INTRODUCTION

Volume 2 of the *Final Report on the US-Japan Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki* contains reports prepared since 1945 which provide additional valuable data regarding the dose reassessment activities. These reports are presented as appendixes to the chapters in Volume 1 and are identified in both Volume 1 and Volume 2. For some chapters there are several appendixes and these are numbered accordingly. Excerpts from the *Historical Review* and *Executive Summary* of Volume 1, including a brief description of each chapter, follow.

Immediately after the bombings, several small groups of Japanese scientists visited Hiroshima and Nagasaki to investigate the extent of the damage. The results of the various investigations were eventually published by the Science Council of Japan in a book entitled, *Collection of the Reports on the Investigation of the Atomic bomb Casualties*. In late September 1945 US Army, Navy, and Manhattan Project teams entered Japan and began working with the Japanese scientists. The medical personnel from the various American and Japanese teams were combined on 12 October 1945 to form a US-Japan Joint Commission for studies of acute biological effects associated with exposure to atomic radiation. A comprehensive report, *Medical Effects of the Atomic Bomb in Japan*, was prepared by the Joint Commission.

In November 1946, President Harry S Truman approved a directive to the National Academy of Sciences to initiate a long-term study of the surviving populations in Hiroshima and Nagasaki. The Academy established the Atomic bomb Casualty Commission (ABCC) in 1947, and investigation began shortly thereafter. The Japanese National Institute of Health (JNIH) aided the investigations by establishing branch laboratories within ABCC at Hiroshima and Nagasaki. In April 1975, ABCC was officially dissolved and replaced by a binational organization known as the Radiation Effects Research Foundation (RERF). The Government of Japan, through the Ministry of Health and Welfare, and the United States Government, through the US Department of Energy (DOE), share equally in the funding of RERF. The US funds are made available through the National Academy of Sciences.

By the mid-1950s, several early ABCC studies had already reported an elevated incidence of cataracts and leukemia among survivors, especially in Hiroshima. Both the need for accurate dosimetric data and the technology for obtaining it had reached the point that an organized dosimetry study was judged necessary.

In 1956 US Atomic Energy Commission (later DOE) assigned the task to the Oak Ridge National Laboratory (ORNL) in a project called ICHIBAN. With consultants from ORNL, ABCC determined map coordinates for most of the survivors then residing within the two cities and compiled detailed shielding data for those survivors located within 1600 m from the hypocenter (ground zero) in Hiroshima and within 2000 m from the hypocenter in Nagasaki.

Table 1. Members of the Task Group on A-Bomb Survivor Dosimetry of the National Council on Radiation Protection.

Dr. Harold O. Wyckoff (Chairman), International Commission on Radiation Units and Measurements.
Mr. Charles M. Eisenhauer, Physicist, Radiation Physics Division, Center for Radiation Research, National Bureau of Standards.
Dr. Payne S. Harris, retired, Santa Fe, NM.
Dr. William E. Ogle, Energy Systems, Inc.
Dr. Malcolm L. Randolph, Staff Scientist, Health and Safety Research Division, Oak Ridge National Laboratory (retired).
Dr. William C. Roesch, Staff Scientist, Pacific Northwest Laboratory (retired).
Dr. Lewis V. Spencer, Physicist Radiation Theory Group, Radiation Physics Division, National Bureau of Standards.
Dr. John B. Storer, former Director, Biology Division, Oak Ridge National Laboratory.

As most of the survivors were exposed in residential wood-frame structures, the highly modular and uniform construction of Japanese houses made a definitive dosimetry study feasible.

The first dose estimates for survivors were designated Tentative 1957 Doses (T57D). In 1965 a revised dosimetry system was adopted by ABCC, and designated as Tentative 1965 Doses (T65D).

An important step leading to the current reassessment of A-bomb radiation dosimetry was a presentation by H. H. Rossi in 1976 to the US National Council on Radiation Protection and Measurements (NCRP). Estimates of the absorbed dose for critical organs of concern in the medical and epidemiological investigations conducted at ABCC and RERF were now possible. Rossi combined the results of the new calculations for the absorbed dose in active bone marrow with the T65D estimates for survivors and concluded that a radiation worker continually exposed to neutrons at the maximum permissible level recommended by NCRP had a probability of developing leukemia that was several times greater than that of a person receiving the maximum permissible level of x or gamma rays. An article by Rossi and Mays entitled *Leukemia Risk from Neutrons* was published in Health Physics in 1978 which recommended that the NCRP reduce its permissible dose limits for neutrons by an order of magnitude.

A Task Group was set up by NCRP (Table 1) to investigate the accuracy of the T65D system. After considerable study, the Task Group concluded that the material available in the open literature was insufficient for determination of the accuracy of the T65D system. As some documents needed in the review were classified the Task Group recommended that a person with the proper security clearance review the classified documents. DOE responded to the Task Group's recommendation by funding G. D. Kerr of ORNL in 1979. Fortunately, Kerr not only had access to classified data on the bombs dropped on Japan and on bombs used in weapons test, but also was aware of newer data that was relevant to the problem.

Consequently, other investigators were drawn into the review at the request of NCRP.

Independently of Kerr and the NCRP Task Group, a study of A-bomb radiation dosimetry was undertaken at Lawrence Livermore National Laboratory (LLNL). This study was initiated because the recommendation in the Rossi-Mays article was of concern to H. W. Patterson, who was Editor-in-Chief of Health Physics and also Head of the Hazard Control Department at LLNL. As a result, E. Mendelsohn and W.E. Loewe made a detailed investigation of the radiation dose in Hiroshima and Nagasaki, particularly the air transport of radiation from the atomic bombs.

In the spring of 1981 NCRP cosponsored with the North American Late Effects Group a workshop on A-bomb survivor dosimetry that was held at the 29th annual meeting of the Radiation Research Society. The attendant publicity in both the scientific and lay press regarding the validity of the T65 system brought the problem to the attention of interested scientists and of political representatives of the United States and Japanese Governments. In 1981 the DOE convened another symposium to review what was known and to determine what further work was needed. Subsequently, a Working Group on A-Bomb Dosimetry Reassessment was organized and R. F. Christy of the California Institute of Technology was appointed Chairman (Table 2). The Japanese Ministry of Health and Welfare, also organized a research team in 1981 headed by T. Hashizume (Table 3).

Arrangements were completed in early 1983 for a US-Japan joint research program for reassessment of atomic bomb radiation dosimetry which was coordinated through RERF. NAS was asked to form a Panel on Reassessment of A-bomb Dosimetry (Table 4) to function as an oversight committee for the DOE Working Group. Frederick Seitz, President Emeritus of both NAS and Rockefeller University, was appointed to head the Panel. Two similar committees, the Review Committee to Evaluate the Radiation Dose from the Atomic Bomb (Japanese Senior Dosimetry Committee) and the Japanese Dosimetry Working Group, were also established in 1983 under the chairmanship of Eizo Tajima, Vice-Chairman of the Nuclear Safety Commission (Tables 5 and 6). The Japanese Working Group incorporated the research activities of the Hashizume team sponsored by the Ministry of Health and Welfare and several other research groups sponsored by the Ministry of Education.

Four US-Japan Joint Workshops for Reassessment of Atomic Bomb Radiation Dosimetry were held (1) at Nagasaki, Japan, 16 and 17 February 1983, (2) at Hiroshima, Japan, 8 and 9 November 1983, (3) at Pasadena, California, 12 to 14 March 1985, and (4) at Hiroshima, Japan, 15 to 17 March 1986. The proceedings of the first two workshops were published by RERF.

The final report was prepared from materials submitted by members of both DOE and Japanese Working Groups. These groups organized their efforts into ten major areas: yields of the bombs, radiation leakage from the bombs, transport of radiation in air over ground, thermoluminescence measurements of gamma rays, measurements of neutrons, residual radioactivity, house and terrain shielding, organ dosimetry, preparation of a dosimetry system, and uncertainty analysis. In Volume 1, one chapter is devoted to each of the first nine areas; a future report will deal with the last area, uncertainty analysis. The chapters were prepared by writing groups, and are based on a large number of individual papers, some of which are included in Volume 2.

Table 2. Members of the Working Group on the Reassessment of A-Bomb Dosimetry of the US Department of Energy.

Dr. Robert F. Christy (Chairman), Institute Professor of Theoretical Physics Emeritus, California Institute of Technology.
Mr. Gilbert C. Binninger, Staff Scientist, Science Applications International Corporation.
Dr. Daniel G. Cacuci, Section Head, Engineering Physics and Mathematics Division, Oak Ridge National Laboratory.
Dr. Stephen D. Egbert, Staff Scientist, Science Applications International Corporation.
Mr. Michael L. Gritzner, Staff Scientist, Science Applications International Corporation.
Dr. John H. Harley, retired, former Director, Environmental Measurements Laboratory, Department of Energy.
Dr. Edwin H. Haskell, Research Assistant Professor, and Director, Thermoluminescence Laboratory, University of Utah.
Mr. Dean C. Kaul, Manager, Radiation Physics Division, Science Applications International Corporation.
Dr. George D. Kerr, Staff Scientist, Health and Safety Research Division, Oak Ridge National Laboratory.
Dr. William E. Loewe, Senior Physicist, Lawrence Livermore National Laboratory.
Dr. John Malik, Staff Member, Los Alamos National Laboratory.
Mr. Jess Marcum, Consultant, R & D Associates.
Mr. Edgar Mendelsohn, Staff Physicist, Lawrence Livermore National Laboratory.
Mr. Joseph V. Pace, III, Staff Scientist, Computing and Telecommunications Division, Oak Ridge National Laboratory.
Mr. William H. Scott, Jr., Assistant Manager, Radiation Transport Division, Science Applications International Corporation.
Mr. Paul P. Whalen, Fellow, Los Alamos National Laboratory.
Dr. William A. Woolson, Assistant Vice-President, Science Applications International Corporation.
DOE Liaison Officer: Mr. Wayne M. Lowder, Environmental Measurements Laboratory, Department of Energy.

Chapter 1. Yields of the Bombs

Most avenues to a determination of the neutron and gamma-ray doses at Hiroshima and Nagasaki start with the determination of the bomb yields as a basic measure leading to the total number of fissions in the sources and thereby, a measure of the source strength for prompt neutrons and gamma rays.

A number of different measures and some calculations provide information on the yields of the Hiroshima and Nagasaki bombs. The Nagasaki bomb was identical to ones studied at bomb tests where yields were determined by radiochemical evaluation of the debris in the fireball and by measuring the fireball expansion. All these measures gave yields between 20 and 22 kt and agree with a calculated yield of 22 kt.

The measurements that bear on the yield of the Hiroshima bomb or the ratio of the

Table 3. Members of the Research Team on Atomic Bomb Radiation Dosimetry of the Japanese Ministry of Health and Welfare.

Dr. Tadashi Hashizume (Chairman), Professor, Department of Radiology, School of Veterinary Medicine, Azabu University, and former Chief, Radiation Protection Section, Department of Physics, National Institute of Radiological Sciences.

Mr. Shoichiro Fujita, Research Associate, Department of Statistics, Radiation Effects Research Foundation.

Dr. Masaharu Hoshi[a], Instructor, Department of Radiation Physics, Research Institute for Nuclear Medicine and Biology, Hiroshima University (deceased).

Dr. Yoshikazu Kumamoto, Senior Investigator, Cyclotron Section, Division of Technical Services, National Institute of Radiological Sciences.

Dr. Takashi Maruyama, Chief, Radiation Protection Section, Physics Division, National Institute of Radiological Sciences.

Dr. Shunzo Okajima, Consultant, Radiation Effects Research Foundation, and former Director, Atomic Disease Institute, Medical School, Nagasaki University.

Mr. Yoshio Okamoto[b], Chief, General Affairs and Accounting Sections, Radiation Effects Research Foundation, Nagasaki

Mr. Hiroaki Yamada[b], Chief, Master File Section, Radiation Effects Research Foundation, Hiroshima (deceased).

[a]Appointed in 1981 to fill the committee position held by Dr. Kenji Takeshita, Professor, Department of Radiobiology, Research Institute of Nuclear Medicine and Biology, Hiroshima University (decreased).

[b]Involved in the early shielding history studies of the Atomic Bomb Casualty Commission.

yields of the two weapons, are a number of thermal effects such as surface melting of tiles, flaking of granite, and charring of telephone poles. These various measures are not very self-consistent and are suspect at large distances because of the attenuation due to the air but are consistent with a yield of 12 to 18 kt. The recommended yields for the two explosions are 15 kt for Hiroshima and 21 kt for Nagasaki.

Chapter 2. Calculation and Verification of Source Terms

Given the yield, it is then necessary to determine the number and the distribution in energy and angle of the neutrons and gamma rays emerging from the bomb case. The actual emission of neutrons and gamma rays from the bombs can be determined only by complex calculations of the transport and the accompanying hydrodynamics in the exploding bombs. These calculations were carried out at LANL and LLNL.

At LANL, a critical assembly was set up using parts of a bomb of the type exploded at Hiroshima, but with a reduced amount of ^{235}U. A number of measurements of neutron emission were conducted and compared to calculations made using the same technique as that used in the bomb explosions. These various calculated and measured neutron fluences now show good agreement at energies above 0.6 MeV and at all polar angles except 0° (nose direction) where the fluence is in any case very low.

Table 4. Members of the Panel on Reassessment of A-Bomb Dosimetry of the US National Academy of Sciences.

Dr. Frederick Seitz (Chairman), President Emeritus, Rockefeller University, and former President, National Academy of Sciences.

Dr. Michael A. Bender, Senior Scientist, Medical Department, Brookhaven National Laboratory.

Dr. Victor P. Bond, former Associate Laboratory Director for Life and Environmental Sciences, Brookhaven National Laboratory.

Dr. Merril Eisenbud, Professor Emeritus, Institute of Environmental Medicine, New York University Medical Center.

Mr. Charles M. Eisenhauer, Physicist, Radiation Physics Division, Center for Radiation Research, National Bureau of Standards.

Dr. Mortimer L. Mendelsohn, Associate Director Biomedical and Environmental Research, Lawrence Livermore National Laboratory.

Dr. William C. Roesch[a], retired, former Staff Scientist, Pacific Northwest Laboratory.

Dr. James H. Schulman, Consultant, National Materials Advisory Board, National Research Council - National Academy of sciences.

Dr. Warren K. Sinclair, President, National Council on Radiation Protection and Measurements.

Dr. Lewis V. Spencer, retired, former Physicist, Radiation Theory Group, Radiation Physics Division, National Bureau of Standards.

Dr. Arthur C. Upton, Professor and Chairman, Institute of Environmental Medicine, New York University Medical Center.

Dr. Harold O. Wyckoff, Principal Scientific Counselor, International Commission on Radiation Units and Measurements.

Staff Officer: Dr. William H Ellett, Board on Radiation Effects Research, National Research Council - National Academy of Sciences.

[a]Resigned in September 1986 to become Editor of *Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki. Final Report.*

A significant source of prompt gamma rays is the capture of neutrons by the nitrogen in air. These gamma rays are, therefore, controlled by the total neutron emission. Several independent measurements of the total neutron emission agreed with calculations. This provides a verification of the calculations of prompt gamma rays from the Hiroshima weapon.

As a result of these tests there is considerable confidence in the calculated neutron energy and angular distributions from the Hiroshima weapon.

Chapter 3. Transport of Initial Radiations in Air-over-ground

From the source of neutrons and gamma rays from the bomb, the radiations propagate through the air to the region where the dose is to be evaluated. Important input data for the calculations of dose are the location and height of the burst, the atmospheric density and humidity profiles, and the ground composition.

The propagation in air is a major computational effort, which can now be carried out

Table 5. Members of the Review Committee to Evaluate the Radiation Dose from the Atomic Bomb (Japanese Senior Dosimetry Committee).

Dr. Eizo Tajima (Chairman), Professor Emeritus, St. Paul's University, and Vice-Chairman, Nuclear Safety Commission.

Dr. Tadayoshi Doke, Professor, Science and Engineering Research Laboratory, Waseda University.

Dr. Tatsuji Hamada, Board Member, Japan Radioisotope Association.

Dr. Sohei Kondo, Professor, Atomic Energy Research Institute, Kinki University and former Professor, Department of Fundamental Biology, Medical School, Osaka University.

Dr. Toshiyuki Kumatori, Chairman, Radiation Effects Association, and former Director, National Institute of Radiological Sciences.

Dr. Nobuo Oda, Professor, Faculty of Science, Science University of Tokyo, and former Professor, Research Laboratory for Nuclear Reactors, Tokyo Institute of Technology.

Dr. Masanobu Sakanoue, Professor, Low Level Radiation Laboratory, School of Science, Kanazawa University.

Dr. Itsuzo Shigematsu, Chairman, Radiation Effects Research Foundation.

with considerable confidence for the radiations emitted from the bomb and for the gamma rays produced by neutron capture in the air.

The determination of the free-in-air kerma in tissue at various relevant distances up to about 2000 m ground range is an essential step in estimating the dose to the survivors at Hiroshima and Nagasaki.

In addition to the prompt radiations, there is a considerable contribution to the gamma-ray dose from delayed radiations from the fission products in the rising fireball. At a few bomb tests the gamma rays were measured as a function of time from a few tenths of a second to several tens of seconds. These measurements were used to verify models of the delayed gamma-ray calculation although the measurements do not deal with weapons of similar yield or similar height of burst to Hiroshima and Nagasaki. The final models of the delayed gamma radiation agree to about 10% with the time-dependent measurements at the weapon tests and lead to predictions at Hiroshima and Nagasaki that are expected to be accurate to better than 15%. The delayed neutrons appear to make a significant contribution to the thermal neutron activation in Nagasaki and an apparently smaller contribution in Hiroshima.

In Chapter 3, the free-in-air kermas in tissue for neutrons and gamma rays for the new DS86 calculations are compared with the T65D system. At Nagasaki, the gamma-ray kerma for DS86 is smaller than that for T65D by about 10 to 30%, depending on ground range; the DS86 neutron kerma is about one-half to one-third that of T65D.

At Hiroshima, the gamma-ray kerma for DS86 is larger than that for T65D by a factor ranging from about two to three and one-half, depending on ground range; the DS86 neutron kerma is about one-tenth that of T65D. A small part of these changes is due to a change in the yield used in the two dosimetry systems, from 12.5 to 15 kt. The rest of the change in the gamma-ray kermas (factors from 1.7 to 2.9) is due to changes in the method of determining

Table 6. Members of the Japanese Dosimetry Working Group.

The Japanese dosimetry working group is chaired by Dr. Eizo Tajima and consists of members of the Japanese Senior Dosimetry Committee (Table 5), members of a Research Team headed by Dr. Tadashi Hashizume (Table 3), and other investigators.

Mr. Shoichiro Fujita, Research Associate, Department of Statistics, Radiation Effects Research Foundation.

Dr. Tadashi Hashizume, Professor, Department of Radiology, School of Veterinary Medicine, Azabu Univeristy, and former Chief, Radiation Protection Section, Department of Physics, National Institute of Radiological Sciences.

Dr. Masaharu Hoshi, Instructor, Department of Radiation Physics, Research Institute for Nuclear Medicine and Biology, Hiroshima University.

Dr. Yoneta Ichikawa, Professor, Department of Physics, Nara University of Education, and former Professor, Department of Nuclear Science, Kyoto University.

Dr. Keiji Kanda, Associate Professor, Research Reactor Institute, Kyoto University.

Dr. Hiroo Kato, Chief, Department of Epidemiology, Radiation Effects Research Foundation.

Dr. Toshiso Kosako, Associate Professor, Research Center for Nuclear Energy, Tokyo University.

Dr. Yoshikazu Kumamoto, Senior Investigator, Cyclotron Section, Division of Technical Services, National Institute of Radiological Sciences.

Dr. Takashi Maruyama, Chief, Radiation Protection Section, Physics Division, National Institute of Radiological Sciences.

Dr. Tsuneto Nagatomo, Assistant Professor, Department of Physics, Nara University of Education.

Dr. Shunzo Okajima, Consultant, Radiation Effects Research Foundation, and former Director, Atomic Disease Institute, Medical School, Nagasaki University.

the kermas.

The estimated errors in kerma in tissue from delayed gamma rays are of the order of 10 to 20%; the estimated errors in total neutron and total gamma-ray kermas between 1000 and 2000 m in Hiroshima and Nagasaki should be in the 10 to 20% range, assuming the initial sources to be correct.

Chapter 4. Thermoluminescence Measurements of Gamma Rays

Thermoluminescence (TL) dosimetry has been developed in the last 30 years, and one of its goals was to evaluate the age of pottery specimens exposed to natural radiations. It has proved possible to use similar TL techniques to evaluate the gamma-ray dose delivered to small quartz inclusions in kiln-fired brick and tile taken from structures present in Hiroshima and Nagasaki at the time of the bombs. Such measurements were first made in 1963. Direct measures of the gamma-ray doses have been made at distances from the hypocenter of more than 2000 m, where the doses are about 20 rad. Recently, measurements were made by six laboratories, three in Japan, one in the United States, and two in England. These laboratories engaged in extensive intercomparisons and also in absolute calibrations. Measurements were made on a large number of well documented samples collected at various distances out to nearly 2100 m in Nagasaki and in Hiroshima.

Gamma-ray spectra at various distances in Hiroshima and Nagasaki were used and the sample in its actual location in a building was modeled in calculation of dose in the sample. The final results of this process give agreement in Nagasaki to within about 10% out to 1500 m, whereas they are within 25 or 30% out to 2100 m in Hiroshima.

Chapter 5. Measurements of Neutron Fluences

Shortly after the bomb exploded in Hiroshima, Japanese investigators measured the activity of ^{32}P induced by fast neutrons in sulfur used as glue on electric insulators at ground ranges out to 1000 m. The activity induced in cobalt impurities in iron and the activity of ^{152}Eu induced in rock by thermal neutrons was also measured.

The ^{32}P activity was measured by a Lauritsen electroscope. These data have recently been reexamined and reviewed and have been compared with calculations based on a bomb yield of 15 kt and the neutron spectrum calculated to have been emitted. Comparison of these measurements with calculations gives a yield of about 13 kt. Within the accuracy of the measurements, this agrees with the accepted 15 kt. It appears that further work will be needed before the thermal neutron activation data are understood. The results of the ^{152}Eu activation in rocks show a general correspondence with the calculations, but the experimental (and calculational) uncertainties are too great to permit an accurate evaluation of the neutron fluences.

Chapter 6. Radiation Doses from Residual Radioactivity

Fallout of fission products contributed additional irradiation to certain individuals in a few locations. The fallout was measured some weeks or months later and the initial activity could be inferred approximately providing storms had not washed away a large portion of the activity. Another source of irradiation was radioactivity induced in the ground and other materials present in the vicinity of the hypocenter by neutrons from the bombs. Survivors who entered the area within 1000 m from the hypocenter a few hours or days after the explosions could have received additional radiation from this source. Although it is generally agreed that the direct radiations dominated the radiation doses to survivors, there may have been some survivors who received significant doses from fallout or from induced activity. At the present time doses due to residual activity are not calculated by the DS86 system. It is recommended that the few individuals from areas of high residual radioactivity not be included in the nonexposed cohort for epidemiological studies.

Chapter 7. House and Terrain Shielding

Most survivors of the bombs in Hiroshima and Nagasaki who were close enough to the hypocenter to receive significant radiation doses were shielded in some way from the thermal effects of the bombs. This shielding may have been from a "typical" Japanese house, or by a wall or obstruction, or by terrain. Any shielding gave a reduction in dose compared with the dose received by a person in the open. To evaluate the shielding a computer model of a typical house and house cluster was constructed using the best information available about the dimensions and materials of actual houses or house clusters. Using adjoint Monte Carlo techniques, coupled to the free fields, the energy and angular distributions of neutrons and gamma rays was calculated at an arbitrary location inside or adjacent to the house cluster.

The technique has been validated by its use on the house and house clusters used in the BREN experiments in Nevada. This validation showed good agreement for gamma-ray measurements with a ^{60}Co source and a variety of house configurations and locations; good agreement for neutron measurements inside houses with a bare reactor source; but poor agreement for gamma rays measured inside houses exposed to the same neutron source.

The principal difference between the shielding calculated here and in T65D lies in the gamma-ray shielding. Both the measurements and the calculations of the gamma rays inside a house include the gamma rays produced by neutrons in the materials of the house. The gamma-ray transmission factor in T65D was taken to be 0.9. The present study gives 0.53 for prompt and 0.46 for delayed gamma rays at 1500 m ground range. The neutron transmission factors for houses in T65D averaged 0.32 whereas in this study it averaged 0.38.

The existing computerized files at RERF contain only limited sets of data on the location of shielding elements with respect to a survivor. One of these contains a set of so-called nine parameters. In the computer model 21 points in the six-house cluster and 40 in the tenement cluster were selected. For each point and for 16 different orientations with respect to the hypocenter, the nine parameters were assigned. Only five of the nine parameters appeared to be correlated well with the calculated transmissions.

Chapter 8. Organ Dosimetry

In order to make the maximum use of the information on each survivor, the actual dose delivered to each relevant organ is being calculated. The determination of dose at the site of any organ involves:

1. Selecting a phantom or calculational model appropriate for typical young and adult Japanese in the year 1945.
2. Methodology to compute energy and angular distributions for neutrons and gamma rays at an appropriate location in the phantom for the proper location of the survivor.
3. Determination of the kerma from the fluence and some aspects of the detailed structure of the organ.
4. Verification and validation by comparison with experiment and other calculations.

The method of calculation is the same as that used for the shielding calculations. An adjoint calculation of the radiation transfer through the phantom to the organ in question can be coupled to the appropriate energy- and angle-dependent fluence in the house to give the energy- and angle-dependent fluence at the organ site. Using 30,000 particle histories about 5% precision in kerma can be achieved. With 400,000 histories, precision in kerma better than 1% is possible. In the final system, 6,000 histories are needed per organ to calculate dose and about 40,000 histories to calculate the spectrum. The organs chosen for dosimetry in DS86 are active marrow, bladder, bone, brain, breast, eye, fetus/uterus, large intestine, liver, lung, ovary, pancras, stomach, testes, and thyroid.

Chapter 9. Dosimetry System 1986

This chapter describes the computerized Dosimetry System 1986 (DS86), for calculating the organ doses received by A-bomb survivors. DS86 incorporates state-of-the-art computations and models describing the yield and radiation output of the bombs, the free-field radiation environment, the shielding by Japanese houses and "globe" cases, and the body shielding to the various organs.

The shielding data bases include, at present, models for all survivors with nine-parameter shielding and all survivors with globe-data shielding descriptions. It is intended to add a module to describe factory shielding later in 1987.

The DS86 system is based on the present status of A-bomb dosimetry. As new knowledge or data become available revision may become necessary, but no major changes are expected. DS86 was reviewed by the Japanese and US oversight committees on 16 and 17 March 1986 and recommended for use at RERF. It was adopted by RERF shortly after and is now being used in the estimation of radiation dose to survivors.

Uncertainty Analysis

It is planned to provide a thorough discussion of errors, uncertainty, and sensitivity in a future report. This analysis has not yet been carried out except in parts.

For complete texts of the HISTORICAL REVIEW and EXECUTIVE SUMMARY see Volume 1.