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Subject: Temperature Rise Calculations for the Beam Pipe in the SLC Arcs.

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SUMMARY.

This note presents the results of EGS calculations for 50 GeV electron beams showering in 1mm thick slabs of copper and aluminum at glancing angles. The maximum temperature rise for 50 μ (Gaussian σ) beams of $5 \times 10^{10} e^-/\text{pulse}$ was found to increase with angle, ranging from about:

- 300 to 700 °C/pulse (copper)
- 50 to 100 °C/pulse (aluminum)

for angles of incidence between 0.1 and 10 mradians. The results are also applicable to slabs thicker than 1mm within this angular range. For larger angles, where shower leakage out the back becomes important, the slabs were made thicker. These extended results (see last figure) are applicable for all angles of incidence and should be useful for calculating the maximum temperature rise in such devices as collimators and slits.

DESCRIPTION OF CALCULATIONS.

It was pointed out in CN-135¹ that the danger of accidental damage to SLC components due to heating is greater than previously encountered at SLAC, necessitating the use of beam spoilers to increase the beam spot size, thereby decreasing the energy-densities for each beam pulse. In this present note, however, we address the problem of small electron beams ($\sigma \approx 0.05\text{mm}$) striking thin slabs ($\approx 1\text{mm}$) of copper or aluminum at glancing angles (0.1 to 10 mradians). The wall thickness of the cylindrical beam pipe was approximated by a slab geometry.

A single 50 GeV shower generated by EGS in a 1mm copper slab is shown in Fig. 1 (five frames), where only charged particle trajectories have been plotted and these only inside the copper slab. The scale has been expanded in the direction of the slab thickness, which is 1mm. Each frame is 2 radiation lengths long ($1r.l. = 1.49\text{cm}$) for an overall slab length of 10 radiation lengths. The incident angle is 3 mradians with the point of incidence being at the lower left corner of the topmost frame. It is quite easy to 'see' the beam direction in each slab since it is the line of most particle density, and thus the greatest energy deposition. The arrows at the beginning and end of each frame simply indicate the 3 mradian beam direction.

A new version of EGS, called EGS4,^{*} was employed using a slab geometry User Code.^{**} With EGS4, it is now easy to introduce variance reduction schemes in order to improve the efficiency for generating showers. This was found to be important for the problem of beam pipe heating since the beam spot had to be sampled over a Gaussian distribution (we used $\sigma = 0.05\text{mm}$). For example, a typical 50 GeV shower event takes slightly less than one minute on the IBM-3081 using EGS3; consequently, very few samples can be taken over the beam spot in any reasonable time (e.g., 20 showers per 20 minute run). By introducing importance sampling into EGS4, however, we were able to generate between 1000 and 6000 showers per minute, depending on the material, slab thickness, and angle of incidence, which is a tremendous improvement in efficiency.

The importance sampling technique used in EGS4 is known as 'leading particle biasing'.² The procedure is quite simple. Since we know that the electromagnetic shower predominantly involves bremsstrahlung and pair production interactions, and since the high energy particles are the most influential, we should be able to speed up the calculation by forcing the selection of the 'leading

^{*} To use EGS4 issue the command GIME EGS4 followed by EGS4RUN.

^{**} SLAC VM Ellis UCCLBP4 MORTAN (on the WRNRP 103 disk).

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particle'—i.e., the higher of two energies in any bremsstrahlung or pair production interaction—discarding the lower energy partner. However, to 'play the game fairly', one must

- (1) select (i.e., random sample) the lower energy particle some of the time, and
- (2) assign an appropriate weight factor to the particle selected each time.

Then instead of counting particles, we sum weights and also weight the energy deposition.

In order to demonstrate that this technique indeed gives accurate results, the EGS3 calculations presented in CN-135¹ were repeated for electron beams of various sizes at normal incidence on infinite slabs of Cu and Al. Typical results are shown for copper in Figs. 2 through 4. At the beginning of the shower (Fig. 2) the radial distributions calculated by EGS3 and EGS4 (with biasing) are identical everywhere. Deep in the shower (e.g., 10 to 11 r.l., Fig. 3) the results are identical except for the first radial bin, where the EGS3 results are systematically higher. The reason for this difference is not clear, but it is also not important for the present problem since the maximum temperature rise occurs early in the shower. This is shown in Fig. 4, where the maximum from each of the radial distributions is plotted as a function of the shower depth. The agreement between EGS3 and EGS4 (with biasing) is excellent for the $\sigma = 0\text{ mm}$ beam except around 10 r.l., as we have just discussed. For $\sigma = 0.05\text{ mm}$, EGS4 also agrees with the EGS3 points, which were obtained by means of a convolution scheme applied to the $\sigma = 0\text{ mm}$ results (see CN-135).

Assuming that EGS4 (with biasing) works, we are then able to take advantage of the dramatic increase in speed in order to obtain a fairly large sampling over the beam spot itself. In Fig. 5 we plot the maximum energy deposition and corresponding temperature rise in Cu for $\sigma = 0.05\text{ mm}$, where the plus symbols are for a glancing angle of 0.7 mradians (1mm slab) and the histogram is for 90° incidence (thick slab). Clearly, the effect of the glancing angle is to push the maximum deeper along the shower axis, and to flatten out the energy deposition (with a corresponding reduction in the maximum temperature rise). The explanation is simple. Particles selected with $\pm 1\sigma$ enter the slab at $\pm 5\text{ r.l.}$ relative to the origin of the shower coordinates, and the average longitudinal development of the cascade is shifted accordingly.

In Figs. 6 and 7 we give the maximum temperature rise for both Cu and Al, respectively, and for glancing angles of incidence ranging from 0.1 to 10 mradians. The curves were drawn by eye. The rapid drop at 10 mradians for both materials is caused by the shower penetrating the back side of the slab. A simple calculation will reveal that this is expected to occur at 6.9 and 1.1 r.l. for 1mm slabs of Cu and Al, respectively. For aluminum the maximum temperature has probably not quite been reached before the 10 mradian shower leaks out the back side of the slab; in the case of copper, it has.

The 0.1 to 10 mradian data should be applicable to slabs thicker than 1mm for the simple reason that the maximum temperature rise is caused by the early development of the 'core' of the shower, which remains inside the slab. In order to extend the calculations to larger angles of incidence, the slab thickness was increased. The results are plotted in Figs. 8 and 9 for angles between 0.1 mradians and 90°. The straight lines are least square fits to the data in this range.

CONCLUSIONS.

For the range of practical interest for the SLC arc beam pipe (0.1 to 10 mradians), the maximum temperature was found to increase from 300 to 700 °C/pulse for copper, and from 50 to 100 °C/pulse for aluminum. For thicker pipes and larger angles the highest temperature is reached at 90°, where it is about 1100 °C for copper and almost a decade lower (125 °C) in aluminum.

REFERENCES

1. S. Ecklund and W. R. Nelson, "Energy Deposition and Thermal Heating in Materials Due to Low Emittance Electron Beams", CN-135, 1981.
2. A. Van Ginneken, Lecture 14 in Computer Techniques in Radiation Transport and Dosimetry, W. R. Nelson and T. M. Jenkins, eds. (Plenum Press, New York, 1980).

FIG.1: Five frames of an electromagnetic cascade initiated in a 1 mm slab of Cu by a single 50 GeV electron incident at a 3 mradian glancing angle. To avoid confusion, only charged particle tracks inside the slab are shown.

FIG.2: E-DEPOSITION AND TEMPERATURE RISE
FOR ELECTRON BEAMS OF VARIOUS SIZES

FIG.3: E-DEPOSITION AND TEMPERATURE RISE
FOR ELECTRON BEAMS OF VARIOUS SIZES

FIG.4: MAXIMUM E-DEPOSITION AND TEMPERATURE
RISE FOR ELECTRON BEAMS OF VARIOUS SIZES

FIG.5: MAXIMUM E-DEPOSITION AND TEMPERATURE
RISE FOR ELECTRON BEAMS WITH $\sigma = 0.0$ mm

FIG.6: MAXIMUM E-DEPOSITION AND TEMPERATURE
RISE FOR ELECTRON BEAMS WITH $\sigma=0.05$ MM

FIG.7: MAXIMUM E-DEPOSITION AND TEMPERATURE
RISE FOR ELECTRON BEAMS WITH $\sigma=0.05$ MM

FIG.8: MAXIMUM TEMPERATURE RISE VERSUS
SIN θ FOR ELECTRON BEAMS WITH $\sigma=0.05$ MM

FIG.9: MAXIMUM TEMPERATURE RISE VERSUS
SIN θ FOR ELECTRON BEAMS WITH $\sigma=0.05$ MM