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TO: W. E. Unger

FROM: H. E. Williamson

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DISCLAIMER

To: W. E. Unger

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Subject: HRT Chemical Facility Carrier Shielding Calculations

Date: August 30, 1955

SUMMARY

Calculations were made to estimate the radiation exposure from an HRT chemical facility fission product carrier. The shielding weight is limited to 5 tons by the capacity of the crane available to remove items from the chemical process cell. The results are shown in Fig. 7.

The calculated radiation exposure of 2.5 r/hr at the carrier surface and 11 mr/hr ten feet from the carrier seems reasonably low, but it is suggested a meeting with Health Physics personnel be called to discuss this radiation level and proper means of handling.

INTRODUCTION

The chemical facility for the HRT will concentrate fission products insoluble in reactor "soup" at reactor operating temperature and pressure into a relatively small volume container (about four gallons). Uranium, unavoidably collected in this container, will be recovered by periodically sending the container to a solvent extraction plant. For protection of personnel from an extremely high level of radioactivity it will be necessary to envelope the container in a gamma ray shield.

A weight limitation is imposed on the shielding by the capacity of the 5 ton crane available for removing items from the chemical processing cell. This coupled with the size and shape container desired, limits the shield to a maximum thickness of 8 inches of lead. A further reduction in radiation is obtained by allowing a cooling period before handling the carrier. Of course, more shielding can be used where the service of the crane is not required.

The following calculations were made to establish the feasibility of this limited shielding, and to obtain an estimate of the cooling time required before the carrier could be removed from the cell and approached.

DISCUSSION

An examination of literature on the gamma activity of fission products from uranium-235[1,2,3] revealed that, after 50 days cooling, the radiation exposure in this case could be calculated by considering only four fission product chains. They are Zr^{95}-Nb^{95}, Ru^{106}-Rh^{106}, Ba^{140}-La^{140}, and Ce^{144}-Pr^{144}. The activity and important radiations as a function of cooling time were calculated[4] for a reactor operating at the design power level of the HRT, 5 MW, using the nuclear data shown in Tables 1 and 2. These results are illustrated in Figs. 1 and 2.

The shielding calculations were greatly simplified by a couple of conservative assumptions. The four chains mentioned, particularly the two of greatest interest here, will have a very limited solubility[5] in the reactor at operating conditions. Although the distribution of these insolubles throughout the reactor system and chemical facility is unknown, it is reasonable and conservative for carrier design purposes to consider them collected entirely in the carrier. In addition, since it is conceivable that this solid material may settle in a relatively small volume in the carrier, the radiation source for shielding calculations was considered a point, emitting radiation isotropically. This, of course, neglects some self-shielding and geometry effects that should represent a reduction in calculated exposure, perhaps by a factor of 2 or 3.

The exposure under the above conditions is calculated from this equation:

$$1) \quad E_A = \frac{\mu S}{4\pi t^2} e^{-\mu_o t} B_t$$

where:

E_A = radiation exposure

μ = gamma energy absorption coefficient for air

S = total gamma energy emission

t = shield thickness

μ_o = coefficient for all gamma interactions in shielding material

B_t = buildup factor to allow for accumulation of forward scattered gamma photons.

[1] Nuclear Properties of U^{235} Fission Products, ORNL CF-54-12-52, J. O. Blomeke, December 20, 1954.

[2] Fission Product Decay Gamma Energy Spectrum, APEX 134, John Moteff

[3] Decay of Fission Product Gammas, NDA-27-39, F. H. Clark, Dec. 30, 1954

[4] Appendix A

[5] The Reactor Handbook, Volume 2, Engineering, Chapter 4.3, pp. 718-734.

Table 1

Fission Product Data*

Isotope	Fission Yield[+] %	Decay Constant Sec^{-1}
Zr^{95}	6.4	1.23×10^{-7}
Nb^{95}	6.4	2.29×10^{-7}
Ru^{106}	0.38	2.20×10^{-8}
Rh^{106}	0.38	2.31×10^{-2}
Ba^{140}	6.3	6.27×10^{-7}
La^{140}	6.3	4.81×10^{-6}
Ce^{144}	6.1	2.84×10^{-8}
Pr^{144}	6.1	6.60×10^{-4}

+ Yield for first member of chain.

* Nuclear Properties of U-235 Fission Products, revisions unpublished, J. O. Blomeke.

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Table 2

Important Radiation*

Isotope	Radiation Energy	Fraction of Disintegrations Yield this Photon
Zr^{95}	0.721	0.99
Nb^{95}	0.745	1.0
Ru^{106}	2.41	0.0025
La^{140}	1.6	1.0
La^{140}	2.5	0.054
La^{140}	3.0	0.01
Pr^{144}	2.19	0.005

*Ibid.

If t is expressed in centimeters, and S in Mev/sec, then the equation is modified to express E_A in r/hr[6] as follows:

(2) $E_A = 1.88 \times 10^{-6} F_1 F_2 S$ r/hr

where:

$\mu = 3.5 \times 10^{-5}$ cm^{-1} for gamma energies 0.05 Mev $< E <$ 4 Mev[7]

$F_1 = e^{-\mu_o t} B_t$

$F_2 = \frac{1}{4\pi t^2}$

The attenuation by lead of several interesting gamma energies is illustrated in Figs. 3, 4, and 5. Cross sections for all gamma interactions[7] and buildup factors[8] were used to calculate factor F_1.

The reduction in radiation intensity by distance from the source or inverse square factor, F_2, is shown in Fig. 6.

Taking F_1, F_2 and S from Figs. 2, 4, 5, and 6 for use in equation (2) the radiation exposure at the surface of the carrier was calculated for cooling times from 50 to 300 days and reactor operating periods of 150, 300, and an infinite number of days. This is illustrated in Fig. 7. Incidentally, La^{140} and Pr^{144} contribute at least 95% of the radiation exposure at all cooling times shown.

CONCLUSION

For 150 days reactor operation, which is the expected period of feed to a single carrier, the radiation exposure at the carrier surface is about 2.5 r/hr after 150 days cooling time. At a distance of ten feet from the carrier this is reduced to about 11 mr/hr, almost laboratory tolerance.

This seems reasonably safe since the period of time the carrier must be handled by the crane is short (perhaps one hour). However, it is suggested that this be discussed with Health Physics personnel for agreement and suggestions for proper handling of this radiation source.

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[6] Appendix B

[7] Introduction to Shield Design, ORNL CF-51-10-70, Part I, E. P. Blizard, Jan. 30, 1952, page 35.

[8] The Reactor Handbook, Volume 1, Physics, Chapter 2.3, page 776.

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H. E. Williamson

HEW/nh

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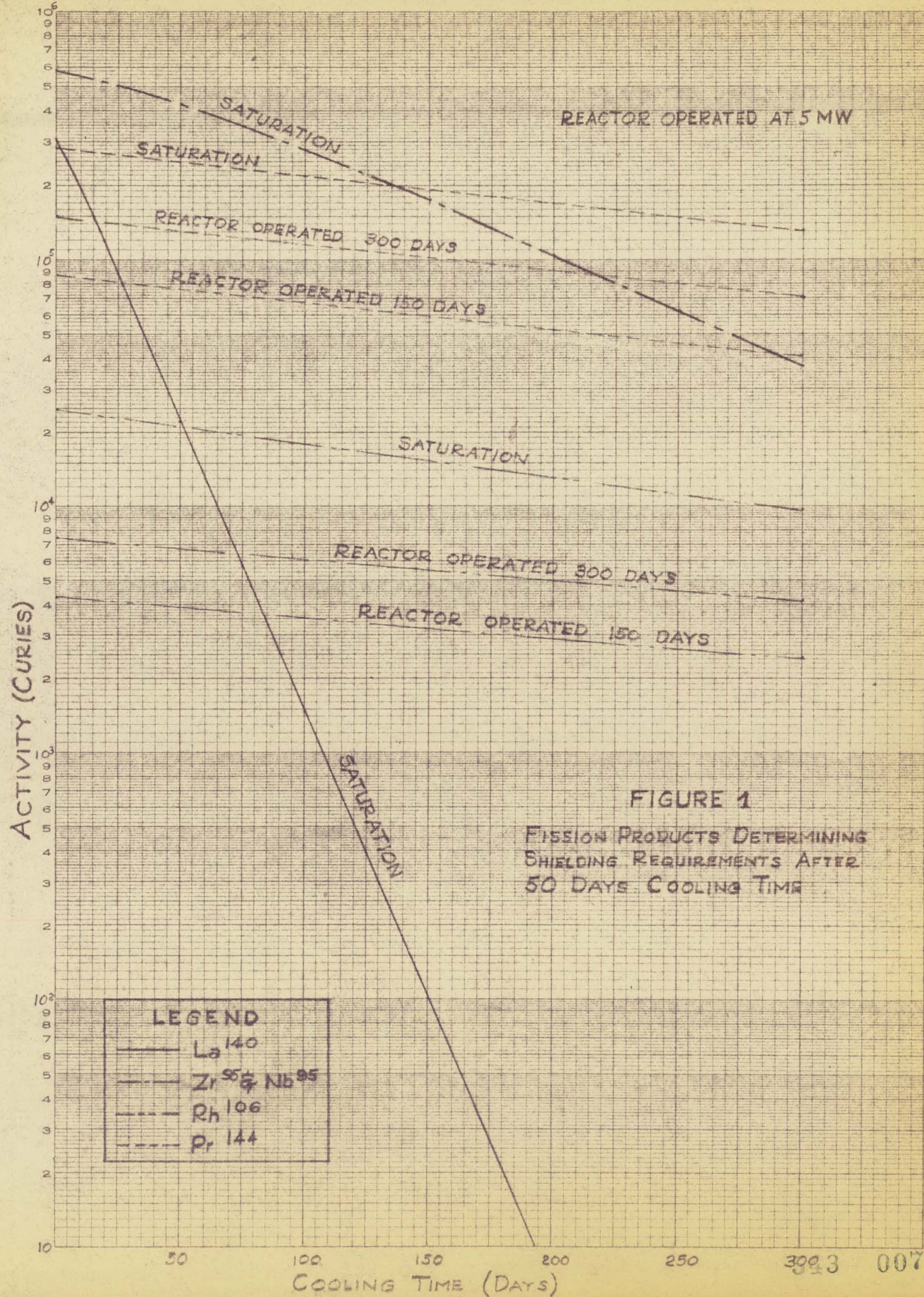

FIGURE 1

Fission Products Determining Shielding Requirements After 50 Days Cooling Time

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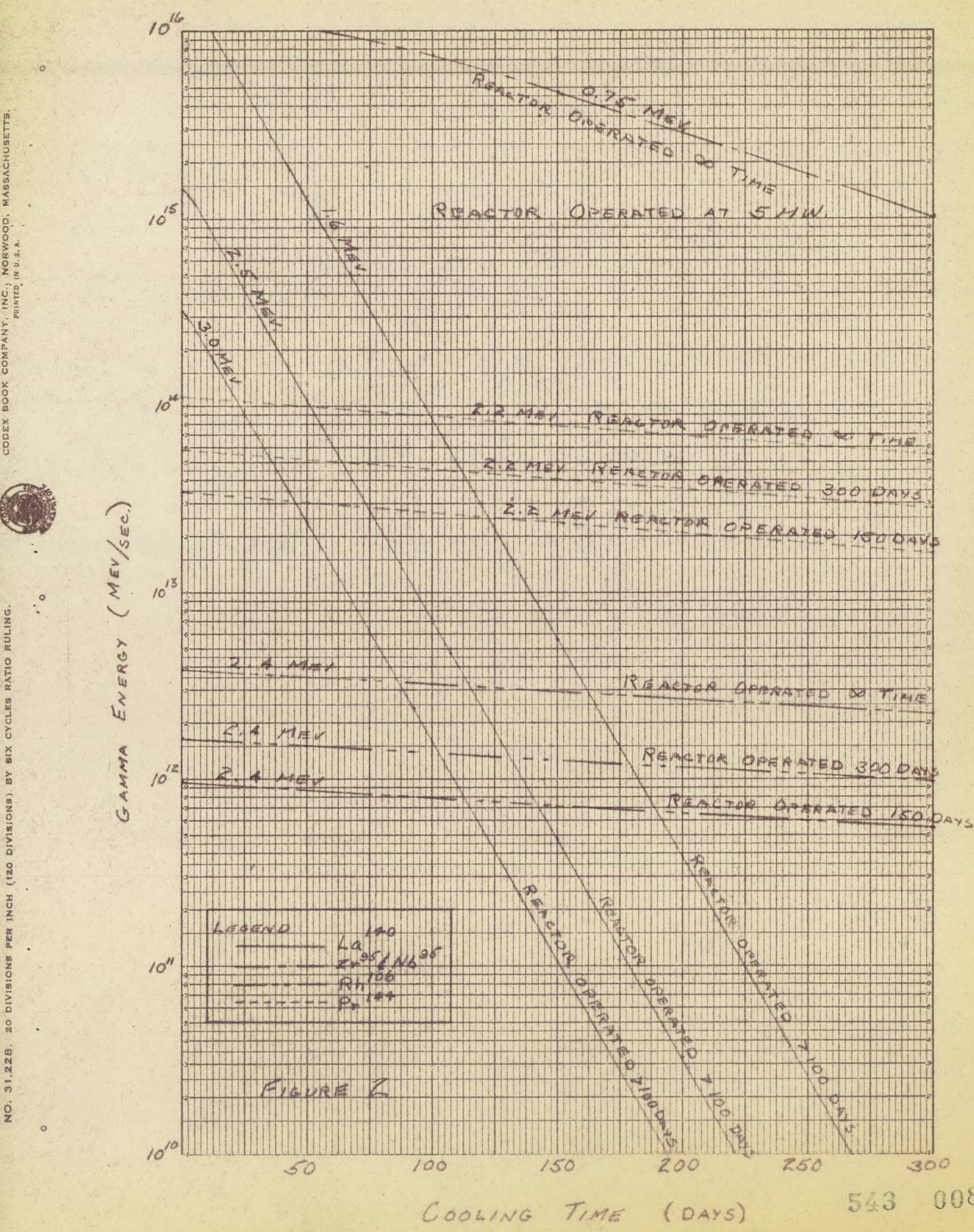

RADIATION DETERMINING SHIELDING AFTER 50 DAYS COOLING

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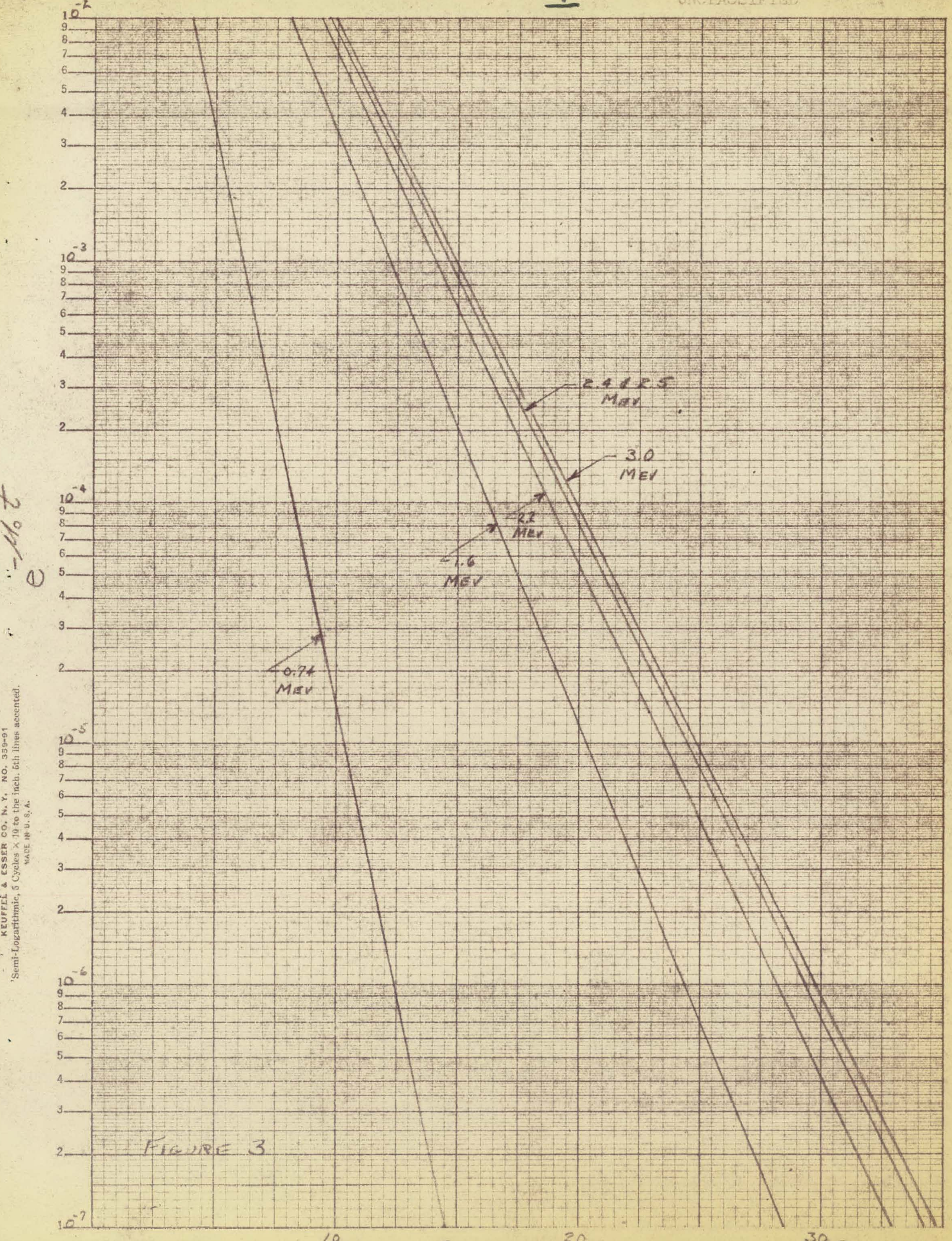

FIGURE 3

GAMMA RAY ATTENUATION

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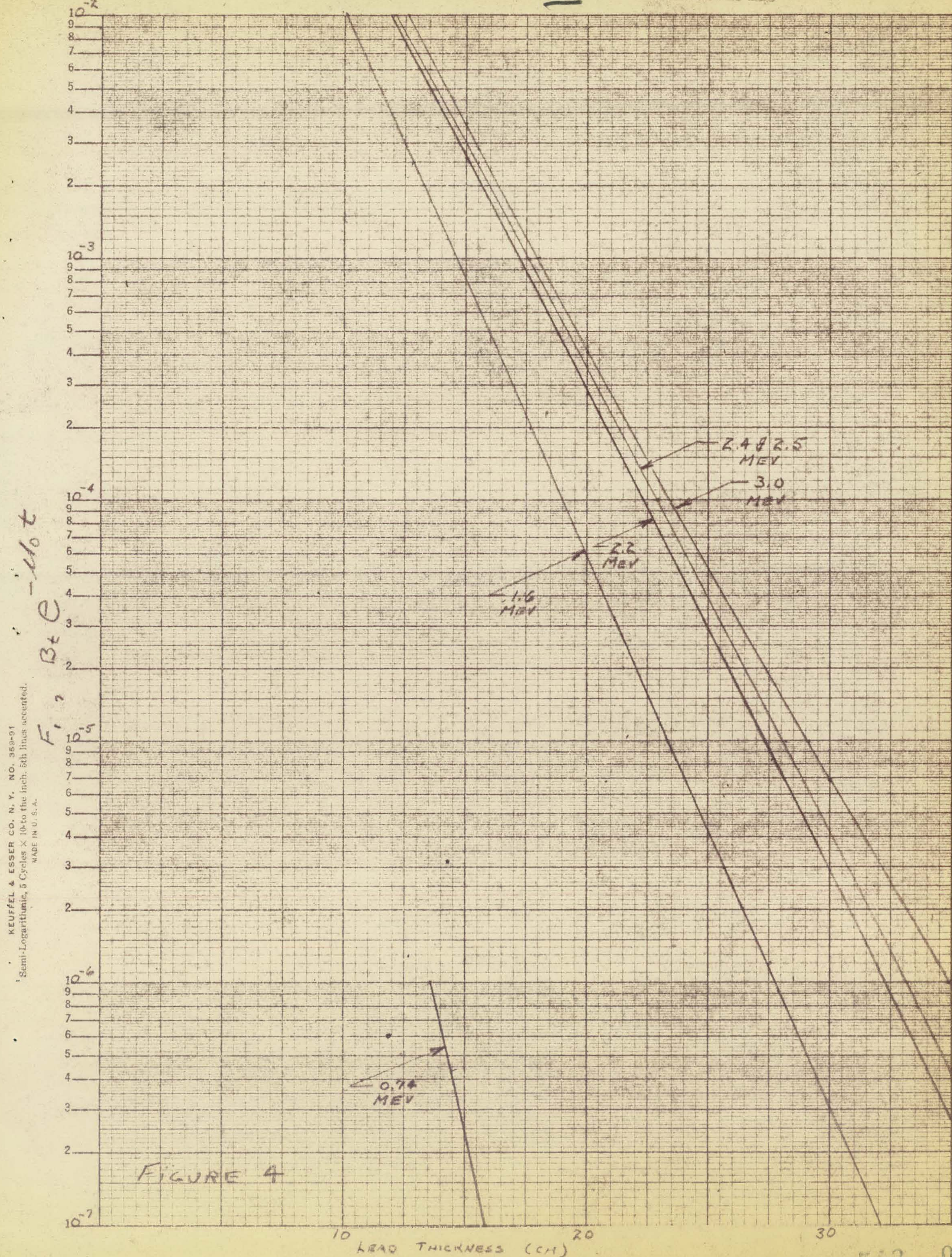

GAMMA ATTENUATION ALLOWING FOR BUILD-UP

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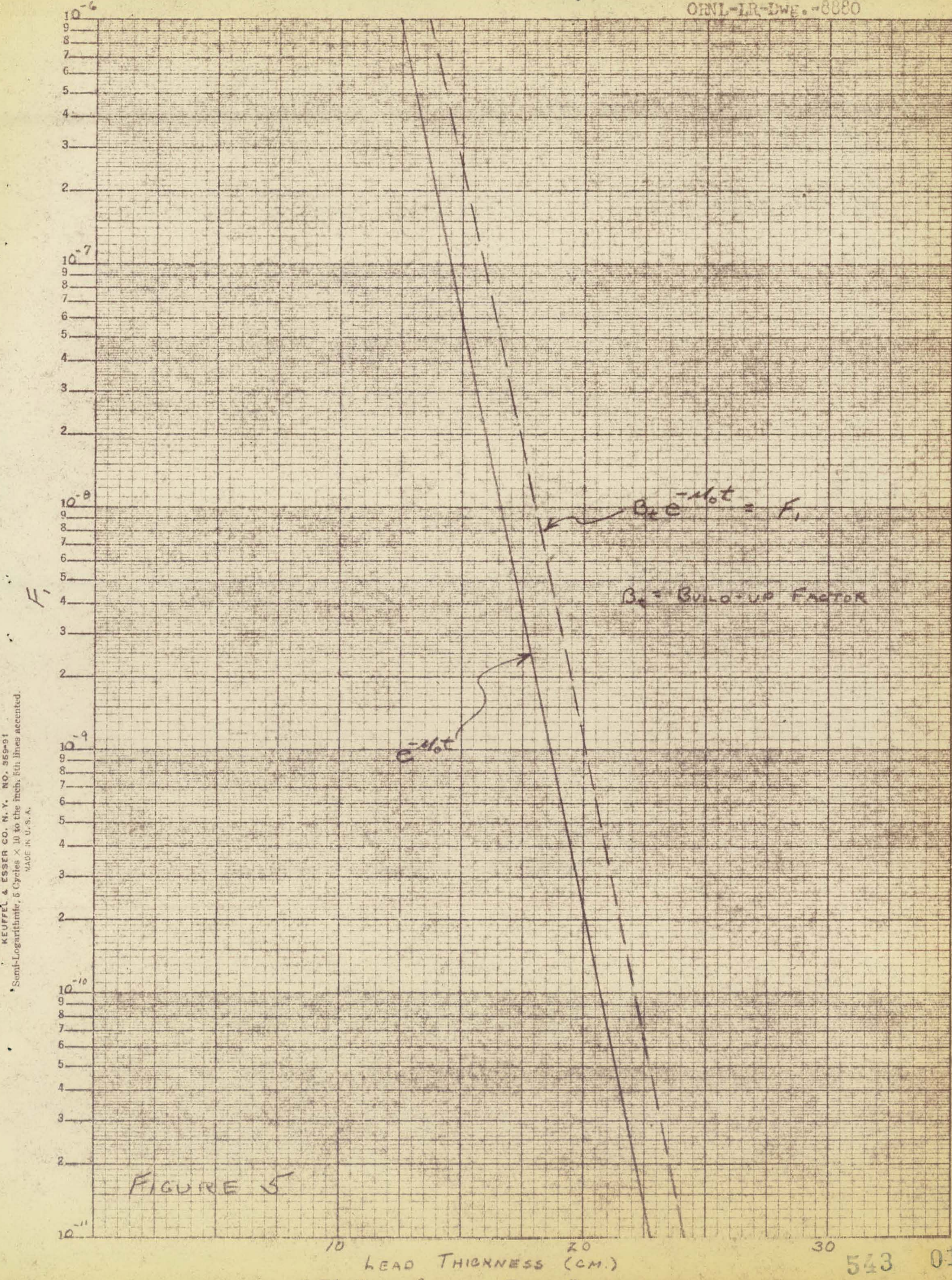

0.74 MEV. GAMMA RAY ATTENUATION

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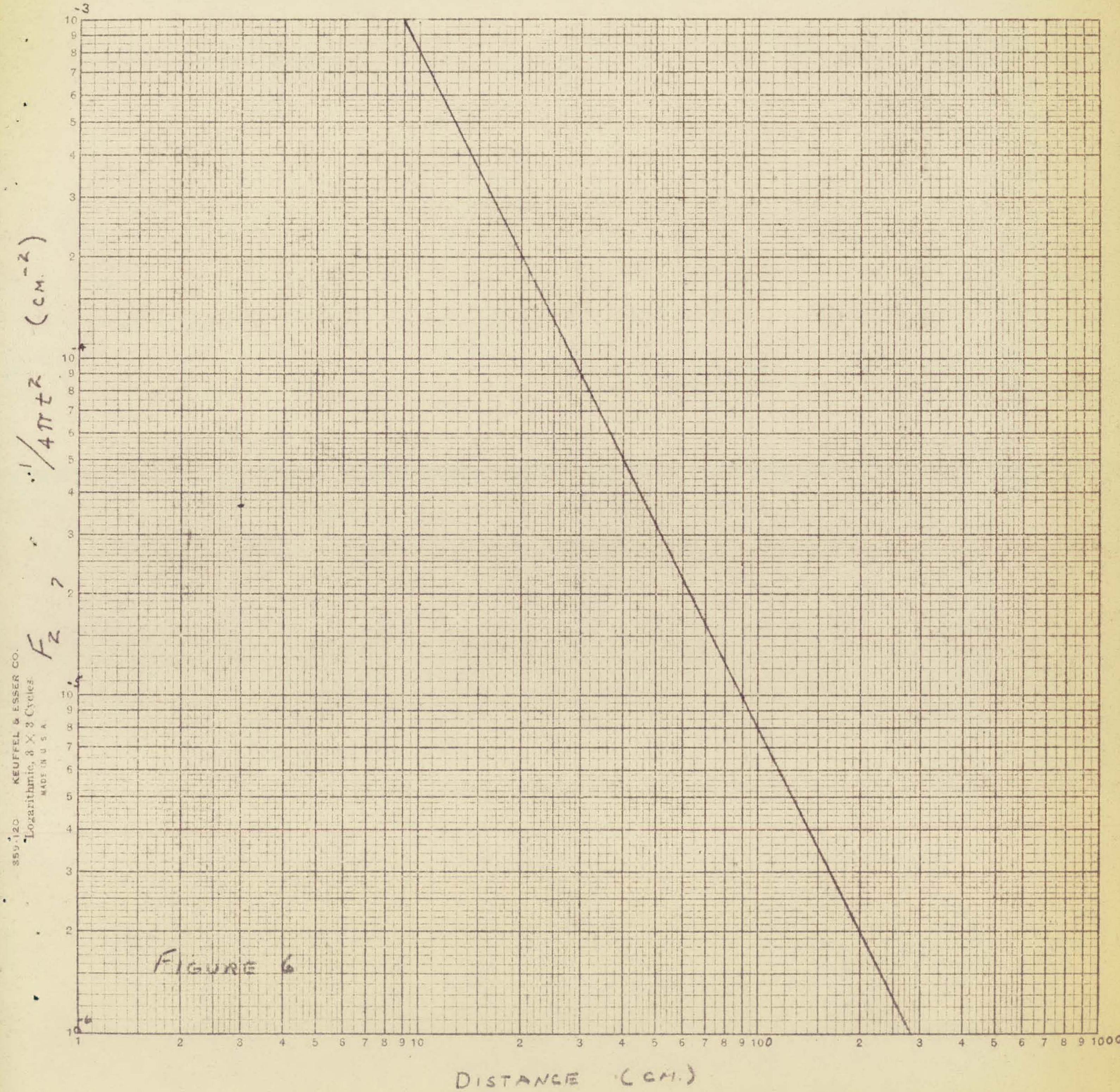

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INVERSE SQUARE FACTOR, F_z

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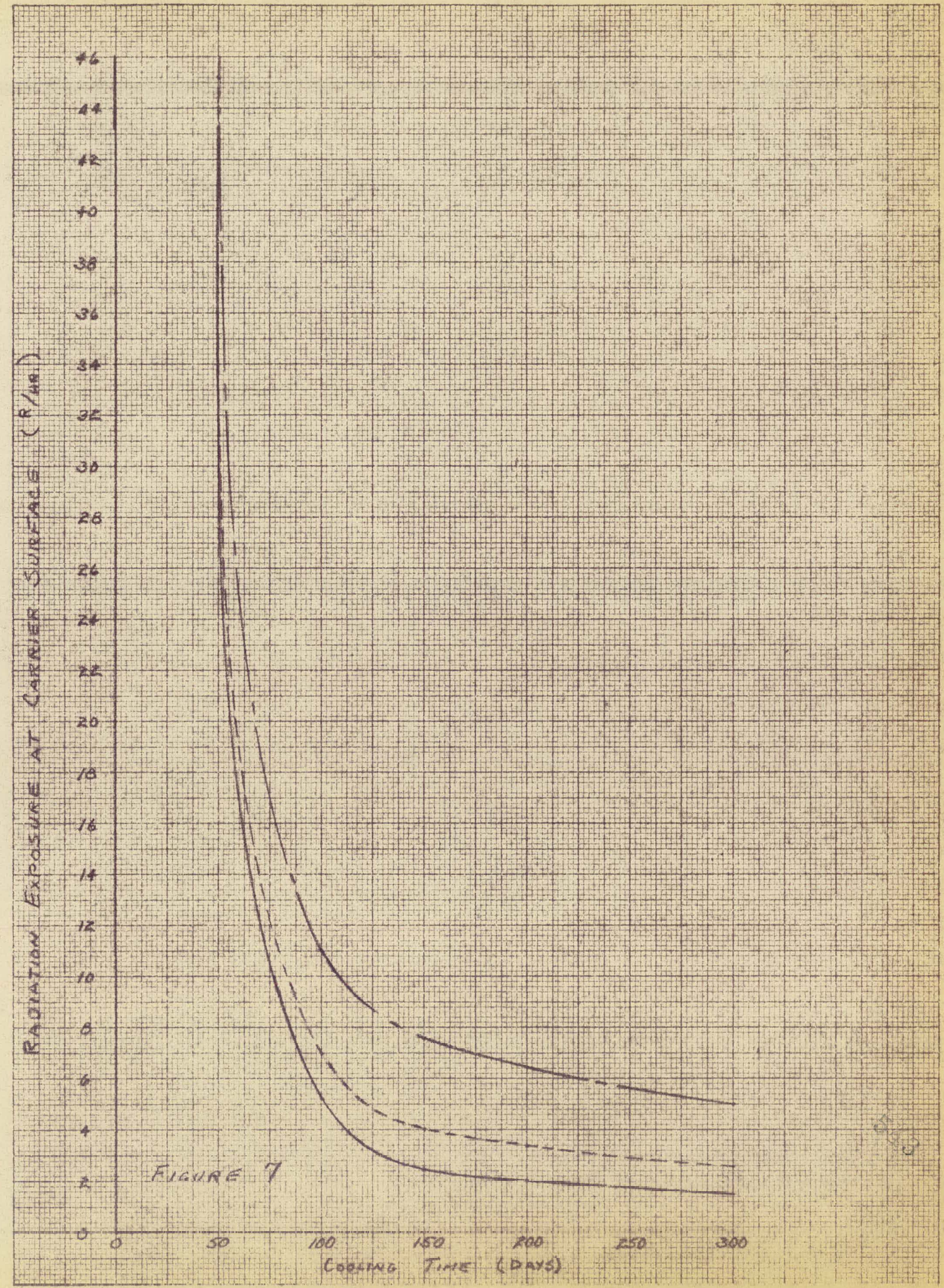

EFFECT OF COOLING TIME ON RADIATION EXPOSURE

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APPENDIX A

Activity and Radiation Calculations

Fission product activity in this case is calculated by one of the two following formulas.

$$(3) \quad A_1(T) = Y_1 \Sigma_f \phi (1 - e^{-\lambda_1 t})\, e^{-\lambda_1 T}$$

$$(4) \quad A_2(T) = Y_1 \Sigma_f \phi \frac{\lambda_1 \lambda_2}{\lambda_2 - \lambda_1} \left[\frac{(1 - e^{-\lambda_1 t})}{\lambda_1} e^{-\lambda_1 T} - \frac{(1 - e^{-\lambda_2 t})}{\lambda_2} e^{-\lambda_2 T} \right]$$

where:

$A_1(T)$ = Activity of fission product formed directly from fission or short-lived percursors

$A_2(T)$ = Activity of fission product percursed by a reasonably long-lived parent.

Y_1 = Fission yield of first member of chain

$\Sigma_f \phi$ = Fission rate

λ = Decay constant

t = period of time reactor operated

T = cooling time

For a 5 MW homogeneous circulating fuel reactor, the fission rate is about 1.69×10^{17} fission per second. Using the data from Table 1, the activity of each isotope of interest was calculated and plotted in Fig. 1.

The radiation energy from each was computed by the following equation:

$$(5) \quad S(T) = A(T)\, \gamma\, E_\gamma$$

where:

A(T) = Activity as a function of cooling time

γ = Fraction of disintegrations yielding photons of energy, E_γ

E_γ = Energy of gamma photons

S(T) = Total emission as function of cooling time.

The values of γ and E_γ were obtained from Table 2 and the results plotted in Fig. 2.

APPENDIX B

RADIATION EXPOSURE

The following equation is converted into a more convenient form

(1) $E_A = \frac{\mu s}{4\pi t} e^{-\mu_o t} B_t$

by letting

$F_1 = e^{-\mu_o t} B_t$

$F_2 = \frac{1}{4\pi t^2}$

where:

S = Total emission

μ = Gamma absorption coefficient for air

μ_o = All interaction coefficient for shield material

t = Shield thickness

B_t = buildup factor

then:

$E_A = \mu S F_1 F_2$

By definition the Roentgen is that quantity of electromagnetic radiation that will dissipate 0.107 ergs per cubic centimeter of dry air.[9]

Thus,

1 r/sec = 0.107 ergs/cm^3-sec

1 Mev = 1.6 x 10^{-6} ergs

$1 \text{ R/sec} = \frac{0.107 \text{ ergs/cm}^3\text{-sec}}{1.6 \times 10^{-6} \text{ ergs/mev}}$

1 R/sec = 6.69 x 10^4 Mev/cm^3-sec

1 R/hr = 18.6 Mev/cm^3-sec

Expressing t in centimeters, S in Mev/sec, and μ_o in cm^{-1}, and inserting the value for μ, 3.5 x 10^{-5} cm^{-1},

$$E_A = \frac{3.5 \times 10^{-5} \text{ cm}^{-1} \times S \text{ Mev/sec}}{4\pi t^2 \text{ cm}^2} B_t e^{-\mu_o t} \div 18.6 \frac{\text{Mev/cm}^3\text{-sec}}{\text{R/hr}}$$

(2) $E_A = 1.88 \times 10^{-6} F_1 F_2 S$ R/hr

[9] Introduction to Shield Design, Part I, ORNL CF-51-10-70, E. P. Blizard, p. 37.

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