

Appendix I. Swimming Risk

This appendix provides supplemental information on the swimming risks discussed in Chapter 3. Swimming risks were assumed to come from two sources; (1) ingestion and (2) immersion. In the drinking water discussion of Chapter 3 of the main report, we identified a recreational exposure scenario of 10 years of exposure, 14 days a year, and drinking 2 liters of water a day. For this recreational scenario, the lifetime cancer risk from drinking water contaminated with a range of uranium concentrations was in the 10^{-5} to 10^{-6} risk range. However, the analysis in Chapter 3 did identify that long-term use of pit-lake water could pose cancer risks. The potential hazard from the pit lakes may be greater from metals, such as arsenic, than from radionuclides. Since ingestion risks from ranges of radionuclide concentrations were discussed in Chapter 3, they are not discussed further here.

To calculate the immersion risks from exposure to radionuclides, we first calculated a dose using the formula modified from Whelan et al. (2006), and then applied a dose to risk coefficient from Tables 7.3 and 7.6 of Federal Guidance Report No. 13 (U.S. EPA 1999) to develop age-averaged site-specific cancer mortality and morbidity risk estimates. The formula for the immersion dose is as follows:

$$\text{swimming external dose} = C_w * \text{EDFS} * T \text{ exposure}$$

where C_w is the radionuclide concentration in the water in pCi/L, the EDFS is the External Dose Factor for Swimming in rem/hr per pCi/L, and the time of exposure is length of time a swimmer would be in the water in hours. To calculate the EDFS for the uranium and thorium decay series, we used the DCAL program (Eckerman et al. 2006), a comprehensive software system for the calculation of tissue dose and subsequent health risk from intakes of radionuclides or exposure to radionuclides present in environmental media. The results are listed below in Tables AI.1 and AI.2 for the U-238 and Th-232 decay series. Note that Ra-226 is included in the U-238 dose and risk calculations. The totals would apply if secular equilibrium were assumed; this is an unlikely case, because of the tendency for the radionuclides to settle into the sediment, as well as being dissolved in the water column. Table AI.3 shows the dose equivalent and risks per pCi/L for both decay series combined as a function of time spent immersed in the water.

In summary, the cancer risks from immersion due to swimming are very small per pCi/L from the U-238 and Th-232 decay series. Even if secular equilibrium were assumed and all the radionuclides in either series were present, the cancer risks from immersion while swimming are negligible for the recreational scenario, even at concentrations of 10s to 100s of pCi/L. The cancer risks from ingesting water while swimming are also anticipated to be low, based on the drinking water discussion in Chapter 3 of the main report.

**Table AI.1. Uranium-238 Dose Equivalent Rate and Risk per pCi/L per hour (EDFS):
Water Immersion**

Nuclide	Dose Equiv. Rate [(rem/hr) per (pCi/L)]	Mortality Risk ¹	Morbidity Risk
U-238	7.8E-14	4.5E-17	6.6E-17
Th-234	8.8E-12	5.0E-15	7.4E-15
Pa-234m	2.7E-11	1.5E-14	2.2E-14
Pa-234	2.5E-09	1.4E-12	2.1E-12
U-234	1.9E-13	1.1E-16	1.6E-16
Th-230	4.5E-13	2.6E-16	3.8E-16
Ra-226	8.3E-12	4.8E-15	7.1E-15
Rn-222	5.1E-13	3.0E-16	4.3E-16
Po-218	1.2E-14	7.0E-18	1.0E-17
At-218	3.0E-12	1.7E-15	2.5E-15
Pb-214	3.2E-10	1.8E-13	2.7E-13
Bi-214	2.1E-09	1.2E-12	1.8E-12
Po-214	1.1E-13	6.3E-17	9.3E-17
Pb-210	1.4E-12	8.0E-16	1.2E-15
Bi-210	4.0E-12	2.3E-15	3.4E-15
Po-210	1.1E-14	6.5E-18	9.5E-18
Total	5.0E-09	2.9E-12	4.2E-12

Table AI.2. Thorium-232 Dose Equivalent Rate per pCi/L per hour(EDFS): Water Immersion

Nuclide	Dose Equiv. Rate [(rem/hr) per (pCi/L)]	Mortality Risk	Morbidity Risk
Th-232	2.20E-13	1.26E-16	1.86E-16
Ra-228	0.00E+00	0.00E+00	0.00E+00
Ac-228	1.29E-09	7.44E-13	1.10E-12
Th-228	2.41E-12	1.39E-15	2.04E-15
Ra-224	1.25E-11	7.21E-15	1.06E-14
Rn-220	5.00E-13	2.87E-16	4.23E-16
Po-216	2.24E-14	1.29E-17	1.89E-17
Pb-212	1.82E-10	1.05E-13	1.54E-13
Bi-212	2.54E-10	1.46E-13	2.15E-13
Po-212	0.00E+00	0.00E+00	0.00E+00
Tl-208	4.86E-09	2.80E-12	4.11E-12
Total	6.61E-09	3.80E-12	5.59E-12

¹ Mortality risk is 5.575 E-4 per rem; Morbidity risk is 8.46 E-4 per rem.

Table AI.3. Total Dose Equivalent and Risk per pCi/L per hour (EDFS): Water Immersion

Time Spent Swimming (hours)	Dose Equivalent (rem per pCi/L)	Mortality Risk (per pCi/L)	Morbidity Risk (per pCi/L)
1	1.2E-08	6.5E-12	9.8E-12
2	2.3E-08	1.3E-11	2.0E-11
3	3.5E-08	1.9E-11	2.9E-11
4	4.6E-08	2.6E-11	3.9E-11
5	5.8E-08	3.2E-11	4.9E-11
10	1.2E-07	6.5E-11	9.8E-11
15	1.7E-07	9.7E-11	1.5E-10
20	2.3E-07	1.3E-10	2.0E-10
25	2.9E-07	1.6E-10	2.5E-10
30	3.5E-07	1.9E-10	2.9E-10
40	4.6E-07	2.6E-10	3.9E-10
50	5.8E-07	3.2E-10	4.9E-10
75	8.7E-07	4.9E-10	7.4E-10
100	1.2E-06	6.5E-10	9.8E-10

Appendix I References

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