

SLAC MEMORANDUM

August 1, 2005
RSO-05-06

To: Heinz Vincke and Hesham Khater

From: Sayed Rokni, Radiation Safety Officer



Title: New Electron Source at the NLCTA

Thank you for your memo of July 27, 2005 [1], and your note of July 15, 2005 [2] analyzing the radiation safety aspects of replacing the thermionic gun in NLCTA with a new photoemission gun. Your analysis is thorough and the FLUKA simulations are informative. The request is approved; the work needs to be controlled through the issuance of a new NLCTA BAS.

References:

- 1) H. Vincke and H. Khater, "New Electron Source at the NLCTA," SLAC Memo, July 27, 2005,
- 2) H. Vincke and H. Khater, "Radiation Safety Analysis of the New Electron Source at the NLCTA", Radiation Physics Technical Note, RP-TN-05-12, July 15 2005.

CC:

Jim Allan (RP)
Eric Colby (ARD)
Robert Siemann (ARD)
Keith Jobe (NLCTA)
M. Ross (NLCTA)
F. Asiri (ILC)
T. Raubenheimer (ILC)
Mike Saleski (ADSO)
Paul Miller (ADSO)
William Wisniewski (Chair RSC)
RPG
RSO File

SLAC MEMORANDUM

July 27, 2005

Subject: New Electron Source at the NLCTA
To: S. Rokni
From: H. ~~Vincke~~ ^{HK} and H. Khater
Cc:

We analyzed the request¹ 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.

Approved S.H. Park 8/1/05

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

Radiation Safety Analysis of the New Electron Source at the NLCTA

H. Vincke and H. Khater

Radiation Protection Department, Stanford Linear Accelerator Center
2575 Sand Hill Road, M/S 48, Menlo Park, CA 94025

Introduction:

A memo from Eric Colby [1] describes the installation of a new RF-powered photoemission electron source to be installed at the NLCTA. This gun will replace the old Thermionic gun in the NLCTA. The average beam power of the new gun is about a factor of 5-6 smaller than for the old gun. At the NLCTA chicane the beam power is already a factor of 100 smaller for the new gun, whereas the beam energy is similar (60 - 70 MeV). At 500 MeV electron beam energy the beam power of the new gun is only 5 W compared to ~ 600 W for the old gun. Details are given in [1]. A new 7 MeV spectrometer beam line will be installed down beam of the gun. In the following paragraph a radiation safety analysis for this spectrometer beam line will be discussed.

A vertical bend magnet will direct the full photocurrent (10nA/0.07W) at a 72 degree angle upwards towards the NLCTA roof. The beam will be stopped in a Faraday Cup made of 0.75" thick steel. The Faraday cup is an integral part of the vacuum chamber - without it, the beamline is vented and no beam is possible. The Faraday cup itself will be supported from the 6-way vacuum cross beneath it, which in turn will be supported on a unistrut stand. The roof of the NLCTA consists of 4' thick concrete and is at a distance of 154 cm from the faraday cup.

During commissioning the gun will be operated for 50-60 hours per week, then at least 1-2 weeks per month (40-50 hrs/week) thereafter the usage is depending on the evolving ILC and E-163 programs.

Calculations:

Three FLUKA simulations were performed:

1. A 0.07 W (7 MeV) electron beam is stopped in the Faraday cup and the dose rates outside the concrete shielding (i.e. on the NLCTA roof) were calculated. The FLUKA geometry is shown in Fig. 1.
2. A 0.07 W (7 MeV) electron beam is hitting a 1.65 mm thick beam pipe wall at an angle of 8 degrees. This case simulates that the full beam intercept with the beam pipe and misses completely the Faraday cup.
3. A 0.07 W (7 MeV) electron beam hits the concrete roof. Residual activity in the concrete was scored too.

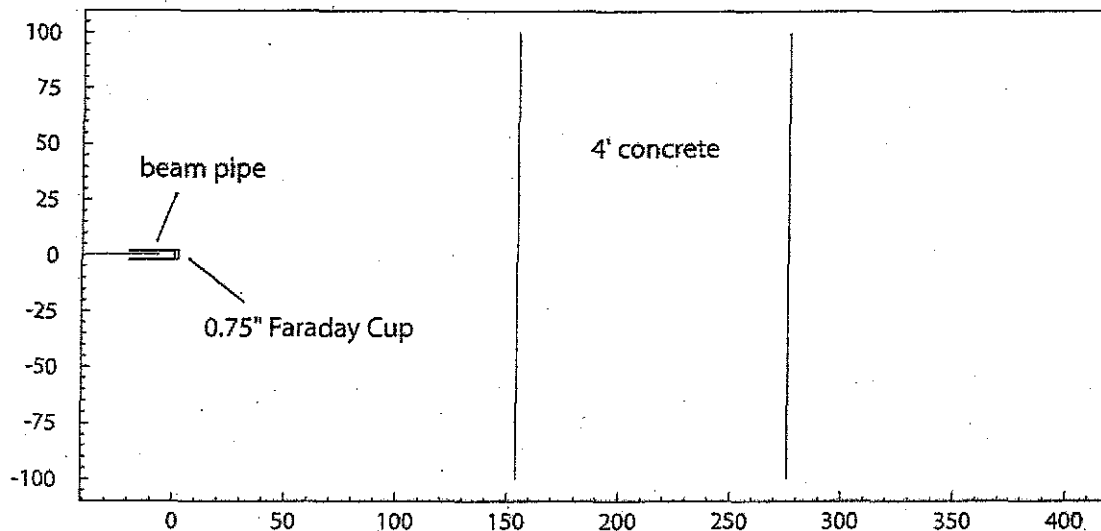


Fig.1: FLUKA geometry – beam hits faraday cup.

For the calculation of the effective dose, the particle fluence was weighted during the scoring procedure by energy- and particle type-dependent conversion factors using the EWMP option of the USRBIN card in FLUKA. This option uses the Pelliccioni data and the concept of the WORST value of effective dose for any body orientation.

Results:

Fig.2 shows dose rate as a function of distance from the Faraday Cup when the beam is stopped in the Faraday cup. A maximum effective dose rate of 0.25 mrem/h at the NCTA roof was calculated. Extrapolating this value to the actual concrete path length (72° compared to 90°) gives approximately 0.1 mrem/h.

At 1 m from the Faraday cup, the dose rate was found to be 4500 mrem/h, see Fig 2. The closest penetration is located ~ 300 cm away from the Faraday cup with an opening of 6" (off beam axis). Scaling the dose rate to 300 cm ($1/r^2$) reduces the dose rate at the beginning of the penetration to 500 mrem/hr. "Universal" attenuation curves for neutron dose published by Goebel et al. [2] was used to determine the dose rate at the NLCTA roof. Applying these curves gives a dose rate of 1 mrem/h on the NLCTA roof. It has been found empirically that photon dose attenuation can also be well predicted by the same curves, and are steeper than the ones of neutrons (i.e. more attenuation). Thus, the real value is lower than 1 mrem/hr. Both of these values are acceptable because the roof is posted as Radiation Area with a gate and very low occupancy factor.

In the second calculation, a 7 MeV (0.07W) beam is intercepted by a 1.65 mm thick beam pipe at an angle of 8°. The effective dose rates due to this beam interaction is shown in Fig. 3. The dose rate on the roof of NLCTA is ~ 0.3 mrem/hr.

In the worst case failure scenario (the so called explosive emission EEE), 92 W of beam power at very large emittances and energy spread and is rapidly lost in the first few meters of transport [1]. Notice that such an event will damage the electron gun. Nevertheless, no hardware interlock will be installed to avoid this event. Assuming that the full 92 W beam is intercepted by the Faraday cup would result in a dose rate of 130 mrem/h outside the concrete shield. This dose rate is well below an accident limit of 25 rem/h.

In the simulation when the electron beam hits the concrete roof, the dose rate at the roof is 1 mrem/hr, see Fig 4. The simulations showed, that the energy of the electron beam is too low to create any neutron or residual activity in the concrete.

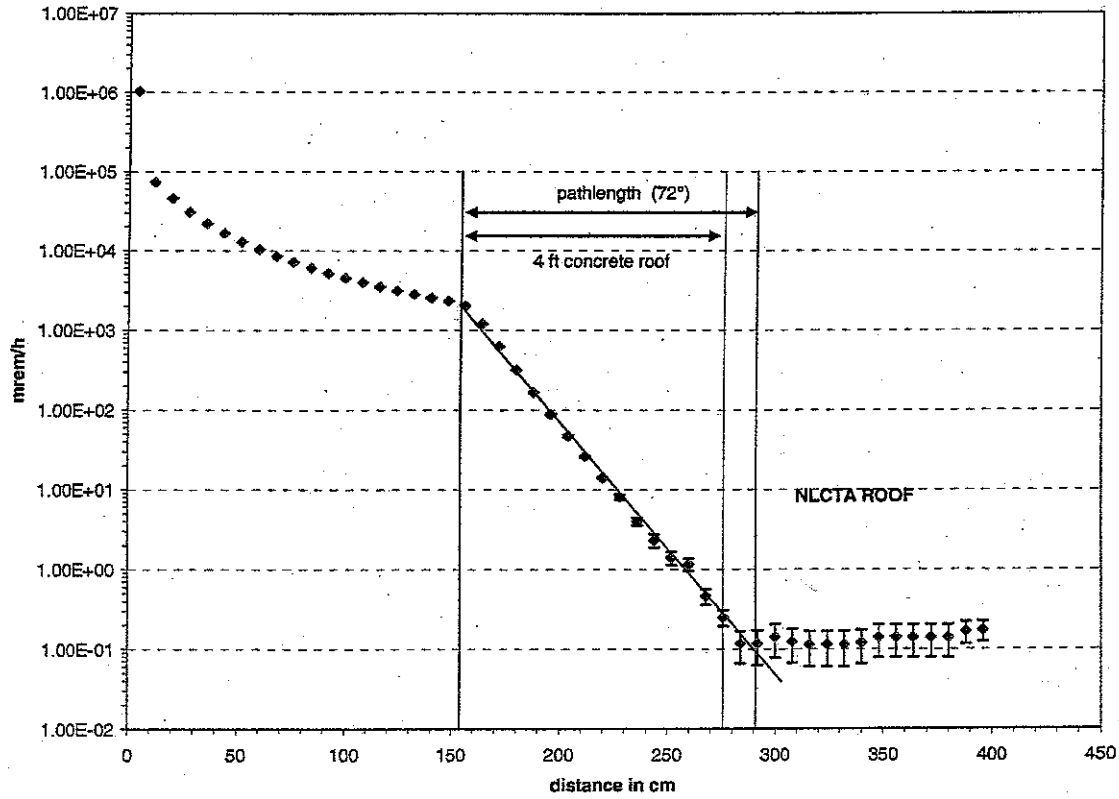


Fig. 2: Total effective dose at the NLCTA roof assuming that a 7 MeV beam is hitting a 1 mm thick beam pipe and with the 0.75 inch thick Faraday Cup (solid symbols). The position of the Faraday cup is at 0 cm.

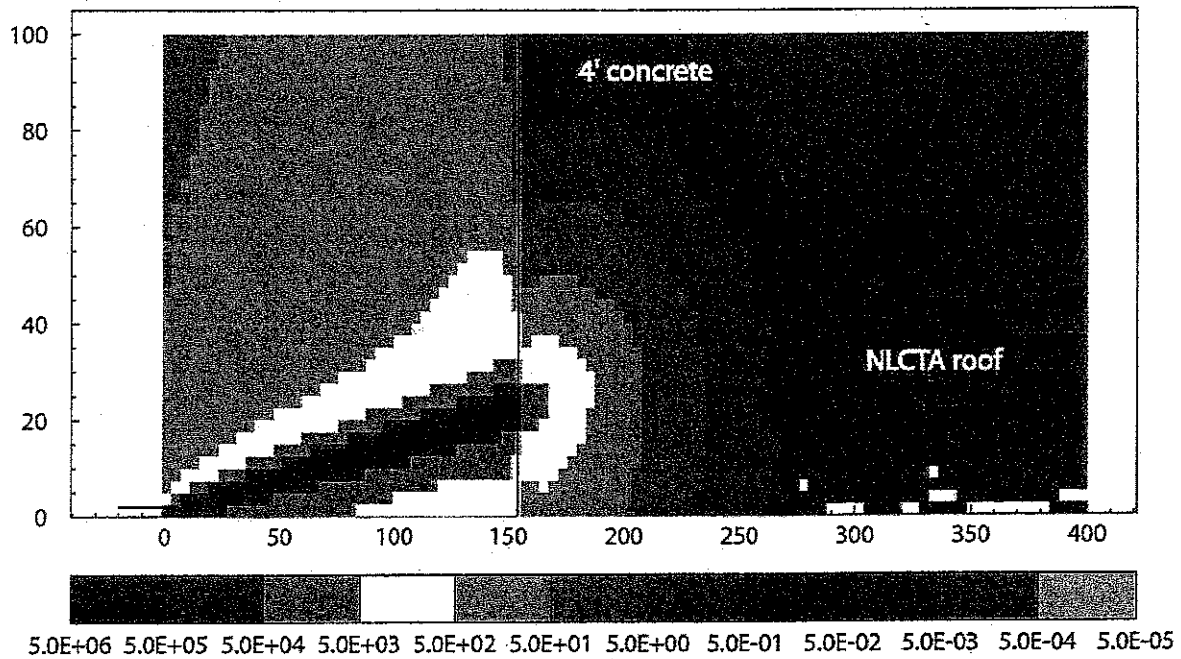


Fig. 3: Total effective dose rate in mrem/h – A 7 MeV (0.07W) electron beam intercepted by 1.65 mm steel pipe at 8°.

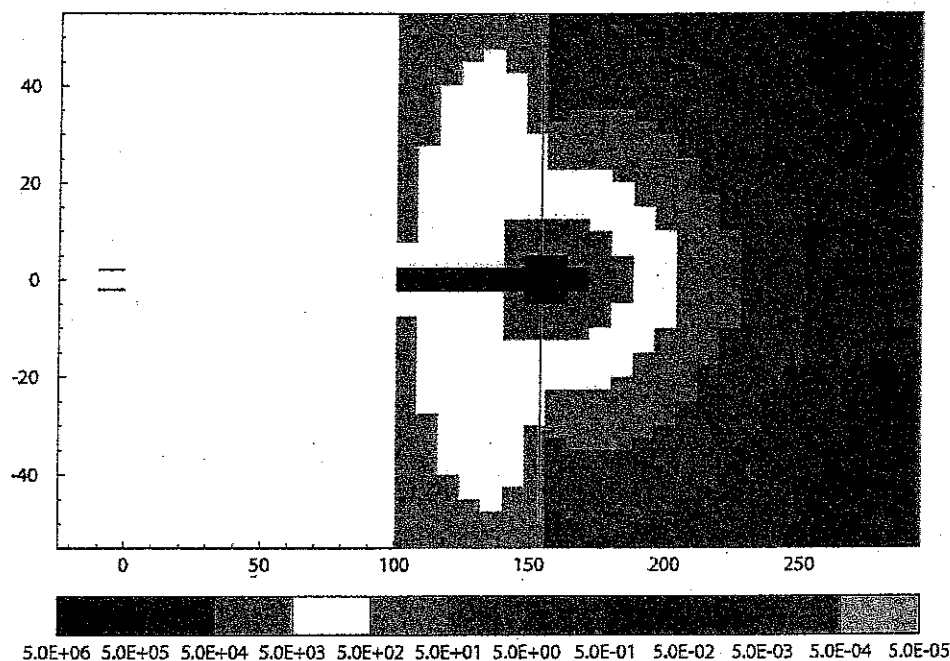


Fig.4: Total effective dose at the NLCTA roof assuming that a 7 MeV beam hits the concrete roof. Units in mrem/h.


Conclusion:

Installation of the new E-163 RF powered gun in the NLCTA does not pose any new radiological hazard in the End Station B. The beam power of the new gun at 500 MeV electron beam energy is a factor of 100 smaller than for the old gun and, therefore, the expected radiation levels during operation are significantly lower. No changes to the present NLCTA shielding or BSOIC placement will be necessary.

References:

- [1] Eric Colby, "Installation of New Electron Source at the NLCTA", SLAC memorandum, May 31, 2005.
- [2] K. Goebel, G.R. Stevenson, J.T. Routti and H.G. Vogt, "Evaluating Dose Rates Due to Neutron Leakage Through the Access Tunnels of the SPS", CERN LABII-RA-Note 75-10 (1975)

SLAC MEMORANDUM

DATE: May 31, 2005
TO: Sayed Rokni, Radiation Safety Officer
FROM: Eric R. Colby, E-163 Spokesman 
SUBJECT: Installation of New Electron Source at the NLCTA

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

The NLCTA presently has a thermionic gun electron source that produces a pulse train of 2 Amperes¹ at 160 kV² with a pulse duration of up to 120 nsec³. 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 μ A, 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 μ C
Beam pulse repetition rate	10 Hz	10 Hz	10 Hz
Average beam current	2.4 μ A	10 nA	23 μ A (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
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

¹ D. Yeremian, *et al*, "NLCTA Injector Experimental Results", in Proc. IEEE Part. Accel. Conf., Vancouver, 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).

As shown in Table 1, even the worst-case failure mode (the so-called explosive electron emission⁴ (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

A 72° 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.

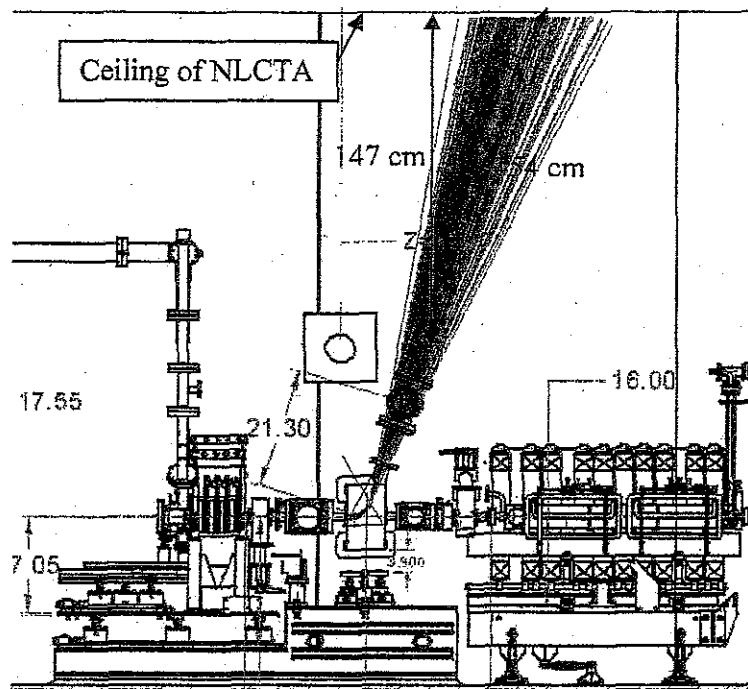


FIGURE 1. Elevation view of photo gun, showing 72° spectrometer and energy analysis beamline. Rays are 200 representative particles showing the EEE beam trajectory in the absence of any materials (e.g. spectrometer iron, dump, flanges, vacuum chamber, etc.)

⁴ E. Colby, "Explosive Electron Emission Loss Calculations for E-163", memo sent to Heinz Vincke, (2004).

In the worst-case scenario, the bend dipole is on when the EEE beam is produced (23 $\mu\text{A}/92\text{W}$). 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.

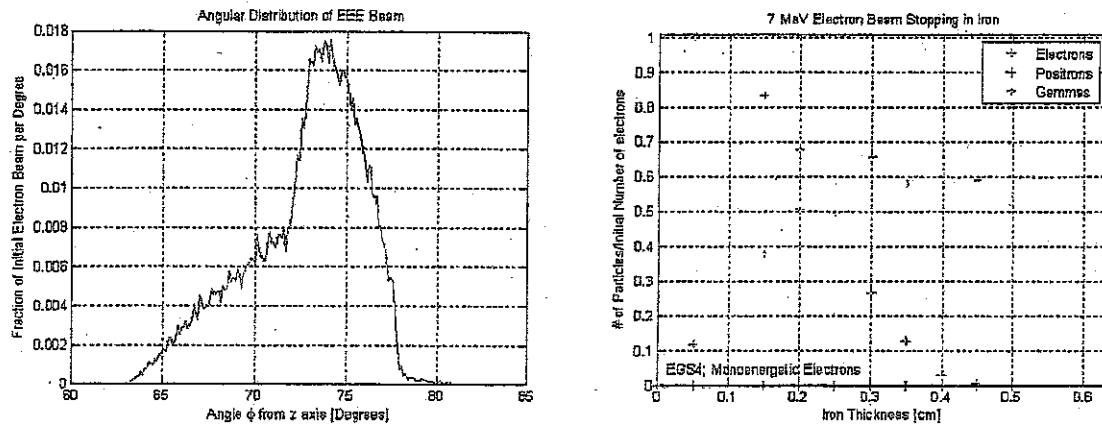


FIGURE 2: Angular distribution (left) of EEE beam at nominal spectrometer bend field, and range out of monoenergetic 7 MeV electrons (right) in elemental iron, from EGS4.

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.