REPORT OF THE JOINT SENIOR REVIEW GROUP FOR DS02

PREFACE

During 2002, the Ministry of Health, Labour and Welfare (MHLW) of Japan and the Department of Energy (DOE) of the United States appointed a Joint Senior Review Group (JSRG) to examine and approve, if appropriate, a new dosimetry system for the atomic-bomb survivors, known as DS02, to replace the existing dosimetry system at the Radiation Effects Research Foundation (RERF) in Hiroshima and Nagasaki, known as DS86.

The membership of the JSRG was as follows:

for Japan	
Dr. Wataru Mori, Co-Chairman	President, The Japanese Association of Medical Sciences, Tokyo
Dr. Tatsuji Hamada	Adviser, Japan Radioisotope Association, Tokyo
Dr. Hiromi Hasai	President, Hiroshima Kokusai Gakuin University, Hiroshima
Dr. Ohtsura Niwa	Professor, Kyoto University Radiation Biology Center, Kyoto
for the U.S.	
Dr. Warren K. Sinclair Co-Chairman	President Emeritus, National Council on Radiation Protection, Bethesda, Md., Emeritus Professor, University of Chicago, retired, Escondido, Ca.
Mr. Harold L. Beck	Environmental Measurements Laboratory (DOE), New York, retired, New York, NY
Dr. Richard E. Faw	Emeritus Professor of Mechanical and Nuclear Engineering, Kansas State University, retired, Winston-Salem, NC
Dr. Nolan E. Hertel	Professor of Nuclear Engineering and Health Physics, Georgia Institute of Technology, Atlanta, Ga.

The group met first on January 21-23, 2003 at the California Institute of Technology in Pasadena, California, together with representatives of the Working Groups of Japan and the U.S. (led by Dr. Hasai and Dr. Young, respectively). The meeting was chaired by Dr. Sinclair and Dr. Mori. It was attended by all members of the JSRG and the following members of the Working Groups: Japan; Dr. H. Hasai, Dr. S. Fujita, Dr. M. Hoshi, Mr. T. Imanaka; U.S.; Dr. R. Young, Dr. G. Kerr, Dr. R. Christy, Dr. H. Cullings, Dr. S. Egbert, Mr. D. Kaul, Mr. R. Santoro, Dr. T. Straume, Mr. S. White; Germany; Dr. W. Rühm.

Dr. B. Bennett, Chairman, and Dr. S. Taira, Vice Chairman, attended for the Radiation Effects Research Foundation (RERF). Dr. M. Kato for the Japanese Ministry of Health, Labour and Welfare (MHLW) and for the U.S. Department of Energy (DOE)—Ms. B. Cook (Assistant Secretary for Environment, Safety and Health), Mr. A. Kindrick (Office of Assistant Secretary for Environment, Safety and Health), Mr. S. Cary (Deputy Assistant Secretary, Office of Health Studies) and Dr. J. Weiss (Japan Program Manager, Office of Health Studies).

The JSRG members met again in Tokyo at the Hotel Heart Inn Nogizaka on March 14-15, 2003, with Dr. Mori and Dr. Sinclair serving as co-chairmen. All members of JSRG were present. Others present included Dr. Young, Dr. Kerr and Dr. Cullings for the U.S. Working Group, Dr. Hasai, Mr. Imanaka, and Dr. Fujita for the Japanese Working Group, Dr. Bennett and Dr. Taira for RERF, Dr. R. Takahara, Mr. T. Niki, Dr. M. Kato, Dr. N. Yoshino, and Mr. T. Nakano for MHLW.

The Pasadena meeting consisted mainly of detailed presentations by the U.S. and Japanese Working Groups on chapter items in the draft DS02 Working Group's report. The JSRG had received preliminary drafts prior to the meeting, describing the new calculations and new or revised corroborative measurements. There was much discussion from the floor. In the interval between meetings further questions and answers were exchanged between the Working Group authors and JSRG reviewers. The Working Groups submitted some additions and changes in the draft report to the JSRG prior to the Tokyo meeting. The Tokyo meeting was spent mainly in discussing these new drafts and especially the Executive Summary of the DS02 report as presented orally by Dr. Young. The Group also discussed, approved and adopted the text of the report of the JSRG, as follows.

SCIENTIFIC FINDINGS OF THE JOINT SENIOR REVIEW GROUP

Introduction

The draft report of the Working Groups of Japan and the U.S. on DS02 consists of

(1) Descriptions of the proposed new dose system itself; i.e., the revised calculations of the source terms and of the fluence of neutrons and gamma rays released as a function of energy, angle, height above ground, and distance from the epicenter, together with some new revised estimates of shielding of individuals at various locations.

(2) Descriptions of older and recent new measurements of gamma rays by thermo-luminescence methods (TLD) and of neutron doses inferred from the activation of materials exposed at known distances from the hypocenter by several methods including those of the radionuclides ^{152}Eu, ^{60}Co, ^{36}Cl, ^{63}Ni and ^{32}P. These measurements are used to validate the new DS02 gamma-ray and neutron fluence calculations.

DS02 Dosimetry System

The main features of the new dosimetry system DS02 are:

1. Calculations

Energy spectra and angular distributions of neutrons and gamma rays issuing from the Hiroshima and Nagasaki weapons have been calculated using the most recent re-evaluated cross-section data and 3-dimensional codes more powerful than the 2-dimensional codes used in DS86. These new calculations resulted in only minor changes from DS86, notably increases in the low-energy and high-energy tails of the spectra. A very accurate simulation of the effect of the tilt of the weapon on the close-in neutron fluence is now possible. Revised

calculations of the delayed gamma rays and neutrons from the fireball were also carried out using data not available at the time DS86 was published.

Both discrete ordinate and Monte Carlo methods were used to re-evaluate the air-over-ground fluence as a function of distance from the epicenter, the neutrons and gamma rays being grouped into a much larger number of energy bins compared to the calculations in DS86, thus providing much improved energy and angular resolution. The transport calculations of these radiations through air over ground were performed for the weather conditions at the time of the explosion, again using improved cross sections compared to those used in DS86. The effects of local variations in soil moisture and ground composition were also investigated. Although the new DS02 is based on the discrete ordinates calculations, the Monte Carlo calculations by independent investigators offer a powerful verification of the new air-over-ground fluences.

2. Hiroshima parameters

Based on detailed reviews of the appropriate evidence by the Working Groups, new parameters have been adopted for some of the key features of the explosion at Hiroshima. These included adjustment of the yield of the Hiroshima weapon to 16 kt (from 15 kt) the height of the burst (HOB) for the Hiroshima weapon to 600 m (from 580 m) and the adjustment of the hypocenter to a position 15 m west of the former position.

3. Gamma-ray and neutron fluences

New air-over-ground calculations together with newly revised fluence to dose factors resulted in re-calculated estimates of the free-in-air doses from the Hiroshima weapon of about 8-10% average increase over DS86 in the total gamma-ray doses, and about 10% increase in the average neutron doses but approximately the same variation of dose with distance from the hypocenter as in DS86. Increasing the height of burst and incorporating new information on exact locations of sites relative to the epicenter did, however, improve the agreement with measurements near the hypocenter and with the slope of measurement data vs. distance.

4. Organ or tissue doses

The gamma-ray and neutron doses to organs or tissues in the body of an individual survivor are less than free-in-air tissue kermas because of structural shielding of that survivor and shielding by his or her body tissues. Adjoint methods are used as in DS86 to determine revised individual tissue and organ doses. To present this process in manageable form, transmission factors applied to each individual circumstance have been established for both gamma rays and neutrons. The tissue kerma factors used in DS86 were re-evaluated for this study and will be incorporated into the new DS02 system.

5. Gamma-ray doses dominate

The gamma rays account for the preponderance of absorbed radiation doses to the survivors, the neutron absorbed dose at most organ depths (and distances from the hypocenter) being about 1% of the gamma-ray absorbed dose at Hiroshima. (Note that the equivalent dose from the neutrons depends on the appropriate RBE for the neutrons, e.g., an RBE of 20 would yield an equivalent dose for the neutrons of perhaps 20% of the total equivalent dose.) In future risk estimations the neutron contribution at Hiroshima, about 4 times that at Nagasaki, should be

accounted for. Because the new DS02 fluences do not differ by much from those in DS86, one would not expect large changes in organ dose estimates for individual survivors. However, improved estimates of shielding and survivor location may result in some changes in the organ doses to some survivors. These changes will be made as part of the installation of DS02 at RERF.

6. Nagasaki parameters

Recalculations were also performed for the Nagasaki weapon using the same methods as for Hiroshima. In this case no change in the explosion parameters was deemed necessary—the yield still at 21 kt, HOB 503 m, hypocenter unchanged. Nevertheless, as a result of the improved delayed source calculations and improved air-over-ground transport, the gamma-ray doses increased by about 10-12% and the neutron doses decreased on average about 17% compared to DS86.

7. Map alignment and referencing

In DS86 survivor locations and sample collection sites were based on U.S. Army maps of the 1940s. Larger scale and more precise Japanese city plan maps have become available, offering a new template for map work at RERF. Geo-referencing each U.S. Army map into the new city plan maps has permitted the DS02 system to be based on and to employ much more accurate survivor and sampling locations, especially for Hiroshima.

8. Shielding re-evaluations

At Nagasaki, the factory workers' shielding was re-evaluated, which lowered the earlier estimates of dose for those survivors (∗see below). Other structural shielding estimates made in DS86 were also re-evaluated, remodeled and revised. Estimates of shielding are still very uncertain however, due to lack of specific information regarding the shielding of some individuals. Similarly, some special shielding adjustments were made based on new model calculations for large terrain features, for example at Hiroshima for the survivors behind Hijiyama, where the hill shielded them from some of the radiation trajectories.

9. Uncertainty analysis

The DS02 will include a comprehensive uncertainty analysis evaluating all sources of systematic and random uncertainty. DS86 lacked such a study, and the National Academy of Sciences senior committee in 1987 strongly supported inclusion of such an analysis in a future revision of the dosimetry system (NAS-NRC 1987).

Furthermore, although a thorough, critical study of the various important biological endpoints examined in the atomic-bomb survivors in recent years (e.g., chromosome aberrations and ESR analysis of doses in teeth) would be very useful, it has not been undertaken as part of the DS02 work. However, it is noted by the JSRG that the biological studies to date broadly confirm both the organ doses estimated in DS02 (see NAS-NRC 2001) and possibly the range of the uncertainties determined in this study (Working Group Report Chapter 13).

∗ The Working Group suggests the following sentence be added for better understanding: However, other changes in the reassessment left the dose for this group of survivors essentially the same as in DS86.

This uncertainty analysis indicates that the major contributor to the overall uncertainty in the dose to any particular individual is the error or uncertainty in the position and orientation of the individual at the time of the explosion and in the radiation attenuation provided by structures around the individual.

Neutron and Gamma-Ray Measurements

The new DS02 calculated fluences are strongly supported by new or re-evaluated measurements. These comparisons are described in a number of chapters of the Working Group report. The results are summarized below.

1. Gamma rays

   Gamma-ray measurements made in thermoluminescent materials, such as roof tiles, etc. used in DS86 to confirm the gamma-ray calculations, have increased in number and quality over the years and have been carefully reviewed in DS02. Agreement between these measurements and DS02 calculations is very good, better than for DS86.

2. Thermal neutrons

   A wealth of measurements of materials activated by thermal neutrons from the explosion is available for comparison with DS02 calculations as compared with the rather few measurements of ^{152}Eu and ^{60}Co available originally at the time of DS86. These now include both new and older re-evaluated measurements from Japanese and American investigators of ^{152}Eu in roof tiles, granite pillars and rocks, ^{60}Co in steel in concrete reinforcements, and measurements of ^{36}Cl in granite or concrete. Extensive ^{36}Cl measurements have been carried out in the U.S., in Japan and in Germany on samples from Hiroshima and Nagasaki. Previously reported (1990s) ^{36}Cl data have been re-evaluated and problems identified, which led to new and improved measurements.

3. Fast neutrons

   Most importantly (because fast neutrons contribute directly to the neutron dose, while thermal neutrons do not and are also heavily influenced by local effects such as moisture) fast neutron activation of ^{63}Cu to ^{63}Ni(n,p) has recently been measured in samples from Hiroshima by accelerator mass spectrometry in both the U.S. and Germany and by measurements of the radioactivity of ^{63}Ni ($T_{1/2}$ = 100 y) made in Japan. These new measurements are in striking agreement with DS02 calculations, although some questions about the composition of the measured fast neutron background remain. Older measurements of fast neutron activation of ^{32}S to ^{32}P(n,p) made soon after the explosion at Hiroshima have been re-evaluated and demonstrate agreement with calculation.

4. Measurement uncertainties

   These neutron activation measurements, many made so long after the event, are intrinsically uncertain and subject to many, many experimental difficulties, especially as the samples extend outward from the hypocenter and the signal in the sample becomes weaker and more difficult to distinguish from background signals and noise. Background features and measurements at great distances then become very important.

5. New measurements

   However, some excellent new studies of activation have been made such as those of Komura of ^{152}Eu in the low background facility at Kanazawa University. A careful intercomparison for ^{152}Eu and ^{36}Cl measurements involving Japanese, U.S. and German scientists using both new and re-evaluated data and appropriate background corrections showed good agreement. This provided strong confirmation of the new calculated DS02 fluences over a wide range of distances from the epicenter.

6. Measurement and calculation

   Generally speaking and embracing the work of many investigators, Japanese, German and American, the measurements of thermoluminescence and neutron activation taken as a whole agree very well with the DS02 calculations up to distances from the hypocenter where measurements become indistinguishable from background.

7. Resolution of the neutron-dose anomaly

   Previous reports, including DS86, suggested that measured neutron fluences differed from calculations, being less close to the hypocenter and greater and increasing with distance at large distances from the hypocenter. Refinement of fluence calculations, especially those at short range influenced by height of burst at Hiroshima and at long range by reduced background and by more extensive background measurements have reconciled previously reported differences between calculations and measurements. The JSRG therefore is pleased to note and support the assertion that the neutron excess at large distances suspected after DS86, no longer exists.

COMMENTS AND RECOMMENDATIONS

1. The JSRG (Joint Senior Review Group) is impressed with the wide ranging and thorough DS02 study of the recalculated survivor dosimetry and finds it very comforting that the much more detailed calculations possible with today's more powerful computers using state-of-the-art codes and cross sections resulted in only relatively small changes in the doses predicted by DS86 calculations. These changes, with correction for yield, height of burst and tilt of the weapon at Hiroshima now show improved agreement with measurements.

2. The measurement data now include new thermal neutron activation studies of ^{36}Cl to add to those of new and revised measurements of ^{152}Eu and ^{60}Co. These, together with the new fast neutron activation studies of ^{63}Ni in ^{63}Cu, are in remarkable agreement with calculation, considering the difficulties and uncertainties involved in such measurements.

3. The JSRG notes that all the advisory recommendations of a recent U.S. NAS-NRC Panel reviewing DS86 (NAS-NRC 2001) that are pertinent to DS02 have been carried out in the new work.

4. The JSRG is convinced the new DS02 system is distinctly superior to the present DS86 and state-of-the-art in all respects and that future changes in the fluence calculations in DS02 are

unlikely to be of sufficient magnitude to warrant further revisions in the basic system for calculating doses to survivors by RERF.

5. The JSRG strongly recommends that the DS02 system be installed at RERF as soon as possible to provide improved survivor doses, replacing those presently based on DS86. The JSRG also recommends that (1) in DS02 the 40,000-history adjoint files for organ doses replace the 10,000-history files used in DS86, and (2) adjoint files for the 1st-, 2nd-, 3rd-trimester fetus be computed and incorporated into the DS02 system.

6. The Senior Group recommends that the report of the Joint Working Group be published promptly by RERF and widely disseminated. The JSRG also encourages the authors of the report to independently publish their work in the peer-reviewed literature.

7. The JSRG has based its conclusions and recommendations not on peer review of all the details in the reassessment but on its overall assessment of the information reported to it and in the presentations made by Working Group members.

8. The JSRG wishes to congratulate all those investigators who contributed to the successful work of DS02 and especially the leadership of Dr. Robert Young and Dr. Hiromi Hasai on what the JSRG considers to be a fine achievement. DS02 is a major advance in the critically important dosimetry for survivors in Hiroshima and Nagasaki, and together with the health and mortality data, will provide a firmer basis for risk assessment of radiation effects than had been possible heretofore.

References

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