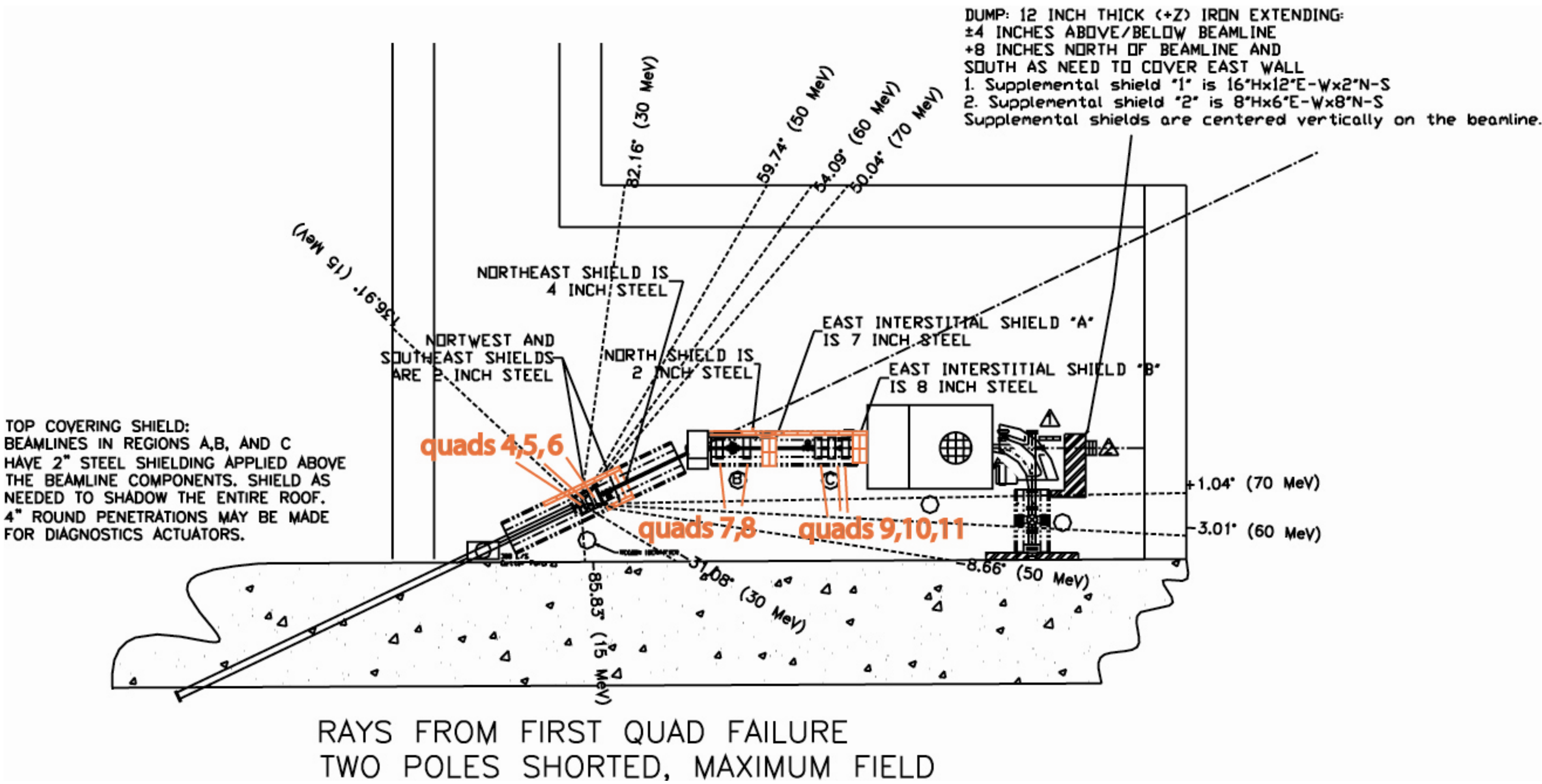

Figure 35: Shielding requirements for E-163 due to quadrupole failures (required shielding is shown in orange, note that 2" fe top covering shielding is also needed).

6.3.7 Summary of beam power losses during “mis-steering” conditions

Table II: Summary of beam power losses during “mis-steering” conditions.

Mis-steering beam loss scenarios: Dose rate limit 400mrem/hr		
Description	**Worst Case**	Dose rate in mrem/hr outside E-163 enclosure
Quads short at start of extraction line	1 watt on beam chamber immediately adjacent the SW corner of the laser room	3
Dipole 2 fails	1 watt on beam chamber near dipole 2	320
Dipole 2 set incorrectly*	1 watt on any of the yokes of quads 7,8,9,10, or 11	<320
Spectrometer fails	1 watt on straight ahead dump	100
Spectrometer set incorrectly*	1 watt on either the yoke of the spectrometer or the bend-line dump	<100
Screen 2	1 watt on Screen 2	0.53
Screen 3	1 watt on Screen 3	1.17
Screen 4	1 watt on Screen 4	1.5
Screen 5	1 watt on Screen 4	1.5
Screen 6	1 watt on Screen 6	1.5
Accelerator Cell	1 watt on accelerator cell + spectrometer failure	25
Gate Valve 1 closes	1 watt on gate valve 1	<320
Gate Valve 2 closes	1 watt on gate valve 2	<320
Gate Valve 3 closes	1 watt on gate valve 3	20
Quad 4,5, 6 fail	1 watt on beam chamber near quads 4,5 or 6	380
Quad 7, 8 fail	1 watt on beam chamber near quads 7 or 8	320
Quad 9,10,11 fail	1 watt on beam chamber near quads 8,9 or 10	240

*Polarity has to be checked before operation and signed off in BAS.

6.4 SUMMARY – Local shielding requirements for E-163

- E-163 beam stoppers in NLCTA -tunnel:
  - *2x 4” long Tungsten stopper*
- Quadrupoles 4, 5 and 6:
  - *2 “ fe north-west, 4” fe down beam, 2” fe above and 2” fe south-east to shadow E-163 east concrete wall*
- Quadrupoles 7 and 8:
  - *2 “ fe north, 7” fe down beam and 2” above*
- Quadrupoles 9, 10 and 11:
  - *2 “ fe north, 8” fe down beam and 2” fe above*
- Screen 2 and 3:
  - *Tungsten back up stopper – 2” dia, 1” long. Note, that the shielding added at quadrupoles 4 to 11 acts also acts as shielding for screens 2 and 3.*
  - *Above: 0.78“ fe*
- 0°-dump:
  - *12 inch thick iron*
  - *±4 inches above/below beamline*
  - *+8 inches north of beamline and south as needed to cover east wall*
  - *Supplemental fe shield between Spectrometer and dump on the north side - 8"Hx12"E-Wx2"N-S*
  - *Supplemental fe shield between Spectrometer and dump on the north side - 8"Hx4"E-Wx8"N-S*
  - *Supplemental fe shield behind dump - 8"Hx6"E-Wx8"N-S*
  - *Supplemental shields are centered vertically on the beamline.*
- Faraday cup:
  - *East: 2” fe from 60-80 degrees with respect of collimator and beamline, 4” fe from 85-120 degrees, 2” fe from 120-140 degrees. Wall height coverage +45° up, -25° down*
  - *Above: 0.78“ fe*

- Main dump:
  - *4 inch diameter tungsten stopper, 2 inch long, surrounded by 4 inch thick fe (12×12 inches)*

7 References

[1] Eric Colby, *“Explosive Electron Emission (EEE) Loss Calculations for E-163)”*, SLAC memorandum, 5/8/2003.
[2] R. Thomas and G. R. Stevenson, *“Radiological Safety Aspects of the Operation of Proton Accelerators”*, International Atomic Energy Agency, Vienna 1988

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11.3 Experimental Hall Personnel Protection System Design

The purpose of this document is to describe the PPS Access Control System for the E-163 Experimental Hall as it pertains to radiation safety. Although the Access Control System also includes laser light hazards, a completely separate, stand alone laser safety system (LSS) will be used to ensure personnel protection from laser light, and details of this function are not addressed in this document. All E163 electrical hazards shall be covered, and therefore not interlocked to the PPS.

Although laser hazards are not discussed in detail here, it is noted that the LSS will make use of the outer doors of the NLCTA and Experimental Hall access modules. The outer door magnalock will be controlled by the LSS under P/A, when a special Laser Test Mode has been enabled. An additional annunciator sign indicating Laser On will be mounted on the outer door of the Experimental Hall. The LSS is not built into the radiation PPS.

The E163 experiment will use electron bunches of maximum energy 70 MeV extracted from the Next Linear Collider Test Accelerator (NLCTA) and transported via a beamline into a separate shielded enclosure (referred to as the Experimental Hall in the following) built alongside the NLCTA (Figure 1). Since this beamline will link the NLCTA (labeled Zone 1 in the figure) to the Experimental Hall (Zone 2), the two PPS systems must be connected. The only source of radiation in the Experimental Hall will be beam originating from the NLCTA.

Beam shall be stopped from entering the Experimental Hall by three beam stoppers. The first stopper will be a bend magnet (BNDS1140), used to kick the beam 25^{o} North of the NLCTA beamline, and into the Experimental Hall extraction beamline. The AC power line to the power supply that drives the magnet will be interrupted by two power contactors placed in series on the line side. The second and third stoppers will be full-power tungsten beam stoppers. The stoppers are driven in under their own weight, and are removed by supplying gas pressure to pneumatic cylinders that lift the tungsten stoppers up out of the beam path. The stoppers are approximately 25 radiation lengths long and completely shadow the available beam tube. Redundant air control valves will supply gas pressure such that both solenoids of the air valves must be powered by the PPS system before the stopper will lift out of the beam path. Beam stoppers are part of the radiation PPS, will be labeled as Radiation Protection Devices, and will require RSWCF's to repair or modify.

The Experimental Hall PPS system shall provide a Beam Permitted signal to the NLCTA PPS that will indicate that it is safe for the NLCTA to generate beam. The presence of this status is required for NLCTA beam. The loss of this status will immediately turn-off NLCTA PPS beam stoppers. The five NLCTA Beam Stoppers are the gun HV power supply and the four power supplies for RF stations 1 through 4, described in NLCTA Note #45 (March 31, 1995). The Beam Permitted state will be logically equal to:

((Experimental Hall Search-Reset=Set) AND
(Experimental Hall access state = No Access) AND
(Radiation warning announcement = Complete))

OR

(All three Experimental Hall Beam Stoppers read valid IN statuses)

There will be Emergency Off buttons in the Experimental Hall. The action of pushing an Emergency Off button in the Experimental Hall when in the No Access state will revoke the NLCTA beam permit, shutting off the electron beam and closing all Transport Line Stoppers thereby disabling the laser hazard in both enclosures.

The Experimental Hall PPS Access Control System will be a three state access system:

PERMITTED ACCESS	(P/A)
CONTROLLED ACCESS	(C/A)
NO ACCESS	(N/A)

Entry into the Experimental Hall is permitted when the mechanical beam stoppers are In and the bend magnet stopper is Off. If the In/Off status of any radiation stopper is lost when the enclosure is in PERMITTED or CONTROLLED ACCESS, then the NLCTA stoppers will be inhibited, the Experimental Hall PPS Access Control System will not allow transfer to other access states and Experimental Hall keybank releases will be inhibited. If the Experimental Hall is in NO ACCESS and the search reset status is violated when any stopper is Out/On, then the NLCTA stoppers will be inhibited until all Experimental Hall stoppers report In/Off status. NLCTA electrical hazard permits will not be affected by the Experimental Hall PPS.

The Experimental Hall has one entrance point (Fig. 1). However the PPS circuitry is designed to accept expansion to a second entrance if the experimental hall is expanded in the future. The entrance is a standard SLAC entry module located at the west end of the labyrinth for the Experimental Hall. The entry 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, and a video camera. The Outer door will use a magnetic lock (magnalock) controlled by the PPS. This device is an electromagnet which secures the door in the closed position.

The PPS Access state sign at the outer door shall be of the standard SLAC type—composed of preprinted translucent panels backlit by conventional lamps.

No flashing blue strobe light shall be installed at the outer door to indicate that the door release button is being pushed. Instead, a “door open” light will be installed near the outer door in a location that is readily visible through the video camera monitoring the PPS entrance.

PPS Control and Status Panels

The Experimental Hall PPS Access Control System will be operated from the SLAC Control Program (SCP), in conjunction with a Hardwired Enable switch, and an Experimental Hall Stopper Disable keyswitch. Status and control functions will be available in the NLCTA Control Room and in building 225, and possibly extended in the future to MCC.

The Hardwired Enable switch is a momentary push-to-make pushbutton in series with a keyswitch that is wired into the PPS. With the keyswitch in the Enabled (and captured) position, pushing and holding the Hardwired Enable switch then permits a SCP command to change PPS states (e.g. change from C/A to N/A or momentarily disable the door magnalock for a C/A entry). With the keyswitch in the Disabled position, the associated Hardwired Enable is inert, and SCP commands to change PPS states are ignored. The Hardwired Enable key is unique, and will travel with the PPS Log when PPS access control is transferred from one control room to another.

The Experimental Hall Stopper Enable switch will be a keyswitch located on the NLCTA PPS console and on the B225 console. Each switch has its own distinct key. With both keys in the “Enabled” (and captured) position, the keyswitches permit the Experimental Hall Stoppers to be pulled out (i.e. the beam hazard can be enabled). With either key removed or in the “Disabled” position, the Experimental Hall Beam Stoppers will be locked “in” (beam hazard disabled) and will not respond to commands to pull out.

Description of the status indicators and control switches is broken down by geographic area:

- **NLCTA Control Room**

The NLCTA control room PPS hardware panel shall have the following items:

1. Hardwired Enable pushbutton and Hardwired Enable keyswitch

2. Experimental Hall Stopper Enable keyswitch
3. Status panel, mounted in or close to the NLCTA PPS Console, showing one LED per state of the Experimental Hall PPS:
   - (NLCTA Beam Permitted)
   - (P/A), (C/A), (N/A)
   - (Stopper 1 In), (Stopper 2 In), (Stopper 3 In)
   - (E/Os OK), (S/R Set), (Door Open), (Gate Open)

- **Building 225**

1. Hardwired Enable pushbutton and Hardwired Enable keyswitch
2. Experimental Hall Stopper Enable keyswitch
3. Status panel, mounted in rack B225-06 (approx 30' to the East of the PPS racks), showing one LED per state of the Experimental Hall PPS
   - (NLCTA Beam Permitted)
   - (P/A), (C/A), (N/A)
   - (Stopper 1 In), (Stopper 2 In), (Stopper 3 In)
   - (E/Os OK), (S/R Set), (Door Open), (Gate Open)

- **MCC (Future)**

1. Hardwired Enable pushbutton and Hardwired Enable keyswitch (future)

A hidden hardware control panel, accessible only to PPS personnel, will be located in the PPS logic racks (B225-02 and B225-03), and will be used by the PPS crew for maintenance and certification purposes only. Standard SLAC best practices will be employed relating to the protection of cable plant, locking of cabinets, redundant logic, etc.

Normal Entry & Exit Procedure for CONTROLLED ACCESS

Assuming that the Experimental Hall is in the NO ACCESS state, the following procedural steps will be followed to bail the enclosure to CONTROLLED ACCESS and make an entry:

1) All Experimental Hall Beam Stoppers will be set to their in/off state by the PPS operator.

2) The PPS operator will set the access state of the E163 hall to CONTROLLED ACCESS by pressing and holding the Hardwired Enable button, then pressing the Controlled Access button on the SCP panel. The Hardwired Enable button may then be released.

At this point access to the Experimental Hall is controlled by the PPS operator as follows:

a) Individuals requesting access to the Experimental Hall will be identified and logged in by the PPS operator via visual and audio communication at the point of entry.

b) The operator releases the keybank and, one key will be removed from the keybank by each individual. This key is to be kept in the personal possession of the individual throughout his/her stay in the housing.

c) One individual of the group will insert his/her key into the Door Control box. In concert with this action the NLCTA PPS operator will push and hold the Hardwired Enable button and release the door. The outer door can then be opened and the individual can remove and retain his/her key. Once all individuals have passed through the outer door, and the last individual entering has closed the outer door, the PPS operator can then release the Hardwired Enable push button.

d) To exit the Experimental Hall, an individual must contact the PPS operator, request to exit, and insert the key in the control box. In concert with this action the PPS operator will depress and hold down the Hardwired Enable button and releases the door. The individual exits through and closes the outer door. The PPS operator may release the Hardwired Enable button once the door has closed.

Note:

If for any reason the Hardwired Enable push button is released prior to the closure of the outer door, the search circuit will be faulted requiring a re-search of the Experimental Hall by qualified operators.

At this point individuals have satisfied all PPS controlled access procedures to enter the Experimental Hall. But since the enclosure is also a laser room, access to the enclosure may be determined by the status of the laser. Detailed procedures for making a Laser-On access are described in the Laser Safety System Design Specification for E-163.

Normal Entry & Exit Procedures for PERMITTED ACCESS

Assuming that the Experimental Hall is in the NO ACCESS state the following procedural steps will be followed to bail the PPS system to PERMITTED ACCESS.

1) All Experimental Hall Beam Stoppers will be set to their in/off state by the NLCTA PPS operator.

2) The PPS operator will bail the access state of the Experimental Hall to CONTROLLED ACCESS by pushing and holding the Hardwired Enable button, then pressing the Controlled Access button on the SCP panel.

3) The PPS operator then will bail the access state of the Experimental Hall to PERMITTED ACCESS by pushing and holding the Hardwired Enable button, then pressing the Permitted Access button on the SCP panel.

Setting this state automatically releases the SEARCH RESET status for the hall.

4) At this point, passage into the Experimental Hall through the outer door is uncontrolled, unless the Laser Safety System is set to Laser Test Mode. Procedures for access in Laser Test Mode are described in the Laser Safety System Design Specification for E-163.

PPS Security Fault Violations

A PPS SECURITY FAULT violation can only occur in the NO ACCESS, or CONTROLLED ACCESS states.

A SECURITY FAULT violation in the NO ACCESS state is defined as :

(1) Operating the Emergency entry/exit button at the outer door located at the Experimental Hall Access Module.

(2) The act of opening the inner gate at the Experimental Hall Access Module. Security Faults for this action occur in NO ACCESS only.

(3) The act of opening the outer door at the Experimental Hall Access Module. Security Faults for this action occur in No Access and Controlled Access without a door bypass.

(4) Operation of any EMERGENCY BEAM SHUTOFF push button inside the Experimental Hall and access labyrinth.

(5) Loss of Experimental Hall Keybank Complete status.

Any of these SECURITY FAULT violations in the absence of valid Experimental Hall Beam Stoppers IN statuses will remove the PPS permits to all NLCTA and Experimental Hall radiation hazards. NLCTA electrical hazard permits will not be affected by the Experimental Hall status. All of the above SECURITY FAULT violations will result in a loss of the SEARCH status thus requiring a re-search of the Experimental Hall. 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 Module. A SECURITY FAULT violation will result in a loss of the SEARCH status thus requiring a re-search of the Experimental Hall.

The act of transferring the enclosure to PERMITTED ACCESS is in itself a security violation of the enclosure. Therefore no further violations are defined.

SEARCH CIRCUIT - Experimental Hall

The SEARCH circuit for the Experimental Hall is comprised of one SEARCH PRESET box located at the east end of the hall. A SEARCH RESET box is mounted outside the Experimental Hall at the Access Module entry. All preset and reset boxes will require a key for actuation. The search logic requires that the Experimental Hall be set to CONTROLLED ACCESS prior to any search activities.

The SEARCH RESET is complete when the following conditions are met.

(1) The SEARCH PRESET for the enclosure is set.

(2) The gate and door are closed.

(3) The Emergency Off buttons are reset.

(4) The Access Module keybank is Complete.

(5) The searcher outside the enclosure at the Access Module, and the 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 Experimental Hall back to PERMITTED ACCESS or having a SECURITY FAULT will trip the SEARCH RESET circuit.

Visual and Audio Warnings

Both visual and audio warnings will be activated when the access state of the Experimental Hall is set to NO ACCESS.

When the Experimental Hall is set to NO ACCESS the hall lighting will flash and a recorded warning message will be as follows.

"Attention. The BEAM is about to come on. Press the nearest Emergency Beam Shutoff button and call extension 2189 immediately."

(**2189** = NLCTA control room extension.)

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. If a security fault trips the search reset, then the warning message will be terminated, the hall lights will come on full bright, and no permits will be issued.

The PPS will have control of the fluorescent lighting in the Experimental Hall in the No Access state. When the state is (N/A)(Timer Running), the lights will flash; when the state is (N/A)(Timer Complete) the lights will be off; for all other states, the light switch at the entrance of the Experimental Hall shall control the lights.

PPS Keybanks

There is one keybank at the entrance of the Experimental Hall Access Module. The keybank is required to be COMPLETE in order to transfer between access states.

PPS Emergency Off

The EMERGENCY OFF circuit is comprised of at least three push button boxes located in the hall and the access labyrinth. The boxes inside the enclosure will be identified with signs EMERGENCY BEAM SHUTOFF .

With the hall in NO ACCESS, pushing any of these buttons will create a SECURITY FAULT. With the hall 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 OFF circuit can only be done in CONTROLLED ACCESS.

PPS Emergency Entry/Exit

The EMERGENCY ENTRY/EXIT controls are located on each side of the outer door. Pushing these buttons will release the door magnalock allowing egress. With the Experimental Hall in NO ACCESS or CONTROLLED ACCESS states, making an emergency entry or exit will create a SECURITY FAULT.

Burn Through Monitors (BTM)

There are no Burn Through Monitors required for the Experimental Hall at this time.

Beam Shutoff Ion Chambers (BSOIC)

There are plans to use 3 BSOICs for the Experimental Hall. At the present time, at least two of the BSOICs will be existing NLCTA BSOICs moved to new physical locations (pending Radiation Physics evaluation and approval). There are presently 10 BSOICs assigned to various locations around the NLCTA housing and 2 unused channels available. If radiation levels exceed their preset threshold, the units will shut off all radiation hazards. Analog readout and reset function will be on the NLCTA control system. BSOIC analog levels will also be in the NLCTA Control System history buffer.

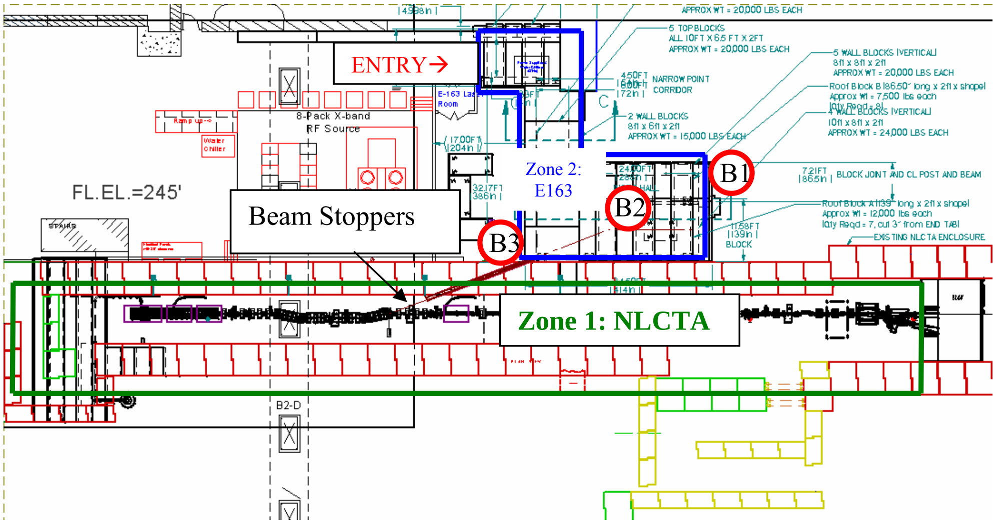

FIGURE 1. NLCTA and E163 Experimental Hall and PPS zone designations, and BSOIC locations. B1—outside at ground level, B2—outside, on the Experimental Hall roof, B3—inside Laser Room at Southeast corner.

Appendix: Radiation PPS interfaces with the E163 Laser Safety System

The NLCTA PPS system shall provide an Emergency Off Button Reset status signal to the E163 Laser Safety System (LSS). The loss of this status will result in the closure of all Transport Line Stoppers leading out of the E163 laser room, and stop any laser light from reaching either the Experimental Hall or the NLCTA enclosure.

The NLCTA PPS system shall provide an NLCTA Ready for Laser Beam status signal to the E163 LSS that will be used to permit remote enabling of laser beam stoppers that protect personnel in the NLCTA enclosure. This status shall be logically equal to:

((NLCTA enclosure Search-Reset=Set) AND

(NLCTA enclosure access state = No Access) AND

(Radiation warning announcement = Complete))

The E163 PPS system shall provide an Experimental Hall Ready for Laser Beam status signal to the E163 LSS that will be used to permit remote enabling of laser beam stoppers that protect personnel in the Experimental Hall. This status shall be logically equal to:

((Experimental Hall Search-Reset=Set) AND

(Experimental Hall access state = No Access) AND

(Radiation warning announcement = Complete))

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11.4 Laser Personnel Protection System Design

11.4.1 Safety System Design

The purpose of this document is to describe the E163 Personnel Protection System (PPS) as it pertains to laser safety. Although the Access Control System also includes ionizing radiation hazards, a completely separate, stand alone radiation personnel protection system (RPPS) will be used to ensure personnel protection from ionizing radiation, and details of this function are not addressed in this document. All E163 electrical hazards shall be covered, and therefore not interlocked to the Laser Personnel Protection System (LPPS) or RPPS. The description of the RPPS is found in the document "Proposed Personnel Protection System (PPS) Access Control System for the E163 Enclosure", January 5, 2004.

Although ionizing radiation hazards are not discussed in detail here, it is noted that the LPPS will make use of the inner gates of the NLCTA and E163 access modules. The inner gate will have a magnalock controlled by the LPPS and an additional annunciator sign indicating "laser on" whenever laser light is enabled in the E163 or NLCTA enclosures. A light-absorbing curtain inside the inner gate will be drawn (if needed) to ensure no laser light leaves the enclosure. Shelves containing laser personal protective equipment will be located between the outer door and inner gate. The LPPS is not part of the radiation PPS. However, the LPPS will use state information from the radiation PPS system to enable the "Laser On" state under certain conditions, described below. The outer gate of the access module continues to serve as the RPPS access control point and is independent of the LPPS.

The E163 experiment will use electron bunches of maximum energy 70 MeV extracted from the Next Linear Collider Test Accelerator (NLCTA) and transported via a beamline into a separate shielded enclosure (referred to as the enclosure or hall in the following) built alongside the NLCTA (Figure 1). For the purposes of laser safety, the NLCTA (labeled Zone 1 in the figure) and the Experimental Hall (Zone 2) are separate enclosures where laser light may be enabled independently. The only source of laser light will be light originating from the Laser Cleanroom (Zone 3), which has light pipes connecting it to the NLCTA and E163 hall with shutters to prevent light propagation when activated by the LPPS.

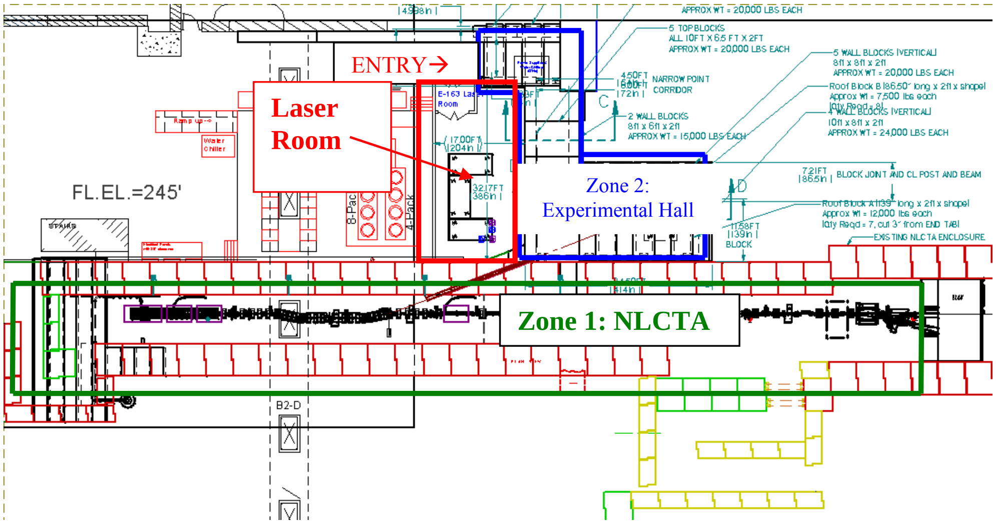

FIGURE 1. NLCTA and the E163 Laser Room and Experimental Hall and PPS zone designations.

Simply stated, laser light will be permitted to leave the Laser Room and enter either one of the Experimental Hall or NLCTA enclosures under either of the following conditions: (1) the enclosure is in the “No Access” state, or (2) a Qualified Laser Operator (“QLO”) has searched the enclosure and has opened the shutters manually from within the enclosure using a unique key.

“No Access” State of the Radiation PPS Systems

The E163 radiation PPS Access Control System will be a three state access system:

PERMITTED ACCESS

CONTROLLED ACCESS

NO ACCESS

Laser shutters allowing light into an enclosure can be opened remotely only in the “No Access” state. They can be opened locally with a unique, captured key in a key box during either “Controlled” or “Permitted Access/laser on” states according to the procedures below.

The NLCTA PPS system shall provide an "NLCTA Ready for Laser Beam" status signal to the Laser Personnel Protection System that will be used to permit remote enabling of laser beam stoppers that protect personnel in the NLCTA enclosure. This status shall be logically equal to:

((NLCTA enclosure Search-Reset=Set) AND

(NLCTA enclosure access state = No Access) AND

(NLCTA enclosure Keybanks=Complete) AND

(Radiation warning announcement = Complete))

The E163 PPS system shall provide an "Experimental Hall Ready for Laser Beam" status signal to the Laser Personnel Protection System that will be used to permit remote enabling of laser beam stoppers that protect personnel in the Experimental Hall. This status shall be logically equal to:

((Experimental Hall Search-Reset=Set) AND

(Experimental Hall access state = No Access) AND

(Experimental Hall Keybanks=Complete) AND

(Radiation warning announcement = Complete))

The NLCTA PPS system shall provide an "Emergency Off Button Not Pressed" status signal to the E163 Laser Personnel Protection System. The loss of this status will result in the closure of all Enclosure Laser Shutters (S1E, S2E, S1N, S2N) leading out of the Laser Room, thus stopping any laser light from reaching either the Experimental Hall or the NLCTA enclosure.

Laser Room PPS

The laser room outer door is always locked for property and personnel control, and may be opened with a K1 laser key. The main LPPS panel resides in the laser room, as does a keybox, which is used to store the unique copies of K2 (="Laser to NLCTA") , K3 (="Laser to Experimental Hall"), K4 (="Power On for Millenia XK5 Laser"), and K5 (="Power On for Evolution 30 Laser") when not in use.

a. "Laser Off" Entry

- Laser Shutters SA, SB, and SC are closed
- Outer door unlocks with K1 key, entry into laser room does not require timed interlock bypass

b. "Laser On" Entry

- Laser Shutters SA, SB, and SC are open
- Micro-switch on both the inner and outer doors are interlocked to insure that if both inner and outer doors open simultaneously, then Laser Shutters close
- Micro-switch on inner door closes Laser Shutters unless QLO uses laser entry key (K1) to enter. Key K1 starts a 20 second timed interlock bypass to permit entry without closing the Laser Shutters.
- Laser Shutters can be opened locally by push button on main LPPS panel. Shutters will open after an audible alarm sounds for 20 seconds.
- Annunciator sign at outer door indicates "Laser On", requiring PPE to be worn upon entry
- Push-button inside laser room initiates a 20-sec timed interlock bypass to exit room without closing Laser Shutters (20 sec bypass of micro-switch)
- Emergency exit (without depressing bypass button) closes Laser Shutters
- Emergency entry (opening door without using the K1 entry bypass) will close Laser Shutters
- Enclosure Laser Shutters S1E, S2E, S1N, S2N do not change state when entry/exit is made to/from the Laser Room under any circumstance.
- If at least one laser power supply is electrically "on", the annunciator sign at outer door indicates "Laser On", requiring PPE to be worn upon entry.

Normal Entry & Exit Procedures under the PERMITTED ACCESS Condition into the NLCTA or Experimental Hall

The following factual statements and procedural steps apply to enter the enclosure under PERMITTED ACCESS:

a. "Laser Off" Entry
- Defining condition: Laser Shutters SA, SB, and SC are closed
- Open entry, which means: (1) Radiation PPS door is open, (2) inner gate magnalock is not controlled, (3) inner gate is latched shut but not locked
- Enclosure Laser Shutters S1E, S2E, S1N, and S2N are closed

b. "Laser On" Entry
- Defining condition: Laser Shutters SA, SB, and SC are open
- Radiation PPS door is open.
- Laser Personnel Protection System (LPPS) powers inner gate magnalock, locking it
- Push-button entry (Emergency Entry or non-QLO Entry) is possible, but Enclosure Laser Shutters for that enclosure will close automatically

- Micro-switch on inner gate will close Enclosure Laser Shutters for that enclosure if the door is opened without a "Laser Entry Key" (designated K1). To exit via this gate, an interior push-button is used to allow a timed interlock bypass without changing the Enclosure Laser Shutter state. If exit is made without pushing the timed interlock bypass pushbutton, the Enclosure Laser Shutters will close.
- Every Qualified Laser Operator (QLO) has a K1 key. K1 performs two functions: (1) it unlocks the outer door to the Laser Room, and (2) it activates the timed interlock bypass entry for the Laser Room, the Experimental Hall, and the NLCTA when any are under LPPS control.
- Enclosure Laser shutters can only be opened locally from within the respective enclosure. To start this process, a Qualified Laser Operator (QLO) must first turn the appropriate "Enclosure Shutter Key" (designated K2 for the NLCTA, K3 for the Experimental Hall) to INITIALIZE position and then return it to LOCAL in the Laser Room Keybox. This key is then removed and carried by QLO to the enclosure. Note this key is unique with no copies.
- QLO entry to enclosure possible via K1 at entry keybox (push button inside for exit). This key 1) releases inner gate magnalock and bypasses the microswitch for twenty seconds, 2) does not open Enclosure Laser Shutters if closed, and does not close Enclosure Laser Shutters if open.
- QLO can now open Enclosure Laser Shutters by closing the inner gate, searching the enclosure (administrative control), proceeding to a keybox in the enclosure, and inserting the unique K2 if opening Enclosure Laser Shutters into the NLCTA or K3 if opening Enclosure Laser Shutters into the Experimental Hall. Enclosure Laser Shutters open with K2 (or K3) in captured position in this keybox after an audible alarm and a twenty second delay. Annunciator sign at gate entrance signals "Laser On", requiring Personal Protective Equipment (PPE) to be worn upon entry.
- Removing K2 closes Enclosure Laser Shutters automatically, permitting QLO to work when necessary without PPE. Search must be performed each time Enclosure Laser Shutters are opened. Keybox is located close to the area where laser work usually occurs. Note K2 (or K3) can be left in keybox, maintaining Enclosure Laser Shutters open, if QLO wishes to exit enclosure with laser on in local mode.
- QLO is responsible for laser safety of all persons inside enclosure.

Normal Entry & Exit Procedure under CONTROLLED ACCESS Conditions to the Experimental Hall or NLCTA

The following procedural steps will be followed to enter the enclosure under CONTROLLED ACCESS with the laser on:

- Radiation PPS door operates in standard fashion with the accelerator operator controlling access to and exit from the radiation enclosure. After passing this PPS door, individuals have satisfied all PPS controlled access procedures to enter the NLCTA or Experimental Hall. But since the enclosure is also a laser room, passage through the INNER GATE is determined by the status of the laser.

- The same LPPS procedures apply for the "Laser On" and "Laser Off" states as written above for the Permitted Access case.

Access under the NO ACCESS state

Under the NO ACCESS state:

- Inner gate magnalock is not powered and does not lock the inner gate; gate latches closed but is otherwise unlocked.
- Enclosure Laser Shutters (S1E, S2E, and/or S1N, S2N) can be opened remotely for each enclosure that is in the "No Access" state. Note that the "No Access" state is the only state under which the Enclosure Laser Shutters may be remotely opened and closed.
- If the Enclosure Laser Shutters to the area are open, a "Laser On" annunicator sign will be illuminated on the inner gate, and PPE must be worn while in the enclosure.
- Leaving "No Access" state for either enclosure automatically closes the corresponding Enclosure Laser Shutters (S1N and S2N if the NLCTA drop out of "No Access", S1E and S2E if the Experimental Hall drops out of "No Access").

Glossary of Terms

Shutter or **Laser Shutter** – an electromechanically actuated metal shutter that completely blocks laser light. Shutters are used as laser Beam Stoppers.

Laser Shutters – shutters SA, SB, SC, which block light output from the Millenia Pump Laser, the Evolution-30 Pump Laser, and a low-power HeNe alignment laser, respectively.

- **SA** – laser shuttered located at the exit of the Millenia XK5 pump laser.
- **SB** – laser shuttered located at the exit of the Evolution-30 pump laser.
- **SC** – laser shuttered located at the exit of the alignment Helium-Neon laser.

Enclosure Laser Shutters – shutters S1E, S2E, S1N, S2N which form redundant pairs of shutters blocking light into the Experimental Area (S1E, S2E) or NLCTA Enclosure (S1N, S2N).

- **S1E** – laser shutter located within the Laser Room, at the point where laser light would exit the Laser Room and enter the Experimental Hall.

- **S2E** – laser shutter located within the Experimental Hall, at the point where laser light would enter the Experimental Hall from the Laser Room. This shutter is redundant with S1E.

- **S1N** – laser shutter located within the Laser Room, at the point where laser light would exit the Laser Room and enter the NLCTA.

- **S2N** – laser shutter located within the NLCTA, at the point where laser light would enter the NLCTA from the Laser Room. This shutter is redundant with S1N.

K1 Key (copied) – held by all Qualified Laser Operators, allows access into the Laser Room, and bypassed access to zones with laser shutters open

K2 Key (unique) – (also called "Enclosure Shutter Key") used to switch between Local and Remote operation of the NLCTA Enclosure Laser Shutters (S1N, S2N)

K3 Key (unique) – (also called "Enclosure Shutter Key") used to switch between Local and Remote operation of the Experimental Hall Laser Shutters (S1E, S2E)

K4 Key (unique) – used to turn on/off the power supplies for the Millenia XK5 laser. Once this laser is disabled, the Tsunami Laser is also disabled.

K5 Key (unique) – used to turn on/off the power supplies for the Evolution-30 laser. Once this laser is disabled, the Spitfire Laser is also disabled.

KBK Key (copied) – radiation personnel protection system key, used only by RPPS for entry under the Controlled Access condition.

Experimental Hall – the E163 Radiation shielding enclosure, located North and parallel to the NLCTA enclosure

Laser Room – the E163 Laser Room, located West of and parallel to the entrance labyrinth of the E163 Radiation shielding enclosure

QLO – Qualified Laser Operator—and individual who has had the Laser Safety Training Course (CBT Core Course 253), a Laser Eye Examination, and E163-specific training.

11.4.2 Laser Safety System Certification Procedure

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The certification of the Laser Safety System is conducted by the PPS Group according to a pre-approved procedure. This procedure is documented as CPE Procedure 18-29-10-03-NLCTA-IAT-LAS3.

Marc Ross, NLCTA Operations Manager	Date
Tor Raubenheimer, NLCTA Facility Head	Date
Persis Drell, Associate Director Particle and Particle Astrophysics	Date
John Cornuelle, Chief Operating Officer	Date
Jonathan Dorfan, Chairman of ES&H Coordinating Council	Date