Appendix II. Calculation of Slope Factors for Naturally Occurring Radionuclides

In developing the target soil screening levels found in Chapter 3 of this report, the slope factors for external exposure to, ingestion of, and inhalation of soil at an infinite depth must be considered. This appendix calculates the slope factors for the naturally occurring radionuclides under consideration. The Radionuclide Table, Radionuclide Carcinogenicity, formerly the Health Effects Assessment Summary Tables or HEAST Tables (http://www.epa.gov/radiation/heast/index.html), lists slope factors for individual radionuclides or for decay chains consisting of a parent nuclide and its short-lived progeny (i.e., radioactive daughter products with half-lives of less than 6 months). As explained below, naturally occurring radionuclides are often associated with their long-lived decay products. The slope factors for three naturally occurring radioactive decay series—natural uranium, Ra-226, and Th-232—used in the present report include the contributions from these decay products. This appendix explains the methodology used to calculate these combined slope factors.

The following guidance is excerpted from U.S. EPA 1996a:

> *Selected radionuclides and radioactive decay chain products are designated with the suffix "+D" (e.g., U-238+D, Ra-226+D, Cs-137+D) to indicate that cancer risk estimates for these radionuclides include the contributions from their short-lived decay products, assuming equal activity concentrations (i.e., secular equilibrium) with the principal or parent nuclide in the environment.*
> *. . . .*
>
> *Note that there may be circumstances, such as long disposal times or technologically enhanced concentrations of naturally occurring radionuclides, that may necessitate the combination of the risks of a parent radionuclide and its decay products over several contiguous subchains. For example, Ra-226 soil analyses at a site might show that all radium decay products are present in secular equilibrium down to stable Pb-206. In this case, Ra-226 risk calculations should be based on the ingestion, inhalation and external exposure slope factors for the Ra-226+D subchain, plus the ingestion, inhalation and external exposure factors for the Pb-210+D subchain.*

Radium-226 slope factors for the external exposure, soil ingestion, and inhalation pathways used in this analysis were calculated according to the guidance cited above. The same logic was applied to Th-232, whose progeny includes Ra-228, which has a half-life of 5.75 y, and Th-228, with a half-life of 1.91 y. Since the naturally-occurring thorium at the uranium mines will be in equilibrium with this progeny, the thorium slope factors are calculated as the sum of the slope factors for Th-232, Ra-228+D, and Th-228+D that are listed in the HEAST tables. Natural uranium is assumed to consist of U-234, U-235, and U-238, in ratios corresponding to natural isotopic abundances. We first calculated a slope factor for the U-238 decay series, which we will call U-238$_{series}$, by taking the sum of the slope factors for U-238+D, U+234, and Th-230. Radium-226 was not included, because separate soil analyses are normally performed for radium which, due to its different chemical properties, is often not in equilibrium with uranium. In

similar fashion, we calculated a slope factor for the U-235 decay series (U-235$_{series}$) as the sum of the slope factors for U-235+D, Pa-231, and Ac-227+D. We then calculated slope factors for natural uranium, by multiplying the slope factor for the U-235 decay series by the ratio of the specific activities of U-235 to U-238 and adding this product to the slope factor for the U-238 decay series, as shown by the following expression:

$$\text{Unat} = \text{U-235}_{series} \times f_{235} + \text{U-238}_{series}$$

where f_{235} is the ratio of the specific activities of U-235 and U-238 in natural uranium and is shown in the following expression:

$$f_{235} = \frac{[U-235]}{[U-238]} = 0.046$$

Because uranium concentrations in soil are commonly reported as pCi/g of U-238, the natural uranium slope factors are normalized to a unit activity concentration of U-238. To apply these slope factors, multiply by the actual activity of U-238, not the total activity of the uranium isotopes.

Details of these calculations are shown in the Table AII-1 below.

Table AII-1. Calculation of Slope Factors for NORM Decay Series

Series	Nuclide	Activity Fraction	SF		
			External (risk/y per pCi/g)	Ingestion (risk/pCi)	Inhalation (risk/pCi)
U-Series	U-238+D	1	1.14E-07	2.10E-10	9.35E-09
	U-234	1	2.52E-10	1.58E-10	1.14E-08
	Th-230	1	8.19E-10	2.02E-10	2.85E-08
	U-235+D	0.046	5.43E-07	1.63E-10	1.01E-08
	Pa-231	0.046	1.39E-07	3.74E-10	4.55E-08
	Ac-227+D	0.046	1.47E-06	1.16E-09	2.09E-07
	Total[a]		2.14E-07	6.48E-10	6.14E-08
Ra-Series	Ra-226+D	1	8.49E-06	7.30E-10	1.16E-08
	Pb-210+D	1	4.21E-09	2.66E-09	1.39E-08
	Total		8.49E-06	3.39E-09	2.55E-08
Th-Series	Th-232	1	3.42E-10	2.31E-10	4.33E-08
	Ra-228+D	1	4.53E-06	2.29E-09	5.23E-09
	Th-228+D	1	7.76E-06	8.09E-10	1.43E-07
	Total		1.23E-05	3.33E-09	1.92E-07

[a]   Sum, weighted by fractional activities

Appendix II References

U.S. EPA (U.S. Environmental Protection Agency). n/d. "Radionuclide Table: Radionuclide Carcinogenicity – Slope Factors" http://www.epa.gov/radiation/heast/docs/heast2_table_4-d2_0401.pdf

U.S. EPA (U.S. Environmental Protection Agency). 1996a. *Soil Screening Guidance: User's Guide.* EPA/540-R-96-018. Washington, DC: U.S. EPA, Office of Solid Waste and Emergency Response, July 1996.