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Comments about Wilcox's SSC-N-580: Neutron and Photon Fluxes at SSC Electronics Racks in Niches

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1. Background

Tim Toohig has proposed that triangular alcoves be dug on the outboard side of the SSC ring to accomodate the cryogenic U-tubes, transformers, power distribution panels, and, incidently, the machine control circuitry for the nearby half-cell. The control circuitry would be in an electronics rack inside a concrete shield, tenatively 2 ft thick with a door 1 ft thick. Smaller alcoves would house the control circuitry at other half-cells which do no require the U-tubes or power distribution. Elevation and plan views of the large alcove are shown in Figs. 1 and 2, and a plan view of a small alcove is shown in Fig. 3.

In an April memo to Peter Limon, I made a rough estimate of the neutron flux attenuation by the shielding enclosure. It was based on the observation that neutrons with a fission spectrum, which is similar to ours, have an attenuation length of 30 cm in concrete [1]. On this basis and with some handwaving about how to average the contributions from different directions, I estimated that the neutron flux would be attenuated by a factor of at least 50—very adequate for electronics survival over the SSC lifetime, even if the number of protons in each ring were increased to 4×10^{14} as part of a future luminosity upgrade.

Better calculations were obviously needed. In August a careful description of the problem was given to Tom Wilcox of LLNL, who performed a preliminary series of calculations using the neutron transport simulation code COG [2]. His results are given in SSC-N-581, for a standard source intensity of 1 neutron cm^{-1} in each ring. It is the purpose of this note to amplify on his results, extending it to the anticipated source strength for the SSC.

2. Spectrum of the source neutrons

In Fig. 4 we show the spectrum in the Tevatron (or SSC) tunnel as simulated by Gabriel and given as Fig. 6 in SSC-110[3]. Drawn over the "1 MeV peak" is a gaussian given by

$$\frac{d\phi}{d(\ln E)} \approx \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{\left(\ln(E/E_0)\right)^2}{2\sigma^2}\right)$$

where $E_0 = 0.55$ MeV and $\sigma = 1.3$. This was used as a source spectrum by Wilcox, as shown in his Fig. 1.

3. Neutron flux results

Wilcox calculated the neutron flux for six cases:

1. No walls (or floor, etc.) and no enclosure. The flux is calculated by the program for a point in the electronics rack at the height of the midpoint between the rings. This case can be calculated analytically in a trival way (if a line source contributes $\mathcal{K}$ neutrons per unit length, the flux a distance R away is $\mathcal{K}/4R$), so that it serves as a check on the program's operation. Wilcox obtained his dimensions from the scales on Figs. 1–3, and the Case 1 entry in his Table 1 (or in Table 1 of this Note) follows for a point 208 cm from the centerpoint between the beams.
2. Black (totally absorbing) walls and no enclosure. This differs from Case 1 in that neutrons from parts of the rings cannot reach the observation point. Since most of the contribution is from nearby parts of the ring, the resulting flux is only slightly smaller than in Case 1.
3. Still no enclosure, but dolomite walls as shown in Fig. 1 (the large alcove). The flux is 6.2 times greater because of reflection from the walls. No energy cut is made; if neutrons below e.g. 100 keV were disregarded the ratio might be reduced to 5 or so, in accord with the reflection factor reported in SSC-110.
4. The same as in Case 3, except that the flux is averaged over a 6 ft high electronics rack. It is not obvious why this flux turns out to be slightly greater than that at the midpoint height, where it should be maximal.
5. For this case the concrete shield around the electronics rack has been added, with full thickness but with half density. The dimensions of the enclosure are taken from Fig. 2, except that the door fits inside. According to Ref. 1 we should expect the flux contribution from neutrons going directly through the shield (2 ft) to be reduced by a factor of 10 by the shield, while the fraction of the flux reflected the walls should be attenuated by a further

factor of 3.2 in going through the door. Wilcox obtains a reduction factor of 20.

6. Same as the last case, except with full-density concrete. We should expect a factor of 100 for direct neutrons and a factor of 10 for those which go through the door after reflection. Alternatively, we might expect to square the factor of 20 Wilcox obtained in Case 5. His reported attenuation factor is 500.

4. Application to the SSC

In SSC-110 we predict a flux of 2900 $cm^{-2}s^{-1}$ for one ring containing 10^{14} protons with a current lifetime of 100 hr. This is evaluated at a point 200 cm from the ring, and 20% of the flux comes directly from the ring, the remainder having been reflected from the tunnel walls. The kinetic energy of the scored neutrons exceeds 40 keV. To scale to the present Case 1, we

- multiply by 0.2 to obtain just the direct component,
- multiply by 2 to include both rings,
- divide by three to scale to a more reasonable 300 hr lifetime,
- multiply by 10^7 to obtain the reult for a standard SSC year,
- and multiply by (200/208) to correct for a slightly different distance.

The result is 3.72×10^9 $cm^{-2}yr^{-1}$. Since Wilcox obtains 2.40×10^{-3} for this case, the desired conversion factor is 1.55×10^{12}.

The first column of Table 1 has been copied from Wilcox's Note. In the second, the entries from the first have been multiplied by this factor. The final entry, 4.04×10^7, may be multipied by a 30 year lifetime and a factor of 4 for possible luminosity upgrade to obtain an estimated dose of 5×10^{10} over the lifetime of the machine. The fluence might be greater in a high-loss region, but we appear to be safe by a substantial factor in any case.

5. Ionizing dose

Since COG also transports the photons made in nuclear deexcitation, these fluxes are also reported. (Those produced in the process of making the 1 MeV neutrons are not.) For example, in Case 3 he reports an electromagnetic energy deposition of 1.39×10^{-5} MeV g^{-1} in silicon in the (unshielded) electronics rack. The same factor derived above may be used to convert this to 2.15×10^7 MeV $g^{-1}yr^{-1}$ under standard SSC conditions. Converting MeV to joules and g to kg, this becomes 3.45×10^{-3} Gy yr^{-1} (where 1 Gy = 1 J/kg), which is totally insignificant. This conclusion is in accord with our measurements in the Tevatron tunnel [4].

Table 1

Wilcox's simulation results scaled to SSC neutron production from distributed beam loss corresponding 300 hr current lifetimes in both rings. Neutron fluxes are given in cm^{-2} yr^{-1} in the proposed electronics enclosure.

Case	Wilcox (SSC-N-580), 1 n cm^{-1} sources	Scaled to SSC-110 with $\tau = 300$ hr
1: No walls, no enclosure	2.40×10^{-3}	3.72×10^{9}
2: Black walls, no enclosure	1.94×10^{-3}	3.01×10^{9}
3: Dolomite walls, no enclosure	1.20×10^{-2}	1.86×10^{10}
4: Same, but ave. over height	1.30×10^{-2}	2.01×10^{10}
5: As 4, but half-density shield	6.18×10^{-4}	9.57×10^{8}
6: As 4, with full shield	2.61×10^{-5}	4.04×10^{7}

REFERENCES

1. R. W. Roussin and F. A. R. Schmidt, "Adjoint SN Calculation of Coupled Neutron and Gamma-Ray Transport through Concrete Slabs," Nucl. Eng. Design **15**, 319-343 (1971).
2. T. P. Wilcox, Jr., E. M. Lent, "COG: A Particle Transport Code Designed to Solve the Boltzman Equation for Deep-Penetration (Shielding) Problems—Volume I, Users Manual," Lawrence Livermore National Laboratory Report M-221-1.
3. T. A. Gabriel, F. S. Alsmiller, R. G. Alsmiller, Jr., B. L. Bishop, O. W. Hermann, and D. E. Groom, "Preliminary Simulations of the Neutron Flux Levels in the Fermilab Tunnel and Proposed SSC Tunnel," SSC Central Design Group Report SSC-110 (1987); these results are summarized in Appendix 10 of "Report of the Task Force on Radiation Levels in the SSC Interaction Regions," SSC Central Design Group Report SSC-SR-1033 (1988).
4. J. B. McCaslin, R-K. S. Sun, and W. P. Swanson; J. J. Elwyn, W. S. Freeman, and P. M. Yurista, SSC Central Design Group Report No. SSC-58 (1986).

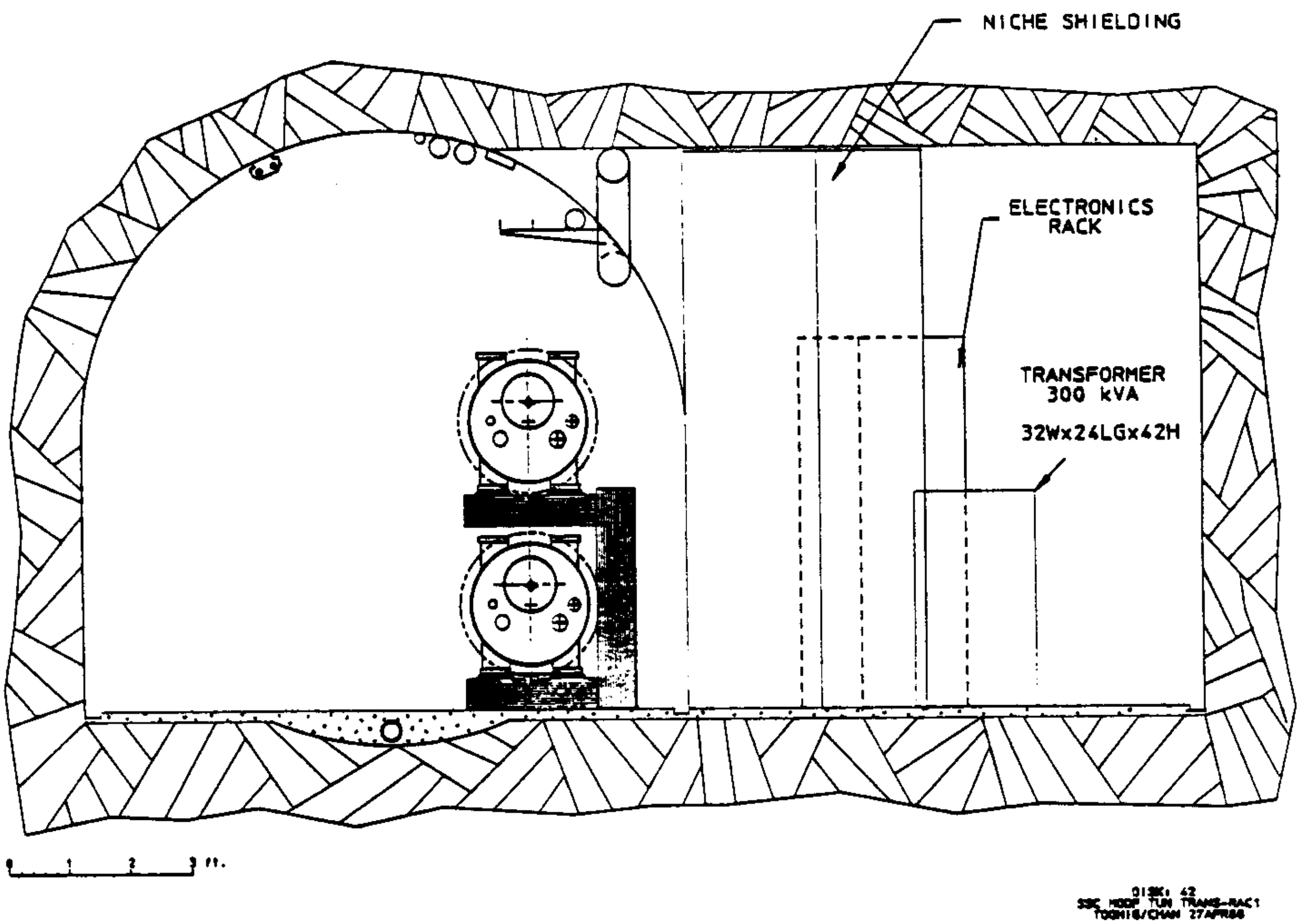

FIG. 1. Elevation view of the niche which contains tunnel power transformers, U-tube assembly, and a cave containing a single rack of electronics. The elevation view of the smaller electronics-only niche is similar.

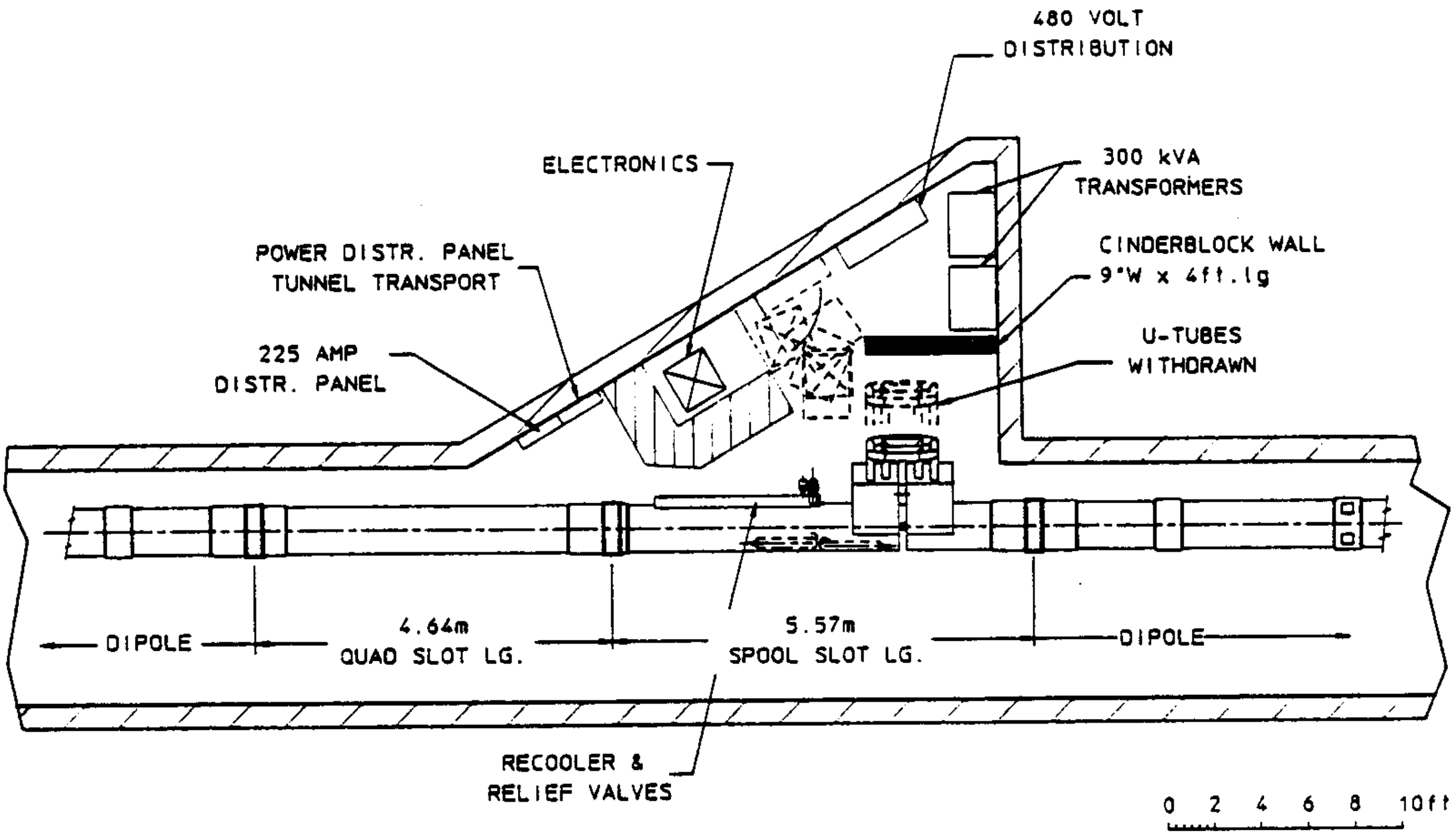

FIG. 2. Plan view of large niche. Door should be inset into the cave. Dotted squares illustrate maneuvering a rack into place.

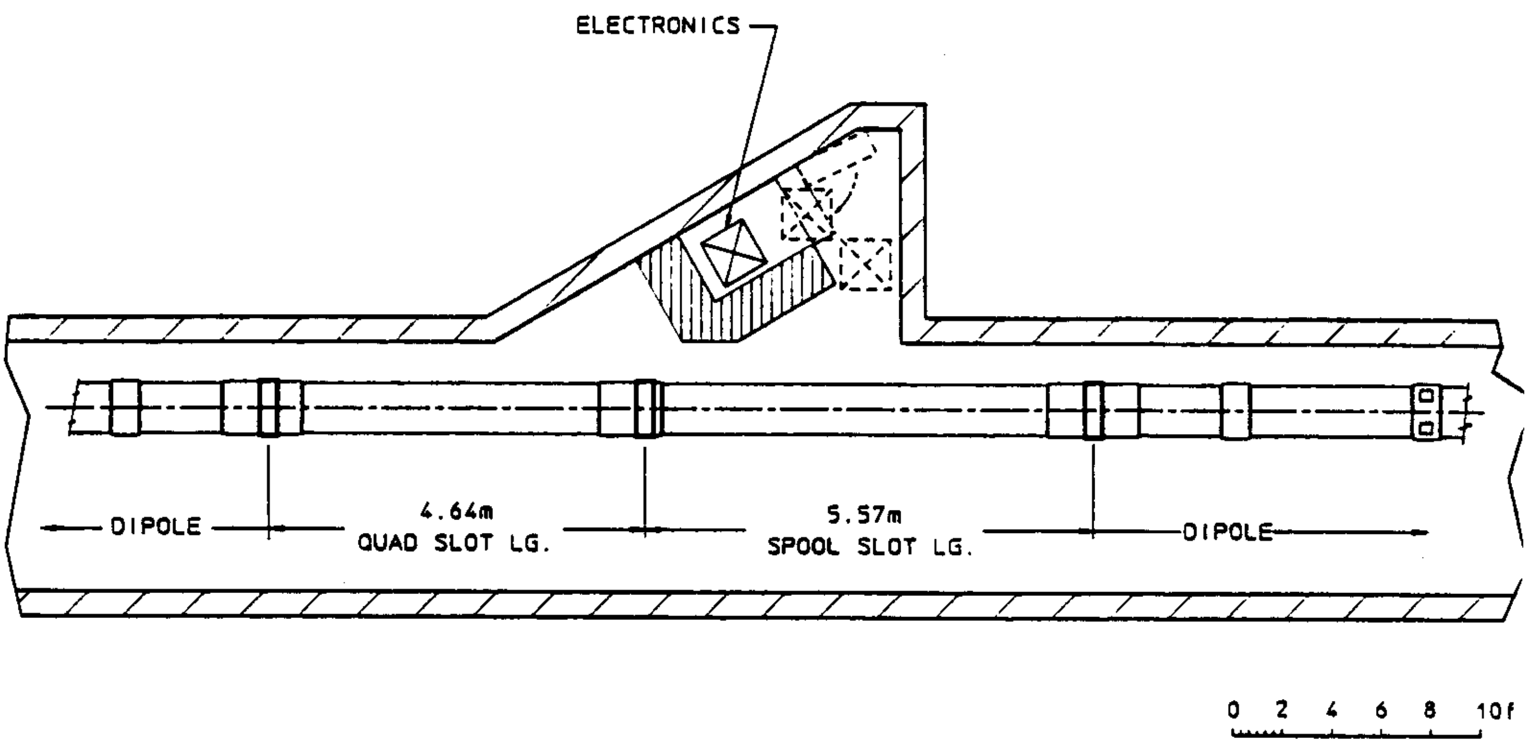

FIG. 3. Plan view of a small niche.

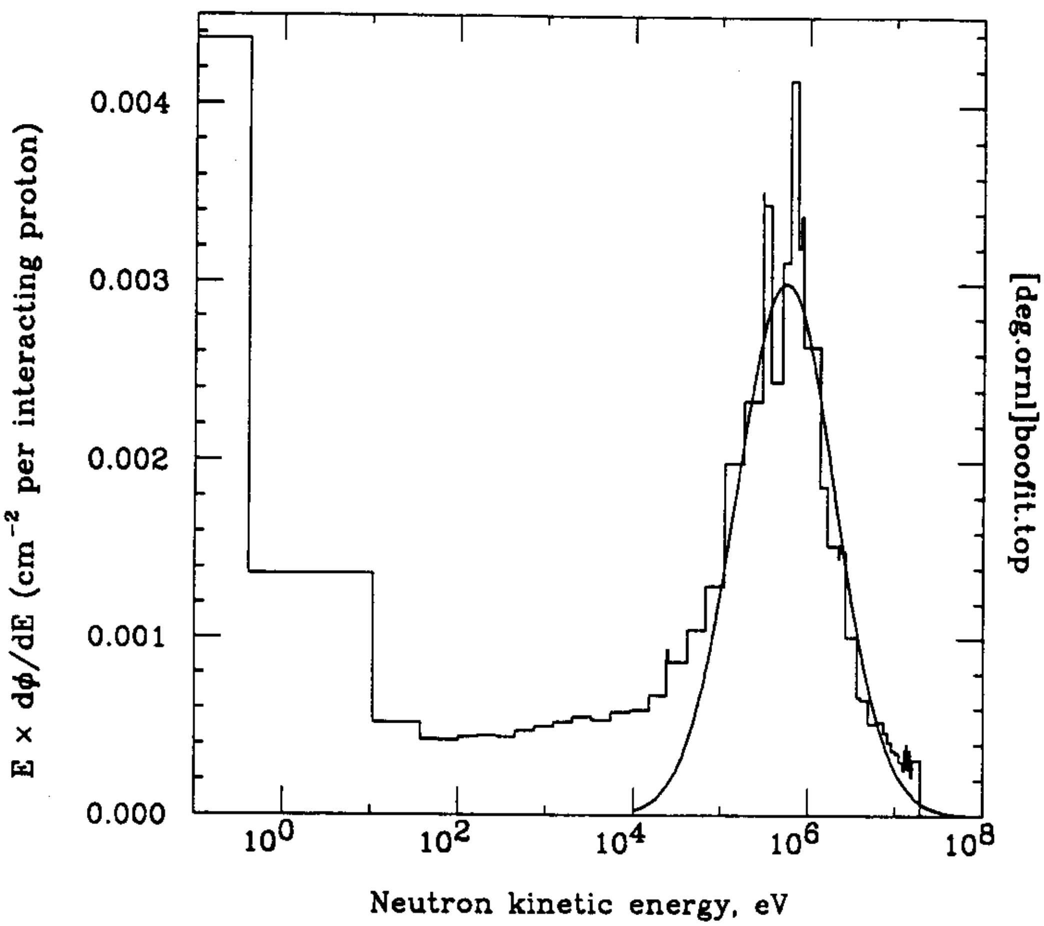

FIG. 4. ORNL simulation of the neutron spectrum in the SSC main ring tunnel [3]. The gaussian adequately describes the spectrum for our present purposes; parameters are given in the text.