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TITLE: STATUS OF LOS ALAMOS EFFORTS RELATED TO HIROSHIMA AND NAGASAKI DOSE ESTIMATES

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SUBMITTED TO: DOE SYMPOSIUM

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STATUS OF LOS ALAMOS EFFORTS RELATED TO HIROSHIMA AND NAGASAKI DOSE ESTIMATES

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September 1981

ABSTRACT

In an unclassified summary fashion, the Los Alamos efforts related to resolution of the Hiroshima, Nagasaki doses will be described.

1. Yield of the Hiroshima Bomb

Using recently located replicas of the Hiroshima bomb, measurements will be made at the Los Alamos Critical Assembly Facility (LACAF), which -- in conjunction with calculations -- will define the upper limit of the Hiroshima yield.

2. Neutron and Gamma-Ray Output

Two-dimensional calculations of the neutron and gamma-ray outputs of the Hiroshima and Nagasaki weapons are in progress. Neutron and gamma-ray leakage spectra measurements will be made at the LACAF on the Hiroshima replica in a near critical configuration. Similar measurements have been proposed on the Mark 9 weapon and on the Ichiban assembly. These measurements, made with modern techniques, will provide a check for present day cross sections and calculations.

3. Air Transport and Ground Effects

Calculations of several air transport experiments are in progress. Comparison of calculated results with experimental results are shown.

4. Debris Output

The neutron and gamma-ray output spectra of several devices tested in the atmosphere at the Nevada Test Site are being calculated. The results of these calculations will allow models of the debris cloud contribution to the total dose to be tested. Calculations have been completed for Ranger Fox and for Upshot-Knothole Grable.

I. INTRODUCTION

The neutron and gamma-ray doses assigned to the atomic bomb survivors at Hiroshima and Nagasaki must be accurate within some limits if conclusions drawn from studies of the survivors are to have value. The doses received by the survivors depend upon the yields of the bombs, the specific radiation outputs of the bombs and of the bomb debris and the transport of the radiation through the air and shielding around each survivor. In addition the self shielding of the body is important for many biological effects.

The accuracy of each element of the dose assignment must be demonstrated by comparison of pertinent calculated and observed data from other experiments and Nevada tests as well as with physical data from Hiroshima and Nagasaki. To help in deriving dose assignments and demonstrating their accuracy, a small program has been started at Los Alamos. This program is aimed at helping resolve the question of the yield of the Hiroshima bomb, providing two-dimensional neutron and gamma-ray output for the Hiroshima and Nagasaki bombs, examining the validity of air transport calculations and providing neutron and gamma-ray output for some selected Nevada test shots so that the accuracy of dose and spectra calculations can be demonstrated by comparison with observations.

The goal of the Los Alamos program is to provide that missing weapons data which will allow the accuracy of dose calculations to be demonstrated.

II. YIELD OF THE HIROSHIMA BOMB

The bomb exploded at Nagasaki, the Fat Man, was a design that has been fired in test situations. Yield data is available from test firings of three weapons nominally identical to the Nagasaki bomb, allowing good estimates of the yield of the Nagasaki explosion as reported by John Malik in this symposium. The bomb exploded at Hiroshima, the Little Boy, was of a radically different design. There have been no other test firings of the Hiroshima type weapon and no yield measurements. Estimates of the yield of the Hiroshima explosion by different investigators using different bits of data have ranged between 1. and 20 kt also as reported by Malik. The yield predicted for the Hiroshima explosion was 15 kt (Schiff, 1945).

To supplement the on going work by Malik, Kerr, and others to resolve the different interpretations of blast, thermal, and canister data, Los Alamos has started a program to establish theoretical limits on the yield of the Hiroshima explosion.

Obviously, if the bomb could be designed and the yield predicted in 1945 with the data available then, the yield can be calculated now with the wealth of data and calculational tools available now. However, as is often the case with good ideas, there is a problem with this one. All of the data available in 1945 is no longer readily available or is expressed in terms not suitable for our current calculational schemes. One of the crucial - indeed critical - numbers available in 1945 is missing. This is the number that determines the criticality of the Little Boy assembly. Of course, the actual value used in 1945 for the infinitely tamped mass of ^{235}U is available as is the 1945 estimate for the criticality of Little Boy. What is missing are enough details of the experiments and experiment analysis to estimate the accuracy of the quoted values. And one very useful measurement was never made in 1945.

The yield of the Hiroshima bomb is very sensitive to the estimate of criticality. Sensitivity calculations using a number of cross section sets available at Los Alamos resulted in a spread of yields from 8 to 24 kt. Using a subset of generally accepted cross sections resulted in a spread of calculated yields from 12 to 18 kt. These were strictly sensitivity studies with no significance to be attached to the central value.

Nuclear archeology at Los Alamos would probably turn up enough details of old experiments and analysis so that, coupled with a fairly complicated calculational program and pertubation analysis, a good theoretical estimate of the Hiroshima yield could be produced. This estimate, however, would be subject to fairly large uncertainties because of the many steps in the calculational program.

Fortunately, Los Alamos is in a position to produce a theoretical estimate of the maximum yield of the Hiroshima explosion that is accurate to the nominal 10% quoted on directly measured yields. This will be accomplished by doing the criticality measurement that was not done in 1945. The measurement will be done in the Los Alamos Critical Assembly Facility (LACAF). The Los Alamos Critical Assembly Facility is set up to allow two pieces of fissile material to be brought safely together into a critical configuration. Most of the critical mass data available to the nuclear community was produced in this facility.

In May of 1981, four objects were located in field storage at Los Alamos. Three of these objects were later identified by Harlow Russ, a retired employee, as non-fissile components of Little Boy weapons which had been retired from stockpile.

The fourth object was a training device without the proper materials. Harold Agnew, the former Director of the Laboratory, had wisely stored these four samples. These components were transferred to the LACAF.

After the publicity in June concerning the Hiroshima-Nagasaki doses, it developed that several people in the Laboratory knew of the existence of these components but had not been aware of any interest in them.

Fissile parts have been ordered which will allow a direct experimental determination of the criticality of the Little Boy in the LACAF. With this information, a calculation of the maximum yield is straightforward. The calculated yield is of necessity the maximum yield because of the possibility of a malfunction of the Hiroshima bomb. Even with this limitation, an accurate theoretical value for the maximum yield will be very valuable. A low theoretical value excludes the higher yields inferred by other techniques. The effect of a high theoretical value is not so clean.However, a high theoretical value for the yield would indicate with high probability that techniques which infer lower yields should be critically examined.

At this point, it always appears that the direct solution to the question of the Hiroshima yield is to simply fire one of the

Little Boy replicas and measure the yield. This is easier said than done Because of the problems of measuring yields of this type of device in an underground environment, the directly measured yield would have very large error bars; larger than the error bars associated with the program we are following. The interpretation of other test diagnostics coupled with calculations would reduce the error bars to 10%. However, even a simple test would cost an order of magnitude more than the measurements in the LACAF.

For the determination of dose, the real question is not the yield of the Hiroshima bomb, but the neutron and gamma-ray output of the bomb and the output of the debris cloud. The measurement of the two-dimensional outputs of the device would be even more expensive than a yield measurement in an underground environment and there are real problems with measurements of debris clouds in underground environments.

There are two more activities to be described: a program of comparison of calculated spectra with spectra measured in the LACAF, and a program of comparison of calculated outputs with outputs measured from atmospheric shots at the Nevada Test Site. These programs should be completed and the results examined before considering a Nevada experiment.

III. NEUTRON AND GAMMA-RAY OUTPUT

Los Alamos is doing two-dimensional calculations of the neutron and gamma-ray output spectra of both the Hiroshima and Nagasaki bombs. The Hiroshima bomb calculations are in progress. The Hiroshima bomb was much more two-dimensional than the Nagasaki bomb which was nearly spherical. Thus more interest attaches to the Hiroshima bomb calculation.

Calculations of the neutron output of the Hiroshima bomb were done by W. Biggers of Los Alamos in 1962 with limited release to the effects community. No report of the results nor other documentation of these calculations has been found. Some records may exist in dead storage. These calculations are mentioned only because the neutron output appears to have been used before for dose estimates at Hiroshima.

In 1975, W.E. Preeg of Los Alamos did one-dimensional (spherical) calculations of the neutron and gamma-ray output spectra of both the Hiroshima and Nagasaki bombs for inclusion in the Defense Nuclear Agency (DNA) classified Nuclear Weapons Output Handbook. These output spectra were declassified by the DOE in 1976 and published as a letter to C.P. Knowles. Because these output spectra are the starting point of all of the re-analyses of dose which have been done to date, the letter is included as an appendix to this report.

In the Preeg letter, in addition to the output data, are comparisons of dose as a function of distance with the dose inferences of Hashizume et al. The Preeg doses are not valid. The doses were not calculated in an air-over-ground geometry but came from a model for infinite air transport and were done for dry air, the debris contribution to the gamma-ray dose was not included and the Nagasaki height of burst was incorrect. This is all pointed out in the letter. The dose calculations were not pursued further.

With the revival of interest in the Hiroshima-Nagasaki doses at Los Alamos, the one dimensional calculations of output spectra done by Preeg were repeated with the computers, operating systems, codes and cross sections currently in use at Los Alamos. Six years is a long time. The Preeg output spectra were confirmed.

The two-dimensional output calculations now being done will allow comparisons to be made with activation data from locations close to ground zero. Because of the anisotropy of the output of the Hiroshima bomb, these comparisons could not be made before. These comparisons will be a new test of the validity of the calculations.

To provide calibration data for the output spectra calculations, neutron and gamma-ray spectra measurements will be made at the LACAF on the Hiroshima replica in a near critical configuration. These measurements, made with the best techniques available, will provide yet another check of codes and cross sections. The spectra measured at the LACAF on a cold static assembly are not the spectra of an exploding bomb. High energy neutrons coming out of an exploding bomb penetrate a constantly changing thickness of material. Low energy neutrons in an exploding bomb experience a thermal environment very different from the thermal environment of a static assembly. Special purpose codes have been developed to handle these effects.

There are proposals to do similar spectra measurements at the LACAF on the MK 9 weapon and on the Ichiban assembly. Most of the parts necessary to do these experiments also exist.

Measurements on the MK 9 assembly would provide a complete loop between the calculational procedures and Nevada Test Site measurements.

Measurements on the Ichiban assembly would resolve a long standing but little known problem. In addition to there being two different calculated neutron speccra for the Ichiban experiment (which has been reported), there were two different neutron dose measurements made on the Ichiban assembly. Only one of the measurements was reported. Modern measurements would clear up the discrepancy.

IV. AIR TRANSPORT CALCULATIONS

Los Alamos has one of the premier transport calculational capabilities in the country. The Los Alamos MCNP code is a continuous energy Monte Carlo code for coupled neutron and gamma-ray transport calculations which is in use at installations around the world. Cross sections for the code can be processed from several sources including the Evaluated Nuclear Data Files (ENDF) library. Many of the features of the MCNP code and cross section libraries are used in calculations of weapon output.

With the intention of doing Monte Carlo dose calculations when the two-dimensional output became available, several tests of the ENDF data for air transport were made. The first calculations were of the liquid oxygen and nitrogen pulsed sphere experiments done under DNA auspices at LLNL (Wong, 1972). In these experiments a pulsed source of DT neutrons is generated in the center of a sphere of the material to be tested. Neutrons emerging from the surface of the sphere are counted by time-of-flight techniques. Typical results from these calculations with ENDF cross sections were that calculated and measured total neutron fluence between 2 and 14 MeV agreed to better than 10%. However, discrepancies up to 50% were seen in sub intervals of the energy spectrum. Generally, the calculated fluences were low at high energies and high at low energies. The results of a typical calculation are shown in Figure 1 with the time-of-flight spectrum at the top and the energy spectrum at the bottom. Calculations done using the LLNL cross sections produced better comparisons, probably because these experiments had been used in the normalization of the LLNL cross sections. Even so, Figure 2 shows discrepancies of 10% in total fluence between 2 and 14 MeV and discrepancies of 30% in sub intervals in comparisons of MCNP calculations using LLNL cross sections and measurements of a liquid air pulsed sphere experiment (Sidhu, 1978).

Somewhat discouraged by these results which indicated that we were not calculating transported spectra very well and that there were systematic trends in the differences, we looked at the "broomstick" experiments (Clifford, 1967). In these Oak Ridge National Laboratory experiments a continuous source of neutrons from a port in the Tower Shielding Reactor II impinged on one end of a thin cylinder of the material under investigation. Neutrons emerging from the other end of the cylinder were counted in an energy discrimination mode. The result is a rather clean transmission experiment. Again, calculations with ENDF cross sections of the neutron tranmission through liquid oxygen and nitrogen were disappointing. The calculated fluence tended to be low at high energies. In addition, the calculated valleys in the transmitted fluence through nitrogen did not agree in magnitude (factor of two) nor in energy (10%-20%) with the observed valleys. The comparisons of calculations with observation are shown in Figure 3. In this figure the snake across the figure is the error band of the observations and the little tick marks are the calculations.

Because the experiments described above are not directly approrpriate for an air-over-ground geometry, we looked at the Aberdeen Proving Ground experiments, which used the U.S. Army Pulse Radiation Division (APRD) reactor as a source. In these experiments a fission reactor mounted 14 m above the ground provides a continuous source of neutrons. Detectors are operated in an energy discrimination mode. Measurements were made at several distances from the reactor. Measurements have been made by several groups with differences of 40% between measurements of different groups (Robitaille, 1980). However, if the measurements of the different groups are compared to the average of all the measurements, the individual measurements are within ~20% of the average over the energy range .6 MeV to 10 MeV as shown in Figure 4. In contrast, the Los Alamos MCNP calculations of fluence using the ENDF cross sections fall well outside the 20% deviation from the average of the measurements and show a strong energy dependence. The Los Alamos calculated fluences are ~40% below the average of the measurements at high energies and ~40% above the average at low energies as shown in Figure 5. Also shown on Figure 5 are the fluences calculated with the S_n DOT code by the Defense Research Establishment Ottawa (DREO). The fluences calculated with DOT show exactly the same pattern with neutron energy as the fluences calculated by the Monte Carlo code. This implies either the cross sections are in question or all three of the experimenters are having the same problem.

Because the ratio of calculated to observed fluence as a function of energy crosses unity, the calculated neutron kerma, being an integral over energy, has a smaller error than the calculated fluence as a function of energy. An examination of the kermas reported by Robitaille indicates an error of calculated neutron kerma of only ~15% at 300 m rising to ~30% at 100 m. This degree of accuracy in the neutron kerma may be completely adequate for the current study of doses. However, because of the spectral dependence of calculational error indicated by the pulsed sphere and APRD experiments, caution must be exercised in the analysis of the sulphur activation data.

V. DEBRIS OUTPUT

Gamma rays from the debris cloud of a nuclear explosion contribute an appreciable fraction of the total dose on the ground at the ranges of interest at Hiroshima and Nagasaki. The modelling of the gamma-ray dose from the debris is not done as accurately as could be desired. The reader may refer to the discussions of this topic by Kerr and Loewe in this symposium. To help in the calibration of more accurate debris models, Los Alamos will provide the calculated prompt neutron and gamma-ray output spectra for several explosions at the Nevada Test Site. These events have been selected by Kaul and Scott representing DNA as having appropriate diagnostics. The total of the calculated air-transported prompt doses and the debris dose should match the observed doses. These dose (and spectral) comparisons will provide stringent tests of the overall accuracy of the Hiroshima and Nagasaki dose calculations.

Two-dimensional calculations have been completed for Upshot-Knothole Grable.

One-dimensional calculations have been completed for Ranger Fox.

Other calculations will be completed as manpower permits. These calculations are not difficult; locating drawings and specifications for these old shots is slow and time consuming.

ACKNOWLEDGMENTS

The author wishes to thank the following Los Alamos individuals who have done all of the work reported in this paper.

X-4 Nuclear Applications

B. Rogers and R. Worlton	for 1-dimensional models and explosion calculations
J. Kammerdiener	for 2-dimensional explosion calculations of the Hiroshima bomb

X-5 Diagnostics Physics

R. Streetman	for the calculations of the radiation outputs of the explosions

X-6 Monte Carlo

P. Soran	for providing cross section sets
R. Seamon	for providing, modifying and checking cross sections
R. Little	for the "broomstick" calculations
G. Estes	for the pulsed sphere and LPRD calculations and the method of data presentation

Q-14 Critical Assemblies

R. Malefant	for enthusiastic support from the Critical Assembly Facility

NSP/T&V Test and Verification

J. Malik	for sharing his encyclopedic knowledge of measurements made on nuclear explosions
H. Russ (retired)	for locating lost drawings

Funding for the output calculations was provided by DNA.

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Robitaille, H.A., and B.E. Hoffarth, 1980, "A Comparison of Measured and Calculated Air-Transported Radiation From a Fast, Unshielded Nuclear Reactor." DREO 835, Defence Research Establishment Ottawa.

Schiff, L.I., August 4, 1945, "Expected Performance of the Gun Gadget: Yield Based on Finished Dimensions," LA-321A, Los Alamos, (SECRET RESTRICTED DATA).

Sidhu, G.S., W.E. Farley, L.F. Hansen, T. Komoto, B. Pohl and C. Wong, 1978, "Transport of Neutron and Secondary Gamma Radiations Through a Liquid Air Sphere Surrounding a 14 MeV Neutron Source," Nuclear Science and Engineering, 66:428-432, Lawrence Livermore Laboratory.

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Wong, C., J.D. Anderson, P. Brown, L.F. Hansen, J.L. Kammerdiener, C. Logan and B. Pohl, 1972, "Livermore Pulsed Sphere Program: Program Summary Through July 1971," UCRL-51144, Rev. 1, Lawrence Livermore National Laboratory.

Captions for the Illustrations

Figure 1. Spectrum from Liquid Oxygen Pulsed Sphere

Figure 2. Spectrum from Liquid Air Pulsed Sphere

Figure 3. Spectrum Transmitted through Nitrogen

Figure 4. Comparison of Measured Spectra from APRD Reactor

Figure 5. Comparison of Calculated Spectra from APRD Reactor

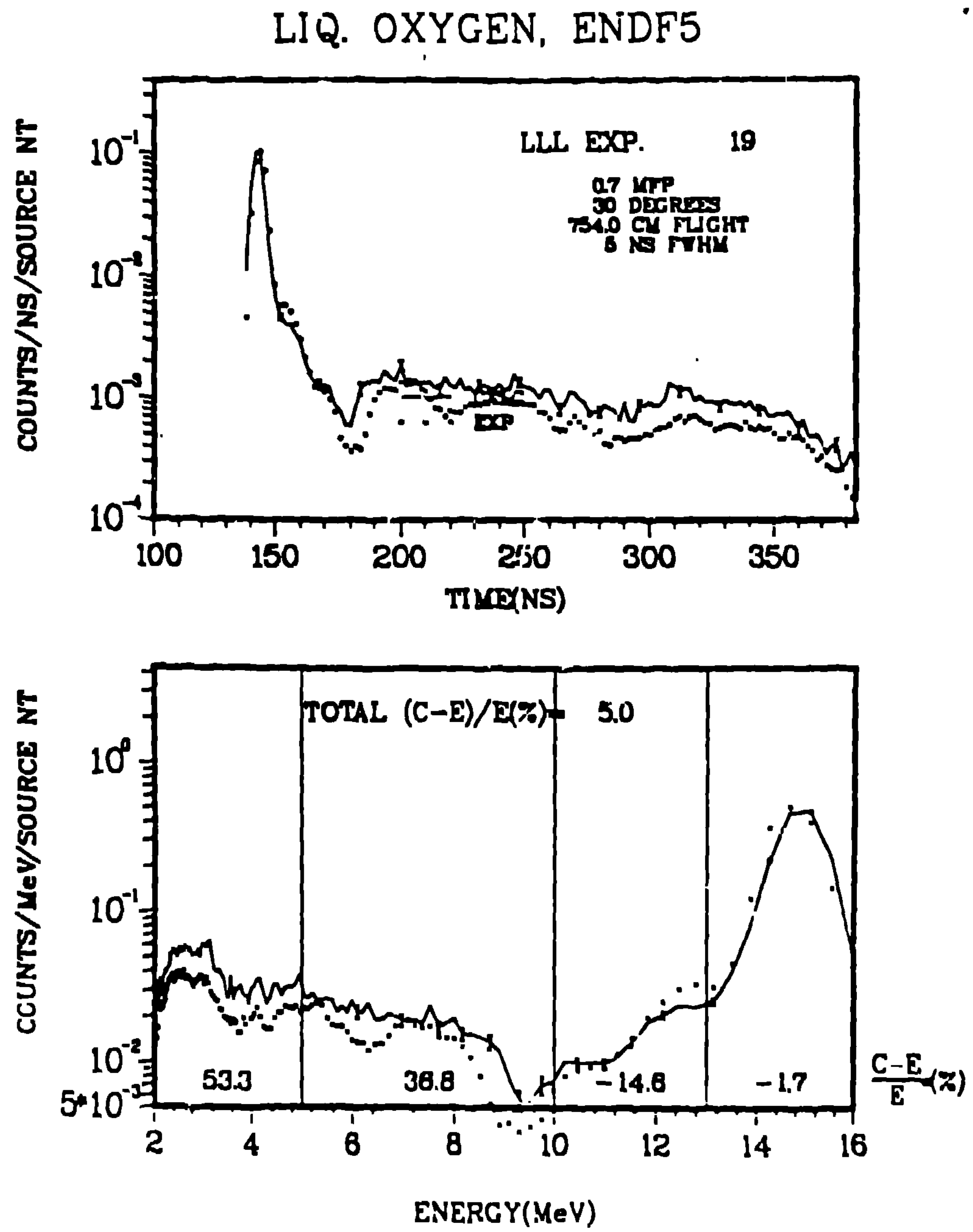
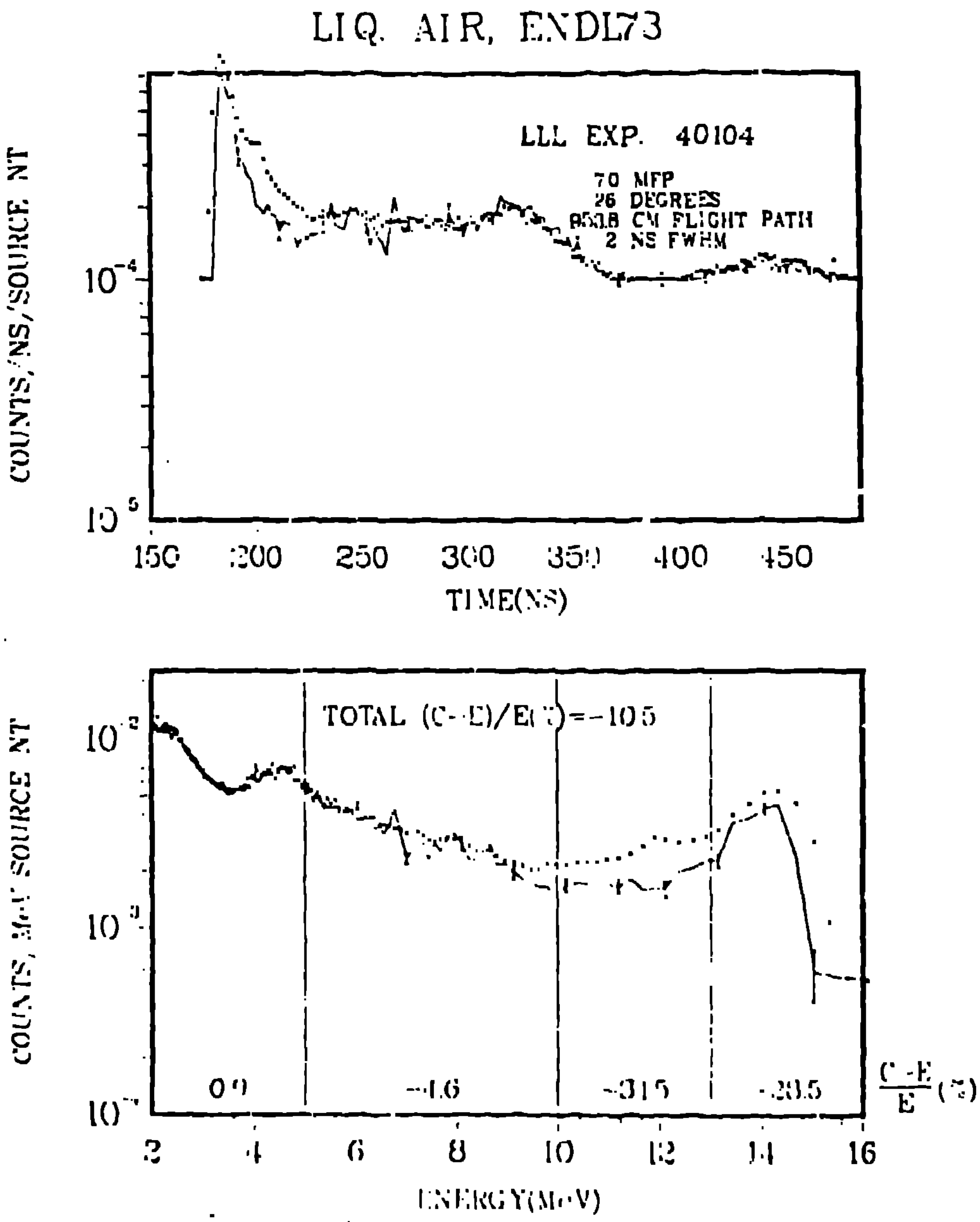

LIQ. OXYGEN, ENDF5
LLL EXP. 19
0.7 MFP
30 DEGREES
754.0 CM FLIGHT
5 NS FWHM
EXP
COUNTS/NS/SOURCE NT
TIME(NS)
TOTAL (C-E)/E(%)= 5.0
53.3
36.8
-14.6
-1.7
C-E/E(%)
COUNTS/MeV/SOURCE NT
ENERGY(MeV)

Figure 1



LIQ. AIR, ENDL73
LLL EXP. 40104
70 MFP
26 DEGREES
2 NS FWHM
COUNTS/NS/SOURCE NT
150
250
450
TOTAL
0
-4.6
16

Figure 2

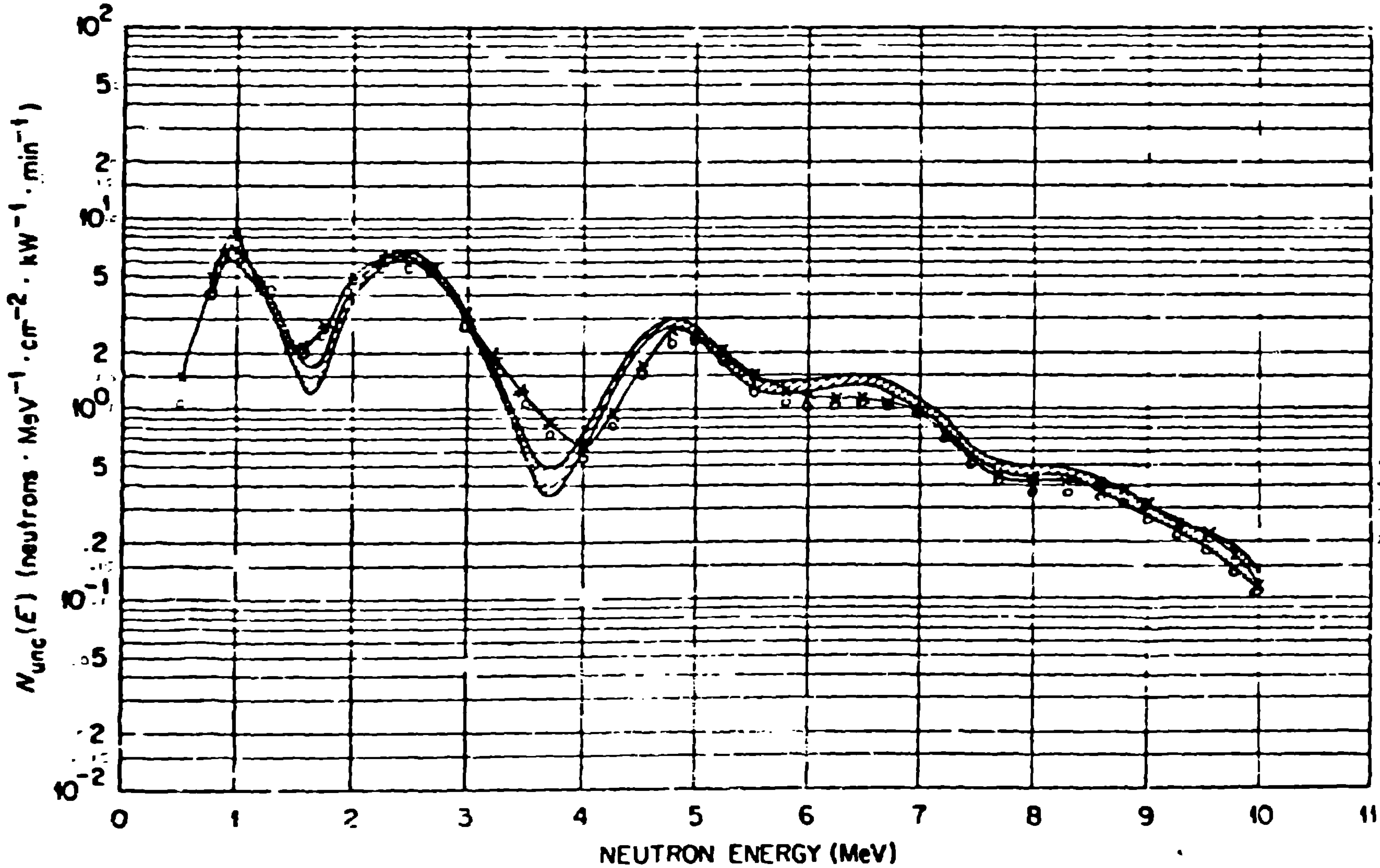


Fig. 3. Transmitted Spect um Through Nitrogen.

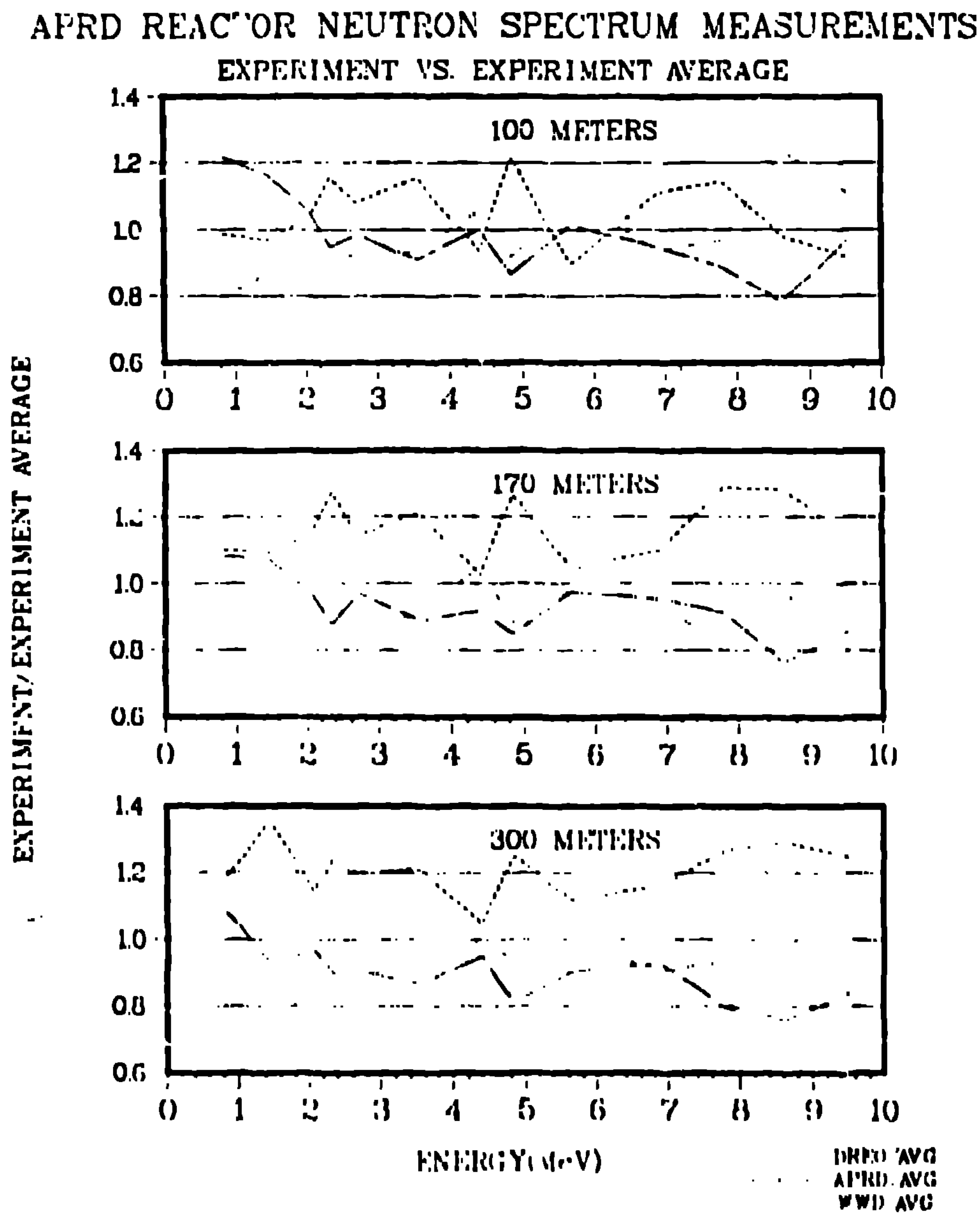

APRD REACTOR NEUTRON SPECTRUM MEASUREMENTS
EXPERIMENT VS. EXPERIMENT AVERAGE
100 METERS
170 METERS
300 METERS
EXPERIMENT/EXPERIMENT AVERAGE
ENERGY(MeV)
DREO AVG
APRD AVG
WWD AVG

Figure 4

APRD REACTOR NEUTRON SPECTRUM MEASUREMENTS

CALCULATIONS VS. EXPERIMENT AVERAGE

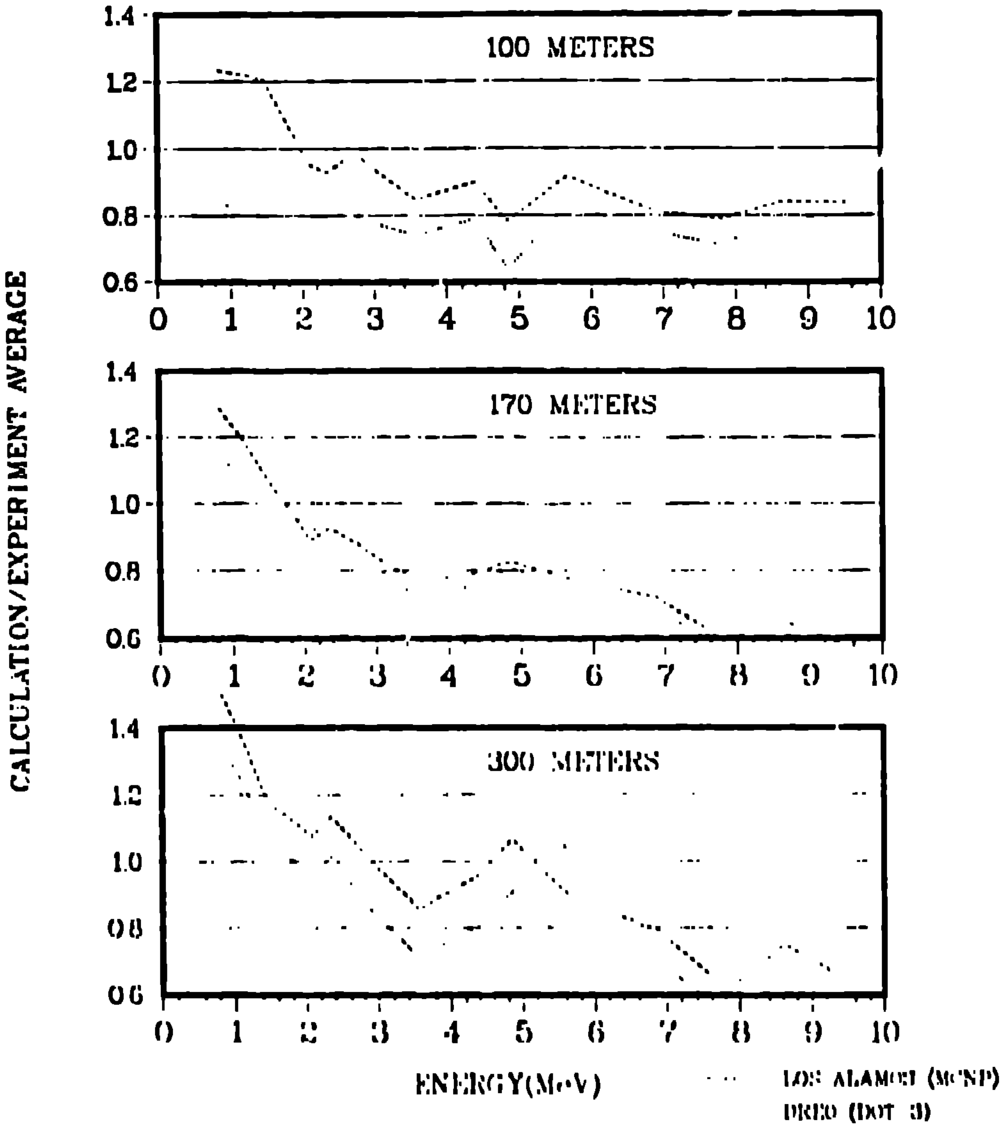


Figure 5

APPENDIX

Memorandum dated, April 5, 1976, to Dr. C.P. Knowles from W.E. Preeg. (8 pages)

UNIVERSITY OF CALIFORNIA
LOS ALAMOS SCIENTIFIC LABORATORY
(CONTRACT W-7405-ENG-36)
P. O. Box 1663
LOS ALAMOS, NEW MEXICO ~~87544~~ 87545

IN REPLY
REFER TO: TD-3
MAIL STOP: MS-232

April 5, 1976

Dr. C. P. Knowles
R and D Associates
P. O. Box 9695
Marina del Rey, CA 90291
RNT
THRU: R. N. Thorn, TD-DO

Dear Skip,

SUBJECT: NEUTRON AND GAMMA-RAY OUTPUT FOR FAT MAN AND LITTLE BOY

There have been several requests for the neutron and gamma-ray spectra out of the Fat Man and Little Boy devices. Since this data is unclassified, ʳ have decided to issue it as an unclassified letter. This is the same data that was given in my letter to you on October 22, 1975 (TD-3:75-87).

Some of the overall device parameters such as yield, mass, total neutron and gamma-ray output are given in Table I for both devices. The only change in this table since my previous letter is the inclusion of two other references for the "observed" Little Boy yield. The neutron and gamma-ray spectra are given in Table II and III, respectively.

These results have also been compared with measurements of dose* vs range. The HEART code was used to transport the neutron and gamma rays through the air. Most of the gamma-ray dose results from (n,γ) reactions in the air as opposed to direct gamma rays from the device. No effects of the ground were considered. The neutron and gamma-ray doses for Hiroshima (Little Boy) are given in Fig. 1 and 2, respectively. The neutron and gamma doses for Nagasaki (Fat Man) are given in Fig. 3. The neutron measurements were obtained from Co activation in steel and the gamma-ray measurements were made from roof tile.

A comparison of the calculated and measured doses still leave some unanswered questions. For Hiroshima, the neutron doses are in good agreement and the gamma ray doses are in good agreement at larger distances. The calculations of the gamma ray dose do not include fission product gamma rays which probably explains the lower dose at small distances. For Nagasaki, the calculated doses are low for both neutrons and gamma rays.

*T. Hashizume, et al., "Estimation of the Air Dose From the Atomic Bombs in Hiroshima and Nagasaki," Health Physics 1967, Vol. 13, pp. 149-161.

TABLE I

FAT MAN AND LITTLE BOY DEVICE PARAMETERS

	Fat Man	Little Boy
Calculated Yield (kt)	24.9	19.5[b]
Observed Yield (kt)[a]	22	14 - 18.5
Mass (kg)	4700	4050
Neutron Output (moles/kt)	0.28	0.21
Average Energy of Leakage Neutrons (MeV)	0.010	0.315
Gamma-Ray Efficiency (%)	0.095	0.044

---

[a] Fat Man measurement based on rad chem for Able event Crossroads, Trinity. Little Boy yields are given in the following reports:
LA-1398, "Yield of the Hiroshima Bomb," April 18, 1952.
NOLTR-65-143, "Yield of the Hiroshima Weapon," December 27, 1965.
RM-4193-PR, "Yield of the Hiroshima Bomb Derived from Pressure Record," September 1964.

[b] Calculated yield used in output calculations.

TABLE II

NEUTRON OUTPUT SPECTRA

Energy Group (MeV)	Neutron Output: Fat Man	Neutron Output: Little Boy
6.07 - 7.79	1.33E+21	1.86E+21
3.68 - 6.07	2.74E+21	7.11E+21
2.865 - 3.68	2.20E+21	8.56E+21
2.232 - 2.865	3.77E+21	1.52E+22
1.738 - 2.232	2.96E+21	2.35E+22
1.353 - 1.738	2.85E+21	3.01E+22
0.823 - 1.353	5.91E+21	1.01E+23
0.500 - 0.823	4.13E+21	2.33E+23
0.303 - 0.500	1.97E+21	3.61E+23
0.184 - 0.303	2.03E+21	3.21E+23
6.76E-2 - 0.184	2.46E+21	5.40E+23
2.48E-2 - 6.76E-2	1.24E+21	2.31E+23
9.12E-3 - 2.48E-2	1.32E+21	3.52E+23
3.35E-3 - 9.12E-3	1.58E+21	7.77E+22
1.235E-3 - 3.35E-3	1.70E+21	6.25E+22
4.54E-4 - 1.235E-3	4.21E+23	4.12E+22
1.67E-4 - 4.54E-4	1.52E+24	1.12E+22
6.14E-5 - 1.67E-4	1.32E+24	3.29E+21
2.26E-5 - 6.14E-5	6.62E+23	7.34E+20
8.32E-6 - 2.26E-5	2.10E+23	—
3.06E-6 - 8.32E-6	5.60E+22	—
1.13E-6 - 3.06E-6	2.38E+22	—
4.14E-7 - 1.13E-6	1.54E+21	—

TABLE III

GAMMA-RAY OUTPUT

Energy Group (MeV)	Gamma-Ray Output Fat Man	Gamma-Ray Output Little Boy
9 - 10	2.37E+20	3.25E+20
8 - 9	9.12E+19	3.07E+20
7 - 8	2.37E+22	1.01E+22
6 - 7	6.38E+21	2.65E+21
5 - 6	4.54E+21	2.05E+21
4 - 5	1.11E+22	4.83E+21
3 - 4	1.75E+22	7.37E+21
2 - 3	4.84E+22	1.04E+22
1 - 2	9.09E+22	1.55E+22
0.5 - 1	2.44E+22	2.80E+22
0.1 - 0.5	4.99E+21	1.22E+21

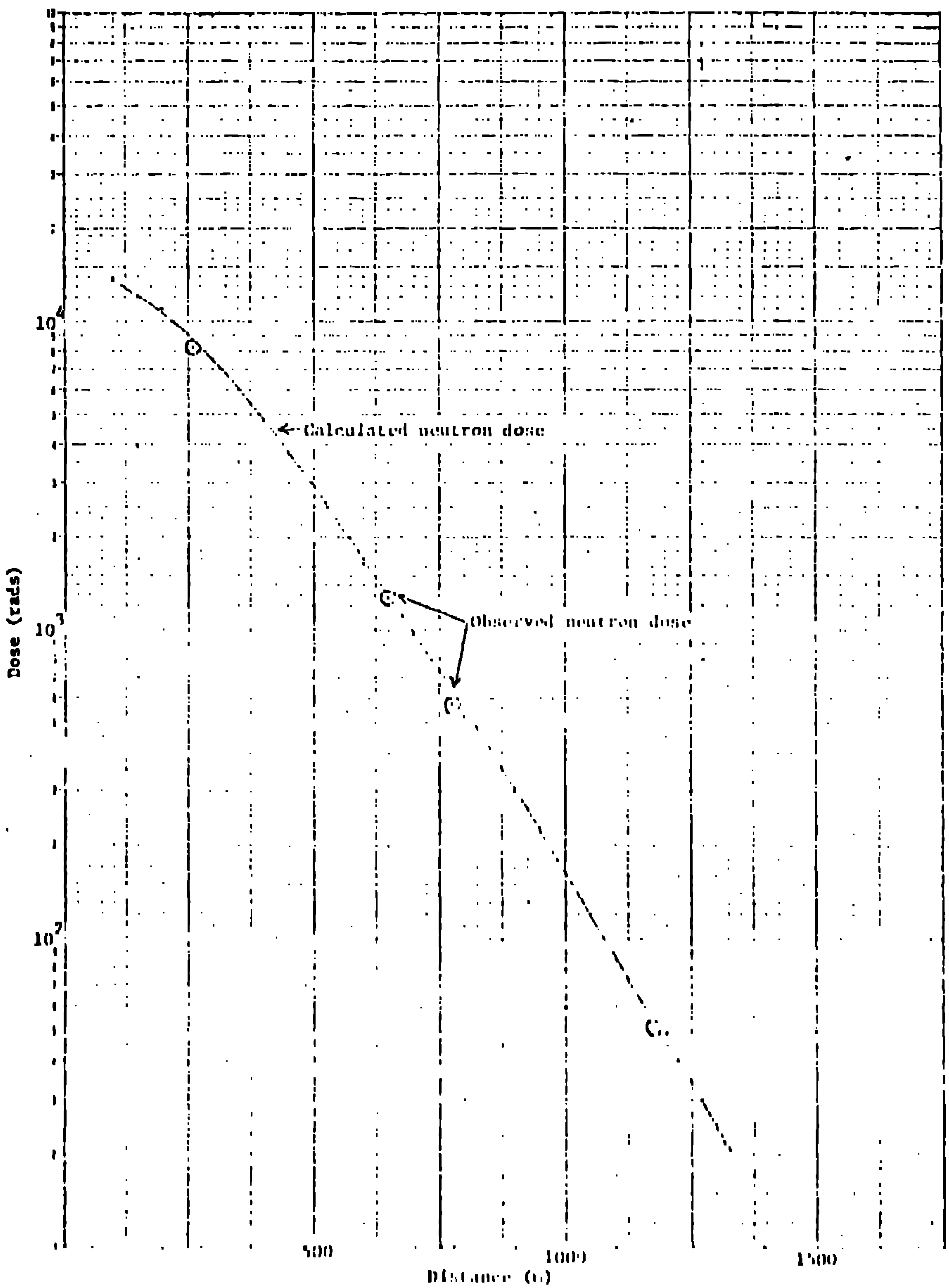


Fig. 1. Air dose due to neutron radiation in Hiroshima as a function of horizontal distance from ground zero.

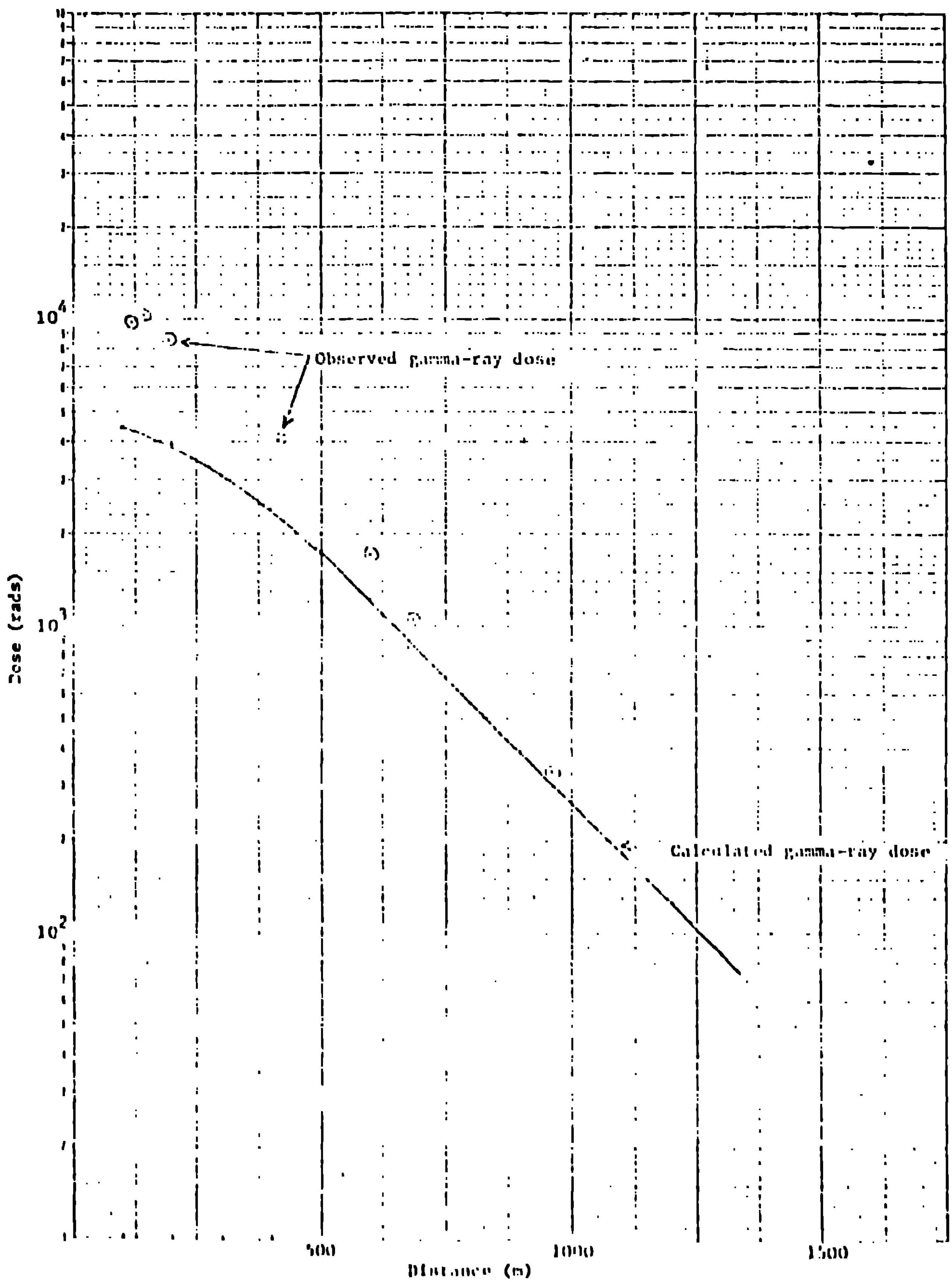


Fig. 2. Air dose due to gamma-ray radiation in Hiroshima as a function of horizontal distance from ground zero.

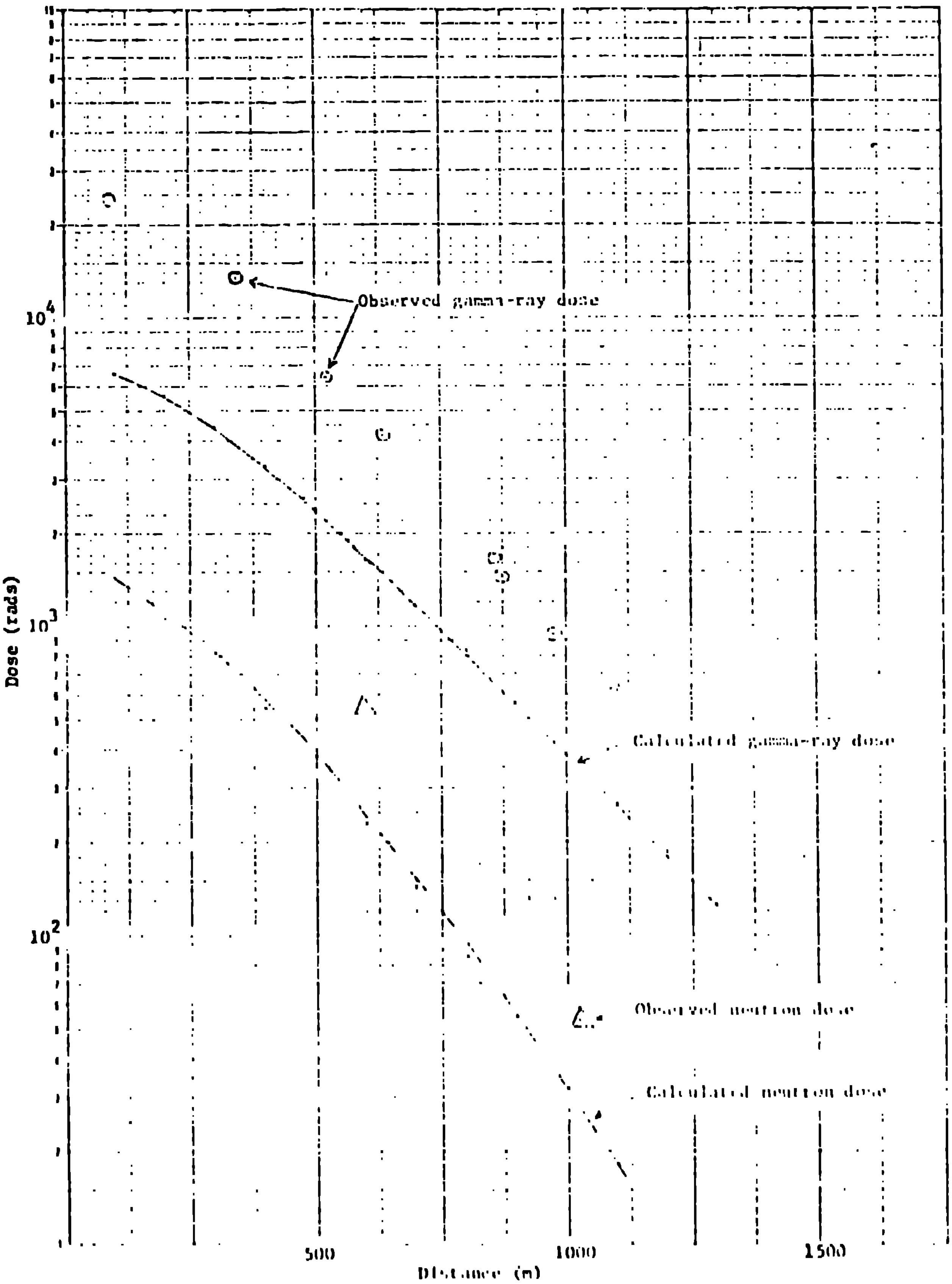


Fig. 3. Air dose due to neutron and gamma-ray radiation in Nagasaki as a function of horizontal distance from ground zero.

There are several possible explanations for these discrepancies. The Fat Man device (Nagasaki) had a very large output of low-energy neutrons. The transport of these neutrons and the resulting gamma-ray production in the air involves times which are comparable with the time for fireball growth. The effect of the fireball growth was not considered in the calculations. Another possibility is that the yield of Little Boy (Hiroshima) was considerably less than calculated, as suggested in some of the references in Table I. This would result in both calculations being lower than the observed values which would suggest an error in the conservation factors of activation to dose or neutron flux to dose. Finally, there is some question of the height of burst for Fat Man. These calculations assumed that it was 580 m. If the height of burst was only 500 m, the observed and calculated doses would be in much better agreement.

These discrepancies can probably be resolved. John Malik (J-DOT, LASL) has mentioned to me that other dose measurements exist on devices that were either the same or very similar to the Fat Man. By comparing these measurements with our calculations, we could determine if the Nagasaki comparisons are accurate and hence whether the Hiroshima comparisons are valid at the calculated yield.

I hope this information will be useful to you.

Sincerely yours,

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