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NEUTRON DOSIMETRY OF THE LITTLE BOY DEVICE

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ABSTRACT

Neutron dose rates at several angular locations and at distances out to 0.5 mile have been measured during critical operation of the Little Boy replica. We used modified remmeters and thermoluminescent dosimetry techniques for the measurements. The present status of our analysis is presented including estimates of the neutron-dose-relaxation length in air and the variation of the neutron-to-gamma-ray dose ratio with distance from the replica. These results are preliminary and are subject to detector calibration refinements.

INTRODUCTION

Los Alamos National Laboratory, at the request of the Department of Energy, assembled a replica of the Hiroshima Little Boy device. This system was made available for the express purposes of (a) determining critical separation of fuel parts for yield calculations and (b) measuring radiation leakage. This report presents data concerning the neutron dose measured during operation of the Little Boy critical assembly at its outdoor location.

The results should be interpreted with several reservations. We believe the data presented are representative of the doses as measured under the existing experimental conditions. Our reservations pertain to scaling to device yield and to the influence of barometric pressure, humidity, and terrain corrections.

THE ASSEMBLY

The Little Boy replica (Malenfant 1984, see Figure 1) features a ^{235}U core, a large steel case, in an assembly high above its outdoor surroundings. The neutron source is the fission process in the ^{235}U core. The intervening material, which affects external neutron-dose measurements, is predominantly steel. There is thicker steel at the nose of the device. The general terrain of the experimental area is presented in Plassmann and Pederson (1984, see Figures 1 and 2). The canyon walls and elevation differences influence the interpretation of our results.

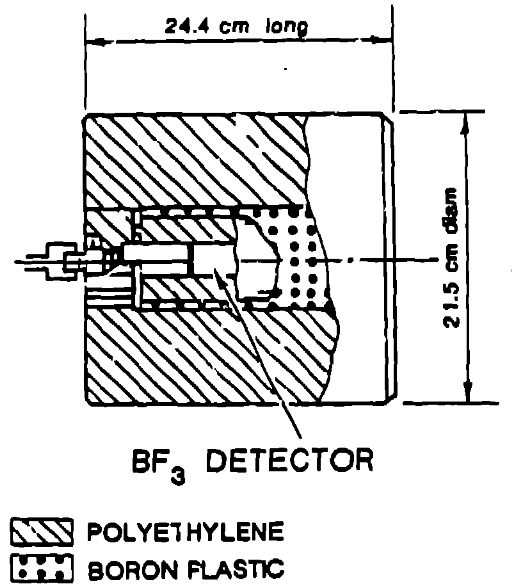

Figure 1. Andersson-Braun detector. The boron plastic has 10-mm-diam holes over 20% of the area.

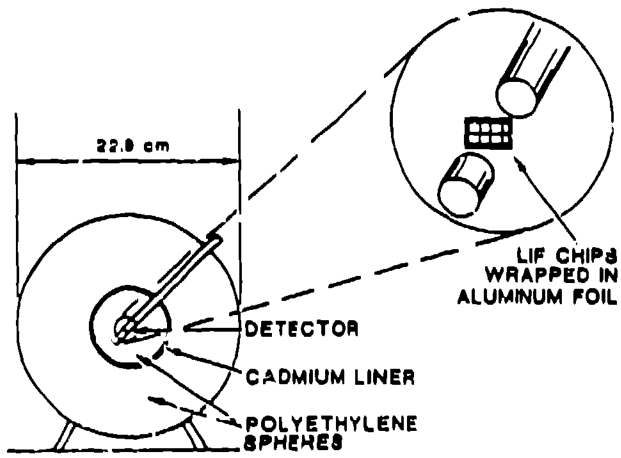

Figure 2. Fast-neutron detector, modified PNR-4.

NEUTRON-DOSE MEASUREMENT METHODS

Neutron-dose leakage from the Little Boy assembly was monitored with two independent remmeters; one was the 9-in. Andersson-Braun cylindrical instrument (Block and Petrock 1964), the other a 9-in. PNR-4 spherical instrument (Hankins 1968). The Andersson-Braun remmeter (Figure 1) is a standard health physics neutron monitoring instrument. The remmeter response closely follows the response quoted by the International Commission on Radiological Protection.

The PNR-4 remmeter was modified (Figure 2) so that ^{6}LiF (hot-pressed 3.2-mm by 3.2-mm by 0.77-mm-thick chip) thermoluminescent dosimeters (TLDs) could be incorporated as neutron detectors. Thermoluminescent dosimeters are used in place of the BF_3 detector, which is normally part of the PNR-4 sphere. The incorporation of ^{7}LiF and normal LiF chips provides a means of subtracting the gamma-ray response from the ^{6}LiF response.

The thermal-neutron detector (Figure 3) contains both bare and 0.51-mm-cadmium-covered ^{6}Li, ^{7}Li, Li chips. The ^{7}LiF also provides a measurement of the gamma-ray dose.

RESULTS

We normalized the fast-neutron dose (Figure 4), monitored with the

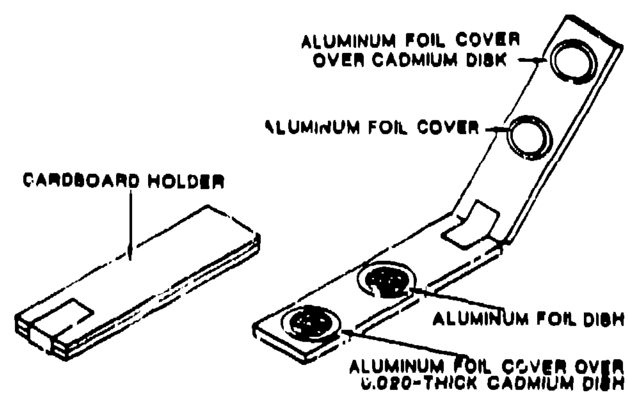

Figure 3. Thermal-neutron dosimeter packet, ^{6}LiF-^{7}LiF-LiF hot-pressed chips.

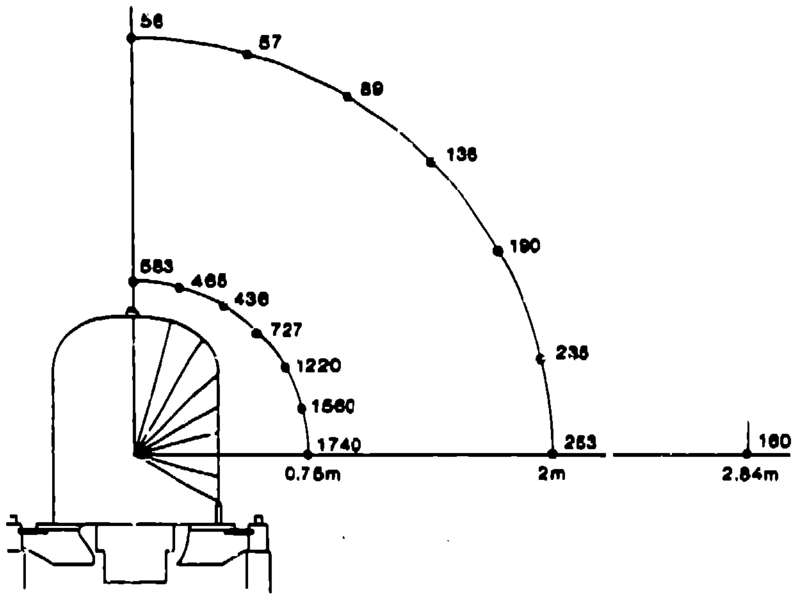

Figure 4. Neutron dose (rem/10^{16} fissions) measured with Andersson-Braun detector.

Andersson-Braun remmeter, to 10^{16} fissions. Measurements are reported for distances of 0.75, 2.0, and 2.84 m from the center of the core. The dose-rate curves also illustrate the effect of increased steel at 30°.

At greater distances (Figure 5), the Andersson-Braun remmeter indicates that the neutron dose-rate follows the inverse square law out to 100 m. The data at 100 m and beyond are used to estimate the neutron radiation relaxation length (Figure 6) by a fit to the equation

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

where $D(r)$ = dose rate at distance r (meters) from the source, G_0 = extrapolated source term, and L = neutron dose relaxation length (in meters).

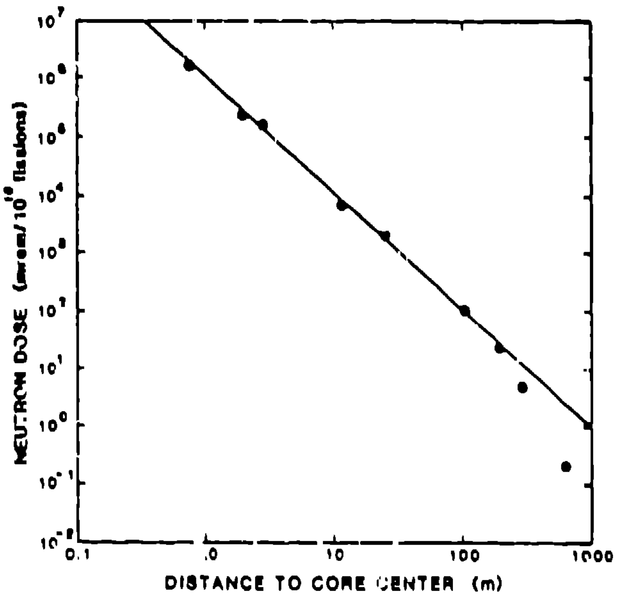

Figure 5. Neutron dose from Little Boy replica measured with Andersson-Braun detector.

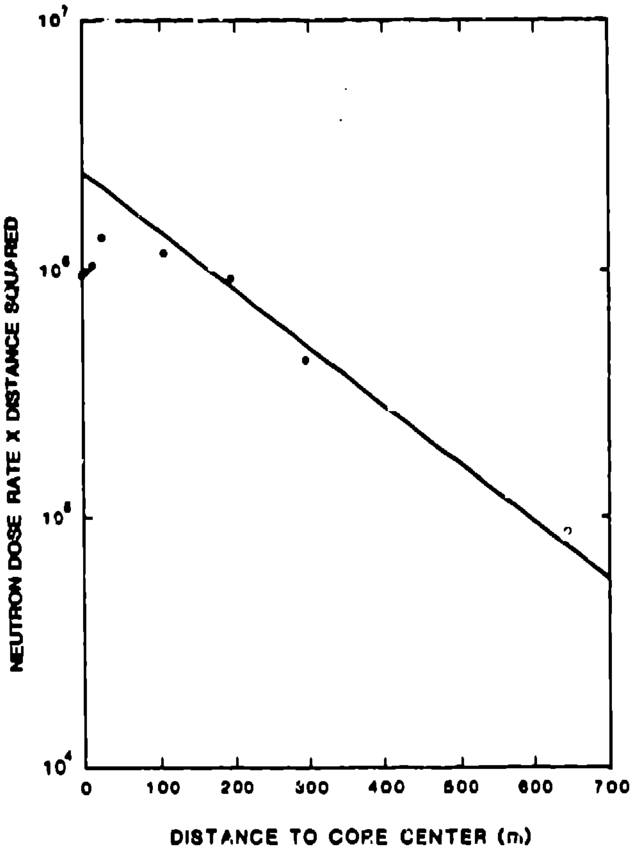

Figure 6. Neutron dose-rate relaxation length, G_0 = 2.14 x 10^6, L = 200 m.

A linear least squares fit to the experimental data for distances greater than 100 m yields a neutron-dose relaxation length of 200 m. This length compares very favorably with the value estimated by Auxier et al. (1966).

The PNR-4, ^{6}LiF, ^{7}LiF, ^{n}Li data (Figure 7) indicate a neutron dose greater than the Andersson-Braun results by about 33%. Of this, 20% may be due to delayed neutrons as these measurements were passive and the Andersson-Braun measurements were active. Note that the fast-neutron dose at 90° is a factor of 3 greater than the dose at 0°. Both the fast- and thermal-neutron dose rates were

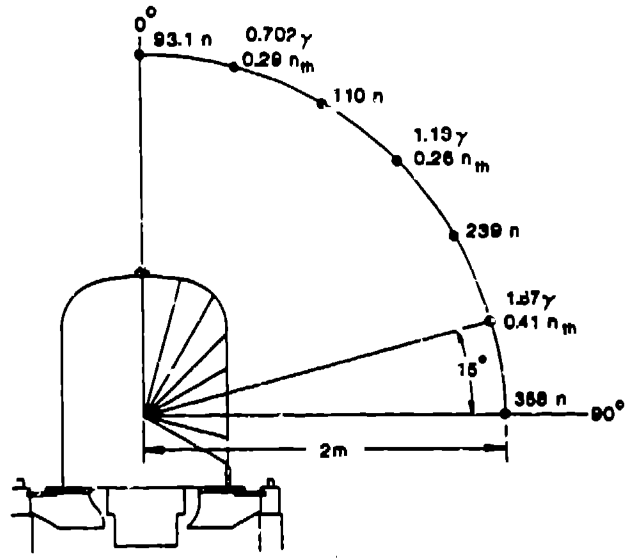

Figure 7. Little Boy assembly, thermoluminescent dosimetry (rem/10^{16} fissions).

taken at 30° intervals to minimize the effect of the 9-in. sphere on adjacent dosimeters.

The TLD data (Figure 8) illustrate the neutron dose at distances out to 200 m. The figure also shows the thermal-neutron and gamma-ray dose results. Note that our measurements show the neutron-rem dose rates to be significantly greater than the dose rates from gamma rays at all the detector positions we used. This is especially true close to the assembly. The thermal-neutron curve also illustrates the effect of neutron energy degradation in air.

We used the Andersson-Braun neutron dose-rate results and the previously reported gamma-ray measurements (Plassmann and Pederson 1984) to obtain a neutron-to-gamma-ray-dose ratio curve (Figure 9) as a function of distance from the Little Boy replica. Near the assembly, at 0.75 m, this ratio reaches a value of 380 and then

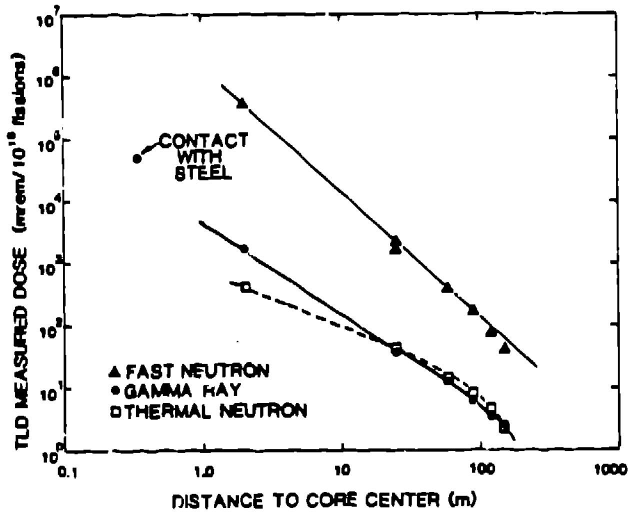

Figure 8. Little Boy assembly, thermoluminescent dosimetry.

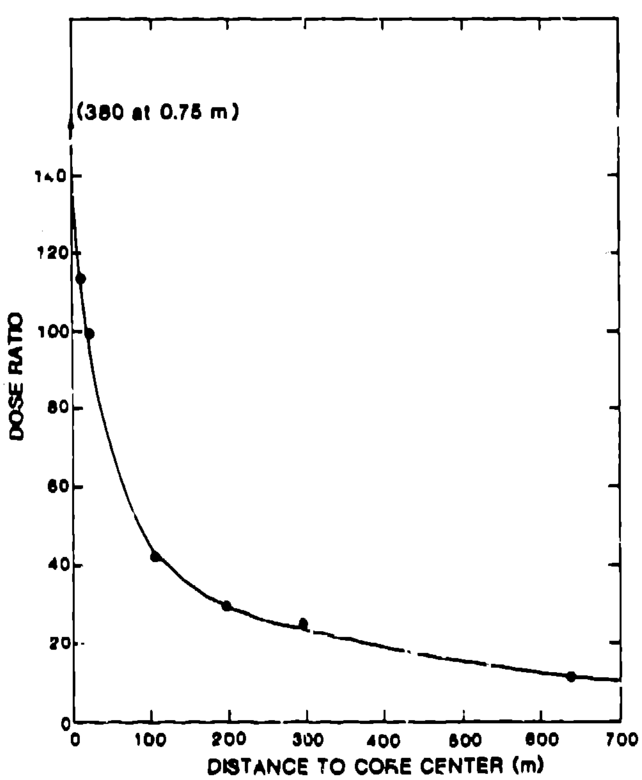

Figure 9. Little Boy assembly neutron to gamma-ray dose ratio.

rapidly decreases to about 10 at the farthest detector position.

Calibration Procedure

The neutron detectors used in our measurements were calibrated with a bare ^{252}Cf source. The source had previously been calibrated in the standard Los Alamos pile and cross checked with a standard from the National Bureau of Standards. The reported strength (Q-value) was within 3% of the originally quoted value. The dose from the source was determined by using the dose-equivalent conversion of 3.33 x 10^{-5} mrem/cm^2. This gives a dose equivalent rate

$$= \frac{3.33 \times 10^{-5}}{4\pi} \cdot 3600 \cdot \frac{Q}{r^2}$$

$$= 9.54 \times 10^{-3}\ Q/r^2 \text{ mrem/hr},$$

where Q = source strength (in neutrons/sec) and r = detector-to-source distance (m).

Calibration of the neutron detectors was done in a very large building featuring special provisions for low return of radiation. The nearest wall or floor was 4 m from the positions of the detector and the source. Detector response measurements were made at several distances from the source and fit to the equation

$$Dr^2 = (B + R)r^2 + D_0 \quad ,$$

where D = measured response at source-to-detector distance r (in meters), D_0 = response at unit distance, R = the room return (assumed to be constant), and B = background counting rate (constant).

Calibration of the thermoluminescent gamma-ray dosimeters was accomplished by the same method using a ^{60}Co source as the calibration standard.

FUTURE WORK

The results reported in this paper represent the present status of our data analysis and should be considered as preliminary. We intend to improve the remmeter calibration technique by incorporating the effects of detector energy response in combination with the neutron leakage spectrum from the replica. The latter is accomplished by calculation or measurement. Results from spectral measurements with an NE-213 liquid scintillator system and a proton-recoil gas ionization detector (Evans 1984) will also be used to corroborate the dose-rate evaluation. The neutron-to-gamma-ray ratios are subject to reevaluation when more precise gamma-ray dose results become available.

ACKNOWLEDGMENTS

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