Interagency Steering Committee on Radiation Standards

Final Report

A Method for Estimating Radiation Risk from Total Effective Dose Equivalent (TEDE)

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A Method for Estimating Radiation Risk from TEDE

Summary

For external sources of low linear energy transfer (LET) radiation that provide nearly uniform irradiation of the body, the risk of cancer incidence (morbidity) and mortality as a function of external dose can be closely approximated using the conversion factors of 8×10^{-2} risk per sievert and 6×10^{-2} risk per sievert respectively. The documentation for these conversion factors can be found in "Estimating Radiogenic Cancer Risks" and its "Addendum: Uncertainty Analysis."[1] These conversion factors can also provide a generally high-sided, but less accurate, estimation of risk from internal dose. A discussion of the sources and limits of this conservatism is presented in the discussion below. Using these factors to convert internal effective dose equivalent to cancer risk may be appropriate when radionuclide-specific data is missing. The conversion of dose to risk referred to in this document refers primarily to a conversion of total effective dose equivalent (TEDE, as defined by the Department of Energy in 10 CFR 835.2)[2] to lifetime cancer incidence and mortality risks. The conversion of TEDE to cancer risks using these conversion factors will not satisfy the requirements for a comprehensive radiation risk assessment, but may be of use for making less rigorous comparisons of risk. For situations in which a radiation risk assessment is required for making risk management decisions, the radionuclide-specific risk coefficients published in Federal Guidance Report No. 13 should be used.[3] For radiation risk assessments required by EPA's Superfund Program, the risk coefficients in EPA's Health Effects Assessment Summary Tables (HEAST)[4] should be used. Although based on the values in FGR 13, the HEAST risk coefficients (slope factors) are for calculating cancer incidence only; include a risk coefficient for soil ingestion; and use traditional units (i.e., picocuries instead of becquerels for activity).

Discussion

The Environmental Protection Agency has published radionuclide-specific risk coefficients (also called slope factors in the Superfund Program) in Federal Guidance Report No. 13 (FGR 13), "Cancer Risk Coefficients for Environmental Exposure to Radionuclides" (EPA 402-R-99-001, September 1999). This report includes separate coefficients for water and food ingestion, inhalation, and external exposure for over 800 radionuclides. These values, along with an additional soil ingestion coefficient, are also presented in the Health Effects Assessment Summary Tables (HEAST) where they are referred to as slope factors. These risk coefficients are recommended for use whenever a quantitative risk assessment is required. There are also times when it is useful to make a general qualitative statement about the risk associated with dose, which in the United States at present is expressed as effective dose equivalent (H_E).

The dose quantity H_E is a risk-weighted mean of the dose equivalent for selected groups of organs and tissues. The values of the weighting factors are defined in International Commission on Radiological Protection (ICRP) Publication 26 which considered nominal estimates of both genetic and cancer mortality risks due to ionizing radiation. The dose coefficients in FGR 11 are consistent with the methodology of ICRP Publication 30 which used age-invariant dose models considered appropriate at the time of its publication and the ICRP Publication 26 weighting factors in its calculations of annual limits on intake and derived air

concentrations for over 700 radionuclides. The cancer risk coefficients in FGR 13/HEAST are calculated using the more recent age-specific dose models developed for ICRP Publication 72 and its supporting publications with the age-specific radiation carcinogenesis models adopted by EPA. (In ICRP 60, the dose quantity, E, is called effective dose to distinguish it from the older quantity, H_E .) Thus the differences in dose models and the prescribed method for the calculation of H_E mean that there can be no unique relationship between the dose coefficients provided by FGR 11 and the risk coefficients provided by FGR 13/HEAST. Further differences arise due to the use of committed dose equivalent for calculating H_E and the use of age-specific high- and low-LET absorbed dose rates for calculating FGR 13/HEAST risks. Another complication for alpha particle emitting radionuclides arises from the use of site-specific relative biological effectiveness values (RBEs) in FGR 13/HEAST as opposed to using ICRP-specified quality factors, which by definition are independent of site, in determining H_E. There are additional factors that make a simple dose to risk conversion unsatisfactory, including the overestimation of H_E for bone-seeking transuranics, the use of a site-specific dose and dose rate effectiveness factor (DDREF), and a life table analysis to account for competing causes of death in FGR 13/HEAST. In short, it is not possible to convert a dose assessment made using FGR 11 dose coefficients into a risk assessment that will be consistent with FGR 13/HEAST.

For external sources of beta and gamma radiation (low LET) that provide nearly uniform irradiation of the body, these problems are greatly mitigated. For cancer incidence (morbidity) and mortality, factors of 8×10^{-2} risk per sievert and 6×10^{-2} risk per sievert may be used, respectively, to estimate cancer risk per H_E. Using these factors to convert internal effective dose equivalent, H_E, to cancer risk must include appropriate caveats as noted above.

An EPA internal document from March 1996[5] examined the degree to which the risk per unit dose for individual radionuclides agreed with a lifetime cancer incidence risk of 3×10^{-4} from receiving 15 millirem/year over 30 years. This relationship corresponded to the estimate at that time of about 7×10^{-2} risk per sievert (or 7×10^{-7} risk per millirem). For the reasons just described, a constant linear relationship between risk and dose is not expected. However, the analysis showed that almost all radionuclides were within a factor of ten of this relationship and most were within a factor of 3. The relationship between risk and dose for some of the bone-seeking transuranics represents the extreme, with the nominal conversion factors overestimating the risk by about a factor of ten. The radionuclides whose risks are underestimated by the given conversion factor do not exceed the predicted risk by more than a factor of 3. The important radionuclides in this category include Cs-137 (factor of 1.7 higher), Pu-244+D (includes all nuclides in secular equilibrium) and Tc-99 (both about a factor of 3 higher). From this analysis, it is reasonable to assume that the current risk to dose relationships are predictive to within about the same degree of uncertainty.

When radionuclide-specific data is missing, it is common to have dose recorded as the TEDE. This quantity is defined by DOE as the sum of the effective dose equivalent (external exposure) and the committed effective dose equivalent (internal exposure). TEDE can be estimated using the conversion factors for uniform low LET external radiation provided the

caveats mentioned above are acknowledged. In general, using these coefficients to convert TEDE to risk for a mixture of radionuclides will usually provide a high-sided estimate of risk.

These factors are recommended for comparison and qualitative presentations only. Only one significant digit should be presented in a calculated risk to avoid implying more certainty than is warranted. Table 1 (below) provides some comparisons between cancer risk coefficients calculated using FGR 11 dose coefficients with these approximations and those in FGR13.

Table 1. Nominal cancer risk coefficients for ingestion of a few radionuclides calculated from FGR 11 dose coefficients and a comparison between them and those in FGR 13.

Nuclide	FGR 11			Ratio($r_{FGR\ 11} : r_{FGR\ 13}$)			
	h_E	$r_{mt} = 0.06 \times h_E$	$r_{mb} = 0.08 \times h_E$	Tap Water		Dietary	
	(Sv/Bq)	(/Bq)	(/Bq)	mortality	morbidity	mortality	morbidity
H-3 (HTO)	1.73e-11	1.0e-12	1.4e-12	1.10	1.01	0.87	0.79
H-3 (org)	n/a			0.50	0.46	0.39	0.36
C-14	5.64e-10	3.4e-11	4.5e-11	1.17	1.07	0.92	0.84
Co-60	7.28e-09	4.4e-10	5.8e-10	1.59	1.37	1.13	0.97
Sr-90	3.85e-08	2.3e-09	3.1e-09	1.72	2.04	1.43	1.66
I-131	1.44e-08	8.6e-10	1.2e-09	6.60	0.94	4.67	0.66
Cs-137	1.35e-08	8.1e-10	1.1e-09	1.43	1.31	1.18	1.07
Po-210 (inorg)	5.14e-07	3.1e-08	4.1e-08	4.17	4.03	3.29	3.14
Po-210 (org)	n/a			0.87	0.86	0.69	0.68
U-238	6.88e-08	4.1e-09	5.5e-09	3.65	3.18	2.73	2.35
Pu-239	9.96e-08	6.0e-09	8.0e-09	2.10	2.19	1.65	1.70

Note that separate dose coefficients for organically bound forms of tritium (H-3) and Po were not calculated for FGR 11. Usually, Po would be considered organic in food but inorganic in water. The FGR 11 dose coefficient normally used as a default is used when dose coefficients for multiple values of f_1 are tabulated.

Notes:

1. The values of 6×10^{-2} risk per sievert for cancer mortality and 8×10^{-2} risk per sievert for cancer incidence from low LET radiation are rounded values that are documented in the EPA publications, "Estimating Radiogenic Cancer Risk" and its "Addendum: Uncertainty Analysis." In particular, the increase in the incidence risk from about 7×10^{-2} to about 8×10^{-2} risk per sievert

is documented on page 1 of the Uncertainty Analysis. These documents can be downloaded from EPA's web site at http://www.epa.gov/radiation/assessment/pubs.html

2. The term total effective dose equivalent or TEDE, was first introduced by the Nuclear Regulatory Commission (NRC) where it is defined as the sum of the committed effective dose equivalent and the deep dose equivalent. The definition used by DOE is consistent with the ICRP definition of effective dose equivalent.

3. Federal Guidance Report No. 13, "Cancer Risk Coefficients for Environmental Exposure to Radionuclides" (EPA 402-R-99-001), is available on the internet at http://www.epa.gov/radiation/assessment/pubs.html.

4.The HEAST slope factors are used in risk assessments conducted under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). To see how HEAST slope factors have been incorporated into EPA risk assessment guidance for CERCLA, please see "Soil Screening Guidance for Radionuclides: User's Guide" (OSWER No. 9355.4-16A, October 2000). An electronic version of the risk assessment equations in this guidance can be found on the Internet at: http://risk.lsd.ornl.gov/rad_start.shtml. HEAST may be found on the internet at http://www.epa.gov/radiation/heast/download.htm.

5. An EPA contractor report, "Comparison of Regulatory Methods for Expressing Radiation Dose Limits and EPA's Methods for Estimating Risks: Implications Concerning the Radiation Site Cleanup Standard" (March, 1996), examined the relationship between risk and dose using risk coefficients in place at the time (pre-FGR 13). It is reasonable to assume that the ratios calculated at that time are still reasonably indicative of the relationships that would be calculated using the current risk coefficients. That is, more radionuclide risks will be overestimated than underestimated and the extremes will likely not exceed about an order of magnitude. This assumption is based on the generally small changes in magnitude between FGR 13 and the risk coefficients it replaced.