TITLE: **SECTOR 30 COLLIMATOR RADIATION****

AUTHORS: Y. Namito*, W. R. Nelson and E. Benson

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INTRODUCTION. The collimators at Sector 30 of the SLAC accelerator are designed to scrape off a significant fraction (e.g., ~ 20%) of the SLC beam. The electromagnetic cascade shower that develops in the collimator, and in the scraper and waveguide downstream, leads to very high radiation exposures of TV cameras (and other devices) located nearby.

EGS4¹ calculations were performed in order to quantify the dose-rate distribution at various locations in the SLAC tunnel. Measurements were also made along the waveguide that are in general agreement with these calculations. Two main sources that lead to radiation exposure of the TV camera are:

1. High-energy shower leakage from the titanium collimator that passes over the top of the downstream copper scraper (a point source).
2. Low-energy (scattered) radiation from the showers in the waveguide (a line source).

The collimator (point) source accounts for one-third of the dose and is best shielded by extending the radius of the copper scraper. Radiation from the waveguide accounts for the remaining two-thirds of the dose, and is difficult to shield since it is a line source. However, the spectrum from the waveguide is expected to be softer than that from the collimator.

It should be noted that after these measurements were made, the camera was shadow-shielded from the waveguide source by a 2-inch lead wall placed near and along the length of the camera. Although this may have effectively reduced the line-source component, the 2-inches only extends the showering of the high energy collimator source so that the total total dose rate has probably not changed significantly from what it was prior to installation of the wall. Placing a 1-inch lead collar around the scraper should improve this situation.

ABSORBED DOSE MEASUREMENTS. Five red perspex dosimeters were taped onto structures above the accelerator along a line-of-site starting near the collimator (at Sector 29-9) and ending at a TV camera located about 40-feet downstream and approximately 40-inches above the centerline of the beam. This is shown in Fig. 1 along with two additional detectors which were positioned below the TV camera.

* On leave from the Ship Research Institute, Japan.

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Figure 1. Locations of red perspex dosimeters.

The detectors were removed after one month of SLC operation at various intensities and at beam energies ranging between 45.5 and 47.0 GeV. After obtaining the dose estimates from the darkened plastic, the data were normalized to a *crude estimate* of the total number of electrons striking the collimator during the integration period (29 June through 26 July 1989).

The total number of electrons accelerated during this period was readily obtained from the SLC computer log ("SLAC Monthly Report"). The fraction of the beam intercepted by the collimator was estimated to be $20 \pm 5\%$. The coloration dosimetry technique, which is subject to a number of external effects including fading, was estimated to be accurate only to $\pm 50\%$ and clearly is the dominating source of uncertainty in this experiment.

EGS4 - GEOMETRY AND SCORING. A cylinder-slab geometry², consisting of five concentric cylinders and 601 planes for a total of 3607 tracking regions, was used in order to simulate fully the collimator, drift spaces, scraper, and disk-loaded waveguide leading up to and past the TV camera location*.

In its fully-closed position, the collimator was represented by a 2.1 r.l. solid cylinder of titanium alloy[†] centered on the accelerator axis, with an outer diameter the same as the 4-inch accelerator waveguide. This was followed by a 22.75-inch vacuum drift space, a 12.0-inch copper scraper (0.67-inch I.D.), another 10.5-inch vacuum space, and finally by the disk-loaded copper structure (0.875/3.24-inch I.D.). A final 100-inch diameter cylinder was placed concentrically around the collimator/waveguide structure for particle-discard purposes in the EGS4 simulation.

Particles leaving the waveguide were scored when they crossed planes at locations where red perspex detectors had been placed. The particle fluence was converted to absorbed dose using surface-dose factors taken from tables by Rogers³.

* EGS4 User Code called UCSECT30 (GIME EGS4)

† 6% Al, 4% V, $\rho = 4.37 \text{ g/cm}^3$, $X_0 = 3.77 \text{ cm}$.

COMPARISON OF RESULTS. In Fig. 2 the experimental results are compared on an absolute basis with the EGS4 simulation as a function of the distance along the waveguide measured from the titanium collimator.

Figure 2. Absorbed dose along the waveguide (per 10^{12} incident $e^\pm$).

Considering the uncertainties involved in both the measurement technique and in estimating the number of electrons striking the collimator during the one-month exposure, the agreement is remarkably good. At the TV camera location ($z \approx 480$ inches), the measured dose is approximately 2×10^{-12} rad/inc, whereas EGS4 calculates 3×10^{-12} rad/inc, which is within the $\pm 56\%$ experimental uncertainty.

The five experimental points were fit to a function of the form $D = C/z^m$. As indicated by the dotted line in Fig. 2, the dose falls off as $1/z^{1.8}$, suggesting that two (or more) sources may be contributing—for example, radiation emanating as a point source from the collimator-scrapers area, and (possibly) a line source of radiation along the waveguide.

Table 1, taken from the EGS4 calculation, shows where all the energy goes. Almost half (45.1%) continues through the waveguide aperture, a significant fraction of which will eventually strike beam components (including waveguide) downstream of $z \approx 522$ inches. Part of the 43.7% that escapes radially from the waveguide contributes to the dose estimates described above.

Table 1
Energy Deposition and Escape Percentages

Backscatter	0.04%
Collimator	1.4%
Scraper	7.6%
Waveguide	2.2%
Downbeam escape	45.1%
Waveguide escape	43.7%

ADDITIONAL EGS4 CALCULATIONS. To understand better the origin of the particles that contribute to the scoring of dose near the TV camera location ($z \approx 480$ inches), the following technique was used.

Whenever a particle *first* exited the outer surface of the waveguide, its z -position was "tagged"—i.e., assigned to a parameter called ZLATCH—and passed along with the particle (or any subsequent progeny) during the transport. At the TV camera plane, the dose was scored into a 2-D histogram as a function of ZLATCH and the radial distance from the waveguide axis. The results are shown for electrons ($\pm$) and photons in Figs. 3A and 4A, respectively, where *two* groups of peaks stand out in both plots.

One group (large radii, small ZLATCH) is due to shower radiation coming directly from the collimator over the top of the 12-inch copper scraper located 25.9-inches downbeam. Figures 3B and 4B are radial slices for the second ZLATCH-bin, corresponding to $20 \leq \text{ZLATCH} < 40$ inches, for electrons and in photons, respectively. In either case, there is a sharp rise at a radius of $R = 36$ to 40 inches which is consistent with the scraper shadowing the collimator at $R = 480 \times 2/25.9 = 37$ inches along the TV plane.

The second group is not as distinct and represents radiation emanating all along the waveguide, but predominately near the scoring plane located near 480-inches. We are primarily interested in radiation crossing the TV camera near $R = 40$ -inches. Figs. 3C and 4C are slices along ZLATCH, representing the sum of 8 radial bins from $R = 36$ to $R = 44$ -inches for electrons and photons, respectively.

From these slices we can determine how the dose is distributed by source location and by particle component, as demonstrated in Table 2.

Table 2

Dose to TV Camera ($\text{rad}/10^{12}$ inc)

	$e^\pm$	γ	TOTAL
Collimator	0.95	0.04	0.99
Waveguide	1.29	0.72	2.01
TOTAL	2.24	0.76	3.00

The 3×10^{-12} rad/inc total is the number that we have previously compared with measurement (2×10^{-12}) and plotted in Fig. 2. From this table we see that one-third of the dose is due to radiation coming directly from the collimator as a result of the beam scraper diameter not being large enough for proper shadowing.

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ELECTRON DOSE - FIG. 3A

Figure 3. Electron dose as a function of radius and ZLATCH.

PHOTON DOSE - FIG. 4A

Figure 4. Photon dose as a function of radius and ZLATCH.

Another way to demonstrate this is shown in Table 3, where the total dose ($\gamma + e^\pm$) is listed for three different radial positions along the TV scoring plane—i.e., the three vertical points shown along the dashed line in Fig. 1.

Table 3

Total Dose vs. Radial Position (rad/ 10^{12} inc)

	Collimator	Waveguide	TOTAL	Measured
40-in.	1.0	2.0	3.0	2
25-in.	-	3.2	3.2	2
10-in.	-	8.0	8.0	4

The 40-inch data come directly from Table 2. The calculated data for the other two radii are scaled from the 40-inch data under the assumption that

1. the direct (collimator) component is shielded by the scraper and drops out below a radius of about 37-inches, and
2. the waveguide acts as a $1/R$ line source.

The measured values, also presented in Table 3, are consistent with an approximate $1/R$ scaling, particularly since the experimental uncertainties are so large.

CONCLUDING REMARKS. It appears that two sources are involved in the irradiation of the TV camera immediately downbeam of Sector 29-9. Of these, 33% comes directly from the collimator and 67% emanates indirectly from a line source located all along the waveguide.

Since the angle from the collimator to the TV camera is about 5° , the energy of the radiation spraying out of the 2-r.l. titanium collimator is expected to be higher than that coming from the waveguide. Stated another way, both the material thicknesses and angles associated with the waveguide are larger, and this should make the spectrum softer.

Subsequent to these measurements, the TV camera was shielded with approximately 2 inches of lead along and parallel to its length. How effective this lead wall is in shielding against the waveguide radiation can be estimated by using Table 2 as follows:

1. Assume that the electron component from the waveguide (1.29×10^{-12}) is reduced to zero by the additional lead.
2. Assume that the remaining photon component (0.72×10^{-12}) transmits with $\mu/\rho = 0.0116 \text{ cm}^2/\text{g}$ as determined by the the Compton minimum in lead at 3 MeV. Also use the Berger form of the buildup factor⁴.
3. The result is a dose reduction factor of 0.19, which leads to a dose of 0.14×10^{-12} rad/inc.

However, the 2 inches of lead is expected to have an adverse effect on the high-energy direct component coming over the top of the scraper. To be specific, the lead wall is 9 r.l. thick and, together with the 2 r.l. of the titanium collimator itself, leads to a substantial buildup of the shower without much attenuation. Fig. 5 shows the

charged-particle buildup of 50-GeV electrons in titanium. The fraction of charged particles at 2 r.l. is 27, whereas at 11 r.l. it is 60—a factor of 2.2 increase.

Figure 5. Charged-particle buildup in a 50 GeV electron shower in titanium.

Therefore, one might expect to see an *increased* radiation level of 2×10^{-12} rad/inc. directly from the collimator as a result of shower buildup in the lead wall, in spite of the fact that the lead wall could effectively reduce the component from the waveguide. Obviously, the solution to this problem is to provide more shadow-shielding near the collimator source, while maintaining the lead wall shielding as is for the waveguide source*. A 1-inch collar is recommended, which represents a slant thickness greater than 50 r.l.

Since scrapers do not exist downstream of the other three titanium collimators, further study of the geometry is warranted in order to determine if there are similar ways of eliminating the direct component.

REFERENCES

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* Note: The backward contribution from the collimator near the TV camera has been calculated to be two orders of magnitude less than the two sources described above).