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Report of Liaison Studies with the Atomic Bomb Casualty Commission—Hiroshima, Japan August 20, 1974 to September 17, 1974

G. D. Kerr

MASTER

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REPORT OF LIAISON STUDIES WITH THE ATOMIC BOMB CASUALTY COMMISSION - HIROSHIMA, JAPAN

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Summary

The liaison studies by the Atomic Bomb Casualty Commission (ABCC) and the Oak Ridge National Laboratory (ORNL) have now moved into a new phase which will produce significant refinements in estimates of risk and radiation quality (RBE) of neutrons derived from epidemiological studies of atomic-bomb survivors. During the latest liaison study, important new data were presented to the ABCC. These data dealt with depth dose distribution which can be used to make in vivo dose estimates for survivors. Estimates of absorbed dose to the breasts of women survivors and survivors exposed in utero were made for immediate use in their studies. These estimates are of great interest at present because of new dose-specific analyses of breast cancer being made at the ABCC and the Jablon-Stewart controversy over the risk of radiation exposure to a fetus.

Examples are presented in this report to show that the new phase of liaison studies can refine current estimates of risk derived from the ABCC's epidemiological studies by factors of two or more. These examples are drawn from data presented in several recent and authoritative reports by committees of the National Academy of Sciences and the United Nations.

Although the emphasis was on in vivo dosimetry, some time was devoted to older, but still important, phases of the liaison studies. These were (a) finalization of tissue kerma-distance curves used in the T65D estimates of radiation exposure to survivors, (b) unknown T65D exposure cases in the major samples of the ABCC, and (c) radiation exposures of survivors who are now residing in the United States. A study of a group of 200 to 250 will be completed in early 1975 and a report summarizing data on this group will be completed by mid-1975. These 200 to 250 survivors represent about one-fourth of the estimated total residing in the United States.

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Introduction

A number of topics were considered in work and study sessions with the staff of the Atomic Bomb Casualty Commission (ABCC) during this liaison study which lasted from August 20 to September 17, 1974. Summaries of these work and discussion sessions are given below for major areas of concern to either the ABCC or ORNL or both.

T65D Estimates of Radiation Exposure to Atomic Bomb Survivors

In reviewing data available on the effects of radiation on man, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in their recent report[1], "Ionizing Radiation: Levels and Effects", acknowledges the importance of the ABCC studies by stating (pp. 403-404):

> In terms of man-year experience, the cohort followed by the Atomic Bomb Casualty Commission with the collaboration of the Japanese National Institute of Health is of far greater significance than other cohorts under study.
>
> The study cohort of the ABCC is generally unbiased with respect to sex, age, and pre-existing disease, an advantage compared to other irradiated populations, such as medically treated groups.

The Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR) for the National Academy of Sciences-National Research Council in their recent report[2], "The Effects on Populations of Exposure to Low Levels of Ionizing Radiations", also acknowledges the importance of both the ABCC studies on the biological effects of radiation on survivors and the T65D estimates of radiation exposure for survivors provided by ORNL by stating (p. 100):

> Some of the most useful data available for the evaluation of the late effect of radiation on man come from the Atomic Bomb Casualty Commission: The population of A-bomb survivors is large and received doses ranging from the trivial to the near lethal; estimated doses are available for almost all; the population is relatively unselected (except for mortality at the upper end of the dose range), in contrast to series arising from therapy administered for pre-existing disease or from occupational exposure.

To stress uncertainties in their estimates of effects of low-level radiation exposures, shortcomings of both the epidemiological and dosimetrical data of all studies were discussed in detail. In discussing the estimated doses to atomic bomb survivors, the BEIR Report (see footnote on page 76 and "Definitions and Notes to Accompany Reference Tables Summarizing Quantitative Data on Carcinogenic Effects of Ionizing Radiations" on page 195 to 199) states:

> These dose estimates, drawn from the ABCC data, are of air doses to the mother. The degree of attenuation of the dose in reaching the fetus would depend on such factors as fetal age; e.g., the younger the fetus, the greater the attenuation. An equation to allow for this attenuation in computing fetal dose has not been formulated.
>
> The mean dose shown in Column 11 is usually the relevant tissue dose, but for the A-bomb survivors, it is the whole-body, free field, or "air" dose. Attenuation factors for atomic bomb survivors have not been published, and hence no effort is made here to provide tissue doses, which might be 60 to 70 percent of the dose given in rads, depending on the tissue and the proportions of neutron and gamma radiation.

The UNSCEAR Report states on page 404 of Annex H:

> It must also be clearly borne in mind that absorbed doses, particularly to deep tissues, are difficult to obtain from the kerma estimates available, and the fact that a substantial neutron contribution was received by the survivors at Hiroshima introduces additional complications owing to the higher biological effectiveness of neutrons relative to gamma rays.

Techniques developed by the Health Physics Division of ORNL to specify the radiation exposure to a survivor are the basis of the so-called tentative 1965 dose (T65D) assignments for most of the 117,000 survivors in the Master Files of the ABCC. The quantity originally used in these techniques was the absorbed dose (i.e., the kinetic energy deposited locally by ionizing particles produced by gamma-ray and neutron interactions) in a small mass of biological tissue. In the literature this quantity has been called "air dose", "free-field dose", "first-collision dose", "whole-body dose", and simply "dose". The energy deposited in a small mass of tissue in free air is a "first collision" absorbed dose, since the probability of additional energy being deposited by a "second collision" is negligibly small. According to more recent recommendations of the International Commission on Radiological Units and Measurements,[3,4] the "first collision" concept of radiation exposure should now be referred to as kinetic energy released in material (tissue in this case) in free air or simply "tissue kerma in free air".

Because the survivor was replaced by a small mass of biological tissue in the T65D assignments of radiation exposure to survivors, reference to these estimates as "whole body" doses in ABCC and other reports have been misleading. The irradiation of atomic bomb survivors was, however, "whole body" in comparison to so-called "partial body" irradiation in therapeutic X-ray beam exposures. Due to multiple scattering (or multiple collisions) and absorption (or attenuation) of radiation by the body, the absorbed dose to organs and tissue of the body or to the whole body (usually interpreted to mean the average absorbed dose to the body) of a survivor was different from his or her T65D assignment of tissue kerma in free air. In general, the absorbed dose to organs and tissues is less than the tissue kerma in free air with the reduction for neutrons being greater than that for gamma ray. These absorbed doses are often referred to in the literature as "tissue dose", "organ dose", and simply "dose". To reduce ambiguities and confusion resulting from the number and similarity of the dosimetric terms used in the literature, it was recommended[5] that in future reports of the ABCC (a) terms used in discussing the T65D estimates of a survivor's radiation exposure be limited to tissue kerma in free air and (b) terms used in discussing doses to a tissue or organ of a survivor or to a fetus be limited to absorbed dose or dose equivalent if an absorbed dose is modified by use of an RBE factor. These recommendations have been followed in this report.

In-Vivo Estimates of Absorbed Dose to Atomic Bomb Survivors

The ultimate need to correlate effects, such as leukemia, thyroid carcinoma, etc., with biologically significant doses was recognized from the start of the Japanese dosimetry program (i.e., the Ichiban program), and research on depth dose distributions has been an important part of this program. Computer codes employing Monte Carlo techniques for calculating absorbed dose within a human-type phantom have been verified experimentally (see for example ref. 6), and they have been generalized recently to calculate depth dose distributions from fields having complex angular distributions.[7,8] Calculations have been completed for gamma rays and neutrons with energy and angular distributions typical of fields produced by a fission weapon,[9,10] and techniques for estimating absorbed dose to a fetus and to some organs or tissues of survivors based on their T65D assignments have been presented to the ABCC. In addition to estimating absorbed doses from gamma rays and neutrons incident on the body of a survivor, the techniques also permit estimation of the absorbed dose to an organ or tissue or fetus from gamma rays produced by neutron interactions in the body of a survivor.

During the latest liaison trip, estimates of the absorbed doses to the breasts of women survivors and survivors exposed in utero were made at the request of the ABCC for immediate use in their studies. These estimates shown in Table 1 give the absorbed dose from heavy charged particles ($D_{n,p}$) and gamma rays ($D_{n,\gamma}$) produced by neutrons incident on the body and from gamma rays (D_{γ}) incident on the body of a survivor in terms of the T65D assignments of the tissue kerma in free air from neutrons (K_n) and gamma rays (K_{γ}) for survivors.

Absorbed doses to the fetus, which are given in Table 1, were obtained by combining calculations of the distribution of absorbed dose in a homogeneous phantom with a radius of 12 cm and length of 60 cm with information on fetal size[10] and distance from the front skin surface to the center of the uterus[13] at the different stages of fetal development. In the first trimester of fetal development, the fetus and slightly enlarged uterus remain centrally located within the body at an average distance (or penetration depth for the incident radiation) from the front skin surface of the abdomen to the center of the uterus of about 8 cm. In the second trimester, the fetus and greatly enlarged uterus move upward and forward decreasing the average penetration depth to a minimum of about 6 cm, but in the third trimester, the greatly enlarged fetus and uterus settle back down in the body increasing the average penetration depth to about 8 cm. Because of small variations in the penetration depth from the front skin surface to the center of the uterus, which was assumed to be the center of the fetus, and because of small variations in the distribution of absorbed dose at these penetration depths, the variations in average absorbed dose to the fetus obtained by integrating the absorbed dose distribution over the volume of the fetus and dividing by the volume of the fetus were also small as shown in Table 2. Due to the small variations in these calculations of absorbed dose to the fetus for the first, second, and third trimesters and some uncertainties involved in the calculations, use of the one set of values given in Table 1 seems reasonable for all stages of fetal development. The absorbed doses to the breasts of women given in Table 1 are based on the assumption that the tissue at greatest risk lies at a penetration depth of one centimeter below the skin surface. This is consistent with the assumption used in estimating the absorbed dose to the breasts of women who were subjected to multiple fluoroscopies during artificial pneumothorax for pulmonary tuberculosis (BEIR Report, pp. 141-143).

These estimates are of great interest at present because of new dose-specific analyses of breast cancer being made at the ABCC and the

Jablon-Stewart controversy over the risk of radiation exposure to a fetus. In brief, this controversy arose because the number of "radiogenic cancers" predicted by the Stewart-Kneale formula derived from an epidemiological study involving fetal diagnostic X-ray exposures in England simply did not occur among Japanese children exposed in utero.[14] Estimates of absorbed dose to a fetus given in Table 1 are less, especially for neutrons, than the "conservative assumption" used by Jablon and Kato that the absorbed dose to the fetus was one-half of the mother's T65D assignment of tissue kerma in free air, for both neutrons and gamma rays (i.e., $D_\gamma/K_\gamma = 0.5$ and $D_n/K_n = (D_{n,p} + D_{n,\gamma}) / K_n = 0.5$), but the difference may not be great enough to resolve this controversy. Other factors which could be responsible for the discrepancies between the two studies have been discussed by Stewart[15] and Jablon[16] and some third parties (see, for example, pages 427 and 428 in the UNSCEAR Report and pages 160 to 166 of the BEIR Report).

Another possible discrepancy between ABCC findings and those of others which needs to be investigated was pointed out by Dr. G. W. Beebe in a memo [17] which states:

> In their 1965 paper (Brit. Med. J., 4 Dec., 1965, ff.) Court-Brown and Doll report a statistically significant excess of stomach cancer, but apparently did not have a significant excess of breast cancer, which they failed to mention specifically. At ABCC, the results are just the opposite, and one would think that dosimetry might have much, or everything to do with the difference. I wonder if you or your group has any opinion on this discrepancy for either organ? It is something that merits inclusion in any discussion of our findings with respect to the breast.

The immediate importance of absorbed dose estimates to the breasts and other organs of survivors, such as the thyroid and stomach, can be demonstrated by the following example. Estimates of absolute risk of breast cancer (BEIR Report, pp. 136 to 144) from studies of tubercular women in Nova Scotia subjected to repeated chest fluoroscopy for artificial pneumothorax, women in New York State given localized X-ray treatment for acute partum mastitis, and women atomic bomb survivors are 8.4, 6.0, and either 2.9 (RBE of 1 assumed for neutrons) or 1.8 (RBE of 5 assumed for neutrons), respectively, with units of deaths or cases/10^6 women/year/rem. In summarizing these data, the BEIR Report states, "If an RBE of 1 for the neutron component at Hiroshima is assumed, the absolute risk from the studies are remarkably close. For example, if it is assumed that a factor of 2 can be applied to correct deaths from, to incidence of, breast cancer in Japanese women, then the estimated values of the absolute risk, in cases/10^6 women/year/rad, are 6.0 for the Japanese study. . .," but, "If an RBE of 5 for the neutron component in Hiroshima is assumed, then neither the absolute nor relative risk estimates for the Japanese would appear to agree with those of the two western studies". The above estimates of risk from the ABCC studies are, of course, based on the radiation exposure of women in terms of tissue kerma in free air. If they are recalculated, based on absorbed dose to the breasts given in Table 1, these become approximately 3.8 (RBE of 1) and 2.7 (RBE of 5) deaths/10^6 women/year/rem. If the factor of 2 is used to convert these estimates to cases of breast cancer, as in the BEIR Report, estimates of risk based on absorbed doses to the breast of Japanese women survivors become 7.6 (RBE of 1) and 5.4 (RBE of 5) cases/10^6 women/year/rem and both estimates are in agreement with the two western studies. In general, use of tissue kerma in free air, rather than absorbed dose to a tissue or organ of interest, will tend to underestimate the absolute risk and the RBE of neutrons.

Estimates of absorbed dose to the stomach of atomic bomb survivors will be provided as soon as possible, and the possibility of providing an estimate of absorbed dose to the breasts of women studied by Court-Brown and Doll will be investigated in cooperation with the Medical Physics and Internal Dosimetry Section of the Health Physics Division at ORNL. Hopefully, these dose estimates and those for the breasts of women atomic bomb survivors will resolve some discrepancies between the ABCC and Court-Brown and Doll studies.

Because a homogeneous tissue equivalent phantom was used in our depth dose calculations and because most of the absorbed dose to organs and tissues was found to have been delivered by gamma rays, the absorbed dose distributions should not be used to estimate absorbed dose to bone or bone marrow. Significant differences in interaction cross sections (i.e., photoelectric cross sections) between tissue and bone at lower gamma-ray energies could result in a gross underestimate of absorbed dose to bone and marrow in small bone cavities. For this reason, calculations of absorbed dose to bone and bone marrow of survivors have been started recently, using a heterogeneous phantom with a skeletal system.[18] This phantom has a physical size characteristic of American or Western European adults, but techniques[19] exist for scaling the phantom to body sizes typical of either Japanese children or adults. Age dependent estimates of absorbed dose are, of course, needed by the ABCC because of the distribution in ages of survivors at the time of bombing. Information was requested from the ABCC [20] on body and organ sizes of Japanese, and a number of publications applicable to Japanese survivors were received during the trip.[21-27] Because differences in interaction cross sections between tissue and bone are small for higher energy gamma rays (i.e., Compton and pair production cross sections) and for neutrons, the penetration of weapon radiation in the body is not affected significantly by a skeletal system; therefore, the present depth dose calculations in homogeneous phantoms are adequate for estimating absorbed doses to organs other than bone or bone marrow.

A technique for estimating absorbed dose to a fetus, more specifically the head of the fetus in the later developmental stages, has also been proposed by Dr. Tadashi Hashizume [28], a dosimetry consultant to the ABCC, from the National Institute of Radiological Sciences (NIRS), Chiba, Japan. For purposes of comparison, the NIRS estimates of absorbed dose to a fetus in the first trimester and those of ORNL are given in Table 3. Also given in the table are estimates for a first trimester fetus made from experimental data presented by V. P. Bond et al.[29] on depth dose in phantoms exposed to radiation from nuclear weapons tested in the atmosphere. A summary in the BEIR Report (p. 101), which made extensive reference to the measurements of Bond et al. states:

> The dose of gamma radiation, referenced to the dose "free in air", falls off from 100 percent on the side of the body trunk nearest the weapon to about 65 percent on the opposite side of the body. The neutron dose, also referenced to the "air dose", is about 75 percent at the body surface nearest the weapon, of the order of 15 percent or 20 percent at the midline and approximately 40 percent on the side most distant from the weapon. These considerations should in principle be taken into account in specifying the absorbed dose to the bone marrow and other tissue of the body.

Some serious discrepancies, especially in estimates of absorbed dose from gamma rays, are found in Table 3. Our neutron calculations and the neutron depth dose measurements of Bond et al. are in reasonable agreement, but our gamma ray calculations and their gamma ray measurements are not. Their measurements of the depth dose from gamma rays in the phantom are more indicative of plane-beam irradiation,[30] than angular distributions of gamma rays measured from nuclear weapons,[31] and are probably due to a combination of gamma rays produced by the weapon, gamma rays produced by neutron interactions in the phantom, and thermal neutron sensitivity of the gamma ray dosimeters. Some further calculations on our part should resolve the discrepancies between these often referenced measurements and our present calculations.

In the technique used by NIRS, experimental measurements of absorbed dose from gamma ray and neutron spectra similar to those of a fission weapon made at different angles of slant incidence (i.e., different polar and azimuthal angles) about the phantom were summed to represent the angular distributions of weapons radiation. The NIRS values in Table 3 were based on angular distributions measured in the open (i.e., in the absence of any shielding).

Because the population exposed inside Japanese residential structures constituted the most important group of survivors in the Master Files of the ABCC, this group influenced most of the assumptions and approximations concerning the energy and angular distributions of radiation incident on a survivor in our calculations. The angular distribution of neutrons inside a typical Japanese house has not been measured for a transported fission spectrum; however, some measurements have been made in a Japanese-type house for a degraded $^{3}H(d,n)\,^{4}He$ spectrum denoted as a D-T spectrum.[32] The leakage spectrum from a D-T source is sharply peaked at about 14 MeV, but the spectrum is softened and the average energy is degraded very quickly by scattering in air. Because the angular distribution is not sensitive to the spectral distribution, no serious errors should result from using the angular distribution from a degraded D-T spectrum. The angular distribution of gamma rays is difficult to predict, even for the light shielding provided by Japanese residential structures, because of gamma rays produced by neutrons as they are absorbed by the shielding materials surrounding the survivor, but past experience[33] indicates that it is approximately correct to assume that the gamma rays are isotropically incident above the horizon.

If the NIRS data on the slant penetration of gamma rays (Table 3 of Hashizume et al.) are converted to a 2π- isotropic distribution above the horizon, the value of D_{γ}/K_{γ} is 0.65 compared to the NIRS values of 0.67 to 0.70 for an angular distribution of gamma rays measured in the open. This, of course, rules out differences in angular distributions as a reason for the discrepancy between the ORNL and NIRS data shown in Table 3. In comparisons with other fragmentary data on slant penetration of radiation in the literature, significant differences were found between the data of Hashizume et al. for 12 MV X-ray and $^{9}Be(d,_n)$ ^{10}B neutron spectra with average energies of 1.46 and 1.9 MeV, respectively, and similar experimental measurements with 0.66 MeV gamma rays[34] at the Defense Research Establishment Ottawa (DREO) and theoretical calculations for 1 MeV neutrons [35-36] at ORNL. Although the energies of these comparisons shown in Figure 1 are not the same, it is expected that the behavior of the slant penetration curves should not be significantly different, since slant penetration data for other gamma ray and neutron energies in the DREO and ORNL references show a behavior similar to that for the 0.66 MeV gamma rays from ^{137}Cs and 1 MeV neutrons. Hence, the disagreement between the NIRS and ORNL data, especially that for D_γ/K_γ, appear to be more fundamental than differences in either angular or energy distributions of the radiation fields.

Further calculational and experimental work is necessary to resolve the discrepancies in the slant penetration data of NIRS and that of DREO and ORNL, and thereby, the discrepancies in NIRS and ORNL estimates of absorbed dose to a fetus. Due to the ultimate need to establish absorbed doses to many organs and tissues of survivors as a function of age, the slant penetration method, which requires measurements or calculations at numerous angles of slant incidence for each organ with different size phantoms to represent various age groups, does not appear to be a feasible approach. Slant penetration data for a few organs of an adult would, however, provide useful information on variations in absorbed doses to organs or tissues that might result from angular distributions, other than those for a typical Japanese residential structure. These data would also be useful in investigating dose to organs for angular distributions encountered in nuclear accident dosimetry, radiation therapy, shielding evaluation, and radiation protection.[34,37]

Finalization of Tissue Kerma-Distance Curves Used in T65D Estimates

Before publishing correlations of observed medical effects with absorbed doses to organs or tissues of survivors, the ABCC would like to finalize the curves giving the variation of tissue kerma with distance from the hypocenters in Hiroshima and Nagasaki. These are the basis of the T65D estimates of a survivor's radiation exposure. Finalizations will probably require a recalculation of the T65D assignments for survivors of Nagasaki.

In a reevaluation of all available physical data on the epicenters of the atomic bombs for Hiroshima and Nagasaki at ORNL,[38] it was stated:

> The differences in Hiroshima (15m between epicenters) do not seem to us sufficient to warrant any dose recalculations. In Nagasaki, however, the T65D coordinates were chosen on the basis of a calculation from one set of data which we feel could contain serious errors. That hypocenter is well outside the region where most other estimates of the hypocenter fall, and is unlikely to be close to the "best" point. Our epicenter point and the T65D point are about 35 m apart, so a recalculation of doses would seem to be justified in Nagasaki, since such a difference would make a change in estimated dose of the order of about 10% at 1000 m from the hypocenter, and even more change closer to the hypocenter. In correlating medical effects this could be magnified to 20% when comparing cases in opposite directions with respect to the hypocenter.

Concern has been expressed by some of the ABCC staff because none of the outlying points were rejected in the averaging process used to reevaluate the available hypocenter data. To eliminate the effects of some very remote outlying points in the data, attempts are being made at present to determine a weighted median, rather than weighted average, of all the available hypocenter points. These results should yield a hypocenter location agreeable to all concerned individuals at the ABCC and ORNL.

Unknown T65D Exposure Cases in the Major Samples of the ABCC

A number of unknown T65D exposure cases have been isolated from the ST-100 sample which are important in dose-specific studies of the ABCC. Categories chosen were HE-39 leukemia living cases, A-286 breast cancer living cases, ME-200 thyroid cancer, A-255 multiple neoplasms in the autopsy sample, and A-323 malignant lymphoma in the autopsy series, and 128 deaths in TR 15-73 from all forms of cancer. It was agreed that ORNL would review the shielding histories of these cases, which total about 200, on a low priority basis, because of a reduction of staff associated with the Japanese dosimetry program at ORNL. Shielding histories on these cases are to be forwarded to ORNL by Mr. S. Fujita of the ABCC.

Study of Radiation Exposure to Survivors Residing in the United States

A total of 135 questionnaires on persons in the United States (42 obtained from the Office of the Chief Medical Examiner-Coroner for the County of Los Angeles, California, and 93 obtained from the Department of Public Health for the City and County of San Francisco, California) were checked against the Master Files of the ABCC.[40] Of these 135, 65 persons were registered in the Master Files, and radiation exposure estimates were available for 25 of these 65 persons.[41] Information on 187 persons has now been checked against the Master Files of the ABCC during two trips to the ABCC in 1973 and 1974. Of these 187 persons, 92 were listed in the Master Files, and radiation exposure estimates had been made by the ABCC for 37 of these 92 persons. A number of nontrivial radiation exposures have been identified from either radiation exposure data obtained from the files of the ABCC or reviews of questionnaires with Mr. Hiroaki Yamada of the ABCC in Hiroshima and Mr. Yoshio Okamoto of the ABCC in Nagasaki, Japan.

Arrangements were also completed for Mr. Yamada's trip to ORNL to participate in the study for a period of one year, starting about October 1, 1974. During this period, his services will be needed (1) in California to help some persons pinpoint their location at the time of bombing, using either prestrike or poststrike photographs of the cities, and to compile shielding histories on survivors exposed close to the hypocenters and (2) at ORNL in making radiation exposure estimates and in filing data for future reference. The Office of the Chief Medical Examiner-Coroner in Los Angeles and the Department of Public Health in San Francisco will provide office space for Mr. Yamada and will arrange interviews with the survivors. No interviews are anticipated with survivors who have been reliably located at distances greater than 3000 meters from the hypocenters or have radiation exposure estimates made previously by the ABCC.

Radiation exposure estimates will be completed for a group of 200 to 250 survivors in California in early 1975 and a report summarizing the findings for this group will be available by mid-1975.

Comments by the ABCC and others on a study of acute symptoms in survivors exposed to fallout in Hiroshima, which was published as an ORNL report,[42] will also be reviewed with Mr. Yamada during his stay at ORNL. With some additional refinements of this well received exploratory study, it will be submitted for publication in either the ABCC series of reports or the open literature.

Future of ORNL Liaison Studies with the ABCC

Liaison studies in dosimetry with the ABCC are now moving into a new phase in which correlations of medical effects with estimates of absorbed dose to critical organs for each effect will provide better estimates of risk associated with gamma ray and neutron exposures and of radiation quality (RBE) of neutrons. These studies can add factors of two or more to some current estimates of risk based on tissue kerma in free air. For example, the absolute risk of leukemia from studies of survivors in Nagasaki is 0.56 cases/10^6 persons/ year/rem (see Table a-7, page 117, BEIR Report). Based on some very preliminary calculations at ORNL and some data published by DREO,[34] the absorbed dose to bone marrow is of the order of 1/2 of the tissue kerma in free air for these survivors, who were 10 years of age or older and were exposed almost entirely to gamma radiation. Therefore, an estimate of absolute risk based on absorbed dose to bone marrow would be of the order of 1 case/10 persons/year/rem. An estimate of this order is, of course, in better agreement with estimates of 0.9 to 1.3 and of 1.2

cases/10^6 persons/year/rem from studies of adult spondylitic and menorrhagia patients, respectively, given in Table a-7 of the BEIR Report. In Hiroshima, the survivors also received significant radiation exposures from neutrons, as well as gamma rays. Hence, the magnitude of the increased absolute risk of leukemia based on absorbed dose to red bone marrow, rather than tissue kerma in free air, will be even greater in Hiroshima than in Nagasaki, and the RBE's for neutrons derived from the leukemia studies in the two cities will be larger than current estimates (see pages 100 to 106 of the BEIR Report).

In a recent report, "Research Needs for Estimating the Biological Hazards of Low Doses of Ionizing Radiation", by an ad hoc panel of the National Academy of Science,[43] it is stated on pages 28 to 30:

> Undoubtedly the most useful data available for evaluation of the late effects of radiation on man come from the Atomic Bomb Casualty Commission (ABCC). We regard the continued study of this unique population as essential to the elucidation of risk estimates for carcinogenic effect of radiation on man. Not only is the population under study of a large size (over 100,000 individuals) and irradiated for other than medical reasons (which often introduces uncertainty into the interpretation of data from patients), but, also, the survivors received irradiation at all ages and in doses ranging from a few rads to near lethal levels. Many important questions remain to be answered in connection with these A-bomb survivors, which have a direct bearing on our estimation of the risk to human populations from exposure to radiation at or near background levels.
>
> Estimated excess cancer rates are derived from observations on survivors of Hiroshima and Nagasaki averaged over the period 1960 to 1970. We do not know whether the excess cancer death rates of these survivors will rise, remain the same, or decrease during the coming years.
>
> We would estimate that definitive answers to these questions will take a further 20 to 30 years of follow-up by the ABCC and could refine present risk estimates down by a factor of 2 or up by a factor of 3 to 4.

As demonstrated by the examples on leukemia and breast cancer, use of in vivo doses in estimating risks from the ABCC studies can result in refinements equal in magnitude to those deemed important by this panel. Moreover, correlations of observed medical effects with in vivo doses are a necessity in interpreting differences in dose specific analyses and deriving valid RBE's for neutrons from data for the two cities.

Hopefully, the importance of the current liaison studies between the ABCC and ORNL, especially in the area of in vivo dosimetry, have been pointed out in this report. The future of these liaison studies is, however, unknown at present because of uncertainties involved in (a) the proposed reorganization of the ABCC and (b) the level of funding provided by the Energy Research and Development Administration for ABCC dosimetry support programs at ORNL and liaison activities.

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TABLE 1. ESTIMATES OF ABSORBED DOSE TO THE BREASTS AND FETUS OF AN ATOMIC BOMB SURVIVOR IN TERMS OF TISSUE KERMA IN FREE AIR

Absorbed Dose/Tissue Kerma in Free Air	Breasts	Fetus
D_{γ}/K_{γ}	0.80	0.42
$D_{\gamma,p}/K_{n}$	0.55	0.14
$D_{n,\gamma}/K_{n}$	0.045	0.077

TABLE 2. ESTIMATES OF ABSORBED DOSE TO THE FETUS OF AN ATOMIC BOMB SURVIVOR IN TERMS OF TISSUE KERMA IN FREE AIR AS A FUNCTION OF FETAL DEVELOPMENT BY TRIMESTERS

	Stage of Fetal Development by Trimesters		
	First	Second	Third
Penetration depth for incident radiation measured from surface of abdomen to center of uterus*	8 cm	6 cm	8 cm
Geometry of Embryo or Fetus:**			
Radius	0.13-1 cm	2-3 cm	4-5 cm
Crown-Rump Length	0.13-5.5 cm	10-20 cm	23-30 cm
Absorbed Dose/Tissue Kerma:			
D_γ/K_γ	0.40	0.43	0.42
$D_{n,p}/K_n$	0.12	0.15	0.14
$D_{n,\gamma}/K_n$	0.078	0.076	0.077

*A. Tabuchi, *et al.*, Hiroshima Daigaku Igakubu Zasshi 12(1.2), 57-69, February 1964.

**T. D. Jones *et al.*, to be published in Health Physics.

TABLE 3. ESTIMATES OF ABSORBED DOSE TO A FIRST-TRIMESTER FETUS OF AN ATOMIC BOMB SURVIVOR IN TERMS OF TISSUE KERMA IN FREE AIR

Absorbed Dose/Tissue Kerma	ORNL	NIRS*	Bond et al.
D_γ/K_γ	0.42	0.67-0.70	0.90
$D_{n,p}/K_n$	0.14	0.15-0.17**	0.17
$D_{n,\gamma}/K_n$	0.077	0.10-0.11	--

*Range covers differences in orientation and burst heights in Hiroshima and Nagasaki considered by Hashizume et al.

**Recoil protons and other recoil nuclei plus N(n,p)C reaction.

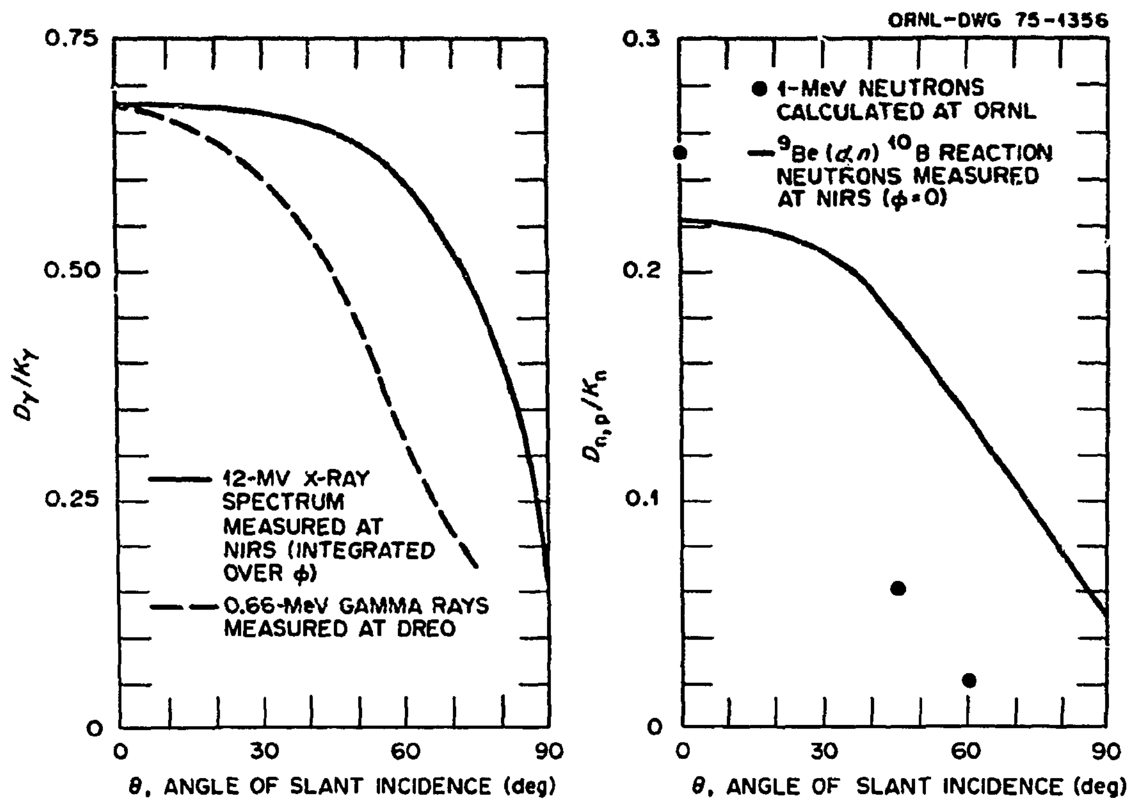

FIGURE 1. ABSORBED DOSE AT CENTER OF ABDOMEN PER UNIT KERMA IN FREE AIR AS A FUNCTION OF THE SLANT ANGLE OF INCIDENCE, θ, OF THE RADIATION ON THE BODY. NORMAL INCIDENCE CORRESPONDS TO θ = 0.