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TITLE: ADDITIONAL MUON CALCULATIONS FOR THE SLC POSITRON SOURCE

SUMMARY

This note is an update to the muon calculations presented in CN-221 (ref. 1) and takes into account:

- 1) A more complete muon production and transport model, including an estimate of wide angle production based on experimental data.
- 2) Additional earth shielding that will be added on top and on both sides of the 2/3 tunnel areas.
- 3) A detailed analysis of the earth profile as it pertains to shielding in the direction of the SLAC site boundary.

The highest annual dose at the SLAC boundary is found to be 13 mrem/year (4000 hours of operation at 50 kW), and this occurs at a horizontal angle of 0 degrees and a vertical angle of 3.6 degrees relative to the incident beam direction (see Figure 2a). Although the shielding criteria is 10 mrem/year at the site boundary*, the radiation transport model becomes somewhat conservative at large distances from the shield, which should bring the 13 mrem/year number actually well below the criteria. This point is also about 28 feet above the roadway. Extension of this line may strike the ground in the Christmas tree farm beyond the SLAC boundary but there will be additional attenuation due to distance. We do not recommend that any additional shielding be added at this time.

In addition, in Figure 4 we give the muon dose rates at various positions in the accessible regions downstream of the last shielding wall inside the 2/3 tunnel. These numbers are based on 50 kW operation and show areas as high as 110 mrem/hour. These high dose rates are the result of wide-angle muon production estimates. Should they prevail, the 2/3 tunnel will not be suitable for personnel occupancy during beam operation.

*The 5 mrem/year number quoted in CN-221 is incorrect

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Finally, we have not considered pion and/or kaon production with subsequent decay into muons. Under certain conditions this kind of source could dominate at large angles (e.g., 5-10 degrees); namely, if the pions/kaons do not interact in the target-solenoid complex prior to entering a relatively large drift space where they may decay into muons. This is subject to further study based on details of the positron source.

MUON PRODUCTION AND TRANSPORT MODEL

The calculations in CN-221 are based on a fairly simple model (ref. 2) in which Bethe-Heitler muon pairs are produced by photons in an electromagnetic cascade, and are then multiple scattered (with energy loss) as they penetrate a massive shield downstream of the source. Experimental evidence was presented in the 1968 paper (ref. 2) that showed a discrepancy in the forward direction and, in addition, suggested the possibility of a wide angle component of muons. Further theoretical (ref. 3) and experimental (ref. 4) work was published in 1974 that explains the discrepancy found in the forward direction, as well as confirms the production of muons at wide angles. The calculations presented in this note are based on the 1974 theoretical model of muon pair production in an EM shower with subsequent radiation transport in the downstream shield---a model that agrees to within 10% with experiment at 0 degrees. The wide angle muon component is estimated from the measurement-to-theory ratio data obtained in the 1974 study (with 18 GeV incident electrons).

In Figure 1 we have provided an extensive family of curves from which the muon dose rate can be obtained as a function of aluminum shield thickness and for various angles. The dose rate has been normalized for 1 kW of incident electron beam power and for a source-to-detector distance of 1 meter. We have assumed that the EM shower is fully developed in a tantalum target. Aluminum was chosen as the shield material and all earth (1.8 g/cu.cm) and concrete (2.4 g/cu.cm) shields were converted to equivalent thickness of aluminum (2.7 g/cu.cm).

TUNNEL AND EARTH PROFILES

In order to obtain the amount of shielding along various trajectories from the positron target in the 2/3 tunnel to the SLAC site boundary, we have made use of the following drawings:

- 1) D-501-208: ACCELERATOR HOUSING EXCAVATION
STA.63+33.33 TO STA.76+66.67
(As Built Drawing, 10/19/65).
- 2) 950-065-01: SECTOR 20 SITE WORK
SLC POSITRON SOURCE (2/28/85).

Figure 2 (a through c) were constructed from these drawings. The target is located at Sta.64+62.929 (two-mile accelerator z-coordinate), 3'11" from the north wall of the 2/3 tunnel, and at a distance of 3' from the tunnel floor. The muon production angle ($\theta \approx \sqrt{\alpha^2 + \phi^2}$) is shown in parentheses.

RESULTS OF SITE BOUNDARY CALCULATIONS

The site boundary dose (mrem/year) is given in the small plot in the upper right-hand corner of Figures 2a through 2c. As the vertical angle decreases one observes an increase in the muon dose corresponding to the strong dependence on production angle demonstrated in Figure 1. The range of a 33 GeV muon in aluminum is 55.4 meters (273 feet of earth), so that the level vanishes when the trajectory passes through enough earth shielding. The small hill located at the horizontal distance around 300 feet is the dominating shield in this case.

The highest level is found to be 7.7 mrem/year (4000 hours at 50 kW), and it occurs at a vertical angle of 3.6 degrees directly above the incident electron beam direction. However, this number is based on Bethe-Heitler muon pair production only. From the experimental data obtained in 1974 (ref. 4) another source of muons contributes to the overall level as the angle increases. In Figure 3 we give the measurement vs. theory ratio as a function of angle. We do not understand the origin of this wide angle component at this time, other than to state that muons from pions and kaons have been ruled out. We have elected to use the measured data as a correction to the pair production results, even though Figure 3 is based on 18 GeV incident electron data and the SLC beam will operate at 33 GeV.

At a production angle of 3.6 degrees the correction factor is 1.7, resulting in a muon level of 13 mrem/year. This number is somewhat higher than the site boundary shielding criteria of 10 mrem/year, and could even be higher if the source of wide angle muons changes dramatically with the electron beam energy (i.e., 33 vs.

18 GeV). However, the radiation transport model that we have used only takes into account the lateral spread of the muon fluence due to multiple scattering, and it ignores the fact that the muons emanate from the surface of the shield with an angular distribution that, together with the "moment arm" to the SLAC boundary, will result in a fluence that drops off faster than inverse square with distance. The 13 mrem/year estimate does not seem too high in this context, even if it does not accurately reflect the wide angle contribution from a 33 GeV beam.

In addition to this, one should point out that the highest levels occur rather high above the boundary road (>20 feet). Therefore, we do not recommend any additional shielding for this area.

MUON DOSE RATES IN THE 2/3 TUNNEL

In Figure 4 we show the location of the shielding wall that will be positioned downstream of the positron target (the exact thickness of the concrete is not important in this calculation). The muon dose rate at five different locations is shown, both near the shielding wall and half-way downstream towards the tunnel entrance. The numbers in parentheses are for the Bethe-Heitler pair production component which, when multiplied by the wide angle measurement/theory factors (Fig. 3), gives the larger values outside the parentheses. If this wide angle component prevails, then it would appear that this tunnel area will probably not be suitable for personnel occupancy while the beam is on.

REFERENCES

1. T. M. Jenkins, "A Note on Shielding the SLC Positron Source", CN-221 (April 21, 1983).
2. W. R. Nelson, "The Shielding of Muons Around High Energy Electron Accelerators: Theory and Measurement", Nucl. Instr. and Meth. 66 (1968) 293.
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MEASUREMENT VS. THEORY RATIO

MUON DOSE RATE IN 2/3 TAKE-OFF TUNNEL
(50kW operation)

Fig. 4