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TITLE: NEUTRON AND GAMMA-RAY DOSE-RATES FROM THE LITTLE BOY REPLICA

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NEUTRON AND GAMMA-RAY DOSE-RATES FROM THE LITTLE BOY REPLICA

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ABSTRACT

We report dose-rate information obtained at many locations in the near vicinity of, and at distances out to 0.64 km from, the Little Boy replica while it was operated as a critical assembly. The measurements were made with modified conventional dosimetry instruments that used an Anderson-Braun detector for neutrons and a Geiger-Müller tube for gamma rays with suitable electronic modules to count particle-induced pulses. Thermoluminescent dosimetry methods provide corroborative data. Our analysis gives estimates of both neutron and gamma-ray relaxation lengths in air for comparison with earlier calculations. We also show the neutron-to-gamma-ray dose ratio as a function of distance from the replica. Current experiments and further data analysis will refine these results.

INTRODUCTION

An exact replica of the Hiroshima Little Boy Device (Malenfant 1984) was reconstructed during 1983 at the Los Alamos Critical Assemblies Facility in a manner that allows delayed-critical operation at powers up to 0.5 kW. In this way, spectral and dosimetric measurements of the leakage radiation can be made at various locations around the replica. We previously reported on gamma-ray (Plassmann and Pederson 1984) and neutron (Pederson and Plassmann 1984) data obtained with modified conventional dosimetry instruments. Analysis of this information continues and in this paper we present the current status of our results.

DETECTION SYSTEMS

For the active detection of neutrons and gamma rays, we use conventional dosimetry instruments that have been modified in an attempt to increase their accuracy. These modifications are described in detail in the previously cited references and are summarized here for convenience.

Gamma-ray detection is accomplished with a Geiger-Müller (GM) tube taken from an Eberline E-112B dosimeter. The required high voltage is supplied with an external regulated source and the gamma-ray-induced pulses, after proper amplification and discrimination, are recorded with suitable timing and scaling circuits. Recent efforts to improve the precision of dose-rate measurements with this system (Plassmann, Pederson, and Moss 1984) have resulted in a response curve for the GM detector in the energy range from 60 keV to 2.6 MeV. A source-specific calibration factor is obtained by folding this response curve into the energy spectrum of the radiation source being measured. Work on the extension of this curve to higher energies is in progress.

We would like to define the GM response out to at least 10 MeV because spectral measurements (Moss et al. 1984) near the replica show many intense high-energy gamma rays. These are produced by neutron capture reactions in the thick iron reflector that surrounds the fissile core. At present, we have to extrapolate the GM response curve out into this energy region, which introduces a significant source of error in data analysis. It is interesting to note that when we use this new calibration method in interpreting the Little Boy measurements, our quoted dose rates are about 57% of the values we would have obtained had we used a calibration factor based only on the GM response to ^{137}Cs and ^{60}Co sources.

An Anderson-Braun detector is used for the active neutron measurements. This polyethylene-moderated BF_3 tube, with an energy-compensating internal boron-plastic sheath, is the detector in the Tracerlab NP-1 neutron rem-meter. Again we supply the required high voltage with an external power source and record the neutron-induced pulses with the same scaling modules used in the GM system already described. The Anderson-Braun detector is calibrated with a ^{252}Cf standard source.

As an independent check of these detection systems we also employ the passive measurement techniques available with thermoluminescent dosimetry (TLD) methods. Hot-pressed normal LiF, and isotopically separated ^{6}LiF and ^{7}LiF, chips are placed at the center of a modified PNR-4 polyethylene sphere (which has an internal cadmium energy compensator) to measure the dose attributed to neutrons with energies above thermal. The incorporation of the ^{7}LiF and normal LiF chips provide a means of subtracting the gamma-ray portion from the total ^{6}LiF response. Cardboard packets of both bare and cadmium-covered LiF chips (again including normal and isotopically separated lithium) measure thermal neutron and gamma-ray dose. The calibration of these neutron TLDs is based on our ^{252}Cf standard source. Finally, packets of CaF_2:Mn chips inside tantalum energy-compensating covers are used to directly measure gamma-ray dose. For these, the dose-rate calibration is relative to a standard ^{60}Co source.

STATUS OF RESULTS

Counting-rate measurements with both the GM gamma-ray and the Anderson-Braun neutron detection systems were made at 15° intervals from the nose (0°) to the mid-plane (90°) of the Little Boy replica. The resulting inferred dose rates, all normalized to 10^{16} fissions in the uranium core, are shown in Figure 1 for the gamma rays and Figure 2 for neutrons. At 0.75 m, the dose rate

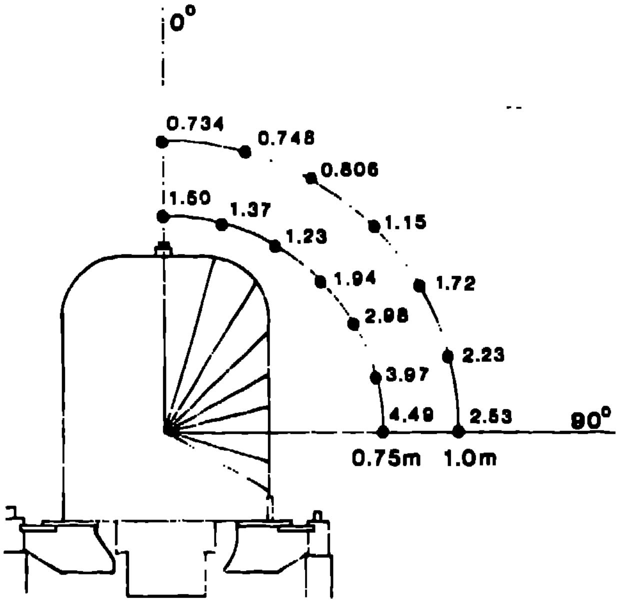

Figure 1. Gamma-ray dosimetry measurements of the Little Boy replica made with GM detector (rem/10^{16} fissions).

(both gamma-ray and neutron) at the mid-plane appears to be three times greater than at the nose, and this ratio increases at larger distances from the core center. Also, we note a dose-rate minimum at 30° (and 0.75-m radius) presumably caused by internal structural material.

The dose-rate curves we found with these detection systems at distances out to 640 m from the assembly (Figure 3) spanned many orders of magnitude and hence are shown in a logarithmic plot. The dashed lines indicate an inverse-distance-squared relationship. The neutron data follow this relationship out to about 100 m whereas only the two gamma-ray data points at $\leq$1.0 m are fitted. Air attenuation, atmospheric (n,γ) reactions, and the proximity of canyon walls in the experimental area all contribute to the "shapes" of these observed curves.

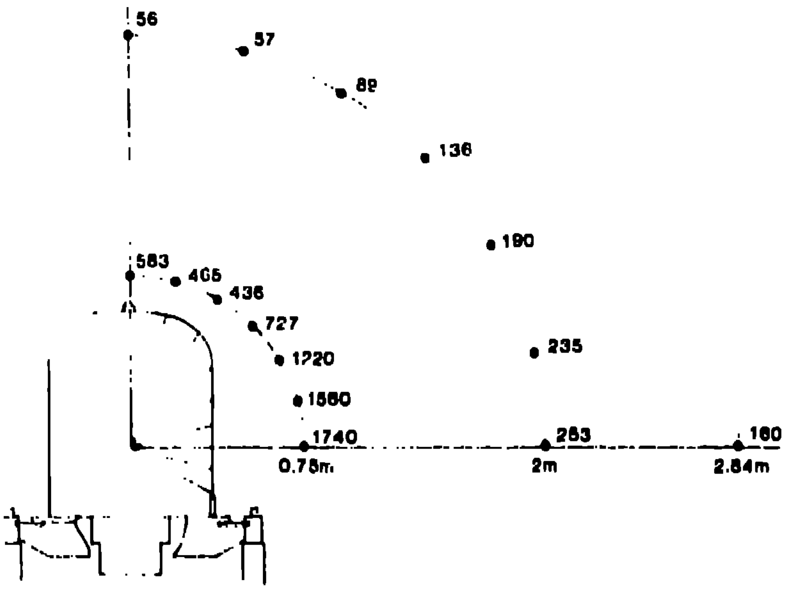

Figure 2. Neutron dose (rem/10^{16} fissions) measured with Anderson-Braun detector.

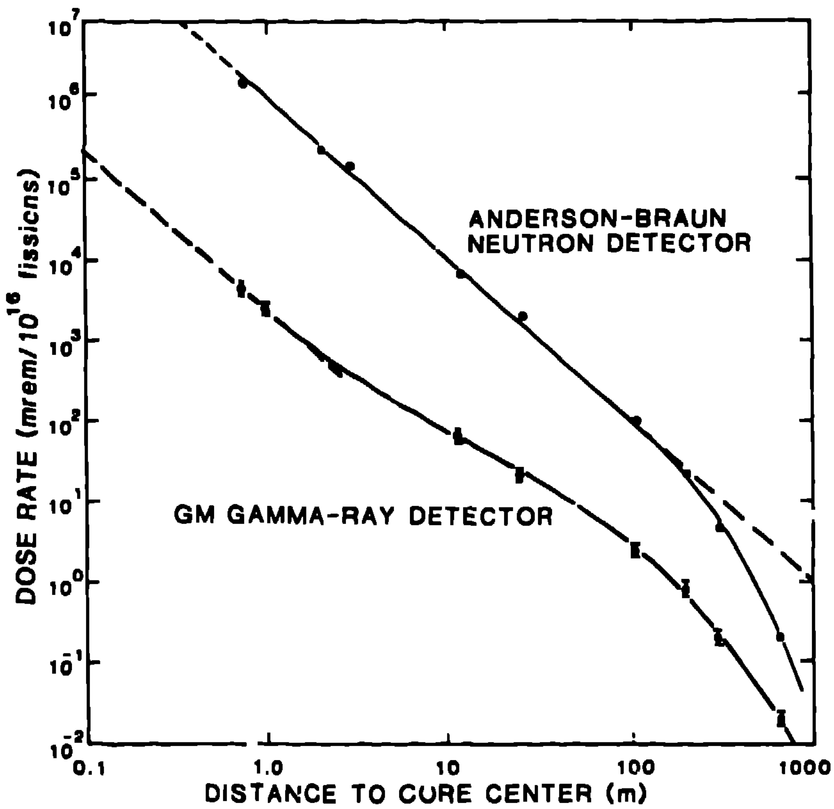

Figure 3. Dosimetry measurements of the Little Boy replica.

The smoothed curves drawn in Figure 3 to fit the data points are used to estimate the radiation relaxation lengths for the Little Boy replica observations. At large distances from the assembly, the dose rates should follow the relation

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

where D(r) = dose rate (mrem/h) at distance r (m) from the assembly, G_0 = extrapolated source term, and L = the dose rate relaxation length (m). When $r^2D(r)$ is plotted against r (Figure 4), the slope of the linear portion, at large r, is the relaxation length and the linear intercept on the ordinate axis is the extrapolated source term. We find relaxation lengths of 200 m for the neutron data and 325 m for gamma-ray data. The neutron value compares favorably with that estimated by Auxier et al. (1966). The gamma-ray result, however, is larger than Auxier's 250 m, but it is consistent with the more recent independent calculations of J. V. Pace and W. H. Scott (Kerr 1981).

We also used the smoothed curves of Figure 3 to plot the neutron-to-gamma-ray dose-ratio (Figure 5) as a function of distance from the replica. This ratio is a maximum near the assembly, where we find a value of 380 at 0.75 m, and then it rapidly decreases to about 10 at the farthest detector position.

Our passive TLD measurements in the near vicinity of the replica are presented in Figures 6 and 7, respectively, for the gamma-ray and neutron dose-rate results. Because the CaF_2:Mn chips were arranged in flat cardboard packets, they could be placed directly on the iron casing to give gamma-ray-dose reading on the device surface. Again we see a maximum dose at the mid-plane (90°) and a minimum at about

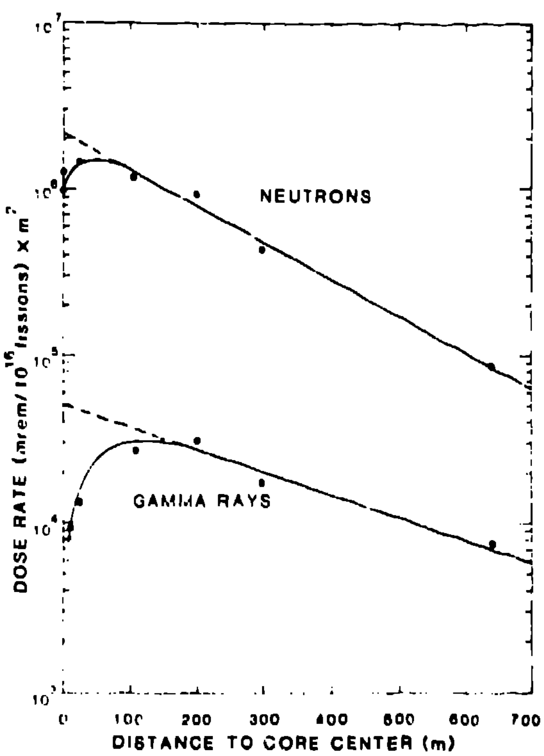

Figure 4. Estimate of dose-rate relaxation lengths from Little Boy replica. For neutrons, $G_0 = 2.14 \times 10^6$ and L = 200 m. For gamma rays, $G_0 = 5.10 \times 10^4$ and L = 325 m.

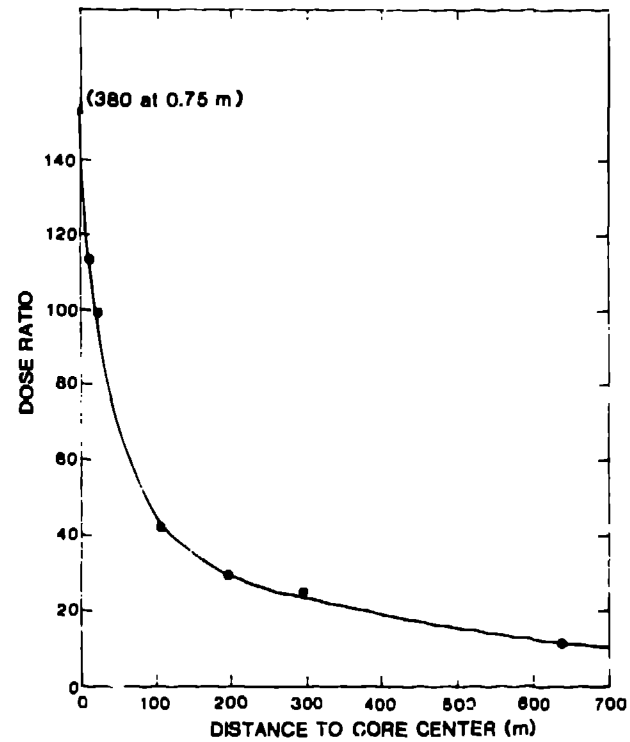

Figure 5. Neutron to gamma-ray dose ratio for the Little Boy assembly.

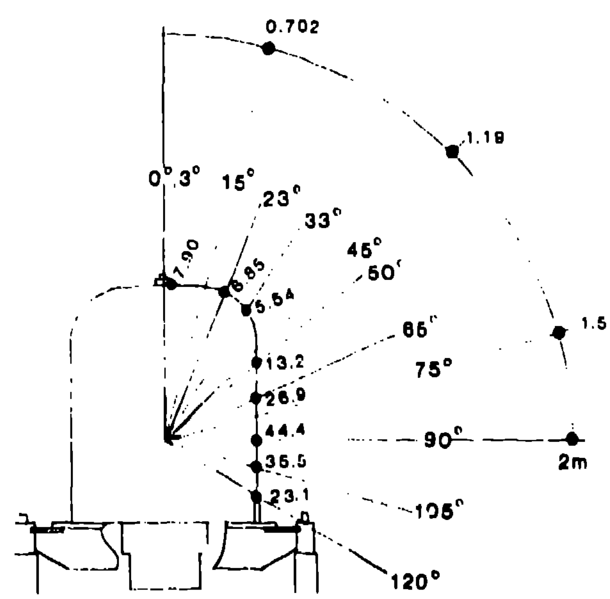

Figure 6. TLD gamma-ray measurements of the Little Boy replica (rem/10^{16} fissions).

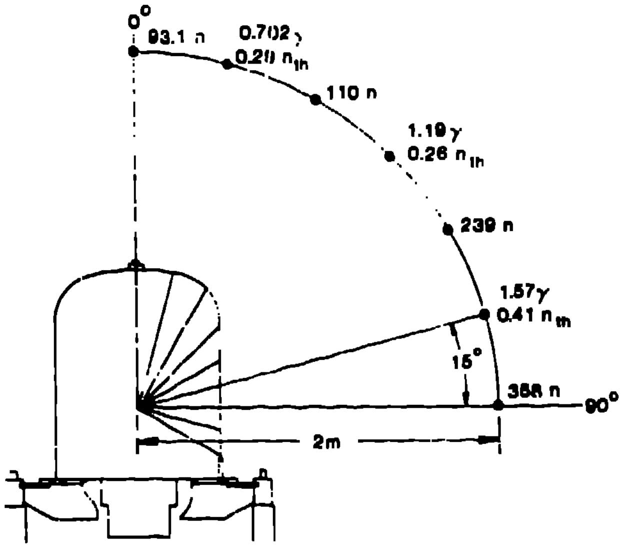

Figure 7. Thermoluminescent dosimetry of the Little Boy assembly (rem/10^{16} fissions).

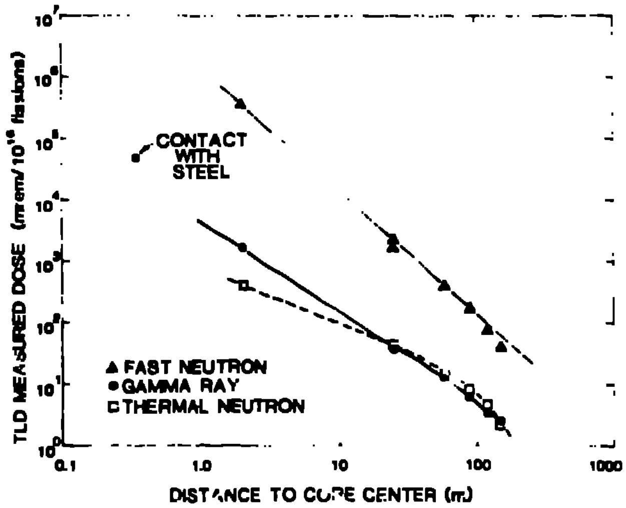

Figure 8. Thermoluminescent dosimetry at large distances for the Little Boy assembly.

30° from the nose. The relation between the thermal and greater-than-thermal neutron dose rates is shown at the 2.0-m radius. This close-in thermal dose is only a small fraction of the total.

The TLD results at large distances (Figure 8) again show a small thermal neutron dose relative to the total measured. However, the dose fraction due to the thermal neutrons increases with distance to illustrate the effect of neutron-energy degradation in air. The ratio between the TLD-measured neutron and gamma-ray dose rates is consistent with the results found with the active detection systems. In general, the dose rates we inferred from the TLD measurements are some 30 to 40% greater than our results with the active Anderson-Braun and GM detector systems. Over half of this discrepancy can be attributed to the extra activation the TLDs received during the wait to recover them following high power runs.

DISCUSSION

The construction and operation of the Little Boy replica as a critical assembly in both indoor and outdoor environments was and still is a unique experience for the staff of the Los Alamos Critical Assemblies Facility. To our knowledge, this is the first time that a nuclear device--albeit a 40-year-old one--was operated in a controlled mode that included delayed critical and positive periods above delayed critical. As might be expected, the task was not easy and we were plagued with many frustrating problems. The accomplishment, however, was an interesting and rewarding experience. We feel that, as a result of this work, answers to many long-standing and continuing health physics concerns are forthcoming. These include the study of long-term radiation effects on human populations and the quantification of realistic maximum-permissible-doses for workers in the nuclear industry.

As with any experimental endeavor, the preliminary results probably raise more new questions than settle old ones. In this paper we note the discrepancies between active and passive dose-rate measurements. Moreover, the gamma-ray dose rates we infer differ from those reported by other experimenters at Los Alamos (Moss, Lucas, and Tisinger, 1984). It is almost certain that, since many laboratories across the country participated in these measurements, we will find even more differences as the data are evaluated. This is not unexpected. These differences will be resolved as techniques and procedures improve during the current operations with the Little Boy replica. Certainly, a concensus will evolve as the data analysis continues.

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