ORNL/TM-2023/3001

Quantifying the Impact of Excluding the Submersion Exposure Route for Existing Superfund Radionuclide Screening Level Calculator Soil and Tap Water Models

Sierra D. Begley
Fredrick G. Dolislager
Debra J. Stewart
Karessa L. Manning
Katie A. Noto
Anthony Q. Armstrong
Richard W. Leggett

July 2023

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

ORNL/TM-2023/3001

Environmental Sciences Division
Environmental Risk and Energy Analysis Group
Center for Radiation Protection Knowledge

Quantifying the Impact of the Exclusion of the Submersion Exposure Route in Soil and Tap Water Models in Existing Superfund Radionuclide Screening Level Calculators

Sierra D. Begley, Fredrick G. Dolislager, Debra J. Stewart, Karessa L. Manning, Katie A. Noto, Anthony Q. Armstrong, Richard W. Leggett

Date Published: July 2023

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831-6283
managed by
UT-BATTELLE, LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists, (EDTS) under the Science Undergraduate Laboratory Internship Program.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

LIST OF ACRONYMS AND ABBREVIATIONS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act 1980
DCC	Dose Compliance Concentration
DCF	Dose Conversion Factor
DL	Dose Limit
DOE	Department of Energy
ED	Exposure Duration
EF	Exposure Frequency
ELCR	Excess Lifetime Cancer Risk
EPA	Environmental Protection Agency
ET	Exposure Time
IRA	Inhalation rate
ORNL	Oak Ridge National Laboratory
pCi	Picocurie
pCi/g	Picocuries per gram
pCi/L	Picocuries per liter
PEF	Particulate Emission Factor
PRG	Preliminary Remediation Goal
ROPC	Radionuclide of Potential Concern
SF	Slope Factor
TM	Technical Memorandum
TR	Target Risk
U.S.	United States

ABSTRACT

The U.S. Environmental Protection Agency (EPA) provides initial data screening guidelines for radionuclide-contaminated Superfund sites using preliminary remediation goals (PRGs) and dose compliance concentrations (DCCs). PRGs and DCCs are target concentration values based on acceptable excess lifetime cancer risk and annual dose limits, respectively. They are calculated for various environmental media that may be encountered by residential and worker land uses. PRGs and DCCs typically consist of multiple exposure routes. One of these routes is submersion, which is exposure to a gaseous or particulate radionuclide that is suspended in air. Currently, submersion is only included in air calculations. This study focused on determining whether factoring submersion into total PRG/DCC calculations for soil and tap water created a significant difference in the target concentrations. New equations for individual submersion PRGs/DCCs for each land use of interest for soil and tap water were developed. A wind-driven particulate emission factor and Andelman's constant were used to model the amount of soil and vapor in the air from soil and household use of tap water, respectively. The submersion PRG/DCC was then included in the total PRG/DCC for each radionuclide, followed by a percent difference comparison of the old and new totals to quantify the impact of the change. For total soil PRGs/DCCs, with and without submersion, the difference was less than 1 percent; however, many of the tap water radionuclides analyzed – including multiple radon and polonium isotopes – showed as high as a 200 percent difference.

This technical memorandum (TM) presents recommendations for updates to current EPA guidelines for initial data screens of radionuclide contaminated tap water.

1. INTRODUCTION

In accordance with the Comprehensive Environmental Response, Compensation, and Liability Act ("CERCLA" or "Superfund"), the U.S. Environmental Protection Agency (EPA) provides initial screening guidelines for radionuclide-contaminated sites, using preliminary remediation goals (PRGs) and dose compliance concentrations (DCCs). PRGs and DCCs are target concentration values based on acceptable excess lifetime cancer risk and annual dose limits, respectively. If a radionuclide concentration at a Superfund site is above the associated PRG or DCC, it is deemed a radionuclide of potential concern (ROPC), and further evaluation of the ROPC is required.

The EPA provides online PRG and DCC calculators that allow users to generate screening values according to various parameters – land use, media, target risk/dose limit, etc. There are four output options to choose from that are based on different decay and equilibrium assumptions. The two discussed in the following analysis are output options 2 and 4. Option 2 assumes secular equilibrium with no decay, such that the parent and progeny are in constant equilibrium throughout the chain. Option 4, the primary output used for this analysis, only calculates values for the selected isotopes with decay applied throughout the exposure duration. For half-lives shorter than the exposure duration, application of decay can cause the PRGs/DCCs to be larger. The calculator outputs include the total PRG/DCC for each selected isotope and the individual PRG/DCC for each exposure route.

The exposure routes used to calculate the total PRG/DCC for a given radionuclide vary depending on the media (soil, air, or tap water) and the land use (resident, farmer, or indoor/outdoor/ composite/construction worker). Submersion, which is exposure to a gaseous or particulate radionuclide that is suspended in air, is presently only used in calculations for air PRGs/DCCs. As such, EPA guidelines for soil and tap water may understate the potential radiation from suspended particles and vapors from soil and tap water. This analysis aims to demonstrate that the addition of submersion to total PRG and DCC calculations for soil and tap water will cause a significant change in target screening concentrations, indicative of a need to update current guidelines.

2. CALCULATION OF PRGS AND DCCS WITH SUBMERSION

PRGs are calculated using slope factors, which represent the excess lifetime cancer risk (ELCR) per unit of exposure to a given radionuclide. Slope factors vary based on the exposure pathway – inhalation, ingestion, external exposure, etc. In order to calculate submersion for soil, a generic soil inhalation PRG equation (Equation 1) was modified.

$$PRG_{sol-inh}\left(\frac{pCi}{g}\right) = \frac{TR}{SF_i\left(\frac{risk}{pCi}\right) * EF\left(\frac{day}{yr}\right) * ED(yr) * ET\left(\frac{hr}{day}\right) * \left(\frac{1\ day}{24hr}\right) * IRA\left(\frac{m^3}{day}\right) * \left(\frac{1}{PEF\left(\frac{m^3}{kg}\right)}\right) * \left(\frac{1000g}{kg}\right)} \quad \textbf{[1]}$$

In Equation 1, *TR* is the target risk, which for the purpose of this study is 1 x 10^{-6}; SF_i is the inhalation slope factor; *EF*, *ED*, and *ET* are the exposure frequency, duration, and time, respectively (see Table 1 for land-use-specific and age-adjusted constants); *IRA* is the inhalation

rate; and *PEF* is the particulate emission factor, which indicates the volume of air necessary to hold a kilogram of soil.

SF_i was substituted with SF_{sub}, the submersion slope factor, and a unit conversion factor of 1 year per 365 days was added.

$$PRG_{sol-sub-decay}\left(\frac{pCi}{g}\right) = \frac{TR}{SF_{sub}\left(\frac{risk/yr}{pCi/m^3}\right) * EF\left(\frac{day}{yr}\right) * ED(yr) * ET\left(\frac{hr}{day}\right) * \left(\frac{1\ day}{24hr}\right) * \left(\frac{1}{PEF\left(\frac{m^3}{kg}\right)}\right) * \left(\frac{1000g}{kg}\right) * \left(\frac{1\ yr}{365\ day}\right) * \left(\frac{t(yr) * \lambda\left(\frac{1}{yr}\right)}{1 - e^{-\lambda\left(\frac{1}{yr}\right) * t(yr)}}\right)} \quad \textbf{[2]}$$

The final term seen in Equation 2 is a decay function, where lambda represents the decay constant of the isotope as determined by its half-life ($\lambda = 0.693/\text{half-life}$). It is assumed that the contaminated soil is not being replenished.

For tap water, the same process was used to generate Equation 3,

$$PRG_{wat-sub}\left(\frac{pCi}{L}\right) = \frac{TR}{SF_{sub}\left(\frac{risk/yr}{pCi/m^3}\right) * EF\left(\frac{day}{yr}\right) * ED(yr) * ET\left(\frac{hr}{day}\right) * \left(\frac{1\ day}{24hr}\right) * K\left(\frac{0.5L}{m^3}\right) * \left(\frac{1\ yr}{365\ day}\right)} \quad \textbf{[3]}$$

where *K* represents Andelman's constant, the volatilization constant indicating the volume of air that holds 0.5L of water. Tap water equations assume constant replenishing of the contaminated water, so no decay function is included. Individual DCCs were calculated using these two formulas, with *TR* substituted by the selected dose limit (DL) and submersion *SF* substituted by the submersion dose conversion factor (DCF).

$$DCC_{wat-sub}\left(\frac{pCi}{L}\right) = \frac{DL\left(\frac{mrem}{yr}\right)}{DCF_{sub}\left(\frac{mrem/yr}{pCi/m^3}\right) * EF\left(\frac{day}{yr}\right) * ED(yr) * ET\left(\frac{hr}{day}\right) * \left(\frac{1\ day}{24hr}\right) * K\left(\frac{0.5L}{m^3}\right) * \left(\frac{1\ yr}{365\ day}\right)} \quad \textbf{[4]}$$

For each land use of interest (resident, farmer, composite worker, construction worker, indoor worker, and outdoor worker), the EPA PRG calculator was used to generate air and soil PRGs for as many radionuclides as possible out of the 1,252 included in the EPA tools. Tap water PRGs were generated for the noble gases and their short-lived progeny, carbon-14, and tritium, according to the radionuclides of interest used for radon vapor intrusion screening levels. Gases that escape from the tap water may produce short-lived progeny that remain airborne. For the initial analysis, Output Option 4 (no secular equilibrium, with decay where appropriate) was used. Results were generated in tables including the individual PRGs, total PRGs, and applicable slope factors and constants. The submersion slope factors included in each air PRG table were plugged into the water and soil submersion equations to generate individual water and soil PRGs for each

radionuclide under each land use. The submersion PRGs were then factored into a total PRG for each radionuclide (Equation 5).

$$PRG_{tot}\left(\frac{pCi}{g\ or\ L}\right) = \frac{1}{\frac{1}{PRG_{ing}} + \frac{1}{PRG_{inh}} + \ldots + \frac{1}{PRG_{sub}}} \quad \textbf{[5]}$$

The current total PRG generated by the calculator was then compared to the new total PRG including submersion using a percent difference evaluation.

$$Percent\ Difference = \left| \frac{(Final - Initial)}{\left(\frac{(Final + Initial)}{2}\right)} * 100 \right| \quad \textbf{[6]}$$

Individual and total DCC values were calculated and compared using the same process to double check results; Output Option 4 PRGs were also compared to Output Option 2 PRGs (assumes secular equilibrium, no decay) to ensure consistency.

Table 1. Exposure frequency (EF), exposure duration (ED), and exposure time (ET) by land use

	Exposure Frequency (*EF*) (days/year)	**Exposure Duration (*ED*) (years)**	**Exposure Time (*ET*) (hours/day)**
Resident	350	26 $ED_{res-adj} = ED_{res-c}(6yr) + ED_{res-a}(20yr)$	24
Composite Worker	250	25	8
Indoor Worker	250	25	8
Outdoor Worker	225	25	8
Construction Worker	250	1	8
Farmer	350	40 $ED_{far-adj} = ED_{far-c}(6yr) + ED_{far-a}(34yr)$	24

3. RESULTS AND DISCUSSION

The results of this study were graphed by land use and media. Each graph contains the total standard PRGs, total PRGs with submersion, and percent difference between the two data sets for each land use. Sections 3.1 and 3.2 discuss soil and tap water PRG/DCC comparisons, respectively.

3.1 SOIL IMPACTS

For the soil media analysis, the PRGs of 1,246 radionuclides were compared for six different land uses. For the resident land use (Figure 1), values were calculated including and excluding produce consumption. Produce consumption is often removed from PRG/DCCs because this route often dominates the PRG/DCC, and at times gardening is not practical or allowed.

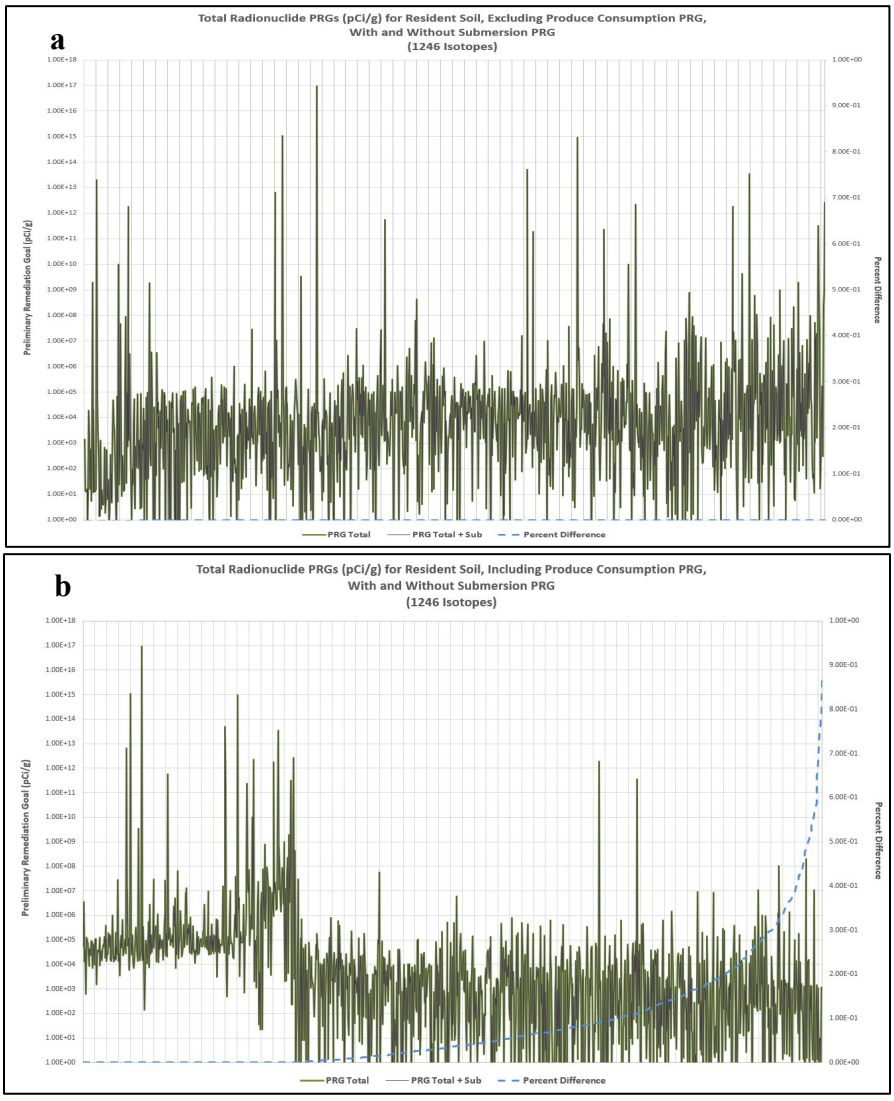

Figure 1. Total radionuclide PRG comparison with and without submersion for resident land use and soil media

(Including (a) and excluding (b) produce consumption route. Percent difference is graphed with a range of 0 to 1 percent.)

For both conditions, the percent difference between PRGs with submersion and without submersion remained below 1 percent, with values excluding produce never exceeding 2.0×10^{-6} percent. The same trend was seen for the farmer land use PRGs, with percent differences never exceeding 1 percent regardless of whether produce and biota PRGs were included in the total.

For the four worker land uses, results closely mirrored those obtained for the resident land use including produce consumption (Figure 1a). Figure 2 shows the results for composite worker land use, which applies to workers who spend time both indoors and outdoors and serves as a representative for the worker land uses. None of the examined isotopes displayed a percent difference greater than 1 percent when submersion was included in the total PRG.

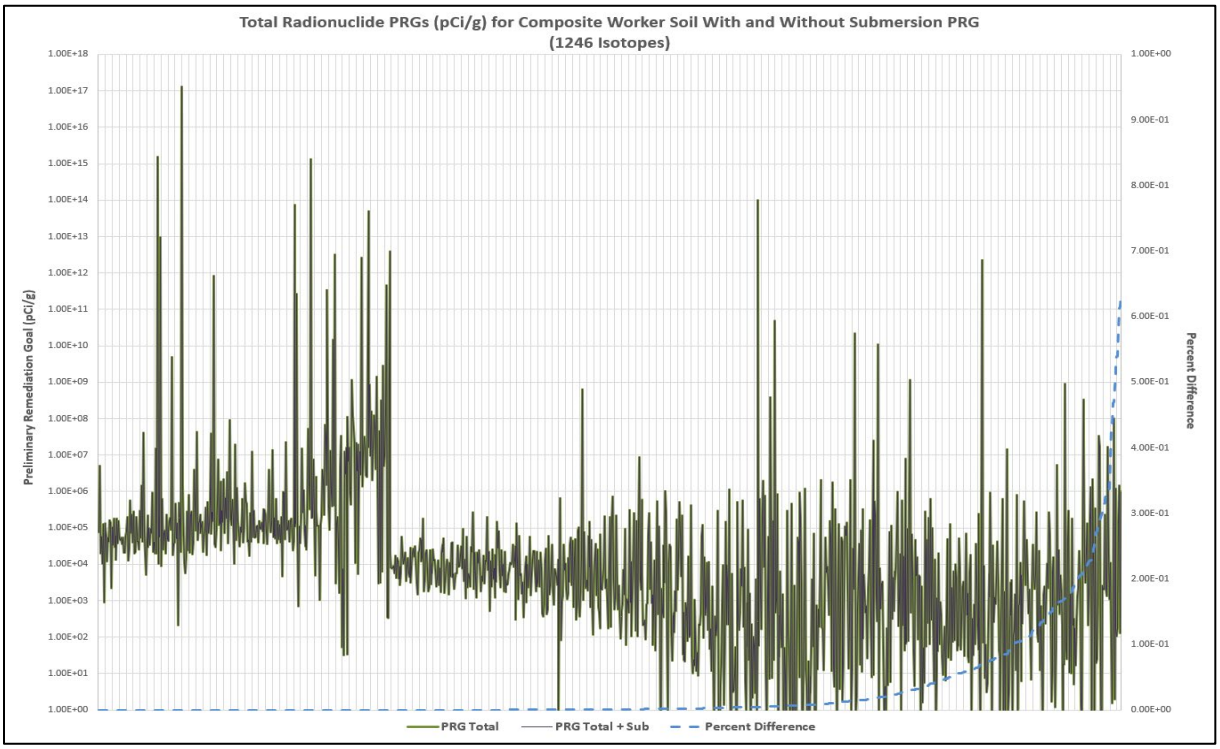

Figure 2. Total radionuclide PRG comparison with and without submersion for composite worker land use and soil media
(Percent difference is graphed with a range of 0 to 1 percent.)

None of the radionuclides analyzed under any of the selected conditions yielded a percent difference greater than 1 for soil media. The data compiled during this portion of the study suggest that including submersion in calculations for soil PRGs/DCCs creates a negligible impact. Therefore, for radionuclides in soil, submersion is an insignificant exposure route.

3.2 TAP WATER IMPACTS

The tap water media analysis compared 77 isotopes – the noble gases and their short-lived progeny, carbon-14, and tritium. Heavy metals are only able to become suspended in air in particulate soil, not gaseous emissions from tap water, and were therefore excluded from this portion of the study. For the resident land use (Figure 3), 71 radionuclides produced a greater than 1 percent difference

when comparing with and without submersion. Sixty-one radionuclides had greater than 100 percent differences. This trend was consistent for both resident and farmer land uses, with and without produce consumption and biota PRGs/DCCs. The worker exposure to tap water land use was not evaluated, as the results are anticipated to be similar to the resident and farmer land uses. Additionally, the EPA calculators do not include tap water exposure for the worker land use. See Appendix A, Table A-1 for tap water PRGs by isotope for resident and farmer land uses.

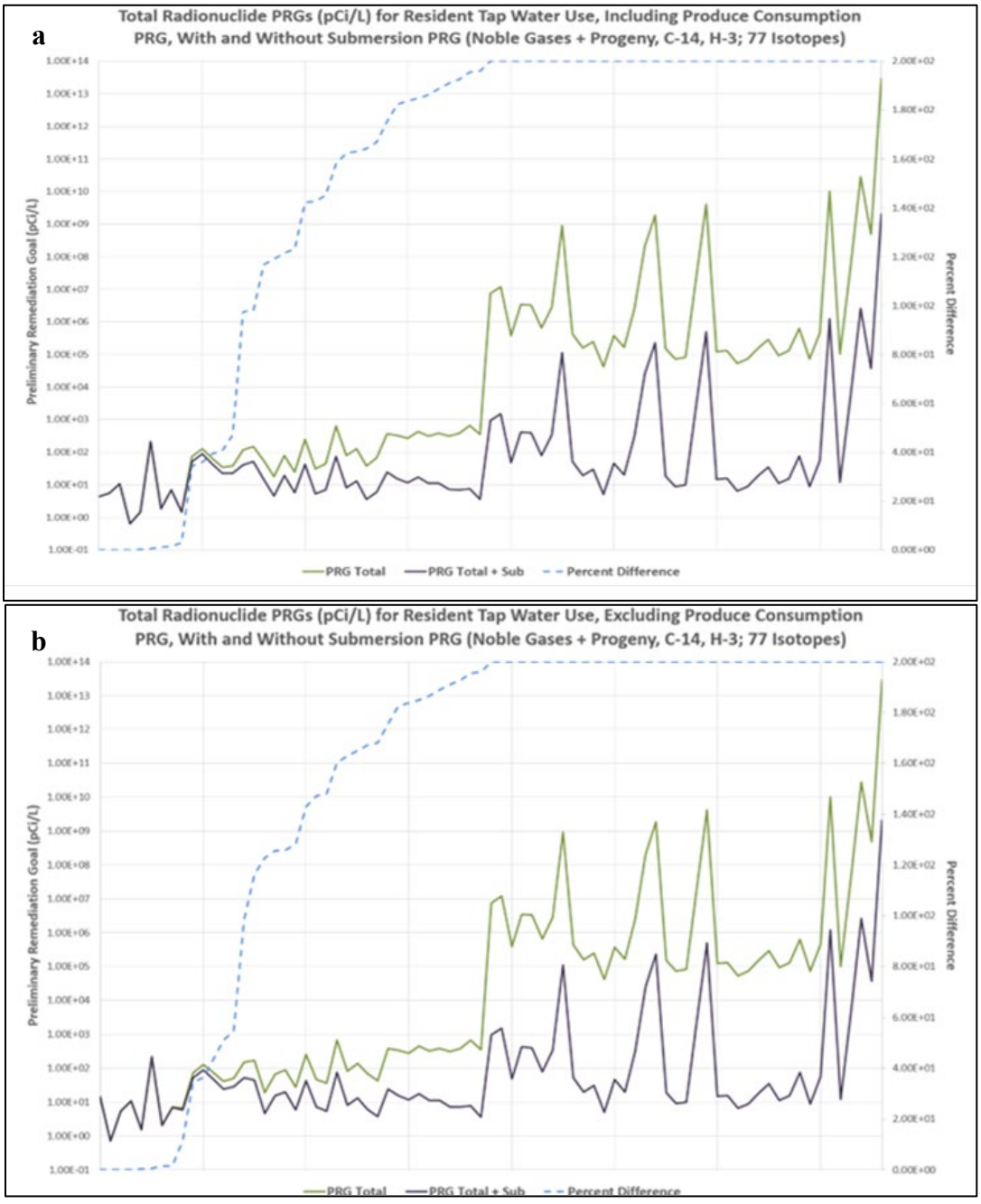

Figure 3. Total radionuclide PRG comparison with and without submersion for resident land use and tap water media

(Including (a) and excluding (b) produce consumption route. Percent difference is graphed with a range of 0 to 200 percent.)

The initial investigation of tap water was followed by tests using the secular equilibrium output option of the EPA's PRG and DCC calculator tools. These analyses found similar results. The secular equilibrium PRG results for the resident land use including produce consumption included 55 isotopes with over 1 percent differences and 17 above 100 percent (Figure 4); the DCC calculations for the same conditions included 74 isotopes over 1 percent and 68 over 100 percent (Figure 5). See Appendix B, Table B-1 for tap water DCCs by isotope for the resident land use.

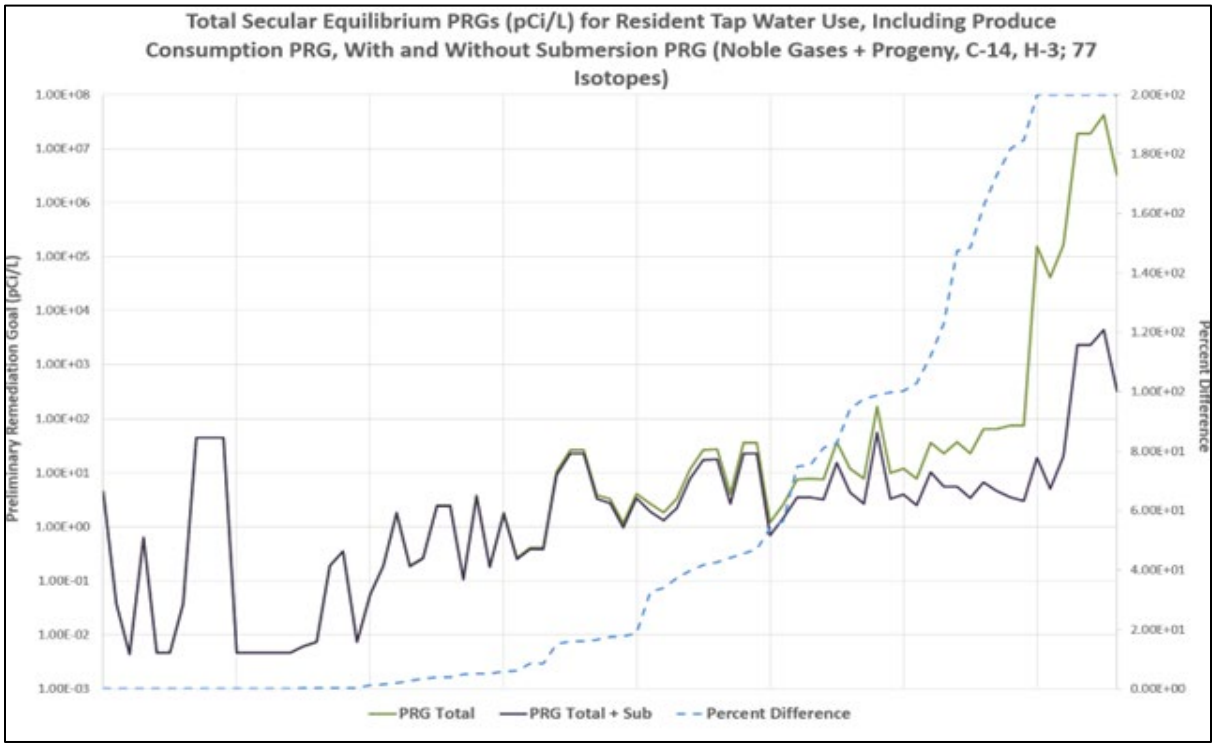

Figure 4. Total secular equilibrium PRG comparison with and without submersion for resident land use and tap water media

(Including produce consumption route. Percent difference is graphed with a range of 0 to 200 percent.)

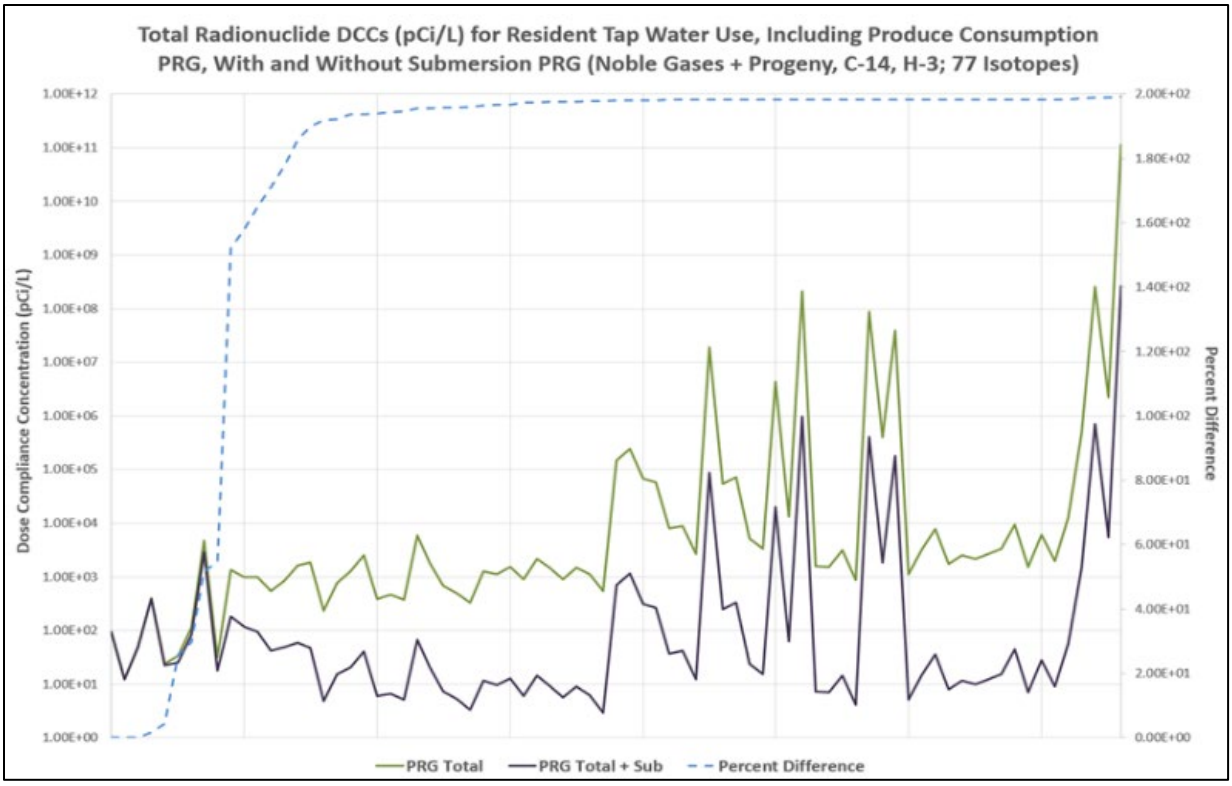

Figure 5. Total secular equilibrium PRG comparison with and without submersion for resident land use and tap water media

(Including produce consumption route. Percent difference is graphed with a range of 0 to 200 percent.)

Lower PRGs and DCCs indicate a greater potential health risk associated with a given radionuclide. In every case with the tap water media, total PRG/DCCs including submersion were equal to or less than the standard, frequently by as much as 200 percent. This shows that submersion exposure to vapors from tap water poses a noticeable human health risk that has not yet been quantified by the EPA in its PRG/DCC calculators.

4. CONCLUSION

The analysis of total PRGs/DCCs with and without submersion for radionuclides in soil did not yield sufficient evidence to conclude that the submersion exposure route is of notable impact to soil screening and remediation guidelines. However, the large percent differences seen in the tap water portion of this study indicate that submersion may play a much larger role in risk- and dose-based calculations for radionuclides in water than previously believed. For all tested land uses, outputs, and calculators, the PRG/DCC that included submersion was always equal to or less than the original PRG/DCC, with a lower PRG/DCC suggesting a greater danger.

These data suggest that current screening guidelines provided by the EPA without submersion for radioactive contaminants in tap water – including radon and other radionuclides of concern – are less protective of human health. More investigation is needed to confirm the significance of these results; however, our recommendation is that the existing guidelines be updated to include

submersion in the calculation of tap water PRGs and DCCs using the equations outlined in this study.

5. REFERENCES

Eckerman, K.F., R.W. Leggett, C.B. Nelson, J.S. Puskin, A.C.B. Richardson. 1999. Cancer Risk Coefficients for Environmental Exposure to Radionuclides, Federal Guidance Report No. 13. United State Environmental Protection Agency, Office of Radiation and Indoor Air, EPA 402-R-99-001.

Molinari, C.J., E.A. Asano, F.G. Dolislager, K.L. Manning, D.J. Stewart, K.A. Noto, C.E. Samuels, L.D. Galloway, A.Q. Armstrong. 2022. Air Exchange Rate Impact on Activity Equilibrium Factors and Inhalation Fractional Equilibrium Factors for Rn, Xe, Kr, Ar, Ne, and Their Progeny in Vapor Intrusion, Risk, and Dose Models – Appendix B. Decay Series Data. Oak Ridge National Laboratory.

U.S. Environmental Protection Agency (EPA). 2022a. Preliminary Remediation Goals for Radionuclide Contaminants at Superfund Sites. June. https://epa-prgs.ornl.gov/radionuclides/

U.S. EPA. 2022b. Dose Compliance Concentrations for Radionuclide Contaminants at Superfund Sites. June. https://epa-dccs.ornl.gov/

APPENDIX A. Radionuclide PRGs for Tap Water Media

Table A-1. Total Radionuclide PRGs (pCi/L) for Resident and Farmer Land Use and Tap Water Media.

	Resident Land Use				*Farmer Land Use*			
Isotope	***Total PRG Without Sub (+ Prod)***	***Total PRG With Sub (+ Prod)***	***Total PRG Without Sub (- Prod)***	***Total PRG with Sub (- Prod)***	***Total PRG Without Sub (+ Prod/ Biota)***	***Total PRG With Sub (+ Prod/ Biota)***	***Total PRG Without Sub (+ Prod/ Biota)***	***Total PRG With Sub (+ Prod/ Biota)***
Ar-42	4.84E+08	3.71E+04	4.84E+08	3.71E+04	3.08E+08	2.41E+04	3.08E+08	2.41E+04
Ar-43	9.38E+04	1.13E+01	9.38E+04	1.13E+01	5.98E+04	7.36E+00	5.98E+04	7.36E+00
Ar-44	7.40E+04	8.98E+00	7.40E+04	8.98E+00	4.72E+04	5.84E+00	4.72E+04	5.84E+00
At-207	7.88E+01	8.18E+00	8.01E+01	8.19E+00	2.64E+01	4.84E+00	4.89E+01	5.29E+00
At-209	4.39E+01	6.98E+00	4.63E+01	7.03E+00	1.50E+01	3.96E+00	2.82E+01	4.53E+00
At-210	1.79E+01	4.54E+00	1.93E+01	4.62E+00	6.17E+00	2.41E+00	1.18E+01	2.96E+00
At-211	1.45E+00	1.45E+00	1.55E+00	1.55E+00	4.96E-01	4.95E-01	9.46E-01	9.44E-01
At-218	2.80E+10	2.60E+06	2.80E+10	2.60E+06	1.78E+10	1.69E+06	1.78E+10	1.69E+06
Bi-203	2.42E+01	5.76E+00	2.70E+01	5.91E+00	6.53E+00	2.81E+00	1.65E+01	3.79E+00
Bi-211	3.43E+06	4.20E+02	3.43E+06	4.20E+02	2.19E+06	2.73E+02	2.19E+06	2.73E+02
Bi-212	7.21E+01	5.10E+01	7.28E+01	5.13E+01	1.85E+01	1.59E+01	4.44E+01	3.19E+01
Bi-214	2.70E+02	1.15E+01	2.71E+02	1.15E+01	6.99E+01	7.01E+00	1.66E+02	7.44E+00
Bi-215	6.21E+05	7.50E+01	6.21E+05	7.50E+01	3.95E+05	4.87E+01	3.95E+05	4.87E+01
Br-74	3.51E+02	3.66E+00	3.53E+02	3.66E+00	1.42E+00	8.91E-01	2.15E+02	2.38E+00
Br-75	3.31E+02	1.53E+01	3.36E+02	1.53E+01	1.34E+00	1.19E+00	2.05E+02	9.94E+00
Br-76	3.16E+01	5.30E+00	3.64E+01	5.42E+00	1.45E-01	1.40E-01	2.22E+01	3.49E+00
Br-76m	7.54E+06	9.54E+02	7.54E+06	9.54E+02	4.80E+06	6.20E+02	4.80E+06	6.20E+02
Br-77	1.16E+02	4.00E+01	1.70E+02	4.50E+01	6.88E-01	6.76E-01	1.04E+02	2.88E+01
Br-77m	1.20E+07	1.50E+03	1.20E+07	1.50E+03	7.68E+06	9.76E+02	7.68E+06	9.76E+02
C-14	6.37E-01	6.37E-01	7.17E-01	7.17E-01	5.33E-04	5.33E-04	4.46E-01	4.46E-01
Cs-138	3.12E+02	7.25E+00	3.13E+02	7.26E+00	8.95E-01	7.55E-01	1.91E+02	4.71E+00
Fr-223	7.07E+00	6.97E+00	7.10E+00	6.99E+00	2.35E+00	2.33E+00	4.33E+00	4.27E+00
H-3	4.43E+00	4.43E+00	1.45E+01	1.45E+01	2.70E+00	2.70E+00	8.98E+00	8.98E+00
I-120	6.72E+01	6.08E+00	6.81E+01	6.09E+00	6.90E+00	2.67E+00	4.16E+01	3.93E+00
I-121	2.50E+02	4.22E+01	2.55E+02	4.23E+01	2.60E+01	1.45E+01	1.56E+02	2.72E+01
I-122	1.63E+05	1.98E+01	1.63E+05	1.98E+01	1.04E+05	1.29E+01	1.04E+05	1.29E+01
I-123	6.54E+01	4.39E+01	7.39E+01	4.76E+01	7.20E+00	6.65E+00	4.51E+01	2.97E+01

Table A-1. Total Radionuclide PRGs (pCi/L) for Resident and Farmer Land Use and Tap Water Media.

	Resident Land Use				*Farmer Land Use*			
Isotope	*Total PRG Without Sub (+ Prod)*	*Total PRG With Sub (+ Prod)*	*Total PRG Without Sub (- Prod)*	*Total PRG with Sub (- Prod)*	*Total PRG Without Sub (+ Prod/ Biota)*	*Total PRG With Sub (+ Prod/ Biota)*	*Total PRG Without Sub (+ Prod/ Biota)*	*Total PRG With Sub (+ Prod/ Biota)*
K-42	3.70E+01	2.29E+01	4.14E+01	2.45E+01	7.45E-02	7.44E-02	2.53E+01	1.54E+01
K-43	5.57E+01	1.46E+01	6.72E+01	1.53E+01	1.23E-01	1.21E-01	4.10E+01	9.82E+00
K-44	3.75E+02	7.03E+00	3.77E+02	7.03E+00	6.86E-01	5.98E-01	2.30E+02	4.56E+00
Kr-74	1.52E+05	1.84E+01	1.52E+05	1.84E+01	9.65E+04	1.20E+01	9.65E+04	1.20E+01
Kr-75	1.23E+05	1.49E+01	1.23E+05	1.49E+01	7.83E+04	9.69E+00	7.83E+04	9.69E+00
Kr-76	3.85E+05	4.72E+01	3.85E+05	4.72E+01	2.45E+05	3.07E+01	2.45E+05	3.07E+01
Kr-77	1.54E+05	1.87E+01	1.54E+05	1.87E+01	9.80E+04	1.22E+01	9.80E+04	1.22E+01
Kr-88	7.19E+04	8.71E+00	7.19E+04	8.71E+00	4.58E+04	5.66E+00	4.58E+04	5.66E+00
Kr-89	7.40E+04	8.93E+00	7.40E+04	8.93E+00	4.72E+04	5.81E+00	4.72E+04	5.81E+00
Na-24	3.73E+01	3.65E+00	4.24E+01	3.70E+00	2.83E+00	1.36E+00	2.59E+01	2.39E+00
Ne-24	2.91E+05	3.52E+01	2.91E+05	3.52E+01	1.85E+05	2.29E+01	1.85E+05	2.29E+01
Pb-199	4.31E+02	1.71E+01	4.38E+02	1.71E+01	4.72E+01	9.28E+00	2.66E+02	1.11E+01
Pb-201	7.97E+01	1.94E+01	8.72E+01	1.99E+01	9.17E+00	5.92E+00	5.32E+01	1.27E+01
Pb-203	3.43E+01	2.27E+01	5.03E+01	2.87E+01	4.93E+00	4.43E+00	3.06E+01	1.80E+01
Pb-209	2.10E+02	2.09E+02	2.17E+02	2.16E+02	2.26E+01	2.26E+01	1.32E+02	1.31E+02
Pb-211	1.26E+02	8.77E+01	1.27E+02	8.81E+01	1.36E+01	1.27E+01	7.76E+01	5.48E+01
Pb-212	1.88E+00	1.86E+00	2.08E+00	2.05E+00	2.18E-01	2.17E-01	1.27E+00	1.25E+00
Pb-214	1.51E+02	5.17E+01	1.52E+02	5.18E+01	1.63E+01	1.23E+01	9.25E+01	3.29E+01
Po-203	3.81E+02	1.10E+01	3.83E+02	1.10E+01	5.46E+01	6.47E+00	2.34E+02	7.12E+00
Po-205	3.16E+02	1.12E+01	3.21E+02	1.13E+01	4.59E+01	6.51E+00	1.96E+02	7.30E+00
Po-207	1.29E+02	1.31E+01	1.37E+02	1.32E+01	1.92E+01	6.34E+00	8.35E+01	8.50E+00
Po-211	1.89E+07	2.29E+03	1.89E+07	2.29E+03	1.20E+07	1.49E+03	1.20E+07	1.49E+03
Po-213	4.11E+09	4.98E+05	4.11E+09	4.98E+05	2.62E+09	3.24E+05	2.62E+09	3.24E+05
Po-214	1.85E+09	2.25E+05	1.85E+09	2.25E+05	1.18E+09	1.46E+05	1.18E+09	1.46E+05
Po-215	9.04E+08	1.10E+05	9.04E+08	1.10E+05	5.76E+08	7.15E+04	5.76E+08	7.15E+04
Po-216	1.01E+10	1.22E+06	1.01E+10	1.22E+06	6.42E+09	7.91E+05	6.42E+09	7.91E+05
Po-218	2.84E+13	2.03E+09	2.84E+13	2.03E+09	1.81E+13	1.32E+09	1.81E+13	1.32E+09
Rb-88	3.71E+02	2.43E+01	3.72E+02	2.43E+01	3.57E-01	3.50E-01	2.27E+02	1.58E+01

Table A-1. Total Radionuclide PRGs (pCi/L) for Resident and Farmer Land Use and Tap Water Media.

	Resident Land Use				*Farmer Land Use*			
Isotope	*Total PRG Without Sub (+ Prod)*	*Total PRG With Sub (+ Prod)*	*Total PRG Without Sub (- Prod)*	*Total PRG with Sub (- Prod)*	*Total PRG Without Sub (+ Prod/ Biota)*	*Total PRG With Sub (+ Prod/ Biota)*	*Total PRG Without Sub (+ Prod/ Biota)*	*Total PRG With Sub (+ Prod/ Biota)*
Rb-89	6.70E+02	7.70E+00	6.72E+02	7.70E+00	6.53E-01	5.80E-01	4.10E+02	5.00E+00
Rn-207	1.60E+05	1.95E+01	1.60E+05	1.95E+01	1.02E+05	1.27E+01	1.02E+05	1.27E+01
Rn-209	1.29E+05	1.56E+01	1.29E+05	1.56E+01	8.20E+04	1.02E+01	8.20E+04	1.02E+01
Rn-210	2.61E+06	3.17E+02	2.61E+06	3.17E+02	1.66E+06	2.06E+02	1.66E+06	2.06E+02
Rn-211	8.14E+04	9.88E+00	8.14E+04	9.88E+00	5.18E+04	6.42E+00	5.18E+04	6.42E+00
Rn-218	2.07E+08	2.51E+04	2.07E+08	2.51E+04	1.32E+08	1.63E+04	1.32E+08	1.63E+04
Rn-219	2.76E+06	3.37E+02	2.76E+06	3.37E+02	1.76E+06	2.19E+02	1.76E+06	2.19E+02
Rn-220	1.08E+01	1.08E+01	1.08E+01	1.08E+01	6.71E+00	6.71E+00	6.71E+00	6.71E+00
Rn-222	5.45E+00	5.45E+00	5.45E+00	5.45E+00	3.39E+00	3.39E+00	3.39E+00	3.39E+00
Rn-223	4.62E+05	5.57E+01	4.62E+05	5.57E+01	2.94E+05	3.62E+01	2.94E+05	3.62E+01
Se-75	1.51E+00	1.46E+00	6.51E+00	5.79E+00	7.15E-03	7.15E-03	3.97E+00	3.56E+00
Tl-199	6.36E+02	7.43E+01	6.81E+02	7.49E+01	5.42E+00	4.93E+00	4.16E+02	4.83E+01
Tl-207	4.21E+07	4.43E+03	4.21E+07	4.43E+03	2.68E+07	2.88E+03	2.68E+07	2.88E+03
Tl-208	4.15E+04	5.04E+00	4.15E+04	5.04E+00	2.64E+04	3.28E+00	2.64E+04	3.28E+00
Tl-210	5.34E+04	6.47E+00	5.34E+04	6.47E+00	3.40E+04	4.20E+00	3.40E+04	4.20E+00
Xe-120	4.28E+05	5.21E+01	4.28E+05	5.21E+01	2.73E+05	3.39E+01	2.73E+05	3.39E+01
Xe-121	1.02E+05	1.23E+01	1.02E+05	1.23E+01	6.47E+04	7.98E+00	6.47E+04	7.98E+00
Xe-122	3.28E+06	4.01E+02	3.28E+06	4.01E+02	2.09E+06	2.61E+02	2.09E+06	2.61E+02
Xe-123	2.48E+05	3.02E+01	2.48E+05	3.02E+01	1.58E+05	1.96E+01	1.58E+05	1.96E+01
Xe-135	6.50E+05	7.94E+01	6.50E+05	7.94E+01	4.14E+05	5.16E+01	4.14E+05	5.16E+01
Xe-135m	3.75E+05	4.56E+01	3.75E+05	4.56E+01	2.39E+05	2.96E+01	2.39E+05	2.96E+01
Xe-138	1.29E+05	1.56E+01	1.29E+05	1.56E+01	8.21E+04	1.01E+01	8.21E+04	1.01E+01

APPENDIX B. Radionuclide DCCs for Tap Water Media

Table B-1. Total Radionuclide DCCs (pCi/L) for Resident Land Use and Tap Water Media

Isotope	*Total DCC Without Sub (+ Prod)*	*Total DCC Without Sub (+ Prod)*	*Total DCC Without Sub (+ Prod)*	*Total DCC Without Sub (+ Prod)*
Ar-42	4.84E+08	4.84E+08	4.84E+08	4.84E+08
Ar-43	1.97E+03	9.05E+00	1.97E+03	9.05E+00
Ar-44	1.56E+03	7.26E+00	1.56E+03	7.26E+00
At-207	6.80E+02	7.28E+00	6.83E+02	7.28E+00
At-209	4.70E+02	6.59E+00	4.82E+02	6.59E+00
At-210	2.31E+02	4.82E+00	2.41E+02	4.82E+00
At-211	2.36E+01	2.26E+01	2.48E+01	2.37E+01
At-218	2.55E+08	7.02E+05	2.55E+08	7.02E+05
Bi-203	3.83E+02	5.98E+00	4.05E+02	5.99E+00
Bi-211	7.08E+04	3.30E+02	7.08E+04	3.30E+02
Bi-212	9.99E+02	1.17E+02	1.00E+03	1.17E+02
Bi-214	1.12E+03	9.58E+00	1.12E+03	9.58E+00
Bi-215	1.27E+04	5.79E+01	1.27E+04	5.79E+01
Br-74	5.40E+02	2.97E+00	5.40E+02	2.97E+00
Br-75	1.54E+03	1.27E+01	1.55E+03	1.27E+01
Br-76	3.70E+02	5.07E+00	3.96E+02	5.08E+00
Br-76m	1.46E+05	7.06E+02	1.46E+05	7.06E+02
Br-77	1.86E+03	4.79E+01	2.37E+03	4.82E+01
Br-77m	2.42E+05	1.15E+03	2.42E+05	1.15E+03
C-14	1.25E+01	1.25E+01	1.39E+01	1.39E+01
Cs-138	8.87E+02	5.95E+00	8.89E+02	5.95E+00
Fr-223	1.13E+02	8.38E+01	1.14E+02	8.39E+01
H-3	9.50E+01	9.50E+01	2.91E+02	2.91E+02
I-120	5.02E+02	5.33E+00	5.05E+02	5.33E+00
I-121	2.55E+03	4.01E+01	2.57E+03	4.01E+01
I-122	3.38E+03	1.56E+01	3.38E+03	1.56E+01
I-123	9.90E+02	9.48E+01	1.07E+03	9.55E+01
K-42	5.43E+02	4.25E+01	5.87E+02	4.27E+01

Table B-1. Total Radionuclide DCCs (pCi/L) for Resident Land Use and Tap Water Media

Isotope	*Total DCC Without Sub (+ Prod)*	*Total DCC Without Sub (+ Prod)*	*Total DCC Without Sub (+ Prod)*	*Total DCC Without Sub (+ Prod)*
K-43	7.69E+02	1.55E+01	8.59E+02	1.56E+01
K-44	9.02E+02	5.73E+00	9.01E+02	5.73E+00
Kr-74	3.13E+03	1.45E+01	3.13E+03	1.45E+01
Kr-75	2.53E+03	1.17E+01	2.53E+03	1.17E+01
Kr-76	7.98E+03	3.73E+01	7.98E+03	3.73E+01
Kr-77	3.19E+03	1.48E+01	3.19E+03	1.48E+01
Kr-88	1.52E+03	7.07E+00	1.52E+03	7.07E+00
Kr-89	1.55E+03	7.13E+00	1.55E+03	7.13E+00
Na-24	3.27E+02	3.27E+00	3.45E+02	3.27E+00
Ne-24	5.99E+03	2.75E+01	5.99E+03	2.75E+01
Pb-199	2.17E+03	1.43E+01	2.18E+03	1.43E+01
Pb-201	1.25E+03	2.02E+01	1.31E+03	2.03E+01
Pb-203	8.34E+02	4.93E+01	1.07E+03	5.00E+01
Pb-209	4.79E+03	2.82E+03	4.90E+03	2.86E+03
Pb-211	1.35E+03	1.84E+02	1.36E+03	1.84E+02
Pb-212	3.31E+01	2.56E+01	3.55E+01	2.70E+01
Pb-214	1.61E+03	5.94E+01	1.61E+03	5.94E+01
Po-203	1.48E+03	9.04E+00	1.48E+03	9.04E+00
Po-205	1.46E+03	9.33E+00	1.46E+03	9.33E+00
Po-207	1.27E+03	1.16E+01	1.30E+03	1.16E+01
Po-211	3.95E+05	1.83E+03	3.95E+05	1.83E+03
Po-213	8.61E+07	3.99E+05	8.61E+07	3.99E+05
Po-214	3.88E+07	1.80E+05	3.88E+07	1.80E+05
Po-215	1.88E+07	8.76E+04	1.88E+07	8.76E+04
Po-216	2.10E+08	9.77E+05	2.10E+08	9.77E+05
Po-218	1.12E+11	2.62E+08	1.12E+11	2.62E+08
Rb-88	1.80E+03	2.02E+01	1.80E+03	2.02E+01
Rb-89	1.11E+03	6.28E+00	1.11E+03	6.28E+00
Rn-207	3.33E+03	1.55E+01	3.33E+03	1.55E+01

Table B-1. Total Radionuclide DCCs (pCi/L) for Resident Land Use and Tap Water Media

Isotope	***Total DCC Without Sub (+ Prod)***	***Total DCC Without Sub (+ Prod)***	***Total DCC Without Sub (+ Prod)***	***Total DCC Without Sub (+ Prod)***
Rn-209	2.68E+03	1.25E+01	2.68E+03	1.25E+01
Rn-210	5.42E+04	2.53E+02	5.42E+04	2.53E+02
Rn-211	1.71E+03	7.91E+00	1.71E+03	7.91E+00
Rn-218	4.32E+06	2.01E+04	4.32E+06	2.01E+04
Rn-219	5.70E+04	2.67E+02	5.70E+04	2.67E+02
Rn-220	3.95E+02	3.89E+02	3.95E+02	3.89E+02
Rn-222	4.93E+01	4.92E+01	4.93E+01	4.92E+01
Rn-223	9.53E+03	4.39E+01	9.53E+03	4.39E+01
Se-75	3.11E+01	1.77E+01	1.08E+02	2.99E+01
Tl-199	5.85E+03	6.61E+01	6.02E+03	6.61E+01
Tl-207	4.91E+05	1.49E+03	4.91E+05	1.49E+03
Tl-208	8.77E+02	4.07E+00	8.77E+02	4.07E+00
Tl-210	1.12E+03	5.18E+00	1.12E+03	5.18E+00
Xe-120	8.87E+03	4.14E+01	8.87E+03	4.14E+01
Xe-121	2.13E+03	9.83E+00	2.13E+03	9.83E+00
Xe-122	6.64E+04	3.12E+02	6.64E+04	3.12E+02
Xe-123	5.15E+03	2.40E+01	5.15E+03	2.40E+01
Xe-135	1.34E+04	6.24E+01	1.34E+04	6.24E+01
Xe-135m	7.81E+03	3.61E+01	7.81E+03	3.61E+01
Xe-138	2.71E+03	1.25E+01	2.71E+03	1.25E+01