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AUTHOR(S): E. A. Plassmann and R. A. Pederson

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Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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E. A. Plassmann and R. A. Pederson
Los Alamos National Laboratory
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ABSTRACT

We present the current status of our gamma-ray dosimetry results for the Little Boy replica. Both Geiger-Müller and thermoluminescent detectors were used in the measurements. Future work is needed to test assumptions made in data analysis.

INTRODUCTION

As part of an extensive series of measurements made with the Little Boy replica assembly (Malenfant 1984) while it was operating at delayed critical, we determined gamma-ray dose rates at a multitude of detector positions. Of interest are measurements at various locations on the casing surface, angular distributions at 0.75, 1.0, and 2.0 m from the core center, and long-range measurements at distances up to 650 m from the assembly. Our detectors are Geiger-Müller (GM) tubes taken from available commercial survey meters and CaF_2:Mn thermoluminescent dosimeter (TLD) chips. We used a new method (Plassmann, Pederson, and Moss 1984) to calibrate the GM detectors, which takes into account the energy dependence of the GM response and the output gamma-ray spectrum of the Little Boy assembly.

EXPERIMENTAL DETAILS

At the Los Alamos Critical Experiments Facility, our assemblies are normally operated by remote control inside experimental buildings separated from the control room by about 400 m. The Little Boy replica, however, was set up outdoors in an open area to eliminate the complication of room-scatter. Moreover, with the core center at a height of 4.0 m, the effect of groundscatter was minimized for measurements at 2 m or less from the assembly. Contour maps (Figures 1 and 2) of the experimental area show the proximity and elevations of nearby canyon walls that can affect the results at great distances from the assembly. The indicated gate location shows the extent of a personnel exclusion area during critical operation. Our equipment had to be portable and adapted to field operation.

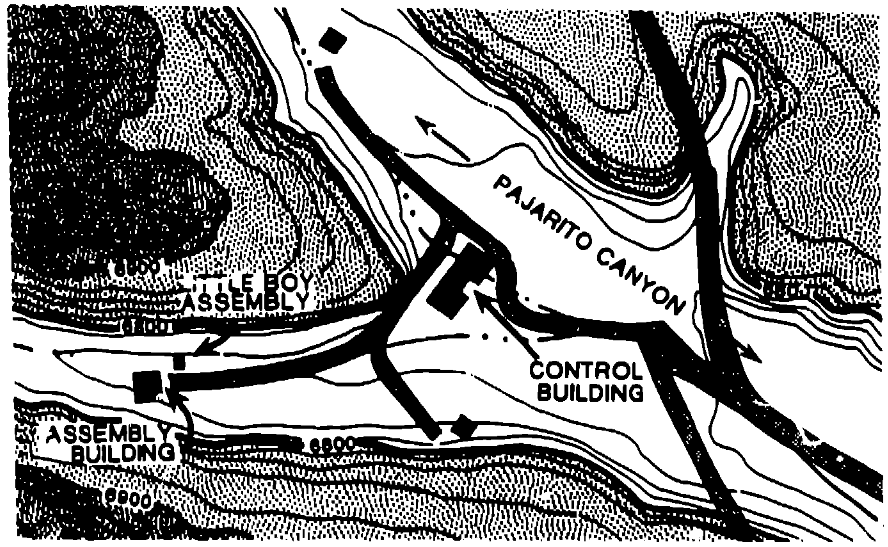

Figure 1. Contour map of experimental area at the Los Alamos Critical Assemblies Facility. The canyon rim (bold line) is at 6800-ft elevation.

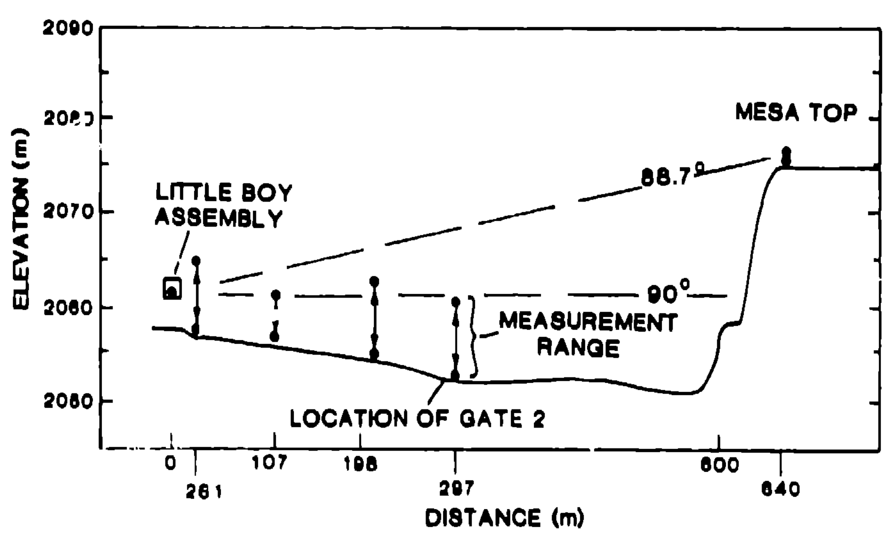

Figure 2. Ground elevations for line-of-sight measurements from the Little Boy replica.

The GM detector system is described in detail in Plassmann, Pederson, and Moss (1984). Briefly, it consists of a GM tube, taken from an Eberline E112B dosimeter, with the required high voltage supplied from an external, regulated source. The gamma-ray-induced pulses are amplified and recorded with suitable scaling and timing circuits. Plassmann, Pederson, and Moss also discuss recent efforts to improve the precision of dose-rate measurements. As a result of this work, the response curve (Figure 3) was determined for the GM detector by using 13 accurately calibrated sources with gamma-ray energies from 60 keV to 2.6 MeV. Here we used the flux-to-dose-rate conversion table, based on the work of Dimbylow and Francis (1979), which Lawrence Livermore National Laboratory adopted as a standard. A source-specific calibration factor is obtained by folding this response curve into the energy spectrum of the radiation source being measured.

Thermoluminescent dosimetry (TLD) was employed as an independent measurement technique to augment and check the GM detector results. We used 3.18-mm^2 by 1.5-mm-thick CaF_2:Mn chips placed inside tantalum energy-compensating shields. Dose-rate calibration is relative to a standard ^{60}Co source. At a typical measurement location, four of these shielded TLD chips are placed in a cardboard packet (Figure 4). After exposure, the subsequent light output is read with a Victoreen Model 2800 system and the activities of the four chips are combined to give an average dose rate at the packet location. Using the TLDs in this manner allows us to obtain measurements at positions that are inconvenient for the GM detector, such as directly on the Little Boy casing surface.

MEASUREMENTS

Gamma-ray output spectra were measured at several positions around

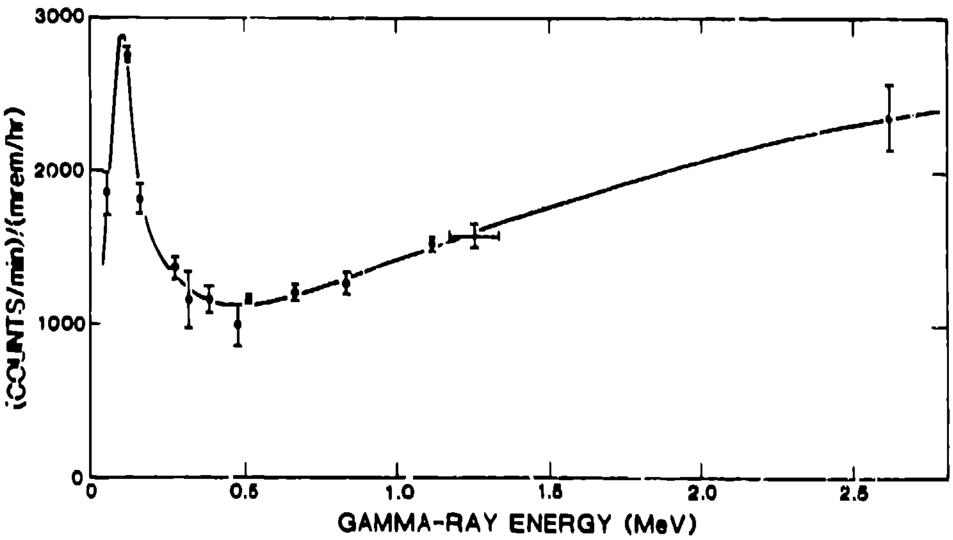

Figure 3. GM counting response curve based on Livermore flux-to-dose-rate conversion table.

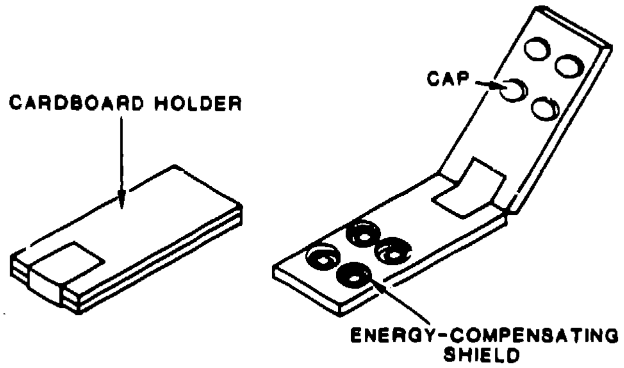

Figure 4. Packet arrangement for TL-33 TLD CdF_2:Mn chips.

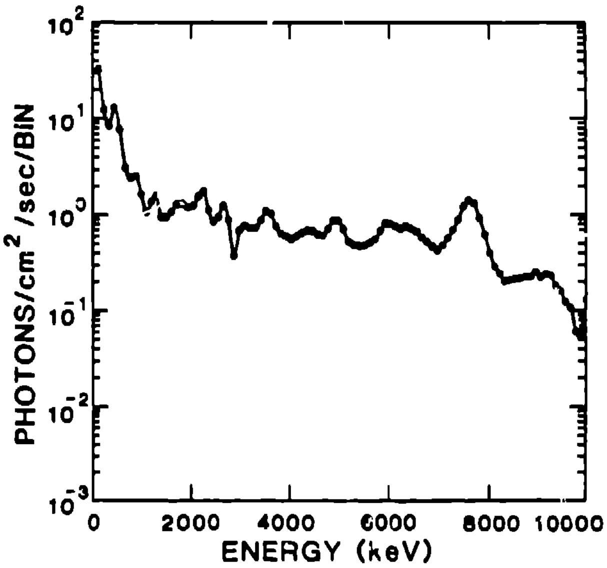

Figure 5. BGO-measured spectrum of the Little Boy replica at 90° and 2 m from core center.

the Little Boy replica using a bismuth-germanate (BGO) detector system (Moss et al. 1984). The spectrum found at 90° (i.e., at right angles to the axis of the assembly) and 2 m from the core center, appears in Figure 5. Capture, or n-γ reactions in the thick iron reflector are responsible for the many peaks at the higher energies. Unfortunately, our GM detector response curve (Figure 2) is not known above 2.6 MeV. We have to assume a smooth extrapolation out to 10 MeV. Doing this, and using our folding technique with the measured spectrum, an energy-corrected calibration factor of 2473 (counts/min)/(mrem/hr) is obtained for the GM detector. This value is 75% greater than that obtained by using only the average of the ^{137}Cs and ^{60}Co responses. Thus the latter, older method of calibration would have greatly overestimated the Little Boy gamma-ray dose rates. BGO spectra found at other angles at the 2-m radius and also closer to the assembly yielded GM calibration factors that differed by only about 2% from the above value. No spectra were measured at distances greater than 2 m, and although the spectrum undoubtedly changes at great distances due to air attenuation, we have assumed the effect on the calibration factor is probably less than that produced by our response curve extrapolation above 2.6 MeV. Thus the quoted calibration factor is used at all detector locations. The values reported in this paper could be in error by as much as 15 to 20% because of the assumptions made. A more precise interpretation of the data will be made when we have experimentally extended the GM response curve and calculated the spectral changes to be expected at great distances.

Our present results for the GM detector-derived dose rates (Figure 6) are presented at 15° intervals from 0° to 90° (i.e., from the replica nose to its mid-plane) at distances of 0.75 and 1.0 m from the core center. All the quoted values are based on 10^{16} fissions generated in the core. The calibration of assembly power, as it

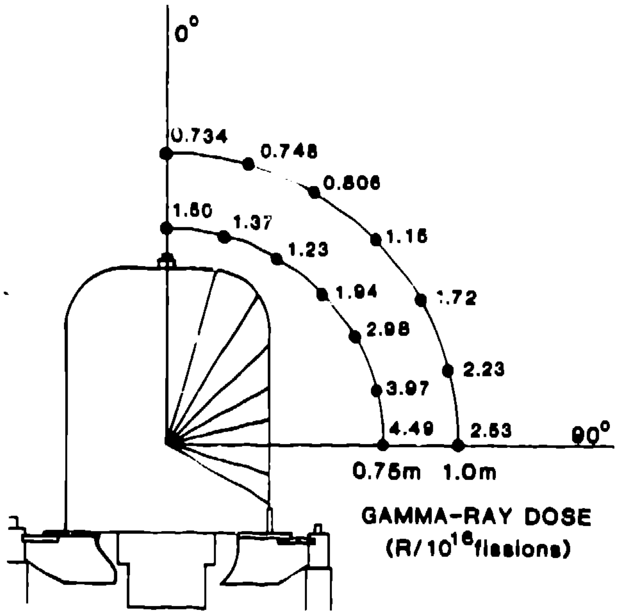

Figure 6. Gamma-ray dosimetry measurements with GM detector of the Little Boy replica. Values given in rem/10^{16} fissions.

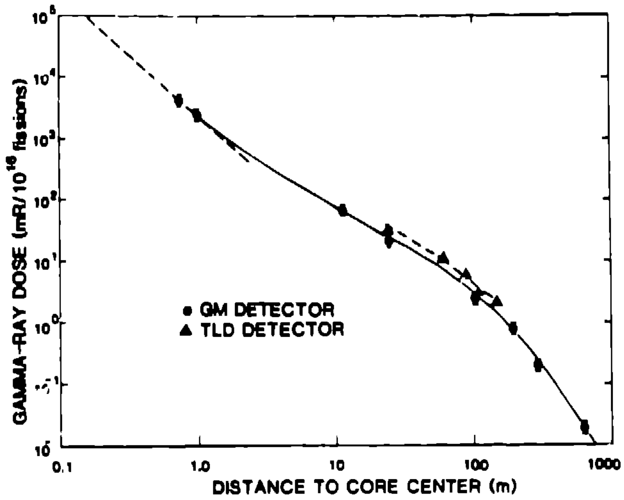

Figure 7. Gamma-ray dosimetry measurements of the Little Boy replica.

was adjusted for the measurement requirements, was accomplished by radiochemical analysis of fission foils.

The dose-rate curve we found at distances out to 650 m from the assembly (Figure 7) is drawn as a log plot since the results spanned six orders of magnitude. An inverse-distance-squared line is drawn through the data points below 1 m to show that the results at greater distances vary markedly from this relationship.

Also plotted in Figure 7 are the TLD measurements made far from the assembly. These measurements were intended to verify the GM detector results; however, one can see about a 40% difference between them. Part of this disparity is because the TLD packets could not be recovered until some time after assembly shut down and thus received additional activation during the cool-down period.

Our other TLD results appear in Figure 8. The TLD packets were placed at several positions on the outside surface of the replica casing and also at 2 m from the core center. Again, the values given are significantly greater than we would have expected from the GM detector measurements.

For better visualization, all of our gamma-ray measurements out to 2 m from the core center are plotted as dose-rate curves in Figure 9. The maximum values occur at the equatorial plane and there is a pronounced minimum at about 30° from the front end. Internal material structure is responsible for this shape.

Finally, we have taken the limited available information to estimate a relaxation length for the output gamma-ray dose-rate in air. The plot in Figure 10 is determined from the smoothed curve drawn through the GM

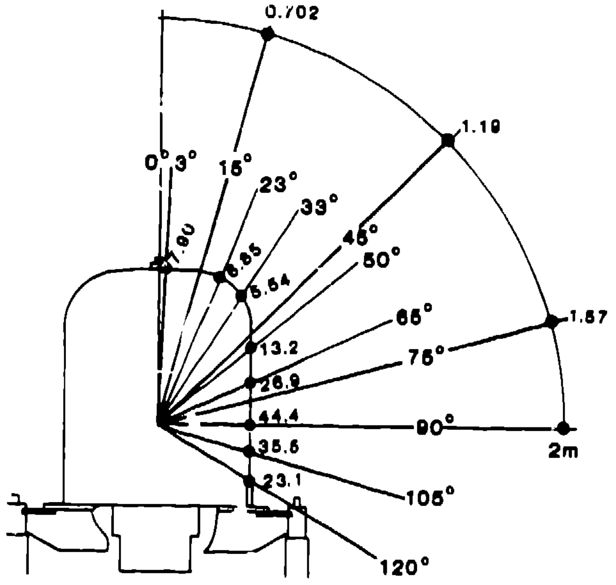

Figure 8. TLD gamma-ray measurements of the Little Boy replica (values in rem/10^{16} fissions).

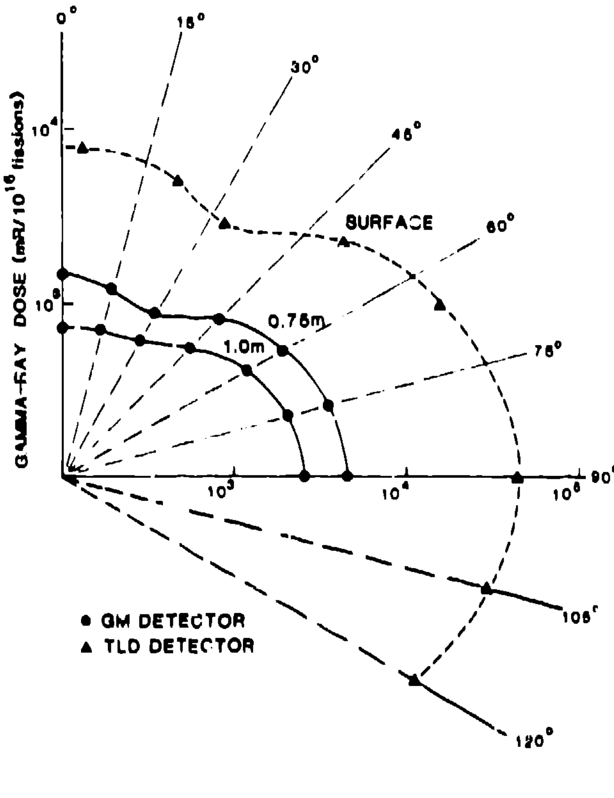

Figure 9. Gamma-ray dosimetry measurements of the Little Boy replica.

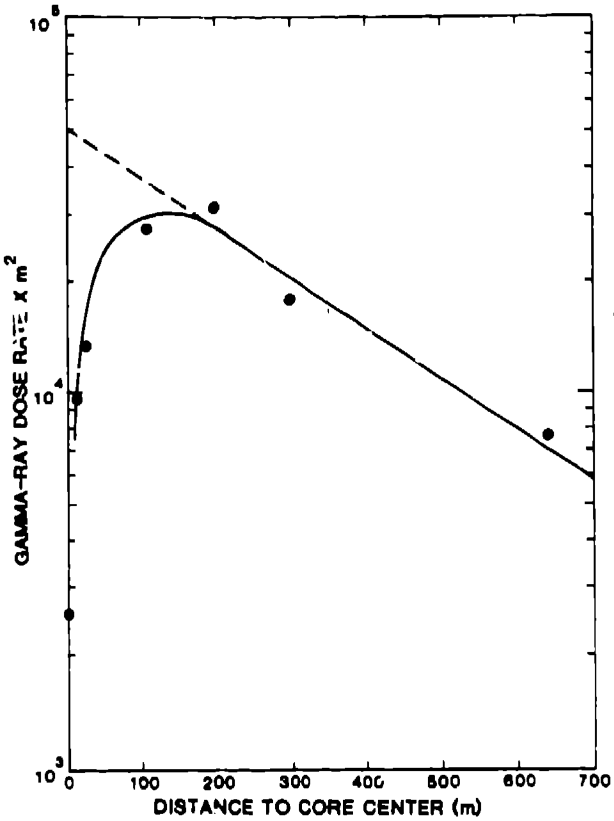

Figure 10. Estimation of gamma-ray dose-rate relaxation length from Little Boy replica, G_0 = 5.10 x 10^4, L = 325 m

detector experimental points of Figure 7. A fit of this curve, at distances greater than 200 m, to the equation

$$D(r) = G_0 \frac{e^{-r/L}}{r^2} ,$$

where D(r) = dose-rate (mrem/h) at distance r (meters) from the assembly, G_0 = extrapolated source term, and L = dose rate extrapolation length (m),

yields an extrapolation length of 325 m. This is larger than the value of 250 m suggested by John Auxier in

1965 (Auxier et al. 1966), but is consistent with the more recent independent calculations of J. V. Pace and W. H. Scott (Kerr 1981).

ACKNOWLEDGMENTS

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