MASTER

REVIEW OF DOSIMETRY FOR THE ATOMIC BOMB SURVIVORS*

G. D. Kerr, Health and Safety Research Division, Oak Ridge National Laboratory, Oak Ridge, TN 37830, USA

CONF-810673--1

Abstract: An up-to-date review of dosimetry for the atomic bomb survivors was recently requested by the National Council on Radiation Protection through the U.S. Department of Energy. The impetus for their request was a 1976 letter by W. E. Preeg concerning the neutron output of the weapons dropped in Japan and a 1978 report by H. H. Rossi and C. W. Mays concerning the incidence of leukemia and other cancers in the atomic bomb survivors. A primary purpose of the review was to determine if the large leukemia risk found by Rossi and Mays at low neutron exposure levels in Hiroshima was real or if it was the result of a bias in the current T65D system of dosimetry for the atomic bomb survivors. The possibility of a bias existed because the Nagasaki and Hiroshima weapons were of radically different design and construction.

Results of calculations which provided more detail than previously available on the output and spectra of neutrons from the weapons were circulated in the 1976 letter by Preeg of the Los Alamos National Laboratory. Included in this letter were results of additional calculations of neutron penetration in an infinite air medium which predicted significantly less neutron exposure in Hiroshima than the T65D estimates used by Rossi and Mays. This was also found to be the case in more realistic air-over-ground calculations in 1977 by D. C. Kaul and R. Jarka of Science Applications, Inc., and by J. V. Pace of the Oak Ridge National Laboratory. It now appears that there is a significant bias in the T65D estimates of neutron exposure to Hiroshima survivors based on extensive investigations of available theoretical and experimental data on both the neutron output of the weapon and the neutron field in Hiroshima.

This paper summarizes and discusses results of some 1980-1981 studies of neutron and γ-ray exposure to the atomic bomb survivors by W. E. Loewe and E. Mendelsohn of the Lawrence Livermore National Laboratory, D. C. Kaul and W. H. Scott of Science Applications, Inc., and J. V. Pace of the Oak Ridge National Laboratory. Some other special studies which are now underway to complete the review will also be discussed. The expert assistance of others in these special studies is being supported in part by the U.S. Department of Energy and in part by the U.S. Defense Nuclear Agency.

INTRODUCTION

The epidemiological studies of the atomic bomb survivors by the Radiation Effects Research Foundation (RERF), formerly the Atomic Bomb Casualty Commission (ABCC), are the most extensive source of human data on the late effects of radiation exposure. Due to the importance attached to these data in the assessment of radiation exposure risks, an up-to-date review of the dosimetry for the atomic bomb survivors was requested recently by the National Council on Radiation Protection (NCRP) through the U.S. Department of Energy. The expert assistance of others in the review has been provided at the request of the NCRP by

*Research sponsored by the Office of Energy Research, U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

both the U.S. Department of Energy (DOE) and the U.S. Defense Nuclear Agency (DNA).

A primary objective of the review was to determine if the large leukemia risk found by Rossi and Mays (1) at low exposure levels in Hiroshima was real or if it was a result of a bias in the current T65D system of dosimetry for the atomic bomb survivors (2). The possibility of a bias existed because the two weapons dropped in Japan were of radically different design and construction. The Nagasaki weapon, code named Fat Man, was a massive implosion-type device, and the Hiroshima weapon, code named Little Boy, was a massive gun-assembly device. The Little Boy Device was the only one of its particular construction ever fired. Numerous Fat Man implosion-type devices were fired during early weapon tests, and results from the most appropriate tests indicated that the energy yield of the Nagasaki weapon was equivalent to 22 kton ±10%.

Most of the atomic-bomb survivors were exposed inside Japanese houses and the uniformity of their construction made a definite dosimetry study feasible. The current radiation-exposure estimates for survivors take into account a survivor's shielding against radiation from the weapon by surrounding structures primarily through the house shielding factors developed by Cheka et al. (3) and a survivor's distance from ground zero through the tissue kerma vs distance relationships developed by Auxier et al. (4). These estimates are designated T65D (or Tentative 1965 Doses). In the case of the Nagasaki weapon, some radiation-exposure data were available from weapon tests. No similar data exist in the case of the Hiroshima weapon, and the tissue kerma vs distance relationships were constructed using data from several of the most nearly appropriate weapon tests and data from reactor experiments. One reactor experiment at the Los Alamos National Laboratory (LANL) using the Ichiban Critical Assembly provided data on the neutron output of Little Boy, and another reactor experiment at the Nevada Test Site (NTS) using the ORNL Health Physics Research Reactor (HPRR) provided data on the penetration of neutrons in air-over-ground. The resulting tissue kerma vs distance relationships were normalized to an estimated energy yield for the Hiroshima weapon of 12.5 kton ±10%.

The T65D tissue kerma vs distance relationships were found to agree in general with results of independent studies reported in 1967 by Hashizume et al. (5) of the Japanese National Institute of Radiological Sciences (JNIRS) and in 1966 by Ichikawa et al. (6) of the University of Kyoto, Japan. The γ-ray exposure at various ground distances in both Hiroshima and Nagasaki were estimated by Ichikawa et al. from thermoluminescent measurements using the crystalline component of roof tiles. Some rather large uncertainties were involved in the distance estimates of their study. Since roof tiles were only used on Japanese houses and all houses close to ground zero were destroyed, the exact location of each roof tile at the time of explosion (ATE) was in doubt (5). The estimates of γ-ray and neutron exposure from the JNIRS study by Hashizume et al. were derived from measurements of the γ-ray induced thermoluminescence in decorative-tile and brick samples and the neutron induced ^{60}Co radioactivity in steel reinforcing-rod samples taken from buildings that had been repaired and used for a number of years after the bombings. Thus, the exact location of each sample ATE was well known, and the uncertainty in the ground distance was miminized. The JNIRS study tended to confirm the T65D study by Auxier et al. (2), and the T65D estimates of radiation exposure to survivors were used with a great deal of confidence until recently.

RESULTS OF RECENT STUDIES

Theoretical data which provided more detail than previously available on the output and spectra of neutrons from Little Boy and Fat Man were circulated in a 1976 letter by W. E. Preeg of LANL (7). In the case of Fat Man, there were no experimental neutron-output data that could be compared directly with Preeg's theoretical data. However, excellent agreement was found between Preeg's theoretical data and experimental neutron-output data from measurements using the Ichiban Critical Assembly which had nuclear characteristics similar to Little Boy (8).

Included in the 1976 letter by Preeg (7) were results of additional calculations of neutron penetration in an infinite air medium that predicted significantly less neutron exposure per unit energy yield of Little Boy than the T65D estimates. This was also found to be the case in more realistic air-over-ground calculations in 1977 by J. V. Pace (9) of the Oak Ridge National Laboratory (ORNL) and by D. C. Kaul and R. Jarka (10) of Science Applications, Inc. (SAI). Some troublesome discrepancies existed in the air-over-ground calculations, however. It was shown in 1979 by Pace (11) that the moisture content of the air was an extremely important parameter (see Fig. 1). Kaul and Jarka had used a dry NTS-type air in their 1977 calculations, while Pace in his 1977 calculations had used a moist air composition derived from data on atmospheric conditions existing in Hiroshima ATE.

The LANL neutron-output and ORNL air-transport calculations were further substantiated in a 1980 study by Kerr (12) using sulfur activation data from early tests of Fat Man devices and from Japanese studies made immediately after the bombings in 1945. The Japanese data came from measurements of fast-neutron induced ^{32}P radioactivity in pure sulfur used as an adhesive material in binding the metallic holders to the porcelain insulators on utility poles (13). These various experimental data on sulfur activation were found to be in good agreement with theoretical values based on results of Pace's 1977 calculations except at smaller ground distances in Hiroshima (see Fig. 2). It was later determined that this was probably due to the spherical mockup of Little Boy used by Preeg and his calculated one-dimensional neutron output (i.e., 1-D neutron output)(14). The 1-D neutron-output approximation becomes less important at the larger ground distances since neutron scattering in air will tend to mask any initial anisotropy in the actual neutron output of the cylindrically symmetrical Little Boy device.

The JNIRS estimates of neutron exposure were based on the fast-neutron induced ^{60}Co radioactivity in a steel sample embedded at a depth of 8 cm in a concrete wall facing ground zero. To convert the measured ^{60}Co activation to tissue kerma from fast neutrons, Hashizume et al. (5) used the HPRR output spectrum which provides a mean tissue kerma of about 2.5×10^{-11} Gy per n cm^{-2} from fast neutrons having energies greater than 1 keV. Since Pace's 1977 calculations indicated a mean tissue kerma in Hiroshima of about 1.0×10^{-11} Gy per n cm^{-2} from fast neutrons having energies greater than 1 keV, the JNIRS estimates of neutron exposure in Hiroshima should be high by a factor of two and one-half or more (13). It was discovered before a more detailed study of the JNIRS ^{60}Co-activation data was started at ORNL that a study of these data was also being conducted at the Lawrence Livermore National Laboratory (LLNL). A revised JNIRS value of about 0.11 Gy at a ground distance of 1180 m in Hiroshima compared to the original JNIRS value of 0.51 Gy (see

Fig. 3) was eventually obtained in some 1980 calculations by W. E. Loewe and E. Mendelsohn (15).

Calculations of the weapon radiation fields in air-over-ground at the large distances of interest demanded the use of both a computer code employing discrete ordinate transport (DOT) techniques and a relatively small set of coupled neutron and γ-ray interaction cross sections. One such set, developed by ORNL at the request of DNA for general use in modern nuclear weapon calculations, consists of 37 neutron and 22 γ-ray groups (16). It employs a 300°K Maxwellian weighting spectrum for the thermal neutron group and a 1/E weighting spectrum for all other higher-energy neutron groups. This cross-section set was used in Pace's 1977 calculations for Little Boy and Fat Man. The 1980 calculations by Loewe and Mendelsohn of LLNL suggested that this ORNL 37 neutron-group set overestimated the neutron exposure in the case of the unusually soft output spectrum of fast neutrons from the Little Boy device.

Updated 1981 calculations by Pace of ORNL (17) and Kaul of SAI (18) using revised neutron cross-section sets are shown in Figs. 3 and 4. These 1981 calculations by Kaul also use an air composition typical of that existing in each of the two cities ATE rather than the dry NTS-type air of his 1977 calculations (8). Note that there is only a small difference between Pace's 1977 and 1981 calculations of the neutron exposure in Nagasaki from the Fat Man device. The results of the 1980-1981 calculations by SAI (18), ORNL (17), and LLNL (15) which used different neutron-groups and cross-section data but similar calculation techniques are all in close agreement with regard to the neutron exposure in Hiroshima from Little Boy.

The DOT calculations using Preeg's neutron (and γ-ray) output give the radiation exposure to neutron and γ-rays from the weapon and to neutron capture γ-rays produced in air and in ground. To these radiation components, one must add the radiation exposure to γ-rays emitted by the decay of fission products in the fireball formed after the explosion. These latter calculations are quite complex due to the shock-wave enhancement of the fireball γ-ray field, the rise of the fireball, and the rapid decay of fission products in the fireball. The relative source strength of the γ-rays from the various fissionable isotopes of uranium and plutonium also appears to be an important parameter that has not been considered in a number of recent calculations including those by L. G. Mooney and R. L. French (19).

A 1978 review of data related to the dosimetry for the atomic bomb survivors by J. Marcum of R & D Associates pointed out that γ-rays from the fission products of the three isotopes, ^{235}U, ^{239}Pu, and ^{238}U, have relative source strengths of about 1.00, 0.67, and 1.75 (20). The Little Boy was all ^{235}U, while Fat Man, according to both Preeg and Marcum, had about 80% of its fissions from ^{239}Pu and 20% from ^{238}U. If ^{235}U is used as a standard, then Fat Man would have a relative source strength of about 0.88 (20). These source values are reflected in an important way in the calculated γ-ray exposure since the fireball γ-ray component is comparable to that from γ-rays produced by neutron interactions in air and ground.

A study to better model the fireball γ-ray field of a nuclear weapon was undertaken in 1980 by W. H. Scott of SAI (21), and he concluded that comparisons with the best available weapon test data were improved when the time-dependent γ-ray decay spectra of the various fissionable isotopes of uranium and plutonium were included in the calculations. The agreement between measured and calculated values was within 10 to

20% when the appropriate isotopic time-dependent sources for a weapon were incorporated in the NUIDEA code of SAI (22) which uses the so-called LAMB shock-enhancement and fireball-rise model (23). One important finding of Scott's 1980 study was that the data in DNA Effects Manual No. 1 (or EM-1) (24) and the 1977 edition of The Effects of Nuclear Weapons (25) overestimates the radiation exposure from the fireball γ-ray field of Little Boy and Fat Man by factors of two or more.

Values for the γ-ray exposure to Hiroshima and Nagasaki survivors obtained by summing results of best state-of-the-art calculations by Scott of SAI (21) and Pace of ORNL (17) are shown in Figs. 5 and 6. Energy yields and burst heights of 22 kton and 503 m were used for the Nagasaki explosion, and 12.5 kton and 580 m for the Hiroshima explosion. Note that the calculated values and the experimental JNIRS values, which for reasons discussed earlier are usually considered to be the more reliable of the two Japanese-data sets, agree to within ± 10% in Hiroshima. The overall agreement is not as good in Nagasaki where a difference of about 20% is observed between the experimental JNIRS values and the calculated values at a ground distance of about 1000 m. Some sensitivity studies, which are planned to set limits of precision on the calculated values, may help to resolve the reasons for the larger observed difference in Nagasaki.

The results of the 1980-1981 calculations by Pace (17) and Scott (21) are further compared in Figs. 7 and 8 with the T65D values for the two cities. Some of the difference between the calculated and T65D values can be attributed to moisture content in the air. A simple Zerby-type scaling (26) from one atmospheric density to another is not valid when very dry NTS-type air and very humid air in the Japanese cities ATE are involved.

The most important different between the two sets of neutron values (calculated vs T65D) for Hiroshima can be attributed to the fact that the neutron-output spectrum of Little Boy was much softer or less energetic than the neutron-output spectrum of the HPRR used in constructing the T65D tissue kerma vs distance relationship. Neutrons from the HPRR were simply not attenuated by the atmosphere as rapidly as neutrons from Little Boy. Data from the HPRR studies were also used in constructing the T65D tissue kerma vs distance relationship for γ-rays in Hiroshima. The extrapolation of the neutron-capture γ-ray measurements made within a distance of about 1200 m from the HPRR to larger distances in Hiroshima appears to account for most, if not all, of the observed differences between the T65D and calculated values for the γ-ray exposure (20).

The T65D tissue kerma vs distance relationship for γ-rays in Nagasaki are based on LANL film measurements made during a test firing of a Fat Man implosion-type device. Simultaneous film measurements made during later weapon tests by the Evans Signal Laboratory (ESL) and LANL (26) and laboratory studies by LANL (27) indicated that their film measurements overestimated the γ-ray exposure with the degree of overestimation varying with distance. This is a moot issue since the T65D values came from a test firing of a Fat Man imposion-type device which had a core and tamper that were quite different from those of the Nagasaki weapon. One cannot assume based on present knowledge that either the γ-ray or neutron source values of these two devices were the same.

DISCUSSION

A reanalysis of the data on leukemia among the atomic bomb survivors was published by Loewe and Mendelsohn of LLNL in 1980 (15). They simply replaced the T65D tissue kerma vs distance values of the Rossi and Mays study (see Fig. 9) with radiation-exposure values obtained by summing data from their DOT calculations and data on the fireball γ-ray field from EM-1. The LLNL results (see Fig. 9) suggested that there was no longer any evidence of a neutron effect in Hiroshima. However, Loewe and Mendelsohn (15) state that they had reason to believe that the data from EM-1 underestimated the γ-ray exposure from the decay of fission products in the fireball of the weapons. Their view is contrary to the findings of Scott's 1980 study (21) which clearly demonstrated that the data from EM-1 grossly overestimates the fireball γ-ray fields of the Hiroshima and Nagasaki weapons.

If the radiation-exposure values obtained from the 1980-1981 calculations by Scott of SAI (21) and Pace of ORNL (17) are used, then the correlation between leukemia incidence among the survivors and absorbed dose to the active marrow of the survivors in the two cities is not as good as that obtained by Loewe and Mendelsohn (15). The results of any reanalysis of data on observed biological effects in the survivors should be regarded as highly tentative until the following side issues have been investigated in more detail.

1. Organ dose factors. The T65D assignments for survivors which take into account a survivor's distance from ground zero and shielding by surrounding structures are specified in terms of tissue kerma in air. Factors from studies by T. D. Jones (29) and by G. D. Kerr (30) for converting these tissue kerma assignments to an absorbed dose in an organ of a survivor should be updated using data from the newer calculations of energy and angular distributions for the neutron and γ-ray fields in the open and inside a Japanese house.

2. Shielding factors for Japanese houses. The radiation exposure to survivors located inside houses has been estimated using the "9-parameter formulas" developed by Cheka et al. (3). An investigation of a large number of actual house-shielding cases by R. C. Milton and T. Shohoji (31) indicated that typical shielding factors (or transmission factors) for γ-rays and neutrons were about 0.90 and 0.31 in Hiroshima and about 0.81 and 0.35 in Nagasaki. It has been recently suggested by J. Marcum of RDA (32) that the house shielding factors for γ-rays were probably more like 0.55 in Hiroshima and 0.50 in Nagasaki.

3. Energy yield of Hiroshima weapon. The energy yield used in the T65D study by Auxier et al. (2) was 12.5 kton, and the probable error was later estimated (4) to be ±10% (or about 1 kton). It has recently been suggested by J. Malik of LANL (33) that the energy yield was 15 ±2 kton. A probable error greater than 1 kton in the T65D value is clearly indicated by Malik's reanalysis of data related to the energy yield of the weapon. His findings do not appear sufficient at present to warrant changing the estimated yield to 15 ktons, however.

4. Neutron output of Little Boy. The gun-type device was cylindrically symmetrical, and Preeg of LANL knew that the 1-D calculation was approximate, but he thought in view of time and effort constraints that it would sufficient (20). A cylindrical mockup of Little Boy and a 2-D calculation of the energy and angular distributions of the neutron output is needed to establish the neutron field and the neutron exposure in Hiroshima more precisely.

ACKNOWLEDGEMENTS

The author wishes to thank the following individuals who have in some cases offered constructive criticism and in some cases graciously provided unpublished data used in writing this paper.

David Auton, Defense Nuclear Agency, Alexandria, VA
D. E. Bartine, Oak Ridge National Laboratory, Oak Ridge, TN
D. C. Kaul, Science Applications, Inc., Schaumburg, IL
John Malik, Los Alamos National Laboratory, Los Alamos, NM
Jess Marcum, R & D Associates, Marina del Rey, CA
J. V. Pace, III, Oak Ridge National Laboratory, Oak Ridge, TN
W. H. Scott, Jr., Science Applications, Inc., La Jolla, CA
P. S. Whalen, Los Alamos National Laboratory, Los Alamos, CA

REFERENCES*

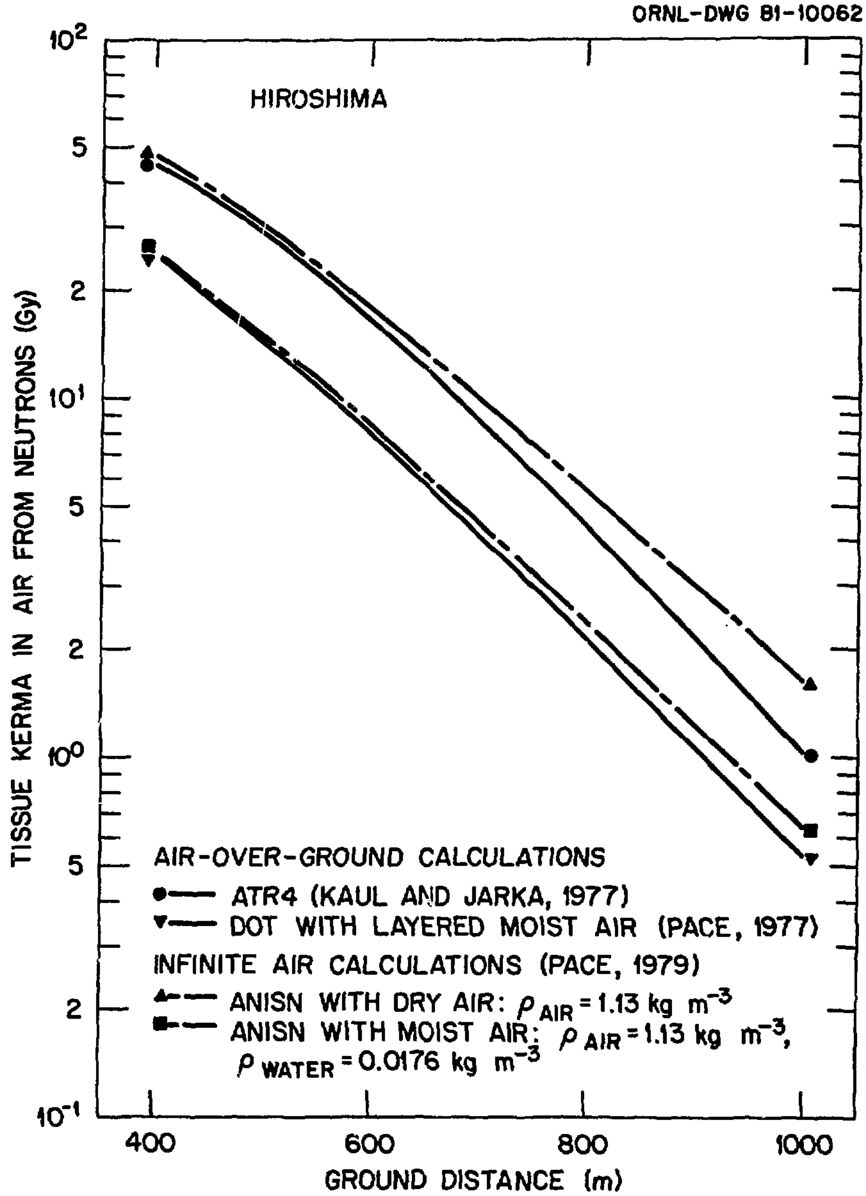
(1) H. H. Rossi and C. W. Mays, Health Phys. 34, 353 (1969).
(2) J. A. Auxier, J. S. Cheka, F. F. Haywood, T. D. Jones and J. H. Thorngate, Health Phys. 12, 425 (1966).
(3) J. S. Cheka, F. W. Sanders, T. D. Jones, and W. H. Shinpaugh, CEX-62.11 (August 1965).
(4) J. A. Auxier, Ichiban: Radiation Dosimetry for the Survivors of the Bombings of Hiroshima and Nagasaki (Oak Ridge, TN: Tech. Info. Center, 1977).
(5) T. Hashizume, T. Maruyama, A. Shiragai, E. Tanaka, M. Izawa, S. Kawamura, and S. Nagaoka, Health Phys. 13, 149 (1967).
(6) Y. Ichikawa, T. Higashimura, and T. Sidei, Health Phys. 12, 395 (1966).
(7) W. E. Preeg, LASL Letter to C. P. Knowles, RDA (April 5, 1976).
(8) G. D. Kerr, ORNL Letter to C. W. Edington, DOE (November 19, 1979).
(9) J. V. Pace, ORNL Memorandum to G. D. Kerr (March 4, 1977).
(10) D. C. Kaul and R. Jarka, DNA 4442-F (October 1977).
(11) J. V. Pace, ORNL Letter to J. Marcum, RDA (December 12, 1979).
(12) G. D. Kerr, ORNL Letter to C. W. Edington, DOE (August 18, 1980).
(13) N. Pace and R. E. Smith, ABCC TR 26-59 (1959).
(14) G. D. Kerr, ORNL Letter to C. W. Edington, DOE (October 8, 1980).
(15) W. E. Loewe and E. Mendelsohn, LLNL D-80-14 (September 1980).
(16) D. E. Bartine, J. R. Knight, J. V. Pace, and R. Roussin, ORNL/TM-4840 (March 1977).
(17) J. V. Pace, Personal Communications (April 1981).
(18) D. C. Kaul, SAI Letter to G. D. Kerr, ORNL (March 4, 1981).
(19) L. G. Mooney and R. L. French, ORNL-RSIC-33 (D. K. Trubey and H. E. Comolander, Eds.) pp. 251-277 (May 1972).
(20) J. Marcum, RDA-IR-110004-001 (December 1978).
(21) W. H. Scott, Jr., SAI Letter to G. D. Kerr, ORNL (May 5, 1981).
(22) E. A. Straker and L. Husar, DNA 0001-76-C-0085 (November 1976).
(23) C. E. Needham and L. A. Wittmer, AFWL-DYT-TN-75-2 (1975).
(24) Effects Manual No. 1, DNA EM-1 (July 1972).
(25) S. Glasstone and P. J. Dolan (Eds.), The Effects of Nuclear Weapons (Washington, D.C.: U.S. Govt. Print. Off. 1977).

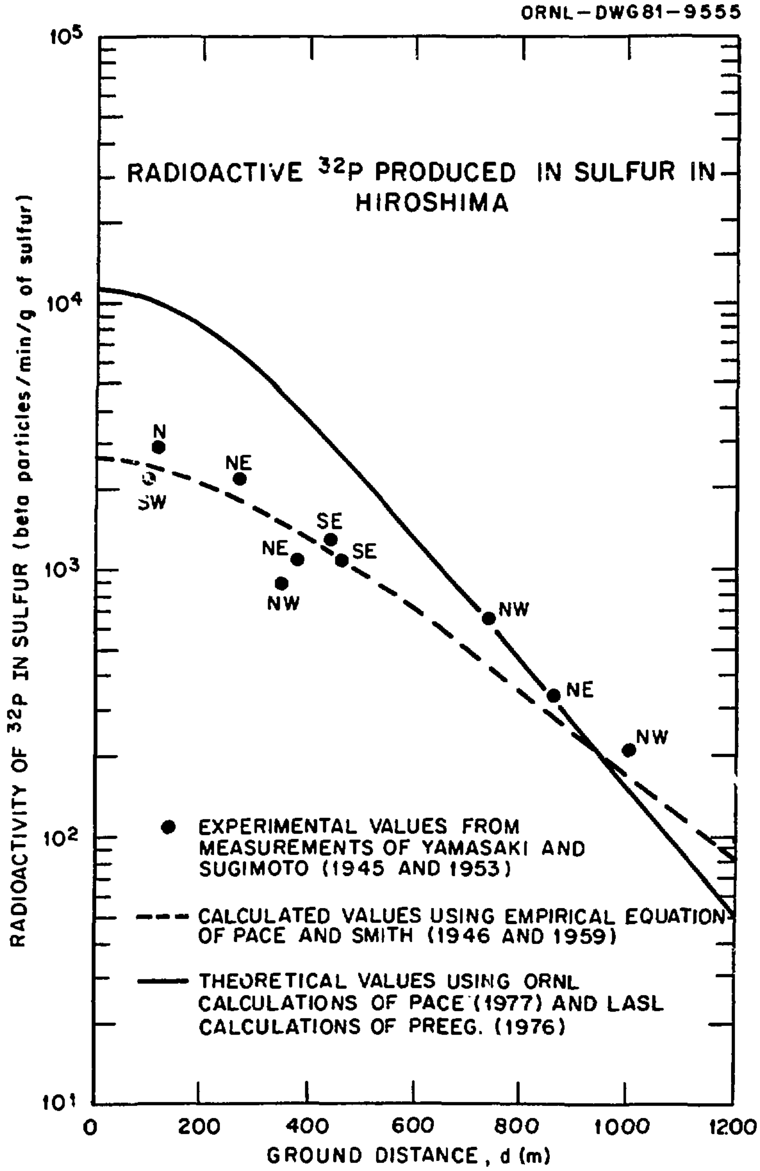
*Some of these references are not generally available since they contain either confidential or secret-restricted data on nuclear weapons.

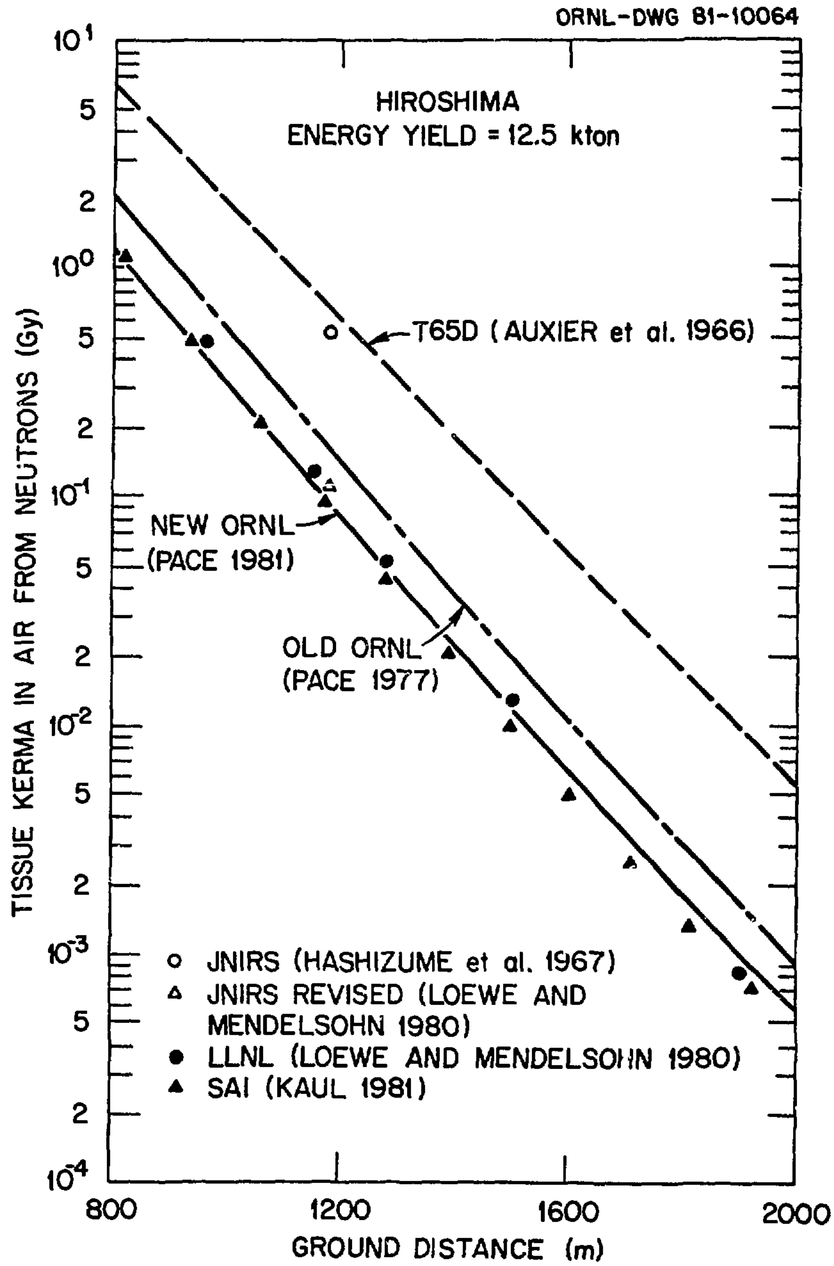
(26) C. D. Zerby, ORNL-2000 (October 1956).
(27) Nuclear Radiation Handbook, AFSWP 1100 (March 1957).
(28) E. Storm and E. Bennis, WT-1208 (October 1955).
(29) T. D. Jones, Rad. Res. 71, 269 (1977).
(30) G. D. Kerr, Health Phys. 37, 487 (1979).
(31) R. C. Milton and T. Shohoji, ABCC TR 1-68 (1968).
(32) J. Marcum, RDA Letter to G. D. Kerr, ORNL (May 15, 1981).
(33) J. Malik, LASL Letter to G. D. Kerr (September 2, 1980).

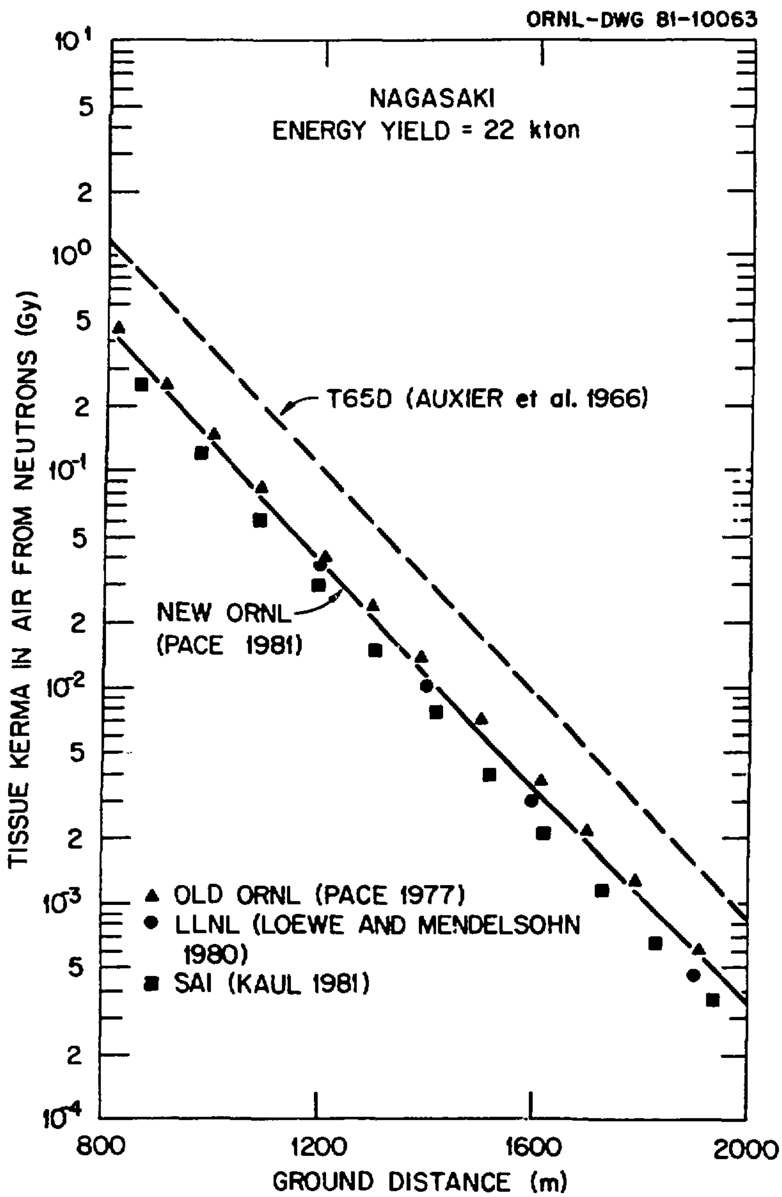
FIGURE LISTING

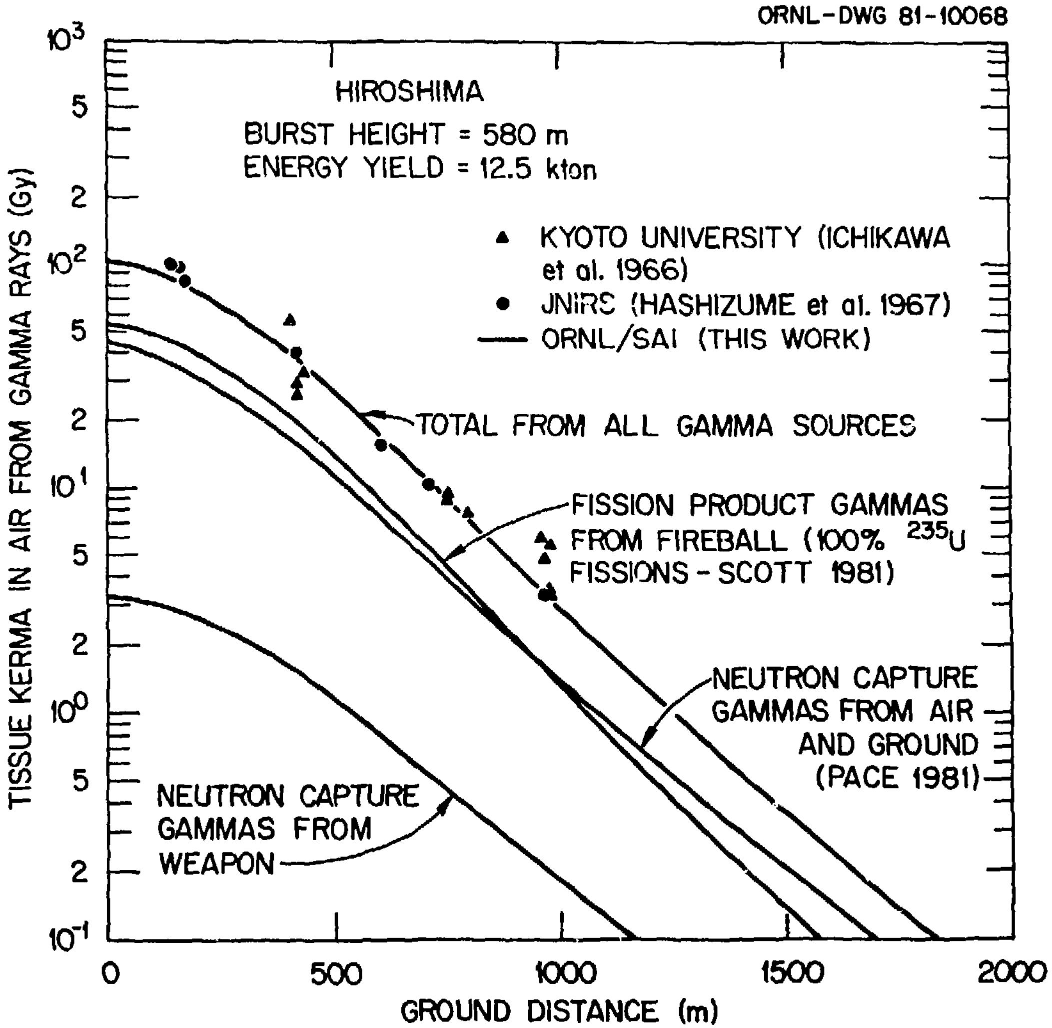
ORNL-DWG 81-10062



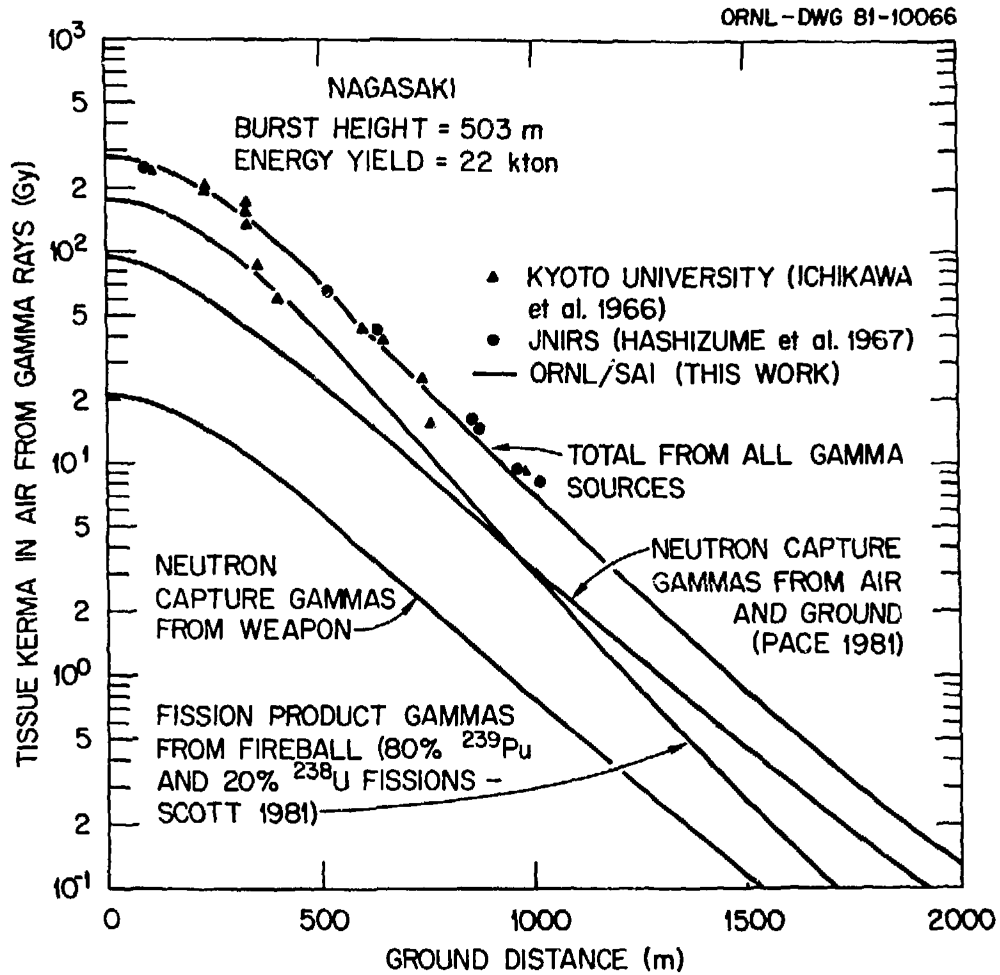

ORNL—DWG81—9555
RADIOACTIVE 32P PRODUCED IN SULFUR IN HIROSHIMA
RADIOACTIVITY OF 32P IN SULFUR (beta particles/min/g of sulfur)
GROUND DISTANCE, d (m)
10^5
10^4
10^3
10^2
10^1
0
200
400
600
800
1000
1200
N
SW
NE
SE
NE
SE
NW
NW
NE
NW
EXPERIMENTAL VALUES FROM MEASUREMENTS OF YAMASAKI AND SUGIMOTO (1945 AND 1953)
CALCULATED VALUES USING EMPIRICAL EQUATION OF PACE AND SMITH (1946 AND 1959)
THEORETICAL VALUES USING ORNL CALCULATIONS OF PACE (1977) AND LASL CALCULATIONS OF PREEG. (1976)

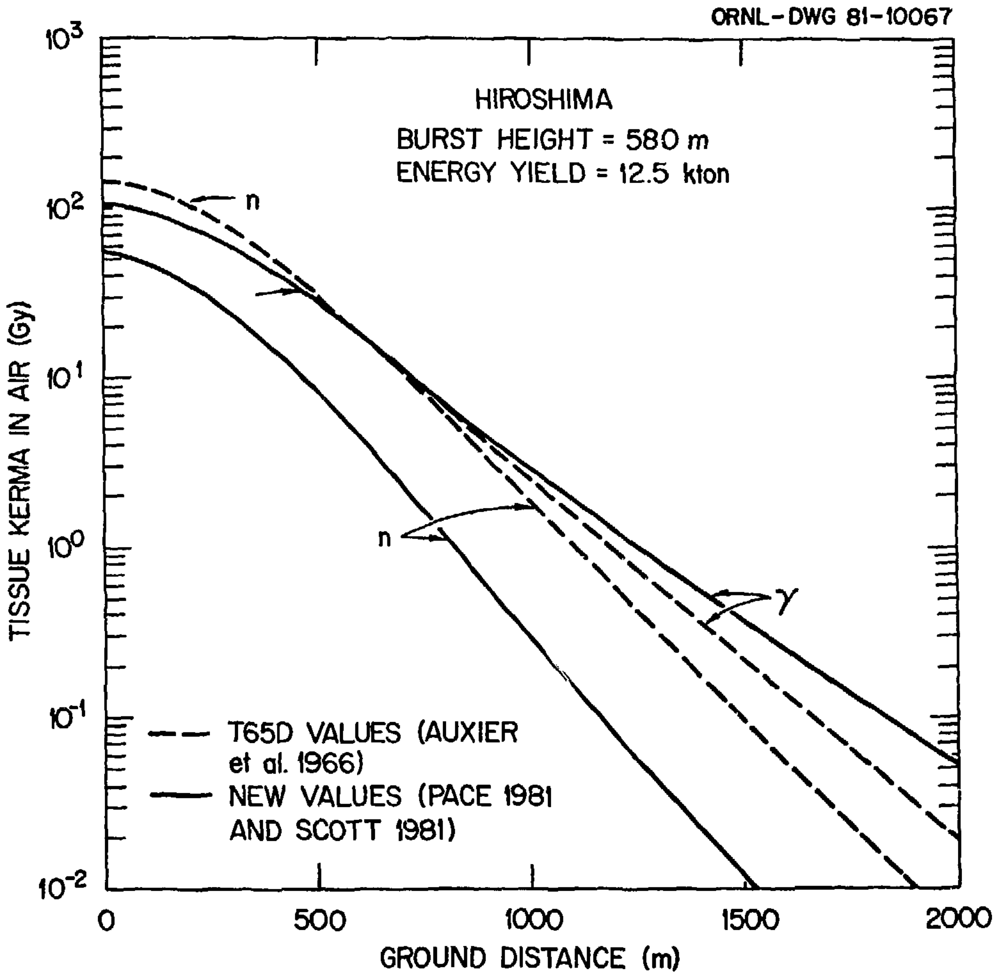

ORNL-DWG 81-10064
HIROSHIMA
ENERGY YIELD = 12.5 kton
T65D (AUXIER et al. 1966)
NEW ORNL
(PACE 1981)
OLD ORNL
(PACE 1977)
JNIRS (HASHIZUME et al. 1967)
JNIRS REVISED (LOEWE AND MENDELSOHN 1980)
LLNL (LOEWE AND MENDELSOHN 1980)
SAI (KAUL 1981)
TISSUE KERMA IN AIR FROM NEUTRONS (Gy)
GROUND DISTANCE (m)
800
1200
1600
2000
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}

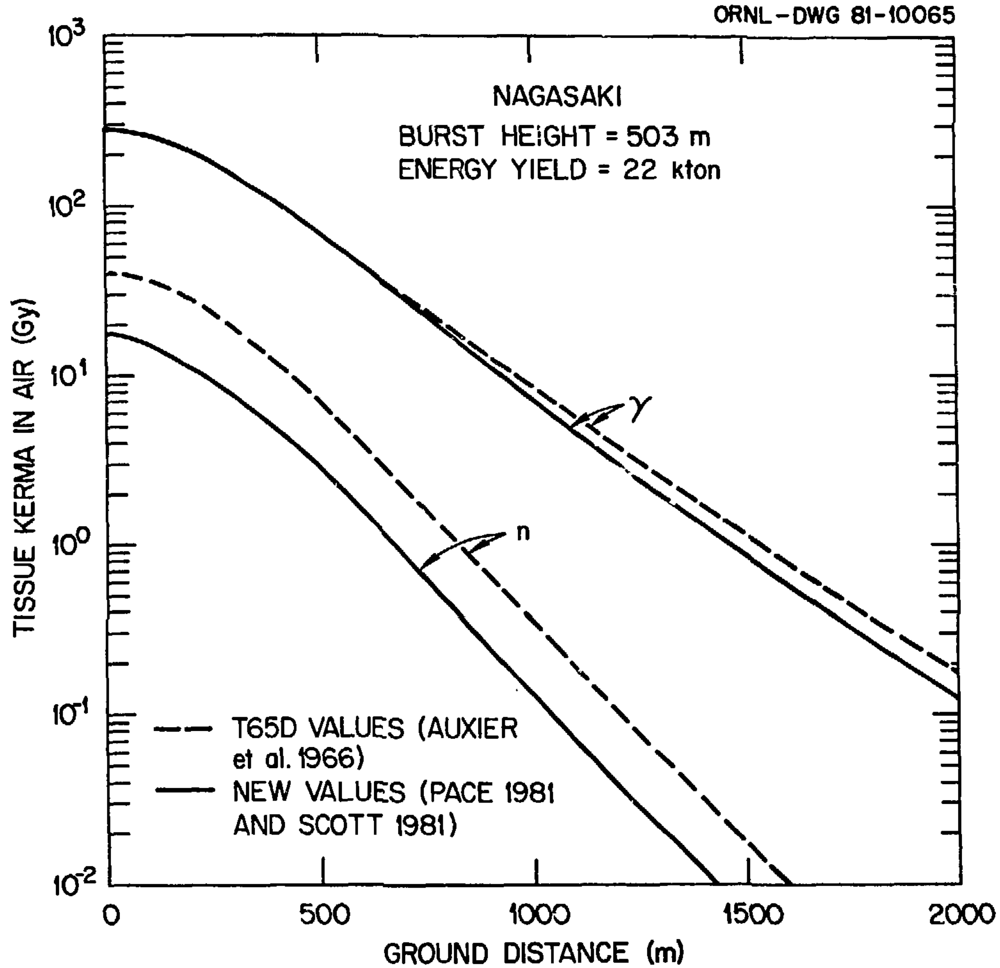

ORNL-DWG 81-10063
NAGASAKI
ENERGY YIELD = 22 kton
T65D (AUXIER et al. 1966)
NEW ORNL
(PACE 1981)
OLD ORNL (PACE 1977)
LLNL (LOEWE AND MENDELSOHN 1980)
SAI (KAUL 1981)
TISSUE KERMA IN AIR FROM NEUTRONS (Gy)
GROUND DISTANCE (m)
800
1200
1600
2000



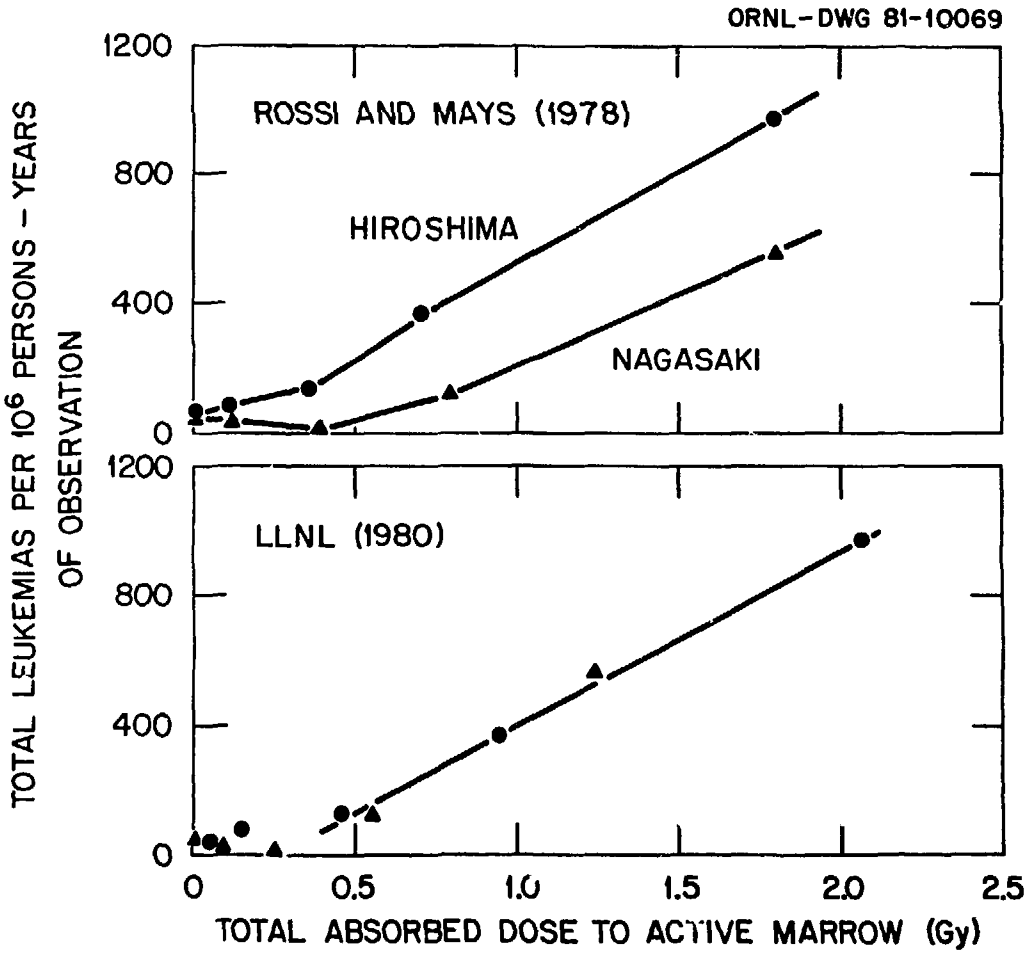
ORNL-DWG 81-10068
HIROSHIMA
BURST HEIGHT = 580 m
ENERGY YIELD = 12.5 kton
KYOTO UNIVERSITY (ICHIKAWA et al. 1966)
JNIRS (HASHIZUME et al. 1967)
ORNL/SAI (THIS WORK)
TOTAL FROM ALL GAMMA SOURCES
FISSION PRODUCT GAMMAS FROM FIREBALL (100% 235U FISSIONS - SCOTT 1981)
NEUTRON CAPTURE GAMMAS FROM AIR AND GROUND (PACE 1981)
NEUTRON CAPTURE GAMMAS FROM WEAPON
TISSUE KERMA IN AIR FROM GAMMA RAYS (Gy)
GROUND DISTANCE (m)


ORNL-DWG 81-10066
NAGASAKI
BURST HEIGHT = 503 m
ENERGY YIELD = 22 kton
KYOTO UNIVERSITY (ICHIKAWA et al. 1966)
JNIRS (HASHIZUME et al. 1967)
ORNL/SAI (THIS WORK)
TOTAL FROM ALL GAMMA SOURCES
NEUTRON CAPTURE GAMMAS FROM AIR AND GROUND (PACE 1981)
NEUTRON CAPTURE GAMMAS FROM WEAPON
FISSION PRODUCT GAMMAS FROM FIREBALL (80% 239Pu AND 20% 238U FISSIONS - SCOTT 1981)
TISSUE KERMA IN AIR FROM GAMMA RAYS (Gy)
GROUND DISTANCE (m)


ORNL-DWG 81-10067
HIROSHIMA
BURST HEIGHT = 580 m
ENERGY YIELD = 12.5 kton
TISSUE KERMA IN AIR (Gy)
GROUND DISTANCE (m)
n
n
γ
T65D VALUES (AUXIER et al. 1966)
NEW VALUES (PACE 1981 AND SCOTT 1981)
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
0
500
1000
1500
2000



ORNL-DWG 81-10065
NAGASAKI
BURST HEIGHT = 503 m
ENERGY YIELD = 22 kton
γ
n
T65D VALUES (AUXIER et al. 1966)
NEW VALUES (PACE 1981 AND SCOTT 1981)
TISSUE KERMA IN AIR (Gy)
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
0
500
1000
1500
2000
GROUND DISTANCE (m)


ORNL-DWG 81-10069
ROSSI AND MAYS (1978)
HIROSHIMA
NAGASAKI
LLNL (1980)
TOTAL LEUKEMIAS PER 10^6 PERSONS - YEARS OF OBSERVATION
TOTAL ABSORBED DOSE TO ACTIVE MARROW (Gy)
0
400
800
1200
0
0.5
1.0
1.5
2.0
2.5