

Health Effects of Internally Deposited Radionuclides

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Abstract

A comparative evaluation has been conducted of the ionizing radiation dose-response relationships in both human and laboratory animal studies involving internal deposition of radionuclides including alpha-emitters Ra-226, Pu-238, Pu-239, and Am-241 and beta-emitters Sr-90, Y-90 and Ce-144. Intake routes included inhalation, injection, and ingestion. Observed radiation-induced cancer rates were contrasted with the current ICRP risk estimates.

The preeminent importance of dose rate was revealed in this analysis. The lifetime effects of the ionizing radiation from internal emitters are best described by three-dimensional dose-rate/time/response surfaces that compete with other causes of death during an individual's lifetime. Using maximum likelihood survival regression methods, the characteristic logarithmic slope for cancer induction was found to be about negative one-third for alpha-emitters or about negative two-thirds for beta-emitters. The relative biological effectiveness (RBE) of alpha radiation for cancer induction is a strong function of dose rate with the effectiveness of the beta irradiation dropping off more rapidly than that of the alpha irradiation as average dose rate decreases. The apparent RBE of alpha versus beta is near one at high dose rates and greater than 30 at low dose rates. The cumulative dose required to yield any level of induced-cancer risk is less at lower dose rates than at higher dose rates showing an apparent inverse-dose effect (up to a factor of 10 for high LET alpha radiation and a factor of 3 for low LET beta radiation).

The competing risks of death associated with radiation injury, radiation-induced cancer, and natural aging are graphically shown using three-dimensional illustrations. At the higher average dose rates the principal deleterious effects are those associated with radiation-induced injury while at intermediate average dose rates radiation-induced cancer predominates. At the lower average dose rates the long latency time required for radiation-induced cancer may exceed natural life span, yielding an apparent lifespan effective threshold for death associated with radiation-induced cancer for cumulative doses to the target tissue below from 1.1 to 1.4 Gy for alpha-emitters or below from 28 to 130 Gy for beta-emitters, depending on the target organ and the distribution of the deposited radionuclide. An apparent lifespan effective threshold for radiation-induced cancer occurs for lifetime total alpha radiation doses below 1 Gy for people, beagles, and rodents for bone cancer from Ra-226 or for lung cancer from Pu-239.

ICRP cancer risk estimates were found to be appropriate at higher cumulative doses but to over-estimate the risk for low cumulative doses delivered at low average dose rates for both beta and alpha internal radiation exposures.