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LS Note LS-139(ANL)
H. J. Moe
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Dose Estimates for the 1104 m APS Storage Ring

1.0 Introduction

The estimated dose equivalent rates outside the shielded storage ring, and the estimated annual dose equivalent to members of the public due to direct radiation and skyshine from the ring, have been recalculated. The previous estimates found in LS-84 (MOE 87) and cited in the 1987 Conceptual Design Report of the APS (ANL 87) required revision because of changes in the ring circumference and in the proposed location of the ring with respect to the nearest site boundary. The values assumed for the neutron quality factors were also overestimated (by a factor of 2) in the previous computation, and the correct values have been used for this estimate.

The methodology used to compute dose and dose rate from the storage ring is the same as that used in LS-90 (MOE 87a). The calculations assumed 80 cm thick walls of ordinary concrete (or the shielding equivalent of this) and a roof thickness of 1 meter of ordinary concrete. The circumference of the ring was increased to 1104 m, and the closest distance to the boundary was taken as 140 m. The recalculation of the skyshine component used the same methodology as that used in LS-84.

2.0 Direct Radiation

The following assumptions were used in the recalculation of the direct radiation component:

Beam Current - 0.3 A
Circumference - 1104 m
Positron Energy - 7 GeV
Mean Lifetime of Beam - 10 h
Shielding - 1 m normal concrete on the roof, 0.8 m of normal concrete on the sides
Total Beam Energy - 7728 J
Shortest Distance to Dose Point - 1.3 m

The shielding on the outer side of the tunnel (experimental area side) is in the form of a ratchet but for computational purposes is considered circular. The calculations should be conservative, because the distance from the positron orbit to the outside of the shielding wall does vary around the ratchet but the minimum value has been assumed for the entire

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perimeter.

To estimate the losses around the ring, the following expression, adapted from Swanson et al. (SWA 85), was used to estimate the variation with angle of the bremsstrahlung dose at 1 m due to positron interactions in the vacuum chamber:

$$H/W = 16.7E_o\, 2^{-(\theta B/\theta_{1/2})} + 833(10^{-\theta B/21}) + 25(10^{-\theta B/110}),$$

in which H is in mrem, W is in joules, E_o is the positron energy in MeV, θB is the bremsstrahlung angle in degrees and $\theta_{1/2} E_o = 100$ MeV deg. The first term on the right side of the expression accounts for the highly peaked forward component of the bremsstrahlung radiation. Figure 1 illustrates the geometry for the continuous loss, assuming uniform interactions in the vacuum chamber around the circumference. As indicated in the figure, θB is the angle between the forward direction of the positron beam at Q and the line segment QP to the dose point P. For a positron striking the vacuum chamber at point Q, the bremsstrahlung dose (mrem/J) at P will be

$$H_{BREM} = \frac{H\, e^{-(\mu_{BREM} x)}}{W\, (QP)^2},$$

in which H/W is evaluated for the appropriate angle θB, x is the slant shield thickness (cm) at that angle, and μ_{BREM} is the attenuation coefficient (cm^{-1}) for the given shield material.

Isotropic emission is assumed for the two neutron components, the giant resonance neutrons (GRN) and the high energy neutrons (HEN). Their dose contributions (mrem/J) to the point P are given by

$$H_{GRN} = \frac{0.63\, e^{-(\mu_{GRN} x)}}{(QP)^2} \quad \text{and} \quad H_{HEN} = \frac{0.075\, e^{-(\mu_{HEN} x)}}{(QP)^2}.$$

For the calculations using normal concrete, μ_{BREM}, μ_{GRN}, and μ_{HEN} were taken as 0.048, 0.059, and 0.02 cm^{-1}, respectively.

When the contribution from each of the individual components is integrated over all angles($0^{o} <= \theta <= 360^{o}$, see Figure 1 for θ), the result is the cumulative contribution from each component at the point P due to a uniformly distributed loss around the ring (mrem deg/J). For a total stored energy of 7728 J and a mean lifetime of 10 h, the energy loss rate is 1.357 J/h deg. Multiplying each of the integrated contributions by the energy loss rate and summing the results gives the total dose rate at the dose point P (mrem/h).

The total dose rate at various distances from the positron orbit is shown in Figure 2. Table 1 lists the annual dose equivalent from direct radiation at various distances from the positron orbit for an assumed operation time of 8000 h. These data are also plotted in Figure 3.

TABLE 1
Annual Dose Equivalent
(Direct Radiation for 8000 h Operation)

Distance, m	mrem/y
1.3	400.6
2	261.3
10	49.6
20	23.4
50	8.0
100	3.3
150	1.8
200	1.2
500	0.27
1000	7.8E-02
1500	3.7E-02
2000	2.1E-02
5000	3.6E-03

3.0 Skyshine

The skyshine contribution from scattered neutron radiation was estimated using the following assumptions:

Positrons lost in 10 h - 0.63 $(6.9 \times 10^{12}) = 4.36 \times 10^{12}\ e^{+}$

Safety Factor - 3, since equation is good only to a factor of 3

Neutron Fluence - 80% fast neutrons (1-2 MeV) and 20% high energy neutrons (100-400 MeV) at the dose point

Quality Factor - Values were obtained from Figure 3 of DOE Order 5480.11 (DOE 88, Section 9.f.(5))

Fluence Rate to Dose Equivalent Rate Conversion Factor -

$$\bar{\phi} = 7.8\ n/cm^2\ s/mrem/h \text{ for 1-2 MeV n}$$

$$\bar{\phi} = 4.6\ n/cm^2\ s/mrem/h \text{ for 100-400 MeV n}$$

$$\text{Avg. } \bar{\phi} = 0.8(7.8) + 0.2(4.6) = 7.16 \sim 7.2\ n/cm^2\ s/mrem/h$$

The source term for the neutron skyshine component was computed from the yield 0.12 n/e, obtained from Bathow et al. (BAT 67) for 6.3 GeV e^-:

$$Q = \frac{0.12(n/e)4.36 \times 10^{12}\ (e)\ e^{-.02(100)}}{3.6 \times 10^{4}\ (s)} = 1.97 \times 10^{6}\ n/s$$

for an assumed 10 h mean lifetime. This source strength was conservatively increased by a factor of 3, giving 5.91×10^{6}.

An expression for the skyshine contribution from a well-shielded accelerator (RIN 75) was used to estimate the skyshine dose equivalent:

$$\phi(r) \sim \frac{a\ Q\ e^{-r/\lambda}}{4 \pi r^2}$$

in which a and λ are constants, $\phi(r)$ is the fluence rate

(n/cm^2 s), Q is the source strength (n/s) and r is the distance to the dose point (cm). Values of the constants a and λ quoted from measurements at DESY by Rindi and Thomas (RIN 75) were used in the computation. The values chosen ($a = 7$ and $\lambda = 3.3 \times 10^4$ cm) give the largest fluence rate values for the DESY measurements.

Using the conversion factor $7.2\ n/cm^2\ s/mrem/h$, the dose equivalent rate $\dot{H}$ becomes

$$\dot{H} = 4.57 \times 10^5 \frac{e^{-(r/3.3 \times 10^4)}}{r^2} \quad (mrem/h),$$

in which r is expressed in cm. Table 2 contains the estimates of the annual skyshine dose contribution at various distances from the positron orbit, assuming 8000 h of operation. Figure 3 shows the annual dose data of Table 2 plotted along with the annual dose data from direct radiation.

TABLE 2
Annual Dose Equivalent
(Skyshine Radiation for 8000 h Operation)

Distance, m	mrem/y
100	27.0
150	10.3
200	5.0
300	1.6
400	0.68
500	0.32
1000	1.77E-02
1500	1.73E-03
2000	2.13E-04
3000	4.58E-06
4000	1.24E-07
5000	3.85E-09

4.0 Remarks

From Figure 2, it is seen that the ALARA design criterion of < 0.5 mrem/h for occupational exposure (DOE 88, Section 9.j.(b)) is met at the distance of closest approach (1.3 m). The dose rate at this location is 0.05 mrem/h. From Figure 3, it is seen that the projected total annual dose equivalent at the new assumed boundary (140 m from the positron orbit) is about 14.2 mrem/y. This comprises ~ 2 mrem/y from direct radiation and 12.2 mrem/y from skyshine. The total annual dose is only slightly higher than the estimate in LS-84 (~ 10 mrem/y), as the dose increase due to moving closer to the boundary is almost offset by the correction in the neutron quality factor. The estimated total annual dose of 14.2 mrem meets the criterion of Draft DOE Order 5400.XX (DOE 88a), which limits annual dose to the public to 100 mrem/y.

REFERENCES

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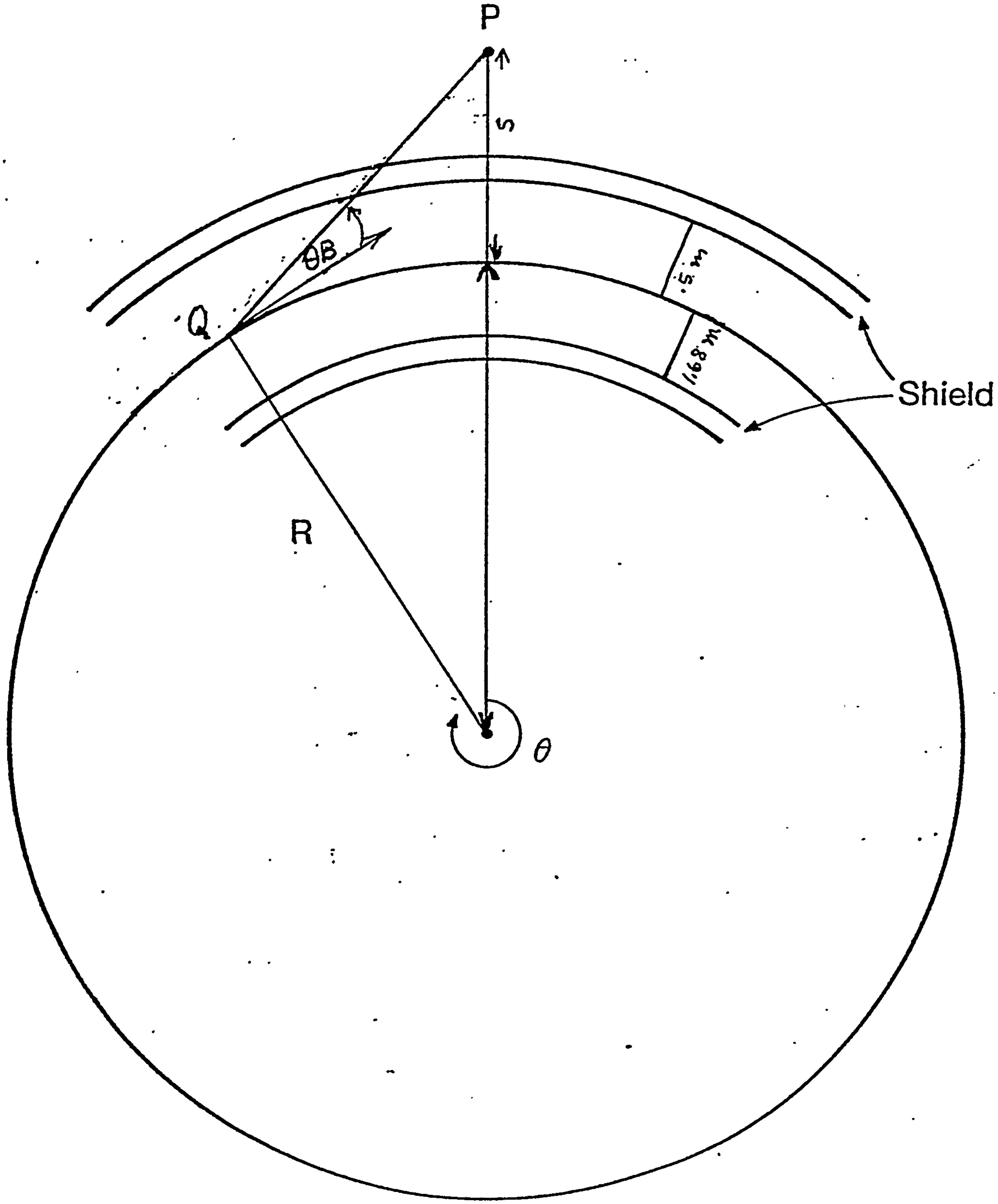
FIGURE 1

Geometry for Component Doses due to Continuous Loss around the Storage Ring



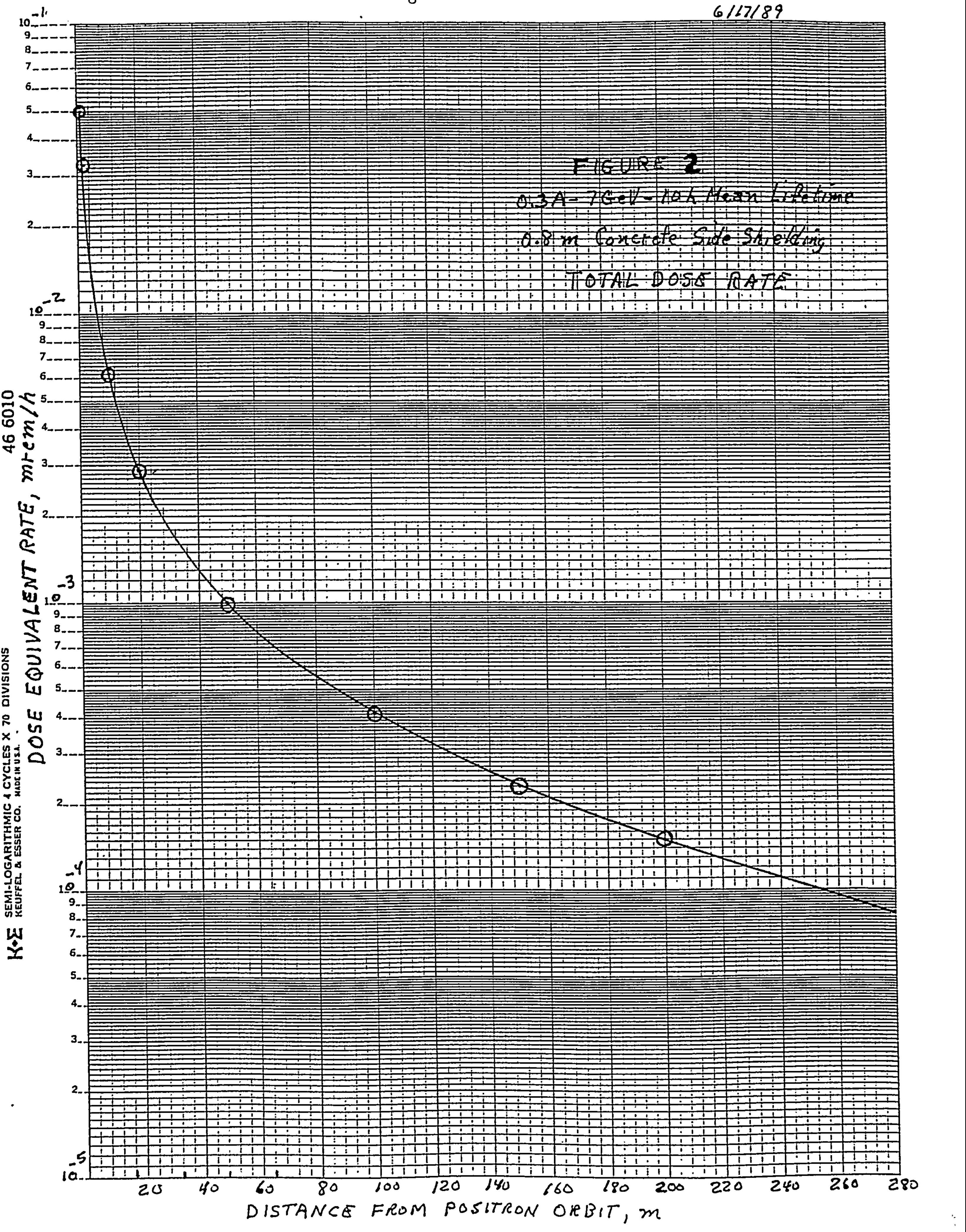

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FIGURE 2
0.3A - 7GeV - 10h Mean Lifetime
0.8 m Concrete Side Shielding
TOTAL DOSE RATE
DOSE EQUIVALENT RATE, mrem/h
DISTANCE FROM POSITRON ORBIT, m
20 40 60 80 100 120 140 160 180 200 220 240 260 280
K+E SEMI-LOGARITHMIC 4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6010

FIGURE 3

ANNUAL DOSE