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# Radiation Safety Considerations for the Parasitic Final Focus Test Beam at SLAC*

**S. H. Rokni, R. H. Iverson and L. P. Keller**

**Stanford Linear Accelerator Center**
**Stanford University, Stanford, Ca 94309**

## Abstract

A low intensity electron beam parasitic to the operation of the Stanford Linear Collider (SLC) has been transported through the Final Focus Test Beam (FFTB) facility making secondary test beams available for users. Photons generated in collimation of the SLC electron and positron beams in the linac pass through a splitter magnet that deflects the primary beams away from the linac axis into the SLC beam lines. These photons are converted to electrons and positrons in a secondary production target located down beam on the linac axis. The secondary electrons are then transported through the FFTB beam line onto experimental detectors. The average power of the parasitic beam is very low, thus, it presents no hazards. However, various accident scenarios involving failure of the splitter magnet and the active protection devices could send much more powerful SLC beams (up to 90 kilo-watts) into this zero-degree secondary beam line. For the accident case, the average power in the transmitted beam was calculated using the Monte Carlo programs EGS4 and TURTLE. Results from analysis of the radiation protection systems that assure safety during the parasitic operation are presented.

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## Introduction

The FFTB components are installed in a shielded enclosure in the straight-ahead channel at the end of SLAC linac (Balakin et al. 1994, see Fig. 1). This tunnel is comprised of two sections; the first 107 m of the FFTB is in the beam-switch yard (a two-level structure that is shielded on the roof by more than 12 m of concrete and earth). The remaining 88 m of the beam line is in a concrete structure that extends beyond the beam-switch yard into an area known as the research yard. The thickness of the roof and side walls of this section of the FFTB tunnel are 1.2 m and 1 m, respectively. While the full FFTB (which is a 47 GeV electron beam that has an average power of 1 kW) can be parked on beam stops in the first section of the tunnel in the beam-switch yard, resulting in negligible increase in radiation levels outside the tunnel, the shielding in the research yard limits the amount of the beam loss in this section of the tunnel to less than 0.1% of the beam (1 watt) only before the design limits are exceeded.

In addition to the shielding, other components of the radiation protection systems for the primary FFTB beam line are the Beam Containment System (BCS) and the Personnel Protection System (PPS). The BCS is designed to ensure that beam parameters (current and energy) do not exceed the preset values, and that the beam is delivered to the main dump with minimal loss. The PPS controls entry to the tunnel, ensuring that personnel are excluded from the tunnel during the FFTB operation. A detailed discussion of the radiation safety features of the primary FFTB is given in Rokni et al., 1996.

The primary FFTB operates in a dedicated mode in which the average beam power in the linac is 1 kW. However, in the parasitic mode, SLC beams with an average power of

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45 kW each, are present in the linac. During the operation of SLC 5 to 10% of the primary electron and positron beams are scraped off at collimators located in the last three sectors of the linac. A splitter dc magnet, dipole 50B1, directs the positron and electron beams into the SLC lines. Bremsstrahlung photons generated in these collimators travel straight ahead, pass through the splitter magnet, and strike a secondary production target located down beam on the linac axis (Fig. 2). The secondary electrons can then be transported to various beam lines. The maximum electron intensity in the FFTB is calculated to reach up to 3000 electrons per pulse at 15 GeV. However, for checking response of most of the experimental detectors a beam intensity of around 1 electron per pulse is sufficient. This technique, established at End Station A previously (Cavelli-Sforza et al. 1993), was used to generate electron beams in the FFTB facility as well. The main safety concern for the parasitic operation of the FFTB is the accident case in which the splitter magnet trips and the full SLC beams are transported through the FFTB causing large radiation levels outside the FFTB tunnel in the research yard.

## Safety Analysis

### *Accident Beam*

In order to analyze the worst accident case it was assumed that the splitter magnet and all the active protection devices (see next section on BCS) fail and both SLC beams impinge on the secondary production target. The Monte Carlo shower program EGS4 (Nelson et al. 1985), and ray-tracing program TURTLE (Carey 1978) were used to estimate the average power in the transmitted beam for such a scenario. In TURTLE, the moveable apertures in the FFTB were assumed to be open for maximum transmission to the experimental detector location. The beam spot size on the secondary target was taken to be 1 mm in radius. The angular and energy acceptance of the FFTB given by TURTLE are: $\sigma_{x'o}$(rms)=234 μrad, $\sigma_{y'o}$(rms)=23 μrad, $\delta_E/E$= 3.5%. In the EGS4 simulations, a 47 GeV electron beam was assumed to be incident on a 0.54 r.l. iron target representing the secondary beam production target. Electrons exiting the target that passed both angular cuts were recorded as function of energy (positrons are bent away from the transport line by the first set of dipole magnets). Applying the $\delta_E$ and multiplying by the number of incident particles on the target results in the number of secondary electrons that could reach the experimental appratus. Fig. 3 shows the maximum number of transmitted electrons reaching the experimental detector location as function of the FFTB energy. At 30 GeV, the number of secondary electrons reaching the experimental detector location, per $1\times10^{11}$ incident electrons on the target, is $2\times10^{8}$ electrons per pulse. Therefore, less than 0.2% of the beam intensity entering the FFTB will be transported through the beam line and strike the experimental detectors located in the research yard section of the tunnel.

For the secondary beam production target a stainless steel pressure vessel, called a Burn Through Monitor (BTM), was used. If an errant beam ruptures a BTM, it causes a loss of the gas pressure to below a preset level. The pressure loss is detected with a pressure switch which shuts off the beam through the PPS and inserts various beam stoppers in the beam line. The choice of the BTM as the target serves two purposes:

1-Before the complete burn-through, it acts as a “spoiler” to diffuse the beam such that a small fraction of the incident beam (e.g. 0.2% at 30 GeV) will reach the experimental target.

2-Shuts off all beams if high power primary beams rupture the unit.

Radiation levels outside the concrete walls of the FFTB tunnel due to photons and neutrons were estimated using SHIELD11 computer program (Nelson and Jenkins[¶] 1990). For the accident case in which SLC beams at $1x10^{11}$ electrons /pulse impinge on the production target, the outside radiation level from the transmitted beam on an experimental target is 2.2 $mSvh^{-1}$ before burn-through. For comparison, the same calculation would result in a dose rate level of 112 $mSvh^{-1}$ outside the shielding walls if there was no BTM and the 45 kW SLC electron beam impinged on the experimental target.

EGS4 simulations show that the rest of the incoming beam (positrons and off-energy electrons) that is not transported to the experimental apparatus location is deposited in beam line components immediately after the muon shield (Fig. 2). This segment of beam line is located well inside the BSY section of the FFTB tunnel and is shielded heavily. Beam tests were performed in which the largest radiation level outside the FFTB tunnel from a 1 kW beam parked on a beam stop in this section of the beam line was measured to be 5 $\mu Svh^{-1}$. Therefore, the total dose outside the FFTB tunnel from an accident in which both SLC beams (90 kW) impinge on the BTM is 2.7 $mSvh^{-1}$.

### *Beam Containment System (BCS)*

The BCS devices in the FFTB ensure that beams would shut-off in all accidental cases (Fig. 4). An interlock on magnet 50 B1 monitors the "on" status and the current through the magnet. Two bi-polar average current monitors on Torroids I4 and I5 provide extra layers of safety. An ion chamber on the collimator that would absorb most of the off-energy particles, is also set to trip at average power of 1 kW or more. There are other components of the BCS that provide further layers of protection: namely, sensitive ion chambers (LIONs) inside the research yard section of the FFTB tunnel that are set to trip the beam for losses of larger than 1 W. Especially designed Beam Shut-Off Ion Chambers were placed at fixed locations outside the FFTB tunnel and are set to trip the beam at 100 $\mu Svh^{-1}$.

Additionally, to prevent the transport of accidental primary beam through the FFTB, a meter relay was added on the power supply for the first set of dipoles on the beam line. The maximum allowed energy for the FFTB was set at 30 GeV, well below that needed to transmit normal SLC beams, such that in the event of failure of 50B1 dipole there is a mis-match in energy of the incoming primary beams and the FFTB transport lines. In such a case, the accident beam would strike the lead shielding placed down beam of the bend series and not be transported to the experimental target placed in the research yard section of the FFTB tunnel. To provide another mechanism for terminating such an accident, another BTM is placed at the down beam end of the lead shield. The redundancy and variety in the active protection system for the parasitic FFTB operation minimizes the possibility of a common mode of failure.

## Summary

A secondary beam parasitic to the operation of SLC has been established in the FFTB at SLAC. A splitter magnet deflects SLC primary beams away from the FFTB which is located straight ahead along linac axis. A Burn Through Monitor was used as the production target for the secondary beam. The safety analysis based on results from EGS4/TURTLE calculations show that in the accident case in which the splitter magnet fails the target will either rupture, thus, turning off the beam; or spoil the beam such that the power in the transmitted beam reaching the experimental target is only a small fraction of the primary beam. The maximum radiation level outside the FFTB enclosure was calculated to be less than 2.2 mSv$h^{-1}$ in the worst possible case failure of all active devices. Redundant layers of Beam Containment System interlocks which are based on different technologies are deployed and turn-off the beam in such cases. The FFTB parasitic beam has been commissioned and several experiments have used this facility.

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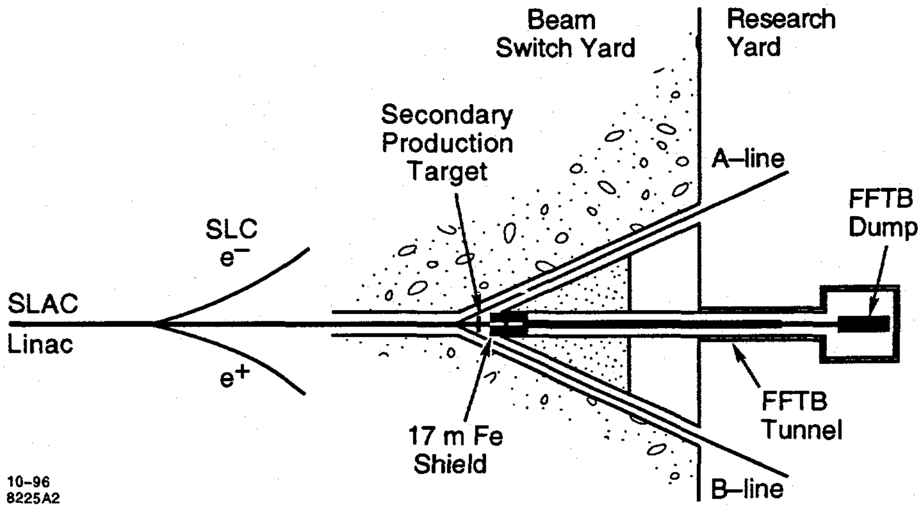
## *FIGURE CAPTIONS*

1. Location of the Final Focus Test Beam (FFTB) at the end of the linear accelerator at SLAC (not to scale).
2. Layout of the FFTB in the parasitic test beam mode (not to scale).
3. Number of transmitted electrons reaching the experimental detector location as function of FFTB energy for the accident case.
4. Layout of the Beam Containment System for the parasitic operation of FFTB (not to scale).

## *FOOTNOTES*

[¶] Nelson, W. R.; Jenkins, T. M. Computer code SHIELD11 MORTRAN. Stanford, CA: Stanford Linear Accelerator Center, Radiation Physics Department; 1990.


Beam
Switch Yard
Research
Yard
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Production
Target
A–line
FFTB
Dump
SLC
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Linac
e⁺
FFTB
Tunnel
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Shield
B–line
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Fig. 1

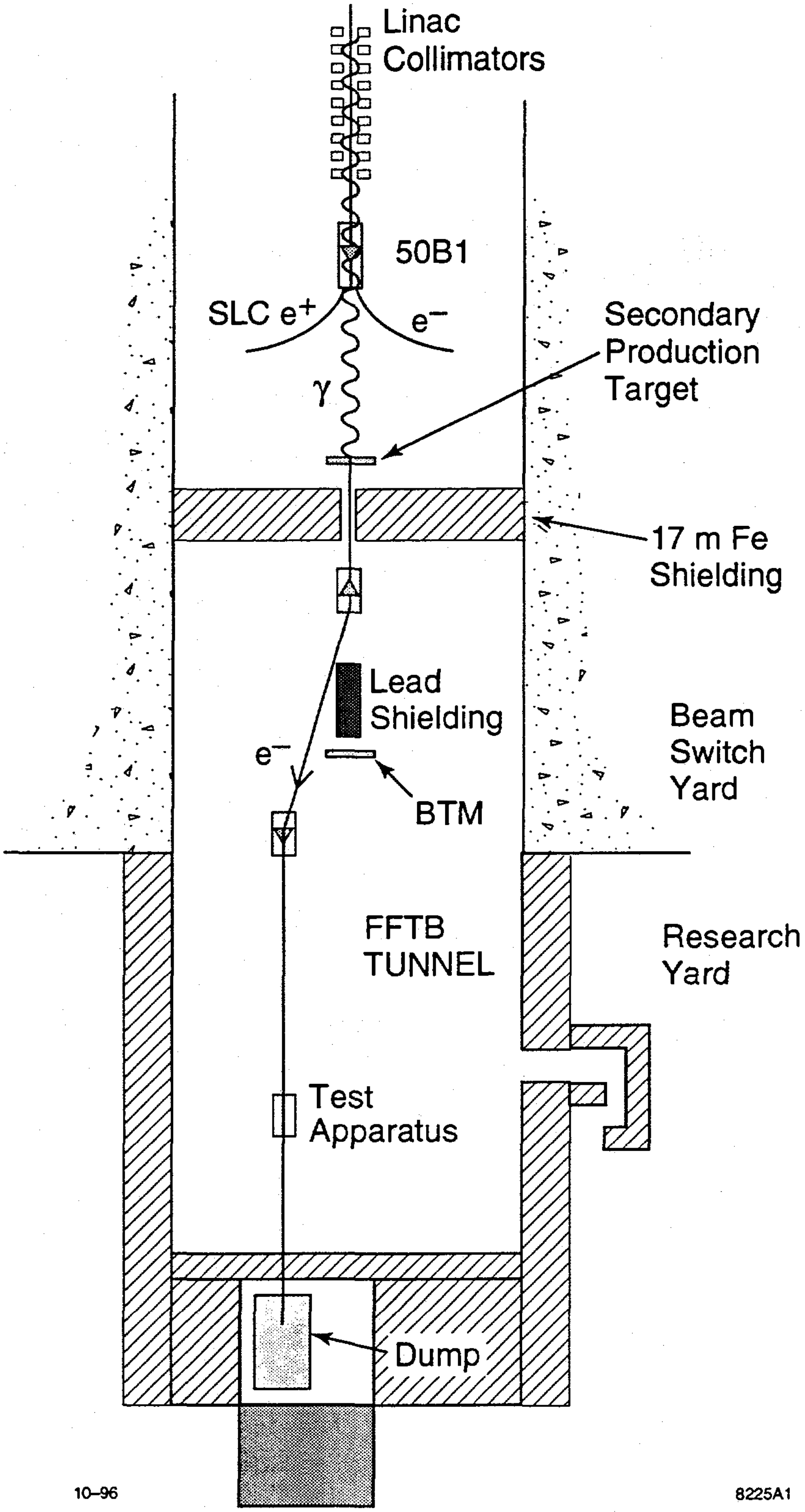
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Fig. 2

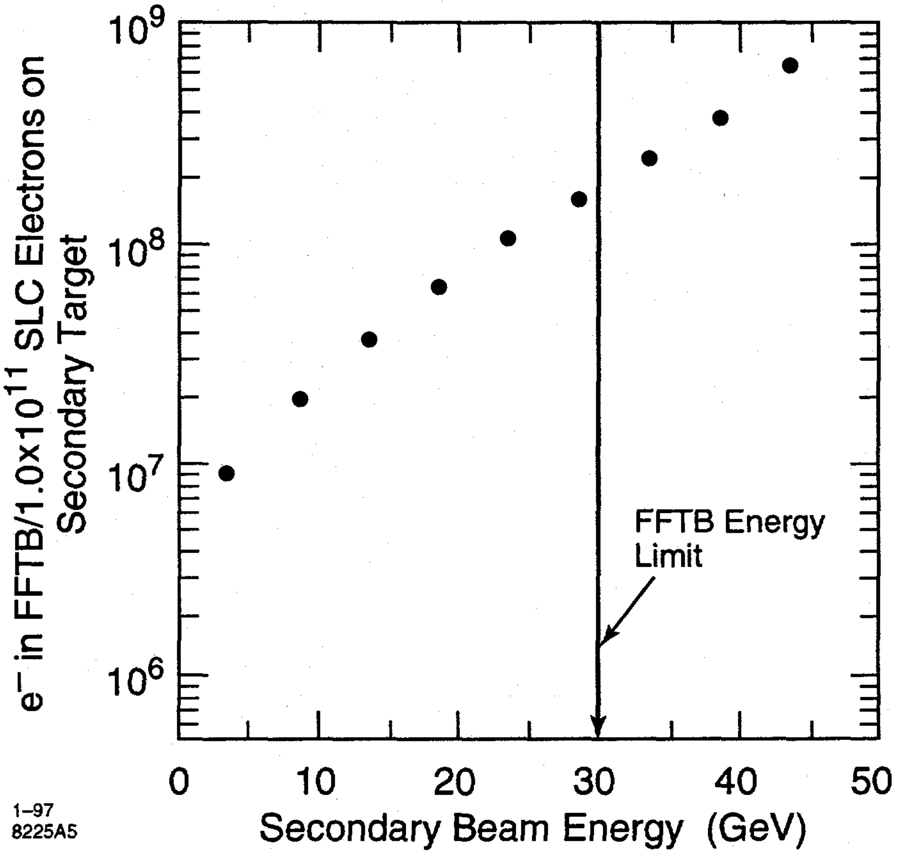
10^9
10^8
10^7
10^6
e⁻ in FFTB/1.0x10^11 SLC Electrons on Secondary Target
0
10
20
30
40
50
Secondary Beam Energy (GeV)
FFTB Energy Limit
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Fig. 3

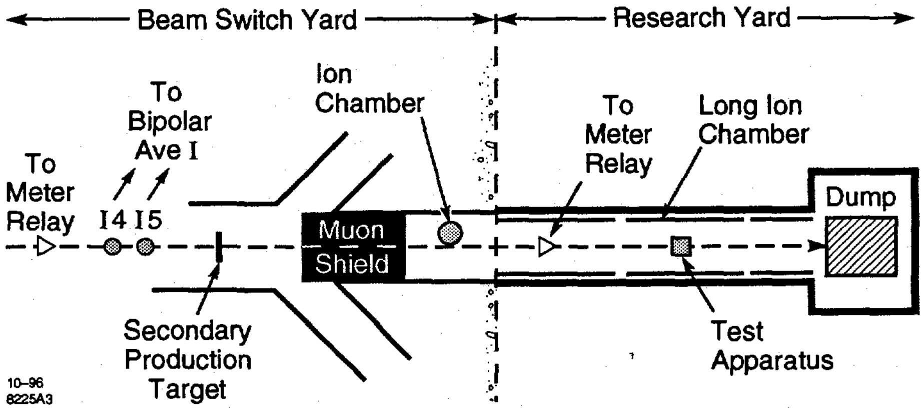
Beam Switch Yard
Research Yard
To Bipolar Ave I
Ion Chamber
To Meter Relay
Long Ion Chamber
To Meter Relay
I4 I5
Dump
Muon Shield
Secondary Production Target
Test Apparatus
10-96
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Fig. 4

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