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CALCULATION OF SHIELDING FOR MARK II ACCELERATOR

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June 30, 1951

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I. Production of Neutrons

The neutrons of concern here are produced by lost deuteron beam bombarding the copper and iron of the drift tubes and magnets. Production processes may be considered in the following categories:

(1) Nuclear evaporation.
Spectrum: Typical evaporation spectrum with maximum in region of 2-4 Mev, and tail extending out to about 15 Mev.

Angular distribution : Spherical symmetry

(2) Stripping
Spectrum: Effectively monochromatic at 1/2 deuteron energy (E_d).

Angular Distribution: Approximately gaussian, with half intensity at $0.8\sqrt{\frac{2.2}{E_d}}$ from deuteron direction; 1/10 intensity at twice this angle.

(3) Single and Plural nucleon collisions

Spectrum: Approximately $1/2\ E_d \cos^2\theta$ at angle θ.

Angular distribution: $\cos\theta$.

In Figure 1 the estimated yields of neutrons per deuteron incident upon thick copper (or iron) are plotted vs E_d. These estimates are made from known values of total and inelastic collision cross sections supplemented by stripping theory, secondary particle experiments, and known yields of some typical reactions.

II. Beam Loss Assumptions

Since the beam loss problem is not subject to confident calculation, four different loss patterns will be treated in the present discussion.

(1) 20% beam loss, uniformly distributed.
This gives .0133 ma/ft. for a 100 ma target beam.

(2) 2% beam loss, uniformly distributed.

(3) 20% loss, exponentially distributed, with a 1/e reduction in 200 ft.
Thus:

$$\frac{dI}{dZ} = (0.91 \times 10^{-4})\, e^{.005 Z} \quad \text{ma/ft.}$$

where Z is distance from exit end.
At exit end, the last cell is 43 ft. long, so beam lost in it is 4 microamps. At Z = 1400 ft., cell length is 11 ft., and beam loss per cell is here 1.1 ma.

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(4) 2% loss, exponentially distributed as in (3).

For conditions (1) and (3) the neutron production rates (per foot per second) are shown in Figures (2) and (3), respectively, as a function of Z.

III. Method of Calculation

It is assumed that the exterior surfaces of the side walls of the accelerator shielding are located at $s = 40$ ft. from the centerline (see figures 4 and 5). The contribution of flux density at the exterior surface at a point P due to a given one of the neutron production processes, and for a given beam loss pattern, is then (see figures 4 and 5):

$$J_P = \int N(X)\,dX \left(\frac{F(\theta)}{X^2 + S^2}\right) e^{-\mu t \csc\theta} \quad ;$$

where: $N(X)$ is neutron/ft. sec for the production process considered, $F(\theta)$ is the angular distribution function for this particular process. μ = attenuation coefficient of concrete for the neutrons delivered at angle θ by this process. See Figure 6.

In Figure 4 is shown the contribution of neutron flux density at a point P, at $Z = 100$ ft., due to production process (3), under beam loss assumption 1. This is for a trial shield thickness $t = 12$ ft., and integration of the dJ_P/dX curve shows a flux density at P of $J_P = 23$ neutrons/cm^2 sec.

In Figure 5 is shown a similar analysis for P at $Z = 1000$ ft. with a trial shield thickness of $t = 6$ ft. Curves of the contribution by production processes (1) and (3) are both shown, under beam loss assumption 1.

It is then necessary to try various values of "t" until the thickness is found for which the total neutron flux density from all production processes is below the desired level, which is here taken to be 5 neutrons/cm^2 sec.

Because of the strong forward concentration of the neutrons from stripping (process (2)) it can be shown that essentially all such neutrons are intercepted by the drift-tube magnets. Those not intercepted meet the shield walls with such obliquity that their attenuation to negligible values is assured.

Near the exit end, the shielding demanded by production process (3) makes process (1) inconsequential.

It will be noticed that the evaluations have been made for an assumed target beam of 125 ma. An adjustment of the data to correspond to 100 ma makes a non-significant change in shield thickness because of the exponential character of the attenuation.

IV. Summary of Results

Evaluations have been made by numerical integration for $Z = 100$ ft., 500 ft., 1000 ft., and 1340 ft. The proper roof thickness to correspond with a given side wall thickness has been estimated from experience with the 184" cyclotron, which has indicated that a roof of about 1 1/2 ft. should accompany a wall of 5 ft., and a roof of 4 ft. should accompany a wall of 15 ft. For the roof area involved, this should bring about the condition that down-scattered neutrons in the working areas are but a small fraction of the neutrons coming through the side walls.

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SUBJECT CALCULATION OF SHIELDING FOR MARK II ACCELERATOR

NAME B.J. Moyer

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		z = 1340'		z = 1000'		z = 500'		z = 100'	
		wall	roof	wall	roof	wall	roof	wall	roof
A	125 ma	5.0'	1.5'	6.8'	1.9'	9.6'	2.6'	12.5'	3.3'
	500 ma	5.7'	1.6'	7.5'	2.1'	10.5'	2.9	13.6'	3.6
B	125 ma	3.9'	1.2'	5.7'	1.6	8.1'	2.2	10.6'	2.9
	500ma	4.6'	1.4	6.4	1.8	9.0'	2.5	11.7'	3.1
C	125 ma	5.9'	1.7	6.8'	1.9	8.0'	2.2	8.8'	2.4
	500 ma	6.6'	1.9	7.5'	2.1	8.9'	2.4	9.9'	2.7
D	125 ma	4.8'	1.4	5.7'	1.6	6.5'	1.8	6.9'	1.9
	500 ma	5.5'	1.6	6.4'	1.8	7.4'	2.1	8.0'	2.2

A. Beam loss assumption 1., 20% uniform

B. Beam loss assumption 2., 2% uniform

C. Beam loss assumption 3., 20% exponential

D. Beam loss assumption 4., 2% exponential

In Figure 7 is a graphical representation of shield thickness vs. z, for side walls. The entrance end wall should be the same thickness as the local side wall, but the exit end wall requirement will have to be determined after further decisions are made about exit end arrangements.

V. Beam Dumping Problem

In case a circumstance arises whereby the entire accelerator beam is caused to strike a drift-tube structure at some point, the instantaneous neutron flux density will be locally very high; and it is necessary to estimate how serious such an occurrence could be.

Let 100 ma of deuterons bombard a point near the exit end. If this 100 ma is incident at, say, z = 140 ft., then the maximum neutron flux density outside the shielding will occur at about z = 100 ft. (see Fig. 4). The magnitude of this neutron flux density for the shielding thickness listed in the table for z = 100 ft., Case "A", 125 ma, (namely, 12.5') is $\frac{100}{.0167}$ (.4) = 2400 cm^{-2} sec^{-1}.

If the beam cut-off time is of the order of one millisecond the neutron exposure produced would thus be 2.4 cm^{-2}, which is of course negligible.

But if the shielding of Case "D", 125 ma, (6.7') is considered, the instantaneous flux density will be about 2×10^6 cm^{-2} sec^{-1}; and for 1 millisecond an exposure of 2000 cm^{-2} is produced. This is still, however, only about 1/500 of a permissible daily exposure.

Evaluations at larger values of z give even less exposure.

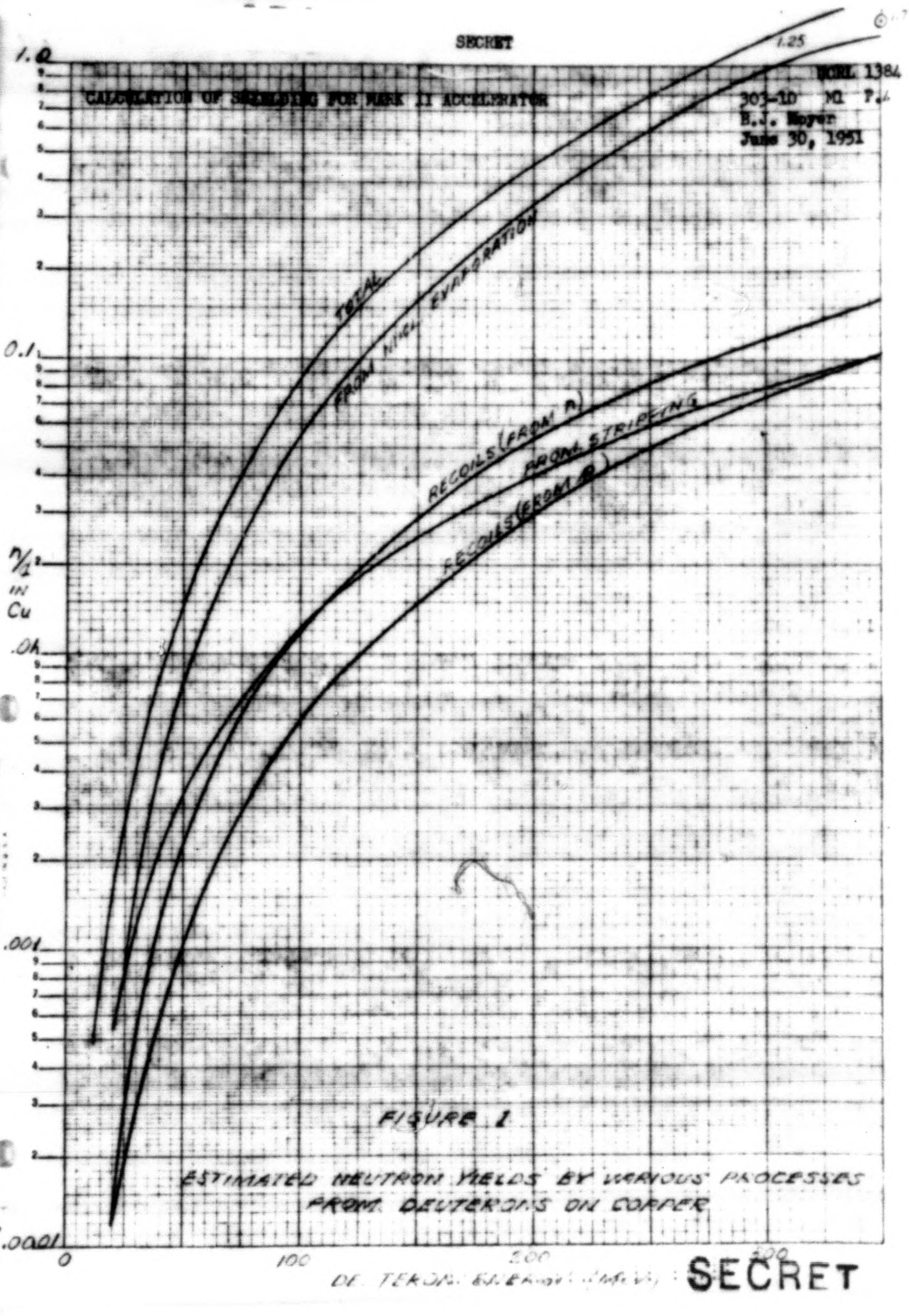

FIGURE 1

ESTIMATED NEUTRON YIELDS BY VARIOUS PROCESSES FROM DEUTERONS ON COPPER

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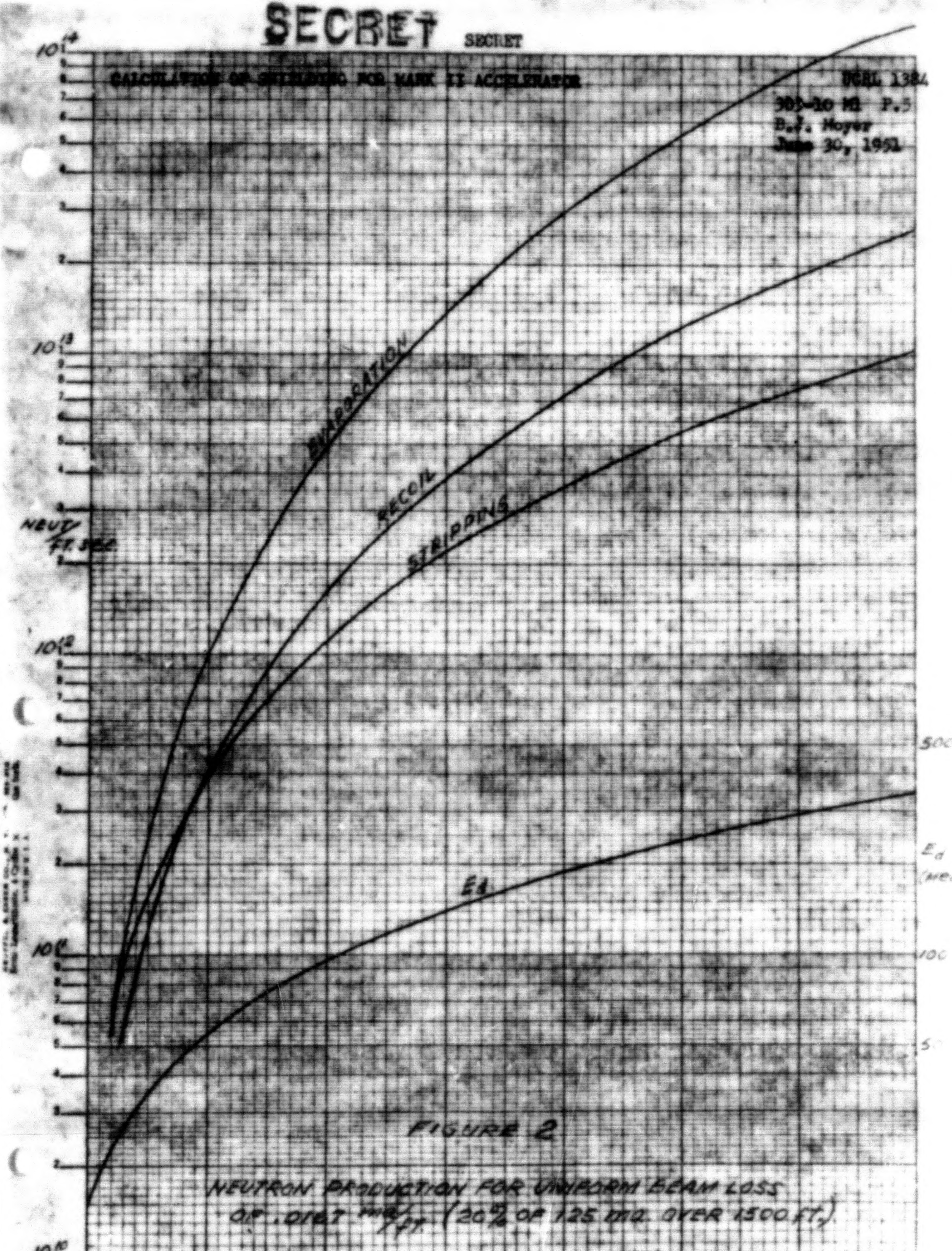

FIGURE 2

NEUTRON PRODUCTION FOR UNIFORM BEAM LOSS OF .0167 ma/FT. (20% OF 125 ma OVER 1500 FT.)

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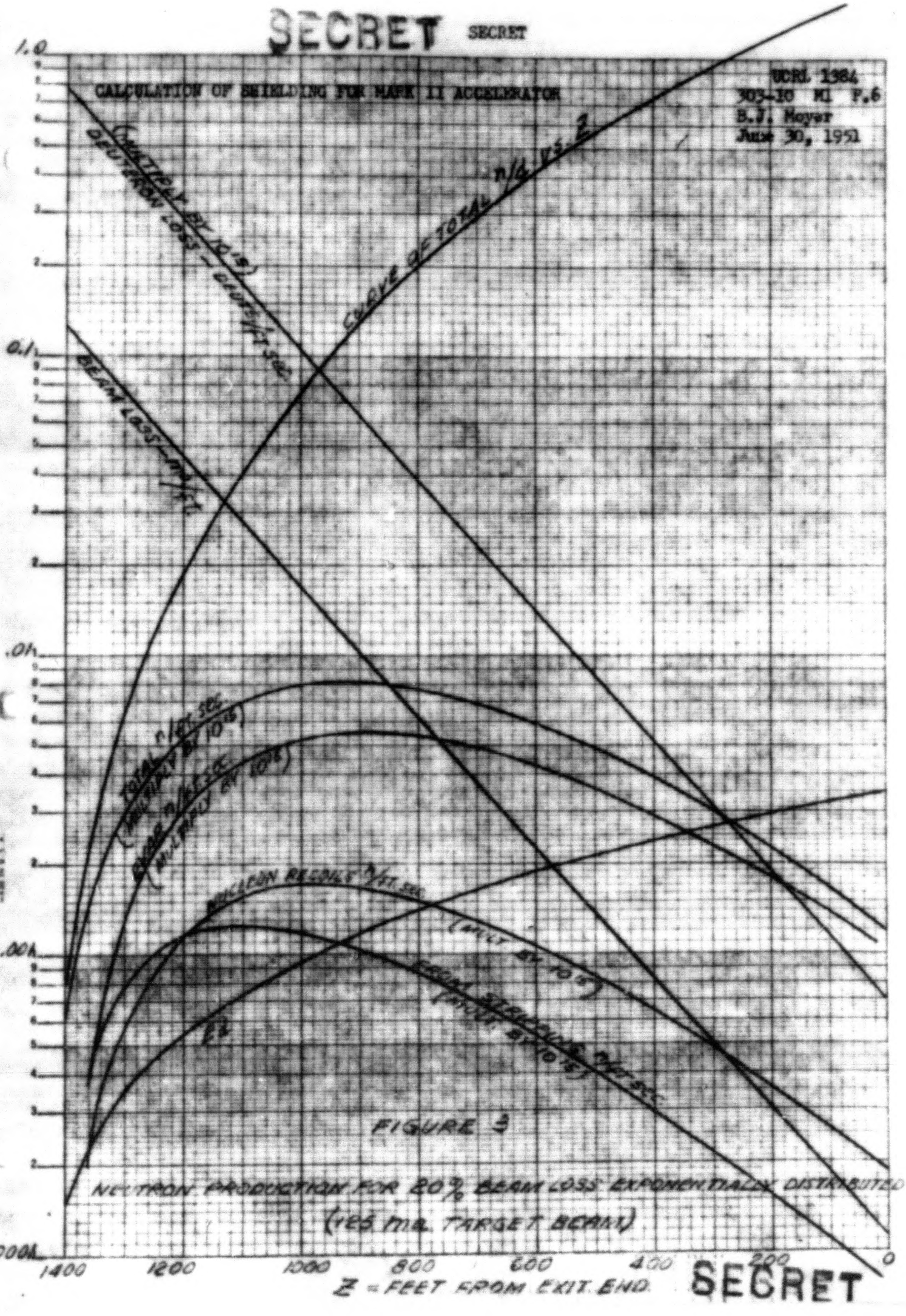

FIGURE 3

NEUTRON PRODUCTION FOR 20% BEAM LOSS EXPONENTIALLY DISTRIBUTED
(125 ma. TARGET BEAM)

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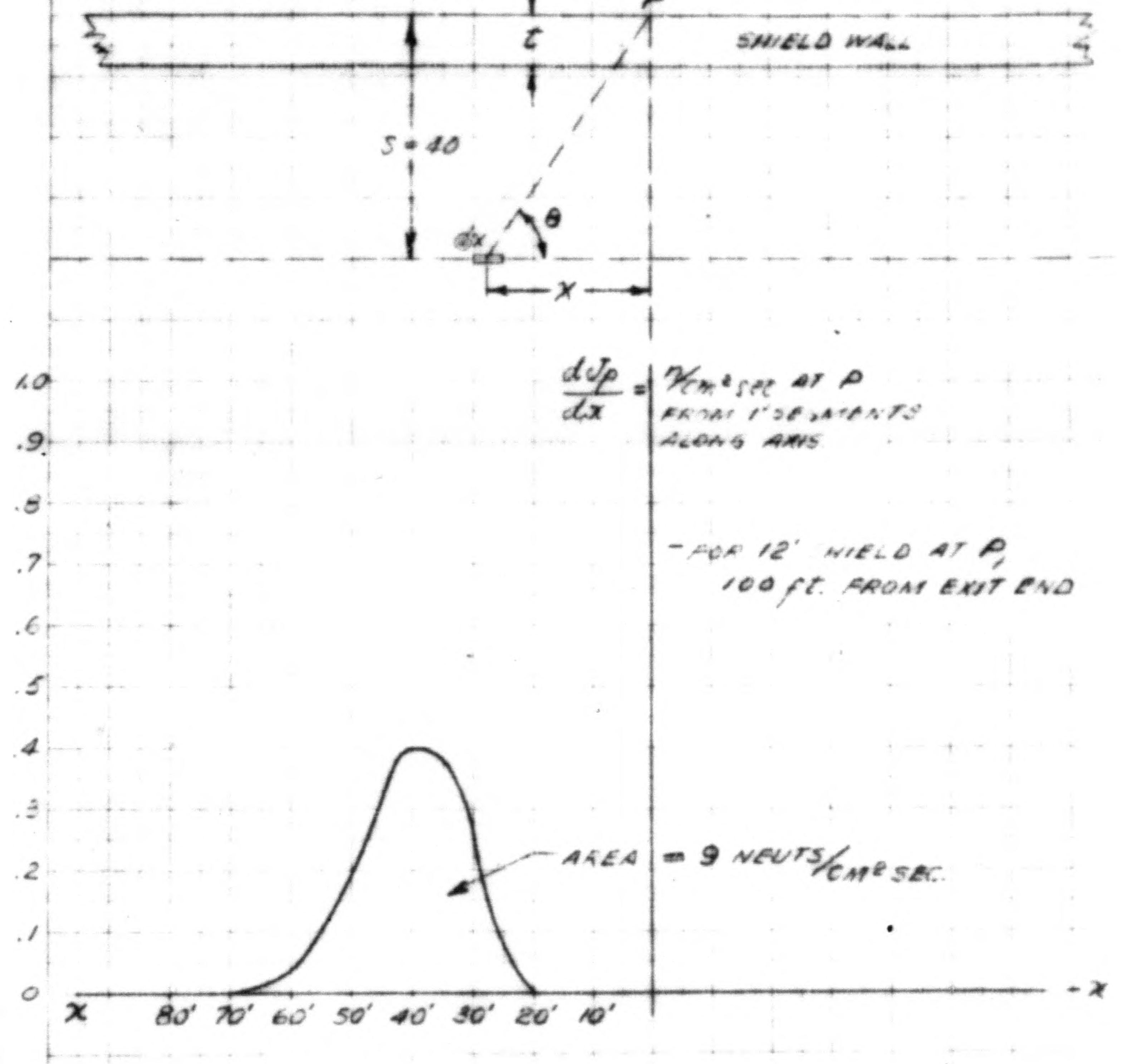

FIGURE 4

EVALUATION OF NEUTRON FLUX AT Z = 100 ft.
FOR PRODUCTION PROCESS (3), BEAM LOSS ASSUMPTION 1,
AND t = 12 ft. (FOR 125 mA TARGET BEAM)

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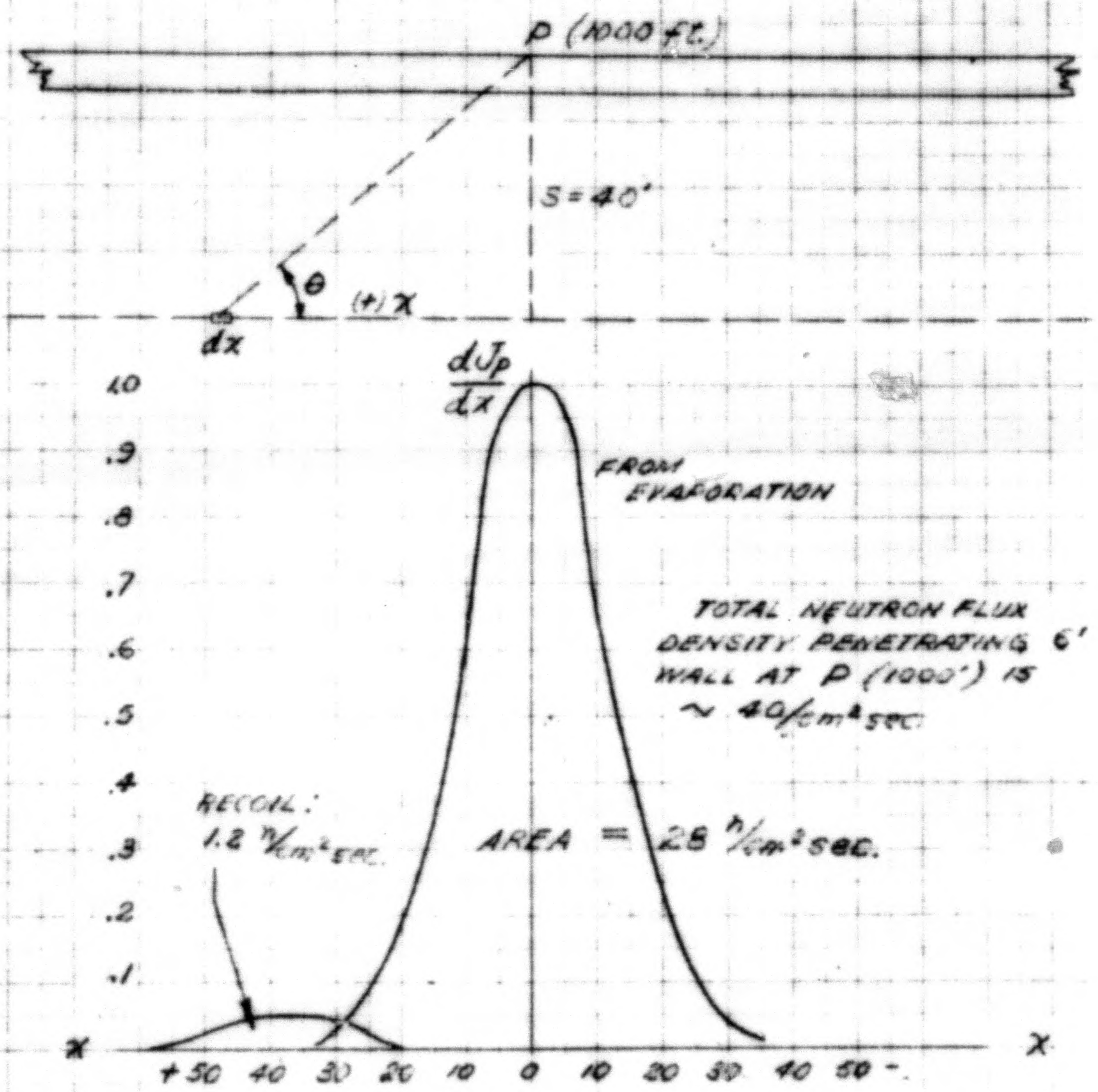

FIGURE 5

NEUTRON FLUX AT Z = 1000 FT. PRODUCTION PROCESSES (1) AND (3), BEAM LOSS ASSUMPTION 1., t = 6 FT., AND TARGET BEAM = 125 ma.

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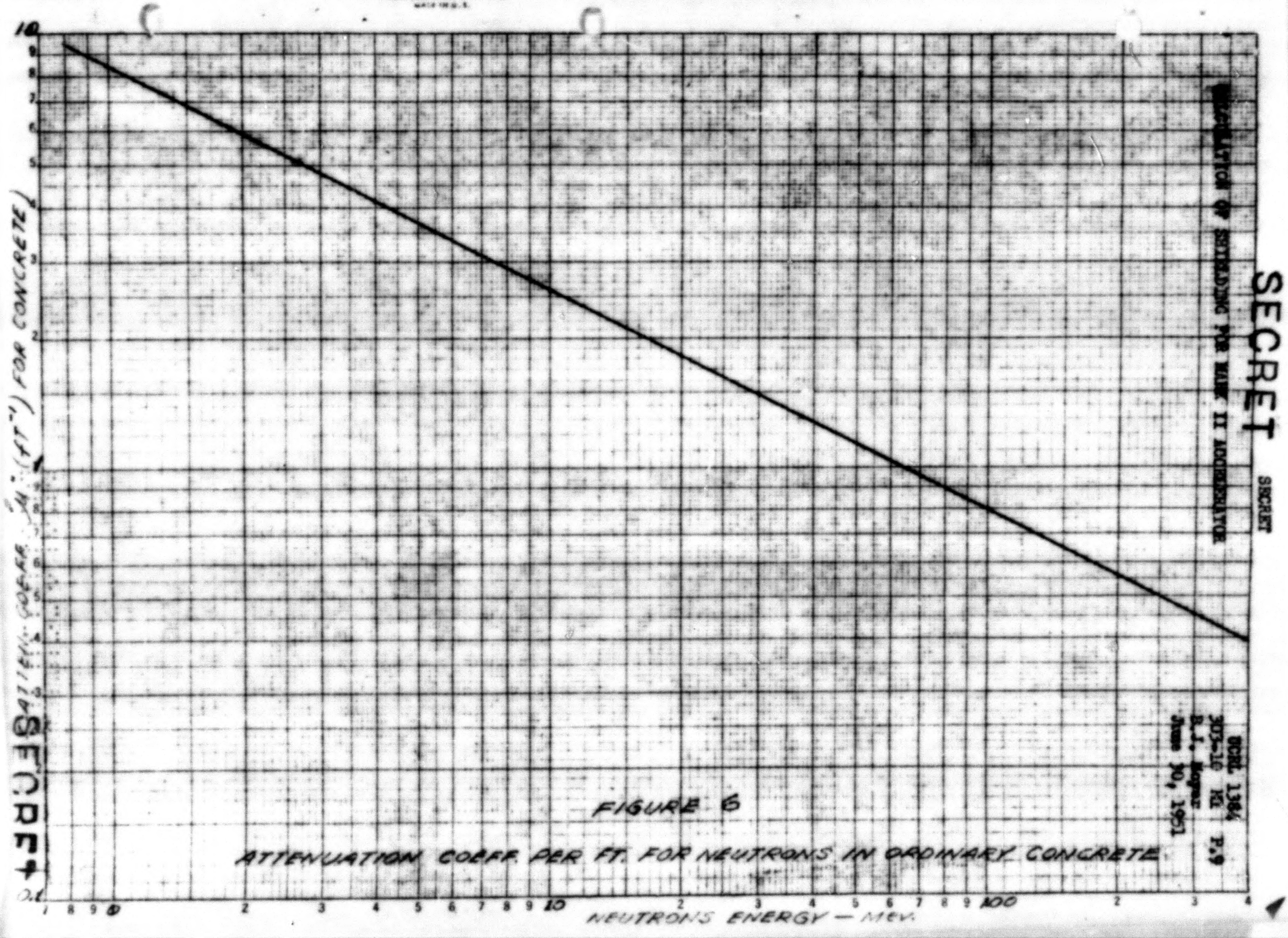

FIGURE 6

ATTENUATION COEFF. PER FT. FOR NEUTRONS IN ORDINARY CONCRETE

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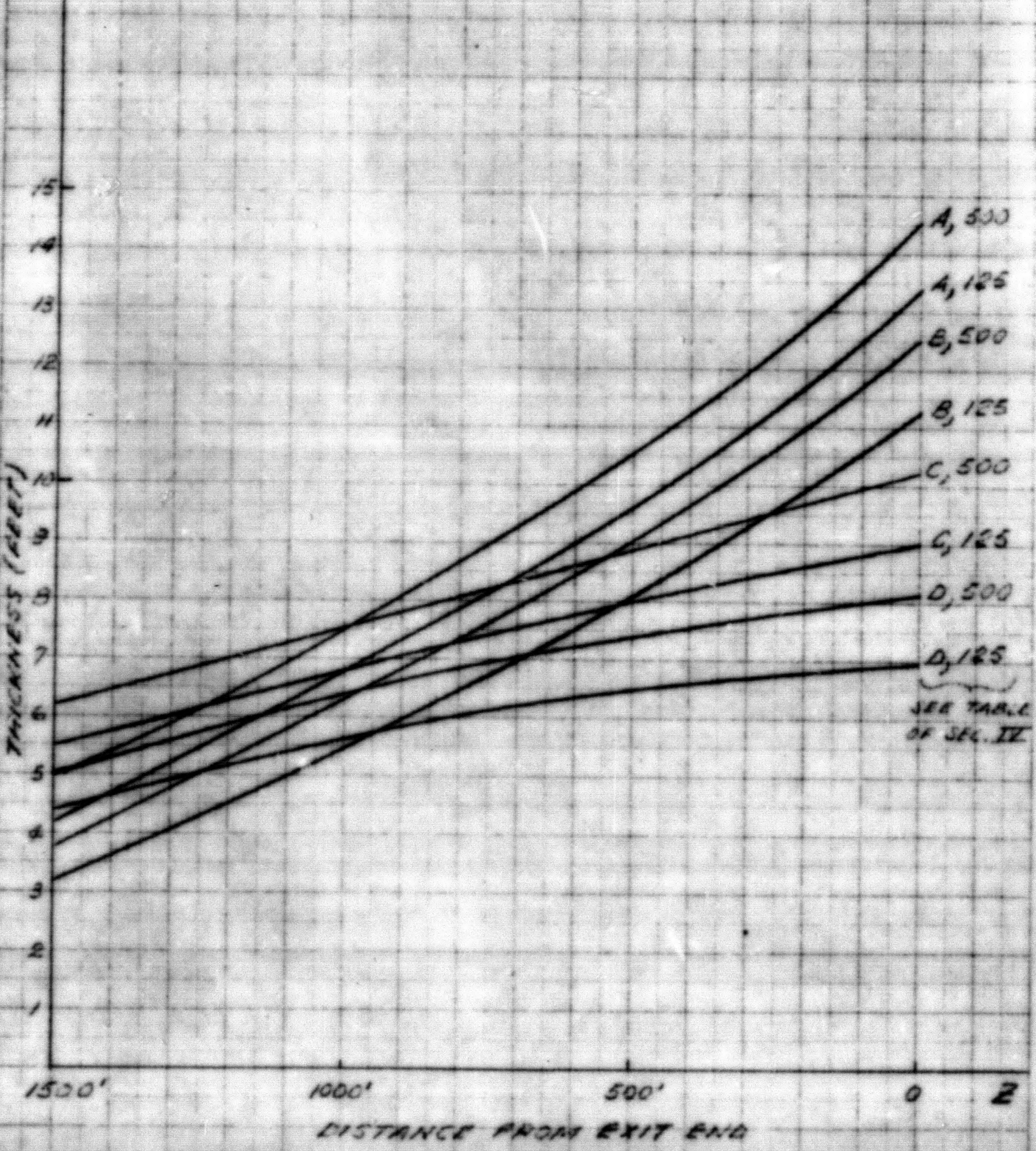

FIGURE 7

SIDE WALL THICKNESS VS. Z

END