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LOS ALAMOS SCIENTIFIC LABORATORY

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NEUTRON TISSUE DOSE SURVEY FOR THE LITTLE EVA CRITICAL ASSEMBLY

by

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ABSTRACT

A neutron tissue dose survey was made for the Little Eva critical assembly using the Hurst neutron proportional counter. Comparisons were also made with the Los Alamos "Converted Pee Wee" neutron counter. The data indicate the Pee Wee counter measurements to be a factor of 7 higher than those obtained with the Hurst counter. This difference in the measurements is mainly attributed to an "over response" of the Pee Wee (on a dose per neutron basis) in the intermediate and thermal neutron energy region.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Wendell Biggers and Leon Brown of J-12, who operated the critical assembly, and to Groups H-1 and H-4, who aided in the laborious task of assembling the equipment in the field. The authors are also indebted to G. S. Hurst for his loan of a polyethylene-wall, ethylene-gas proportional counter.

INTRODUCTION

This investigation was performed to provide an estimate of the neutron dose rate as a function of distance for the Los Alamos Little Eva critical assembly. Neutron dose measurements were carried out with the Hurst polyethylene-wall, ethylene-gas proportional-flow counter. A hand-carried neutron survey instrument [Nuclear-Chicago Model 48-N (Converted Pee Wee)] was also used in the control trailer to establish permissible working times for the operating personnel.

DESCRIPTION OF THE LITTLE EVA ASSEMBLY*

The Little Eva critical assembly is made up of a number of cubes of U^{235} totaling 22 to 23 kg arranged in a pseudosphere and surrounded by a tamper of U^{238}. The tamper is similar to a cube and its exterior dimensions are approximately 10 inches on a side. The skeleton of the machine is the base and column of an ordinary drill press (Fig. 1). Occupying the position of the table of the drill press is a frame containing approximately half of the active material and the tamper. Also mounted on this frame is the "fine control" of the assembly, a 2-1/2-inch cube of U^{238} which can be moved into or away from the active material by a small motor and gear system. Mounted in place of the spindle of the drill press is an air cylinder with a frame containing blocks of tamper on the piston. This frame is held up by springs. When compressed air is admitted into the cylinder, the tamper is forced down into contact with the material on the table; when the air is released, the springs immediately separate the tamper from the material on the table.

The remaining portions of the active material and the tamper are enclosed in a frame mounted on the piston of an air cylinder which stands on the base of the drill press. Compressed air in the cylinder raises this portion of the assembly into contact with the material on the table, thus completing the assembly. There are numerous mechanisms and interlocks

*The material in this subsection was largely taken from LA-1487.[1]

which provide a maximum degree of safety. The control point for this remotely operated assembly is normally 1/4 mile away, but for this survey it was 270 meters distant. The critical material was 1.69 meters above ground in a trailer. No shielding was used around the assembly.

DESCRIPTION OF THE HURST PROPORTIONAL COUNTER AND ASSOCIATED ELECTRONICS

A Hurst proportional counter (HPC), with a polyethylene wall and ethylene gas, was used.[2,3,4] The counter was used as a flow counter and was connected to a voltage divider which placed 0.285 of the collecting voltage on the field tubes. The voltage applied to the central wire was +2200 volts. The output of the counter was connected first to a 130 N line-driving preamplifier, then to a 101 A linear amplifier with delay line clipping, and finally to a 10-channel analyzer. Alpha calibrations were taken before and after each field change. Background readings were subtracted from each neutron run.

The Hurst proportional counter was mounted on a table in the bed of a pickup truck. The height of the counter above ground was 2.06 meters. The 10-channel analyzer was mounted in the bed of another pickup truck stationed at the east end of the control trailer. Two cables, each 500 feet long, were used; one was a signal cable (RG-71/U) and the other was #12 rubber-covered three-wire cable for carrying 110 volt power. Measurements were made at the various distances shown in Fig. 2.

CALCULATION OF THE TISSUE DOSE

The absorbed dose in ethylene, D_{eth}, was evaluated from the formula

$$D_{eth} = 1.602 \times 10^{-8} \frac{E_{\alpha}}{M_{eth}} \times \frac{A_{LE}}{A_{\alpha}} ,$$

where

1.602×10^{-8} = conversion factor from Mev/g to rads

E_{α} = total alpha energy of calibrating Pu^{239} source

M_{eth} = mass of ethylene gas in sensitive volume (0.0734 g at STP)

A_{LE} = area under the Little Eva integral bias curve, Fig. 3.

A_{α} = area under the alpha integral bias curve, Fig. 3.

The dose in tissue, D_T, was calculated from the expression

$$D_T = \frac{D_{eth}}{1.45 \pm 0.15} ,$$

where the factor 1.45 ± 0.15 is the ratio of first collision dose in ethylene to that in tissue.[2,4]

DESCRIPTION OF THE "CONVERTED PEE WEE"[5]

The portable field survey meter used was the Nuclear-Chicago Model 48-N (Converted Pee Wee) proportional counter. This instrument is a Model 48-A Pee Wee (alpha survey meter) modified for use with a boron-lined probe; a 1-inch-thick polyethylene moderator surrounded by a 20-mil-thick cadmium absorber is used with the probe. The large energy-dependent response of this instrument is shown in the General Handbook for Radiation Monitoring,[5] page 54.

This instrument is the primary neutron field survey meter used at Los Alamos. It has four ranges of sensitivity, the least sensitive range measuring from 0 to 20,000 neutrons/cm^2-sec. Since it is calibrated to a Pu-Be spectrum, correction factors for other neutron energies are needed.

RESULTS

Table I shows the results obtained from the Hurst proportional counter measurements at four distances. The uncertainty of these measurements is estimated to be approximately 20 per cent. Two sets of measurements were made at 270 meters, one inside the control trailer where the results might have been affected by the occupants, and the other outside the trailer in the bed of a pickup truck. Within the uncertainties of the measurements, no difference was found between the dose rates inside and outside the trailer. Assuming an RBE factor of 10 for neutrons,[6] one would obtain a radiation level of 12.5 mrem/hr in the trailer.

The observed results are shown graphically in Fig. 4. It can be seen that the decrease in dose rate is much more rapid than one would predict

Table I. Survey with HPC

Distance (meters)	Neutron Tissue Dose Rate (mrads/hr)*
23	322
170	10.6
270 (inside trailer)	1.25
270 (outside trailer)	1.27
395	0.42

*All readings normalized to 100 watts reactor power.

from the inverse square law. This additional attenuation is the net result of air scattering and absorption. If the dose rate times distance squared is plotted vs distance, the inverse square attenuation is eliminated and the net effect of scattering and air absorption can be seen. This relation is shown in Fig. 5. The data at 170 meters indicate an unexpected increase well outside of 20 per cent uncertainty in the function. Therefore, in the region from 23 to 170 meters it appears that the effects of scattering are greater than the effects of air absorption. It is difficult to arrive at a more quantitative explanation because of the limited data obtained. The results at 270 and 395 meters appear to be consistent with a mean free path of approximately 250 meters, as shown in Figs. 4 and 5 and calculated from reference 7.

Measurements made with the Model 48-N Converted Pee Wee indicated a neutron dose rate of 87 mrem/hr in the trailer. For this evaluation a degraded fission spectrum with an average energy of 1 Mev was assumed. This measurement differed from the Hurst proportional counter evaluation by a factor of 7. It is believed that this discrepancy is mainly due to an over-response of the Pee Wee (on a dose per neutron basis) in the intermediate and thermal neutron energy region. A secondary consideration in the case of the Hurst proportional counter is the uncertainty of the extrapolation to zero bias. This would contribute a large error only in the case of highly moderated spectra.

Appendix I

SAMPLE CALCULATION OF NEUTRON TISSUE DOSE

Figure 3 shows the integral bias curves obtained with the Hurst proportional counter. An example to illustrate the calculation of neutron tissue dose is as follows:

1. The areas under the curves are obtained using a planimeter and are in arbitrary units. In the calculation the units cancel out. The area under the alpha integral bias calibration curve is $A_\alpha = 3555$ units. The area under the Little Eva integral bias curve is $A_{LE} = 1277$ units.

2. The average number of alphas times the alpha energy (for plutonium, 5.14 Mev) gives the energy absorbed by the counter and is represented by the alpha calibration curve;

$$4.75 \times 10^3 \ \alpha\text{'s} \times \frac{5.14 \text{ Mev}}{\alpha} = 2.442 \times 10^4 \text{ Mev.}$$

The mass of the ethylene gas is 0.0734 g at STP. Conditions at the time of measurement were T = 10°C, P = 59 cm Hg.
Thus

$$M_{eth} = \frac{59}{76} \times \frac{273}{283} \times 7.34 \times 10^{-2} = 5.50 \times 10^{-2} \text{ g;}$$

since 1 rad = 100 ergs/g in tissue, then

$$\frac{2.442 \times 10^4 \text{ Mev}}{5.5 \times 10^{-2} \text{ g}} \times \frac{1.602 \times 10^{-6} \text{ erg}}{\text{Mev}} \times \frac{1}{100 \text{ ergs/g/rad}} = 7.11 \times 10^{-3} \text{ rad in ethylene}$$

Therefore,

$$\frac{7.11 \times 10^{-3} \text{ rad}}{1.45} = 4.90 \text{ tissue mrads for the } \alpha\text{-area,}$$

and

$$D_{LE} = \frac{D_\alpha A_{LE}}{A_\alpha} = \frac{4.90 \text{ tissue mrads} \times 1277}{3555} \times \frac{1}{2} \times \frac{1}{4.16}$$

where

the factor 1/2 is the ordinate scale ratio in Fig. 3,
the factor 1/4.16 is the amplifier gain ratio.

Therefore

$$D_{LE} = 0.211 \text{ tissue mrad/10 min}$$

or

$$D_{LE} = 1.27 \text{ tissue mrads/hr.}$$

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Fig. 1 Little Eva critical assembly.

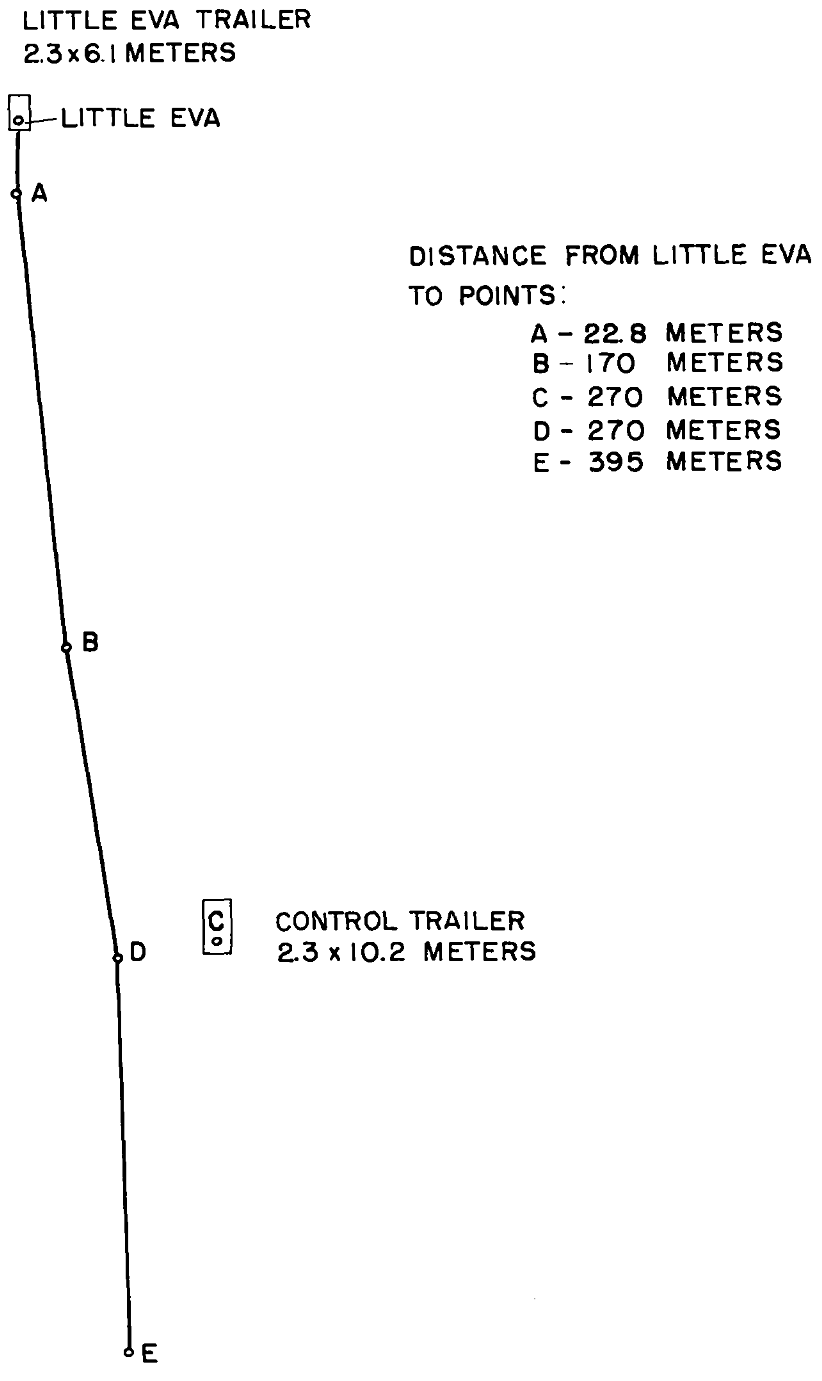

Fig. 2 Little Eva placement with respect to field survey geometry.

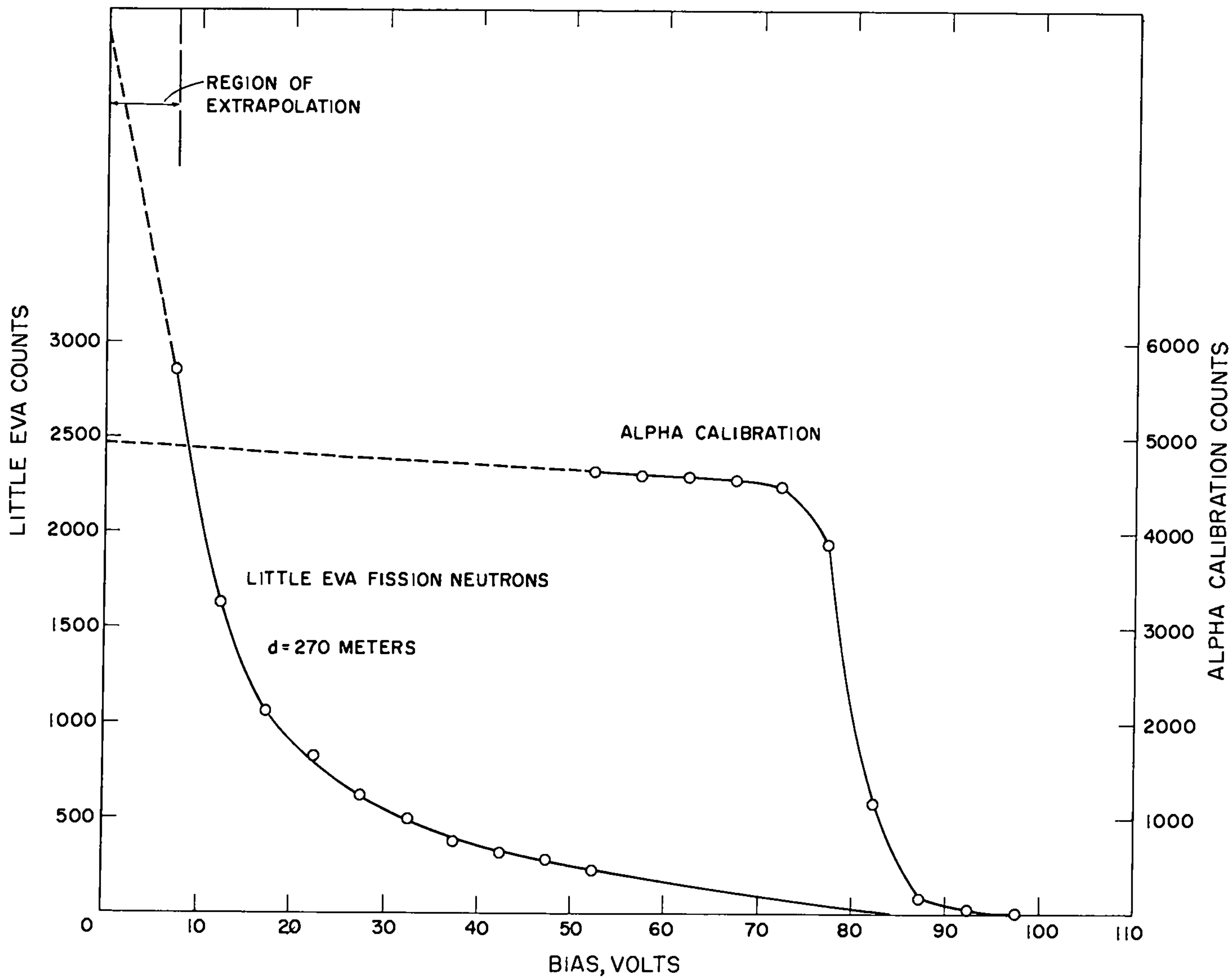

Fig. 3 Integral bias curves taken with the Hurst proportional counter.

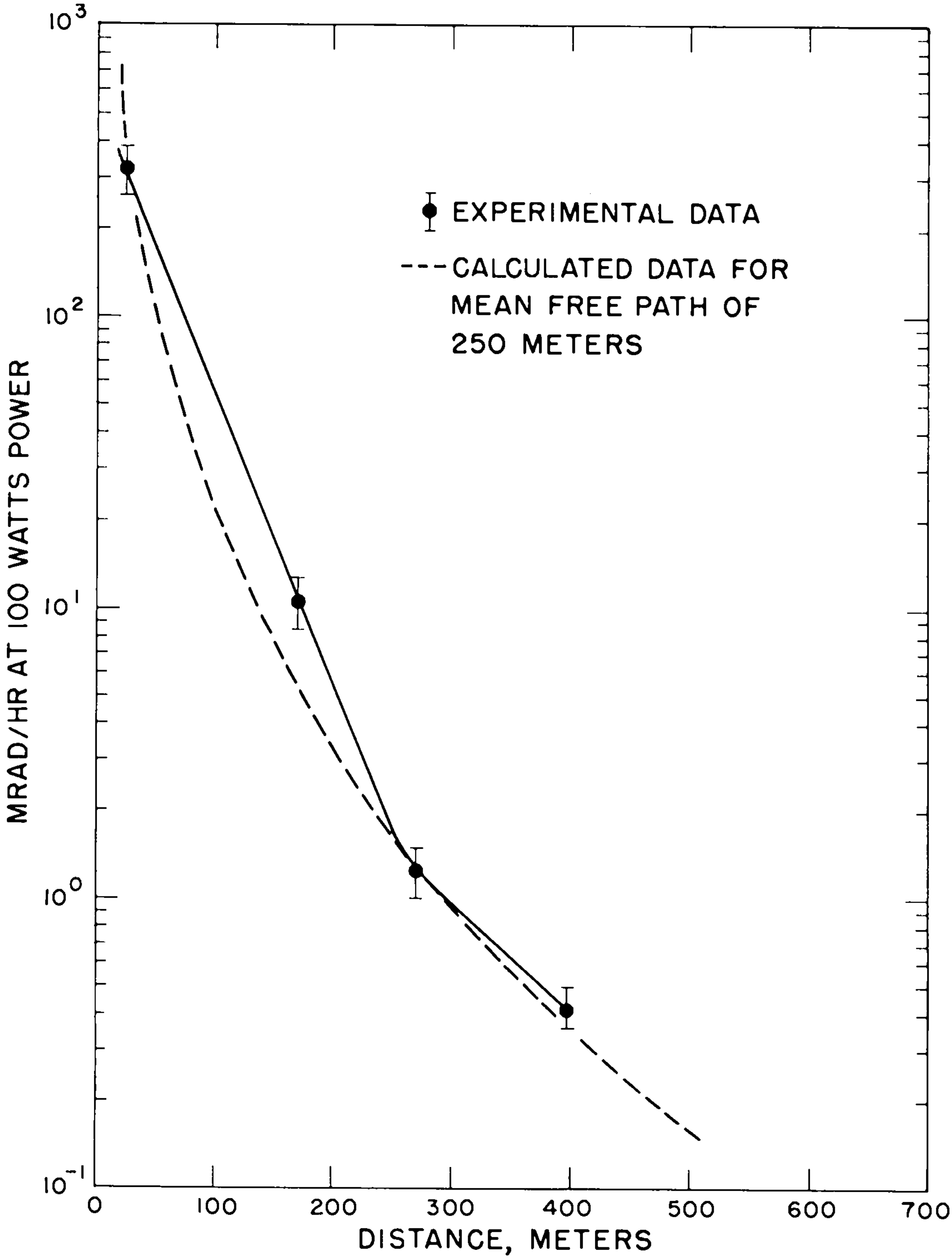

Fig. 4 Calculated and experimentally determined variation of tissue dose rate with distance.

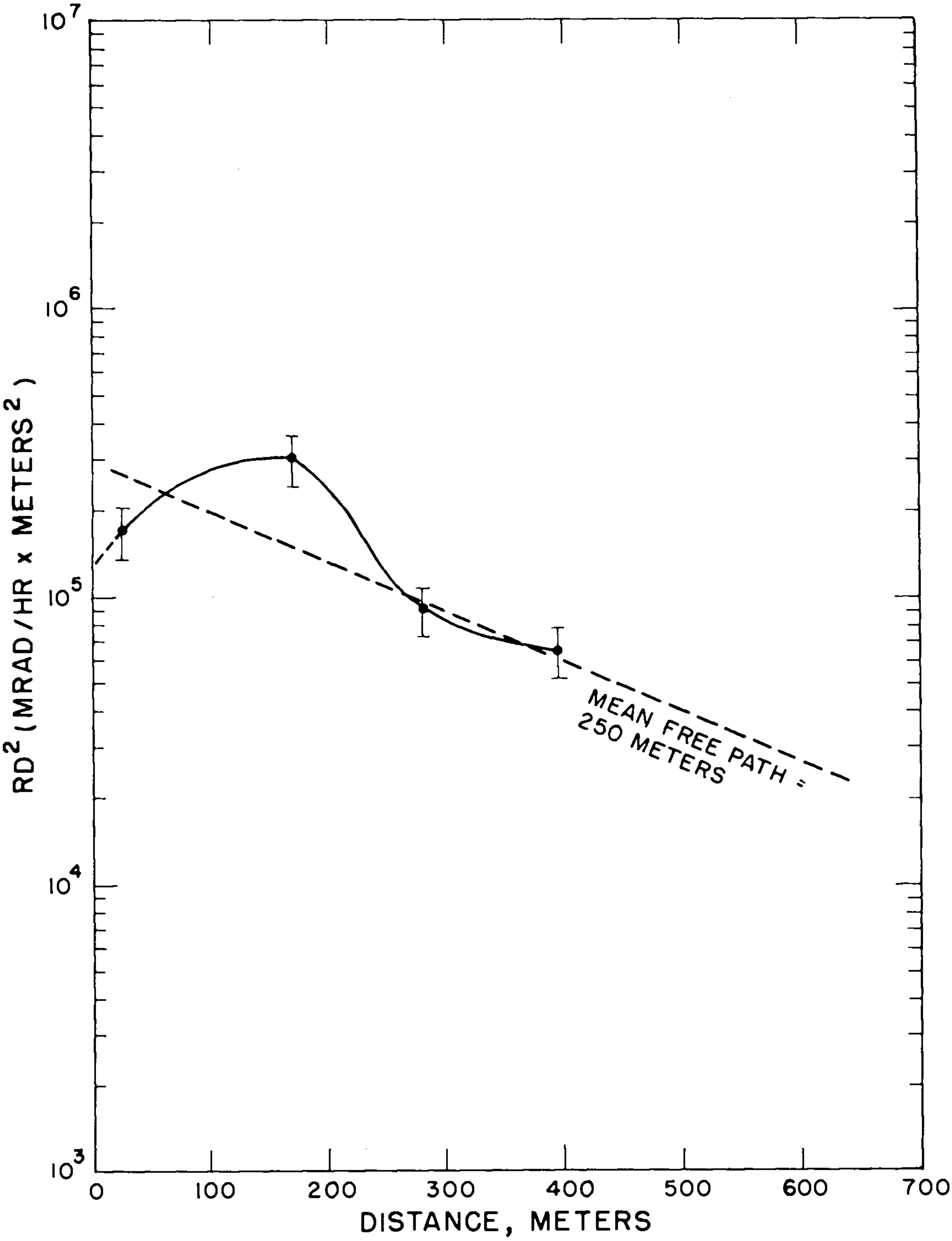

Fig. 5 Plot of dose rate times distance squared versus distance for the Little Eva critical assembly survey.