Verification Study of the Radon Vapor Intrusion Screening Level Calculator

External Verification Study Record
November 9, 2021 - June 10, 2022

CONTENTS:

Verification Study Charge for the U.S. Environmental Protection Agency (EPA), *Radon Vapor Intrusion Screening Level Calculator*

Background:

EMS, Inc., under contract EP-W-13-016 with EPA's Office of Superfund Remediation and Technology Innovation, has been asked to conduct an external, independent verification study of the *Radon Vapor Intrusion Screening Level* electronic calculator. The RVISL calculator output provides screening values and risk and dose estimates for residential and commercial/industrial exposures to radon in soil gas, air, and groundwater. The RVISL calculator provides default parameters that can be modified to reflect site-specific conditions. In addition, the calculator presents the option to compare the indoor air concentration, entered by the user or derived from groundwater or soil gas activities, to state standards or Uranium Mill Tailings Radiation Control Act (UMTRCA) standards.

EPA developed the RVISL calculator website with the U.S. Department of Energy's Oak Ridge National Laboratory under an Interagency Agreement. The RVISL calculator provides updated guidance for developing screening levels or preliminary remediation goals (PRGs) for indoor radon-222, radon-220, and radon-219 that are risk- or dose-based and for showing compliance with the UMTRCA indoor radon standards for radon-222 and radon-220. It is now the generally recommended source of radon screening levels for all 10 EPA regions. The RVISL calculator output provides comparison values and risk and dose estimates for residential and commercial/industrial exposures to radon in soil gas, air, and groundwater.

The RVISL calculator is available at https://epa-visl.ornl.gov/cgi-bin/radionuclides/rvisl_search , and the User's Guide is available at https://epa-visl.ornl.gov/radionuclides/rvisl_guide.html.

The RVISL calculator results were previously internally verified and externally peer reviewed. Links to documentation of the verification and review are included on the Home Page.

Charge:

According to EPA's Guidance on the Development, Evaluation, and Application of Environmental Models (2009), v*erification* refers to activities designed to confirm that the mathematical framework embodied in the module is correct and that the computer code for a module is operating according to its intended design so that the results obtained compare favorably with those obtained using known analytical solutions or numerical solutions from simulators based on similar or identical mathematical frameworks.

The purpose of this verification study is to ascertain that the computer code has no inherent numerical problems with obtaining a solution and that the code performs according to design

specifications. In addition, the study will ensure that the equations are programmed correctly and that sources of error, such as rounding, are minimal. **The equations used in the calculator are listed at** https://epa-visl.ornl.gov/radionuclides/equations.html

We are enlisting two subject matter experts for this verification study. Your comments and recommendations will be used to verify existing equations and calculations so that the final version will reflect sound technical information and guidance.

As an independent tester of the RVISL electronic calculator, we ask you to examine the numerical technique in the computer code for consistency with the conceptual model and governing equations.

When your verification study is complete, e-mail your comments to EMS's Verification Study Manager (Sarah Kallgren, sarah.kallgren@emsus.com) on or before **June 10, 2022**. Please submit your comments in Microsoft Word and reference each comment to a specific step in the calculator and equation (https://epa-visl.ornl.gov/radionuclides/equations.html). For specific comments or text edits on the user's guide, you may copy and paste text into Microsoft Word and indicate edits or comments using track changes or the comments feature. *Please do not hand write your comments.*

Riley Carey
U.S. Army Corps of Engineers

VERIFICATION OF THE U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA) RADON VAPOR INTRUSION SCREENING LEVEL (RVISL) CALCULATOR

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1.0 Introduction

The Radon Vapor Intrusion Screening Level (RVISL) Calculator (https://epa-visl.ornl.gov/radionuclides/) has been developed to calculate isotopic (i.e., radon[Rn]-219, Rn-220, and Rn-222) risk- and dose-based screening levels or Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) preliminary remediation goals (PRG) for indoor air, and for demonstrating compliance with Uranium Mill Tailings Radiation Control Act (UMTRCA) standards. Additionally, the RVISL calculator provides risk and dose estimates for residential and commercial worker exposures to ambient indoor air and vapor intrusion from contaminated groundwater and soil gas.

This report independently evaluates the computational accuracy of the RVISL Calculator against its documented procedures (USEPA, 2021); no comments are provided regarding the validity of the procedures. Specifically, this review evaluated eight elements: transcription of the activity equilibrium factors (Aeq) from the original source (ORNL, 2020), screening levels to the default resident, screening levels to the default commercial worker, screening levels to a site-specific resident, screening levels to a site-specific commercial worker, calculated exposure to a resident from measured media concentrations, calculated exposure to a commercial worker from measured media concentrations, and unit conversion.

One apparent miscalculation is identified in site-specific screening level calculations for Rn-222, and is discussed in Section 4.0 with an example in Appendix A.

2.0 Verification Procedure

The RVISL Calculator is heavily dependent on the radionuclide-specific air concentration which, in this context, is a numerical function of the indoor air exchange rate; the proportion of ingrowth progeny to parent radon concentration decreases non-linearly as the air exchange rate increases (ORNL, 2020). This relationship neglects exhalation, solid particle concentration, surface deposition, and air quality for simplification, and assumes both radon and its progeny are uniformly distributed over the air volume (ORNL, 2020). Because the activity equilibrium factors (Aeq), defined as the concentration ratio of progeny to parent radon activity per air exchange rate, and the fractional equilibrium factors (Feq), defined as the unitless disequilibrium ratio of the total emitted alpha energy from the present progeny to the total emitted alpha energy of the progeny in full equilibrium with the parent radon, are not intrinsically derived in the calculator (rather they are called based on the air exchange rate selection from a dropdown window), the first verification procedure was to confirm accurate transcription from the source (ORNL, 2020).

Next, an independent verification calculator was created in Microsoft Excel© to evaluate the computational accuracy of the RVISL Calculator against the specified equations and procedures outlined in the user's guide (USEPA, 2021). This verification calculator utilized the same Aeq and Feq values (ORNL, 2020) and toxicity criteria (ORNL 2014, 2017) as the RVISL calculator. The calculations were coded in Excel© directly from the user's guide (USEPA, 2021) for both screening level calculations and working level, ELCR, and annual dose calculations. Six cases were considered to independently compare the RVISL output against the verification calculator for each function: screening levels to the default resident, screening levels to the default commercial worker, screening levels to a site-specific resident, screening levels to a site-specific commercial worker, calculated exposure to a resident from measured media concentrations, and calculated exposure to a commercial worker from measured media concentrations.

The screening levels and exposures to site-specific receptors included changes to each available user-defined value to examine the internal parameter modifiers such as for the unitless Henry's Law Constant at a temperature other than 25 degrees Celsius. The calculated working level, ELCR, and annual dose from measured environmental media assumed the default receptor and setting parameters because each run in inherently site-specific. Each output from the RVISL calculator was compared to that of the verification calculator using a relative percent difference (RPD):

$$RPD = \frac{|RVISL\ Output - Verification\ Output|}{Verification\ Output}$$

2.1 Activity Equilibrium Factor Verification

The RVISL calculator was run for the default resident screening level calculation at each air exchange rate to verify accurate transcription of the Aeq values per radionuclide from the source (ORNL, 2020) and evaluated for rounding error.

2.2 Case 1: Default Resident Screening Levels

The verification calculator was run with the same input parameters assumed in the RVISL default resident scenario with target screening metrics of 1.00E-06 ELCR, 1 millirem per year (mrem/year), and a working level (WL) of 0.02. These parameters include an air exchange rate of 0.18 per hour, a total lifetime exposure of 26 years (20 years as an adult and 6 years as a child), an annual exposure of 350 days (both as an adult and child), a daily exposure of 24 hours (both as an adult and child), an adult breathing rate of 20 cubic meters per day (m^3/day), a child breathing rate of 10 m^3/day, a unitless gamma shielding factor of 1.0, a unitless soil gas attenuation factor of 0.03, a unitless groundwater attenuation factor of 0.001, and a mean groundwater temperature of 25 degrees Celsius.

2.3 Case 2: Default Commercial Worker Screening Levels

The verification calculator was run with the same input parameters assumed in the RVISL default commercial worker scenario with target screening metrics of 1.00E-06 ELCR, 1 mrem/year, and a 0.02 WL. These parameters include an air exchange rate of 0.6 per hour, a total lifetime exposure of 25 years (25 years as an adult and 0 years as a child), an annual exposure of 250 days (only as an adult), a daily exposure of 8 hours (only as an adult), a breathing rate of 60 m^3/day, no child breathing rate, a unitless gamma shielding factor of 1.0, a unitless soil gas attenuation factor of 0.03, a unitless groundwater attenuation factor of 0.001, and a mean groundwater temperature of 25 degrees Celsius.

2.4 Case 3: Site-Specific Resident Screening Levels

The verification and RVISL calculators were run with the same site-specific resident parameters with target screening metrics of 1.00E-04 ELCR, 25 mrem/year, and an arbitrary 0.03 WL. These site-specific parameters include an air exchange rate of 0.5 per hour, a total lifetime exposure of 30 years (22 years as an adult and 8 years as a child), an annual exposure of 200 days as an adult and 300 days as a child, a daily exposure of 14 hours as an adult and 16 hours as a child, an adult breathing rate of 24 m^3/day, a child breathing rate of 14 m^3/day, a unitless gamma shielding factor of 0.7, a unitless soil gas attenuation factor of 0.06, a unitless groundwater attenuation factor of 0.05, and a mean groundwater temperature of 30 degrees Celsius.

2.5 Case 4: Site-Specific Commercial Worker Screening Levels

The verification and RVISL calculators were run with the same site-specific commercial worker parameters with target screening metrics of 1.00E-04 ELCR, 25 mrem/year, and an arbitrary 0.03 WL. These site-specific parameters include an air exchange rate of 1.0 per hour, a total lifetime exposure of 20 years (20 years as an adult and 0 years as a child), an annual exposure of 200 days (only as an adult), a daily exposure of 14 hours (only as an adult), a breathing rate of 65 m^3/day, no child breathing rate, a unitless gamma shielding factor of 0.7, a unitless soil gas attenuation factor of 0.02, a unitless groundwater attenuation factor of 0.002, and a mean groundwater temperature of 20 degrees Celsius.

2.6 Case 5: Calculated Exposure to a Resident

The verification and RVISL calculators were run with the same resident parameters with the following media radon concentrations:

- Rn-219 in air: 1 picocurie per liter (pCi/L)
- Rn-220 in air: 1 pCi/L
- Rn-222 in air: 4 pCi/L

- Rn-219 in soil gas: 100 pCi/L or 100,000 picocuries per cubic meter (pCi/m^3)
- Rn-220 in soil gas: 100 pCi/L or 100,000 pCi/m^3
- Rn-222 in soil gas: 1,300 pCi/L or 1,300,000 pCi/m^3

- Rn-219 in groundwater: 100 pCi/L
- Rn-220 in groundwater: 100 pCi/L
- Rn-222 in groundwater: 100 pCi/L

These receptor and setting parameters include an air exchange rate of 0.18 per hour, a total lifetime exposure of 26 years (20 years as an adult and 6 years as a child), an annual exposure of 350 days (as an adult and a child), a daily exposure of 24 hours (as an adult and child), an adult breathing rate of 20 m^3/day, a child breathing rate of 10 m^3/day, a unitless gamma shielding factor of 1.0, a unitless soil gas attenuation factor of 0.03, a unitless groundwater attenuation factor of 0.001, and a mean groundwater temperature of 25 degrees Celsius.

2.7 Case 6: Calculated Exposure to a Commercial Worker

The verification and RVISL calculators were run with the same commercial worker parameters with the media radon concentrations listed for the Case 5 in Section 2.6.

These receptor and setting parameters include an air exchange rate of 0.6 per hour, a total lifetime exposure of 25 years (25 years as an adult and 0 years as a child), an annual exposure of 250 days (only as an adult), a daily exposure of 8 hours (only as an adult), a breathing rate of 60 m^3/day, no child breathing rate, a unitless gamma shielding factor of 1.0, a unitless soil gas attenuation factor of 0.03, a unitless groundwater attenuation factor of 0.001, and a mean groundwater temperature of 25 degrees Celsius.

2.8 Unit Conversion Verification

The unit conversion from picocuries (pCi) to becquerel (Bq) was evaluated by applying a 0.037 Bq/pCi conversion to the default resident dose-based screening levels generated in the RVISL calculator. It should be noted that the RVISL calculator still calculates screening levels to a prescribed dose metric in mrem/year although the DCFs listed in the output are in units of sievert (Sv).

3.0 Results

Table 1 summarizes the results of this RVISL verification.

No discernable differences were observed between the Aeq values in the RVISL Calculator and the original source (ORNL, 2020). No discernable differences were observed between manually converted RVISL output values and the unit conversion intrinsic to the calculator. Numeric comparisons of the test cases with the RPD of the output values are presented in Table 2 through Table 7.

Table 1: Summary of Verification Results

Verification Task	Discrepancies Identified	Description
Aeq transcription		
Default resident screening level		
Default worker screening level		
Site-specific resident screening level	X	Appendix A
Site-specific worker screening level	X	Appendix A
Calculation of ELCR, annual dose, and WL to a resident from measured media concentrations		
Calculation of ELCR, annual dose, and WL to a worker from measured media concentrations		
Unit conversion		

Table 2: Default Resident Target Screening Levels

Indoor Air (pCi/L)				Sub-Slab and Exterior Soil Gas (pCi/L)				Groundwater (pCi/L)			
To Meet Working Level (0.02 WL)				To Meet Working Level (0.02 WL)				To Meet Working Level (0.02 WL)			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	3.78E+00	3.78E+00	0.0%	Rn-219	1.26E+02	1.26E+02	0.0%	Rn-219	8.71E+02	8.73E+02	0.2%
Rn-220	7.12E-01	7.12E-01	0.0%	Rn-220	2.37E+01	2.37E+01	0.0%	Rn-220	1.64E+02	1.64E+02	0.0%
Rn-222	2.25E+00	2.25E+00	0.0%	Rn-222	7.49E+01	7.49E+01	0.0%	Rn-222	5.18E+02	5.19E+02	0.2%
Risk-Based (1.00E-06)				Risk-Based (1.00E-06)				Risk-Based (1.00E-06)			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	1.78E-04	1.78E-04	0.0%	Rn-219	5.92E-03	5.92E-03	0.0%	Rn-219	4.09E-02	4.10E-02	0.2%
Rn-220	3.23E-05	3.23E-05	0.0%	Rn-220	1.08E-03	1.08E-03	0.0%	Rn-220	7.44E-03	7.45E-03	0.1%
Rn-222	4.57E-05	4.57E-05	0.0%	Rn-222	1.52E-03	1.52E-03	0.0%	Rn-222	1.05E-02	1.05E-02	0.0%
Dose-Based (1 mrem/year)				Dose-Based (1 mrem/year)				Dose-Based (1 mrem/year)			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	3.70E-03	3.70E-03	0.0%	Rn-219	1.23E-01	1.23E-01	0.0%	Rn-219	8.52E-01	8.54E-01	0.2%
Rn-220	1.38E-03	1.37E-03	0.7%	Rn-220	4.59E-02	4.58E-02	0.2%	Rn-220	3.17E-01	3.17E-01	0.0%
Rn-222	1.87E-03	1.87E-03	0.0%	Rn-222	6.23E-02	6.24E-02	0.2%	Rn-222	4.31E-01	4.32E-01	0.2%

Table 3: Default Commercial Worker Target Screening Levels

Indoor Air (pCi/L)				Sub-Slab and Exterior Soil Gas (pCi/L)				Groundwater (pCi/L)			
To Meet Working Level (0.02 WL)				To Meet Working Level (0.02 WL)				To Meet Working Level (0.02 WL)			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	5.08E+00	5.08E+00	0.0%	Rn-219	1.69E+02	1.69E+02	0.0%	Rn-219	1.17E+03	1.17E+03	0.0%
Rn-220	2.87E+00	2.87E+00	0.0%	Rn-220	9.57E+01	9.57E+01	0.0%	Rn-220	6.61E+02	6.62E+02	0.2%
Rn-222	2.77E+00	2.77E+00	0.0%	Rn-222	9.25E+01	9.25E+01	0.0%	Rn-222	6.39E+02	6.40E+02	0.2%
Risk-Based (1.00E-06)				Risk-Based (1.00E-06)				Risk-Based (1.00E-06)			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	3.01E-04	3.01E-04	0.0%	Rn-219	1.00E-02	1.00E-02	0.0%	Rn-219	6.94E-02	6.96E-02	0.3%
Rn-220	1.17E-04	1.17E-04	0.0%	Rn-220	3.88E-03	3.88E-03	0.0%	Rn-220	2.68E-02	2.69E-02	0.4%
Rn-222	7.80E-05	7.80E-05	0.0%	Rn-222	2.60E-03	2.60E-03	0.0%	Rn-222	1.80E-02	1.80E-02	0.0%
Dose-Based (1 mrem/year)				Dose-Based (1 mrem/year)				Dose-Based (1 mrem/year)			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	6.04E-03	6.04E-03	0.0%	Rn-219	2.01E-01	2.01E-01	0.0%	Rn-219	1.39E+00	1.39E+00	0.0%
Rn-220	4.75E-03	4.75E-03	0.0%	Rn-220	1.58E-01	1.58E-01	0.0%	Rn-220	1.09E+00	1.10E+00	0.9%
Rn-222	3.04E-03	3.04E-03	0.0%	Rn-222	1.01E-01	1.01E-01	0.0%	Rn-222	6.99E-01	7.01E-01	0.3%

Table 4: Site-Specific Resident Target Screening Levels

Indoor Air (pCi/L)				Sub-Slab and Exterior Soil Gas (pCi/L)				Groundwater (pCi/L)			
To Meet Working Level (0.03 WL)				To Meet Working Level (0.03 WL)				To Meet Working Level (0.03 WL)			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	7.15E+00	7.15E+00	0.0%	Rn-219	1.19E+02	1.19E+02	0.0%	Rn-219	3.05E+01	3.05E+01	0.0%
Rn-220	3.37E+00	3.37E+00	0.0%	Rn-220	5.62E+01	5.62E+01	0.0%	Rn-220	1.44E+01	1.44E+01	0.0%
Rn-222	3.98E+00	3.98E+00	0.0%	Rn-222	6.64E+01	6.64E+01	0.0%	Rn-222	1.70E+01	1.70E+01	0.0%
Risk-Based (1.00E-04)				Risk-Based (1.00E-04)				Risk-Based (1.00E-04)			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	4.23E-02	4.23E-02	0.0%	Rn-219	7.05E-01	7.05E-01	0.0%	Rn-219	1.80E-01	1.81E-01	0.6%
Rn-220	1.47E-02	1.47E-02	0.0%	Rn-220	2.44E-01	2.45E-01	0.4%	Rn-220	6.25E-02	6.27E-02	0.3%
Rn-222	1.09E-02	1.09E-02	0.0%	Rn-222	1.82E-01	1.82E-01	0.0%	Rn-222	4.66E-02	4.66E-02	0.0%
Dose-Based (25 mrem/year)				Dose-Based (25 mrem/year)				Dose-Based (25 mrem/year)			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	2.54E-01	2.54E-01	0.0%	Rn-219	4.23E+00	4.24E+00	0.2%	Rn-219	1.08E+00	1.09E+00	0.9%
Rn-220	1.79E-01	1.80E-01	0.6%	Rn-220	2.99E+00	3.00E+00	0.3%	Rn-220	7.65E-01	7.67E-01	0.3%
Rn-222	1.43E-01	1.28E-01	11.7%	Rn-222	2.38E+00	2.13E+00	11.7%	Rn-222	6.08E-01	5.45E-01	11.6%

BOLD: Represents a significant difference and source of potential error

Table 5: Site-Specific Commercial Worker Target Screening Levels

Indoor Air (pCi/L)				Sub-Slab and Exterior Soil Gas (pCi/L)				Groundwater (pCi/L)			
To Meet Working Level (0.03 WL)				To Meet Working Level (0.03 WL)				To Meet Working Level (0.03 WL)			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	9.55E+00	9.55E+00	0.0%	Rn-219	4.77E+02	4.77E+02	0.0%	Rn-219	1.20E+03	1.20E+03	0.0%
Rn-220	9.02E+00	9.02E+00	0.0%	Rn-220	4.51E+02	4.51E+02	0.0%	Rn-220	1.13E+03	1.13E+03	0.0%
Rn-222	4.82E+00	4.82E+00	0.0%	Rn-222	2.41E+02	2.41E+02	0.0%	Rn-222	6.05E+02	6.05E+02	0.0%
Risk-Based (1.00E-04)				Risk-Based (1.00E-04)				Risk-Based (1.00E-04)			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	3.05E-02	3.06E-02	0.3%	Rn-219	1.53E+00	1.53E+00	0.0%	Rn-219	3.83E+00	3.84E+00	0.3%
Rn-220	1.55E-02	1.55E-02	0.0%	Rn-220	7.76E-01	7.76E-01	0.0%	Rn-220	1.95E+00	1.95E+00	0.0%
Rn-222	7.95E-03	7.95E-03	0.0%	Rn-222	3.97E-01	3.97E-01	0.0%	Rn-222	9.97E-01	9.98E-01	0.1%
Dose-Based (25 mrem/year)				Dose-Based (25 mrem/year)				Dose-Based (25 mrem/year)			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	1.22E-01	1.22E-01	0.0%	Rn-219	6.12E+00	6.12E+00	0.0%	Rn-219	1.54E+01	1.54E+01	0.0%
Rn-220	1.26E-01	1.26E-01	0.0%	Rn-220	6.30E+00	6.30E+00	0.0%	Rn-220	1.58E+01	1.58E+01	0.0%
Rn-222	7.01E-02	6.09E-02	15.1%	Rn-222	3.50E+00	3.04E+00	15.1%	Rn-222	8.79E+00	7.65E+00	14.9%

BOLD: Represents a significant difference and source of potential error

Table 6: Calculated Exposures to a Default Resident from Measured Media Values

Measured Indoor Air				Measured Sub-Slab and Exterior Soil Gas				Measured Groundwater			
Working Level				Working Level				Working Level			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	5.29E-03	5.29E-03	0.0%	Rn-219	1.59E-02	1.59E-02	0.0%	Rn-219	2.30E-03	2.29E-03	0.4%
Rn-220	2.81E-02	2.81E-02	0.0%	Rn-220	8.42E-02	8.42E-02	0.0%	Rn-220	1.22E-02	1.22E-02	0.0%
Rn-222	3.56E-02	3.56E-02	0.0%	Rn-222	3.47E-01	3.47E-01	0.0%	Rn-222	3.86E-03	3.86E-03	0.0%
Lifetime Risk				Lifetime Risk				Lifetime Risk			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	5.63E-03	5.60E-03	0.5%	Rn-219	1.68E-02	1.67E-02	0.6%	Rn-219	2.44E-03	2.43E-03	0.4%
Rn-220	3.05E-02	3.05E-02	0.0%	Rn-220	8.87E-02	8.87E-02	0.0%	Rn-220	1.33E-02	1.33E-02	0.0%
Rn-222	8.39E-02	8.38E-02	0.1%	Rn-222	5.74E-01	5.74E-01	0.0%	Rn-222	9.50E-03	9.44E-03	0.6%
Annual Dose (mrem/year)				Annual Dose (mrem/year)				Annual Dose (mrem/year)			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	2.70E+02	2.70E+02	0.0%	Rn-219	8.11E+02	8.09E+02	0.2%	Rn-219	1.17E+02	1.17E+02	0.0%
Rn-220	7.27E+02	7.26E+02	0.1%	Rn-220	2.18E+03	2.18E+03	0.0%	Rn-220	3.15E+02	3.15E+02	0.0%
Rn-222	2.14E+03	2.14E+03	0.0%	Rn-222	2.09E+04	2.08E+04	0.5%	Rn-222	2.32E+02	2.32E+02	0.0%

Table 7: Calculated Exposures to a Default Commercial Worker from Measured Media Values

Measured Indoor Air				Measured Sub-Slab and Exterior Soil Gas				Measured Groundwater			
Working Level				Working Level				Working Level			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	3.94E-03	3.94E-03	0.0%	Rn-219	1.18E-02	1.18E-02	0.0%	Rn-219	1.71E-03	1.71E-03	0.0%
Rn-220	6.97E-03	6.97E-03	0.0%	Rn-220	2.09E-02	2.09E-02	0.0%	Rn-220	3.02E-03	3.02E-03	0.0%
Rn-222	2.88E-02	2.88E-02	0.0%	Rn-222	2.81E-01	2.81E-01	0.0%	Rn-222	3.13E-03	3.12E-03	0.3%
Lifetime Risk				Lifetime Risk				Lifetime Risk			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	3.32E-03	3.31E-03	0.3%	Rn-219	9.95E-03	9.90E-03	0.5%	Rn-219	1.44E-03	1.44E-03	0.0%
Rn-220	8.58E-03	8.54E-03	0.5%	Rn-220	2.54E-02	2.54E-02	0.0%	Rn-220	3.72E-03	3.71E-03	0.3%
Rn-222	5.00E-02	5.00E-02	0.0%	Rn-222	3.93E-01	3.93E-01	0.0%	Rn-222	5.56E-03	5.54E-03	0.4%
Annual Dose (mrem/year)				Annual Dose (mrem/year)				Annual Dose (mrem/year)			
Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD	Isotope	EPA RVISL	Verification	RPD
Rn-219	1.66E+02	1.66E+02	0.0%	Rn-219	4.97E+02	4.97E+02	0.0%	Rn-219	7.19E+01	7.17E+01	0.3%
Rn-220	2.11E+02	2.11E+02	0.0%	Rn-220	6.32E+02	6.32E+02	0.0%	Rn-220	9.14E+01	9.12E+01	0.2%
Rn-222	1.32E+03	1.32E+03	0.0%	Rn-222	1.28E+04	1.28E+04	0.0%	Rn-222	1.43E+02	1.43E+02	0.0%

4.0 Conclusion

Independent evaluation of the EPA RVISL Calculator using a Microsoft Excel© verification calculator confirmed the computational accuracy of screening level calculations to default receptors. Dose-based Rn-222 screening levels to site-specific receptors, however, appear to drop the polonium-218 DCF from the calculations and therefore overestimate the screening level (Appendix A). The dose-based Rn-222 screening levels again match the verification calculator for site-specific receptors when the polonium-218 DCF of 7.62E-06 millirem per picocurie (mrem/pCi) is manually entered by the user. This is observable for both site-specific residents and commercial workers.

All working level, risk, and annual dose calculations from measured radon concentrations in environmental media were within 1% of the verification calculator when the one-hit rule is applied to aggregate risk.

5.0 References

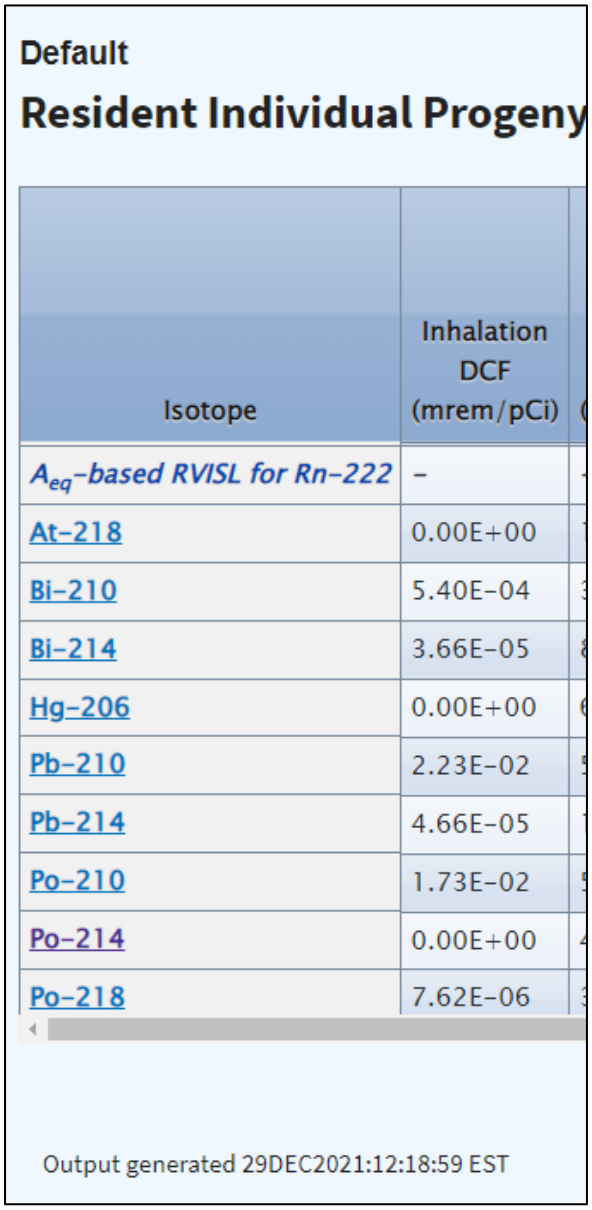
Oak Ridge National Laboratory (ORNL), 2014. *Calculation of Slope Factors and Dose Coefficients* and *appendix*. Center for Radiation Protection Knowledge. September.

ORNL, 2017. *Radon Cancer Risk Coefficients & Age-Specific Effective Dose Coefficients*. ORNL/TM-2017/47. Center for Radiation Protection Knowledge. January.

ORNL, 2020. *Air Exchange Rate Impact on Actinon, Thoron, and Radon Activity Equilibrium Factor and Fractional Equilibrium Factor Determination for Use in Vapor Intrusion Risk and Dose Models*. September.

U.S. Environmental Protection Agency (USEPA), 2021. *RVISL User's Guide*.

Appendix A: Polonium-218 DCF Omission in Site-Specific Rn-222 Screening Level Calculations

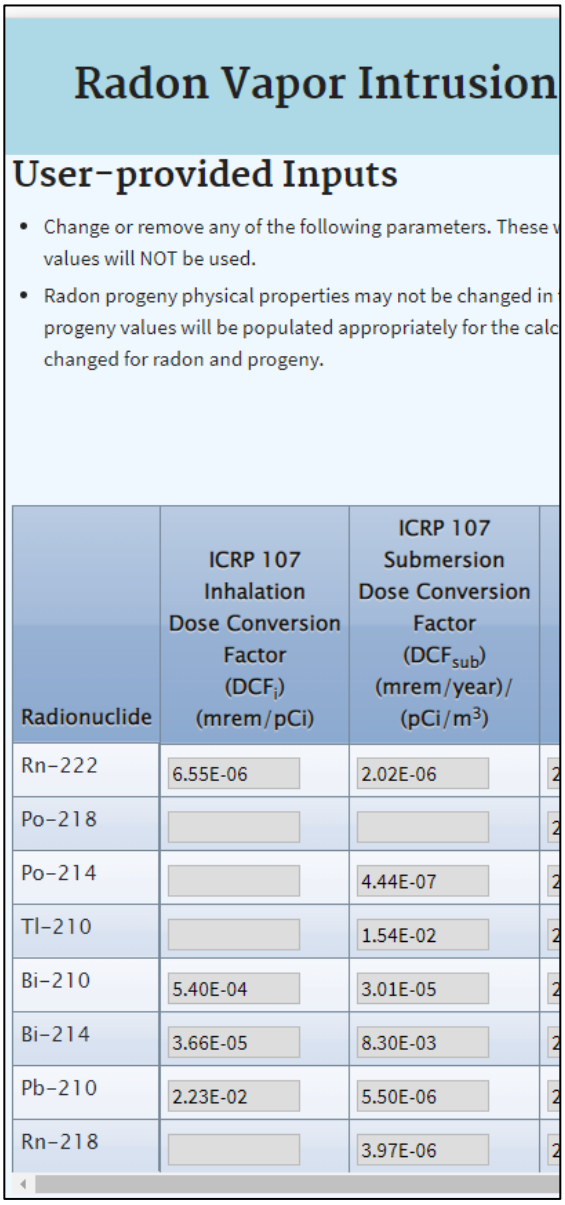


Default

Resident Individual Progeny

Isotope	Inhalation DCF (mrem/pCi)
A_{eq}-based RVISL for Rn-222	–
At-218	0.00E+00
Bi-210	5.40E-04
Bi-214	3.66E-05
Hg-206	0.00E+00
Pb-210	2.23E-02
Pb-214	4.66E-05
Po-210	1.73E-02
Po-214	0.00E+00
Po-218	7.62E-06

Output generated 29DEC2021:12:18:59 EST



Radon Vapor Intrusion

User-provided Inputs

- Change or remove any of the following parameters. These v values will NOT be used.
- Radon progeny physical properties may not be changed in progeny values will be populated appropriately for the calc changed for radon and progeny.

Radionuclide	ICRP 107 Inhalation Dose Conversion Factor (DCF_i) (mrem/pCi)	ICRP 107 Submersion Dose Conversion Factor (DCF_{sub}) (mrem/year)/(pCi/m^3)
Rn-222	6.55E-06	2.02E-06
Po-218		
Po-214		4.44E-07
Tl-210		1.54E-02
Bi-210	5.40E-04	3.01E-05
Bi-214	3.66E-05	8.30E-03
Pb-210	2.23E-02	5.50E-06
Rn-218		3.97E-06

(Left): Web-based output of the default resident screening level focused on the inhalation DCFs of the Rn-222 decay chain. Note the value 7.62E-06 mrem/pCi for polonium-218. **(Right):** Web-based user provided input screen for a site-specific resident screening level focused on the inhalation DCFs of the Rn-222 decay chain. Note the value 7.62E-06 mrem/pCi is absent for polonium-218 by default. The DCF is also omitted for site-specific commercial workers.

Working Level Concentration

Rn-219	162	pCi/L
Rn-220	7.5	pCi/L
Rn-222	100	pCi/L

Conversions

Day	24	hours
Year	365	days
Celsius add.	273.15	Kelvin

Radon Chemical Properties

Heat of Vaporization	18.1	kJ/mol
	4325.9	cal/mol
Critical Temperature	377	K
Normal Boiling Point	211.5	K
tb/tc	0.561008	-
n	0.3	-
Rc	1.9872	cal/mol/K
R	8.21E-05	atm m3/mol/K
TR	25	C
	298.15	K
HLC	4.34	-
HR	1.06E-01	atm m3/mol

Isotope	Inhalation Slope Factor (risk/pCi)	Submersion External Exposure Slope Factor (risk/pCi)	Inhalation DCF (mrem/pCi)	Submersion External Exposure DCF (mrem/yr per pCi/m3)	Half-Life (years)
Rn-219 Chain					
Bi-211	0.00E+00	1.91E-10	0.00E+00	2.42E-04	
Pb-211	4.03E-11	2.79E-10	5.03E-05	3.76E-04	
Po-211	0.00E+00	3.50E-11	0.00E+00	4.36E-05	
Po-215	0.00E+00	7.29E-13	0.00E+00	9.11E-07	
Rn-219	0.00E+00	2.38E-10	0.00E+00	2.99E-04	
Tl-207	0.00E+00	1.81E-11	0.00E+00	5.38E-05	
Rn-220 Chain					
Bi-212	1.13E-10	4.61E-10	6.11E-05	6.04E-04	
Pb-212	6.29E-10	5.57E-10	3.89E-04	7.13E-04	
Po-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Po-216	0.00E+00	6.59E-14	0.00E+00	8.17E-08	
Rn-220	1.15E-12	2.63E-12	8.18E-07	3.28E-06	
Tl-208	0.00E+00	1.59E-08	0.00E+00	1.96E-02	
Rn-222 Chain					
At-218	0.00E+00	3.08E-14	0.00E+00	1.14E-07	
Bi-210	4.55E-10	5.29E-12	5.40E-04	3.01E-05	
Bi-214	6.18E-11	6.69E-09	3.66E-05	8.30E-03	
Hg-206	0.00E+00	4.96E-10	0.00E+00	6.49E-04	
Pb-210	1.59E-08	3.93E-12	2.23E-02	5.50E-06	
Pb-214	7.77E-11	1.02E-09	4.66E-05	1.30E-03	
Po-210	1.45E-08	4.18E-14	1.73E-02	5.20E-08	
Po-214	0.00E+00	3.57E-13	0.00E+00	4.44E-07	
Po-218	1.39E-11	3.95E-17	7.62E-06	3.06E-10	
Rn-218	0.00E+00	3.19E-12	0.00E+00	3.97E-06	
Rn-222	2.28E-12	1.62E-12	6.55E-06	2.02E-06	
Tl-206	0.00E+00	9.40E-12	0.00E+00	4.64E-05	
Tl-210	0.00E+00	1.24E-08	0.00E+00	1.54E-02	

	Air Exchanges per Hour							
Isotope	0	0.1	0.18	0.2	0.3	0.4	0.5	0.6
Rn-219 Chain								
Bi-211	1.00E+00	9.15E-01	8.57E-01	8.43E-01	7.81E-01	7.27E-01	6.80E-01	6.38E-01
Pb-211	1.00E+00	9.20E-01	8.65E-01	8.52E-01	7.93E-01	7.42E-01	6.97E-01	6.58E-01
Po-211	2.80E-03	2.50E-03	2.40E-03	2.30E-03	2.20E-03	2.00E-03	1.90E-03	1.80E-03
Po-215	9.97E-01	9.97E-01	1.00E+00	9.96E-01	9.96E-01	9.96E-01	9.95E-01	9.95E-01
Rn-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-207	9.97E-01	9.02E-01	8.37E-01	8.22E-01	7.53E-01	6.93E-01	6.41E-01	5.95E-01
Rn-219 FEQ	1.00E+00	9.15E-01	8.57E-01	8.43E-01	7.81E-01	7.27E-01	6.80E-01	6.38E-01
Rn-220 Chain								
Bi-212	1.00E+00	3.44E-01	2.11E-01	1.90E-01	1.24E-01	8.85E-02	6.67E-02	5.23E-02
Pb-212	1.00E+00	3.95E-01	2.66E-01	2.46E-01	1.78E-01	1.40E-01	1.15E-01	9.79E-02
Po-212	6.41E-01	2.21E-01	1.35E-01	1.22E-01	7.96E-02	5.67E-02	4.28E-02	3.35E-02
Po-216	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-208	3.59E-01	1.23E-01	7.46E-02	6.73E-02	4.36E-02	3.09E-02	2.31E-02	1.80E-02
Rn-220 FEQ	1.00E+00	3.44E-01	2.11E-01	1.90E-01	1.24E-01	8.85E-02	6.68E-02	5.23E-02
Rn-222 Chain								
At-218	2.00E-04	1.99E-04	1.97E-04	1.97E-04	1.96E-04	1.94E-04	1.93E-04	1.91E-04
Bi-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bi-214	1.00E+00	8.90E-01	8.14E-01	7.97E-01	7.17E-01	6.48E-01	5.89E-01	5.36E-01
Hg-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-214	1.00E+00	9.33E-01	8.84E-01	8.73E-01	8.20E-01	7.72E-01	7.29E-01	6.90E-01
Po-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-214	1.00E+00	8.90E-01	8.14E-01	7.97E-01	7.17E-01	6.48E-01	5.89E-01	5.36E-01
Po-218	1.00E+00	9.93E-01	9.87E-01	9.85E-01	9.78E-01	9.71E-01	9.64E-01	9.57E-01
Rn-218	2.00E-07	1.99E-07	1.97E-07	1.97E-07	1.96E-07	1.94E-07	1.93E-07	1.91E-07
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl-210	2.10E-04	1.86E-04	1.70E-04	1.66E-04	1.49E-04	1.34E-04	1.22E-04	1.11E-04
Rn-222 FEQ	1.00E+00	9.35E-01	8.90E-01	8.79E-01	8.31E-01	7.90E-01	7.53E-01	7.21E-01

Isotope	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4
Rn-219 Chain								
Bi-211	6.00E-01	5.67E-01	5.37E-01	5.09E-01	4.84E-01	4.61E-01	4.40E-01	4.21E-01
Pb-211	6.22E-01	5.90E-01	5.61E-01	5.35E-01	5.12E-01	4.90E-01	4.70E-01	4.51E-01
Po-211	1.70E-03	1.60E-03	1.50E-03	1.40E-03	1.30E-03	1.30E-03	1.20E-03	1.20E-03
Po-215	9.90E-01	9.92E-01	9.93E-01	9.94E-01	9.95E-01	9.96E-01	9.97E-01	9.97E-01
Rn-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-207	5.54E-01	5.18E-01	4.85E-01	4.55E-01	4.29E-01	4.04E-01	3.82E-01	3.62E-01
Rn-219 FEQ	6.00E-01	5.67E-01	5.37E-01	5.09E-01	4.84E-01	4.61E-01	4.40E-01	4.21E-01
Rn-220 Chain								
Bi-212	4.22E-02	3.48E-02	2.92E-02	2.49E-02	2.15E-02	1.87E-02	1.65E-02	1.46E-02
Pb-212	8.51E-02	7.53E-02	6.75E-02	6.12E-02	5.59E-02	5.15E-02	4.77E-02	4.45E-02
Po-212	2.70E-02	2.23E-02	1.87E-02	1.60E-02	1.38E-02	1.20E-02	1.06E-02	9.40E-03
Po-216	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-208	1.44E-02	1.18E-02	9.80E-03	8.30E-03	7.10E-03	6.20E-03	5.40E-03	4.80E-03
Rn-220 FEQ	4.21E-02	3.48E-02	2.92E-02	2.49E-02	2.15E-02	1.87E-02	1.65E-02	1.47E-02
Rn-222 Chain								
At-218	1.90E-04	1.89E-04	1.87E-04	1.86E-04	1.85E-04	1.83E-04	1.82E-04	1.81E-04
Bi-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bi-214	4.91E-01	4.50E-01	4.15E-01	3.83E-01	3.54E-01	3.29E-01	3.06E-01	2.85E-01
Hg-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-214	6.55E-01	6.23E-01	5.93E-01	5.66E-01	5.41E-01	5.18E-01	4.96E-01	4.76E-01
Po-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-214	4.91E-01	4.50E-01	4.15E-01	3.83E-01	3.54E-01	3.29E-01	3.06E-01	2.85E-01
Po-218	9.50E-01	9.44E-01	9.37E-01	9.31E-01	9.24E-01	9.18E-01	9.12E-01	9.06E-01
Rn-218	1.90E-07	1.89E-07	1.87E-07	1.86E-07	1.85E-07	1.83E-07	1.82E-07	1.81E-07
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl-210	1.01E-04	9.23E-05	8.47E-05	7.80E-05	7.20E-05	6.66E-05	6.17E-05	5.74E-05
Rn-222 FEQ	6.92E-01	6.67E-01	6.44E-01	6.23E-01	6.04E-01	5.87E-01	5.72E-01	5.57E-01

Isotope	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2
Rn-219 Chain								
Bi-211	4.03E-01	3.87E-01	3.71E-01	3.57E-01	3.44E-01	3.31E-01	3.20E-01	3.09E-01
Pb-211	4.34E-01	4.19E-01	4.04E-01	3.90E-01	3.77E-01	3.65E-01	3.54E-01	3.44E-01
Po-211	1.10E-03	1.10E-03	1.00E-03	1.00E-03	9.00E-04	9.00E-04	9.00E-04	9.00E-04
Po-215	9.98E-01	9.99E-01	9.99E-01	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Rn-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-207	3.43E-01	3.26E-01	3.10E-01	2.95E-01	2.81E-01	2.69E-01	2.57E-01	2.46E-01
Rn-219 FEQ	4.03E-01	3.87E-01	3.71E-01	3.57E-01	3.44E-01	3.31E-01	3.20E-01	3.09E-01
Rn-220 Chain								
Bi-212	1.31E-02	1.17E-02	1.06E-02	9.60E-03	8.80E-03	8.10E-03	7.40E-03	6.80E-03
Pb-212	4.16E-02	3.91E-02	3.69E-02	3.49E-02	3.31E-02	3.15E-02	3.01E-02	2.88E-02
Po-212	8.40E-03	7.50E-03	6.80E-03	6.20E-03	5.60E-03	5.20E-03	4.80E-03	4.40E-03
Po-216	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-208	4.20E-03	3.80E-03	3.40E-03	3.10E-03	2.80E-03	2.50E-03	2.30E-03	2.10E-03
Rn-220 FEQ	1.31E-02	1.17E-02	1.06E-02	9.65E-03	8.75E-03	8.11E-03	7.46E-03	6.85E-03
Rn-222 Chain								
At-218	1.80E-04	1.79E-04	1.77E-04	1.76E-04	1.75E-04	1.74E-04	1.73E-04	1.72E-04
Bi-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bi-214	2.66E-01	2.49E-01	2.34E-01	2.19E-01	2.06E-01	1.94E-01	1.83E-01	1.73E-01
Hg-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-214	4.57E-01	4.40E-01	4.24E-01	4.08E-01	3.94E-01	3.80E-01	3.67E-01	3.55E-01
Po-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-214	2.66E-01	2.49E-01	2.34E-01	2.19E-01	2.06E-01	1.94E-01	1.83E-01	1.73E-01
Po-218	8.99E-01	8.93E-01	8.88E-01	8.82E-01	8.76E-01	8.70E-01	8.65E-01	8.59E-01
Rn-218	1.80E-07	1.79E-07	1.77E-07	1.76E-07	1.75E-07	1.74E-07	1.73E-07	1.72E-07
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl-210	5.34E-05	4.98E-05	4.66E-05	4.36E-05	4.09E-05	3.84E-05	3.61E-05	3.40E-05
Rn-222 FEQ	5.44E-01	5.32E-01	5.20E-01	5.10E-01	5.00E-01	4.91E-01	4.82E-01	4.74E-01

Isotope	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3
Rn-219 Chain								
Bi-211	2.98E-01	2.89E-01	2.79E-01	2.71E-01	2.63E-01	2.55E-01	2.47E-01	2.40E-01
Pb-211	3.34E-01	3.24E-01	3.15E-01	3.07E-01	2.99E-01	2.91E-01	2.84E-01	2.77E-01
Po-211	8.00E-04	8.00E-04	8.00E-04	7.00E-04	7.00E-04	7.00E-04	7.00E-04	7.00E-04
Po-215	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Rn-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-207	2.35E-01	2.26E-01	2.17E-01	2.08E-01	2.00E-01	1.92E-01	1.85E-01	1.78E-01
Rn-219 FEQ	2.98E-01	2.89E-01	2.80E-01	2.71E-01	2.63E-01	2.55E-01	2.47E-01	2.40E-01
Rn-220 Chain								
Bi-212	6.30E-03	5.90E-03	5.50E-03	5.10E-03	4.80E-03	4.50E-03	4.20E-03	4.00E-03
Pb-212	2.75E-02	2.64E-02	2.54E-02	2.44E-02	2.36E-02	2.27E-02	2.20E-02	2.12E-02
Po-212	4.10E-03	3.80E-03	3.50E-03	3.30E-03	3.10E-03	2.90E-03	2.70E-03	2.50E-03
Po-216	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-208	1.90E-03	1.80E-03	1.70E-03	1.50E-03	1.40E-03	1.30E-03	1.20E-03	1.20E-03
Rn-220 FEQ	6.37E-03	5.92E-03	5.47E-03	5.14E-03	4.83E-03	4.52E-03	4.21E-03	3.93E-03
Rn-222 Chain								
At-218	1.70E-04	1.69E-04	1.68E-04	1.67E-04	1.66E-04	1.65E-04	1.64E-04	1.63E-04
Bi-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bi-214	1.64E-01	1.55E-01	1.47E-01	1.40E-01	1.33E-01	1.26E-01	1.20E-01	1.14E-01
Hg-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-214	3.44E-01	3.33E-01	3.23E-01	3.13E-01	3.04E-01	2.95E-01	2.87E-01	2.79E-01
Po-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-214	1.64E-01	1.55E-01	1.47E-01	1.40E-01	1.33E-01	1.26E-01	1.20E-01	1.14E-01
Po-218	8.54E-01	8.48E-01	8.43E-01	8.38E-01	8.32E-01	8.27E-01	8.22E-01	8.17E-01
Rn-218	1.70E-07	1.69E-07	1.68E-07	1.67E-07	1.66E-07	1.65E-07	1.64E-07	1.63E-07
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl-210	3.21E-05	3.03E-05	2.86E-05	2.71E-05	2.57E-05	2.44E-05	2.31E-05	2.20E-05
Rn-222 FEQ	4.66E-01	4.59E-01	4.52E-01	4.46E-01	4.39E-01	4.34E-01	4.28E-01	4.23E-01

Isotope	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8
Rn-219 Chain								
Bi-211	2.34E-01	2.27E-01	2.21E-01	2.15E-01	2.10E-01	2.04E-01	1.99E-01	1.95E-01
Pb-211	2.71E-01	2.65E-01	2.59E-01	2.53E-01	2.48E-01	2.42E-01	2.37E-01	2.33E-01
Po-211	6.00E-04	6.00E-04	6.00E-04	6.00E-04	6.00E-04	6.00E-04	5.00E-04	5.00E-04
Po-215	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Rn-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-207	1.72E-01	1.66E-01	1.60E-01	1.54E-01	1.49E-01	1.44E-01	1.40E-01	1.35E-01
Rn-219 FEQ	2.34E-01	2.27E-01	2.21E-01	2.15E-01	2.10E-01	2.05E-01	2.00E-01	1.95E-01
Rn-220 Chain								
Bi-212	3.70E-03	3.50E-03	3.30E-03	3.20E-03	3.00E-03	2.80E-03	2.70E-03	2.60E-03
Pb-212	2.06E-02	1.99E-02	1.94E-02	1.88E-02	1.83E-02	1.78E-02	1.73E-02	1.69E-02
Po-212	2.40E-03	2.30E-03	2.10E-03	2.00E-03	1.90E-03	1.80E-03	1.70E-03	1.70E-03
Po-216	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-208	1.10E-03	1.00E-03	1.00E-03	9.00E-04	9.00E-04	8.00E-04	8.00E-04	7.00E-04
Rn-220 FEQ	3.73E-03	3.56E-03	3.28E-03	3.14E-03	2.97E-03	2.81E-03	2.67E-03	2.64E-03
Rn-222 Chain								
At-218	1.62E-04	1.61E-04	1.60E-04	1.59E-04	1.58E-04	1.57E-04	1.56E-04	1.55E-04
Bi-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bi-214	1.09E-01	1.04E-01	9.96E-02	9.52E-02	9.11E-02	8.73E-02	8.37E-02	8.02E-02
Hg-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-214	2.71E-01	2.64E-01	2.57E-01	2.50E-01	2.44E-01	2.37E-01	2.32E-01	2.26E-01
Po-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-214	1.09E-01	1.04E-01	9.96E-02	9.52E-02	9.11E-02	8.73E-02	8.37E-02	8.02E-02
Po-218	8.12E-01	8.07E-01	8.03E-01	7.98E-01	7.93E-01	7.88E-01	7.84E-01	7.79E-01
Rn-218	1.62E-07	1.61E-07	1.60E-07	1.59E-07	1.58E-07	1.57E-07	1.56E-07	1.55E-07
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl-210	2.09E-05	1.99E-05	1.90E-05	1.81E-05	1.73E-05	1.65E-05	1.57E-05	1.51E-05
Rn-222 FEQ	4.17E-01	4.13E-01	4.08E-01	4.03E-01	3.99E-01	3.95E-01	3.91E-01	3.87E-01

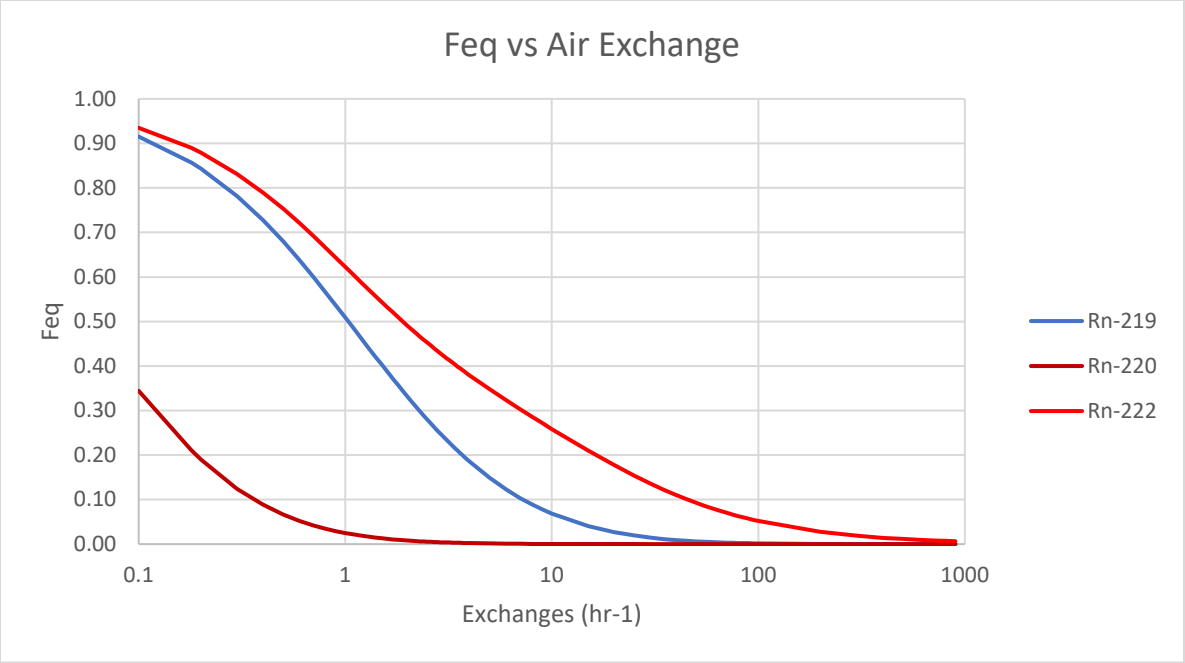
Isotope	3.9	4	5	6	7	8	9	10
Rn-219 Chain								
Bi-211	1.90E-01	1.85E-01	1.49E-01	1.23E-01	1.04E-01	8.91E-02	7.75E-02	6.81E-02
Pb-211	2.28E-01	2.24E-01	1.87E-01	1.61E-01	1.41E-01	1.26E-01	1.13E-01	1.03E-01
Po-211	5.00E-04	5.00E-04	4.00E-04	3.00E-04	3.00E-04	2.00E-04	2.00E-04	2.00E-04
Po-215	1.00E+00	1.00E+00	9.97E-01	9.93E-01	1.00E+00	1.00E+00	1.00E+00	9.96E-01
Rn-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-207	1.31E-01	1.27E-01	9.43E-02	7.26E-02	5.74E-02	4.63E-02	3.80E-02	3.16E-02
Rn-219 FEQ	1.90E-01	1.85E-01	1.49E-01	1.23E-01	1.04E-01	8.91E-02	7.76E-02	6.82E-02
Rn-220 Chain								
Bi-212	2.50E-03	2.30E-03	1.60E-03	1.10E-03	8.00E-04	6.00E-04	5.00E-04	4.00E-04
Pb-212	1.64E-02	1.60E-02	1.29E-02	1.07E-02	9.20E-03	8.10E-03	7.20E-03	6.50E-03
Po-212	1.60E-03	1.50E-03	1.00E-03	7.00E-04	5.00E-04	4.00E-04	3.00E-04	3.00E-04
Po-216	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.99E-01
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-208	7.00E-04	7.00E-04	4.00E-04	3.00E-04	2.00E-04	1.00E-04	1.00E-04	1.00E-04
Rn-220 FEQ	2.50E-03	2.33E-03	1.57E-03	1.09E-03	7.86E-04	6.17E-04	4.77E-04	4.49E-04
Rn-222 Chain								
At-218	1.55E-04	1.54E-04	1.45E-04	1.38E-04	1.31E-04	1.25E-04	1.19E-04	1.14E-04
Bi-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bi-214	7.70E-02	7.39E-02	5.09E-02	3.67E-02	2.74E-02	2.11E-02	1.66E-02	1.33E-02
Hg-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-214	2.21E-01	2.15E-01	1.73E-01	1.42E-01	1.19E-01	1.02E-01	8.80E-02	7.70E-02
Po-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-214	7.70E-02	7.39E-02	5.09E-02	3.67E-02	2.74E-02	2.11E-02	1.66E-02	1.33E-02
Po-218	7.75E-01	7.70E-01	7.28E-01	6.91E-01	6.57E-01	6.26E-01	5.98E-01	5.73E-01
Rn-218	1.55E-07	1.54E-07	1.45E-07	1.38E-07	1.31E-07	1.25E-07	1.19E-07	1.14E-07
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl-210	1.44E-05	1.38E-05	9.24E-06	6.49E-06	4.73E-06	3.55E-06	2.72E-06	2.13E-06
Rn-222 FEQ	3.83E-01	3.79E-01	3.48E-01	3.24E-01	3.04E-01	2.87E-01	2.72E-01	2.59E-01

Isotope	15	20	25	30	35	40	45	50
Rn-219 Chain								
Bi-211	4.02E-02	2.68E-02	1.92E-02	1.45E-02	1.13E-02	9.10E-03	7.50E-03	6.30E-03
Pb-211	7.12E-02	5.43E-02	4.39E-02	3.68E-02	3.17E-02	2.78E-02	2.48E-02	2.24E-02
Po-211	1.00E-04	1.00E-04	1.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-215	9.95E-01	9.95E-01	9.94E-01	9.93E-01	9.92E-01	9.92E-01	9.91E-01	9.90E-01
Rn-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-207	1.47E-02	8.10E-03	4.90E-03	3.20E-03	2.30E-03	1.60E-03	1.20E-03	9.00E-04
Rn-219 FEQ	4.03E-02	2.68E-02	1.94E-02	1.45E-02	1.14E-02	9.17E-03	7.48E-03	6.28E-03
Rn-220 Chain								
Bi-212	2.00E-04	1.00E-04	1.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-212	4.30E-03	3.20E-03	2.60E-03	2.20E-03	1.90E-03	1.60E-03	1.40E-03	1.30E-03
Po-212	1.00E-04	1.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-216	9.99E-01	9.99E-01	9.99E-01	9.98E-01	9.98E-01	9.98E-01	9.97E-01	9.97E-01
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-208	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-220 FEQ	1.68E-04	1.40E-04	2.79E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-222 Chain								
At-218	9.36E-05	7.93E-05	6.88E-05	6.07E-05	5.43E-05	4.91E-05	4.47E-05	4.11E-05
Bi-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bi-214	5.42E-03	2.74E-03	1.58E-03	9.94E-04	6.66E-04	4.68E-04	3.42E-04	2.57E-04
Hg-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-214	4.43E-02	2.89E-02	2.04E-02	1.52E-02	1.18E-02	9.38E-03	7.66E-03	6.37E-03
Po-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-214	5.42E-03	2.74E-03	1.58E-03	9.94E-04	6.66E-04	4.68E-04	3.42E-04	2.57E-04
Po-218	4.72E-01	4.01E-01	3.49E-01	3.09E-01	2.77E-01	2.51E-01	2.30E-01	2.12E-01
Rn-218	9.36E-08	7.93E-08	6.88E-08	6.07E-08	5.43E-08	4.90E-08	4.47E-08	4.10E-08
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl-210	7.76E-07	3.54E-07	1.86E-07	1.08E-07	6.68E-08	4.37E-08	2.98E-08	2.11E-08
Rn-222 FEQ	2.10E-01	1.78E-01	1.54E-01	1.36E-01	1.22E-01	1.10E-01	1.01E-01	9.29E-02

Isotope	55	60	65	70	75	80	85	90
Rn-219 Chain								
Bi-211	5.30E-03	4.60E-03	4.00E-03	3.50E-03	3.10E-03	2.70E-03	2.50E-03	2.20E-03
Pb-211	2.04E-02	1.87E-02	1.73E-02	1.60E-02	1.50E-02	1.40E-02	1.32E-02	1.25E-02
Po-211	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-215	9.89E-01	9.88E-01	9.87E-01	9.89E-01	9.88E-01	9.87E-01	9.86E-01	9.85E-01
Rn-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-207	7.00E-04	6.00E-04	5.00E-04	4.00E-04	3.00E-04	3.00E-04	2.00E-04	2.00E-04
Rn-219 FEQ	5.38E-03	4.59E-03	3.99E-03	3.49E-03	3.09E-03	2.79E-03	2.49E-03	2.19E-03
Rn-220 Chain								
Bi-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-212	1.20E-03	1.10E-03	1.00E-03	9.00E-04	9.00E-04	8.00E-04	8.00E-04	7.00E-04
Po-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-216	9.97E-01	9.97E-01	9.96E-01	9.96E-01	9.96E-01	9.95E-01	9.95E-01	9.95E-01
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-208	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-220 FEQ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-222 Chain								
At-218	3.80E-05	3.53E-05	3.29E-05	3.09E-05	2.90E-05	2.74E-05	2.59E-05	2.46E-05
Bi-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bi-214	1.98E-04	1.56E-04	1.25E-04	1.02E-04	8.42E-05	7.03E-05	5.93E-05	5.05E-05
Hg-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-214	5.38E-03	4.61E-03	3.99E-03	3.49E-03	3.08E-03	2.73E-03	2.44E-03	2.20E-03
Po-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-214	1.98E-04	1.56E-04	1.25E-04	1.02E-04	8.42E-05	7.03E-05	5.93E-05	5.05E-05
Po-218	1.96E-01	1.83E-01	1.71E-01	1.61E-01	1.52E-01	1.44E-01	1.36E-01	1.30E-01
Rn-218	3.79E-08	3.52E-08	3.29E-08	3.08E-08	2.90E-08	2.74E-08	2.59E-08	2.46E-08
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl-210	1.53E-08	1.14E-08	8.68E-09	6.72E-09	5.29E-09	4.22E-09	3.40E-09	2.78E-09
Rn-222 FEQ	8.61E-02	8.02E-02	7.51E-02	7.06E-02	6.66E-02	6.30E-02	5.98E-02	5.69E-02

Isotope	95	100	200	300	400	500	600	700
Rn-219 Chain								
Bi-211	2.00E-03	1.80E-03	5.00E-04	2.00E-04	1.00E-04	1.00E-04	1.00E-04	0.00E+00
Pb-211	1.18E-02	1.12E-02	5.60E-03	3.70E-03	2.70E-03	2.10E-03	1.80E-03	1.50E-03
Po-211	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-215	9.84E-01	9.83E-01	9.73E-01	9.63E-01	9.46E-01	9.28E-01	9.22E-01	9.08E-01
Rn-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-207	2.00E-04	1.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-219 FEQ	1.99E-03	1.89E-03	4.98E-04	1.99E-04	9.97E-05	9.97E-05	9.97E-05	0.00E+00
Rn-220 Chain								
Bi-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-212	7.00E-04	6.00E-04	3.00E-04	2.00E-04	2.00E-04	1.00E-04	1.00E-04	1.00E-04
Po-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-216	9.95E-01	9.94E-01	9.89E-01	9.83E-01	9.77E-01	9.72E-01	9.66E-01	9.61E-01
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-208	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-220 FEQ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-222 Chain								
At-218	2.34E-05	2.23E-05	1.12E-05	7.25E-06	5.23E-06	4.02E-06	3.21E-06	2.65E-06
Bi-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bi-214	4.33E-05	3.75E-05	5.12E-06	1.57E-06	6.79E-07	3.53E-07	2.07E-07	1.32E-07
Hg-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-214	1.99E-03	1.81E-03	4.84E-04	2.20E-04	1.25E-04	8.08E-05	5.64E-05	4.16E-05
Po-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-214	4.33E-05	3.75E-05	5.13E-06	1.58E-06	6.84E-07	3.57E-07	2.10E-07	1.34E-07
Po-218	1.24E-01	1.18E-01	6.29E-02	4.28E-02	3.25E-02	2.61E-02	2.19E-02	1.88E-02
Rn-218	2.34E-08	2.23E-08	1.12E-08	7.22E-09	5.20E-09	3.99E-09	3.19E-09	2.62E-09
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Tl-206	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl-210	2.29E-09	1.91E-09	1.48E-10	3.19E-11	1.06E-11	4.46E-12	2.20E-12	1.21E-12
Rn-222 FEQ	5.43E-02	5.19E-02	2.76E-02	1.88E-02	1.42E-02	1.15E-02	9.59E-03	8.24E-03

Isotope	800	900
Rn-219 Chain		
Bi-211	0.00E+00	0.00E+00
Pb-211	1.30E-03	1.10E-03
Po-211	0.00E+00	0.00E+00
Po-215	8.95E-01	8.83E-01
Rn-219	1.00E+00	1.00E+00
Tl-207	0.00E+00	0.00E+00
Rn-219 FEQ	0.00E+00	0.00E+00
Rn-220 Chain		
Bi-212	0.00E+00	0.00E+00
Pb-212	1.00E-04	1.00E-04
Po-212	0.00E+00	0.00E+00
Po-216	9.56E-01	9.50E-01
Rn-220	1.00E+00	1.00E+00
Tl-208	0.00E+00	0.00E+00
Rn-220 FEQ	0.00E+00	0.00E+00
Rn-222 Chain		
At-218	2.23E-06	1.91E-06
Bi-210	0.00E+00	0.00E+00
Bi-214	8.90E-08	6.30E-08
Hg-206	0.00E+00	0.00E+00
Pb-210	0.00E+00	0.00E+00
Pb-214	3.19E-05	2.53E-05
Po-210	0.00E+00	0.00E+00
Po-214	9.12E-08	6.49E-08
Po-218	1.65E-02	1.47E-02
Rn-218	2.20E-09	1.88E-09
Rn-222	1.00E+00	1.00E+00
Tl-206	0.00E+00	0.00E+00
Tl-210	7.19E-13	4.54E-13
Rn-222 FEQ	7.23E-03	6.44E-03


Feq vs Air Exchange
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Feq
0.1
1
10
100
1000
Exchanges (hr-1)
Rn-219
Rn-220
Rn-222

FROM ORNL, 2020

	0	0.1	0.18	0.2	0.3	0.4	0.5	0.6	0.7
Ra-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-215	9.97E-01	9.97E-01	1.00E+00	9.96E-01	9.96E-01	9.96E-01	9.95E-01	9.95E-01	9.90E-01
Pb-211	1.00E+00	9.20E-01	8.65E-01	8.52E-01	7.93E-01	7.42E-01	6.97E-01	6.58E-01	6.22E-01
Bi-211	1.00E+00	9.15E-01	8.57E-01	8.43E-01	7.81E-01	7.27E-01	6.80E-01	6.38E-01	6.00E-01
Tl-207	9.97E-01	9.02E-01	8.37E-01	8.22E-01	7.53E-01	6.93E-01	6.41E-01	5.95E-01	5.54E-01
Po-211	2.80E-03	2.50E-03	2.40E-03	2.30E-03	2.20E-03	2.00E-03	1.90E-03	1.80E-03	1.70E-03
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-216	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Pb-212	1.00E+00	3.95E-01	2.66E-01	2.46E-01	1.78E-01	1.40E-01	1.15E-01	9.79E-02	8.51E-02
Bi-212	1.00E+00	3.44E-01	2.11E-01	1.90E-01	1.24E-01	8.85E-02	6.67E-02	5.23E-02	4.22E-02
Po-212	6.41E-01	2.21E-01	1.35E-01	1.22E-01	7.96E-02	5.67E-02	4.28E-02	3.35E-02	2.70E-02
Tl-208	3.59E-01	1.23E-01	7.46E-02	6.73E-02	4.36E-02	3.09E-02	2.31E-02	1.80E-02	1.44E-02
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-218	1.00E+00	9.93E-01	9.87E-01	9.85E-01	9.78E-01	9.71E-01	9.64E-01	9.57E-01	9.50E-01
Pb-214	1.00E+00	9.33E-01	8.84E-01	8.73E-01	8.20E-01	7.72E-01	7.29E-01	6.90E-01	6.55E-01
At-218	2.00E-04	1.99E-04	1.97E-04	1.97E-04	1.96E-04	1.94E-04	1.93E-04	1.91E-04	1.90E-04
Bi-214	1.00E+00	8.90E-01	8.14E-01	7.97E-01	7.17E-01	6.48E-01	5.89E-01	5.37E-01	4.91E-01
Rn-218	2.00E-07	1.99E-07	1.97E-07	1.97E-07	1.96E-07	1.94E-07	1.93E-07	1.91E-07	1.90E-07
Po-214	1.00E+00	8.90E-01	8.14E-01	7.97E-01	7.17E-01	6.48E-01	5.89E-01	5.37E-01	4.91E-01
Tl-210	2.10E-04	1.86E-04	1.70E-04	1.66E-04	1.49E-04	1.34E-04	1.22E-04	1.11E-04	1.01E-04

ORNL - RVISL CALCULATOR

Po-215	0.0002	-0.0002	0.0000	0.0004	0.0000	-0.0004	0.0001	-0.0004	0.0004
Pb-211	0.0000	0.0001	-0.0002	0.0001	0.0004	0.0002	0.0003	-0.0005	0.0000
Bi-211	0.0000	0.0004	-0.0001	0.0004	0.0003	0.0003	-0.0002	-0.0002	0.0004
Tl-207	0.0000	0.0003	0.0001	0.0000	0.0000	0.0003	0.0000	-0.0001	0.0001
Po-211	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-216	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Pb-212	0.0000	-0.0005	-0.0003	-0.0003	0.0004	0.0001	0.0003	0.0000	0.0000
Bi-212	0.0000	0.0003	-0.0004	0.0003	0.0002	0.0000	0.0000	0.0000	0.0000
Po-212	0.0000	-0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tl-208	0.0000	-0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-218	0.0000	-0.0004	-0.0002	0.0003	0.0001	0.0000	0.0001	0.0002	0.0004
Pb-214	0.0000	-0.0005	0.0002	-0.0002	-0.0003	0.0000	0.0001	0.0003	0.0000
At-218	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-214	0.0000	0.0001	0.0003	-0.0002	-0.0001	0.0002	-0.0005	0.0005	-0.0002
Rn-218	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-214	0.0000	0.0001	0.0003	-0.0002	-0.0001	0.0002	-0.0005	0.0005	-0.0002
Tl-210	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6
Ra-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-215	9.92E-01	9.93E-01	9.94E-01	9.95E-01	9.96E-01	9.97E-01	9.97E-01	9.98E-01	9.99E-01
Pb-211	5.90E-01	5.61E-01	5.35E-01	5.12E-01	4.90E-01	4.70E-01	4.51E-01	4.34E-01	4.19E-01
Bi-211	5.67E-01	5.37E-01	5.09E-01	4.84E-01	4.61E-01	4.40E-01	4.21E-01	4.03E-01	3.87E-01
Tl-207	5.18E-01	4.85E-01	4.55E-01	4.29E-01	4.04E-01	3.82E-01	3.62E-01	3.43E-01	3.26E-01
Po-211	1.60E-03	1.50E-03	1.40E-03	1.30E-03	1.30E-03	1.20E-03	1.20E-03	1.10E-03	1.10E-03
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-216	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Pb-212	7.53E-02	6.75E-02	6.12E-02	5.59E-02	5.15E-02	4.77E-02	4.45E-02	4.16E-02	3.91E-02
Bi-212	3.48E-02	2.92E-02	2.49E-02	2.15E-02	1.87E-02	1.65E-02	1.46E-02	1.31E-02	1.17E-02
Po-212	2.23E-02	1.87E-02	1.60E-02	1.38E-02	1.20E-02	1.06E-02	9.40E-03	8.40E-03	7.50E-03
Tl-208	1.18E-02	9.80E-03	8.30E-03	7.10E-03	6.20E-03	5.40E-03	4.80E-03	4.20E-03	3.80E-03
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-218	9.44E-01	9.37E-01	9.31E-01	9.24E-01	9.18E-01	9.12E-01	9.06E-01	8.99E-01	8.93E-01
Pb-214	6.23E-01	5.93E-01	5.66E-01	5.41E-01	5.18E-01	4.96E-01	4.76E-01	4.57E-01	4.40E-01
At-218	1.89E-04	1.87E-04	1.86E-04	1.85E-04	1.83E-04	1.82E-04	1.81E-04	1.80E-04	1.79E-04
Bi-214	4.51E-01	4.15E-01	3.83E-01	3.55E-01	3.29E-01	3.06E-01	2.85E-01	2.66E-01	2.49E-01
Rn-218	1.89E-07	1.87E-07	1.86E-07	1.85E-07	1.83E-07	1.82E-07	1.81E-07	1.80E-07	1.79E-07
Po-214	4.51E-01	4.15E-01	3.83E-01	3.55E-01	3.29E-01	3.06E-01	2.85E-01	2.66E-01	2.49E-01
Tl-210	9.23E-05	8.47E-05	7.80E-05	7.20E-05	6.66E-05	6.17E-05	5.74E-05	5.34E-05	4.99E-05

Po-215	-0.0003	-0.0001	0.0000	0.0000	-0.0001	-0.0003	0.0004	0.0001	-0.0003
Pb-211	0.0001	0.0003	0.0002	-0.0005	-0.0003	-0.0003	0.0003	0.0003	-0.0005
Bi-211	-0.0002	-0.0005	0.0001	0.0001	0.0002	0.0003	0.0000	0.0002	-0.0003
Tl-207	-0.0004	-0.0002	0.0003	-0.0004	0.0002	0.0000	-0.0003	0.0000	-0.0003
Po-211	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-216	0.0000	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
Pb-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tl-208	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-218	-0.0003	0.0001	-0.0004	0.0002	-0.0001	-0.0003	-0.0005	0.0004	0.0004
Pb-214	-0.0003	0.0001	-0.0001	-0.0002	-0.0004	0.0001	0.0000	0.0004	-0.0001
At-218	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-214	0.0005	-0.0003	-0.0001	0.0005	-0.0001	-0.0001	0.0002	0.0004	0.0002
Rn-218	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-214	0.0005	-0.0003	-0.0001	0.0005	-0.0001	-0.0001	0.0002	0.0004	0.0002
Tl-210	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5
Ra-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-215	9.99E-01	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Pb-211	4.04E-01	3.90E-01	3.77E-01	3.65E-01	3.54E-01	3.44E-01	3.34E-01	3.24E-01	3.15E-01
Bi-211	3.71E-01	3.57E-01	3.44E-01	3.31E-01	3.20E-01	3.09E-01	2.98E-01	2.89E-01	2.79E-01
Tl-207	3.10E-01	2.95E-01	2.81E-01	2.69E-01	2.57E-01	2.46E-01	2.35E-01	2.26E-01	2.17E-01
Po-211	1.00E-03	1.00E-03	9.00E-04	9.00E-04	9.00E-04	9.00E-04	8.00E-04	8.00E-04	8.00E-04
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-216	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Pb-212	3.69E-02	3.49E-02	3.31E-02	3.15E-02	3.01E-02	2.88E-02	2.75E-02	2.64E-02	2.54E-02
Bi-212	1.06E-02	9.60E-03	8.80E-03	8.10E-03	7.40E-03	6.80E-03	6.30E-03	5.90E-03	5.50E-03
Po-212	6.80E-03	6.20E-03	5.60E-03	5.20E-03	4.80E-03	4.40E-03	4.10E-03	3.80E-03	3.50E-03
Tl-208	3.40E-03	3.10E-03	2.80E-03	2.50E-03	2.30E-03	2.10E-03	1.90E-03	1.80E-03	1.70E-03
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-218	8.88E-01	8.82E-01	8.76E-01	8.70E-01	8.65E-01	8.59E-01	8.54E-01	8.48E-01	8.43E-01
Pb-214	4.24E-01	4.08E-01	3.94E-01	3.80E-01	3.67E-01	3.55E-01	3.44E-01	3.33E-01	3.23E-01
At-218	1.77E-04	1.76E-04	1.75E-04	1.74E-04	1.73E-04	1.72E-04	1.71E-04	1.69E-04	1.68E-04
Bi-214	2.34E-01	2.19E-01	2.06E-01	1.94E-01	1.83E-01	1.73E-01	1.64E-01	1.55E-01	1.47E-01
Rn-218	1.77E-07	1.76E-07	1.75E-07	1.74E-07	1.73E-07	1.72E-07	1.71E-07	1.69E-07	1.68E-07
Po-214	2.34E-01	2.19E-01	2.06E-01	1.94E-01	1.83E-01	1.73E-01	1.64E-01	1.55E-01	1.47E-01
Tl-210	4.66E-05	4.36E-05	4.09E-05	3.84E-05	3.61E-05	3.40E-05	3.21E-05	3.03E-05	2.87E-05

Po-215	0.0002	-0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Pb-211	-0.0002	0.0002	0.0004	0.0004	0.0001	-0.0004	-0.0004	0.0002	0.0003
Bi-211	0.0004	0.0001	-0.0002	0.0003	-0.0004	-0.0004	0.0003	-0.0004	0.0004
Tl-207	-0.0002	0.0001	0.0004	-0.0003	-0.0002	-0.0003	0.0003	-0.0004	-0.0005
Po-211	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-216	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
Pb-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tl-208	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-218	-0.0005	-0.0003	-0.0001	0.0003	-0.0003	0.0001	-0.0003	0.0003	-0.0001
Pb-214	-0.0005	0.0002	-0.0002	0.0002	0.0004	0.0003	-0.0001	0.0001	-0.0002
At-218	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-214	-0.0003	0.0004	0.0004	0.0004	0.0004	0.0002	-0.0002	0.0001	0.0001
Rn-218	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-214	-0.0003	0.0004	0.0004	0.0004	0.0004	0.0002	-0.0002	0.0001	0.0001
Tl-210	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

	2.6	2.7	2.8	2.9	3	3.1	3.2	3.3	3.4
Ra-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-215	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Pb-211	3.07E-01	2.99E-01	2.91E-01	2.84E-01	2.77E-01	2.71E-01	2.65E-01	2.59E-01	2.53E-01
Bi-211	2.71E-01	2.63E-01	2.55E-01	2.47E-01	2.40E-01	2.34E-01	2.27E-01	2.21E-01	2.15E-01
Tl-207	2.08E-01	2.00E-01	1.92E-01	1.85E-01	1.78E-01	1.72E-01	1.66E-01	1.60E-01	1.54E-01
Po-211	7.00E-04	7.00E-04	7.00E-04	7.00E-04	7.00E-04	6.00E-04	6.00E-04	6.00E-04	6.00E-04
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-216	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Pb-212	2.44E-02	2.36E-02	2.27E-02	2.20E-02	2.12E-02	2.06E-02	1.99E-02	1.94E-02	1.88E-02
Bi-212	5.10E-03	4.80E-03	4.50E-03	4.20E-03	4.00E-03	3.70E-03	3.50E-03	3.30E-03	3.20E-03
Po-212	3.30E-03	3.10E-03	2.90E-03	2.70E-03	2.50E-03	2.40E-03	2.30E-03	2.10E-03	2.00E-03
Tl-208	1.50E-03	1.40E-03	1.30E-03	1.20E-03	1.20E-03	1.10E-03	1.00E-03	1.00E-03	9.00E-04
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-218	8.38E-01	8.33E-01	8.27E-01	8.22E-01	8.17E-01	8.12E-01	8.07E-01	8.03E-01	7.98E-01
Pb-214	3.13E-01	3.04E-01	2.95E-01	2.87E-01	2.79E-01	2.71E-01	2.64E-01	2.57E-01	2.50E-01
At-218	1.67E-04	1.66E-04	1.65E-04	1.64E-04	1.63E-04	1.62E-04	1.61E-04	1.60E-04	1.59E-04
Bi-214	1.40E-01	1.33E-01	1.26E-01	1.20E-01	1.15E-01	1.09E-01	1.04E-01	9.96E-02	9.52E-02
Rn-218	1.67E-07	1.66E-07	1.65E-07	1.64E-07	1.63E-07	1.62E-07	1.61E-07	1.60E-07	1.59E-07
Po-214	1.40E-01	1.33E-01	1.26E-01	1.20E-01	1.15E-01	1.09E-01	1.04E-01	9.96E-02	9.52E-02
Tl-210	2.71E-05	2.57E-05	2.44E-05	2.31E-05	2.20E-05	2.09E-05	1.99E-05	1.90E-05	1.81E-05

Po-215	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Pb-211	-0.0001	0.0000	0.0004	0.0002	0.0003	-0.0002	-0.0004	-0.0004	0.0000
Bi-211	-0.0003	-0.0005	-0.0003	0.0003	0.0003	-0.0004	0.0002	0.0001	0.0003
Tl-207	-0.0001	-0.0002	0.0002	0.0000	0.0002	-0.0002	-0.0003	-0.0001	0.0004
Po-211	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-216	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002
Pb-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tl-208	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-218	-0.0003	0.0005	0.0003	0.0003	0.0002	0.0003	0.0004	-0.0004	-0.0002
Pb-214	0.0001	-0.0002	0.0000	-0.0004	-0.0004	0.0000	-0.0003	-0.0003	0.0000
At-218	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-214	-0.0004	-0.0004	0.0002	0.0001	0.0005	0.0002	0.0002	0.0000	0.0000
Rn-218	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-214	-0.0004	-0.0004	0.0002	0.0001	0.0005	0.0002	0.0002	0.0000	0.0000
Tl-210	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

	3.5	3.6	3.7	3.8	3.9	4	5	6	7
Ra-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-215	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.97E-01	9.93E-01	1.00E+00
Pb-211	2.48E-01	2.42E-01	2.37E-01	2.33E-01	2.28E-01	2.24E-01	1.87E-01	1.61E-01	1.41E-01
Bi-211	2.10E-01	2.04E-01	1.99E-01	1.95E-01	1.90E-01	1.85E-01	1.49E-01	1.23E-01	1.04E-01
Tl-207	1.49E-01	1.44E-01	1.40E-01	1.35E-01	1.31E-01	1.27E-01	9.43E-02	7.26E-02	5.74E-02
Po-211	6.00E-04	6.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04	4.00E-04	3.00E-04	3.00E-04
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-216	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Pb-212	1.83E-02	1.78E-02	1.73E-02	1.69E-02	1.64E-02	1.60E-02	1.29E-02	1.07E-02	9.20E-03
Bi-212	3.00E-03	2.80E-03	2.70E-03	2.60E-03	2.50E-03	2.30E-03	1.60E-03	1.10E-03	8.00E-04
Po-212	1.90E-03	1.80E-03	1.70E-03	1.70E-03	1.60E-03	1.50E-03	1.00E-03	7.00E-04	5.00E-04
Tl-208	9.00E-04	8.00E-04	8.00E-04	7.00E-04	7.00E-04	7.00E-04	4.00E-04	3.00E-04	2.00E-04
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-218	7.93E-01	7.88E-01	7.84E-01	7.79E-01	7.75E-01	7.70E-01	7.29E-01	6.91E-01	6.57E-01
Pb-214	2.44E-01	2.38E-01	2.32E-01	2.26E-01	2.21E-01	2.15E-01	1.73E-01	1.42E-01	1.19E-01
At-218	1.58E-04	1.57E-04	1.56E-04	1.56E-04	1.55E-04	1.54E-04	1.45E-04	1.38E-04	1.31E-04
Bi-214	9.11E-02	8.73E-02	8.37E-02	8.02E-02	7.70E-02	7.39E-02	5.09E-02	3.67E-02	2.75E-02
Rn-218	1.58E-07	1.57E-07	1.56E-07	1.56E-07	1.55E-07	1.54E-07	1.45E-07	1.38E-07	1.31E-07
Po-214	9.11E-02	8.73E-02	8.37E-02	8.02E-02	7.70E-02	7.39E-02	5.09E-02	3.67E-02	2.75E-02
Tl-210	1.73E-05	1.65E-05	1.58E-05	1.51E-05	1.44E-05	1.38E-05	9.25E-06	6.49E-06	4.73E-06

Po-215	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0003	-0.0002	-0.0003
Pb-211	-0.0005	0.0003	0.0003	-0.0005	-0.0001	-0.0005	0.0001	-0.0001	0.0002
Bi-211	-0.0003	0.0004	0.0004	-0.0005	-0.0002	0.0003	-0.0002	0.0000	-0.0002
Tl-207	0.0002	0.0003	-0.0005	0.0000	-0.0002	-0.0003	0.0000	0.0000	0.0000
Po-211	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-216	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0003	-0.0003	-0.0004
Pb-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tl-208	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-218	0.0001	0.0004	-0.0002	0.0003	-0.0002	0.0003	0.0005	0.0000	0.0001
Pb-214	-0.0004	0.0005	-0.0004	0.0000	-0.0005	0.0003	-0.0005	0.0000	0.0002
At-218	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-214	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Rn-218	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-214	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tl-210	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

	8	9	10	15	20	25	30	35	40
Ra-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-215	1.00E+00	1.00E+00	9.96E-01	9.95E-01	9.95E-01	9.94E-01	9.93E-01	9.92E-01	9.92E-01
Pb-211	1.26E-01	1.13E-01	1.03E-01	7.12E-02	5.43E-02	4.39E-02	3.68E-02	3.17E-02	2.78E-02
Bi-211	8.91E-02	7.75E-02	6.81E-02	4.02E-02	2.68E-02	1.92E-02	1.45E-02	1.13E-02	9.10E-03
Tl-207	4.63E-02	3.80E-02	3.16E-02	1.47E-02	8.10E-03	4.90E-03	3.20E-03	2.30E-03	1.60E-03
Po-211	2.00E-04	2.00E-04	2.00E-04	1.00E-04	1.00E-04	1.00E-04	0.00E+00	0.00E+00	0.00E+00
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-216	1.00E+00	1.00E+00	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.98E-01	9.98E-01	9.98E-01
Pb-212	8.10E-03	7.20E-03	6.50E-03	4.30E-03	3.20E-03	2.60E-03	2.20E-03	1.90E-03	1.60E-03
Bi-212	6.00E-04	5.00E-04	4.00E-04	2.00E-04	1.00E-04	1.00E-04	0.00E+00	0.00E+00	0.00E+00
Po-212	4.00E-04	3.00E-04	3.00E-04	1.00E-04	1.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl-208	1.00E-04	1.00E-04	1.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-218	6.26E-01	5.99E-01	5.73E-01	4.72E-01	4.02E-01	3.49E-01	3.09E-01	2.77E-01	2.51E-01
Pb-214	1.02E-01	8.80E-02	7.70E-02	4.43E-02	2.89E-02	2.04E-02	1.52E-02	1.18E-02	9.38E-03
At-218	1.25E-04	1.19E-04	1.14E-04	9.36E-05	7.93E-05	6.88E-05	6.07E-05	5.43E-05	4.91E-05
Bi-214	2.11E-02	1.66E-02	1.33E-02	5.42E-03	2.74E-03	1.58E-03	9.94E-04	6.66E-04	4.68E-04
Rn-218	1.25E-07	1.19E-07	1.14E-07	9.36E-08	7.93E-08	6.88E-08	6.07E-08	5.43E-08	4.90E-08
Po-214	2.11E-02	1.66E-02	1.33E-02	5.42E-03	2.74E-03	1.58E-03	9.94E-04	6.66E-04	4.68E-04
Tl-210	3.55E-06	2.72E-06	2.13E-06	7.76E-07	3.54E-07	1.86E-07	1.08E-07	6.68E-08	4.37E-08

Po-215	0.0000	0.0000	0.0001	0.0004	-0.0003	-0.0001	0.0002	0.0003	-0.0005
Pb-211	-0.0003	0.0003	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-211	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tl-207	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-211	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-216	-0.0005	-0.0005	0.0004	0.0001	-0.0002	-0.0005	0.0003	0.0000	-0.0003
Pb-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tl-208	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-218	0.0004	0.0005	-0.0001	0.0001	0.0005	0.0002	0.0000	0.0001	0.0002
Pb-214	-0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
At-218	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-214	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Rn-218	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-214	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tl-210	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

	45	50	55	60	65	70	75	80	85
Ra-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-215	9.91E-01	9.90E-01	9.89E-01	9.88E-01	9.87E-01	9.89E-01	9.88E-01	9.87E-01	9.86E-01
Pb-211	2.48E-02	2.24E-02	2.04E-02	1.87E-02	1.73E-02	1.60E-02	1.50E-02	1.40E-02	1.32E-02
Bi-211	7.50E-03	6.30E-03	5.30E-03	4.60E-03	4.00E-03	3.50E-03	3.10E-03	2.70E-03	2.50E-03
Tl-207	1.20E-03	9.00E-04	7.00E-04	6.00E-04	5.00E-04	4.00E-04	3.00E-04	3.00E-04	2.00E-04
Po-211	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-216	9.97E-01	9.97E-01	9.97E-01	9.97E-01	9.96E-01	9.96E-01	9.96E-01	9.95E-01	9.95E-01
Pb-212	1.40E-03	1.30E-03	1.20E-03	1.10E-03	1.00E-03	9.00E-04	9.00E-04	8.00E-04	8.00E-04
Bi-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl-208	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-218	2.30E-01	2.12E-01	1.96E-01	1.83E-01	1.71E-01	1.61E-01	1.52E-01	1.44E-01	1.36E-01
Pb-214	7.66E-03	6.37E-03	5.38E-03	4.61E-03	3.99E-03	3.49E-03	3.08E-03	2.73E-03	2.44E-03
At-218	4.47E-05	4.11E-05	3.80E-05	3.53E-05	3.29E-05	3.09E-05	2.90E-05	2.74E-05	2.59E-05
Bi-214	3.42E-04	2.57E-04	1.98E-04	1.56E-04	1.25E-04	1.02E-04	8.42E-05	7.03E-05	5.93E-05
Rn-218	4.47E-08	4.11E-08	3.79E-08	3.53E-08	3.29E-08	3.08E-08	2.90E-08	2.74E-08	2.59E-08
Po-214	3.42E-04	2.57E-04	1.98E-04	1.56E-04	1.25E-04	1.02E-04	8.42E-05	7.03E-05	5.93E-05
Tl-210	2.98E-08	2.11E-08	1.53E-08	1.14E-08	8.68E-09	6.72E-09	5.29E-09	4.22E-09	3.40E-09

Po-215	-0.0004	-0.0003	-0.0002	-0.0002	-0.0002	0.0001	0.0002	0.0003	0.0004
Pb-211	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-211	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tl-207	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-211	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-216	0.0004	0.0001	-0.0002	-0.0005	0.0002	-0.0001	-0.0003	0.0004	0.0001
Pb-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tl-208	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-218	-0.0003	-0.0004	0.0001	-0.0003	0.0001	-0.0002	-0.0003	-0.0004	0.0003
Pb-214	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
At-218	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-214	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Rn-218	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-214	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tl-210	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

	90	95	100	200	300	400	500	600	700
Ra-219	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-215	9.85E-01	9.84E-01	9.83E-01	9.73E-01	9.63E-01	9.46E-01	9.28E-01	9.22E-01	9.08E-01
Pb-211	1.25E-02	1.18E-02	1.12E-02	5.60E-03	3.70E-03	2.70E-03	2.10E-03	1.80E-03	1.50E-03
Bi-211	2.20E-03	2.00E-03	1.80E-03	5.00E-04	2.00E-04	1.00E-04	1.00E-04	1.00E-04	0.00E+00
Tl-207	2.00E-04	2.00E-04	1.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-211	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-220	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-216	9.95E-01	9.95E-01	9.94E-01	9.89E-01	9.83E-01	9.77E-01	9.72E-01	9.66E-01	9.61E-01
Pb-212	7.00E-04	7.00E-04	6.00E-04	3.00E-04	2.00E-04	2.00E-04	1.00E-04	1.00E-04	1.00E-04
Bi-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl-208	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-222	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Po-218	1.30E-01	1.24E-01	1.18E-01	6.29E-02	4.28E-02	3.25E-02	2.61E-02	2.19E-02	1.88E-02
Pb-214	2.20E-03	1.99E-03	1.81E-03	4.84E-04	2.20E-04	1.25E-04	8.09E-05	5.64E-05	4.16E-05
At-218	2.46E-05	2.34E-05	2.23E-05	1.12E-05	7.25E-06	5.23E-06	4.02E-06	3.22E-06	2.65E-06
Bi-214	5.05E-05	4.33E-05	3.75E-05	5.12E-06	1.57E-06	6.79E-07	3.53E-07	2.07E-07	1.32E-07
Rn-218	2.46E-08	2.34E-08	2.23E-08	1.12E-08	7.22E-09	5.20E-09	3.99E-09	3.19E-09	2.62E-09
Po-214	5.05E-05	4.33E-05	3.75E-05	5.13E-06	1.58E-06	6.84E-07	3.57E-07	2.10E-07	1.34E-07
Tl-210	2.78E-09	2.29E-09	1.91E-09	1.48E-10	3.19E-11	1.06E-11	4.46E-12	2.20E-12	1.21E-12

Po-215	0.0004	0.0004	0.0003	0.0000	-0.0001	0.0004	-0.0003	0.0004	-0.0002
Pb-211	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-211	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tl-207	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-211	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-216	-0.0002	-0.0005	0.0002	-0.0005	-0.0001	0.0003	-0.0002	0.0003	-0.0001
Pb-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-212	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tl-208	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-218	-0.0003	-0.0003	0.0003	0.0000	0.0000	-0.0001	0.0000	0.0000	0.0000
Pb-214	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
At-218	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Bi-214	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Rn-218	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Po-214	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tl-210	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

	800	900
Ra-219	1.00E+00	1.00E+00
Po-215	8.95E-01	8.83E-01
Pb-211	1.30E-03	1.10E-03
Bi-211	0.00E+00	0.00E+00
Tl-207	0.00E+00	0.00E+00
Po-211	0.00E+00	0.00E+00
Rn-220	1.00E+00	1.00E+00
Po-216	9.56E-01	9.50E-01
Pb-212	1.00E-04	1.00E-04
Bi-212	0.00E+00	0.00E+00
Po-212	0.00E+00	0.00E+00
Tl-208	0.00E+00	0.00E+00
Rn-222	1.00E+00	1.00E+00
Po-218	1.65E-02	1.47E-02
Pb-214	3.19E-05	2.53E-05
At-218	2.23E-06	1.91E-06
Bi-214	8.90E-08	6.30E-08
Rn-218	2.20E-09	1.88E-09
Po-214	9.12E-08	6.49E-08
Tl-210	7.19E-13	4.54E-13

Po-215	0.0001	0.0001
Pb-211	0.0000	0.0000
Bi-211	0.0000	0.0000
Tl-207	0.0000	0.0000
Po-211	0.0000	0.0000
Po-216	-0.0004	0.0003
Pb-212	0.0000	0.0000
Bi-212	0.0000	0.0000
Po-212	0.0000	0.0000
Tl-208	0.0000	0.0000
Po-218	0.0000	0.0000
Pb-214	0.0000	0.0000
At-218	0.0000	0.0000
Bi-214	0.0000	0.0000
Rn-218	0.0000	0.0000
Po-214	0.0000	0.0000
Tl-210	0.0000	0.0000

Exposure Parameters

Definition	*Symbol*	*Value*	*Units*
Exposure Duration	ED	26	years
as Adult	EDa	20	years
as Child	EDc	6	years
Age adjustment factor (adult)	AAFa	0.77	-
Age adjustment factor (child)	AAFc	0.23	-
Exposure Frequency (adult)	EFa	350	days
Exposure Frequency (child)	EFc	350	days
Air Exposure Time (adult)	ETa	24	hours
Air Exposure Time (child)	ETc	24	hours
Inhalation Rate (adult)	IRa	20	m3/day
Inhalation Rate (child)	IRc	10	m3/day
Age-Adjusted Inhalation Fraction (annual)	IFA	6192	m3/y
Age-Adjusted Inhalation Fraction (total)	IFA	161000	m3
Gamma Shielding Factor	GSF	1	-
Air Exchanges per Hour		0.18	hr-1
INDEX Lookup	-	4	
Sub-slab Attenuation	AFss	0.03	-
Groundwater Attenuation	AFgw	0.001	-
Groundwater Temperature	Tgw	25	C
Groundwater Temperature	Tgw	298.15	K
Enthalpy of vaporization at Tgw	ΔHvgw	3463.2	cal/mol
Henry's Law Constant	H'	4.333038	-

Target Values

Lifetime Risk	1.00E-06	cancer risk
Annual Dose	1	mrem/year
Working Level	0.2	WL

Target Indoor Air Concentration (inhalation and submersion)

Isotope	*Risk-based*	*Dose-based*	*To Meet Target Working Level*
Rn-219 (pCi/L)	1.78E-04	3.70E-03	3.78E+01
Rn-220 (pCi/L)	3.23E-05	1.37E-03	7.12E+00
Rn-222 (pCi/L)	4.57E-05	1.87E-03	2.25E+01

Target Sub-Slab and Exterior Soil Gas Concentration

Isotope	*Risk-based*	*Dose-based*	*To Meet Target Working Level*
Rn-219 (pCi/L)	5.92E-03	1.23E-01	1.26E+03
Rn-220 (pCi/L)	1.08E-03	4.58E-02	2.37E+02
Rn-222 (pCi/L)	1.52E-03	6.24E-02	7.49E+02

Target Groundwater Concentration

Isotope	*Risk-based*	*Dose-based*	*Meet Target WL*
Rn-219 (pCi/L)	4.10E-02	8.54E-01	8.73E+03
Rn-220 (pCi/L)	7.45E-03	3.17E-01	1.64E+03
Rn-222 (pCi/L)	1.05E-02	4.32E-01	5.19E+03

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Target Screening Level Calculations

Isotope	***Aeq***	***Feq***	Half-life (years)	Inhalation Slope Factor (risk/pCi)	Submersion External Exposure Slope Factor (risk/y per pCi/m3)	Inhalation DCF (mrem/pCi)	Submersion External Exposure DCF (mrem/yr per pCi/m3)	Reference Inhalation Risk Concentration pCi/m3)
Bi-211	8.57E-01	-	0	0.00E+00	1.91E-10	0.00E+00	2.42E-04	0.00E+00
Pb-211	8.65E-01	-	0	4.03E-11	2.79E-10	5.03E-05	3.76E-04	1.54E-01
Po-211	2.40E-03	-	0	0.00E+00	3.50E-11	0.00E+00	4.36E-05	0.00E+00
Po-215	1.00E+00	-	0	0.00E+00	7.29E-13	0.00E+00	9.11E-07	0.00E+00
Rn-219	1.00E+00	-	0	0.00E+00	2.38E-10	0.00E+00	2.99E-04	0.00E+00
Tl-207	8.37E-01	-	0	0.00E+00	1.81E-11	0.00E+00	5.38E-05	0.00E+00
Rn-219 FEQ	-	8.57E-01	-	-	-	-	-	-
Bi-212	2.11E-01	-	0	1.13E-10	4.61E-10	6.11E-05	6.04E-04	5.50E-02
Pb-212	2.66E-01	-	0	6.29E-10	5.57E-10	3.89E-04	7.13E-04	9.87E-03
Po-212	1.35E-01	-	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-216	1.00E+00	-	0	0.00E+00	6.59E-14	0.00E+00	8.17E-08	0.00E+00
Rn-220	1.00E+00	-	0	1.15E-12	2.63E-12	8.18E-07	3.28E-06	5.40E+00
Tl-208	7.46E-02	-	0	0.00E+00	1.59E-08	0.00E+00	1.96E-02	0.00E+00
Rn-220 FEQ	-	2.11E-01	-	-	-	-	-	-
At-218	1.97E-04	-	0	0.00E+00	3.08E-14	0.00E+00	1.14E-07	0.00E+00
Bi-210	0.00E+00	-	0	4.55E-10	5.29E-12	5.40E-04	3.01E-05	1.37E-02
Bi-214	8.14E-01	-	0	6.18E-11	6.69E-09	3.66E-05	8.30E-03	1.01E-01
Hg-206	0.00E+00	-	0	0.00E+00	4.96E-10	0.00E+00	6.49E-04	0.00E+00
Pb-210	0.00E+00	-	0	1.59E-08	3.93E-12	2.23E-02	5.50E-06	3.91E-04
Pb-214	8.84E-01	-	0	7.77E-11	1.02E-09	4.66E-05	1.30E-03	7.99E-02
Po-210	0.00E+00	-	0	1.45E-08	4.18E-14	1.73E-02	5.20E-08	4.28E-04
Po-214	8.14E-01	-	0	0.00E+00	3.57E-13	0.00E+00	4.44E-07	0.00E+00
Po-218	9.87E-01	-	0	1.39E-11	3.95E-17	7.62E-06	3.06E-10	4.47E-01
Rn-218	1.97E-07	-	0	0.00E+00	3.19E-12	0.00E+00	3.97E-06	0.00E+00
Rn-222	1.00E+00	-	0	2.28E-12	1.62E-12	6.55E-06	2.02E-06	2.72E+00
Tl-206	0.00E+00	-	0	0.00E+00	9.40E-12	0.00E+00	4.64E-05	0.00E+00
Tl-210	1.70E-04	-	0	0.00E+00	1.24E-08	0.00E+00	1.54E-02	0.00E+00
Rn-222 FEQ	-	8.90E-01						

Target Screening Level Calculations (Continued)

Isotope	1 / Concentration per Aeq	Reference Inhalation Dose Concentration (pCi/m3)	1 / Concentration per Aeq	Reference Submersion Risk Concentration pCi/m3)	1 / Concentration per Aeq	Reference Submersion Dose Concentration (pCi/m3)	1 / Concentration per Aeq
Bi-211		0.00E+00		2.10E+02	4.08E-03	4.31E+03	1.99E-04
Pb-211	5.6123795	3.21E+00	2.69E-01	1.44E+02	6.02E-03	2.77E+03	3.12E-04
Po-211		0.00E+00		1.15E+03	2.09E-06	2.39E+04	1.00E-07
Po-215		0.00E+00		5.50E+04	1.82E-05	1.14E+06	8.74E-07
Rn-219		0.00E+00		1.69E+02	5.93E-03	3.49E+03	2.87E-04
Tl-207		0.00E+00		2.22E+03	3.78E-04	1.94E+04	4.32E-05
Rn-219 FEQ	-	-	-	-	-	-	-
Bi-212	3.838723	2.64E+00	7.98E-02	8.70E+01	2.43E-03	1.73E+03	1.22E-04
Pb-212	26.937554	4.15E-01	6.41E-01	7.20E+01	3.69E-03	1.46E+03	1.82E-04
Po-212		0.00E+00		#DIV/0!		#DIV/0!	
Po-216		0.00E+00		6.09E+05	1.64E-06	1.28E+07	7.83E-08
Rn-220	0.18515	1.97E+02	5.07E-03	1.53E+04	6.56E-05	3.18E+05	3.15E-06
Tl-208		0.00E+00		2.52E+00	2.96E-02	5.32E+01	1.40E-03
Rn-220 FEQ	-	-	-	-	-	-	-
At-218		0.00E+00		1.30E+06	1.51E-10	9.15E+06	2.15E-11
Bi-210		2.99E-01		7.58E+03		3.46E+04	
Bi-214	8.0991372	4.41E+00	1.84E-01	6.00E+00	1.36E-01	1.26E+02	6.48E-03
Hg-206		0.00E+00		8.09E+01		1.61E+03	
Pb-210		7.24E-03		1.02E+04		1.90E+05	
Pb-214	11.0585748	3.47E+00	2.55E-01	3.93E+01	2.25E-02	8.02E+02	1.10E-03
Po-210		9.33E-03		9.60E+05		2.01E+07	
Po-214		0.00E+00		1.12E+05	7.25E-06	2.35E+06	3.47E-07
Po-218	2.2088073	2.12E+01	4.66E-02	1.02E+09	9.72E-10	3.41E+09	2.90E-10
Rn-218		0.00E+00		1.26E+04	1.57E-11	2.63E+05	7.50E-13
Rn-222	0.36708	2.47E+01	4.06E-02	2.48E+04	4.04E-05	5.16E+05	1.94E-06
Tl-206		0.00E+00		4.27E+03		2.25E+04	
Tl-210		0.00E+00		3.23E+00	5.26E-05	6.77E+01	2.51E-06
Rn-222 FEQ							

Exposure Parameters

Definition	*Symbol*	*Value*	*Units*
Exposure Duration	ED	25	years
as Adult	EDa	25	years
as Child	EDc	0	years
Age adjustment factor (adult)	AAFa	1.00	-
Age adjustment factor (child)	AAFc	0.00	-
Exposure Frequency (adult)	EFa	250	days
Exposure Frequency (child)	EFc	0	days
Air Exposure Time (adult)	ETa	8	hours
Air Exposure Time (child)	ETc	0	hours
Inhalation Rate (adult)	IRa	60	m3/day
Inhalation Rate (child)	IRc	0	m3/day
Age-Adjusted Inhalation Fraction (annual)	IFA	5000	m3/y
Age-Adjusted Inhalation Fraction (total)	IFA	125000	m3
Gamma Shielding Factor	GSF	1	-
Air Exchanges per Hour		0.6	hr-1
INDEX Lookup	-	9	
Sub-slab Attenuation	AFss	0.03	-
Groundwater Attenuation	AFgw	0.001	-
Groundwater Temperature	Tgw	25	C
Groundwater Temperature	Tgw	298.15	K
Enthalpy of vaporization at Tgw	ΔHvgw	3463.2	cal/mol
Henry's Law Constant	H'	4.333038	-

Measured Media Values (pCi/L)

Isotope	*Indoor Air*	*Soil Gas*	*Groundwater*
Rn-219	1	100	100
Rn-220	1	100	100
Rn-222	4	1300	100

Indoor risk/dose/WL from measured indoor air concentration

Isotope	*ELCR (risk)*	*Dose (mrem/y)*	*Working Level*
Rn-219	**3.31E-03**	**1.66E+02**	3.94E-03
Rn-220	**8.54E-03**	**2.11E+02**	6.97E-03
Rn-222	**5.00E-02**	**1.32E+03**	2.88E-02

Indoor risk/dose/WL from measured soil gas concentration

Isotope	*ELCR (risk)*	*Dose (mrem/y)*	*Working Level*
Rn-219	**9.90E-03**	**4.97E+02**	1.18E-02
Rn-220	**2.54E-02**	**6.32E+02**	2.09E-02
Rn-222	**3.93E-01**	**1.28E+04**	2.81E-01

Indoor risk/dose/WL from measured groundwater concentration

Isotope	*ELCR (risk)*	*Dose (mrem/y)*	*Working Level*
Rn-219	**1.44E-03**	**7.17E+01**	1.71E-03
Rn-220	**3.71E-03**	**9.12E+01**	3.02E-03
Rn-222	**5.54E-03**	**1.43E+02**	3.12E-03

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Risk and Dose from Indoor Air Parameters

Isotope	***Aeg or Feg***	Indoor Air Concen. (pCi/m3)	Indoor Air from Soil Gas (pCi/m3)	Indoor Air from Groundwater(pCi/m3)	Inhalation Slope Factor (risk/pCi)	Submersion External Exposure Slope Factor (risk/y per pCi/m3)	Inhalation DCF (mrem/pCi)	Submersion External Exposure DCF (mrem/yr per pCi/m3)
Bi-211	6.38E-01	6.38E+02	1.91E+03	2.76E+02	0.00E+00	1.91E-10	0.00E+00	2.42E-04
Pb-211	6.58E-01	6.58E+02	1.97E+03	2.85E+02	4.03E-11	2.79E-10	5.03E-05	3.76E-04
Po-211	1.80E-03	1.80E+00	5.40E+00	7.80E-01	0.00E+00	3.50E-11	0.00E+00	4.36E-05
Po-215	9.95E-01	9.95E+02	2.99E+03	4.31E+02	0.00E+00	7.29E-13	0.00E+00	9.11E-07
Rn-219	1.00E+00	1.00E+03	3.00E+03	4.33E+02	0.00E+00	2.38E-10	0.00E+00	2.99E-04
Tl-207	5.95E-01	5.95E+02	1.79E+03	2.58E+02	0.00E+00	1.81E-11	0.00E+00	5.38E-05
Rn-219 FEQ	**6.38E-01**	-	-	-	-	-	-	-
Bi-212	5.23E-02	5.23E+01	1.57E+02	2.27E+01	1.13E-10	4.61E-10	6.11E-05	6.04E-04
Pb-212	9.79E-02	9.79E+01	2.94E+02	4.24E+01	6.29E-10	5.57E-10	3.89E-04	7.13E-04
Po-212	3.35E-02	3.35E+01	1.01E+02	1.45E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-216	1.00E+00	1.00E+03	3.00E+03	4.33E+02	0.00E+00	6.59E-14	0.00E+00	8.17E-08
Rn-220	1.00E+00	1.00E+03	3.00E+03	4.33E+02	1.15E-12	2.63E-12	8.18E-07	3.28E-06
Tl-208	1.80E-02	1.80E+01	5.40E+01	7.80E+00	0.00E+00	1.59E-08	0.00E+00	1.96E-02
Rn-220 FEQ	**5.23E-02**	-	-	-	-	-	-	-
At-218	1.91E-04	7.64E-01	7.45E+00	8.28E-02	0.00E+00	3.08E-14	0.00E+00	1.14E-07
Bi-210	0.00E+00				4.55E-10	5.29E-12	5.40E-04	3.01E-05
Bi-214	5.36E-01	2.14E+03	2.09E+04	2.32E+02	6.18E-11	6.69E-09	3.66E-05	8.30E-03
Hg-206	0.00E+00				0.00E+00	4.96E-10	0.00E+00	6.49E-04
Pb-210	0.00E+00				1.59E-08	3.93E-12	2.23E-02	5.50E-06
Pb-214	6.90E-01	2.76E+03	2.69E+04	2.99E+02	7.77E-11	1.02E-09	4.66E-05	1.30E-03
Po-210	0.00E+00				1.45E-08	4.18E-14	1.73E-02	5.20E-08
Po-214	5.36E-01	2.14E+03	2.09E+04	2.32E+02	0.00E+00	3.57E-13	0.00E+00	4.44E-07
Po-218	9.57E-01	3.83E+03	3.73E+04	4.15E+02	1.39E-11	3.95E-17	7.62E-06	3.06E-10
Rn-218	1.91E-07	7.64E-04	7.45E-03	8.28E-05	0.00E+00	3.19E-12	0.00E+00	3.97E-06
Rn-222	1.00E+00	4.00E+03	3.90E+04	4.33E+02	2.28E-12	1.62E-12	6.55E-06	2.02E-06
Tl-206	0.00E+00				0.00E+00	9.40E-12	0.00E+00	4.64E-05
Tl-210	1.11E-04	4.44E-01	4.33E+00	4.81E-02	0.00E+00	1.24E-08	0.00E+00	1.54E-02
Rn-222 FEQ	**7.21E-01**	-	-	-				

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Risk and Dose from Indoor Air Measurement Calculations

Isotope	Inhalation Lifetime Risk	Inhalation Annual Dose (mrem/yr)	Submersion Lifetime Risk	Submersion Annual Dose (mrem/yr)
Bi-211				
Pb-211	3.31E-03	1.65E+02	1.05E-06	5.65E-02
Po-211				
Po-215				
Rn-219				
Tl-207				
Rn-219 FEQ	-	-	-	-
Bi-212	7.39E-04	1.60E+01	1.38E-07	7.21E-03
Pb-212	7.70E-03	1.90E+02	3.11E-07	1.59E-02
Po-212				
Po-216				
Rn-220	1.44E-04	4.09E+00	1.50E-08	7.49E-04
Tl-208				
Rn-220 FEQ	-	-	-	-
At-218				
Bi-210				
Bi-214	1.66E-02	3.92E+02	8.19E-05	4.06E+00
Hg-206				
Pb-210				
Pb-214	2.68E-02	6.43E+02	1.61E-05	8.19E-01
Po-210				
Po-214				
Po-218	6.65E-03	1.46E+02	8.63E-13	2.67E-07
Rn-218				
Rn-222	1.14E-03	1.31E+02	3.70E-08	1.84E-03
Tl-206				
Tl-210				
Rn-222 FEQ				

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Risk and Dose from Soil Gas and Groundwater Measurement Calculations

Isotope	(Soil Gas) Inhalation Lifetime Risk	(Soil Gas) Inhalation Annual Dose (mrem/yr)	(Soil Gas) Submersion Lifetime Risk	(Soil Gas) Submersion Annual Dose (mrem/yr)	(Groundwater) Inhalation Lifetime Risk	(Groundwater) Inhalation Annual Dose (mrem/yr)	(Groundwater) Submersion Lifetime Risk	(Groundwater) Submersion Annual Dose (mrem/yr)
Bi-211								
Pb-211	9.94E-03	4.96E+02	3.14E-06	1.69E-01	1.44E-03	7.17E+01	4.54E-07	0.024475529
Po-211								
Po-215								
Rn-219								
Tl-207								
Rn-219 FEQ	-	-	-	-	-	-	-	-
Bi-212	2.22E-03	4.79E+01	4.13E-07	2.16E-02	3.20E-04	6.92E+00	5.96E-08	0.00312505
Pb-212	2.31E-02	5.71E+02	9.34E-07	4.78E-02	3.34E-03	8.25E+01	1.35E-07	0.006905428
Po-212								
Po-216								
Rn-220	4.31E-04	1.23E+01	4.50E-08	2.25E-03	6.23E-05	1.77E+00	6.50E-09	0.000324483
Tl-208								
Rn-220 FEQ	-	-	-	-	-	-	-	-
At-218								
Bi-210								
Bi-214	1.61E-01	3.83E+03	7.98E-04	3.96E+01	1.79E-03	4.25E+01	8.87E-06	0.440110001
Hg-206								
Pb-210								
Pb-214	2.61E-01	6.27E+03	1.57E-04	7.99E+00	2.90E-03	6.97E+01	1.74E-06	0.088738238
Po-210								
Po-214								
Po-218	6.48E-02	1.42E+03	8.41E-12	2.61E-06	7.20E-04	1.58E+01	9.35E-14	2.89702E-08
Rn-218								
Rn-222	1.11E-02	1.28E+03	3.61E-07	1.80E-02	1.23E-04	1.42E+01	4.01E-09	0.000199834
Tl-206								
Tl-210								
Rn-222 FEQ								

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Verification Study Conflict of Interest Certification

Verification study: **Radon Vapor Intrusion Screening Level Verification Study**

A conflict of interest or lack of impartiality exists when the proposed participant personally (or the reviewer's immediate family), or his or her employer, has financial interests that may be affected by the results of the verification study; or may provide an unfair competitive advantage to the participant (or employer); or if the participant's objectivity in performing the verification study may be impaired due to other factors. When the Participant knows that a reasonable person with knowledge of the facts may question the participant's impartiality or financial involvement, an apparent lack of impartiality or conflict of interest exists.

The following questions, if answered affirmatively, represent potential or apparent lack of impartiality (*any affirmative answers should be explained in an attachment*):

- Did you contribute to the development of the calculator being verified, or were you consulted during its development, or did you offer comments or suggestions to any drafts or versions of the document during its development? ■ No □ Yes
- Do you know of any reason that you might be unable to provide impartial advice on the matter under consideration in this verification study, or any reason that your impartiality in the matter might be questioned? ■ No □ Yes
- Have you had any previous involvement with the calculator under consideration? ■ No □ Yes
- Have you served on previous advisory panels, committees, or subcommittees that have addressed the topic under consideration? ■ No □ Yes
- Have you made any public statements (written or oral) on the issue? ■ No □ Yes
- Have you made any public statements that would indicate to an observer that you have taken a position on the issue under consideration? ■ No □ Yes
- Do you, your family, or your employer have any financial interest(s) in the matter or topic under this verification study, or could someone with access to relevant facts reasonably conclude that you (or your family or employer) stand to benefit from a particular outcome of this verification study? ■ No □ Yes

With regard to real or apparent conflicts of interest or questions of impartiality, the following provisions shall apply for the duration of this verification study:

(a) Participant warrants, to the best of his/her knowledge and belief, that there are no relevant facts or circumstances that could give rise to an actual, apparent, or potential organizational or personal conflict of interest, or that Participant has disclosed all such relevant information to EMS or to EPA.
(b) Participant agrees that if an actual, apparent, or potential personal or organizational conflict of interest is identified during performance of this verification study, he/she immediately will make a full disclosure in writing to EMS. This disclosure shall include a description of actions that Participant (or his/her employer) has taken or proposes to take after consultation with EMS to avoid, mitigate, or neutralize the actual, apparent, or potential organizational conflict of interest. Participant shall continue performance until notified by EMS of any contrary action to be taken.

12/09/2021

Signature Date

□ Check here if any explanation is attached

Riley Carey

Printed Name

U.S. Army Corps of Engineers

Affiliation/Organization

Riley J. Carey

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Education

MASTER OF SCIENCE | 2017 | GEORGETOWN UNIVERSITY

- Health Physics

BACHELOR OF SCIENCE | 2015 | UNIVERSITY OF SCRANTON

- Physics

Skills & Abilities

DOSE MODELING AND RISK ASSESSMENT

- Performs environmental and structural dose/risk calculations and derived concentration guideline level (DCGL) calculations primarily using the RESRAD family of codes. Additionally has utilized the U.S. Nuclear Regulatory Commission (NRC) DandD code and the U.S. Environmental Protection Agency (EPA) Preliminary Remediation Goals (PRG) for Radionuclides calculator.

RADIOACTIVE PARTICULATE AND AIR TRANSPORT MODELING

- Performs particulate plume dispersion modeling and associated dose calculations using the EPA CAP88-PC code for National Emissions Standards for Hazardous Air Pollutants (NESHAP) compliance demonstration. Has additionally utilized the NRC MILDOS code for atmospheric radon dispersion and the RnMod3D code for modeling radon soil gas diffusive and advective transport across variable environmental conditions.

RADON, RADON PROGENY, AND VAPOR INTRUSION MEASUREMENTS

- Routinely performs surficial radon flux measurements of subsurface radon-generating sources using activated charcoal canisters and alpha track accumulators. Has experience with measuring radon air concentrations using alpha track and passive alpha spectrometry devices, measuring immediate progeny/working levels in ambient air, and evaluating relative long-lived progeny ingrowth in soils as historic flux indicators. Additionally, has experience with measuring vapor intrusion of volatile organic soil gas contaminants using summa canisters.

Experience

HEALTH PHYSICIST | U.S. ARMY CORPS OF ENGINEERS | 2017 - PRESENT

- Serves as a staff health physicist for the Buffalo District and is responsible for the investigation, dose/risk characterization, remediation, and final status survey of sites designated under the Formerly Utilized Sites Remedial Action Program (FUSRAP) including the Niagara Falls Storage Site. Additionally, provides radiological support for the U.S. Army Corps of Engineers Radiation Safety Support Team (RSST), the greater U.S. Army, and other state and federal agencies.

CAD SPECIALIST | ANCHOR CONSTRUCTION CORPORATION | 2016 - PRESENT

- Works as the staff computer-aided design (CAD) specialist for underground utility instillation and emergency repairs under contract throughout the District of Columbia. The primary client is the District of Columbia Water and Sewer Authority.

GRADUATE INTERN | SANDIA NATIONAL LABORATORIES | 2016

- Worked as a graduate intern in the Storage and Transportation research and development department. The primary task was beginning the development of a material flow model for centrifugal uranium enrichment facilities and to evaluate strategic mass and enrichment measurements in key process locations against theft and diversion scenarios. All work was designed in the MATLAB Simulink environment.

Relevant Works

Carey, R., *Influence of Decreasing Barometric Pressure Frequencies on Heterogeneous Underground Radon Sources*, Presented at the American Association of Radon Scientists and Technologists (AARST) International Radon and Vapor Intrusion Symposium, Bethesda, Maryland, October 11-13, 2021.

Carey, R., *Lead-210 and Polonium-210 as Indicators of Historic Radon Flux Tendencies at the Niagara Falls Storage Site*, Presented at the U.S. Army Corps of Engineers Technical Innovation Forum, virtual, April 20-21, 2021.

Carey, R. and N. Miller, *Complexities of Evaluating Radon Flux from Uranium Mill Tailings: A Case Study of Niagara Falls Storage Site Residues*, Presented at the Waste Management Symposium, Phoenix, Arizona, March 7-11, 2021.

Carey, R. et. al., *Challenges and Practical Solutions for Conducting Structural MARSSIM Surveys in Elevated Radon Environments*, Presented at the Waste Management Symposium, Phoenix, Arizona, March 8-12, 2020.

Carl Spreng
Retired: U.S. Department of Energy

RVISL Calculator Peer Review

Carl Spreng

June 10, 2022

RVISL Calculator Equations

1. A double check of the equations in the Equations section determined that they are the same as those in Section 4 of the User's Guide. The equations seem to be consistent with equations in other electronic calculators and to produce realistic results.
2. Observations of the RVISL Calculator in comparison to the PRG Calculator and the VISL Calculator:
   - The RVISL Calculator is more comprehensive since it has UMTRCA-based and dose-based screening level output options as well as inputs for groundwater temperature and attenuation in soil or water.
   - The exposure duration for inhalation in the Resident Air SL in the VISL Calculator is 26 years without designating separate child and adult inhalation rates as done in the PRG and RVISL Calculators.
   - The respective equations for Resident Air and Worker Air in the RVISL are equivalent to those in the PRG calculator.
3. The difference between scenarios in risk-based or dose-based results is entirely due to the different volumes of inhaled air.
4. A separate file (*RVISL calculator output*) presents key risk and dose results for Resident – Air and Commercial Worker – Air calculations. As a quick way to look for correlations between those risk and dose results, the values were compared by dividing the dose results by their respective risk results. My assumption was that the compared values would all vary by a fixed factor, but the last table in the file shows that there appears to be 2 distinct areas of correlation.
5. A similar comparison was done between calculated WLs and risk-based and dose-based results. The lack of correlation between these values is assumed to be due at least in part to the varying F_{eq} factors used in the equations. Section 2.4 of the User's Guide explains that the equation to convert RVISLs to WLs corrects for the F_{eq} differences.
6. Section 2.3 of the User's Guide explains that the SFs and DCFs used in the Calculator were calculated similarly and differ from values in HEAST. To determine if there is any significant variation between SFs and DCFs for key isotopes, DCF values were divided by the SF values. The reason for the difference in a couple of the ratios is not obvious.

Isotope	Inhalation DCF / SF	External Exposure DCF / SF
Pb-211	1.2E06	1.3E06
Rn-220	0.7E06	1.2E06
Rn-222	2.8E06	1.2E06

7. User's Guide – Section 7: Using alternatives to the recommended default exposure values is mentioned several places. It might be useful to provide a sensitivity analysis for key parameters to highlight those that may make a significant difference in calculation results. For example, doubling the air exchange rate appears to nearly double the RVISL result.

Editorial suggestions

1. See attached "User's Guide comments" file for additional redline/strikeout comments.
2. In Section 2.2 of the User's Guide, the first sentence ("This calculator only offers one output option….") contrasts with the title of the section ("RVISL WL, Risk, & Dose Screening Level Output Options").
3. The link to "RVISL Download Area" in Section 3 of the User's Guide is "Unavailable until further notice".
4. "Celsius" is misspelled in the reference column for Absolute Temperature (symbol = T) in the Miscellaneous Variables section of Table 1, Section 7 of the User's Guide.
5. It would be helpful to calculator users to have an explanation of acronyms readily available:
   - below each equation, or
   - in a hover feature, or
   - a reference to Table 1 in Section 7 of the User's Guide.
6. There is an inconsistent mixing of some terms within the RVISL Calculator text and in comparison with the PRG and VISL Calculators, e.g.,
   - "worker" vs. "commercial worker" vs. "composite worker",
   - "risk-based" vs. "ELCR",
   - "Working Level equation" (Equations section) vs. "UMTRCA-based (RVISL Calculator), and
   - "submersion" vs. "external exposure".

   The differences (or equivalencies) of these terms should be explained.
7. In the last section of the "Home Page" ("Related CERCLA Calculators and Guidance"), it might be useful to provide a table/matrix of the various listed calculators vs. the intended type of assessment for each one.
8. In the title for index box that appears in the upper right of each section, "for Radon" is redundant.
9. In the risk-based and dose-based output tables, the units (pCi/m^3) in the title of the "Inhalation RVISL" column is repeated; the first set is extraneous.
10. It might be useful to add a link to EPA's Radon Frequently Asked Questions web site to the RVISL Frequently Asked Questions (FAQ) section: https://www.epa.gov/radon/radon-frequently-asked-questions

RVISL CALCULATOR RESULTS

RESIDENT – AIR (default parameters; risk-based; TR = 1E-06)

Isotope	Inhalation RVISL (pCi/m^3)	Submersion RVISL (pCi/m^3)	Target Indoor Air Concentration $C_{i,a}$ (pCi/L)	Target Sub-Slab and Exterior Soil Gas Concentration (pCi/L)	Target Groundwater Concentration (pCi/L)
Rn-219	*1.78E-01*	*6.08E+01*	*1.78E-04*	*5.92E-03*	*4.09E-02*
Rn-220	*3.23E-02*	*2.80E+01*	*3.23E-05*	*1.08E-03*	*7.44E-03*
Rn-222	*4.60E-02*	*6.31E+00*	*4.57E-05*	*1.52E-03*	*1.05E-02*

RESIDENT – AIR (default parameters; dose-based; TDL = 1)

Isotope	Inhalation RVISL (pCi/m^3)	Submersion RVISL (pCi/m^3)	Target Indoor Air Concentration $C_{i,a}$ (pCi/L)	Target Sub-Slab and Exterior Soil Gas Concentration (pCi/L)	Target Groundwater Concentration (pCi/L)
Rn-219	*3.71E+00*	*1.19E+03*	*3.70E-03*	*1.23E-01*	*8.52E-01*
Rn-220	*1.38E+00*	*5.85E+02*	*1.38E-03*	*4.59E-02*	*3.17E-01*
Rn-222	*1.90E+00*	*1.32E+02*	*1.87E-03*	*6.23E-02*	*4.31E-01*

COMMERCIAL WORKER – AIR (default parameters; risk-based; TR = 1E-06)

Isotope	Inhalation RVISL (pCi/m^3)	Submersion RVISL (pCi/m^3)	Target Indoor Air Concentration $C_{i,a}$ (pCi/L)	Target Sub-Slab and Exterior Soil Gas Concentration (pCi/L)	Target Groundwater Concentration (pCi/L)
Rn-219	*3.02E-01*	*3.15E+02*	*3.01E-04*	*1.00E-02*	*6.94E-02*
Rn-220	*1.17E-01*	*4.77E+02*	*1.17E-04*	*3.88E-03*	*2.68E-02*
Rn-222	*7.81E-02*	*4.08E+01*	*7.80E-05*	*2.60E-03*	*1.80E-02*

COMMERCIAL WORKER – AIR (default parameters; dose-based; TDL = 1)

Isotope	Inhalation RVISL (pCi/m^3)	Submersion RVISL (pCi/m^3)	Target Indoor Air Concentration $C_{i,a}$ (pCi/L)	Target Sub-Slab and Exterior Soil Gas Concentration (pCi/L)	Target Groundwater Concentration (pCi/L)
Rn-219	*6.04E+00*	*5.97E+03*	*6.04E-03*	*2.01E-01*	*1.39E+00*
Rn-220	*4.75E+00*	*9.57E+03*	*4.75E-03*	*1.58E-01*	*1.09E+00*
Rn-222	*3.05E+00*	*8.18E+02*	*3.04E-03*	*1.01E-01*	*6.99E-01*

RVISL Calculator result comparison for Resident & Commercial Worker scenarios (dose result / risk result)

Isotope	Inhalation RVISL	Submersion RVISL	Target Indoor Air Concentration	Target Sub-Slab and Exterior Soil Gas Concentr.	Target Groundwater Concentration
Rn-219			19 - 21		
Rn-220				39 - 43	
Rn-222					

RVISL Calculator User's Guide

Welcome to the EPA's Radon Vapor Intrusion Screening Level (RVISL) Calculator User's Guide for Radionuclide Contaminants at Superfund Sites. This guide contains descriptions, equations, and default exposure parameters used to calculate cancer risk- and dose-based RVISLs. Additional guidance is also provided on sources of parameters and proper RVISL use. It is suggested that users read the RVISL Frequent Questions page before proceeding. The User's Guide is extensive, so please use the "Open All Sections" and "Close All Sections" links below as needed. Individual sections can be opened and closed by clicking on the section titles. Before proceeding through the User's Guide, please read the Disclaimer below.

This tool provides screening level (SL) concentrations of radon (Rn) for groundwater, soil gas (sub-slab and exterior), and indoor air to assist Agency staff with making a RVISL determination based on limited, initial data. In addition to calculating SLs, this tool can calculate indoor air concentrations from radon in soil gas and groundwater concentrations entered by the user. The cancer risk and dose from calculated indoor air concentrations and user-provided indoor air concentrations can also be calculated. The equations for these features are presented in the following sections.

Since background radon levels are typically outside the risk range, the RVISL calculator is likely to be used primarily for compliance with Applicable or Relevant and Appropriate Requirements (ARARs). For Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial actions, dose assessment is generally done only to show compliance with a dose-based ARAR. In addition, the calculator presents the option to compare the indoor air concentration, entered by the user or derived from groundwater or soil gas activities, to state standards or Uranium Mill Tailings Radiation Control Act (UMTRCA) standards, which also may be potential ARARs. For more information on when UMTRCA indoor radon standards are potential ARARs, see the guidance document "Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination" Attachment A: Likely Federal Radiation (AEA, UMTRCA, CAA, CWA, SDWA) ARARs, page 3 (OSWER Directive 9200.4-18, August 1997). There are

some state standards expressed in pCi/l or mrem/yr that, if more stringent than the UMTRCA standards, may be selected as ARARs.

RVISLs are a type of preliminary remediation goal (PRG) and both are a specific variety of the broad SL category. The RVISL calculator provides updated guidance for developing SLs for indoor Rn-222, Rn-220, and Rn-219 that are risk- or dose-based and for showing compliance with the UMTRCA indoor radon standards for Rn-222 and Rn-220. The RVISL, therefore, supersedes the risk assessment approach in Preliminary Remediation Goals for Radionuclides in Buildings (BPRG) electronic calculator, the dose assessment approach in ARAR Dose Compliance Concentrations Goals for Radionuclides in Buildings (BDCC) electronic calculator, and Q17 of the guidance document "Radiation Risk Assessment At CERCLA Sites: Q & A" issued on May 2014. Computer codes such as the RVISL, which were developed to predict hazards from potential human exposure to radon concentrations in indoor air, are based on simplified equations and protective assumptions. While RVISLs may be imprecise for an individual house or structure they are protective in nature for screening a wide variety of buildings. EPA would recommend, where possible, Regions use measurements of radon indoors rather than rely on the transport portions of the RVISL. In particular, testing of groundwater or soil gas is not required to demonstrate compliance with RVISL WL, pCi/L, risk, or dose targets.

Disclaimer

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The RVISL calculator provides updated guidance for developing SLs or PRGs for indoor Rn-222, Rn-220, and Rn-219 that are risk- or dose-based and for showing compliance with the UMTRCA indoor radon standards for Rn-222 and Rn-220. The RVISL calculator approach, therefore, supersedes the risk assessment approach in Preliminary Remediation Goals for Radionuclides in Buildings (BPRG) electronic calculator, the dose assessment approach in ARAR Dose Compliance Concentrations Goals for Radionuclides in Buildings (BDCC) electronic calculator, and Q17 of the guidance document "Radiation Risk Assessment At CERCLA Sites: Q & A" issued on May 2014.

1. Introduction

In addition to this guidance, for relevant training, see the internet-based course "Radiation Risk Assessment: Updates and Tools."

Verification Study Conflict of Interest Certification

Verification study: **Radon Vapor Intrusion Screening Level Verification Study**

A conflict of interest or lack of impartiality exists when the proposed participant personally (or the reviewer's immediate family), or his or her employer, has financial interests that may be affected by the results of the verification study; or may provide an unfair competitive advantage to the participant (or employer); or if the participant's objectivity in performing the verification study may be impaired due to other factors. When the Participant knows that a reasonable person with knowledge of the facts may question the participant's impartiality or financial involvement, an apparent lack of impartiality or conflict of interest exists.

The following questions, if answered affirmatively, represent potential or apparent lack of impartiality (*any affirmative answers should be explained in an attachment*):

- Did you contribute to the development of the calculator being verified, or were you consulted during its development, or did you offer comments or suggestions to any drafts or versions of the document during its development? ■ No □ Yes
- Do you know of any reason that you might be unable to provide impartial advice on the matter under consideration in this verification study, or any reason that your impartiality in the matter might be questioned? ■ No □ Yes
- Have you had any previous involvement with the calculator under consideration? ■ No □ Yes
- Have you served on previous advisory panels, committees, or subcommittees that have addressed the topic under consideration? ■ No □ Yes
- Have you made any public statements (written or oral) on the issue? ■ No □ Yes
- Have you made any public statements that would indicate to an observer that you have taken a position on the issue under consideration? ■ No □ Yes
- Do you, your family, or your employer have any financial interest(s) in the matter or topic under this verification study, or could someone with access to relevant facts reasonably conclude that you (or your family or employer) stand to benefit from a particular outcome of this verification study? ■ No □ Yes

With regard to real or apparent conflicts of interest or questions of impartiality, the following provisions shall apply for the duration of this verification study:

(a) Participant warrants, to the best of his/her knowledge and belief, that there are no relevant facts or circumstances that could give rise to an actual, apparent, or potential organizational or personal conflict of interest, or that Participant has disclosed all such relevant information to EMS or to EPA.
(b) Participant agrees that if an actual, apparent, or potential personal or organizational conflict of interest is identified during performance of this verification study, he/she immediately will make a full disclosure in writing to EMS. This disclosure shall include a description of actions that Participant (or his/her employer) has taken or proposes to take after consultation with EMS to avoid, mitigate, or neutralize the actual, apparent, or potential organizational conflict of interest. Participant shall continue performance until notified by EMS of any contrary action to be taken.

Carl Spreng — 5/3/22

Signature — Date

□ Check here if any explanation is attached

Carl Spreng

Printed Name

(sole proprietor)

Affiliation/Organization

CARL SPRENG
RESUME

U.S. Department of Energy c/o Navarro Research & Engineering
11035 Dover St., Ste. 600
Westminster, CO 80021-5587

DATES OF EMPLOYMENT: June 2020 – September 2020

DUTIES: Provide expert technical services to produce a white paper on *Residual Subsurface Radiological Contamination in the Central Operable Unit*.

Colorado Department of Public Health & Environment
Hazardous Materials and Waste Management Division
4300 Cherry Creek Drive South, HMWMD-B2
Denver, CO 80246-1530

JOB TITLE: Rocky Flats Project Coordinator
(Environmental Protection Specialist III)

DATES OF EMPLOYMENT: April 1992 – July 1993; May 1994 – July 2018

DUTIES: Provide technical lead and staff authority for development, implementation, and oversight of corrective action involving radioactive and chemical contamination at RCRA facilities; advise and provide technical guidance to management and external agencies on these issues. Assure and determine adequate treatment and environmental cleanup of hazardous waste facilities and contaminated sites by investigating, analyzing, and evaluating the chemistry, geology, hydrogeology, and geotechnical aspects of the sites. Evaluate laboratory analytical data, inspect facilities, oversee remediation activities and maintenance of work plans and permits. Regularly meet with local governments and stakeholders, and participate in technical working groups and public participation forums.

Team leader of several technical teams for the Interstate Technology and Regulatory Council (ITRC), a nation-wide organization of state environmental regulators and representatives of federal agencies, industry, academia, and local and tribal stakeholders: *Radionuclides*; *Attenuation Processes for Metals and Radionuclides in Groundwater*; *Remediation Management of Complex Sites*.

CARL SPRENG
RESUME (continued)

Hart Publications, Inc.
Denver, CO

JOB TITLE: Managing Editor

DATES OF EMPLOYMENT: September 1990 – April 1992
August 1993 – May 1994

DUTIES: Oversaw and managed two publications targeting the oil & gas industry; compilation and editing of data; accounting for sales; developing advertising; hiring and other personnel duties; supervised 6 professional employees.

Spreng Geological Consulting
Thornton, CO

JOB TITLE: Independent Consulting Geologist

DATES OF EMPLOYMENT: January 1984 – April 1991

DUTIES: Developed and managed exploration projects; well-site supervision of oil and gas wells; economic/property evaluations; taught hydrogeology course at Front Range Community College; conducted/supervised corrosion engineering projects (cathodic protection of tanks, pipelines, etc.).

Berge Exploration, Inc.
Denver,CO

JOB TITLE: Manager – Special Projects

DATES OF EMPLOYMENT: November 1977 – December 1983

DUTIES: Developed and managed exploration projects (oil & gas, oil shale, tar sands, uranium, coal, etc.); supervised field exploration projects in the western U.S. including U.S. Dept. of Energy NURE project (*US DOE Report GJO-014(82)*); developed project proposals; wrote reports; compiled data, maps, etc.; hired and supervised professional geologists.

CARL SPRENG
RESUME (continued)

Occidental Oil Shale, Inc. (Occidental Petroleum, Inc.)
Grand Junction, CO

JOB TITLE: Geologist

DATES OF EMPLOYMENT: July – December 1975
April – August 1976

DUTIES: Directed fracture mapping program; computer data processing; conducted sampling study of in-situ retort; measured geologic sections; hydrologic well logging.

Seismograph Service Corporation
Tulsa, OK

JOB TITLE: Electronics repairman; jug crew lead

DATES OF EMPLOYMENT: April - August 1974

DUTIES: Electronic instrumentation repairs; led geophone crew on seismic exploration project in western U.S.

Petro-Nuclear, Ltd. (Consolidated Oil & Gas, Inc.)
Denver, CO

JOB TITLE: Geological Field Assistant

DATES OF EMPLOYMENT: June – August 1968

DUTIES: Surveying, mapping, scintillometer surveys in support of uranium exploration in central Wyoming.

EDUCATION

Bachelor of Science – Geology	Brigham Young University (1975)
Master of Science – Geology	Brigham Young University (1978)
Post-graduate courses:	
Geohydrology	University of Colorado
Geophysics	Colorado School of Mines