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Shootout at the Diamond Bypass

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In a worst case scenario, muons produced at one IR will not cause problems at another if the projected beam line from an IR misses any excavated region near another by at least 5 meters.

A diamond-shaped double bypass scheme has recently been proposed for the SSC. While the details remain to be fixed, each of the alternate beam paths has two interaction regions which are between 2.0 km and 2.5 km apart. The size and position of excavated halls around the IRs has not yet been determined. The transverse separation of IRs in the different legs is 40 to 50 meters. The projection of the beam line from one IR misses the interaction point at the next in the same leg by 50 to 60 meters.

An SSC interaction point (IP) is inevitably a source of muons which can propagate for several kilometers through soil, and which present potential background and radiation problems in excavated cavities (experimental halls, garages, etc.) along their path. It is the purpose of this note to comment on these problems.

The muon intensity at great depths is poorly understood, largely because of uncertainties in the production rate of prompt muons in the forward direction (from the leptonic decay of heavy quarks). Cross sections estimates for the relevant processes may be in error by as much as an order of magnitude. A summary of the status of such calculations is given in Ref. 1.

A "worst case" calculation by A. Van Ginneken [2] was made by assuming (a) prompt muon production as per a formula by Ritchie *et al.* [3], (b) 20 m of free space for meson decay, and (c) no magnetic bending. As discussed in Ref. 1, the Ritchie *et al.* prescription probably produces too many hard muons. (b) is not very important at great depths because of the relatively soft spectrum of the decay muons. Assumption (c) is the most pessimistic of all, since the vertical bend magnets in a real IR fan the muons vertically in such a way that a real "muon beam" does not really exist.

The results of Van Ginneken's simulation are given in Ref. 2; see especially Fig. 157, which is reproduced here as Fig. 1. He shows a contour map of per p-p inelastic collision as a function of depth and distance from the beam center line. For $dE/dx \approx 2$ MeV g^{-1}cm^2, 1 muon cm^{-2} $\approx 3\times10^{-8}$ rads ("rads" = "rems" for

our present purposes). The cosmic ray flux at the surface is about 10^{-2} $s^{-1}cm^{-2}$, providing a dose of about 3×10^{-10} rads s^{-1}. Assuming an interaction rate of 10^8 s^{-1}, we can add a reference contour to Fig. 157 about 3×10^{-18} rads per interacting particle for comparison with the cosmic ray intensity. This contour is shown by the dashed line; we see that for a wide range depths (z) in the vicinity of 2 km the dose is less than the cosmic ray dose for distances greater than 4 or 5 m from the projected beam direction.

The flatness of the contours with z in this region is the result of two effects: Lower-energy muons "range out," but higher-energy muons have multiple-scattered to large radii. This effect is more obvious in Fig. 2, which is bases on earlier but similar calculations by Van Ginneken [4].

The most conservative criterion, then, is to require that no excavated cavity in an IR region which can be occupied by people or active detectors (testing or in the beam) should come closer than 4 or 5 m from the beam line as projected from another IR in either beam line.

However, we note that the peak intensity (at the projected beam line) under these assumptions is only two orders of magnitude greater than the cosmic ray intensity. The smearing by the vertical bend magnets is almost certainly large enough to decrease the intensity to below natural backgrounds. Calculations to assess this effect are possible but have not yet been made; if there is good reason to violate the conservative criterion given above, then more detailed calculations can be made to assess the safety and instrumental background situation.

References

1. Report of the Task Force on SSC Environmental Radiation Shielding, ed. by J. D. Jackson, SSC Central Design Group Report SSC-SR-1026 (July, 1987).
2. A. Van Ginneken, P. Yurista and C. Yamaguchi, Fermilab Note FN-447; also published as SSC Central Design Group Report SSC-106 (January, 1987).
3. J. L. Ritchie *et al.*, Phys. Rev. Lett. **44**, 230 (1980) (See footnote 9).
4. A. Van Ginneken, private communication (September 1984).

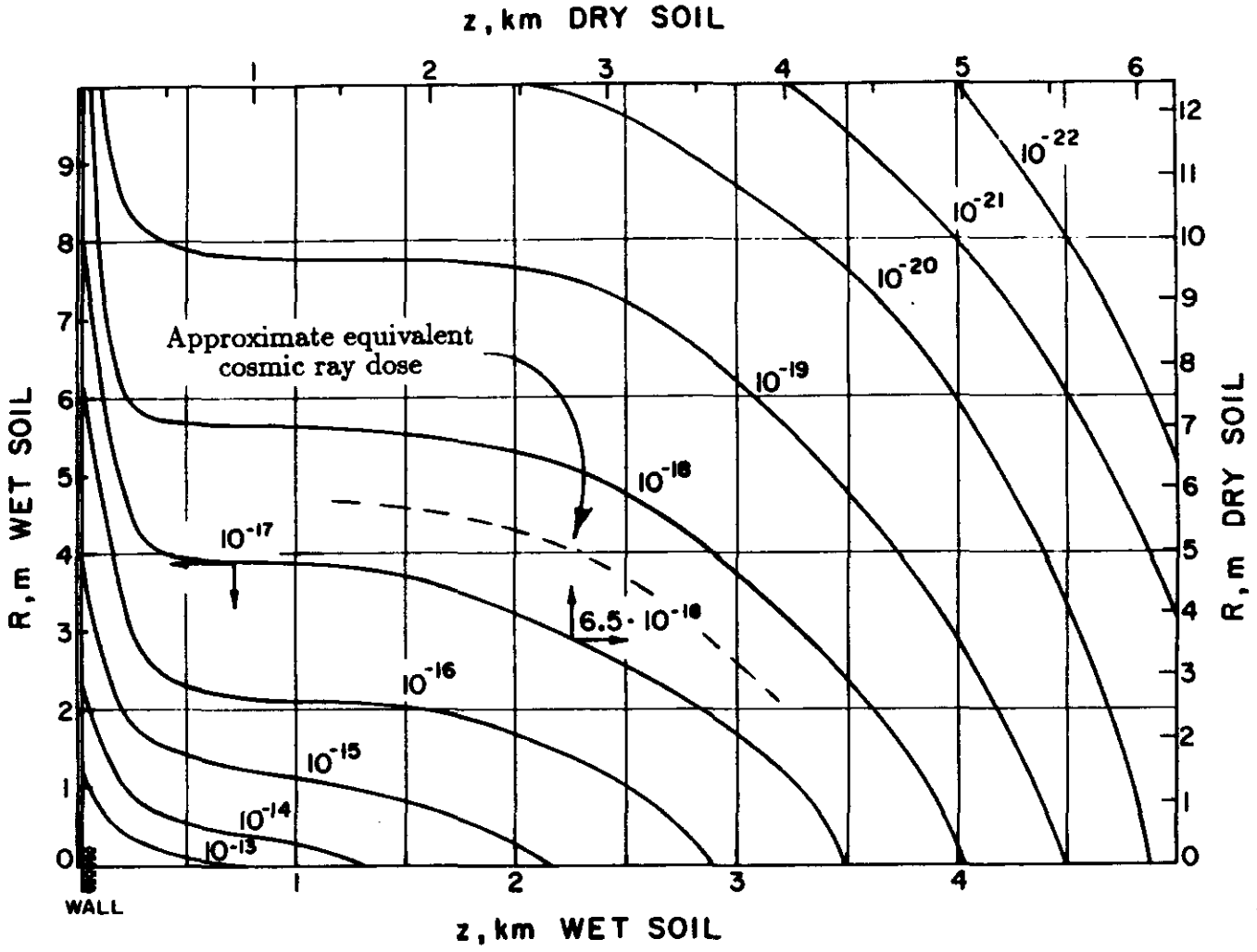

Fig. 157. Contours of equal dose equivalent (in rem/inelastic collision) in soil, due to muons for colliding beams of 20 TeV each followed by a 20m long decay space. Contours for wet soil (left & bottom axes) are integral powers of ten. Contours for dry soil (right & top axes) must be scaled down by 0.65 as shown for one example. Some contours may be omitted for clarity or due to statistical uncertainty.

FIG. 1. Van Ginneken's Fig. 157 from Ref. 2. A dashed contour has been added at roughly the cosmic ray intensity, using 10^8 IR collisions per second to scale the single-collision dose to a dose rate.

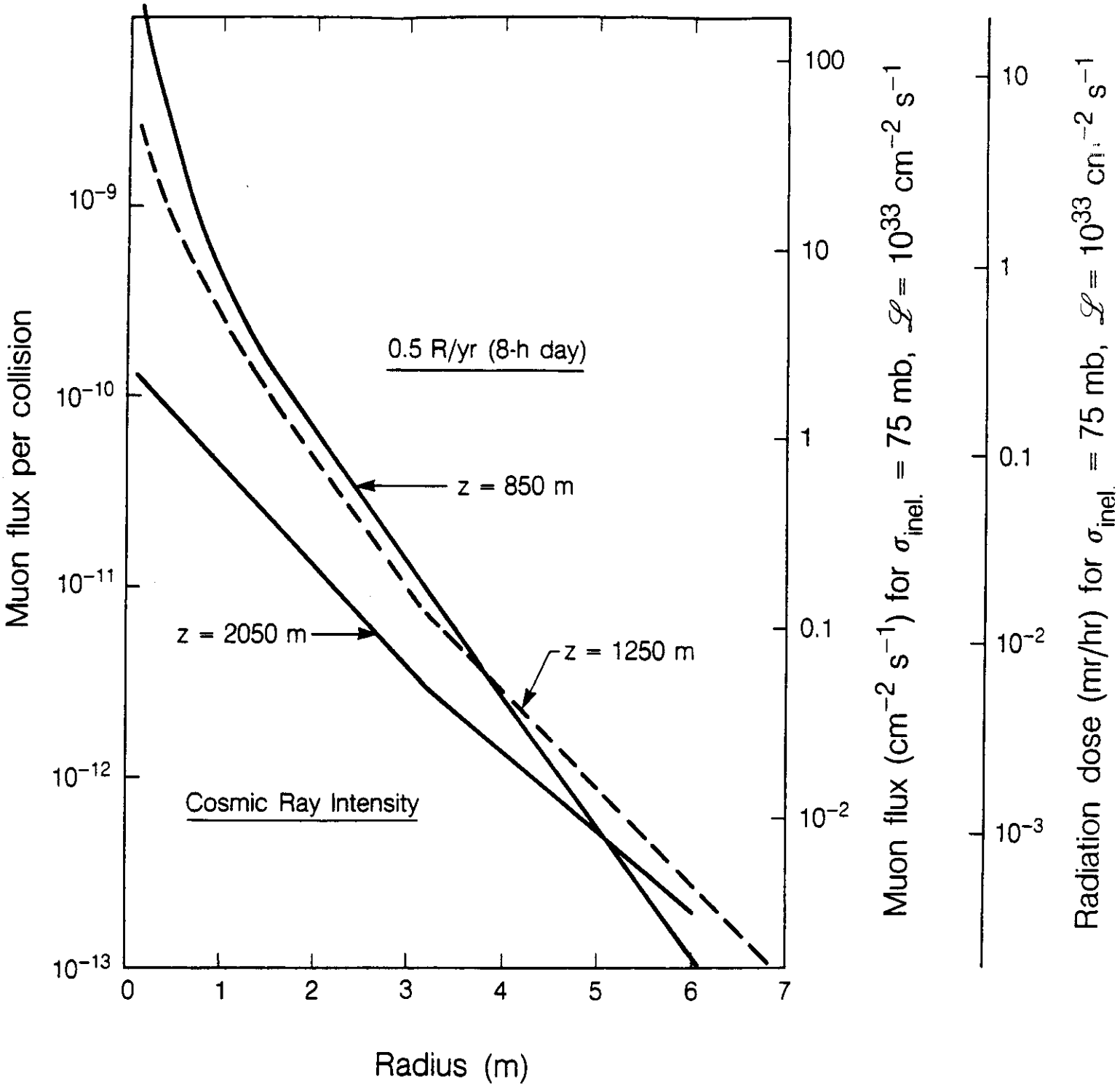

FIG. 2. Muon flux at selected depths as a function of distance from the projected beam line, in the absence of vertical bending magnets. The calculations by Van Ginneken are similar to those of Ref. 2, except that the meson drift space is 80 m rather than 20 m[4].