Ⅱ Dosimetry

1 Physical dose measurement

A Dosimetry System 2002 (DS02)

Summary

The new dosimetry system DS02 was finalized in 2003, following revision of DS86. When DS86 was selected for use, certain discrepancies in measured values compared with DS86 computed values had already been pointed out, including low measured values of thermal-neutron-generated radioactive cobalt-60 (Co-60) at distances of less than 1 km from the hypocenters and high values at distances of greater than 1 km. Since the establishment of DS86, data based on new measurements of thermal neutrons of europium-152 (Eu-152) and other isotopes in addition to Co-60 were obtained. Similar to the Co-60 results, such measurement values were about half of those calculated by DS86 at proximal distances and about five times as high at distal locations. Therefore, an investigation into the cause of disagreement with the DS86 calculations was initiated and first took the form of an independent Japanese study, but later it was conducted jointly by Japan and the U.S. Ultimately, the two countries established the U.S.-Japan Joint Senior Review Group to which the Joint U.S.-Japan Working Group reported the results of its investigation, with procedures for the new system's approval initiated thereafter. In this way, causes of the discrepancies were investigated from a variety of perspectives.

Recalculation of spectra and fluences and of transport measurements for the radiation source peak of the atomic bombings then took place. The numbers of categories for such energies and angle distributions were increased, enabling more accurate calculations to be performed. Therefore, precision of the calculations was enhanced with DS02, but no substantial changes had been necessary when DS02 calculated values were compared with DS86 calculations. Detonation heights also were reinvestigated on the basis of numerous reports conducted in the past that had estimated detonation heights from shadows created by bridge railings and other objects. The detonation height in Hiroshima was increased to 600 m from the previous 580 m, whereas the height in Nagasaki, with no clear rationale for change, was kept at 503 m. By raising the height of detonation in Hiroshima by 20 m with DS02, it was found that calculated values decreased to where they were in agreement with the proximal measurements for distances of 1 km or less from the hypocenter. Measured values of thermal neutrons were investigated, including re-measurements of chlorine-36 (Cl-36), Eu-152, Co-60, and nickel-63 (Ni-63), leading to an understanding that the problems involving proximal distances in the past were resolved by the height increase. However, the cause of the higher measured values at distal locations remained unclear. For that reason, investigation into the various factors related to the calculated and measured values was undertaken. The measured Cl-36 results were announced in 2001 and the Eu-152 results in 2003, and those values were in agreement with the isotope calculations, prompting a meeting of the joint U.S.-Japan Working Group at which it was agreed that the past issues had been resolved.

U.S. army maps, the most accurate maps during the World War II period, were used to confirm survivor location, but discrepancies of as much as 30 m existed in some areas between these maps and the precise Hiroshima city planning maps. These differences were

subsequently corrected, however, and in that way, the sample and hypocenter locations were accurately recorded. With regard to calculations of shielding, shielding effects due to topography and buildings were reassessed. Reassessments of all neutron and γ-ray measurement values and detonation heights ultimately resulted in parameters by which all such values were in perfect agreement, and error analyses of individual A-bomb survivor dose calculations were carried out.

In this way, with regard to the discrepancies between the DS86 and DS02 calculated values, raising the detonation height 20 m led to consistent values observed for proximal distances of 1 km or less, with good consistency obtained for the re-measured more distal locations. Comparing the accuracy of the calculations made with DS86, DS02 versions of the dosimetry system had improved markedly, and as a result, no substantial changes had been necessary to the dosimetry system itself. In terms of revisions exerting effects on estimated radiation risks, DS02 represents an increase of about 10% in γ-ray values for both Hiroshima and Nagasaki compared with those derived with DS86, results that were analyzed by RERF. After deliberation on the results by the International Commission on Radiological Protection (ICRP), appropriate changes will be incorporated in radiation risk calculations.

B Residual radiation

Summary

Atomic bomb residual radiation is classified into two different types: (1) induced radioactivity contained in soil as well as buildings and other materials induced by A-bomb neutrons, and (2) fission products dispersed in the atmosphere. Research into radiation doses from residual radiation to which people were exposed, and the effects of such exposure, has been conducted continuously by many scientists, from immediately after the bombings to the present day. Direct measurements of radioactivity were carried out immediately after the atomic bombing of Hiroshima in a proximal range within about 3 km from the hypocenter in the old districts of the city along its delta region. Radioactive activation and fission products from the cloud formed by the explosion are thought to have fallen to earth in the area from that distance to points around 30 km further out by precipitation in the form of black rain and even in regions beyond that distance, but direct measurements were not made in such areas. For that reason, no investigation of a statistical nature similar to that of DS02 has ever been conducted to assess radiation doses in these regions or to investigate human health effects of such exposure.

Radiation doses from residual radiation have been assessed as part of the DS86 and DS02 investigations, but because the estimated doses are small compared with those generated by the direct explosions and because obtaining information necessary to make radiation dose assessments for individuals is exceedingly difficult, residual dose information was not included in the DS02 system.

As for both internal and external exposures caused by residual radiation, it is often the case that, even were it possible to estimate doses, they would be too small to imply any detectable effects. Nevertheless, some reports have indicated symptoms of epilation in survivors who were exposed distally at distances of at least 2 km from the hypocenters. From the perspective of research into radiation dose assessment, studies into the still inconclusive aspects of the effects of internal exposure (including beta-particle exposure) from residual radiation are considered essential.

2 Biological dose estimation

A Chromosomal aberrations

Summary

A cytogenetic study of A-bomb survivors was initiated in 1967 among members of the Adult Health Study (AHS) program at RERF. Because more than 20 years had passed since the atomic bombings by the time the study was initiated, easily identifiable unstable chromosomal aberrations had mostly disappeared from the peripheral blood of the survivors, leaving stable chromosomal aberrations (mainly translocations) the only choice for study. From the start of the investigation through 1993, a simple Giemsa-staining method was used; it was replaced with the fluorescence in situ hybridization (FISH) method in 1994. The objective of the study is to derive biological dose estimates using chromosomal aberrations as markers. Results from such methods are used to assess and complement the physically estimated doses in individual survivors, which are calculated from such exposure information as distance from the hypocenter and shielding conditions. Research findings to date as of this writing (2011) are: (1) peripheral T lymphocytes of A-bomb survivors more than 60 years after the bombings still contain stable chromosomal aberrations; (2) the average frequency of such aberrations increased significantly with increasing radiation dose; (3) chromosomal data from individual survivors display excessive dispersion when plotted against physical dose estimates; (4) the dose response shape differs by shielding category, which indicates that systematic error may be present in the physically estimated doses; and (5) a difference in the dose responses between Hiroshima and Nagasaki observed with the Giemsa-staining method greatly diminished after the FISH method was introduced, hinting at the distinct possibility that the previously identified inter-city difference was actually due to variation in the rates of aberration detection between laboratories (observer bias). The FISH method continues to be used in such studies today.

B Electron spin resonance (ESR) using tooth enamel

Summary

A technique known as electron spin resonance(ESR; or electron paramagnetic resonance, EPR) has made possible the assessment of radiation doses through the measurement of the carbonate (CO_3^-) radical in tooth enamel. Findings from research conducted to date on the A-bomb survivors have shown good correlation between doses estimated on the basis of chromosome aberrations in blood lymphocytes and those estimated using ESR performed on molars of the same survivors (for both, the estimates are Co-60 γ -ray equivalent dose). However, plotting ESR estimated doses or chromosome-based estimated doses against DS02 individual dose estimates leads to a decrease in the degree of this correlation. This deterioration in correlation is hypothesized to be the result of certain inaccuracies in individual information at the time of A-bomb exposure used in the DS02 calculations, while not much is known about possible biases in DS02 individual dose estimates.

One may ask why cytogenetic data cannot provide information on possible bias This is because there exists no method to know retrospectively the stage of differentiation at

which the lymphocytes under investigation were exposed to radiation. The blood lymphocyte population is heterogeneous with respect to stage of differentiation at the time of irradiation, ranging from hematopoietic stem cells to mature lymphocytes. Because radiation sensitivity may also vary depending on the stage, chromosomal aberration data do not allow us to calculate radiation dose received. In contrast, the ESR technique has the advantage of estimating A-bomb γ-ray dose by correcting the observed Co-60 γ-ray equivalent dose with energy-dependency in the ESR yield. A disadvantage of the ESR method is the difficulty obtaining teeth from study participants; hence large numbers of people cannot be studied, in contrast to the great numbers possible with chromosome testing. It is anticipated that regression analysis can be undertaken between the ESR-derived A-bomb γ-ray dose and the translocation frequency in the same study participants, which provides a function for estimation of A-bomb γ-ray dose from chromosomal aberration frequency. In other words, for the roughly 4,000 A-bomb survivors who have undergone chromosomal testing up to this point in time, estimation of A-bomb γ-ray doses will become possible, opening a path to the potential for assessing average biases (in direction and quantity) inherent in DS02 dose estimates.