Paper published in *Radiation Research*[§]

"Accounting for Neutron Exposure in the Japanese Atomic Bomb Survivors"

Harry M. Cullings, Donald A. Pierce, Albrecht M. Kellerer
Radiat. Res. 2014 (December); 182(6): 589-98
(doi: 10.1667/RR13663.1)

Study Findings

The atomic bomb radiation exposures consisted of primarily gamma rays and a much smaller amount of neutrons. It is well known that neutrons have a larger biological effect per unit of dose than gamma rays or x-rays. The degree to which the effect is greater is known as the relative biological effectiveness (RBE). Some experimental studies have indicated that the RBE values may be greater at low doses of neutrons and gamma rays than at higher doses (that is, a "variable RBE" according to dose level). This study showed that total doses calculated for the atomic bomb survivors studied by RERF do not depend critically on the RBE that is assumed for the neutron portion of the dose, even when a hypothetical variable RBE is applied. This may reduce some concerns raised by investigators who have advocated the importance of variable RBEs in estimating risk at low doses. Furthermore, in some cases the variable RBEs have not been correctly estimated for the mixed neutron and gamma-ray exposure of the atomic bomb survivors.

Explanation

The atomic bomb survivors followed by RERF were directly exposed to both gamma rays and neutrons, with the absorbed dose from neutrons being a small fraction of that from gamma rays in all cases. The main interest of RERF studies is typically to estimate risks from the much larger gamma-ray component of dose, but the risk estimation must be based on an adjusted gamma-ray dose that is equivalent to the combined dose that the survivor received from both gamma rays and neutrons. This equivalent dose is calculated as the sum of the gamma-ray dose plus the neutron dose times a weighting factor that accounts for the greater biological effect of the neutrons per unit dose. The weighting factor used is the RBE of the neutrons.

Because the neutron doses and gamma-ray doses received by the survivors were highly correlated, the neutron RBE cannot be reliably estimated from the survivors' data, and information from radiobiology must be invoked. For many years, RERF has used a constant neutron RBE value of 10, even though radiobiological studies indicate that the RBE takes on considerably larger values at low doses. The use of a constant RBE = 10 as an approximation assumes that if the RBE is variable it takes roughly this value in the range of total dose most relevant for estimating risk as a linear function of dose, namely about 1 Gy. This paper considers some possible RBE functions to explain the correct use and the impact of a dose-dependent RBE.

However, the authors do not advocate a particular choice or even that a variable RBE be employed. Rather they show that the assumed neutron RBE, within a wide range of choices, is far less important to the outcome of risk assessment of the RERF data than has generally been believed. Some of these misperceptions have been related to the consideration of variable RBE functions without due attention to the fact that in the case of the A-bomb survivors' data, the mixed field of neutrons and gamma rays must be considered. In such mixed fields, the RBE value of neutrons is much lower than the RBE in pure neutron fields that are used in radiobiological experiments.

This paper shows that applying the pure-neutron-field RBE to the mixed-field A-bomb radiation can lead to an overestimation of the actual neutron RBE for moderate total dose levels of 1 Gy by a factor of more than four. While in a pure neutron exposure the RBE depends on the neutron dose, and in the mixed field it generally depends on both components of exposure, this

paper shows that in the RERF setting the RBE depends mainly on the accompanying gamma-ray dose. This is primarily because the individual neutron doses are so much smaller than the corresponding gamma-ray doses.

The Radiation Effects Research Foundation has studied A-bomb survivors and their offspring in Hiroshima and Nagasaki for more than 60 years. RERF's research achievements are considered the principal scientific basis for radiation risk assessment by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and for recommendations regarding radiation protection standards by the International Commission on Radiological Protection (ICRP). RERF expresses its profound gratitude to the A-bomb survivors and survivors' offspring for their cooperation in our studies.

[§]***Radiation Research***, which is an official monthly journal of the Radiation Research Society, publishes original, peer-reviewed papers and review articles on radiation effects and related issues in the fields of physics, chemistry, biology, and medicine. (Impact factor in 2013: 2.445)