Brookhaven National Laboratory

MEMORANDUM

Date: 04/19/95

To: A. Etkin, S. Musolino

From: A.J. Stevens *ajS*

Subj.: Roof Thicknesses in the STAR Enclosure

This memorandum is in response to the request[1] to evaluate the thickness required for the roofs which are shown in the proposed STAR enclosure. A cross section illustrating the lateral positions of these roofs is shown in the attached Fig. 1. The roof labeled "roof #1" in this sketch covers the permanent concrete which extends about 7.5 ft. into the 6 o'clock hall from the assembly area. It is about 35 ft. long in the direction orthogonal to the cross section of Fig. 1 (the beam direction). As shown, it is at a very high elevation. The roof labeled "roof #2" in the sketch represents one of the two roofs that cover the proposed access labyrinths. One of these two roofs is 10 ft. long in the beam direction and the other 8 ft. long.

It is clear that roof #1 has essentially no direct exposure to high energy (> 50 MeV) secondaries which might result from a fault on DX which is the worst case possibility.[2] The radiation field which "shines on" the top of this roof will be low energy neutrons which originate in the steel of DX or the steel of the STAR magnet.

Roof #2 has line-of-sight exposure to a part of the yoke steel as shown in Fig. 1, but from a part of the yoke that is at a large transverse distance from the beam line. More importantly, secondaries from DX at a large enough production angle can impinge on the top of the roof at a shallow angle. The original calculations for an earlier version of an enclosure for STAR[2] also considered a roof, but one much closer to the beam line. Fig. 2 is a reproduction of Fig. 3 of Ref [2]. In the geometry calculated in Ref. [2], the roof had a greater exposure to more of the STAR magnet yoke, as seen by comparison of the two figures. Also (again more importantly) the lateral position of the roof immediately in back of the front wall (where people could be) was 5.6m from the beam line in contrast to the ~ 16.8m distance in the current arrangement. Since this corresponds to a much larger transverse momentum for secondaries from DX, the high energy **flux on the top of the roof top should be much smaller than in the previously calculated geometry**. Another mitigating factor in the current geometry is the fact that the lengths of both of the labyrinth roofs is short.[3] Based on a recent calculation[4] of this effect a reduction factor of in the 2 - 3 range would be expected due to this fact alone.

It is nonetheless interesting to plot the CASIM star density vs. position in the roof of Ref. [2]. Fig. 3 shows this quantity averaged over the length of the roof[5] at a transverse distance (Fig. 2) of 6.6m. In this figure a 4 ft. thick wall of heavy concrete has been divided into 10 bins, so that each bin averages over a 4.8 inch thickness. The errors shown are the rms deviations from 5 statistically independent runs; for cases where the rms exceeds the value a downward arrow is shown. Note that **an order of magnitude reduction exists** between the bin at the top of the roof and its neighbor. This is understandable if the source for the top of the roof is secondaries from DX impinging on the roof at a very shallow angle as one expects from the basic geometry. [The rise at the underneath side of the roof is likely real and due to punch through from the front and side walls of the geometry calculated.]. In view of this result and the remarks in the preceding paragraph, **a very thin roof over the labyrinths, perhaps 1 ft. of light concrete, would be expected reduce any dose from high energy hadrons to an acceptable level.** A rough estimate of the dose equivalent due to the "high energy" component is to scale the 10^{-9} level shown in Fig. 3 by $1/R^2$ and take credit for a factor of 2 reduction from the short length of the roofs. This gives:

$$10^{-9} \times (6.6/16.8)^2 \times 1.8 \times 10^{-5} \times .5 \times 1.14 \times 10^{13} = 0.016 rem$$

where 1.8×10^{-5} is twice the star density to rem conversion for heavy concrete, and 1.14×10^{13} is 4 times half the design intensity interacting on DX which is the canonical assumption. Although in principle, another CASIM calculation could be performed to evaluate this more accurately, the large transverse distance would make such a calculation very difficult and (in my opinion) not worthwhile in view of the fact that the roofs must be 2 ft. thick for structural reasons.[6] The labyrinth roofs are however, like roof #1 in Fig. 1, exposed to a low energy neutron flux. It should be noted that low energy neutron flux incident on a shield is never considered in CASIM calculations; it is always *assumed* that about 2 ft. of hydrogeneous material (such as concrete) is present to reduce this dose equivalent to a negligible level.

I estimate the required thickness for the roofs to shield the low energy flux by (a) assuming that the dose incident on any of the roofs is no more than half of the dose incident on the front of the main shield wall, and (b) applying an attenuation length appropriate for an evaporation spectrum in light concrete. As mentioned in a recent memorandum[7], the attenuation of the front shield wall is required to be about 0.05. If the dose incident on any roof is no more than half the dose on the main shield wall, then the roof thickness should achieve a reduction factor of 0.10, i.e.,

$$e^{-t/\lambda_{Eff}} = 0.10$$

where t is the thickness required and λ_{Eff} is the effective attenuation length for low energy neutrons in concrete. A value of λ_{Eff} = 23.4 cm. has recently been deduced from MCNP calculations.[8] This gives the required thickness for t to be 54 cm. or about 1.8 ft.

There are several reasons to believe that this estimate is conservative. Roof #1 has no direct view of the steel which is the primary neutron source. To allow half of the front wall dose is likely to be a substantial overestimate for this roof. The same argument applies, although to a lesser degree, for the labyrinth roofs where the solid angle subtended by the top of the roof from any steel source is very small in comparision with the front wall. In these cases, furthermore, even after penetrating the roofs, the neutrons must take a 90° turn (toward the labyrinth entrance) before reaching a region of human occupation. This is a further reduction factor of about 5![9]

It may well be that 2 ft. thick concrete roofs represent some degree of "overkill", but I believe that it would require a LAHET-MCNP or CASIM coupled with MCNP or some other combination of codes that couple both high energy and low energy transport to demonstrate with confidence the ***minimum*** thickness required. If 2 ft. is required for structural reasons, the question becomes moot.

References/Footnotes

1. Memorandum from A.J. Stevens to S. Musolino dated 04/14/95.

2. A. Stevens, "Local Shielding Requirements for the STAR Detector," RHIC/DET Note 5, June 1992.

3. At one end of each of the labyrinth roofs is the wall of the hall and at the other the shield wall. These higher walls simply shadow the roof. This same limitation in length justifies the 3 ft. backwall thicknesses as explained in a memorandum from A.J. Stevens to W. Christie and S. Musolino dated 05/04/94.

4. A.J. Stevens, "Radiation Field in the Vicinity of the Collider Center," AD/RHIC/RD-77, October 1994.

5. The averaging is required to obtain halfway reasonable statistical precision as explained in Ref. [2]. The loss source for Fig. 3 is 250 GeV/c protons scraping on DX.

6. Private communication, Ralph Brown.

7. Memorandum from A.J. Stevens to A. Etkin and S. Musolino dated 04/17/95.

8. J.R. Preisig and A.J. Stevens, "Estimation of Neutron Punch-Through in Circular Shielding Penetrations," AD/RHIC/RD-81, November 1994. This reference gives λ_{Eff} = 31.25 cm. for BNL soil with density 1.8 g/cc. Assuming a density of 2.4 g/cc for light concrete gives the 23.4 cm. value quoted in the text.

9. This factor is the reduction of a 3 ft. long labyrinth leg in the geometry described in Ref. [7].

cc:

Ralph Brown
Bill Christie
Dave Dayton
Jim Mills

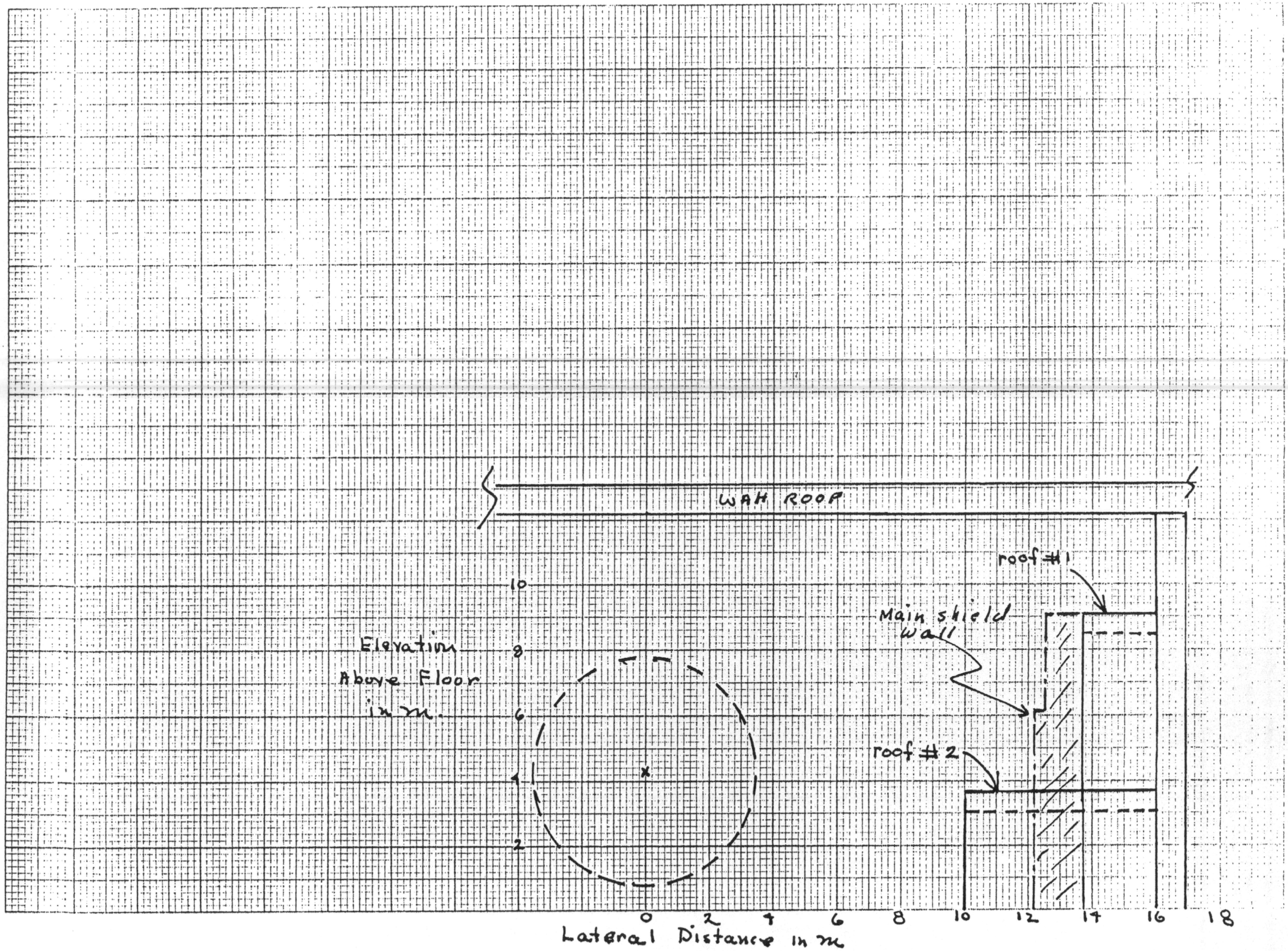

Fig. 1 Lateral Cross Section Showing Roofs Evaluated

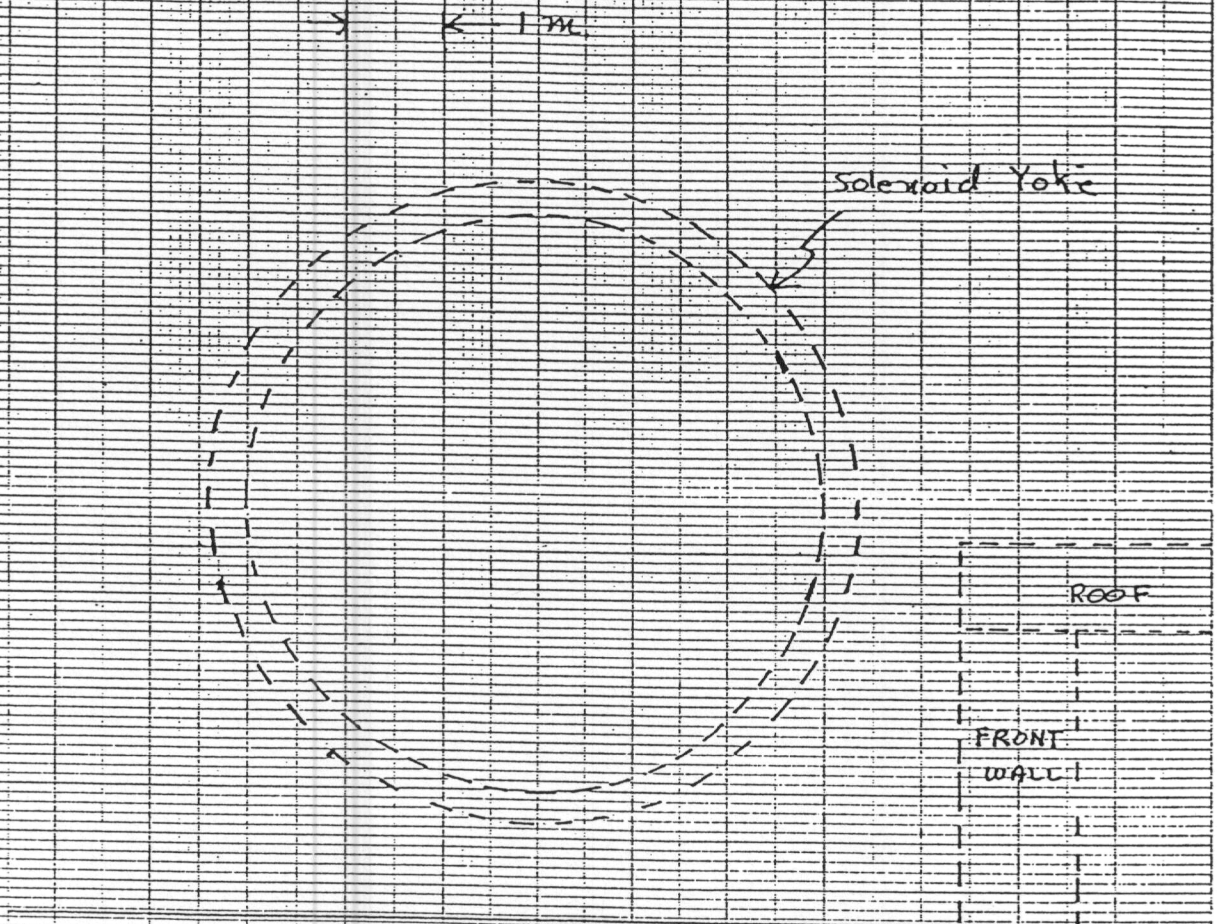

FIG. 3. X, Y CROSS-SECTION AT CONSTANT Z
ILLUSTRATING 3-D GEOMETRY

Fig. 2 Fig. 3 of Ref. [2]
Note that roof # 2 in Fig. 1 is at same height as this roof, but much farther from the beam line.

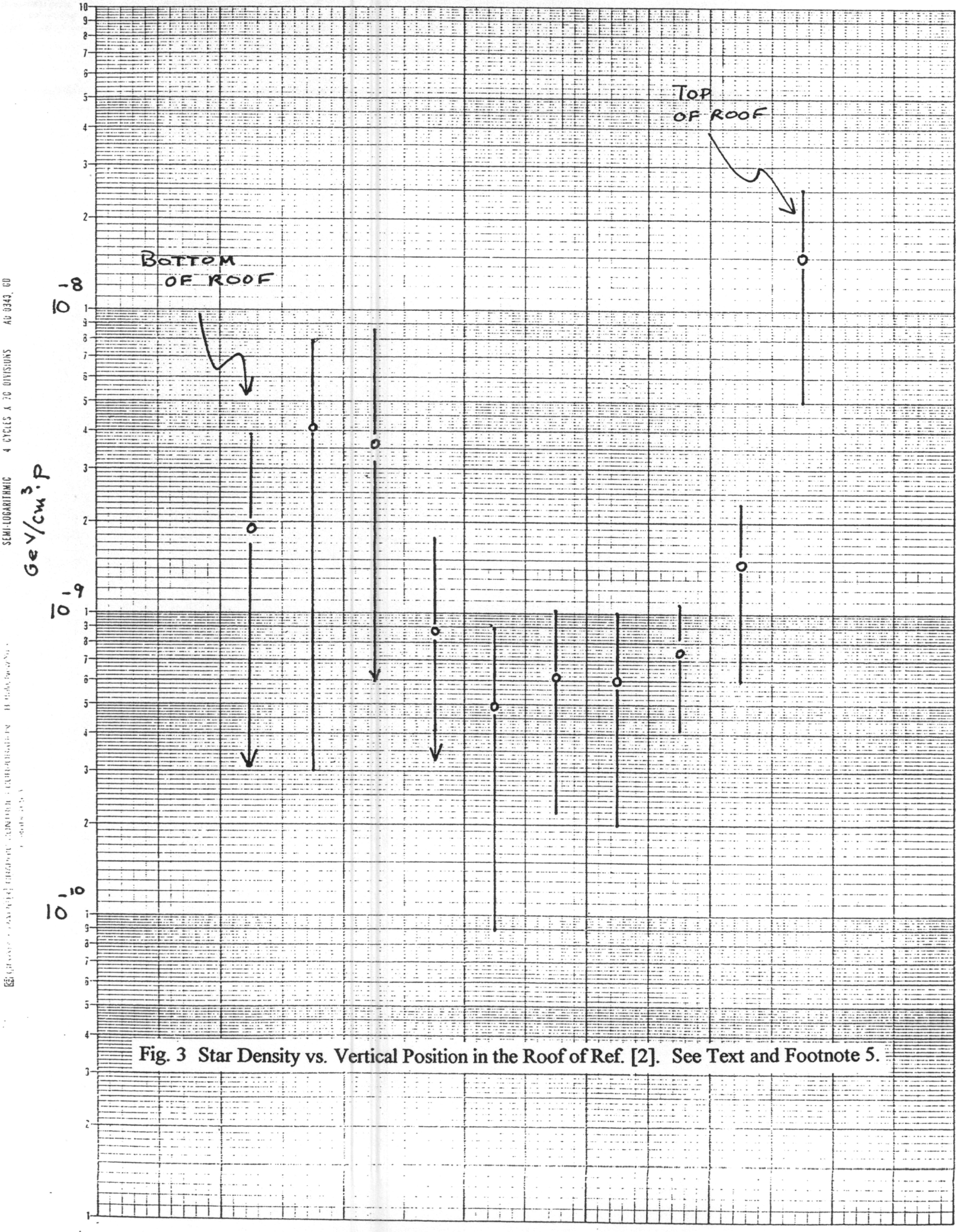

Fig. 3 Star Density vs. Vertical Position in the Roof of Ref. [2]. See Text and Footnote 5.