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Subject: Temperature Rise in the Lambertsen Septum Magnet Associated with the Positron Target.

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ABSTRACT. This note presents the results of EGS calculations and simple analytic models for the temperature rise in a spoiler, and magnet iron following such a spoiler, for a 33 GeV electron beam. Temperature rises in both spoiler and magnet iron of less than $100^\circ\text{C}/\text{pulse}$ are possible for 100μ (Gaussian σ) beams of $5 \times 10^{10} e^-/\text{pulse}$. The results, given in graph form in Fig 5, should allow for easy optimization of spoiler thickness and spoiler-to-magnet separation distances.

INTRODUCTION.

The Lambertsen septum magnet associated with the positron target will have high current, high density beams near the poles of the magnet. To protect the magnet from damage due to heating or thermal shock, a collimator may be placed upstream which will act as a spoiler to any beams which may be missteered. The spoiler should be made thick enough (i.e., $1 X_0$ thick) to blow up the beam through multiple scattering such that the resulting heat rise when the beam strikes the magnet will be within tolerance levels.

There was some concern, however, that since a majority of the beam's energy is converted into bremsstrahlung ($\approx 63\%$ in $1 X_0$) and the angular spread of bremsstrahlung is some 28 times less than the spread of the electron beam due to multiple scattering, the temperature rise would still be too great. That is, the Gaussian width for electrons due to multiple scattering is

$$\theta_{MS} = \frac{14.1 \sqrt{t}}{E_0},$$

and for photons the characteristic angle for bremsstrahlung is

$$\theta_{brems} \approx \frac{m}{E_0}.$$

Therefore, for a $1 X_0$ target,

$$\frac{\theta_{brems}}{\theta_{MS}} \approx \frac{m}{14.1} = \frac{1}{28}.$$

The temperature rise is essentially proportional to energy density which is inversely proportional to area. Thus, with the ratio of areas proportional to θ^2 , we have

$$\left(\frac{\theta_{brems}}{\theta_{MS}}\right)^2 = \left(\frac{28}{1}\right)^2 \approx 800.$$

That is, the energy density from the bremsstrahlung could result in very high temperature rises in the magnet, perhaps $0.63 \times 800 = 500$ times greater than from the multiply scattered electrons.

CALCULATIONS.

EGS.

The new version of EGS, called EGS4^{*} and referenced in CN-245¹, was employed using leading particle biasing. The slab geometry user code, UCLAM01^{**}, was written to follow energy

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

^{**} SLAC VM fileid: UCLAM01 MCRTAN (on the WRNRP 163 disk)

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deposition either in the spoiler or in the septum magnet. For all calculations, the width of the incident electron beam was $\sigma_x = \sigma_y = 100\mu$. Distance between the upstream face of the spoiler and the magnet face was set at 100 cm for the initial calculations, and was reduced to 50 cm to see the effect of moving the spoiler closer to the magnet. The spoiler, an alloy of Ti (92.5%), Al (5%) and Sn (2.5%), has an atomic mass of 48.82 and a density of 4.48 g/cm^3 . For this alloy, the conversion factor, f_T , is $114^\circ\text{C} \sim \text{cm}^3/\text{pulse}$, about 1.5 times that for iron. Input energy, E_0 , was 33 G-V, and the temperature rise calculations were done for 5×10^{10} electrons/pulse.

Fig 1 is an end view sketch giving an idea of the relative positions of the straight-ahead beams (upper) and the bent 'scavenger' beam (lower) with respect to the magnet faces. If misterring were to occur, either beam could impinge on the magnet iron.

The next figure shows the EGS side view representation of the spoiler and magnet which is typical of the geometry of these types of calculations. As shown in this figure, the magnet has been divided into radial as well as longitudinal bins, only some of which are shown. For studies of energy deposition in the spoiler, it too was subdivided into longitudinal bins which are not shown on the figure.

Figs 3 and 4 show the temperature rise in the spoiler and magnet as generated by EGS for spoiler thicknesses of $0.25 X_0$ and $1.0 X_0$, respectively. In these figures, the maximum temperature rise, which may have occurred in one of the outer bins rather than the core bins along the beam center line, is plotted. From these figures, we see that the temperature rise in the magnet is pleasantly quite low after a $1 X_0$ spoiler, on the order of $\approx 100^\circ\text{C}/\text{pulse}$.

EGS was run for different spoiler thicknesses, and for spoiler-to-magnet separation distances of 100 and 50 cm, respectively. The results, presented in Fig 5, should allow one to determine an optimum choice of thickness/distance combination.

Analytic.

Temperature rise also may be calculated analytically for the spoiler only. For $5 \times 10^{10} \text{ e}^-/\text{p}$, the temperature conversion factor, f_T , can be given by

$$f_T (^\circ\text{C} - \text{cm}^3/\text{p}) = \frac{E_0 \cdot 10^6 \cdot 1.6 \times 10^{-19} \cdot 5 \times 10^{10} \cdot A}{c_P \cdot \rho \cdot (4.184)} \\ = \frac{3.2 \times 10^{-4} E_0 A}{\rho}$$

where c_P	= $8 \text{ (cal/mole/}^\circ\text{C)}$,
4.184	= conversion from Joules to calories,
1.6×10^{-19}	= Coulombs per electron,
A	= Atomic mass, (g/mole) ,
ρ	= density, $(\text{g} - \text{cm}^{-3})$,
E_0	= electron energy in MeV.

Let $f(r)$ be the fraction of incident electrons within a cylinder of radius, r . For an incident Gaussian beam of width, σ , $f(r) = 1 - e^{-r^2/2\sigma^2}$. If the innermost cylinder has $r = \sigma$, then $f(r) = 0.393$.

Also, for small bin thicknesses, the fraction of energy lost per unit volume is given by

$$\frac{\Delta E}{\Delta V} = \left(\frac{1}{E_0} \right) \frac{S \cdot \rho}{\pi \sigma^2}$$

where S = stopping power² in $\text{MeV} - \text{cm}^2/\text{g}$ and σ = beam size in cm.

Thus, the temperature rise, ΔT , is

$$\Delta T = f_T \cdot \frac{\Delta E}{\Delta V} \cdot f(r)$$

$$= \frac{3.2 \times 10^{-4} \cdot A S f(r)}{\pi \sigma^2}$$

$$= 1.0 \times 10^{-4} \frac{A S f(r)}{\sigma^2}$$

The temperature rise with $r = \sigma = 100\mu$ (i.e., 10^{-2} cm) is

$$\Delta T = 1.0 \times 10^{-4} \cdot 0.393 \cdot \frac{48.62}{(10^{-2})^2} \cdot S$$

$$= 19 S.$$

If one uses an restricted stopping power for S, then $S = 2.1 \text{ MeV} \cdot \text{cm}^2/\text{g}$. However, some of the delta-rays produced along each incident track will escape the cylinder volume and will not be completely replaced by delta-rays entering from outside the volume. This effect suggests that we use a restricted stopping power for S, which can be determined once we know the energy of those delta-rays that, on the average, will escape the cylinder. The latter can be obtained from a range-energy table² and the mean chord length in the cylinder. For this problem, we use a mean chord length, l , across a cylinder of radius, r , and length, L , of

$$l = \frac{4 \times \text{Volume}}{\text{Surface Area}} = \frac{2L}{(1 + \frac{L}{r})},$$

and this results in $S \approx 1.3 \text{ MeV} \cdot \text{cm}^2/\text{g}$ for $\sigma = 100\mu$, and for $10^{-3} \leq L \leq 10^{-1} \text{ X}_0$.

Using the two values of S given above, the calculated values for ΔT are 25°C/p (restricted S) and 40°C/p (unrestricted S). These are shown by arrows in Fig 5 which, not too surprisingly, lie above and below the EGS value.

DISCUSSION.

Obviously the bremsstrahlung, which contains $\approx 2/3$ of the energy, isn't concentrated in such a small cone as was postulated. The explanation for why this happens can be derived from an examination of the spectra and radial distributions of electrons, photons and positrons emerging from the spoiler and impinging upon the iron of the magnet.

The radial distributions of the particles impinging on the magnet from the spoiler are shown in Figs 6 - 8. The maxima can be seen to occur at radii of $\approx 540\mu$ for electrons, $\approx 210\mu$ for photons and $\approx 650\mu$ for positrons. The radial distributions are of the form,

$$\Delta N = r e^{-r^2/2} r_{ms}^2 \Delta r,$$

so that the maximum should occur at $r = r_{ms}$. Assuming that all distributions are Gaussian, the r_{ms} for the electron radial distribution can be approximated by (adding in quadrature)

$$r_{ms}^2 = r_0^2 + r_{MS}^2 \quad (1)$$

where r_0 is the incident beam width $= 100\mu$, and

$$r_{MS} = \frac{100 \text{ cm} \cdot 14.1 \sqrt{t \cdot 10^6}}{E_0}$$

$$= 427\mu,$$

* The stopping powers were calculated using formulae from reference 2 (See STOPOWER MORTAN on the WRNRP 102 disk). Note: $\lambda_{Fe}^2 = 0.47$ and $\lambda_{Ti}^2 = 0.48$; hence Fe data was used.

for $t = 1 X_0$, as in all subsequent examples. This gives a value for r_{rms} for electrons of 440μ which compares reasonably well with the value from Fig 6 of about 540μ .

For photons, we use an r_{rms} that is given by

$$r_{rms}^2 = r_0^2 + r_{brems}^2 + r_{MS}^2 \quad (2)$$

where the contribution from multiple scattering of the electron before generating bremsstrahlung has been included. For a rough approximation, only half the spoiler thickness (i.e., $t/2$) is considered for this multiple scattering. This gives

$$r_{rms}^2 = 100^2 + \left(\frac{100 \cdot 0.511 \cdot 10^4}{33 \times 10^3} \right)^2 + \left(\frac{100 \cdot 14.1 \sqrt{\frac{1}{2}} \cdot 10^4}{33 \times 10^3} \right)^2$$

$$r_{rms} = 319\mu$$

which one can compare with the value from Fig 7 of about 210μ . This is probably as good as can be expected considering the crude approximations used, especially using $t/2$ as an 'effective' spoiler thickness for multiple scattering before bremsstrahlung. Using an effective thickness of $t/4$ gives an answer close to the EGS value.

The r_{rms} for positrons may be approximated by

$$r_{rms}^2 = [r_{rms}]_{from\ brems}^2 + r_{MS}^2 \quad (3)$$

where we use the EGS value of 210μ for the bremsstrahlung rms term, and again use $t/2$ as an effective thickness. The average energy of the positron is taken from the EGS photon average energy, and is ≈ 11 GeV. Then

$$r_{rms}^2 = 210^2 + \left(\frac{100 \cdot 14.1 \sqrt{\frac{1}{2}} \cdot 10^4}{10 \times 10^3} \right)^2$$

$$r_{rms} = 930\mu.$$

This is to be compared with the EGS value of $\approx 650\mu$.

Essentially these crude models give reasonable approximations of the rms angle for each of the particle types. More importantly, they give insight into why the photon heating isn't as great as was originally suggested in our introduction; that is, multiple scattering of the electrons before bremsstrahlung production is a significant process in scattering the photon energy over wider angles.

Beam on Magnet.

As a final note, we decided to direct the beam onto the magnet face (i.e., no spoiler) to check the temperature rise, and make comparisons with earlier EGS calculations done at 50 GeV³, where a delta function beam was used and the finite beam spread was included by means of a convolution scheme. Fig 9 shows the temperature rise in iron for a 100μ beam at 33 GeV (histogram) compared with the data from 50 GeV adjusted for energy and material (iron vs copper). We note that the maximum temperature rise using the convolution scheme (with EGS3) is some 30% higher than the current EGS4 calculations (i.e., EGS4 gives $309^\circ\text{C}/p$ while the EGS3/convolution scheme gives $410^\circ\text{C}/p$, both at 33 GeV).

The previous method of using delta function electron beams as input, and subsequently convoluting over a beam spread to get an overall picture of thermal heating, is recommended only if it isn't feasible to do all the sampling in the main scheme (i.e., incident beam spot and subsequent shower). EGS4, with its ability to use leading particle biasing, runs so efficiently (per shower event) that one can get very good statistics within the incident beam spot, and we recommend that future problems be solved this way.

REFERENCES

1. W. R. Nelson and T. M. Jenkins, "Temperature Rise Calculations for the Beam Pipe in the SLC Arcs", CN-245 (1983)
2. M. J. Berger and S. M. Seltzer, "Tables of Energy Losses and Range of Electrons and Positrons", NASA SP-3012 (1964)
3. S. Ecklund and W. R. Nelson, "Energy Deposition and Thermal Heating in Materials Due to Low Emittance Electron Beams", CN-135 (1981)

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Fig. 1 - Typical (?) Lambertson septum magnet. The region (3 mm) of iron between scavenger beam and straight-ahead beams may become target of missteered beams.

Fig. 2 - EGS representation of spoiler and magnet in UCLA M01.

MAXIMUM TEMPERATURE RISE (RIGHT-HAND SCALE)
FOR TI-ALLOY SPOILER AND IRON MAGNET

MAXIMUM TEMPERATURE RISE (RIGHT-HAND SCALE)
FOR TI-ALLOY SPOILER AND IRON MAGNET

MAXIMUM TEMPERATURE RISE FOR SPOILER
AND MAGNET VERSUS SPOILER THICKNESS

Fig 5

Fig 9