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ABSTRACT

The neutron-field intensity is estimated for a region proposed as a building site in the vicinity of the Bevatron. The contributions to the field by direct shield penetration of primary neutrons, by direct propagation of secondary neutrons from the shield, and by diffusion of slow neutrons are considered.

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I. SPECIFICATION OF THE PROBLEM

The building tentatively suggested consists of a three-story structure on top of the mezzanine above the present Bevatron shop, counting room, control room, and electrical service and work areas along the south wall of the Bevatron building (see Fig. 1). The question is whether such a location would be satisfactory from the standpoint of radiation, after the Bevatron improvement and shielding enclosure have been accomplished. The answer must be considered in relation to the possible locations of targets. Heretofore, target locations have been principally in quadrant three (Q3), near the exit of quadrant two (Q2), and in the west tangent tank (WTT); also the clipper at the east tangent tank (ETT) is sometimes effectively a target. But the installation of the external beam facility will involve the energy-loss target at the south tangent tank (STT), as well as deflecting magnets in the east and south tanks which may intercept a significant fraction of beam.

Preliminary consideration indicates that targets in Q3 and Q4 will not render the proposed building uninhabitable, and targets in the WTT and NTT should also be allowable if the local tangent-tank shielding were made to provide effectively the same attenuation as the quadrant iron and concrete provide. The target locations needing more detailed evaluation lie in Q1, STT, and the first part of Q2. We will assume that a thick target--about 1 nuclear

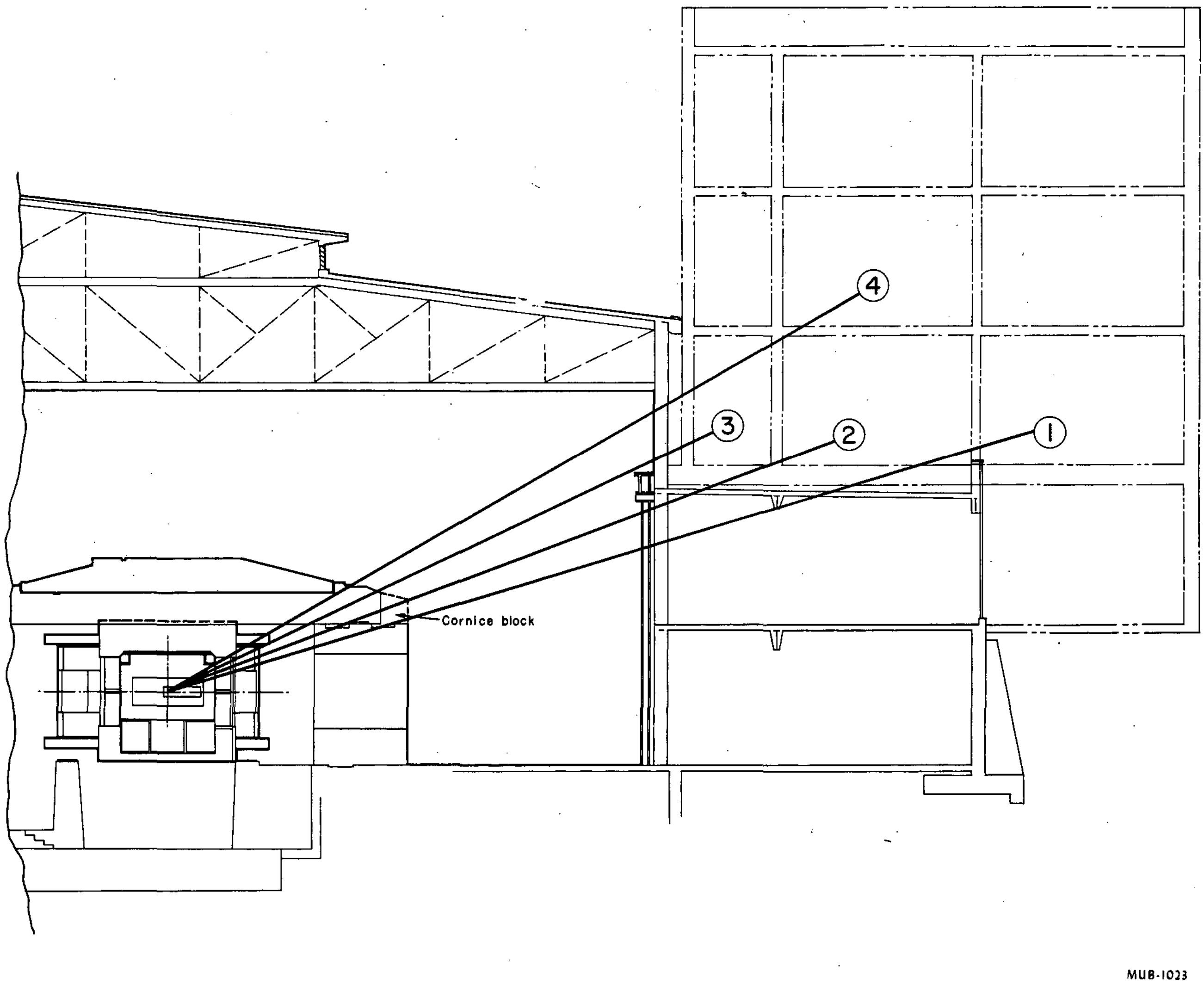

Fig. 1. Vertical section view through a tangent tank of the Bevatron and adjacent proposed service building.

mean free path (mfp)--is located in Q1 near the STT, since the combined effect of the energy-loss target and beam interception by the deflecting magnets may approximately equal this condition.

II. HIGH-ENERGY NEUTRON YIELD AND SURVIVAL

Since effectively all low-energy neutrons generated by the target will be absorbed by the shielding, we must first consider the survival of the penetrating neutrons ($E_n > 150$ Mev) through the iron and concrete to the proposed building region. Subsequently we must consider an additional increment of neutrons, diffusing at low energies from the outer-shield surface in which they were generated as secondary particles.

Because of the obliquity of paths through the magnet iron and shield wall for neutron-emission directions much different from 90 deg, the yield and trajectories near 90 deg, or slightly forward from the direction, represent the most serious pattern of emergence of penetrating primary neutrons. The high-energy neutron ($E_n > 150$) production per steradian in the 90-deg direction from a thick target (1 mfp Cu) has been estimated to be 0.21 per proton (see Fig. 2). The attenuation of these neutrons along the directions leading to various parts of the proposed building will depend upon the path lengths of magnet iron, magnet coil, shielding concrete, and building wall masonry along the directions considered. For the estimates given in Table I, no benefit from building wall or floor has been assumed.

Table I lists the data for four positions in the proposed building. A Bevatron beam of 10^{13} protons/pulse is assumed. These positions are shown in Fig. 1. The intensities in positions one and two are dependent upon whether or not the "cornice" blocks are present along the top outside edge; so double values are given for these positions.

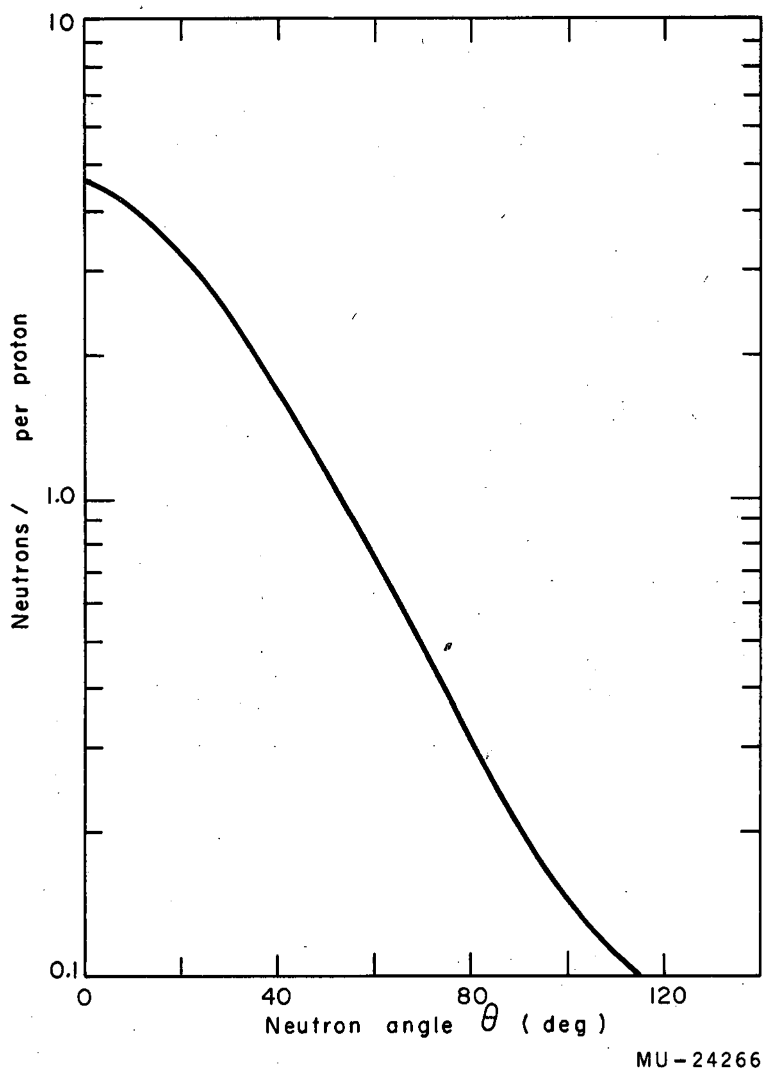

Fig. 2. Angular distribution of neutrons, over 150 Mev in energy, from 1 mfp of Cu traversed by 6.3-Bev protons.

(Integral=$2\pi \int_0^\pi f(\theta) \sin \theta d\theta$=8 neutrons/proton).

Table I. Distance, attentuation, and surviving primary neutrons for certain positions in the proposed building. A flux of 10^{13} protons per pulse is assumed.

Position in Fig. 1	Distance from target (ft)	Equivalent iron path[a] (in.)	Concrete path[b] (ft)	Solid angle per cm^2 ($\times 10^7$) (sr)	Attentuation factor ($\times 10^4$)	Surviving primary flux (per cm^2 sec)
1	96	39.6	6.5(W)	1.17	3.35	13.7
1	96	39.6	10.5(C)	1.17	0.53	2.2
2	76	47.7	7.5(W)	1.87	0.75	4.9
2	76	47.7	11.0(C)	1.87	0.15	1.0
3	64	55.8	8.0	2.62	0.22	2.0
4	86	70.2	8.0	1.45	0.0361	0.2

[a] Iron path, reduced by 10%, plus iron equivalent of magnet coils where applicable.

[b] "W" means without cornice blocks; "C" means with them. Ordinary concrete is involved ($\rho = 2.4 g/cm^3$). None of these paths pass through the high-density, median-plane course.

The fact that the sector structure of the magnet involves nearly 10% open area in a 90-deg view of the outside surface of the iron has been accounted for only by a 10% reduction in the effective iron thickness. This of course does not properly treat the situation where a target is located precisely in the plane of a sector slot, but this situation can be accommodated if necessary by the specific placement of local iron or concrete blocks. An estimate of the result of the location of the target in a slot plane showed it not to be a serious problem, because of the scattering by the concrete of the beam of neutrons released by the slot.

III. CONTRIBUTION OF SECONDARY NEUTRONS FROM THE SHIELD

Emerging from the outer surface of the shield with the surviving primary neutrons will be a spectrum of secondary neutrons. These will contribute to the flux at distant locations both by direct flight and by diffusion, where the latter mechanism applies mainly to the low-energy end of the spectrum.

A. Direct Flight of Cascade Secondary Neutrons

Consideration of the geometry of the shield, and of the angular distribution expected in the emission of secondary neutrons from the shield surface, allows the approximation that the secondaries reaching a distant point come principally from that portion of the shield surface which subtends about 1 sr at the target and which is centered about the ray passing from the target to the distant point. From the type of data given by Metropolis et al.,[1] and from some experimental information, it is estimated that about 3.5 secondary fast neutrons will accompany each surviving high-energy primary neutron emerging from concrete.

The effective radiating surface (subtending 1 sr at the target in the 90-deg direction) will emit a total of 6×10^7 fast neutrons/sec, if we use an averaged value for attenuation by the iron and concrete. The nearest room of the proposed structure is about 50 ft from this radiating area; so it will receive a fast neutron flux of about $26/\text{cm}^2$-sec.

B. Diffusion of Neutrons from the Shield Surface

The radial diffusion of neutrons to a distant point is governed by

$$\phi(r) = \phi_1 \cdot \frac{r_1}{r} \cdot \exp[-(r - r_1)/\sqrt{\lambda_a \lambda_{tr}/3}] ,$$

where ϕ is the diffuse flux density at a spherical surface of radius r_1, λ_a is the mean free path against absorption, and λ_{tr} is the transport mean free path.

For the energy region of "evaporation" neutrons, which we consider here, the λ values are approximately λ_a = 1840 m (6020 ft), and λ_{tr} = 100 m (329 ft). Thus the characteristic attenuation length is

$$(\lambda_a \lambda_{tr}/3)^{1/2} = 250 \text{ m (810 ft).}$$

Consequently the exponential factor here has little influence, and the inverse dependence upon r provides the distance dependence of the diffusing flux. For r_1, we may use 30 ft as an effective distance of the outer shield surface from the target; and for ϕ_1 we use $120/\text{cm}^2$-sec. This implies about 1.5 "diffusing" neutrons per surviving primary emerging from the surface. The result at a distance of 70 ft is 51 neutrons/cm^2-sec.

IV. SUMMARY

At a typical work area in the proposed building, and in the absence of any attenuation from its own walls and floors, the neutron flux density is estimated to be:

a.	from high-energy primaries	a few, say $3/cm^2$ sec
b.	from direct flight of secondaries from the shield	$26/cm^2$ sec
c.	from diffusion from the shield surface	$51/cm^2$ sec
	Total	$80/cm^2$ sec

Contribution (c) is easily absorbed, since a substantial portion of it lies below 1 Mev energy. Component (b) should attenuate with an effective half-value thickness of no more than 6 in. of concrete. Thus a 1-ft-thick wall would reduce these components respectively to approximately 2, 7, and 1, thus leaving a flux density of $10/cm^2$ sec of fast neutrons. This would be tolerable for "radiation workers" (5 rem/yr maximum). But because of the impossibility of precision in such calculations as these, it does not appear wise to locate a building for routine occupancy here. If there were compelling reasons for doing so, it should be constructed with a 1-1/2 ft wall of concrete on the side facing the Bevatron.

V. ACKNOWLEDGMENT

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