LA-UR -83-3349
- CONF

CONF-840202--5

LA-UR--83-3349

DE84 003829

TITLE: A FIELDABLE COMPUTER SYSTEM FOR DETERMINING GAMMA-RAY PULSE-HEIGHT DISTRIBUTIONS, FLUX SPECTRA, AND DOSE RATES FROM LITTLE BOY

AUTHOR(S): C. E. Moss, M. C. Lucas, and E. W. Tisinger
Los Alamos National Laboratory

and

M. E. Hamm
Technical Programming Services

SUBMITTED TO: Health Physics Society
17th Midyear Topical Meeting
Pasco, Washington
February 5-9, 1984

A FIELDABLE COMPUTER SYSTEM FOR DETERMINING GAMMA-RAY PULSE-HEIGHT DISTRIBUTIONS, FLUX SPECTRA, AND DOSE RATES FROM LITTLE BOY

C. E. Moss, M. C. Lucas, and E. W. Tisinger
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

M. E. Hamm
Technical Programming Services
Pleasanton, California 94566

ABSTRACT

Our system consists of a LeCroy 3500 data acquisition system with a built-in CAMAC crate and eight bismuth-germanate detectors 7.62 cm in diameter and 7.62 cm long. Gamma-ray pulse-height distributions are acquired simultaneously for up to eight positions. The system was very carefully calibrated and characterized from 0.1 to 8.3 MeV using gamma-ray spectra from a variety of radioactive sources. By fitting the pulse-height distributions from the sources with a function containing 17 parameters, we determined theoretical response functions. We use these response functions to unfold the distributions to obtain flux spectra. A flux-to-dose-rate conversion curve based on the work of Dimbylow and Francis is then used to obtain dose rates. Direct use of measured spectra and flux-to-dose-rate curves to obtain dose rates avoids the errors that can arise from spectrum dependence in simple gamma-ray dosimeter instruments. We present some gamma-ray doses for the Little Boy assembly operated at low power. These results can be used to determine the exposures of the Hiroshima survivors and thus aid in the establishment of radiation exposure limits for the nuclear industry.

INTRODUCTION

Most of our radiation safety guidelines in the nuclear industry are based on the data concerning the survivors of the nuclear explosions at Hiroshima and Nagasaki. Crucial to determining these guidelines is the radiation output of the explosions. For many years we have believed that the output from the Nagasaki explosion was well determined but that the output from the Hiroshima explosion was less certain.

As part of a recent effort to more accurately determine the output at Hiroshima we have measured the gamma-ray pulse-height distributions from a replica of the Hiroshima device operating at accurately known power levels near critical. We then used a computer code developed at Los Alamos to convert these distributions to flux distributrions, dose-rate distributions, and integral doses. In the present paper we describe our equipment and analysis techniques and present some results. Direct use of measured spectra and the flux-to-dose-rate curve to obtain dose rates avoids the errors that can arise from spectrum dependence in simple gamma-ray dosimeter instruments.

EQUIPMENT AND METHODS

We used two systems to study the gamma rays from the Little Boy device. We used a bismuth-germanate (BGO) detector to measure pulse-height distributions, which we then converted to fluxes and dose rates. We used a high-resolution germanium detector to identify the gamma-ray lines.

The BGO detector, obtained as an integral assembly from the Harshaw Chemical Company, contained a 7.62-cm-diameter by 7.62-cm-long BGO crystal. Bismuth-germanate is a relatively new scintillator that is replacing NaI(Tl) in many applications. We chose BGO because of its high photopeak efficiency, large peak-to-total ratio, and its insensitivity to neutrons (Häusser et al. 1983). The large peak-to-total ratio means that the tail of the response function is small and hence complex spectra can be more easily analyzed. One disadvantage of BGO is its poorer resolution relative to NaI(Tl). For the present application, however, the resolution is not important. At 662 keV, the resolution of our detector was 14.6%, which is about a factor of 2 larger than that of a similar size NaI(Tl) detector. Our BGO system allows us to measure gamma-ray spectra at up to eight positions simultaneously. However, only one detector was used because we could adjust the power level of the Little Boy device and the data could be acquired quickly at each position.

We acquired the BGO pulse-height distributions with standard analog electronics and a LeCroy 3500 data acquisition system (Figure 1). The analog electronics included a Tennelec TC 105 preamplifier and a Tennelec TC 241 amplifier. The LeCroy system, based on an Intel 8085 microprocessor, supports FORTRAN. Peripherals include a video display, light pen, dual-drive floppy disk unit, printer, plotter, video hardcopy unit, built-in CAMAC minicrate, and 1200-baud modem. For the BGO measurements we used the following CAMAC modules: an eight-input LeCroy 3542 mixer/router, an 8192-channel LeCroy 3511 analog-to-digital converter, and a LeCroy 3541 timer. Since CAMAC is the electronics standard in high-energy physics, hundreds of different types of modules are available for configuring a vast variety of experiments. For complicated experiments, the CAMAC minicrate can be expanded with up to seven full-size CAMAC crates. We use the 1200-baud modem for transferring data from the LeCroy 3500 to the central computing facility at Los Alamos. The modem allows the LeCroy 3500 to function as a terminal for running large programs at the computing facility that are not practical to run on the LeCroy 3500.

The germanium detector for the high-resolution measurements was a Princeton GammaTech high-purity detector with an efficiency of 21% relative to a 7.62-cm-diameter by 7.62-cm-long NaI(Tl) detector at 1332 keV. The resolution was 1.8 keV (full width at half maximum) at

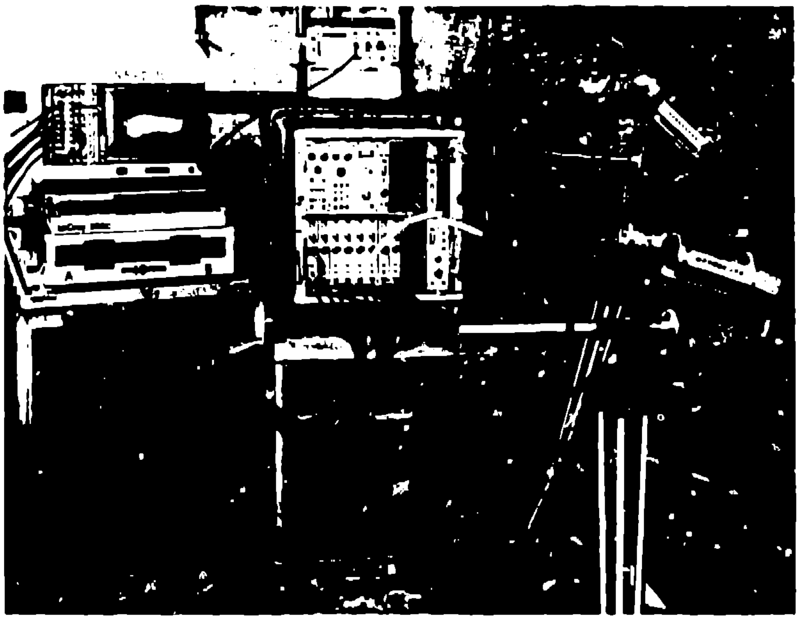

Figure 1. LeCroy 3500 data acquisition system and NIM bin electronics. The shipping box under the NIM bin electronics is for the LeCroy 3500 system.

1332 keV. The detector had an all-attitude dewar for liquid nitrogen with a holding time of 20 hr. This facilitated positioning the detector.

For the BGO measurements and some of the high-purity germanium measurements the Little Boy device was supported outdoors on a stand (Figure 2); the geometrical center of the core of the device when operating was 4.0 m from the ground. The amplifier was close to the detector and connected to the LeCroy 3500 in a control room 400 m away via a coaxial cable. The degradation of the signals by the long cables was significant for the high-purity germanium detector but not for the BGO measurements.

To obtain high-purity germanium pulse-height distributions with good resolution we made another series of measurements with both the analog electronics and an analyzer near the germanium detector. We used a Tennelec TC 205A amplifier and a Tracor Northern 1710 analyzer equipped with an 8192-channel ADC and remote control module. We controlled the analyzer with a terminal in the control room using short-haul modems on a twisted pair cable. For these measurements the Little Boy device and stand were located in a concrete building. We believe the line intensities were not changed significantly by the building from what they were outside. However, the continuum in the spectrum that includes scattering from the surroundings was changed.

CALIBRATION AND ANALYSIS

We calibrated the system from 122 to 8284 keV using radioactive sources and reactions. The gamma-ray "point" sources used were ^{57}Co, ^{139}Ce, ^{203}Hg, ^{113}Sn, ^{51}Cr, ^{7}Be, ^{85}Sr, ^{137}Cs, ^{54}Mn, ^{88}Y, ^{65}Zn, ^{22}Na, ^{60}Co, and ^{208}Tl. The

Figure 2. The Little Boy device on a stand outdoors. The detector on the arm extending out from the device at 90° is the high-purity germanium detector in an all-attitude dewar. The arm can be rotated up to 0°. Two monitor detectors can be seen. One is to the left of the Little Boy device; the second is on the lower right side of the stand. The PortaNIM bins on the ladder are for the germanium detector. The two NIM bins at the lower right are for the BGO detector.

---

reactions used were the $^{9}Be(\alpha,n)^{12}C$ reaction in a plutonium-beryllium source and the $^{14}N(p,\gamma)^{15}O$ reaction produced in a Van de Graaff target. The $^{9}Be(\alpha,n)^{12}C$ reaction produces a 4439-keV gamma ray; the $^{14}N(p,\gamma)^{15}O$ produces a 8284-keV gamma ray at the 1058-keV proton energy resonance. The calibration was extended to such a high energy because the highest energy gamma ray from the Little Boy device with significant strength was the 7645-keV line from $Fe(n,\gamma)$. The photopeak efficiency was calculated by fitting a polynomial containing six parameters to $\ln$(efficiency) versus $\ln$(energy). Detailed studies of BGO efficiency will be reported elsewhere.

To determine the detector response as a function of energy, we fitted an analytical curve containing 17 parameters to pulse-height distributions from some of the sources using a generalized least-squares program on a Control Data Corporation (CDC) 7600 computer. The photopeak, first and second escape peaks, and the backscatter peak were approximated by energy-dependent Gaussian functions. The Compton distribution was approximated by an energy-dependent Gaussian function plus another function. Details of these calculations are given in (Moss et al. 1984). Figure 3 shows the fit of this function to the ^{88}Y pulse-height distribution. Figure 4 shows plots of the analytical response functions for 500- and 5000-keV gamma rays.

We used the resulting response functions in a stripping procedure to calculate the flux in photons/cm^2/sec as a function of energy. Starting with the highest energy bin we assumed that all the counts in that bin were in a photopeak. Using the photopeak efficiency curve we calculated the corresponding flux in photons/cm^2/sec at the photopeak. We also calculated the tail corresponding to this photopeak and subtracted it from all the lower bins in the pulse-height distribution. Next we considered the second highest bin in the pulse-height distribution and assumed that all of the counts in that bin were in a photopeak because the tail from the highest bin

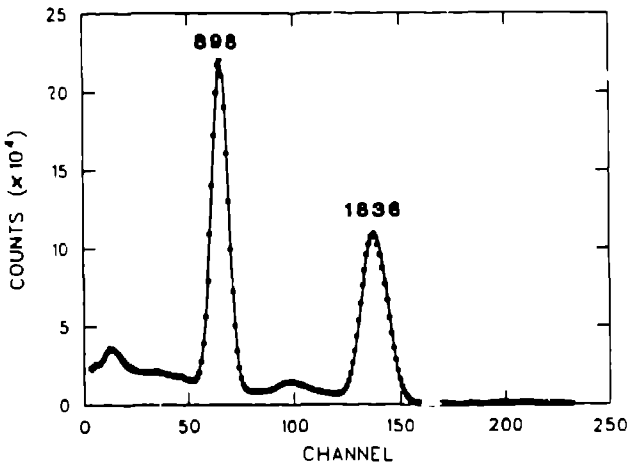

Figure 3. Fit of the analytical response function (curve) to the measured gamma-ray pulse-height distribution (points) from ^{88}Y. The peaks are labeled with the gamma-ray energies in keV.

---

had been subtracted. The procedure was repeated until the lowest bin was reached.

We converted the resulting flux distribution to a dose-rate distribution using a flux-to-dose-rate curve (Figure 5) based on the work of Dimbylow and Francis (1979). In the past other conversion curves have been proposed (American Nuclear Society Standards Committee Working Group 1977).

RESULTS

We identified the gamma-ray lines from the Little Boy device from a high-resolution distribution (Figure 6) acquired with the high-purity germanium detector. As expected, the lines from Fe(n,γ) are dominant, especially the 7645- and 7631-keV lines. The lines at 766, 1001 keV, and higher from ^{234m}Pa (which is a daughter of ^{238}U) are present but only moderately strong because of the

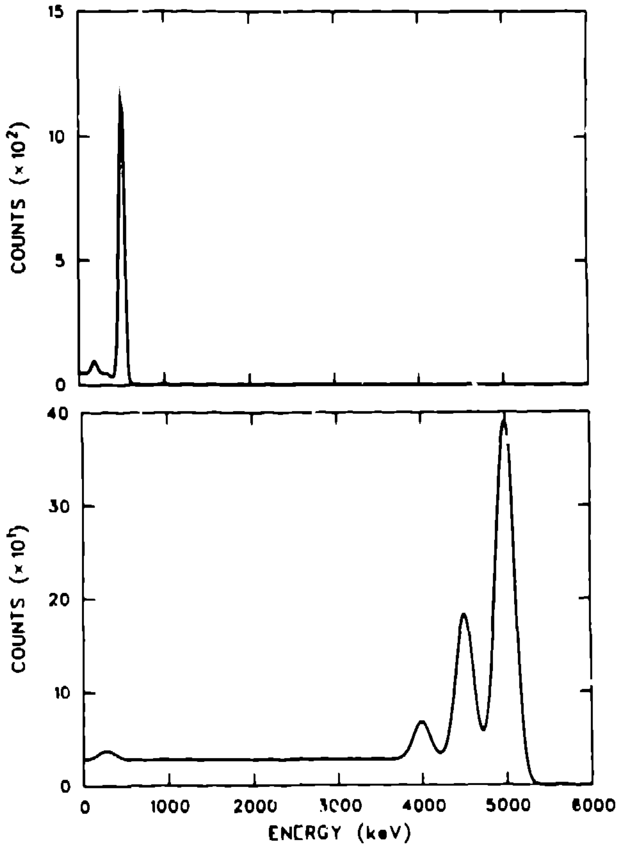

Figure 4. Calculated response function for a 500-keV gamma ray (top) and a 5000-keV gamma ray (bottom).

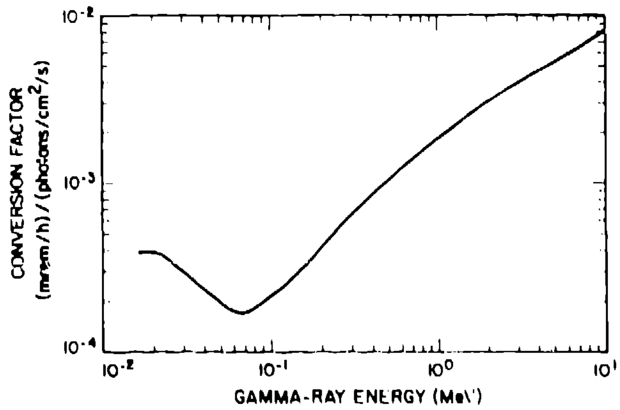

Figure 5. Gamma-ray flux-to-dose-rate curve based on the work of Dimbylow and Francis.

shielding provided by the massive steel case. Similarly the fission product lines are weak and only the strongest ones, such as those from ^{140}La, can be seen. There are many moderate to weak lines from the activation of the steel and other structural material.

Results at (0°, 2 m) and (90°, 0.75 m) are shown in Figures 7 and 8, respectively. Zero degrees is along the cylindrical axis at the rounded end of the device and 90° is perpendicular to the axis. The distances are measured from the center of the core when it is assembled. In each figure the binned pulse-height distribution, flux distribution, and dose-rate distribution are shown. The 7.6-MeV peak from Fe(n,γ) is the most prominent feature. The integral of the dose-rate distribution over energy is the total gamma-ray dose rate.

The integral doses up to 11 MeV at various positions around the Little Boy device, normalized to the number of fissions, are presented in Figure 9 and listed in the Table. The number of fissions is based on one of the monitor detectors that H. M. Forehand and G. E. Hansen of Los Alamos National Laboratory calibrated very

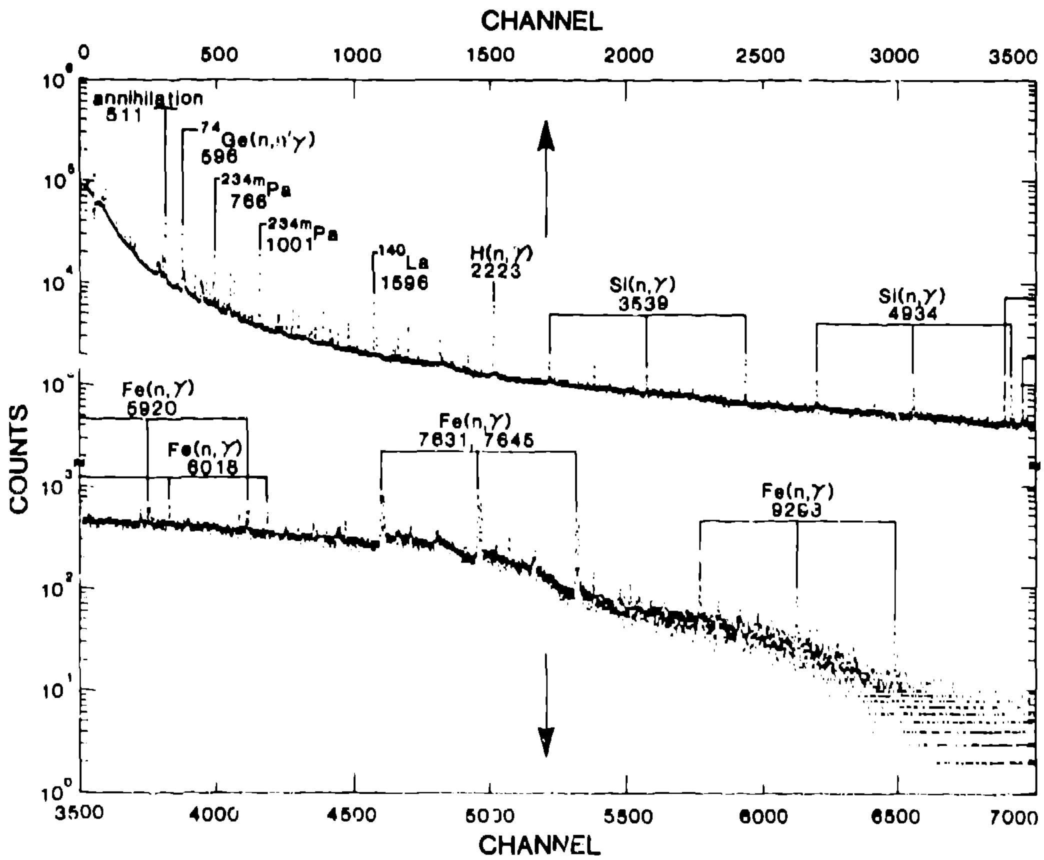

Figure 6. High resolution pulse-height distribution measured at (90°, 2 m). The acquisition live time was 3000 sec and the number of fissions was 1.81 x 10^{12}. The major peaks are labeled with the radioactive nuclide and the gamma-ray energy in keV.

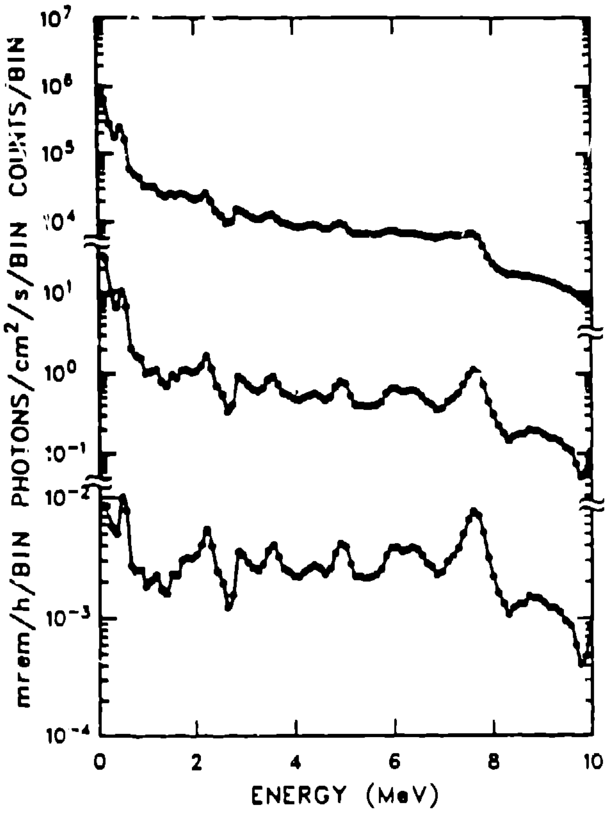

Figure 7. Binned pulse-height distribution (top), flux spectrum (middle), and dose-rate spectrum (bottom) from the Little Boy device at (0°, 2 m). The 7.6 MeV peak from Fe(n,γ) is the most prominent feature of the distribution.

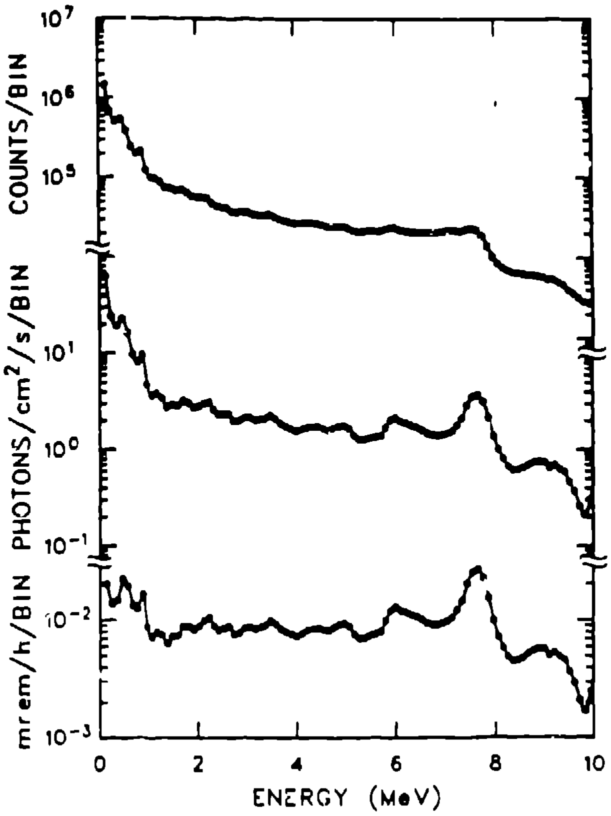

Figure 8. Binned pulse-height distribution (top), flux spectrum (middle), and dose-rate spectrum (bottom) from the Little Boy device at (90°, 0.75 m). Again the 7.6-MeV peak is the most prominent.

carefully from independent experiments. In previous work on devices that produced negligible gamma-ray intensity above 5 MeV we assigned a total uncertainty of ±7% to our results based on measurements of calibration sources. In the present work the spectra extend well above 5 MeV where the detector efficiency and response functions are more uncertain. We assign a total uncertainty of ±15% to our present results. A point at (60°, 2 m) is not shown because we believe our measurement was not valid here; there was no opportunity to repeat the measurement. The dip at (30°, 0.75 m) corresponds to the maximum diagonal thickness of steel.

CONCLUSIONS

We have described a fieldable system for determining gamma-ray flux spectra and dose rates. We use a flux-to-dose-rate curve to obtain dose rates and thus avoid the errors that can arise from spectrum dependence in simple gamma-ray dosimeter instruments.

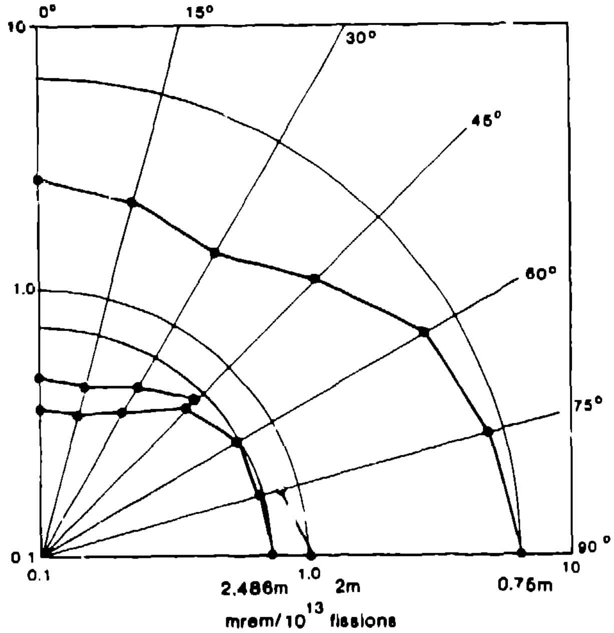

Figure 9. Log polar plot of the gamma-ray dose rates up to 11 MeV around the Little Boy device normalized to the number of fissions. The dip at (30°, 0.75) corresponds to the maximum diagonal thickness of the steel case.

We have presented some doses around the Little Boy device normalized to the number of fissions. Our values can be used to calculate the gamma-ray output of the nuclear explosion at Hiroshima.

We are continuing to refine our calibration and analysis, especially above 5 MeV. We hope to have more precise values in the future for comparison with other experiments and calculations.

ACKNOWLEDGMENTS

We wish to thank the Critical Facilities crew for operating the Little Boy device, and E. J. Dowdy and R. E. Malenfant for providing encouragement and support.

TABLE. Normalized Doses At Positions Around the Little Boy Device[a]

Angle from Vertical (°)	Dose (mrem/10^{13} fissions) at Distance to Source 2.486 m	2.0 m	0.75 m
0	0.358	0.462	2.65
15	0.354	0.452	2.40
30	0.413	0.544	2.05
45	0.500	0.665	2.96
60	0.623	---	4.62
75	0.704	0.865	5.62
90	0.749	1.03	6.58

[a]The uncertainties on all BGO values are ±15%.

REFERENCES

American Nuclear Society Standards Committee Working Group. 1977. American National Standard Neutron and Gamma-Ray Flux-to-Dose-Rate Factors. ANSI/ANS-6.1.1, American Nuclear Society.

Dimbylow, P. J., and T. M. Francis. 1979. A Calculation of the Photon Depth-Dose Distributions in the ICRU Sphere for a Broad Parallel Beam, a Point Source, and an Isotropic Field. Report R92, National Radiological Protection Board Harwell, England.

Häusser, O., M. A. Lone, T. K. Alexander, S. A. Kushneriuk, and J. Gascon. 1983. "The Prompt Response of Bismuth Germanate and NaI(Tl) Scintillation Detectors to Fast Neutrons," Nucl. Instr. & Meth. 213:301.

Hsu, H. H., E. J. Dowdy, G. P. Estes, M. C. Lucas, J. M. Mack, C. E. Moss, and M. E. Hamm. 1983. "Efficiency of a Bismuth-Germanate Scintillator: Comparison of Monte Carlo Calculations with Measurements," IEEE 1983 Nuclear Science Symposium, San Francisco, California, October 19-21, 1983, in press.

Moss, C. E., E. J. Dowdy, A. E. Evans, M. E. Hamm, M. C. Lucas, and E. R. Shunk. 1984. "Unfolding Bismuth-Germanate Pulse-Height Distributions to Determine Gamma-Ray Flux Spectra and Dose Rates," in press at Nucl. Instr. & Meth.