

Draft Radon Vapor Intrusion Screening Level Calculator

External Peer Review Record

September 28, 2020 – November 11, 2020

CONTENTS:

Charge Document

Comments Matrix

Dr. Rodolfo Avila (AF Consult AB, Sweden)

[Curriculum Vitae](#)

[Conflict of Interest](#)

[Certification Review](#)

Cynthia Barr (U.S. Nuclear Regulatory Commission)

[Curriculum Vitae](#)

[Conflict of Interest](#)

[Certification Review](#)

Ryan Schierman (formerly with Wyoming Department of Environmental Quality's Uranium Recovery Program)

[Curriculum Vitae](#)

[Conflict of Interest Certification](#)

[Review](#)

Carl Spreng (Retired, Colorado Department of Public Health and Environment)

[Curriculum Vitae](#)

[Conflict of Interest Certification](#)

[Review](#)

Matthew Williams (Michigan Department of Great Lakes, Energy and the Environment)

[Curriculum Vitae](#)

[Conflict of Interest](#)

[Certification Review](#)

Peer Review Charge for the U.S. Environmental Protection Agency (EPA), Draft 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 peer review of the draft online calculator, *Radon Vapor Intrusion Screening Level Calculator* (RVISL) including the companion Homepage, User's Manual, and Frequently Asked Questions webpages. 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 draft RVISL calculator and companion webpages can be accessed here:

<https://epa-visl.ornl.gov/radionuclides/>

User ID: prg

Password: development

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

PDFs of the Homepage and Frequently Asked Questions (10 pages) and User's Guide (35 pages).

Expertise: The peer review panel will have 5 reviewers (both U.S. and international) with broad range of expertise related to radon gas behavior, assessment of radiation risk, vapor intrusion, and building physics, as well as experience with similar exposure assessment software tools (e.g., NORMALYSA, VISL, or RESRAD).

Peer Review Charge:

Peer reviewers should focus their efforts on answering the charge questions that begin on page "a"¹, with specific recommendations that are practical and implementable. Any additional comments or edits to the text should be provided using either: 1) the text edit/comment mode of Adobe Acrobat to edit the attached PDF of the webpages; or 2) Microsoft Word to list comments that referencing the appropriate section numbers and line number(s). Please do not scan and submit handwritten comments.

We request that you review the overall website, User's Guide, Frequent Questions, and the calculator, and answer the charge questions below. The goal is to identify any shortcomings in

¹ Please use this file to provide your answers.

the explanation of how to use the calculator. Please note any inconsistencies between the user's guide and calculator.

Other Related Directions

- All answers to the charge questions and other suggested edits be submitted to EMS, Inc. by November 9, 2020.
- Keep the link to the draft document and other materials provided by EMS, Inc. confidential. Please do not share or discuss these materials with colleagues or the public.
- Avoid interactions—including with EPA representatives or members of the interested public—that might create a perception of a conflict of interest (COI) regarding the work product under review.
- Inform EMS if you are contacted regarding the peer review or draft document by anyone other than EMS staff.

Charge Questions:

A. Homepage and Overall Website

1. Is the website clearly organized, described, easy to navigate, and generally “user friendly” and appropriate for the target audience? If not, what do you recommend?
2. Have the objectives of the RVISL calculator, as stated in the documentation, been met? If not, what do you recommend?
3. Do you recommend any modifications to the Homepage graphic?
4. Do you have any other recommendations to improve the usability of the website?

B. User’s Guide

1. Does the User’s Guide adequately explain the concepts addressed by the calculator and its limitations?
2. Are the assumptions clear and reasonable? If not, what do you recommend?
3. Are the sources and citations appropriate, and do they represent the current state of knowledge? If not, what do you recommend?

C. Frequent Questions

1. Are the 11 questions clearly worded? If not, what do you recommend?
2. Are the 11 responses clear, concise, and accurate? If not, what do you recommend?
3. Are there other helpful questions and answers that should be added? If yes, please list the questions.

D. Calculator

1. Are the results clearly explained and presented? If not, what do you recommend?
2. Are the results appropriately described and qualified (to the extent that they may be relied upon and defended)? If not, what do you recommend?
3. Do the results provide defensible explanation of how they were derived, or are they the result of a “black box?” Do you recommend anything different?
4. RVISL calculation of the equilibrium level (F_{eq}) of radon progeny that would be present in indoor air is based on air exchange rate. Should other mechanisms (seasonal atmospheric changes, building construction, surface plating, aerosol sizes, regional geology, air flow) be incorporated in the calculation?

5. Is there anything else you recommend for the calculator to improve it for its stated purpose?

E. Anything Else?

Is there anything else you would recommend to improve the RVISL calculator's utility, accuracy, completeness, or supportability?

MATRIX OF PEER REVIEW COMMENTS: Radon Vapor Intrusion Screening Level Calculator

Notes: [Brackets in comments comprised additional explanation inserted by the peer review contractor]

Yellow highlighting is used to indicate responses to charge questions. The table can be sorted by color in column B to show only these responses.

Commenter	Charge Question No.	Document	Line No. (Home Page and FAQs only)	Section No. (User's Guide only)	Paragraph	Line	Other Descriptor	Comment
Avila	A1							Yes, I think the website is clearly organized, easy to navigate, generally "user friendly" and appropriate to the target audience. The text in the home page is too long and could be improved. I provide suggestions in the attached pdf (RVISL Home Page and FAQs)_Avila).
Avila	A2							Yes, the objectives have been met.
Avila	A3							None.
Avila	A4							I would add a link to a Glossary page. This can be added to the existing list of links in the Home Page.
Avila	B1							The User's Guide adequately explains the concepts and their limitations. I have included some comments in the attached pdf.
Avila	B2							The assumptions are clear and reasonable. I have added some comments to the assumptions in the attached pdf.
Avila	B3							The sources and citations cover well the US literature, but it would be good to add references to sources from other countries and international organizations.
Avila	C1							The questions are generally clearly stated. I proposed some changes in the wording of questions 3, 4, 7 and 8, see the attached pdf (RVISL Home Page and FAQs)_Avila) [Reproduced in this table].
Avila	C2							Some of the answers are not concise and accurate. I proposed some changes in the attached pdf (RVISL Home Page and FAQs)_Avila) [Reproduced in this table]. In particular, the answer that is provided to question 8 is not adequate.
Avila	C3							One helpful question could be: How do deal with situations where more than one Radon isotope, for example Rn-220 and Rn-222, is present?
Avila	D1							The results are clearly presented, but not explained. There are explanations in the User's Guide, but it is not obvious where exactly in the Guide each particular result is to be found. One solution could be that each result column points to the corresponding equation listed in the Calculator and/or the User's Guide. This might require that the Equations be numbered. Another alternative would be to provide a footnote to the Table of results, where each result included is listed with a short description and references to the User's Guide. The above shortcoming is illustrated in the attached pdf (Resident_rad_rvisl_results), which presents the results generated by the Calculator for the screening levels of Dose-Type; using default parameter values. It is not obvious what the results presented in the columns Inhalation RVISL , Submersion RVISL and Target Indoor Air Concentration and the terms used in the User's Guide for these results are somewhat different. In the same pdf, I have also added some comments to the table of results.
Avila	D2							The results are mostly appropriated described and qualified in the User's Guide. It is stated in the User's Guide that results obtained using default parameter values correspond to the Reasonable Maximum Exposure (RME), since conservative values are selected as defaults. However, it is not always demonstrated that the chosen default values are conservative. An example is the Attenuation Factor as explained in the comments to the User's Guide (see attached pdf).
Avila	D3							Sufficient explanations of how the results were derived are provided in the User's Guide.
Avila	D4							In my opinion this is not required for screening assessments which is the intention with the RVISL. If such mechanisms are considered, it would be anyway difficult to estimate generic default parameter values, without unduly overestimation of the RVISL.
Avila	D5							The use of several conservative parameters in the same equation, might lead to over conservative estimates. This is a result of multiplication of errors. For example, if several parameters in an equation are multiplied with each other and a low probability value (like a 95 percentile) is given to each parameter; then the probability of the obtained result might be extremely low. One possible approach to overcome this, would be to perform calculations using central values for the parameters and apply an uncertainty factor to the results, so that the screening value is set at a reasonable percentile (like the 95 percentile).
Avila	E							Nothing more comes to my mind right now.
Avila		Welcome	10					Delete: comparison values and
Avila		Welcome	12-14					Delete: Note that for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial actions, dose assessment is generally done only to show compliance with a dose-based Applicable or Relevant and Appropriate Requirement (ARAR).
Avila		Welcome	17					Delete: , which also may be potential ARARs.
Avila		Welcome	22					Change: "site-specific risks" to "site-specific conditions"
Avila		Welcome	26-28					Delete: Below is a general description of screening levels for radon. If the calculator is used with non-default inputs in a decision on a Superfund site, it is recommended that the inputs be clearly identified and justified by the user.

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Avila		Welcome	37-38					Delete: which were developed to predict potential human exposure from radon concentrations in indoor air
Avila		Welcome	38					Change: "highly iprecise for an individual house" to "inaccurate for a particular house"
Avila		Welcome	40-42					Delete: In particular, testing of groundwater or soil gas is not required to demonstrate compliance with RVISL WL, pCi/L, risk, or dose targets.
Avila		Welcome	43-49					Delete: Users should note that since background radon levels are typically outside the risk range, the RVISL calculator is likely to be used primarily for ARAR compliance. For example, the UMTRCA indoor radon standards 40 CFR 192.12(b)(1) and 192.41(b) were identified as likely Federal ARARs for Rn-222 and Rn-220 in Attachment A of the EPA guidance document "Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination." 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.
Avila		Introduction	54					Change: "screening level" to "Radon Vapor Intrusion Screening Levels"
Avila		Introduction	58					Change: thorium to thorium-232
Avila		Introduction	59					Change: actinium to actinium-227
Avila		Introduction	76					Delete: Note: No consideration is given to ecological effects in the values presented in this calculator.
Avila		FAQs	84					Change: "exterior" to "collected exterior to buildings"
Avila		FAQs	84					Delete: "Agency staff"
Avila		FAQs	84-85					Change: "vapor intrusion determination" to "radon vapor intrusion screening"
Avila		FAQs	85					Add: The RVISLs are defined as...
Avila		FAQs	90					Change: "target indoor air concentrations" to "RVISLs for indoor air"
Avila		FAQs	91					Delete: "generic"
Avila		FAQs	92					Delete: "generally reasonable"
Avila		FAQs	106-111					Delete: "The factors listed above may negate the appropriate application of the recommended attenuation factors and the sub-slab, groundwater, and soil gas VISLs for purposes of identifying sites or buildings unlikely to pose a health concern through the vapor intrusion pathway. On the other hand, further evaluation of the vapor intrusion pathway is still appropriate when the sub-slab, groundwater, and soil gas VISLs are exceeded for samples from a building or site where these specific factors are present."
Avila		FAQs	112					Insert: "default" before "attenuation"
Avila		FAQs	114					Change: "methane" to "radon"
Avila		FAQs	112-123					Propose removing since these situations are not relevant for indoor exposures to Radon
Avila		FAQs	124-125					Rephrase to: the assumptions made for deriving the attenuation factors are valid for a given site.
Avila		FAQs	125					Change: "attained" to "valid"
Avila		FAQs	126					Change: "VISLs" to "RVISLs"
Avila		FAQs	128-129					Change: "Where the assumptions regarding the subsurface attenuation factors do not or may not apply" to "In this case"
Avila		FAQs	129					Delete: "generally"
Avila		FAQs	131					Change: "for" to "using"
Avila		FAQs	137-138					[Last sentences is] Vague. Propose removing or making more accurate
Avila		FAQs	139					Change: "forward" to "cancer risk"
Avila		FAQs	140					Delete: "In addition to calculating screening levels,"
Avila		FAQs	146					Change: "their site data" to "site-specific data"
Avila		FAQs	149					Insert: "to a site-specific value" at the end of the sentence.
Avila		FAQs	150-151					Sentence is repeated. Propose removing it.
Avila		FAQs	154					Equation is missing.
Avila		FAQs	160					Change: "a formula" to "equations"
Avila		FAQs	161					Change: "equation is" to "equations are"
Avila		FAQs	173					Change: "were" to "are"
Avila		FAQs	182					Change: "risk-based versus dose-based versus WL" to "risk-based, dose-based, or WL"
Avila		FAQs	198					Change: "transport portions of the RVISL." to "calculations of transport in soil included in the RVISL calculator."
Avila		FAQs	198-200					Delete sentence.
Avila		FAQs	204-205					Delete: "for a J256difference in the risk results"
Avila		FAQs	230					Change: "collocated" to "distributed"
Avila		User's Guide		1	4	1		Have not seen that exposure to tap water is considered
Avila		User's Guide		2.1	4	1		Why direct use of contaminated groundwater in a house has not been considered?. The use in a house (for example for showering) of groundwater containing Radon that is abstracted from a well could lead to increase of Radon concentration in the indoor air.
Avila		User's Guide		2.1	7	1-2	Bullets 1, 2	I think these sources are not relevant for indoor exposures

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Avila		User's Guide		2.1		8	1-3	Yes but these are not leading to increase concentrations indoors
Avila		User's Guide		2.2		1	1-2	Bullets 1, 2, 3 I do not see why write about what the calculator cannot do. Can be removed
Avila		User's Guide		2.2		2	2	Why then isotopes after Pb-210 are included in the results presented by the calculator?
Avila		User's Guide		6.5			Footnote for Attenuation Factors Table	An explanation of why these has been selected and the implications for the use of the screening levels should be discussed. The EPA recommends using measured Radon concentration values for comparison with the screening levels. If the concentrations have been measured then the type of residence is known and there is no reason for using attenuation factor for all types of residences.
Avila		User's Guide		7			Table 1	Insert: ", unitless" following (WL)
Avila		User's Guide		7			Table 1	This [Resident Air Submersion (pCi/m3)] and the following are concentrations [Resident Air Total and Worker Air Inhalation] that are derived differently and therefore should have a different definition
Avila		User's Guide		7			Table 1, Row DCFsub	Change: "risk/year" to "mrem/year"
Avila		User's Guide		7			Table 1, Row Sfsub	Change: "cm" to "cm3"
Avila		User's Guide		7			Table 1, Rows CDI, Cvp, ELCR, Feq, TCR, TDL, TWL, ACH, Aeq	Units?
Avila		User's Guide		7			Table 1, Row Efres	The same definition as the next?
Avila		User's Guide		7			Table 1, Row IRAw	Why the worker has a higher inhalation rate during 24 hours? He is working only 8 hours/day
Barr	A1							Yes the web site is clearly organized, easy to navigate and user friendly.
Barr	A2							I am unsure what the "objectives" of RVISL calculator are. However, the RIVSL appears to do the following as explained in the User's Manual: <i>This tool provides screening level concentrations of radon for groundwater, soil gas (sub-slab and exterior), and indoor air to assist Agency staff with making a radon vapor intrusion screening level (RVISL) determination based on limited, initial data. In addition to calculating screening levels, 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.</i> Several comments are provided in the pdf files of the User's Manual and other documentation that if incorporated I think would provide increased transparency and support for the methodology.
Barr	A3							Yes, several comments were made on the homepage graphic (see file RVISL Home Page and FAQs csb comments.pdf) [Reproduced in this table]
Barr	A4							See comments in pdf files. [Reproduced in this table.]
Barr	B1							Additional detail could be provided. See comments in file RVISL User's Guide csb.pdf. [Reproduced in this table.] Additionally, it would help to provide screen shots of the forms and the output with simple examples of how to use the calculator.
Barr	B2							Yes, the assumptions are generally clear and reasonable.
Barr	B3							Additional detail and supporting information could be provided (e.g., support for risk-significant assumptions and parameters and information on dosimetry). See comments in the file RVISL User's Guide csb.pdf. [Reproduced in this table.]
Barr	C1							Please see comments on RVISL Home Page and FAQs csb comments.pdf file. [Reproduced in this table.]
Barr	C2							Please see comments on RVISL Home Page and FAQs csb comments.pdf file. [Reproduced in this table.]
Barr	C3							Yes, include a basic question and answer on how the screening levels are calculated based on default assumptions and parameters. A table of alternative approaches to using the calculator on the main page or in the User's Manual would be helpful. Describe where the generic screening levels are located (it looks like this information is not yet available on the web site, see empty page when you click on the "generic tables" link although that would be helpful).
Barr	D1							See comment above on User's Manual. It would help to provide screen shots of inputs and outputs from the calculator.
Barr	D2							Additional detail could be provided as noted in the file RVISL User's Guide csb.pdf. [Reproduced in this table.]
Barr	D3							Additional detail could be provided as noted in the file RVISL User's Guide csb.pdf. [Reproduced in this table.]

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Barr	D4							As noted in comment, insufficient information is provided to determine the conservatism or reasonableness of the default values. The capability to adjust the parameter with sufficient support (in addition to adjusting the air exchange rate) would be beneficial particularly if additional credit could be taken to alleviate potential conservatisms using the current approach.
Barr	D5							See comments provided in the file RVISL User's Guide csb.pdf [Reproduced in this table]
Barr	E							Additional information on any benchmarking, verification, and validation studies, including supporting data, would also increase confidence in the results.
Barr		Welcome	1-4				Figure and Figure Caption	<p>It would help to show the contamination in the vadose zone soils--it currently looks like the soil contamination is only in the saturated zone. It would help to depict the upside triangle symbol for the water table surface.</p> <p>By atmospheric conditions do you mean wind effects alone? What about atmospheric pressure and barometric pumping? What are the underlying or implicit assumptions in the RVISL calculator.</p> <p>Why does it look like there are building wake effects considered (rising of air currents above the building roof)?</p> <p>Why does it look like most of the radon goes into the indoor buildings rather than to the outdoor air? Note: Underlying assumption is that radon concentrates in indoor air.</p> <p>Why does it look like outdoor exchange only occurs through the roof and why is there a reference to stack effects as if an elevated release is being simulated?</p> <p>If this is purely a conceptual drawing and only loosely reflects underlying assumptions in the RVISL calculator, this should be clearly stated in the caption.</p>
Barr		Welcome	17					<p>It would be important to note that this screening level approach may not be consistent with the flux or dose modeling approach associated with certain ARARs (e.g., NRC standards). For example, the suggested methodology may not be consistent with NRC standards for LLW and restricted release sites. For LLW disposal, engineered barrier degradation; release and transport of radon and its precursors (e.g., upward radon diffusion and downwards radium transport in infiltrating groundwater) would need to be considered over the performance period. While radon dose does not need to be considered explicitly for decommissioning sites seeking unrestricted release, it may need to be considered for restricted release sites over a 1000 year compliance period.</p> <p>Also, some standards are based on a flux standard and not a concentration standard. How are these type of standards addressed with the current approach which calculates dose, risk or screening levels?</p>
Barr		Welcome	38					If they are highly imprecise, then how is the uncertainty managed in a screening calculator which is inherently supposed to err on the side of higher doses and risk?
Barr		FAQs	83					The FAQ should provide a little more information on where these RVISLs are located (e.g., is a table based on default parameters provided outside of the calculator output or does the calculator have to be run). A basic description of the various alternatives to calculating the RVISLs could be provided in this FAQ (and point to User's Manual for more information).
Barr		FAQs	84					Explain what is meant by a vapor intrusion determination.
Barr		FAQs	85					Provide examples of the types of data needed to make a determination.
Barr		FAQs	139					Add text to the question to explain what a forward calculation is as the user may not understand what that means.
Barr		User's Guide					General Comment	Any benchmarking, verification, or validation studies related to the RVISL calculator would provide increased confidence in the results and should be cited in the documentation.
Barr		User's Guide					General Comment	It would also be useful to provide example output and explain the information provided in the report.

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Barr		User's Guide		1 3				It is unclear if the latest ICRP recommendations are considered in the calculator. ICRP 115, "Lung Cancer Risk from Radon and Progeny and Statement on Radon," published in 2010 proposed a significantly higher nominal risk coefficient of 5x10-04 per working level month (WLM) compared to the value of ICRP Publication 65 of 2.83x10-04 per WLM. ICRP intends to publish dose coefficients for radon isotopes calculated based on biokinetic and dosimetric models. Hunt [2014] presented preliminary values of ICRP dose coefficients including a value of 13 mSv per WLM effective dose using an equilibrium factor of 0.4 and unattached fraction of 8 percent for exposure in the home. Please clarify if dose coefficients consistent with the ICRP 115 recommendations are available in the calculator database, and if not, if there are any plans to include updated values in the future. Hunt, J., "Current and Forthcoming ICPR Recommendations on Radon Exposures", Presented at the International Conference on Occupational Radiation Protection, Vienna, Austria, Occupational Radiation Protection in the Workplace Involving Exposure to Radon. John Hunt for John Harrison, Public Health England, December 2014. http://www-ns.iaea.org/tech-areas/communication-networks/orpnet/documents/cn223/8-hunt-presentation.pdf
Barr		User's Guide		1.3.2	1	2		[DFCs] should be DCFs.
Barr		User's Guide		1.3.2	1			It appears from running the calculator with default parameters that the submersion dose is dominating the concentration based RVISLs. Is that correct?
Barr		User's Guide		1 8	4	1		Typo, missing the "n" in demonstrates.
Barr		User's Guide		1 9	3	1-2		It might be helpful to point out the availability of tools such as RESRAD to assess the risk/dose of radon using more complex transport models to provide a more realistic estimate of dose if needed and adequately supported. Parameters such as the emanation coefficient, diffusion coefficients, building air exchange rate, and others may be important to a site-specific dose assessment.
Barr		User's Guide		2.1.1			Figure	What groundwater dependent pathways are (implicitly) considered by the calculator (e.g., it looks like radon from sink water is depicted on this figure)? Is groundwater used for showering also considered? Please be clear on what pathways that could contribute to radon/progeny air concentration and dose are considered (explain what pathway or other assumptions are made in determining appropriate attenuation factors).
Barr		User's Guide		2.1.2			Figure	See comments on the figure above for the residential scenario. Additionally does it make more sense to depict waste in the unsaturated zone leaching to groundwater?
Barr		User's Guide		5			Table 1, Rows Feq, Aeq	Define and use consistent terminology throughout the documentation. How do the "activity equilibrium factor" and "radon equilibrium factor" (or "inhalation fractional equilibrium factor" referred to in the ORNL 2020 reference on the topic) relate to commonly used terms "equilibrium factor" and "unattached fraction" in radon dosimetry? Additional text on the various terms and how they are used by the calculator would provide increased clarity and assurance that the factors are not being double-counted (or could provide additional information on what additional credit could be taken). The value of Feq and Aeq could be risk-significant and the values should be demonstrably conservative. While this appears to be the case, additional discussion in the supporting documentation on how the air exchange rate was selected to err on the side of conservatism, for example, would provide support that uncertainty in the dose and risk estimates is adequately managed.
Barr		User's Guide		5			Table 1, Rows AFgw	The reference for these values appears to be this document (i.e., the User's Manual). Please confirm. If the groundwater and sub-slab gas attenuation factors are used to calculate RVISLs, then it appears that these attenuation factors could be risk-significant. While underlying assumptions that may invalidate the attenuation factors are provided, adequate support for the default values selected should be provided in supporting documentation. Support could include data on subsurface and indoor concentrations for a variety of site conditions.
Barr		User's Guide		5			Table 1, Row IRares-c	The resident inhalation rate is a little low compared to the characteristics of the average member of the critical group used in NRC screening calculations (see NUREG/CR-5512, Volume 3). The ability to change exposure parameters to account for differences in regulatory approaches is beneficial.
Barr		User's Guide		5			Table 1, Row IRAw	While less of a concern to NRC, the worker inhalation rate used in the RVISL calculator is higher than assumed for the building occupancy inhalation rate of 1.4 m3/hr in NUREG/CR-5512, Volume 3. The ability to change exposure parameters to account for differences in regulatory approaches is beneficial.
Barr		User's Guide		6			Ref 8	Update to Rev. 1 of the document.

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Schierman	A1							<p>On the homepage the reviewer would include the purpose of the screening tool. The user's guide, under the disclaimer has an appropriate statement that could be included in the homepage:</p> <ul style="list-style-type: none"> •“Purpose of this guidance is to provide a radon vapor intrusion screening level (RVISL) calculation tool to assist risk assessors, remedial project managers, and others involved with risk assessment and decision-making at CERCLA sites in developing RVISLs or preliminary remediation goals 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.” •The limitations of the calculator, as discussed under “Potential Problems and Limitations” as well as assumptions made by the calculator, should be more clearly identified as a bullet on the home page. The bullet could be listed as “Assumptions and Limitations.” The reviewer understand that under the first paragraph of the user's guide it states to read disclaimer first however, to prevent misuse of the calculator identifying the limitations and assumptions up front may deter misuse. •Additionally, it should be stressed on the home page that the recommendation contained in Section 3.4 “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, risk, or dose targets.” •On the original homepage the reviewer recommends as done in other sections in the user s guide a clarifying statement that screening levels are synonymous with preliminary remediation goals.
Schierman	A2							The objectives for the RVISL calculator, as stated in the user's guide have been met as described. One item that may be prudent to discuss more in depth is the current shortfall and the need for the RVISL calculator. Discussing how the calculator closes this shortfall would be beneficial.
Schierman	A3							<p>Developers may want to consider changing the graphic to state that the soil contains radium instead of radon. Radon is not attached to the soil particle. It is a nuance and may not be worth changing.</p> <p>The Graphical representation under Radon Vapor Intrusion Screening Level Equations/Air Screening Level Equations/Residential Air and Workers Air is misleading. Representing sources of radon as drums of waste may lead to misconceptions on sources of radon. I prefer the homepage graphic depiction of the source as solely soil containing radon (radium) or just a radiation symbol.</p>
Schierman	A4							<p>On the homepage the “Welcome” and “Introduction” seem to be a little verbose and could be consolidated into one section.</p> <p>Generic Tables Bullet is not functional</p>
Schierman	B1							The reviewer agrees that the guide adequately explained the concepts addressed by the calculator. The reviewer would recommend adding a bullet under “Radon Vapor Intrusion Screening Levels (RVISL) table” stating “Assumptions and Limitations” All assumptions and limitations should be clearly documented under this bullet.
Schierman	B2							See response to B. User's guide question 1.
Schierman	B3							<p>Additional resources for the author to consider:</p> <p>ICRP, 2014. Radiological Protection against Radon Exposure. ICRP Publication 126. Ann. ICRP 43(3) ICRP, 2017.</p> <p>Occupational Intakes of Radionuclides Part 3. ICRP Publication 137. Ann. ICRP 46 (3/4) While ICRP Publication 137 does not specifically address public exposures, it is intended that this same dose coefficient applies to exposures in homes.</p> <p>NCRP Report 97. Measurement of Radon and Radon Daughters in Air</p> <p>NCRP Report 160. Ionizing Radiation Exposure of the Population of the United States. 2009. <i>Radon Equilibrium factors</i>.</p>
Schierman	C1							The questions are clearly worded, I have no further recommendations.
Schierman	C2							I found no issues with the responses and they appeared to be accurate.
Schierman	C3							<p>I would add the following question: Can I change a radon equilibrium factor or activity equilibrium factor to site specific data?</p> <p>With an exchange rate of zero the radon equilibrium fraction is 1 to 1 or 100%. NCRP and other organizations have proposed other equilibrium factors. While I understand the equilibrium factor can be modified using air exchanges, the reviewer believes it would be good to clarify in the frequent question section how equilibrium can be changed.</p>
Schierman	D1							When selecting the target dose (mrem/yr) under the dose-based screening level type the default is 1 mrem. I am unsure where the 1 mrem/year comes from. In the supporting document Analysis of what Radiation Dose Limit is Protective of Human Health at CERCLA Sites (Including Review of Dose Limits in NRC Decommissioning Rule) it states EPA has considered cancer risk from radiation in a number of different contexts, and has consistently concluded that levels of 15 mrem/yr. EDE (which equates to approximately a 3 x 10 ⁻⁴ cancer risk) or less are protective and achievable. Why not set the default to 15 mrem/yr?

MATRIX OF PEER REVIEW COMMENTS: Radon Vapor Intrusion Screening Level Calculator

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Commenter	Charge Question No.	Document	Line No. (Home Page and FAQs only)	Section No. (User's Guide only)	Paragraph	Line	Other Descriptor	Comment
Schierman	D2							From the limited testing of the calculator, the results correspond with the equations described in the user's guide. The question of whether they may be relied upon or defended is harder to answer. The calculator purpose from the reviewer's understanding is to assist risk assessors, remedial project managers, and others to make decision at CERCLA sites in developing screening levels or preliminary remediation goals. As stated in the user's guide "Predicting the amount of radon gas available for vapor intrusion in the natural environment, is not an ideal setting. Several factors make it impossible for this calculator to confidently predict suitable target indoor air concentrations from sources in soil and groundwater." The reviewer agrees with the language in the user's guide and there are such variabilities that make it hard for the calculator to be defensible. With measurement however, the results become much more defensible.
Schierman	D3							I think the user's guide adequately describes how the equations were derived.
Schierman	D4							Ultimately, there are many factors that influence radon concentrations indoors. Incorporating the above items may improve the estimate, however it would also introduce more uncertainty in the estimate. The answer to the question is whether the calculator as presented provides a conservative estimate of the radon air concentrations. As EPA implements the calculator and sets screening levels, it will be interesting to compare actual measurements with what was predicted to understand if more variables are needed in the calculation.
Schierman	E							I think it is important to note that the calculator is a tool to assist decision making at CERCLA sites in developing screening levels. It is not a regulatory requirement or the only way to set screening levels. While the calculator is helpful, as stated by EPA in the documentation where possible regions should use measurements of radon indoors rather than rely on the transport portions of the calculator. Testing of groundwater or soil gas is not required to demonstrate compliance with RVISL, working levels, risk, or dose targets. The calculator is to be used at CERCLA sites. However, the user's guide and the calculator frequently refer back to UMTRCA applicable or relevant and appropriate requirements (ARAR). The reviewer understands that a few UMTRCA sites are also listed as CERCLA sites. Is the utility of the calculator comparing UMTRCA ARAR only for these UMTRCA sites listed as CERCLA? Outside of UMTRCA, is there utility in comparing it back to these standards? Is it the intent of the developers that the calculator would be used outside of CERCLA facilities? These are items to consider that are not clear upon review of the calculator and the accompanying documentation.
Spreng	A1							The website is clearly organized; it progresses from topic to topic generally in a logical sequence. The instructions and descriptions necessarily vary in detail, which likely matches the range of knowledge among the target audience(s).
Spreng	A2							The calculator was created to develop PRGs or SLs that "predict potential human exposure from radon concentrations in indoor air". It meets those objectives.
Spreng	A3							The graphic adequately portrays the various vapor transport concepts. The source – the "soil containing radon" blob – looks like it may have been copied from a chemical spill figure.
Spreng	A4							No. The instructions and information seem to fit the range of potential users. Links to the references cited also improve the usability of the website.
Spreng	B1							Yes, the concepts are fully and clearly explained. The Guide describes uncertainties, assumptions and defaults, and the inherent problems with predicting air concentrations from subsurface sources. It also explains that it does not establish binding rules.
Spreng	B2							The assumptions are generally reasonable and clearly worded. Suggested revisions are shown in an attached file in the text edit/comment mode of Adobe Acrobat.
Spreng	B3							The sources and citations are appropriate and seem to be up to date. The only additional reference that I suggested was in Section 1.7 where it might be worth mentioning that EPA participates in the radon industry-led ANSI/AARST voluntary consensus-based standards (VCS) process: https://standards.aarst.org/ "EPA Guidance on the Use of Voluntary Consensus Standards for State Indoor Radon Grant Recipients." https://www.epa.gov/sites/production/files/2019-08/documents/august_2019_sirg_vcs_program_guidance_-epa402-b19-080.pdf I have also noted in several places where links to documents do not open.
Spreng	C1							The questions are generally clearly worded. Suggested revisions are shown in an attached file in the text edit/comment mode of Adobe Acrobat.
Spreng	C2							The responses are generally clearly worded and accurate. Suggested revisions are shown in an attached file in the text edit/comment mode of Adobe Acrobat.
Spreng	C3							The list of questions/answers seems adequate.
Spreng	D1							The calculator results are clearly displayed. A minor comment: The "time stamp" at the bottom of the output spreadsheet is Eastern Time. If the time is necessary for complete documentation of calculator runs, that should probably be noted.

MATRIX OF PEER REVIEW COMMENTS: Radon Vapor Intrusion Screening Level Calculator

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Spreng	D2							Yes, the results are appropriately described and qualified. The Home Page and User's Guide describe uncertainties and assumptions.
Spreng	D3							The best test of a calculator that tries to replicate natural phenomenon is whether it consistently produces reasonable results. Several "test runs" with various input parameters seem to produce reasonable results.
Spreng	D4							Section 1.1 states that several factors affecting the indoor Feq were omitted for "simplification". It is assumed that the "other mechanisms" may also be minor enough that they, too, could be ignored. Section 1.8 mentions research that provides data on some of these mechanisms, but this research demonstrates how difficult it is to predict Feq values because of them. It is also assumed that additional research may someday allow the effects of some of these "other mechanisms" to be included in the calculator.
Spreng	D5							No - no additional recommendations beyond those in the comments in the attached files.
Spreng	E							No - no additional recommendations beyond those in the comments in the attached files.
Spreng		Welcome	29-30					...developing SLs or PRGs for... Acronyms are already defined above. It might also be useful to distinguish between the two terms (or add a reference that explains the difference, if any). 6.5.2 Scope and Basis for Health-based, Vapor Intrusion Screening Levels EPA developed VISLs for human health protection that are generally recommended, medium-specific, risk-based screening-level concentrations intended for use in identifying areas or buildings that may warrant further investigation of the vapor intrusion pathway.
Spreng		Welcome	43					The term "outside the risk range" may be generally understood within the regulatory community, but probably ought to be explained as being "risk greater than 1×10^{-4} ".
Spreng		Welcome	47					Add a link to "Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination."
Spreng		Welcome	48					[Change "expressed in pCi/l or mrem/yr that" to] expressed in concentrations (pCi/L) or dose (mrem/yr) that
Spreng		Welcome	48					At Rocky Flats, the state dose standards were determined to be ARARs regardless of whether they were more stringent than federal (CERCLA) risk standards. Both risk and dose values were calculated. Risk values were more stringent and so became the "action levels", but the state dose standard was still an ARAR. Also, "pCi/L" is preferred over "pCi/l" in this document.
Spreng		Introduction	56					It might be useful to add a version of the purpose of SLs as written in Section 6 5.2 of the 2015 OSWER Guidance: "EPA developed VISLs for human health protection that are generally recommended, medium-specific, risk-based screening-level concentrations intended for use in identifying areas or buildings that may warrant further investigation of the vapor intrusion pathway."
Spreng		Introduction	57					[insert "as"] referred to as radon
Spreng		Introduction	59					Clicking on this link yields: "Sign in to access this site. Authorization required by https://epa-visl ornl gov". Clicking on "Cancel" takes one to the VISL calculator.
Spreng		Introduction	61					That section of the User's Guide is titled, "2.2 Groundwater Screening Level Equation". Should be Section 1.2 (?).
Spreng		Introduction	67					Change "occurred" to "began"
Spreng		Introduction	71					Suggest: "The RVISL calculator results were previously verified as documented on the Internal Verification and External Verification pages. Documentation of the peer review for the RVISL calculator is also available."
Spreng		Introduction	72					Clicking on these 3 links yields: "Sign in to access this site. Authorization required by https://epa-visl ornl gov" Clicking on CANCEL takes the user to the VISL calculator home page.
Spreng		Introduction	77					Some of the questions unnecessarily use personal pronouns: 2. "How can I change attenuation factors?" (Suggest: "How can attenuation factors be changed?")
Spreng		FAQs	81					[Replace "to solve many problems that arise from calculating and using this SL site." with "to solve problems that may arise from using this calculator."
Spreng		FAQs	87					Suggest changing sentence to:] "The main page of the calculator provides default factors, which can be changed."
Spreng		FAQs	91					I cannot find the terms, "empirically-based conservative 'generic'" or "generally reasonable worst-case conditions" described in any VI guidance. These combinations of adjectives seem somewhat redundant and confusing. Suggest using phrases from the guidance: "...target indoor air concentrations using reasonably conservative generic attenuation factors that are empirically based, as described in the EPA's 2015 vapor intrusion guidance."
Spreng		FAQs	139					A more useful title might be: "Can the calculator predict indoor air concentrations and risk from measured concentrations?" In addition to calculating SLs, the calculator allows the user to input data collected from their site using a "forward calculator" function.
Spreng		FAQs	148					This sentence seems redundant with the first sentence of the next paragraph. Could be combined.

MATRIX OF PEER REVIEW COMMENTS: Radon Vapor Intrusion Screening Level Calculator

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Spreng		FAQs	154					The H' equation is not below. The reference to the Fact Sheet is probably sufficient: "An EPA Fact Sheet describing how H' is derived when groundwater temperature is changed can be found ..." Could also refer to Section 4.1 of the User's Guide.
Spreng		FAQs	162					Change cm2 to cm3
Spreng		FAQs	165					x 10 ⁻¹⁵ (?)
Spreng		FAQs	173					Suggest rewording: "How were the UMTRCA working level (WL) standards converted to units of concentration?"
Spreng		FAQs	175					Unclear what 3 steps are being referred to here. Suggest: "This table depicts the UMTRCA WL standard converted to various units of concentration using different radon equilibrium factors."
Spreng		FAQs	176					The User's Guide only goes to Section 2.4. Should be Section 2.1.1 (?)
Spreng		FAQs	187-188					At Rocky Flats, the state dose standards were determined to be ARARs regardless of whether they were more stringent than federal (CERCLA) risk standards. Also, "pCi/L" is preferred over "pCi/" in this document.
Spreng		FAQs	210-212					Not true. The risk options listed on the calculator main page are in 10-6 superscript style. The "6.2E-02 and 7E-03" could be added parenthetically at the end of the previous sentence.
Spreng		FAQs	213					This mixes scientific notation styles.
Spreng		FAQs	220					There is no Section 2.3.1 in the RVISL User Guide.
Spreng		User's Guide		Introduction		3	1	Here would be a good place to differentiate between SLs and PRGs.
Spreng		User's Guide		1.1		1	1-3	Suggest: "...at room temperature. The criteria used to determine if a chemical is suitable for vapor intrusion analysis (see Section 1 of the VISL User's Guide) will be ignored for this RVISL calculator." With this reference, the following list of criteria could be deleted (why list factors that will be ignored?) and the first 2 paragraphs merged.
Spreng		User's Guide		1.1		2	1	Suggest: "... chemicals, these criteria are not suitable..."
Spreng		User's Guide		1.1		3	4	Suggest "disregarded" instead of "neglected".
Spreng		User's Guide		1.1		4	1	Could reference the Homepage graphic.
Spreng		User's Guide		1.1		6	4-6	Suggest: "On the other hand, further evaluation of the vapor intrusion pathway is still appropriate when sub-slab, groundwater, and soil gas samples from a building or site exceed the RVISLs."
Spreng		User's Guide		1.1		7	Bullet 2	The concept of radon vapor density resulting in downward (advective ?) transport needs to be further explained.
Spreng		User's Guide		1.1		9	1-5	Suggest: "The previously-mentioned assumptions and warnings involving attenuation factors are for generic chemicals and generally apply to radon. Users of the RIVSL calculator should also consider additional radon-specific factors that affect radon concentrations in buildings:"
Spreng		User's Guide		1.1		10	1	...concentrations... Having 2 adjacent lists of factors that influence radon concentrations seems confusing and largely redundant. Suggest combining the 2 lists.
Spreng		User's Guide		1.1		10	Bullet 1 of #4	How is this different than "Barometric pressure changes" listed under "Climate and meteorological factors"?
Spreng		User's Guide		1.1		10	Bullet 3 of #4	Ventilation (air exchange rates)
Spreng		User's Guide		1.2		3	3	The abbreviated forms (e.g., Rn-219) are used elsewhere.
Spreng		User's Guide		1.3.1		1		This link (and some others referenced on this site) cannot be reached on my non-government computer. The error message states that the computer is correctly configured, but the "resource (EPA-visl.ornl.gov) is not responding."
Spreng		User's Guide		1.4		1	#2	...Antoine Equation: logP =A(B/C + T). ???
Spreng		User's Guide		1.7		1	4-5	It might be worth mentioning that EPA participates in the radon industry-led ANSI/AARST voluntary consensus-based standards "EPA Guidance on the Use of Voluntary Consensus Standards for State Indoor Radon Grant Recipients." https://www.epa.gov/sites/production/files/2019-08/documents/august_2019_sirg_vcs_program_guidance_epa402-b19-080.pdf
Spreng		User's Guide		1.8		1	7	This link [to RAGS Part A] does not open.
Spreng		User's Guide		2		1	2	The term "compliance levels" should be explained in relation to the term "screening levels" in this sentence.
Spreng		User's Guide		2		1	3	Source-specific equations seems more appropriate than "land use equations."
Spreng		User's Guide		2		1	8	[Rephrase to:] Both the RVISL and the VISL calculators follow...
Spreng		User's Guide		2.4		1	4	...air screening level (see Section 2.1)...
Spreng		User's Guide		2.4		1	5	[Rephrase to:] "To make this comparison, no equations are necessary..."
Spreng		User's Guide		3		1	3	The term "compliance levels" should be explained in relation to the term "screening levels" in this sentence.
Spreng		User's Guide		3		1	3	Source-specific equations seems more appropriate than "land use equations."
Spreng		User's Guide		3		1	9	[Rephrase to:] "Both this calculator and the VISL calculator follow..."
Spreng		User's Guide		4.2		1	15	Deposition on surfaces is among the conditions described in Section 1.1.
Spreng		User's Guide		4.3		1	4	Deposition on surfaces is among the conditions described in Section 1.1.

MATRIX OF PEER REVIEW COMMENTS: Radon Vapor Intrusion Screening Level Calculator

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Spreng		User's Guide		4.4	1	12-18		These sentences could be combined to avoid the redundancy. If the "more detailed papers" mentioned in the first sentence are the 2 referred to in the last 2 sentences, then the first sentence could simply be deleted. The second sentence could begin: "Air exchange rates can be measured..." The links to the documents do not work (at least on non-government computers).
Spreng		User's Guide		5				Change multiple references to 2 5°C to 25°C
Spreng		User's Guide		6			Ref 10	Most of the links to EPA documents cannot be opened.
Williams	A1							<p><u>Is the website clearly organized, described, easy to navigate, and generally "user friendly" and appropriate for the target audience?</u></p> <p>The welcome section provides good information but it needs to be simplified with similar topics moved together. When the website is final the links will make it easy to navigate and user friendly, but they currently are not pointing to the right documents. Theinfo contained is appropriate, but it is hard to absorb as some of the thoughts are broken apart.</p> <p>Also there needs to be some care as the document uses alot of the information in the VISL for the RVISL and it sometimes is not clear that the concepts and science used in the development of the RVISLs is based in part on the work and concepts utilized in the VISL. It is also not clear if teh RVISL will be completely different than the VISL or if it will be incorporated into it</p> <p><u>If not, what do you recommend?</u></p> <p>Breaking apart some of the longer paragraphs and keeping some of the similar info and thoughts together. Also providing some basic infomration on the infomration that is being applied from the VISL in a unique chapter that describes vapor intrusion in general and then how radon vapor intrusion is similar.</p>
Williams	A2							<p><u>Have the objectives of the RVISL calculator, as stated in the documentation, been met?</u></p> <p>The objectives should be more clearly and simply stated so it is hard to understand if they have been met.</p> <p><u>If not, what do you recommend?</u></p> <p>Clearly state what the objective is. It appears that besides the calculator that there is another goal to provide updated guidance on how to develop screening values. There might be others.</p>
Williams	A3							<p><u>Do you recommend any modifications to the Homepage graphic?</u></p> <p>Understanding that that CVI and PVI behaves similarly to radon VI, it might be more appropriate to develop a specific graphic for RVI or instead of using it as a RVI graphic use the graphic as a more general representation of VI in general. would recommend using the graphic on Page 14 and 18 of the UseGguide or a similar one/color scheme.</p>
Williams	A4							<p><u>Do you have any other recommendations to improve the usability of the website?</u></p> <p>I think as radon is using a lot of the similar concepts of VI and that web page that there is some additions to that web page that point a user to the radon VI web page.</p>
Williams	B1							<p><u>Does the User's Guide adequately explain the concepts addressed by the calculator and its limitations?</u></p> <p>No. If it does, the chapter titles do not make it clear on where a person would go to even find it. The chapter section titles (e.g., 1. Understanding the RVISL Website and 2. Radon Vapor Intrusion Screening Level Equations) do not point to where the information can be found for a user. It does discuss how radon concentration are influenced but it does not appear to describe how the calculator addresses it.</p>
Williams	B2							<p><u>Are the assumptions clear and reasonable? If not, what do you recommend?</u></p> <p>The assumptions should be provided under a single section of the report.</p>
Williams	B3							<p><u>Are the sources and citations appropriate, and do they represent the current state of knowledge?</u></p> <p>Based on my understanding of the VISL the references seem applicable.</p>
Williams	C1							<p><u>Are the 11 questions clearly worded? If not, what do you recommend?</u></p> <p>Q2 - Doesn't really tell the user how "To change the attenuation factors." There is alot of info here that is not related to the specific question. Recommend that the question is answered with additional detail and the rest is removed or moved to a different FAQ if the developer feels that it is important.</p> <p>Q5 - The first paragraph answers the question. The second paragraph should be moved to a unique FAQ</p>
Williams	C2							<p><u>Are the 11 responses clear, concise, and accurate? If not, what do you recommend?</u></p> <p>The recommendations are provided under charge question C1</p>

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Williams	C3							<u>Are there other helpful questions and answers that should be added? If yes please list the questions.</u> Recommendations include breaking questions Q2 and Q5 into 2 different questions.
Williams	D1							<u>Are the results clearly explained and presented? If not what do you recommend?</u> Yes
Williams	D2							<u>Are the results appropriately described and qualified (to the extent that they may be relied upon and defended)? If not what do you recommend?</u> Yes
Williams	D3							<u>Do the results provide defensible explanation of how they were derived, or are they the result of a "black box?" Do you recommend anything different?</u> They are a black box. It is however, a calculator. Possibly put some type of note or link where the explanations can be found.
Williams	D4							<u>RVISL calculation of the equilibrium level (Feg) of radon progeny that would be present in indoor air is based on air exchange rate. Should other mechanisms (seasonal atmospheric changes building construction surface plating aerosol sizes regional geology air flow) be incorporated in the calculation?</u> I would make this modification, but as a higher level site-specific calculator as most users will not have that information.
Williams		Welcome					General Comment	My background is in chemical vapor intrusion (PVI and CVI) and naturally occurring radon. It took several times reading the title and then the introduction to sort out that the radon that being discussed is from radionuclide contamination and not naturally occurring radon or from chemical vapor intrusion, especially as the figure you are using is the exact same figure that was generated for chemical vapor intrusion and the links take you to the VISL vs the RVISL. I would recommend making the title more specific and/or adding some type of call-out box so that when someone hits the homepage that it is clearer what type of vapor intrusion they are dealing with.
Williams		Welcome	1				Figure	Recommend that a figure for RVISL be different then what is used for the chemical VISL similar to the figures in the user guide
Williams		Welcome	1				Figure	Figure did not appear correctly on the website and only was observable on the supplied PDF
Williams		Welcome	1				Figure	This figure is typically associated with chemical vapor intrusion. I would recommend that you change the language so that it states: This figure depicts the migration of radon from radionuclide contaminants in soil gas from contaminated soil and groundwater into buildings. Radon in soil gas from radionuclide contaminants is shown to enter buildings through cracks in the foundation and openings for utility lines similar to other forms of contamination. Atmospheric conditions and building ventilation are shown to influence radon soil gas intrusion.
Williams		Welcome	1				Figure	Recommend that you do not start with the figure. Move the figure down.
Williams		Welcome	2				Figure caption	Insert: "from radionuclide contaminants" after radon
Williams		Welcome	20-23				Links	the Preliminary Remediation Goals link takes you to the right page but the "What's New", "User's Guide", "Frequently Asked Questions" and "Fact Sheet" links do not.
Williams		Welcome					Green callout box	All links in the green box titled "Radon Vapor Intrusion Screening Levels (RVISL)" actually takes you to the EPA's VISL (https://www.epa.gov/vaporintrusion/vapor-intrusion-screening-level-calculator) and not the radon-VISL page. Apparently this was a caching issue which may be a problem for others.
Williams		Welcome	29-49					Recommend the 2nd and 3rd paragraph be moved from the Welcome and into the Introduction
Williams		Welcome	12-14					Note similar to "Note that for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial actions, dose assessment is generally done only to show compliance with a dose-based Applicable or Relevant and Appropriate Requirement (ARAR)." should be in a call out box.
Williams		Overview		Call out box			Green callout box	Recommend that the first paragraph be broken apart to make it easier to read
Williams		Welcome	29-30					"The RVISL calculator provides updated guidance for developing screening levels (SLs) or preliminary remediation goals (PRGs)" is technically not correct. The website is providing the updated guidance and the calc is providing calculated cleanup values.
Williams		Introduction	57-62					This paragraph seems out of place.
Williams		Introduction	59					The chain link in the "Click the decay chain link" should be a link to where you want the user to go.

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Commenter	Charge Question No.	Document	Line No. (Home Page and FAQs only)	Section No. (User's Guide only)	Paragraph	Line	Other Descriptor	Comment
Williams		Introduction	59-62					"Click the decay chain link to see the decay series for Rn-222, Rn-220, and Rn-219. The metal groups in these images are based on Los Alamos National Laboratory literature. See section 2.2 of the User's Guide to learn what progeny are evaluated in this web calculator. More details about the decay chains can be found in the EPA's Decay Chain Tool." This is an example where there appears to be the same though separated by a different one. "Click the decay chain link to see the decay series for Rn-222, Rn-220, and Rn-219." AND "More details about the decay chains can be found in the EPA's Decay Chain Tool." is the same thought and could be combined and the other sentence "See section 2.2 of the User's Guide to learn what progeny are evaluated in this web calculator." can be moved to the end.
Williams		Introduction	71-73					Links go to the wrong page
Williams		FAQs	82				Question 1	It should be made clear that this
Williams		User's Guide		Introduction	3	1		It should be made clear that the RVISL calculator doesn't provide the updated guidance, the user guide does.
Williams		User's Guide		Introduction	2	7-9		I would break the following into a callout box to emphasize: "Note that for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial actions, dose assessment is generally done only to show compliance with adose based Applicable or Relevant and Appropriate Requirement (ARAR)."
Williams		User's Guide		Introduction	3	4-7		This seems to be pretty important and should be called out or emphasized by making only this statement bold: "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.
Williams		User's Guide					General Comment	There should be some description and overview of each section that is in the user's guide
Williams		User's Guide		1.1	6	1		This section identifies specific factors that may render the use of the values inappropriate, but it should also provide direction on what to do and that the values should not be used.
Williams		User's Guide		1.1	9	4-5		It would seem that the concentration of radon (in vapor though not specific) in a building also depends on the distance of the vapor source to the building.
Williams		User's Guide		1 3	1			This statement is important and should be moved to the beginning of the document as well "EPA classifies all radionuclides as Group A carcinogens ("carcinogenic to humans"). Group A classification is used only when there is sufficient evidence from epidemiologic studies to support a causal association between exposure to the agents and cancer. The following sections discuss the sources of inhalation and external exposure via submersion in gas cloud SFs and DCFs used in this cal..."
Williams		User's Guide		1.5.2				Is the "One-Hit Rule" a specific rule or just a "concept" Further explanation is warranted.
Williams		User's Guide		2	1	1		Section 2. Radon Vapor Intrusion Screening Level Equations states: This section presents the screening levels for human exposure to contaminated air. This is not correct. This section provides the equations that are used in the RVISL (but also in combination with Sections 3 and 4 as well. The equations and technical discussion are aimed at developing compliance levels for risk-based and dose-based RVISLs.
Williams		User's Guide		2.1.1			Figure	It appears that the "graphical representation" is alligned with a conceptual site model. Conceptual site model is the term that is used in the VISL and in discussion VI it should be
Williams		User's Guide		2.1.1			Figure	Recommended to use this graphic as part of the overview along with the figure in 2.1.2
Williams		User's Guide		2.1.2			Figure	It appears that the "graphical representation" is alligned with a conceptual site model. Conceptual site model is the term that is used in the VISL and in discussion VI it should be
Williams		User's Guide		2				Recommended to use this graphic as part of the overview along with the figure in 2.1.1
Williams		User's Guide		3				Sections 2, 3, 4 are all equations and should be placed in a single chapter for ease of dscussion
Williams		User's Guide		4				Sections 2, 3, 4 are all equations and should be placed in a single chapter for ease of dscussion
Williams		User's Guide		4 2	1	1-3		Air Exchange Rates is described differently then what is presented in EPA's VISL documentation and should be alligned with that definition
Williams		User's Guide		4 2	1	4-6		Inhalation Fractional Equilibrium Factor is unique to radon and it should be emphasized that it is different then chemical VI and how it impacts the calculated results
Williams		User's Guide		4.4				The collection of ACH should also be descrbed to the user it the calc will allow an inputed value and where it place it
Williams		User's Guide					General Comment	There should be some screen shots of the actual input screen with a description of what inputs are placed in each section.
Williams		User's Guide		5				Some of the input values are not specifically input paramters so a more generic term would be appropaite

MATRIX OF PEER REVIEW COMMENTS: Radon Vapor Intrusion Screening Level Calculator

Notes: [Brackets in comments comprised additional explanation inserted by the peer review contractor]

Yellow highlighting is used to indicate responses to charge questions. The table can be sorted by color in column B to show only these responses.

Commenter	Charge Question No.	Document	Line No. (Home Page and FAQs only)	Section No. (User's Guide only)	Paragraph	Line	Other Descriptor	Comment
Williams		Welcome	6-28					<p>Recommend the first paragraph be broken apart as follows for clarity:</p> <p>Welcome to the "Radon Vapor Intrusion Screening Level (RVISL) Calculator Home Page for Radionuclide Contaminants at Superfund Sites". This website was developed with DOE's Oak Ridge National Laboratory (ORNL) under an Interagency Agreement with the U.S. Environmental Protection Agency (EPA).</p> <p>The RVISL website is now the generally recommended source of radon screening levels for all 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 unified use of the RVISLs to screen radon at Superfund sites promotes national consistency. The RVISL uses the same database of toxicity values, chemical parameters, and inhalation exposure equations as the Preliminary Remediation Goals (PRGs) for Radionuclide Contaminants at Superfund Sites calculator.</p> <p>Note that for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial actions, dose assessment is generally done only to show compliance with a dose-based Applicable or Relevant and Appropriate Requirement (ARAR).</p> <p>The RVISL calculator provides default parameters that can be modified to reflect site-specific risks. 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. If the calculator is used with non-default inputs in a decision on a Superfund site, it is recommended that the inputs be clearly identified and justified by the user.</p> <p>To ensure proper use of the calculator, please review the What's New, User's Guide, and Frequently Asked Questions links.</p> <p>The EPA has prepared a fact sheet for the general public that describes RVISL uses, RVISL calculator operation, and land uses available for assessment. Additionally, this fact sheet describes the RVISL content in greater detail for EPA staff.</p>
Williams		User's Guide		Introduction	3	4		What the RVISL supersedes is an important concept that should be moved to a callout box to provided added emphasis

Dr. Rodolfo Avila
AF Consult AB, Sweden



Rodolfo Avila, Ph.D

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Dr. Avila is a senior consultant with 35 years experience in the nuclear field, specialized in radiological protection and safety. He has a large international experience and has been regularly working as IAEA consultant in projects dedicated to improving radiation safety worldwide. Dr. Avila was the founder and director of Facilia AB that since 2018 has been integrated with AFRY.

WORK EXPERIENCE

AF CONSULT AB, Sweden

Section head

June 2018 – Present

Head of Section. Consultancy work for regulators, industry and international organizations in various countries. Mainly concerning safety assessment of nuclear and radioactive waste management facilities, NORM and legacy sites.

FACILIA AB, Sweden

Technical Director

January 2001 – June 2018

Founder and director of the company. Consultancy work for regulators, industry and international organizations in various countries. Mainly concerning safety assessment of nuclear and radioactive waste management facilities.

SWEDISH RADIATION SAFETY AUTHORITY, Sweden

Senior Researcher

January 1996 – December 2000

Senior researcher at the environmental protection and waste management department. Participated in projects dedicated to development of methods and software for safety assessment of nuclear facilities and radioactive waste repositories, as well as to regulatory review of license applications submitted by operators. He was also involved in the development of regulations and regulatory guides.

RADIATION PROTECTION INSTITUTE, Cuba

Head of Department

January 1985 – November 1994

Head of the department of environmental protection and waste management and the radiological laboratory of the nuclear power plant that was under construction. Was responsible for the safety assessment and environmental surveillance program around the nuclear installations that were under construction at that time in Cuba: a nuclear research reactor (VVER type), a nuclear power plant and an isotopes production plant.

QUALIFICATIONS

Uppsala University, Sweden

Doctorate 1998

Major: Radioecology

Zhdanov University, Leningrad, Soviet Union

Master's Degree 1985

Major: Radiochemistry

Languages:

Russian – fluent

English – fluent

Swedish – fluent

Spanish – mother tongue

RELEVANT EXPERIENCE

Dr, Rodolfo Avila has more than 35 years of experience in the Nuclear field. Since 1985 he has been working in the areas of safety assessment of nuclear installations, radiation protection and radioactive waste management.

Since 2007 he has been participating in international projects dedicated to safety assessment and environmental impact assessments of NORM and legacy sites. He has been key expert in safety assessments in several projects funded by the EC dedicated to management and remediation of NORM and legacy sites.

He was the leader of the NORM and Legacy Sites Working Group of the IAEA MODARIA project. Within this project, he led several studies of the impacts from discharges to the environments from NORM and legacy sites in different countries.

He is the main developer of NORMALYSA – a tool distributed freely by IAEA for assessment of radiological impacts to the environment from NORM industries and legacy sites. NORMALYSA supports assessment of radiological impacts on humans and the environment of discharges to the atmosphere, groundwaters and surface waters from NORM industries, NORM residuals and sites contaminated with NORM.

EXAMPLES OF RELEVANT PROJECTS FOR THIS ASSIGNMENT

Derivation of specific clearance levels in materials being suitable recycling, reuse, or for disposal in landfills (2017-2019). IAEA project.

Developed the models for derivation of specific clearance levels of radionuclides in materials suitable for recycling, reuse, or disposal in landfills. The materials considered include residuals from different types of NORM industries. The models account for the enrichment of radionuclides during technological processes and estimation of radionuclide discharges to the environment. The models were implemented in a software tool that will be distributed by the IAEA. The tool was applied for derivation of generic specific clearance levels that will be published in 2020 as an IAEA TECDOC.

Development of NORMALYSA (2014-2017). IAEA project.

Development of the NORMALYSA Tool for radiological environmental impact assessment of NORM and legacy sites. NORMALYSA supports assessment of radiological impacts on humans and the environment of discharges to the atmosphere, groundwaters and surface waters from NORM industries, NORM residuals and sites contaminated with NORM. Within the project the tool was applied in several countries

for assessments of impacts from NORM industries and sites contaminated with NORM.

**Development of the method (strategy, technology) for the remediation activities at the former uranium facility Pridneprovskiy Chemical Plant (2014-2016)
EC Project (EuropeAid/134871/C/SER/UA)**

The Pridneprovskiy Chemical Plant (Ukraine) was the largest uranium processing facility in the former Soviet Union. The plant hosted several NORM industries, such as Zirconium production. The plant was abandoned after the fall of the Soviet Union becoming a legacy site with a large amount of NORM residual and contaminated territories and buildings. The goal of the project was to develop a strategy and propose technologies for remediation of the site. This included characterization of the residuals and the discharges and proposing approaches for their safe management. The work also included the development of regulations for management of the NORM legacy site since these were not available in the country.

Development of a design and safety assessment of the management of NORM waste in the United Arab Emirates (2015-2017). Project commissioned by Takreer.

The project was dedicated to estimation of the amounts of radioactive waste generated by NORM industries of the UAE, proposing technologies for predisposal management of the radioactive waste and the final disposal. All required waste management facilities, including the final repository, were designed, and licensed by the national regulator. The main role of Rodolfo Avila in the project was to carry out the estimation of the radioactive waste inventory and characteristics and perform safety assessments of the radioactive waste management facilities and activities.

Conducting an integrated environmental impact assessment and feasibility study for the management and remediation of uranium production legacy sites of Charkesar and Yangiabad in Uzbekistan (2014-2015). EC project. (UZ4.01/109).

R. Avila was responsible for the Task 4 dedicated to the safety and risk assessments for the two sites. The contribution led to development of plans for decontamination, decommissioning, remediation, and radioactive waste management in line with international standards, best practices, and national regulations. Under the project, R. Avila worked closely with both operators and regulators to ensure the safe characterization of sites, evaluation of potential impacts on public and the environment, licensing of facilities and activities, regulatory review, and appropriate management options for the resulting waste, including clearance options.

Peer Reviewer Conflict of Interest Certification

Peer Review: **Draft Radon Vapor Intrusion Screening Level Calculator (RIVSL)**

A conflict of interest or lack of impartiality exists when the proposed peer reviewer personally (or the peer reviewer's immediate family), or his or her employer, has financial interests that may be affected by the results of the peer review; or may provide an unfair competitive advantage to the peer reviewer (or employer); or if the peer reviewer's objectivity in performing the peer review may be impaired due to other factors. When the Peer Reviewer knows that a reasonable person with knowledge of the facts may question the peer reviewer'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 RIVSL calculator (and associated webpages) under peer review, 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 peer review, or any reason that your impartiality in the matter might be questioned? No Yes
- Have you had any previous involvement with the RIVSL 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 peer review, 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 peer review? 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 peer review:

- a. Peer Reviewer 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 Peer Reviewer has disclosed all such relevant information to EMS or to EPA.
- b. Peer Reviewer agrees that if an actual, apparent, or potential personal or organizational conflict of interest is identified during performance of this peer review, he/she immediately will make a full disclosure in writing to EMS. This disclosure shall include a description of actions that Peer Reviewer (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. Peer Reviewer shall continue performance until notified by EMS of any contrary action to be taken.



2020-09-26

Check here if any explanation is attached

Signature

Date

Rodolfo Avila

Printed Name

AFRY

Affiliation/Organization

Charge Questions (Avila):

A. Homepage and Overall Website

1. Is the website clearly organized, described, easy to navigate, and generally “user friendly” and appropriate for the target audience? If not, what do you recommend?

Yes, I think the website is clearly organized, easy to navigate, generally “user friendly” and appropriate to the target audience.

The text in the home page is too long and could be improved. I provide suggestions in the attached pdf (RVISL Home Page and FAQs)_Avila).

2. Have the objectives of the RVISL calculator, as stated in the documentation, been met? If not, what do you recommend?

Yes, the objectives have been met.

3. Do you recommend any modifications to the Homepage graphic?

None.

4. Do you have any other recommendations to improve the usability of the website?

I would add a link to a Glossary page. This can be added to the existing list of links in the Home Page.

B. User’s Guide

1. Does the User’s Guide adequately explain the concepts addressed by the calculator and its limitations?

The User’s Guide adequately explains the concepts and their limitations. I have included some comments in the attached pdf.

2. Are the assumptions clear and reasonable? If not, what do you recommend?

The assumptions are clear and reasonable. I have added some comments to the assumptions in the attached pdf.

3. Are the sources and citations appropriate, and do they represent the current state of knowledge? If not, what do you recommend?

The sources and citations cover well the US literature, but it would be good to add references to sources from other countries and international organizations.

C. Frequent Asked Questions

1. Are the 11 questions clearly worded? If not, what do you recommend?

The questions are generally clearly stated. I proposed some changes in the wording of questions 3, 4, 7 and 8, see the attached pdf (RVISL Home Page and FAQs)_Avila).

2. Are the 11 responses clear, concise, and accurate? If not, what do you recommend?

Some of the answers are not concise and accurate. I proposed some changes in the attached pdf (RVISL Home Page and FAQs)_Avila). In particular, the answer that is provided to question 8 is not adequate.

3. Are there other helpful questions and answers that should be added? If yes, please list the questions.

One helpful question could be: How do deal with situations where more than one Radon isotope, for example Rn-220 and Rn-222, is present?

D. Calculator

1. Are the results clearly explained and presented? If not, what do you recommend?

The results are clearly presented, but not explained. There are explanations in the User's Guide, but it is not obvious where exactly in the Guide each particular result is to be found.

One solution could be that each result column points to the corresponding equation listed in the Calculator and/or the User's Guide. This might require that the Equations be numbered.

Another alternative would be to provide a footnote to the Table of results, where each result included is listed with a short description and references to the User's Guide.

The above shortcoming is illustrated in the attached pdf (Resident_rad_rvisl_results), which presents the results generated by the Calculator for the screening levels of Dose-Type; using default parameter values. It is not obvious what the results presented in the columns **Inhalation RVISL**, **Submersion RVISL** and **Target Indoor Air Concentration** and the terms used in the User's Guide for these results are somewhat different. In the same pdf, I have also added some comments to the table of results.

2. Are the results appropriately described and qualified (to the extent that they may be relied upon and defended)? If not, what do you recommend?

The results are mostly appropriated described and qualified in the User's Guide. It is stated in the User's Guide that results obtained using default parameter values correspond to the Reasonable Maximum Exposure (RME), since conservative values are selected as defaults. However, it is not always demonstrated that the chosen default values are conservative. An example is the Attenuation Factor as explained in the comments to the User's Guide (see attached pdf).

4. Do the results provide defensible explanation of how they were derived, or are they the result of a "black box?" Do you recommend anything different?

Sufficient explanations of how the results were derived are provided in the User's Guide.

5. RVISL calculation of the equilibrium level (F_{eq}) of radon progeny that would be present in indoor air is based on air exchange rate. Should other mechanisms (seasonal atmospheric changes, building construction, surface plating, aerosol sizes, regional geology, air flow) be incorporated in the calculation?

In my opinion this is not required for screening assessments which is the intention with the RVISL. If such mechanisms are considered, it would be anyway difficult to estimate generic default parameter values, without unduly overestimation of the RVISL.

6. Is there anything else you recommend for the calculator to improve it for its stated purpose?

The use of several conservative parameters in the same equation, might lead to over conservative estimates. This is a result of multiplication of errors. For example, if several parameters in an equation are multiplied with each other and a low probability value (like a 95 percentile) is given to each parameter; then the probability of the obtained result might be extremely low. One possible approach to overcome this, would be to perform calculations using central values for the parameters and apply an uncertainty factor to the results, so that the screening value is set at a reasonable percentile (like the 95 percentile).

E. Anything Else?

Is there anything else you would recommend to improve the RVISL calculator's utility, accuracy, completeness, or supportability?

Nothing more comes to my mind right now.

Resident Equation Inputs

Variable	Resident Air Default Value	Form-input Value
AF_{rw} (Attenuation Factor Groundwater) unitless	0.001	0.001
AF_{sc} (Attenuation Factor Sub-Slab) unitless	0.03	0.03
ED_{rao} (exposure duration) years	26	26
EF_{rac} (exposure frequency) days/year	350	350
ET_{rac} (exposure time) hours/day	24	24
T_{gw} (groundwater temperature) Celsius	25	25

Resident Individual Progeny Contributions for Air

Isotope	Inhalation DCF (mrem/pCi)	External Exposure DCF (Submersion) (mrem/yr per pCi/m ³)	Lambda (1/yr)	Halflife (yr)	0.18 exchanges per hour A _{eq} (unitless)	0.18 exchanges per hour F _{eq} (unitless)	HLC (atm-m ³ /mole)	Henry's Law Constant (unitless)	Henry's Law Constant Used in Calcs (unitless)
<i>A_m-based RVISL for Rn-219</i>									
Bi-211	0.00E+00	3.87E+02	1.70E+05	4.07E-06	8.57E-01	-	-	-	-
Pb-211	5.03E-05	6.01E+02	1.01E+04	6.87E-05	8.65E-01	-	-	-	-
Po-211	0.00E+00	6.97E+01	4.24E+07	1.64E-08	2.40E-03	-	-	-	-
Po-215	0.00E+00	1.46E+00	1.23E+10	5.65E-11	1.00E+00	-	-	-	-
Rn-219	0.00E+00	4.78E+02	5.52E+06	1.26E-07	1.00E+00	8.57E-01	1.06E-01	4.34E+00	4.34E+00
Tl-207	0.00E+00	8.61E+01	7.64E+04	9.08E-06	8.37E-01	-	-	-	-
<i>A_m-based RVISL for Rn-220</i>									
Bi-212	6.11E-05	9.66E+02	6.02E+03	1.15E-04	2.11E-01	-	-	-	-
Pb-212	3.89E-04	1.14E+03	5.71E+02	1.21E-03	2.66E-01	-	-	-	-
Po-212	0.00E+00	0.00E+00	7.31E+13	9.48E-15	1.35E-01	-	-	-	-
Po-216	0.00E+00	1.31E-01	1.51E+08	4.60E-09	1.00E+00	-	-	-	-
Rn-220	8.18E-07	5.25E+00	3.93E+05	1.76E-06	1.00E+00	2.11E-01	1.06E-01	4.34E+00	4.34E+00
Tl-208	0.00E+00	3.14E+04	1.19E+05	5.81E-06	7.46E-02	-	-	-	-
<i>A_m-based RVISL for Rn-222</i>									
At-218	0.00E+00	1.83E-01	1.46E+07	4.76E-08	1.97E-04	-	-	-	-
Bi-210	5.40E-04	4.82E+01	5.05E+01	1.37E-02	0.00E+00	-	-	-	-
Bi-214	3.66E-05	1.33E+04	1.83E+04	3.79E-05	8.14E-01	-	-	-	-
Hg-206	0.00E+00	1.04E+03	4.47E+04	1.55E-05	0.00E+00	-	-	-	-
Pb-210	2.23E-02	8.80E+00	3.12E-02	2.22E+01	0.00E+00	-	-	-	-
Pb-214	4.66E-05	2.07E+03	1.36E+04	5.10E-05	8.84E-01	-	-	-	-
Po-210	1.73E-02	8.31E-02	1.83E+00	3.79E-01	0.00E+00	-	-	-	-
Po-214	0.00E+00	7.10E-01	1.33E+11	5.21E-12	8.14E-01	-	-	-	-
Po-218	7.62E-06	4.89E-04	1.17E+05	5.90E-06	9.87E-01	-	-	-	-
Rn-218	0.00E+00	6.35E+00	6.24E+08	1.11E-09	1.97E-07	-	-	-	-
Rn-222	6.55E-06	3.23E+00	6.62E+01	1.05E-02	1.00E+00	8.90E-01	1.06E-01	4.34E+00	4.34E+00

Resident Individual Progeny Contributions for Air

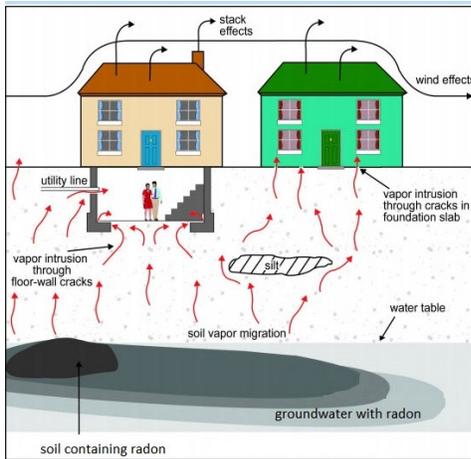
Isotope	Inhalation	Submersion	Target	Target	Target	Target	Target
	RVISL	RVISL	Indoor Air	Indoor Air	Sub-Slab and	Sub-Slab and	Groundwater
	(pCi/m ³)	(pCi/m ³)	Concentration	Concentration	Exterior Soil	Exterior Soil	Concentration
	TDL=1	TDL=1	Concentration	Concentration	Gas	Gas	
	(pCi/m ³)	(pCi/m ³)	C _{ia}	C _{ia}	Concentration	Concentration	(pCi/L)
			(pCi/m ³)	(pCi/L)	(pCi/m ³)	(pCi/L)	(pCi/L)
<i>A_u-based RVISL for Rn-219</i>	3.71E+00	7.43E-04	7.43E-04	7.43E-07	2.48E-02	2.48E-05	1.71E-04
Bi-211	-	3.15E-03	3.15E-03	3.15E-06	-	-	-
Pb-211	3.71E+00	2.00E-03	2.00E-03	2.00E-06	-	-	-
Po-211	-	6.24E+00	6.24E+00	6.24E-03	-	-	-
Po-215	-	7.16E-01	7.16E-01	7.16E-04	-	-	-
Rn-219	-	2.18E-03	2.18E-03	2.18E-06	-	-	-
Tl-207	-	1.45E-02	1.45E-02	1.45E-05	-	-	-
<i>A_u-based RVISL for Rn-220</i>	1.38E+00	3.66E-04	3.65E-04	3.65E-07	1.22E-02	1.22E-05	8.42E-05
Bi-212	1.25E+01	5.13E-03	5.13E-03	5.13E-06	-	-	-
Pb-212	1.56E+00	3.44E-03	3.43E-03	3.43E-06	-	-	-
Po-212	-	-	-	-	-	-	-
Po-216	-	7.98E+00	7.98E+00	7.98E-03	-	-	-
Rn-220	1.97E+02	1.99E-01	1.98E-01	1.98E-04	-	-	-
Tl-208	-	4.45E-04	4.45E-04	4.45E-07	-	-	-
<i>A_u-based RVISL for Rn-222</i>	1.90E+00	8.24E-05	8.24E-05	8.24E-08	2.75E-03	2.75E-06	1.90E-05
At-218	-	2.89E+04	2.89E+04	2.89E+01	-	-	-
Bi-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-
Bi-214	5.42E+00	9.64E-05	9.64E-05	9.64E-08	-	-	-
Hg-206	-	0.00E+00	0.00E+00	0.00E+00	-	-	-
Pb-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-
Pb-214	3.92E+00	5.69E-04	5.69E-04	5.69E-07	-	-	-
Po-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	-	-
Po-214	-	1.80E+00	1.80E+00	1.80E-03	-	-	-
Po-218	2.15E+01	2.16E+03	2.13E+01	2.13E-02	-	-	-
Rn-218	-	8.32E+05	8.32E+05	8.32E+02	-	-	-
Rn-222	2.46E+01	3.23E-01	3.19E-01	3.19E-04	-	-	-

Resident Individual Progeny Contributions for Air

Isotope	Inhalation DCF (mrem/pCi)	External Exposure DCF (Submersion) (mrem/yr per pCi/m ³)	Lambda (1/yr)	Half-life (yr)	0.18 exchanges per hour A _{eq} (unitless)	0.18 exchanges per hour F _{eq} (unitless)	HLC (atm-m ³ /mole)	Henry's Law Constant (unitless)	Henry's Law Constant Used in Calcs (unitless)
TI-206	0.00E+00	7.42E+01	8.67E+04	7.99E-06	0.00E+00	-	-	-	-
TI-210	0.00E+00	2.47E+04	2.80E+05	2.47E-06	1.70E-04	-	-	-	-

Resident Individual Progeny Contributions for Air

Isotope	Inhalation RVISL (pCi/m ³)	Submersion RVISL	Target Indoor Air Concentration C _{ia}	Target Indoor Air Concentration C _{ia}	Target Sub-Slab and Exterior Soil Gas Concentration	Target Sub-Slab and Exterior Soil Gas Concentration	Target Groundwater Concentration
	TDL=1	TDL=1	TDL=1	TDL=1	TDL=1	TDL=1	TDL=1
	(pCi/m ³)	(pCi/m ³)	(pCi/m ³)	(pCi/L)	(pCi/m ³)	(pCi/L)	(pCi/L)
TI-206	-	0.00E+00	0.00E+00	0.00E+00	-	-	-
TI-210	-	2.49E-01	2.49E-01	2.49E-04	-	-	-



1

2 **Figure caption:** This figure depicts the migration of radon in soil gas from contaminated soil and groundwater
 3 into buildings. Radon in soil gas is shown to enter buildings through cracks in the foundation and openings for
 4 utility lines. Atmospheric conditions and building ventilation are shown to influence radon soil gas intrusion.

5 Welcome

6 Welcome to the "Radon Vapor Intrusion Screening Level (RVISL) Calculator Home Page for
 7 Radionuclide Contaminants at Superfund Sites". This website was developed with DOE's Oak
 8 Ridge National Laboratory (ORNL) under an Interagency Agreement with the U.S. Environmental
 9 Protection Agency (EPA). The RVISL website is now the generally recommended source of radon
 10 screening levels for all EPA regions. The RVISL calculator output provides comparison values and
 11 risk and dose estimates for residential and commercial/industrial exposures to radon in soil gas,
 12 air, and groundwater. Note that for Comprehensive Environmental Response, Compensation, and
 13 Liability Act (CERCLA) remedial actions, dose assessment is generally done only to show
 14 compliance with a dose-based Applicable or Relevant and Appropriate Requirement (ARAR). In
 15 addition, the calculator presents the option to compare the indoor air concentration, entered by
 16 the user or derived from groundwater or soil gas activities, to state standards or Uranium Mill
 17 Tailings Radiation Control Act (UMTRCA) standards, which also may be potential ARARs. The
 18 unified use of the RVISLs to screen radon at Superfund sites promotes national consistency. The
 19 RVISL uses the same database of toxicity values, chemical parameters, and inhalation exposure
 20 equations as the [Preliminary Remediation Goals \(PRGs\)](#) for Radionuclide Contaminants at
 21 Superfund Sites calculator. The RVISL calculator provides default parameters that can be
 22 modified to reflect site-specific risks. To ensure proper use of the calculator, please review
 23 the [What's New](#), [User's Guide](#), and [Frequently Asked Questions](#) links. The EPA has prepared a [fact](#)
 24 [sheet](#) for the general public that describes RVISL uses, RVISL calculator operation, and land uses
 25 available for assessment. Additionally, this [fact sheet](#) describes the RVISL content in greater detail
 26 for EPA staff. Below is a general description of screening levels for radon. If the calculator is used
 27 with non-default inputs in a decision on a Superfund site, it is recommended that the inputs be
 28 clearly identified and justified by the user.

29 The RVISL calculator provides updated guidance for developing screening levels (SLs) or
 30 preliminary remediation goals (PRGs) for indoor radon-222, radon-220, and radon-219 that are

31 risk- or dose-based and for showing compliance with the UMTRCA indoor radon standards for
32 radon-222 and radon-220. The RVISL, therefore, supersedes the risk assessment approach in
33 Preliminary Remediation Goals for Radionuclides in Buildings ([BPRG](#)) electronic calculator, the
34 dose assessment approach in ARAR Dose Compliance Concentrations Goals for Radionuclides in
35 Buildings ([BDCC](#)) electronic calculator, and Q17 of the guidance document "[Radiation Risk
36 Assessment At CERCLA Sites: Q & A](#)" issued on May 2014. Computer codes such as the RVISL,
37 which were developed to predict potential human exposure from radon concentrations in indoor
38 air, are based on simplified equations and assumptions and are highly imprecise for an individual
39 house or structure. EPA would recommend, where possible, Regions use measurements of radon
40 indoors rather than rely on the transport portions of the RVISL. In particular, testing of
41 groundwater or soil gas is not required to demonstrate compliance with RVISL WL, pCi/L, risk, or
42 dose targets.

43 Users should note that since background radon levels are typically outside the risk range, the
44 RVISL calculator is likely to be used primarily for ARAR compliance. For example, the UMTRCA
45 indoor radon standards 40 CFR 192.12(b)(1) and 192.41(b) were identified as likely Federal ARARs
46 for Rn-222 and Rn-220 in Attachment A of the EPA guidance document "Establishment of Cleanup
47 Levels for CERCLA Sites with Radioactive Contamination." There are some state standards
48 expressed in pCi/l or mrem/yr that, if more stringent than the UMTRCA standards, may be
49 selected as ARARs.

50 **Introduction**

51 Superfund sites are addressed under the authority of the Comprehensive Environmental
52 Response, Compensation, and Liability Act (CERCLA) of 1980, which was amended by the 1986
53 Superfund Amendments and Reauthorization Act. The purpose of this website is to provide a
54 screening level calculation tool to assist risk assessors, remedial project managers, and others
55 involved with risk assessment and decision-making at CERCLA sites in developing or refining
56 screening levels.

57 Rn-222 is commonly referred to radon because of its parent radium-226. Rn-220 is commonly
58 called thoron because of its parent thorium. Rn-219 is commonly called actinon because of its
59 parent actinium. Click the decay chain link to see the decay series for [Rn-222](#), [Rn-220](#), and [Rn-219](#).
60 The metal groups in these images are based on [Los Alamos National Laboratory](#) literature. See
61 section 2.2 of the User's Guide to learn what progeny are evaluated in this web calculator. More
62 details about the decay chains can be found in the EPA's [Decay Chain](#) Tool.

63 This tool is based on the [Technical Guide for Assessing and Mitigating the Vapor Intrusion
64 Pathway from Subsurface Vapor Sources to Indoor Air \(June 2015\)](#). Vapor intrusion occurs when
65 there is a migration of vapor-forming chemicals or radon from any subsurface source into an
66 overlying building. Recognition of soil vapor intrusion to buildings and other enclosed spaces
67 occurred in the 1980s with concerns over radon intrusion. Subsequently, there was an increasing
68 awareness that anthropogenic chemicals (e.g., petroleum hydrocarbons and chlorinated

69 solvents) in soil, groundwater, and sewers and drainlines could also pose threats to indoor air
70 quality via the vapor intrusion pathway.

71 The RVISL calculator results were previously verified. The documentation from these may be seen
72 on the [Internal Verification](#) and [External Verification](#) pages. The RVISL calculator was also
73 previously peer reviewed, and the documentation of the review may be seen [here](#).

74 Chemicals are not addressed on this website. For chemical vapor intrusion, please go to [EPA's](#)
75 [Vapor Intrusion Screening Level Calculator](#).

76 Note: No consideration is given to ecological effects in the values presented in this calculator.

77 **Frequently Asked Questions**

78 **This page presents many questions asked by site users and the applicable responses. Please**
79 **search this page for answers to your questions prior to contacting technical support staff.**
80 **Researching the questions and answers posted here will greatly reduce the time it takes for**
81 **you to solve many problems that arise from calculating and using this SL site.**

82 1. [What are RVISLs? How are they used?](#)

83 RVISLs are preliminary remediation goal concentrations for groundwater, soil gas (sub-
84 slab and exterior), and indoor air to assist Agency staff with making a vapor intrusion
85 determination based on limited, initial data.

86 2. [How can I change attenuation factors?](#)

87 To change the attenuation factors, run the [calculator](#); the main page has editable cells
88 with the default factors presented.

89 The screening levels for groundwater and soil gas (either sub-slab gas or soil gas
90 collected exterior to buildings) are calculated from the target indoor air concentrations
91 using empirically-based conservative "generic" attenuation factors that reflect
92 generally reasonable worst-case conditions, as described in the EPA's vapor intrusion
93 guidance.

94 A critical assumption for this generic model is that site-specific subsurface
95 characteristics will tend to reduce or attenuate soil gas concentrations as vapors
96 migrate upward from the source and into overlying structures. Specific factors that may
97 result in relatively unattenuated or enhanced transport of vapors into a building
98 include the following:

- 99 ○ Significant openings to the subsurface that facilitate soil gas entry into the building
100 (e.g., sumps, unlined crawl spaces, earthen floors) other than typical utility
101 penetrations.

- 102 ○ Very shallow groundwater sources (e.g., depths to water less than five feet below
103 foundation level)
- 104 ○ Significant routes for preferential, subsurface vapor migration whether naturally
105 occurring (e.g., fractured bedrock) or anthropogenic.

106 The factors listed above may negate the appropriate application of the recommended
107 attenuation factors and the sub-slab, groundwater, and soil gas VISLs for purposes of
108 identifying sites or buildings unlikely to pose a health concern through the vapor
109 intrusion pathway. On the other hand, further evaluation of the vapor intrusion
110 pathway is still appropriate when the sub-slab, groundwater, and soil gas VISLs are
111 exceeded for samples from a building or site where these specific factors are present.

112 Vapor source types that typically make the use of the recommended attenuation
113 factors and health-based VISLs for groundwater and soil gas inappropriate include:

- 114 ○ Those originating in landfills where methane is generated in sufficient quantities to
115 induce advective transport in the vadose zone.
- 116 ○ Those originating in commercial or industrial settings where vapor-forming chemicals
117 can be released within an enclosed space and the density of the chemicals' vapor may
118 result in significant advective transport of the vapors downward through cracks and
119 openings in floors and into the vadose zone.
- 120 ○ Leaking vapors from pressurized gas transmission lines.

121 In each case, the diffusive transport of vapors may be overridden by advective
122 transport, and the vapors may be transported in the vadose zone several hundred feet
123 from the source of contamination with little attenuation in concentration. In general,
124 EPA recommends considering whether the assumptions underlying the generic
125 conceptual model are attained at a given site. If they are not attained, then EPA
126 recommends that the medium-specific VISLs not be relied upon as a line of evidence for
127 identifying sites or buildings unlikely to pose a health concern through the vapor
128 intrusion pathway. Where the assumptions regarding the subsurface attenuation
129 factors do not or may not apply, EPA generally recommends collecting indoor air
130 samples.

131 3. **Why can't I calculate RVISLs for bulk soil samples?**
132 Consistent with the 2015 OSWER Technical Guide for Assessing and Mitigating the Vapor
133 Intrusion Pathway from Subsurface Vapor Sources, "bulk soil (as opposed to soil gas)
134 sampling and analysis is not currently recommended for estimating the potential for
135 vapor intrusion to pose unacceptable human health risk in indoor air, because of the
136 potential for vapor loss due to volatilization during soil sampling, preservation, and
137 analysis. In addition, there are uncertainties associated with soil partitioning
138 calculations."

139 4. **How can I access the "forward calculator" function?**
140 In addition to calculating screening levels, the [calculator](#) allows the user to input data
141 collected from their site. This data is used to model the indoor air concentration,
142 calculate a chronic daily intake, and present cancer risk. On the [calculator](#) main page,
143 select "Yes" under the section titled "**Predict indoor air concentrations and risk from
144 measured media concentrations?**". A choice will be presented for the user to select
145 between air, soil gas, and groundwater data. "Site-specific" mode is automatically
146 activated, and the user will be prompted to enter their site data.

147 5. **How can I adjust groundwater temperatures?**
148 The main page of the [calculator](#) has a cell where the temperature can be changed from
149 the default of 25 °C.
150 Users are given the option to change the groundwater-soil system temperature from
151 the default of 25°C to a site-specific value. Since the unitless Henry's Law Constant (H')
152 is derived based on the partial pressure of a gas in equilibrium with a liquid and the
153 equilibrium changes when temperature changes, H' is changed to reflect the
154 equilibrium at the given temperature. The equation below illustrates how H' is derived
155 when groundwater temperature is changed. An EPA Fact Sheet describing the process
156 can be found at [https://www.epa.gov/vaporintrusion/fact-sheet-correcting-henrys-law-
157 constant-temperature](https://www.epa.gov/vaporintrusion/fact-sheet-correcting-henrys-law-constant-temperature).

158 6. **How are the results converted to a mass basis?**
159 Appendix B of the [Soil Screening Guidance for Radionuclides Technical Background
160 Document](#) presents a formula for converting PRGs in pCi/g to mg/kg and also a formula
161 for converting pCi/L to mg/L. The equation is reproduced here with similar conversions
162 for mg/m³ and mg/cm².

$$C_{i,a} \text{ (mg/L)} = 2.8 \times 10^{-15} \left(\frac{\text{mg} \cdot \text{mole}}{\text{pCi} \cdot \text{g} \cdot \text{year}} \right) \times A_w \left(\frac{\text{g}}{\text{mole}} \right) \times T_{1/2} \text{ (years)} \times C_{gw} \text{ (pCi/L)}$$

and:

$$C_{i,a} \text{ (mg/m}^3\text{)} = 2.8 \times 10^{-15} \left(\frac{\text{mg} \cdot \text{mole}}{\text{pCi} \cdot \text{g} \cdot \text{year}} \right) \times A_w \left(\frac{\text{g}}{\text{mole}} \right) \times T_{1/2} \text{ (years)} \times C_{sg} \text{ (pCi/m}^3\text{)}$$

where:

A_w is the radionuclide atomic weight and $T_{1/2}$ is the radionuclide half-life.

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165 The derivation of the 2.8×10^{-12} conversion is presented below.

$$2.8 \times 10^{-15} \left(\frac{\text{mg} \cdot \text{mole}}{\text{pCi} \cdot \text{g} \cdot \text{year}} \right) = \left(\frac{1 \times 10^{-12} \text{ Ci}}{\text{pCi}} \right) \times \left(\frac{3.7 \times 10^{10} \text{ nt/s}}{\text{Ci}} \right) \times \left(\frac{31,536,000 \text{ s}}{\text{year}} \right) \times \frac{1}{0.693} \times \left(\frac{\text{atoms}}{\text{nt}} \right) \times \left(\frac{1 \text{ mole}}{6.023 \times 10^{23} \text{ atoms}} \right) \times \left(\frac{1000 \text{ mg}}{\text{g}} \right)$$

where:

nt = nuclear transformations (decays)

$$A \left(\frac{\text{nt}}{\text{year}} \right) = \frac{N \text{ (number of atoms)}}{T_{1/2} \text{ (years)}} \times 0.693 \left(\frac{\text{nt}}{\text{atom}} \right)$$

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168 Combination of the derivation of the conversions with the isotope-specific half life and
169 atomic weight is presented here.

$$C_{i,a} \text{ (mg/L)} = C_{gw} \text{ (pCi/L)} \times \left(\frac{1 \times 10^{-12} \text{ Ci}}{\text{pCi}} \right) \times \left(\frac{3.7 \times 10^{10} \text{ nt/s}}{\text{Ci}} \right) \times \left(\frac{31,536,000 \text{ s}}{\text{year}} \right) \times \frac{1}{0.693} \times \left(\frac{\text{atoms}}{\text{nt}} \right) \times \left(\frac{1 \text{ mole}}{6.023 \times 10^{23} \text{ atoms}} \right) \times \left(\frac{1000 \text{ mg}}{\text{g}} \right) \times A_w \left(\frac{\text{g}}{\text{mole}} \right) \times T_{1/2} \text{ (years)}$$

and

$$C_{i,a} \text{ (mg/m}^3\text{)} = C_{sg} \text{ (pCi/m}^3\text{)} \times \left(\frac{1 \times 10^{-12} \text{ Ci}}{\text{pCi}} \right) \times \left(\frac{3.7 \times 10^{10} \text{ nt/s}}{\text{Ci}} \right) \times \left(\frac{31,536,000 \text{ s}}{\text{year}} \right) \times \frac{1}{0.693} \times \left(\frac{\text{atoms}}{\text{nt}} \right) \times \left(\frac{1 \text{ mole}}{6.023 \times 10^{23} \text{ atoms}} \right) \times \left(\frac{1000 \text{ mg}}{\text{g}} \right) \times A_w \left(\frac{\text{g}}{\text{mole}} \right) \times T_{1/2} \text{ (years)}$$

where:

A_w is the radionuclide atomic weight and $T_{1/2}$ is the radionuclide half-life.

nt = nuclear transformations (decays)

$$A \left(\frac{\text{nt}}{\text{year}} \right) = \frac{N \text{ (number of atoms)}}{T_{1/2} \text{ (years)}} \times 0.693 \left(\frac{\text{nt}}{\text{atom}} \right)$$

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7. How were the UMTRCA working level (WL) standards converted to pCi/L?

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This table depicts the three steps to convert the UMTRCA WL standard to pCi/L. For more discussion on WLs, see the [User's Guide](#) Section 2.8.

Assuming Radon Equilibrium Factor (F_{eq}) = 1		
Rn-222	Rn-220	Rn-219
1 WL = 100 pCi/L	1 WL = 7.5 pCi/L	1 WL = 162 pCi/L
1 WL = 100,000 pCi/m ³	1 WL = 7,500 pCi/m ³	1 WL = 162,000 pCi/m ³
1 WL = 3.7 Bq/L	1 WL = 0.2775 Bq/L	1 WL = 5.994 Bq/L
1 WL = 3,700 Bq/m ³	1 WL = 277.5 Bq/m ³	1 WL = 5,994 Bq/m ³
Assuming Radon Equilibrium Factor (F_{eq}) = 0.4 for Rn-222 and 0.02 for Rn-220		
Rn-222	Rn-220	Rn-219
1 WL = 250 pCi/L	1 WL = 375 pCi/L	Unable to provide conversion due to missing F_{eq} from Federal Guidance for Rn-219.
1 WL = 250,000 pCi/m ³	1 WL = 375,000 pCi/m ³	
1 WL = 9.25 Bq/L	1 WL = 13.875 Bq/L	
1 WL = 9,250 Bq/m ³	1 WL = 13,875 Bq/m ³	
Standardized to 0.02 Working Levels (WL)		
Rn-222	Rn-220	Rn-219
0.02 WL = 5 pCi/L	0.02 WL = 7.5 pCi/L	Unable to provide conversion due to missing F_{eq} from Federal Guidance for Rn-219.
0.02 WL = 5,000 pCi/m ³	0.02 WL = 7,500 pCi/m ³	
0.02 WL = 0.185 Bq/L	0.02 WL = 0.2775 Bq/L	

0.02 WL = 185 Bq/m ³	0.02 WL = 277.5 Bq/m ³	
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177 **Working Level Conversion References**

- 178 ○ David Allen. [Dose Conversion Factors for Radon WLM](#). Centers for Disease Control (CDC),
 179 June 2018.
- 180 ○ Health Physics Society (HPS). [Ask the Experts: Environmental and Background
 181 Radiation - Radon, May 2017.](#)

182 **8. When do I use risk-based versus dose-based versus WL screening level types?**

183 The RVISL calculator is likely to be used primarily for ARAR compliance. For example,
 184 the UMTRCA indoor radon standards 40 CFR 192.12(b)(1) and 192.41(b) were identified
 185 as likely Federal ARARs for Rn-222 and Rn-220 in Attachment A of the EPA guidance
 186 document "Establishment of Cleanup Levels for CERCLA Sites with Radioactive
 187 Contamination." There are some state standards that may be expressed in pCi/l or
 188 mrem/yr that if more stringent than the UMTRCA standards may be selected as ARARs.
 189 Background levels of indoor radon will typically exceed the risk range, and it would
 190 generally not be expected that remediation levels for indoor radon would be risk-based
 191 or based on background. The risk portions of the RVISL can still be used to provide risk
 192 estimates for the ARAR-based remediation levels.

193 **9. When should modelling instead of measurements be used for indoor radon?**

194 Computer codes such as the RVISL, which were developed to predict radon
 195 concentrations in indoor air for potential human exposure based on simplified
 196 equations and assumptions, are highly imprecise for an individual house or structure.
 197 EPA would recommend, where possible, Regions use measurements of radon indoors
 198 rather than rely on the transport portions of the RVISL. In particular, testing of
 199 groundwater or soil gas is not required to demonstrate compliance with RVISL WL,
 200 pCi/L, risk, or dose targets.

201 **10. Why do the Superfund RVISL calculator risk results for 4 pCi/L of Rn-222 in air differ
 202 from the reported ORIA health risks for the same activity?**

203 The RVISL calculator risk results for 4 pCi/L of Rn-222 in air differ from the reported
 204 ORIA health risks for the same activity for several reasons. The first reason for a
 205 difference in the risk results is that the RVISL calculator uses risk coefficients based on
 206 morbidity (getting cancer) from inhalation and submersion exposure routes, while the
 207 ORIA tables are based on mortality (death) from inhalation-induced lung cancer only.
 208 The ORIA [Health Risk of Radon](#) web page reports that for smokers and never-smokers,
 209 the mortality risk from lung cancer of 4 pCi/L of Rn-222 is 62 out of 1,000 people and 7
 210 out of 1,000 people, respectively, or 6.2×10^{-2} and 7×10^{-3} . Given in the scientific notation
 211 format used in the RVISL, this relates to a lung cancer mortality risk of 6.2E-02 and 7E-
 212 03, respectively. The RVISL residential risk results for a combination of smokers and

213 never-smokers to 4 pCi/L of Rn-222 in air is 8.39E-02, which rounds to 8.4×10^{-2} .
 214 Additionally, the ORIA risk estimates are based on an average population study, where
 215 the individual's exposure parameters are not considered, while the RVISL results are
 216 based on a reasonably maximum exposed (RME) individual. The individual exposure
 217 parameters considered in Superfund assessments include dwelling air exchange rate,
 218 inhalation rates, exposure duration, and resident time indoors.

219 For more information on different methods for making radon inhalation cancer risk
 220 estimates see section 2.3.1 of the User Guide.

221 **11. I noticed the VISL and RVISL use the same attenuation factors. Are the VISL default**
 222 **attenuation factors appropriate for use in the RVISL calculator?**

223 The default VISL attenuation factors are also used in the RVISL. In fact, radon intrusion
 224 studies were the foundation for recognition that chemical vapors also intrude into
 225 buildings and enclosed spaces from soil and groundwater sources ([EPA 1995](#)). It was
 226 also observed that vapor intrusion mitigation remedies suppress both chemical and
 227 radon gasses and that monitoring radon intrusion is a viable surrogate for predicting
 228 chemical intrusion susceptibility in buildings ([EPA 2015](#)). Many studies reported in [EPA](#)
 229 [2012a](#), demonstrate strong correlation between radon and chemical sub-slab soil gas
 230 attenuation factors calculated when the radon and chemicals are uniformly collocated.

231 The default attenuation factors can be substituted for site-specific attenuation factors if
 232 underlying site conditions are known. [EPA 2012b](#) presents site-specific attenuation
 233 factors for sub-slab soil gas, groundwater, and crawlspaces for chemicals. The
 234 attenuation factors are summarized in the following table. The defaults used in the VISL
 235 and RVISL calculators are highlighted. The defaults are based on the 95th percentile and
 236 are appropriate for adjusting an RME scenario. The 50th percentile values would be more
 237 appropriate for a central tendency exposure scenario where a large amount of
 238 sampling data is available to reduce uncertainty in calculating the exposure
 239 concentration or defining nature and extent of the source term.

Subslab Soil Gas Attenuation Factors		
Residence Type	Median (50 th percentile)	95 th Percentile
All residences	3E-03 (0.003)	3E-02 (0.03)*
Residences with basements	3E-03 (0.003)	3E-02 (0.03)
Residences with slab-on-grade	3E-03 (0.003)	1E-02 (0.01)

Groundwater Attenuation Factors		
Scenario	Median (50th percentile)	95th Percentile
All soil types and water depths	7E-05 (0.00007)	1E-03 (0.001)*
Fine soil type	5E-05 (0.00005)	5E-04 (0.0005)
Coarse soil type	1E-04 (0.0001)	1E-03 (0.001)
Very coarse soil type	2E-04 (0.0002)	4E-03 (0.004)
Depth to water < 1.5 m	6E-04 (0.0006)	7E-03 (0.007)
Depth to water 1.5-3 m	1E-04 (0.0001)	2E-03 (0.002)
Depth to water 3-5 m	4E-05 (0.00004)	2E-03 (0.002)
Depth to water > 5 m	5E-05 (0.00005)	6E-04 (0.0006)
Exterior Soil Gas Attenuation Factors		
Scenario	Median (50th percentile)	95th Percentile
All residences	4E-03 (0.004)	3E-01 (0.3)
Crawlspace Attenuation Factor		
Scenario	Median (50th percentile)	95th Percentile
All residences	4E-01 (0.4)	9E-01 (0.9)

*These are the VISL and RVISL defaults.

Search EPA.gov

To contact the EPA for questions about radiation risk assessment and/or this calculator, please [CONTACT US](#).

Draft Radon VISL User's Guide (September, 2020)

[PDF of User 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 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](#).

This tool provides screening level concentrations of radon for groundwater, soil gas (sub-slab and exterior), and indoor air to assist Agency staff with making a radon vapor intrusion screening level (RVISL) determination based on limited, initial data. In addition to calculating screening levels, 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. Note that for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial actions, dose assessment is generally done only to show compliance with a dose-based Applicable or Relevant and Appropriate Requirement (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 \(OSWER Directive 9200.4-18, August 1997\)](#). Users should note that since background radon levels are typically outside the risk range, the RVISL calculator is likely to be used primarily for ARAR compliance. For example, the UMTRCA indoor radon standards 40 CFR 192.12(b) (1) and 192.41(b) were identified as likely Federal ARARs for Rn-222 and Rn-220 in Attachment A of the EPA guidance document "[Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination](#)." 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.

Radon Vapor Intrusion Screening Levels (RVISL)

- [Home Page](#)
- [User's Guide](#)
- [What's New](#)
- [Frequent Questions](#)
- [Equations](#)
- [RVISL Calculator](#)
- [Generic Tables](#)

The RVISL calculator provides updated guidance for developing screening levels (SLs) 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. 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 potential human exposure from radon concentrations in indoor air, are based on simplified equations and assumptions and are highly imprecise for an individual house or structure. 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.

[Open All Sections](#) | [Close All Sections](#)

Disclaimer

This guidance sets forth a recommended, but not mandatory, approach based upon currently available information with respect to risk and dose assessment for response actions at CERCLA sites. This document does not establish binding rules. Alternative approaches for risk assessment may be found to be more appropriate at specific sites (e.g., where site circumstances do not match the underlying assumptions, conditions, and models of the guidance). The decision whether to use an alternative approach and a description of any such approach should be documented for such sites. Accordingly, comments questioning the use of the approaches recommended in this guidance at individual CERCLA sites should be considered and an explanation provided for the selected approach.

It should also be noted that the radon vapor intrusion screening levels (RVISLs) produced by this calculator are based upon human health risk and do not address potential ecological risk. Some sites in sensitive ecological settings may also need to be evaluated for potential ecological risk. EPA's guidance "[Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessment](#)" contains an eight step process for using benchmarks for ecological effects in the remedy selection process.

The RVISL calculator provides updated guidance for developing screening levels (SLs) 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. 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.

1. Introduction

A purpose of this guidance is to provide a radon vapor intrusion screening level (RVISL) calculation tool to assist risk assessors, remedial project managers, and others involved with risk assessment and decision-making at CERCLA sites in developing RVISLs. This RVISL calculator is based on the [Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air \(June 2015\)](#) which provides guidance on calculating risk-based VISLs with adaptations

specifically for radon. Initially used at the scoping phase of a project using readily available information, risk-based RVISLs may be modified based on site-specific data gathered during the RI/FS study. RVISL development and screening should assist staff in streamlining the consideration of remedial alternatives. Radionuclide-specific RVISLs are from two general sources. These are: (1) concentrations based on potential Applicable or Relevant and Appropriate Requirements (ARARs) and (2) risk-based concentrations. ARARs include concentration limits set by other environmental regulations, such as Safe Drinking Water Act maximum contaminant levels (MCLs). The second source for RVISLs, and the focus of this database tool, is risk-based calculations that set concentration limits using carcinogenic toxicity values under specific exposure conditions.

The recommended approach for developing remediation goals is to identify RVISLs at scoping, modify them as needed at the end of the RI or during the FS based on site-specific information from the baseline risk assessment, and ultimately select remediation levels in the Record of Decision (ROD). In order to set radionuclide-specific RVISLs in a site-specific context, however, assessors must answer fundamental questions about the site. Information on the radionuclides that are present onsite, the specific contaminated media, land-use assumptions, and the exposure assumptions behind pathways of individual exposure is necessary in order to develop radionuclide-specific RVISLs. The RVISL calculator provides the ability to modify the standard default PRG exposure parameters to calculate site-specific RVISLs.

This database tool presents standardized risk- and dose-based RVISLs and variable risk-based RVISL calculation equations for radioactive contaminants. Ecological effects are not considered in the calculator for radionuclide RVISLs.

RVISLs are presented for indoor residents and workers for air, tap water, and sub slab soil gas. The primary RVISLs are based on the carcinogenicity of radon and short-lived progeny. Secondary RVISLs may be calculated based on dose or working levels (WLs). Cancer slope factors (SFs) and dose coefficients (DCFs) used are provided by the [Center for Radiation Protection Knowledge](#). The main report is [Calculations of Slope Factors and Dose Coefficients](#), and the tables of slope factors are in a separate [appendix](#). Inhalation risk and dose coefficients are provided in a more recent report, [Radon Cancer Risk Coefficients & Age-Specific Effective Dose Coefficients](#).

Non-carcinogenic effects are not considered for radon.

The standardized RVISLs are based on default exposure parameters and incorporate exposure factors that present RME conditions. Once this database tool is used to retrieve standard RVISLs or calculate site-specific RVISLs, it is important to clearly demonstrate the equations and exposure parameters used in the calculations. Discussion of the assumptions that go into the calculated RVISLs should be included in the document where the RVISLs are presented, such as a Remedial Investigation (RI) Report or Feasibility Study.

This website combines current [Center for Radiation Protection Knowledge](#) SFs and DCFs with standard exposure factors to estimate contaminant concentrations in environmental media (air, soil gas, and groundwater) that are protective of humans (including sensitive groups) over a lifetime. Sufficient knowledge about a given site may warrant the use of site-specific assumptions, which may differ from the defaults. Exceeding a RVISL usually suggests that further evaluation of the potential risks is appropriate. The RVISL concentrations presented on this website can be used to screen pollutants in environmental media, trigger further investigation, and provide initial cleanup goals, if applicable. RVISLs should be applied in accordance with guidance from EPA Regions.

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

2. Understanding the RVISL Website

2.1 General Considerations

Radon is an inert, cancer-causing, radioactive gas at room temperature, and the following criteria used to determine if a chemical is suitable for vapor intrusion analysis will be ignored for this calculator.

- To determine vapor intrusion of a chemical, the chemical must first meet the criteria for volatility, which is either a Vapor Pressure > 1 mm Hg or a Henry's Law Constant > 1×10^{-5} atm-m³/mol.
- A chemical must be sufficiently volatile and toxic to pose inhalation or external exposure risk via vapor intrusion from a soil source.
- Third, the chemical must be sufficiently volatile and toxic to pose inhalation or external exposure risk via vapor intrusion from groundwater.
- The chemical must contain either a reference concentration (RfC) or an inhalation unit risk (IUR) for a VISL to be calculated.

While radon is suitable for the vapor intrusion models used for chemicals, this language is not suitable for radon. Radon has inhalation and external exposure (submersion) risk coefficients (slope factors) and dose coefficients. Additionally, all radionuclides are considered Group A carcinogens by the EPA.

The concentration ratios between radon and its progeny indoors (i.e., the indoor F_{eq}) is very much influenced by ventilation, exhalation, solid-particle concentration, and surface deposition of radon progeny (Chen & Harley, 2018). Exhalation, solid-particle concentration, and surface deposition were omitted in this study, for simplification. Air quality was also neglected, and it was assumed that actinon, thoron, radon, and subsequent progeny were uniformly distributed over the air volume.

The medium-specific RVISLs for health protection are developed considering a generic conceptual model for vapor intrusion consisting of:

- a source of vapors underneath the building(s) either in the vadose zone or in the uppermost, continuous zone of groundwater, separations between walls and foundation slabs, cracks in foundations;
- vapor migration via diffusion upwards through unsaturated soils from these sources toward the ground surface and overlying buildings; and
- buildings with poured concrete foundations (e.g., basement or slab-on-grade foundations) that are susceptible to soil gas entry.

A critical assumption for this generic model is that site-specific subsurface characteristics will tend to reduce or attenuate soil gas concentrations as vapors migrate upward from the source and into overlying structures. The RVISL relies on default attenuation factors developed from measured VI data; however, **some site-specific characteristics may result in relatively unattenuated or enhanced transport of vapors into a building.** These factors include:

- significant openings to the subsurface that facilitate soil gas entry into the building (e.g., sumps, unlined crawl spaces, earthen floors) other than typical utility penetrations;
- very shallow groundwater sources (e.g., depths to water less than five feet below foundation level); and
- significant routes for preferential, subsurface vapor migration, whether naturally occurring (e.g.,

fractured bedrock) or anthropogenic (e.g., abandoned underground utilities, gravel, highly permeable soil under foundation).

These specific factors may render the use of the recommended attenuation factors and the sub-slab, groundwater, and soil gas RVISLs inappropriate for purposes of identifying sites or buildings unlikely to pose a health concern through the vapor intrusion pathway. On the other hand, further evaluation of the vapor intrusion pathway is still appropriate when the sub-slab, groundwater, and soil gas RVISLs are exceeded for samples from a building or site where these specific factors are present.

In addition, certain vapor sources, listed below, invalidate the recommended attenuation factors and screening levels used for the RVISL:

- those originating in landfills where radon is generated in sufficient quantities to induce advective transport in the vadose zone and
- those originating in commercial or industrial settings where radon can be released within an enclosed space and where the density of the radon vapor may result in significant advective transport of the vapors downward through cracks and openings in floors and into the vadose zone.

In each case, the diffusive transport of vapors may be overridden by advective transport, and the vapors may be transported in the vadose zone several hundred feet from the source of contamination with little attenuation in concentration.

The previously mentioned assumptions and warnings involving attenuation factors are for generic chemicals and do generally apply to radon; however, there are additional considerations for radon entry dynamics. It is recommended that users of this calculator consider all these factors and the ones that are listed below. The concentration of radon in a building depends on:

1. Source of radon and its strength
2. Transport of radon
 - Pathways
 - Soil - high soil porosity or utility trenches, etc.
 - Building Shell - joints, cracks, earthen areas, utility penetrations, etc. in the foundation
 - Driving forces that pull or push radon towards the building and inside the building.
 - air pressure differences
 - diffusion
 - emanation
 - well water
 - environmental effects (e.g., frost or saturated upper soil horizon, rain, pavement around buildings can "cap" the soil)
3. Ventilation rate of building

Radon concentrations are influenced by the complex interaction of:

1. Local geology
2. Soil

- Parent isotope content
 - Moisture content
 - Temperature difference
 - Permeability
 - Water table fluctuation
3. Climate and meteorological factors
- Season
 - Barometric pressure changes
 - Precipitation (e.g., rate, amount)
 - Wind speed and direction
 - Snow cover or soil saturation
 - Temperature inversions
4. Building characteristics
- Pressure differences
 - Heating systems
 - Ventilation
 - Water source
 - Building materials
5. Occupant Activities
- Window opening
 - Fireplace and wood stove use

2.2 RVISL WL, Risk, & Dose Screening Level Output Options

This calculator only offers one output option, whereas other EPA risk and dose calculators offer the following three options:

- Assumes secular equilibrium throughout chain (no decay);
- Does not assume secular equilibrium, provides results for progeny throughout chain; and
- Does not assume secular equilibrium, provides results for selected isotopes only.

The RVISL output is based on an equilibrium relationship of the three parent isotopes to their progeny. In the case of [Rn-222](#), this means the progeny prior to Pb-210; for [Rn-220](#) and [Rn-219](#), all progeny are included. This equilibrium relationship, which is based on air exchange rates within the structure, is dubbed the activity equilibrium fraction (A_{eq}) and is discussed in greater detail in section 6.3.

The calculator output is organized by radon parent. Each radon parent has its own output section. The first row for each radon parent section is a total of the progeny and parent fractional contribution. Radon-219 is first, followed by radon-220 and Rn-222.

$$RVISL_{\text{tot}} = \frac{1}{\left(\sum_{i=1}^n \frac{1}{RVISL_{\text{route } i}} \right)}$$

where:

n = total number of exposure routes;

and:

$$RVISL_{\text{route}} = \frac{1}{\left(\sum_{i=1}^n \left(\frac{RVISL}{A_{\text{eq}}} \right)_i \right)}$$

where:

n = number of short-lived progeny in the decay series;

RVISL = RVISL for isotope in decay chain;

A_{eq} = activity equilibrium factor for isotope.

The RVISL calculator gives the user the option to select either a working level-, risk-, or a dose-based calculation. These outputs are given in pCi, unless the user selects Bq.

The RVISL calculator has an option to include the results in working levels (WLs) for comparison to the UMTRCA standards, in addition to results based on volume (pCi/m³ or pCi/L). The calculator gives the contribution of each short-lived isotope (parent and progeny) to the total RVISL. When WLs are included in the output, only the parent activity is converted to a WL, and the total RVISL value derived for the whole chain is not used for the WL conversion, despite the WL value being displayed in the top row for the chain. For more information on the short-lived progeny included in each RVISL calculation and WL conversions, see section 2.4.

2.3 Slope Factors (SFs) and Dose Conversion Factors (DCFs)

EPA classifies all radionuclides as Group A carcinogens ("carcinogenic to humans"). Group A classification is used only when there is sufficient evidence from epidemiologic studies to support a causal association between exposure to the agents and cancer. The following sections discuss the sources of inhalation and external exposure via submersion in gas cloud SFs and DCFs used in this calculator.

2.3.1 Inhalation

The [Radon Cancer Risk Coefficients and Age-Specific Effective Dose Coefficients](#) report from Oak Ridge National Laboratory lists inhalation cancer slope factors (SFs) (risk coefficients for total cancer morbidity) and dose coefficients (DCFs) for radionuclides in conventional units of picocuries (pCi). Inhalation SFs and DCFs are central estimates in a linear model of the age-averaged, lifetime attributable radiation cancer incidence (fatal and nonfatal cancer) risk or dose per unit of activity inhaled, expressed as risk/pCi or mrem/pCi, respectively.

The inhalation SFs and DCFs from the [Radon Cancer Risk Coefficients and Age-Specific Effective Dose Coefficients](#) report differ from the inhalation values presented in [Health Effects Assessment Summary Tables \(HEAST\)](#). The inhalation SFs and DCFs used in this calculator were calculated using ORNL's DCAL software in the manner of Federal Guidance Reports (FGR) 12 and 13. The values are for inhalation of individual radionuclides without accompanying progeny but include the contribution to risk or dose from ingrowth of radioactive progeny in the body following intake of a parent radionuclide. This approach allows the user to derive cancer risk and effective dose estimates for any known or hypothetical combination of Rn-222 or Rn-220 and its short-lived progeny in air. Rn-219 is not included in the update due to the large uncertainty in the distribution of decays of Rn-219 and its progeny in the body. This is essential for the fractional activity equilibrium factors derived in this calculator based on air exchange rates (see sections 6.2 and 6.3.). Using SFs and DCFs calculated with the methods from HEAST and with the fractional activity equilibrium models in this calculator would result in overestimation of risk and dose.

An alternative approach for assessing cancer risk associated with radon in homes is to use models that express radiogenic lung cancer risk as a function of past exposure, such as those recommended in the National Research Council's report of the sixth Biological Effects of Ionizing Radiation (BEIR VI) (1999) and the World Health Organization (WHO) Handbook (2009). The BEIR VI models and those described in the WHO Handbook do not require dose calculations and were derived by data analysis of epidemiological studies of lung cancer associated with exposure to radon. No recommendation is made here as to which approach is to be preferred for other purposes. The SFs derived in the ORNL report are used here to allow for more direct comparisons with the associated DCFs.

The ORNL Radon report does not include inhalation risk or dose coefficients for Rn-219, because the short half-life creates a large uncertainty in the distribution of decays in the body. That large uncertainty is one reason why the International Commission on Radiological Protection (ICRP) generally does not provide inhalation or ingestion dose coefficients for such short-lived radionuclides.

EPA currently provides guidance on inhalation risk assessment in [RAGS Part F](#) (Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual, Part F, Supplemental Guidance for Inhalation Risk Assessment); however, this guidance only addresses chemicals. The development of inhalation slope factors for radionuclides differs from the guidance presented in RAGS Part F for development of inhalation unit risk (IUR) values for chemicals.

2.3.2 Submersion

The external exposure SFs and DCFs used in this calculator are taken from Calculation of Slope Factors and Dose Coefficients (ORNL 2014). The external SFs and DCFs were calculated using ORNL's DCAL software in the manner of Federal Guidance Report 12 and 13 and differ from the values presented in [HEAST](#). External exposure SFs and DCFs are central estimates of lifetime attributable radiation cancer incidence risk for each year of exposure to external radiation from photon-emitting radionuclides distributed uniformly in a gas cloud and are expressed as risk/yr per pCi/m³ air or mrem/year per pCi/m³ air. When combined with site-specific media concentration data and appropriate exposure assumptions, SFs can be used to estimate lifetime cancer risks, and DCFs can be used to estimate annual dose to members of the general population due to radionuclide

2.4 Working Levels (WLs)

The term Working Level (WL) refers to the activity of the progeny present in air from a specific radon parent (i.e., radon, thoron, or actinon). Specifically, WLs do not include the contribution from the parent. According to the EPA's code of federal regulations [40 CFR 192.11](#), "a working level (WL) means any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of alpha particles with a total energy of 130 billion electron volts." In the case of [Rn-222](#), this means the progeny prior to Pb-210; for [Rn-220](#) and [Rn-219](#), all progeny are included. U.S. EPA 1989 ([RAGS Part A](#)), the Centers for Disease Control and Prevention (CDC) [Dose Conversion Factors for Radon WLM](#) (CDC 2018), the National Council on Radiation Protection and Measurements (NCRP) [Report No.97](#), and The Department of Energy ([DOE-STD-1121-2008](#)) agree with the definition and/or offer equivalent values in units of pCi/L. At 100% equilibrium, one WL is equal to 100pCi/L of Rn-222, 7.5 pCi/L of Rn-220, and 162 pCi/L of Rn-219. While this is a significant difference in the gas concentrations, by definition of the working level, the decay products will ultimately emit the same amount of alpha energy. This, however, does not lead to the same lung dose. This is caused largely by the difference in the half-lives of the decay products. Since Rn-220 products have longer half-lives, the body has longer to transport the activity from one compartment to another and thus deliver dose to different areas of the lung. Since the working level is an air concentration, it is analogous to an exposure rate. To describe exposure, the unit working level month (WLM) is also used. A WLM is the exposure equivalent to breathing one WL for 170 hours (one working month). The NRC in [CFR 20.1003](#) and CDC in [Dose Conversion Factors for Radon WLM](#) identify the individual progeny that are included as "short-lived" daughters. Some of the extremely short-lived daughters are explicitly excluded in WL calculations because they would represent a very small number of atoms inhaled and add computational time without significant precision gains. For this calculator, all short-lived progeny are considered for completeness because of modern computing advances. See details in sections 6.2 and 6.3 of this user's guide to see how the inhalation fractional equilibrium (F_{eq}) and activity equilibrium factor (A_{eq}) values were calculated for short-lived progeny.

"Properties and behaviour of radon and thoron and their decay products in the air" (J. Porstendorfer, Journal of Aerosol Science, Vol 25:2, March 1994, pg 219-263) further supports the WL definition and conversion to pCi/L and offers insight on the consideration of radon daughter aerosol formation and deposition on surfaces. "Measurement of Equilibrium Factor ' F_{eq} ' between Radon and its Progeny and Thoron and its Progeny in the Indoor Atmosphere Using Nuclear Track Detectors" (R. Ramola, Indoor and Built Environment, Vol12:351-355, 2003) discusses the air exchange rate impact on radon progeny plating on surfaces and on the measured equilibrium in air. These papers present many of the difficulties in predicting and measuring F_{eq} values due to seasonal atmospheric changes, building construction, surface plating, aerosol sizes, regional geology, air flow, etc. The F_{eq} is important to establish for determining compliance with WL ARARs, such as the UMTRCA standards described in section 2.7 of this user's guide. Previous EPA guidance on complying with the UMTRCA standard as an ARAR at CERCLA sites assumed a F_{eq} of 0.4 (40%) for Rn-222 and 0.02 (2%) for Rn-220. These F_{eq} values, which when applied to the 0.02 WL ARAR equate to 5 pCi/L of Rn-222 or 7.5 pCi/L of Rn-220, were to be used to demonstrate compliance with the UMTRCA standard. Rn-219 does not have an UMTRCA standard. EPA's new guidance for ARAR compliance is to use this calculator with either default or site/building-specific air exchange rates to determine radon/thoron levels that comply with the 0.02 WL ARAR.

For more information on evaluation of radon working levels, see question 17 in the [Radiation Risk](#)

[Assessment At CERCLA Sites: Q&A](#) and question 7 in the [Frequent Questions](#) page on this site. Note that the RVISL calculator provides updated guidance developing screening levels (SLs) or preliminary remediation goals (PRGs) for showing compliance with the UMTRCA indoor radon standards for radon-222 and radon-220. The RVISL, therefore, supersedes the approach for determining WL in question 17 of the guidance document "Radiation Risk Assessment At CERCLA Sites: Q & A" issued on May 2014.

The following equation demonstrates the conversion of the default Rn-222 RVISL in pCi/L to a WL while correcting for the F_{eq} differences between the conversion and calculated values. The F_{eq} in the conversion assumes 100% equilibrium ($F_{eq}=1$), and the F_{eq} for the RVISL is calculated based on the air exchange rate used.

$$RVISL_{Rn-222}^{WL} \left(2.42 \times 10^{-5} WL \right) = RVISL_{Rn-222}^{pCi} \left(\frac{2.72 \times 10^{-3} pCi}{L} \right) \times \left(\frac{F_{eq} (0.89) \times 1 WL}{\left(\frac{100 pCi}{L} \right)} \right)$$

2.5 Radon-specific Parameters

Several radon-specific parameters are needed for development of the RVISLs.

1. Half-life, lambda (λ), atomic number, and atomic weight are taken from [ICRP 107](#).

Isotope	Half-life (year)	λ (year ⁻¹)	Atomic Number	Atomic Weight
Rn-219	1.26E-07	5.52E+06	86	219.009
Rn-220	1.76E-06	3.93E+05	86	220.011
Rn-222	1.05E-02	6.62E+01	86	222.018

2. Vapor Pressure (VP) (mmHg at 25°C) is taken from Table 11 - Vapor Pressure - Inorganic Compounds of the online version of Yaws' Critical Property Data for Chemical Engineers and Chemists, 2014. The value stated in the source is 12,620 mmHg at 25°C. The value is taken from a [plot](#) of the Antoine Equation $\log P = A - (B/(T+C))$.
3. Density (ρ) (g Rn/cm³ at 0°C) is taken from CRC Handbook of Chemistry and Physics 67th Edition, pg. B-122. The value stated in the source is 9.73 g/L (no temperature is given but thought to be based on 0°C). Density (g/cm³) can be used to calculate water solubility at a temperature other than 0°C but must be converted to the required units as follows:

$$\left(9.73 \times 10^{-3} \frac{g}{cm^3} \right) = \left(\left(9.73 \frac{g}{L} \right) \times \left(1 \frac{L}{1000 cm^3} \right) \right)$$

4. Water Solubility (S) (mg/L at 25°C) is taken from CRC Handbook of Chemistry and Physics 67th Edition, pg. B-122. The value stated in the source is 22.4 cm³Rn/100 cm³ H₂O at 0°C. This assumes that radon acts as an ideal gas. Converting to the required units is as follows, assuming 1cm³ = 1 mL:

$$\left(\frac{2220 \text{ mg Rn gas}}{\text{L H}_2\text{O}} \right) = \left(\left(\frac{22.4 \text{ cm}^3 \text{ Rn}}{100 \text{ cm}^3 \text{ H}_2\text{O}} \right) \times \left(\frac{1000 \text{ mL H}_2\text{O}}{\text{L H}_2\text{O}} \right) \times \left(\frac{1 \text{ L gas}}{1000 \text{ mL gas}} \right) \times \left(\frac{1 \text{ mol}}{22.4 \text{ L gas}} \right) \times \left(\frac{222.018 \text{ g Rn}}{\text{mol}} \right) \times \left(\frac{1000 \text{ mg H}_2\text{O}}{\text{g}} \right) \right)$$

5. Henry's Law Constant (HLC) (atm·m³/mole at 25°C) is taken from [Atmos. Chem. Phys., 15, 2015](#), pg. 4418. The value of 9.3E-05 mol/m³Pa at 25°C is selected as the largest of six values presented. Converting to the required units is as follows:

$$\left(0.106 \text{ atm} \cdot \text{m}^3 / \text{mol} \right) = \left(\left(\frac{1}{9.3 \times 10^{-5} \text{ mol} / \text{m}^3 \text{ Pa}} \right) \times \left(\frac{1 \text{ atm}}{101325 \text{ Pa}} \right) \right)$$

6. Unitless Henry's Law Constant (H') (unitless at 25°C). The value is derived from 0.106 atm·m³/mol / 0.02446 = 4.34. The conversion factor, 0.02446, is calculated by multiplying the universal gas constant, 8.2057E-05 atm·m³/mol K, by the temperature 298.16 K.
7. Critical Temperature (T_c) (K) is taken from CRC Handbook of Chemistry and Physics online version. The value reported is 104°C, which is 377.15 K.
8. Boiling Point (T_b) (K) is taken from CRC Handbook of Chemistry and Physics online version. The value reported is -67.7°C, which is 205.45 K.
9. Lower Explosive Limit (LEL) (% by volume). Radon is an inert gas and the LEL is not of concern as it would be for chemicals.
10. Enthalpy of vaporization at the normal boiling point (cal/mol) is taken from Yaw's Thermophysical Properties of Chemicals and Hydrocarbons [Table 63](#), Enthalpy of Vaporization at Boiling Point - Inorganic Compounds (Electronic Edition). The reported value is 18.098 kJ/mol. Converting to the required units is as follows:

$$\left(4326 \text{ cal} / \text{mol} \right) = \left(\left(\frac{18.098 \text{ kJ}}{\text{mol}} \right) \times \left(\frac{1000 \text{ J}}{\text{kJ}} \right) \times \left(\frac{1 \text{ cal}}{4.184 \text{ J}} \right) \right)$$

2.6 Predicting Indoor Air Concentrations from Measured Media Concentrations

2.6.1 Predicting Indoor Air WLs from Measured Media Concentrations

The working level values presented on this website are radionuclide-specific values for Radon contaminants in air that may warrant further investigation or site cleanup. The UMTRCA standard is the most widely used ARAR and is based on working levels. The RVISL [calculator](#) provides an option to select a working level output by selecting "yes" next to the option and choosing the type of media concentration. Selecting the working level output requires the calculator to be run in "Site Specific" mode. The user will be required to enter a media concentration and select the air exchanges per hour (ACH). Using the equations presented in section 5.1.1, a working level is calculated in the output given the media concentration and F_{eq} associated with the selected ACH. The working level will be highlighted in red if the target working level (TWL), selected on the first page of the calculator, is exceeded.

2.6.2 Predicting Indoor Air Risk from Measured Media Concentrations

The RVISL [calculator](#) provides an option to select risk output by selecting "yes" next to the option. Selecting risk output requires the calculator to be run in "Site Specific" mode. The risk values presented on this site are radionuclide-specific values for Radon contaminants in air that may warrant further investigation or site cleanup.

2.6.2.1 General Considerations for the Risk Output

This portion of the risk assessment process is generally referred to as "Risk Characterization". This step incorporates the outcomes of the exposure and toxicity assessments to calculate the risk resulting from potential exposure to radionuclides via the pathways and routes of exposure determined appropriate for the source area. Risk is calculated in this tool using the following equation.

The basic equation for calculating excess lifetime cancer risk is:

$$\text{Risk} = \text{CDI} \times \text{SF} \times A_{\text{eq}}$$

where:

Risk = a unitless probability of an individual developing cancer over a lifetime;

CDI = chronic daily intake or dose [pCi or pCi-year/m³]

SF = slope factor, expressed in risk/pCi or risk/year per pCi/m³

A_{eq} = Activity Equilibrium Factor of individual isotope (See Section 6.3)

The risk results are color coded to identify risk ranges and potential radionuclides of concern. The colors and the associated risk ranges are presented in the table below.

Excess Lifetime Cancer Risk			
Risk Range*	Risk < 1E-06	Risk > 1E-06	Risk > 1E-04
Color Code	No shading	Yellow	Red

* 1E-06 = 0.000001 = 1×10^{-6} = 10^{-6} = one in a million

2.6.2.2 One-Hit Rule

The linear risk equation, listed above, is valid only at low risk levels (below estimated risks of 0.01). For sites where radiological exposure might be high (estimated risks above 0.01), an alternate calculation should be used. The one-hit equation, which is consistent with the linear low-dose model, should be used instead ([RAGS, part A, ch. 8](#)). The results presented on the preliminary

remediation goal (PRG) calculator use this rule. In the following instances, the one-hit rule is used independently in the risk output tables:

- Risk from a single exposure route for a single radionuclide.
- Summation of single radionuclide risk (without one-hit rule applied to single radionuclide results) for multiple exposure routes (right of each row).
- Summation of risk (without one-hit rule applied to single radionuclide results) from a single exposure route for multiple radionuclides (bottom of each column).
- Summation of total risk (without one-hit rule applied to single radionuclide results or summations listed above) from multiple radionuclides across multiple exposure routes (bottom right hand cell).

2.6.3 Predicting Indoor Air Dose from Measured Media Concentrations

This portion of the risk assessment process is generally referred to as "Dose Characterization". This step incorporates the outcomes of the exposure and toxicity assessments to calculate the dose resulting from potential exposure to radionuclides via the pathways and routes of exposure determined appropriate for the source area. Dose is calculated in this tool using the following equation:

$$\text{Dose} = \text{CDI} \times \text{DCF} \times A_{\text{eq}}$$

where:

Dose = The energy absorbed from radiation by a person (mrem/year)

CDI = Chronic Daily Intake or Dose [pCi/year or pCi/m³]

DCF = Dose Conversion Factor [mrem/pCi or mrem/year per pCi/m³]

A_{eq} = Activity Equilibrium Factor of individual isotope

2.7 Comparison to State and UMTRCA Standards

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 that may be potential ARARs. The state standards are likely only for Rn-222. A preset value of 4 pCi/L of air is given, as it is the most common pCi/L value used in state standards. For the UMTRCA comparison option, a preset value of 0.02 working levels (WL) is given for Rn-222 and Rn-220. Alternative values can be entered for either of these standards on the first page of the calculator. For more information on evaluation of radon working levels, see section 2.4.

2.8 Problems Predicting the Activity of Radium, Thorium, and Actinium based on Radon, Thoron, and Actinon RVISLs

Ra-226, Th-232, and Ac-227 are the namesakes and the long-lived near chain member sources of Rn-222, Rn-

220, and Rn-219, respectively. In an ideal setting, the amount of solid source is directly related to the amount of gas product via the fractional decay of the parent. Ra-226 and Th-232 have a straight decay chain to Rn-222 and Rn-220, respectively. Ac-227 decay to Rn-219 is a branched decay chain; 98.6% of Ac-227 decays to Rn-219. Predicting the amount of radon gas available for vapor intrusion in the natural environment, however, is not an ideal setting. Several factors make it impossible for this calculator to confidently predict suitable default radon, thoron, and actinon target indoor air concentrations from subsurface (soil and groundwater) radium, thorium, and actinium concentrations. The IAEA has published Technical Report Series No. 474, [Measurement and Calculation of Radon Releases from NORM Residues](#), that addresses many of these difficulties.

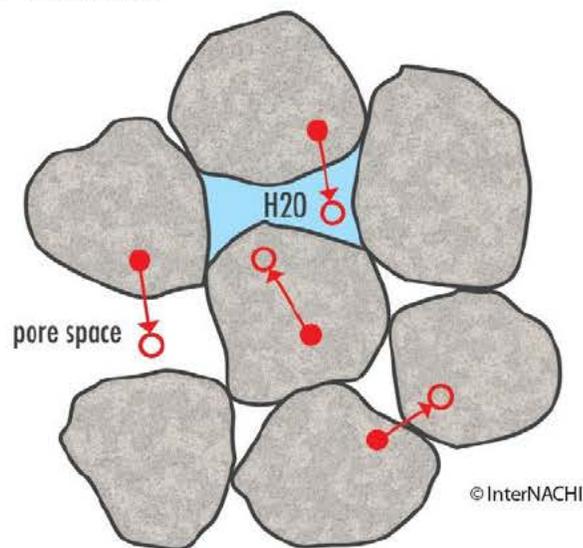
The newly formed radon atom must first escape from the ore material to the interstitial space between grains. This emanation happens when the recoil energy is sufficient for the radon atom to break from the ore grains. Once in the interstitial space, the radon must be able to be transported to the surface via diffusion and advective flow. Depending on the distance to the surface and media properties, the relatively short-lived radon may decay before exhalation to the atmosphere. Most recoiling atoms do not make it out of the ore material into the interstitial space and, because of the very small diffusion coefficient through dense minerals, even fewer atoms are likely to be exhaled to the atmosphere.

Emanation

Radon Within Mineral Grains

- Radium atom before it decays
- Newly formed radon atom

Most of the radon produced within a mineral grain remains embedded in the grain. Only about 10 to 50% escapes to enter the pore space. If the pore space is dry, the radon can remain there more easily. The radon atom may shoot across the pore and embed in another grain where it cannot move.



Detailed modeling of the subsurface environment may be possible to estimate the amount of a solid source that results in gaseous exhalation. One such model is the NORM And Legacy Site Assessment ([NORMALYSA](#)) software. This software is able to simulate transport from a source medium through clean cover layers to the surface. The [User's Manual](#) details how NORMALYSA employs emanation, diffusion, and exhalation to predict radon air concentrations. Chapters 2 and 4 of [TRS No. 474](#) present details on emanation coefficient determination that may be useful for site-specific analysis.

3. Using the RVISL Table

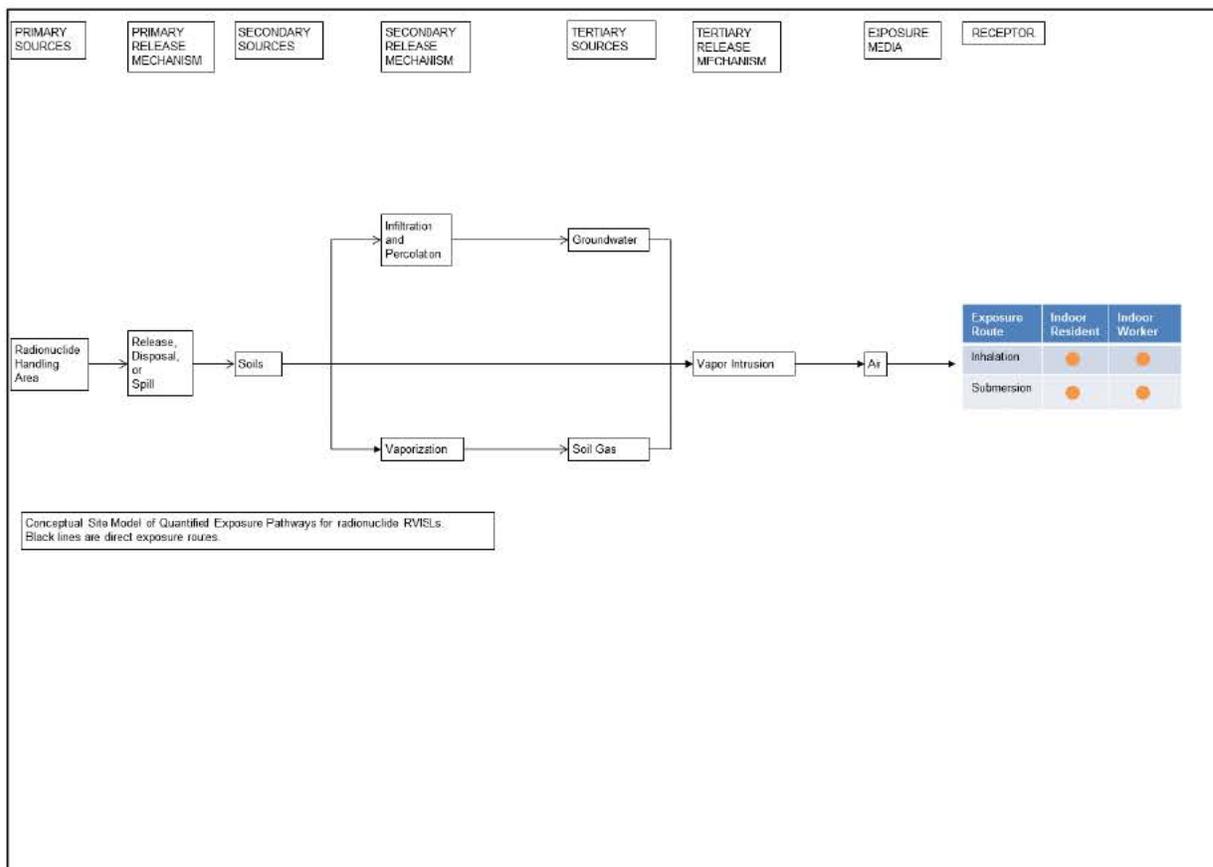
The tables in the [RVISL Download Area](#) provide generic concentrations in the absence of site-specific exposure assessments. Screening concentrations can be used for:

- Prioritizing multiple sites within a facility or exposure units
- Prioritizing risk-based detection limits for contaminants of potential concern (COPCs)
- Focusing future risk assessment efforts
- When appropriate for the site, considering as risk-based cleanup levels

3.1 Developing a Conceptual Site Model

When using RVISLs, the exposure pathways of concern and site conditions should match those taken into account by the screening levels. (Note, however, that future uses may not match current uses. Future uses of a site should logically be conditions that might occur at the site in the future.) Thus, it is necessary to develop a conceptual site model (CSM) to identify likely contaminant source areas, exposure pathways, and potential receptors. This information can be used to determine the applicability of screening levels at the site and the need for additional information. The final CSM diagram represents linkages among contaminant sources, release mechanisms, exposure pathways, and routes and receptors based on historical information. It summarizes the understanding of the contamination problem. [Part 2 and Attachment A](#) of the Soil Screening Guidance for Radionuclides: Users Guide (U.S. EPA 2000) contains the steps for developing a CSM.

A conceptual site model for the land uses presented in this calculator is presented below.



As a final check, the CSM should answer the following questions:

- Is there potential for land use other than those listed in the RVISL calculator (i.e., indoor resident and indoor worker)?
- Are there other likely human exposure pathways that were not considered in development of the RVISLs?
- Are there unusual site conditions (e.g., cracks in the foundation, large areas of contamination, high fugitive dust levels, increased potential for other sources of indoor radon contamination)?

The RVISLs may need to be adjusted to reflect the answers to these questions.

3.2 Background Radiation

Natural background radiation should be considered prior to applying RVISLs as cleanup levels. Background and site-related levels of radiation will be addressed as they are for other contaminants at CERCLA sites. The levels of each constituent of potential concern at a site typically are compared with background levels of those constituents to determine whether site activities have resulted in elevated levels. For example, background levels for radium-226 and radon-222 would generally not be relevant at a site if these radionuclides were not site-related contaminants. Remedial site risk-based cleanup levels for individual radionuclides generally are not set below site-specific background levels. When background levels exceed the remedial risk range, background levels may be selected as the cleanup levels. For further information on how to address background, see EPA's guidance "Role of Background in the CERCLA Cleanup Program", April 2002 (U.S. EPA, 2002a). It should be noted that certain ARARs specifically address how to factor background into cleanup levels. For example, some radiation ARAR levels are established as increments above background concentrations. In these circumstances, background should be addressed in the manner prescribed by the ARAR. The UMTRCA indoor radon standards under 40 CFR 192.12(b)(1) are inclusive of background.

3.2.1 Rn-222

[Uranium](#), naturally found in the earth, is called a primordial radionuclide and is one of the sources of terrestrial radiation. Uranium decays into radium, which decays to [radon-222](#). Radon-222 is commonly called radon after its parent radium. Trace amounts of uranium and its decay products can be found everywhere.

3.2.2 Rn-220

[Thorium](#), naturally found in the earth, is called a primordial radionuclide and is one of the sources of terrestrial radiation. Thorium decays to [radon-220](#). Radon-220 is commonly called thoron after its parent thorium. Trace amounts of thorium and its decay products can be found everywhere.

3.2.3 Rn-219

[Uranium](#), naturally found in the earth, is called a primordial radionuclide and is one of the sources of terrestrial radiation. A small fraction of uranium (0.72%) is isotope U-235. U-235 decays into actinium, which decays into radon-219. Radon-219 is commonly called actinon after its parent actinium. Trace amounts of uranium and its decay products can be found everywhere.

According to the [ATSDR Radon Toxicological Profile](#), radon-219 usually is not considered in the evaluation of

radon-induced health effects because it and its parent (U-235) are not abundant in the environment, and it has an extremely short half-life (4 seconds). Significant radon-219 risk or dose contribution would only be expected in unique circumstances.

3.3 Potential Problems and Limitations

As with any risk- or dose-based tool, the potential exists for misapplication. In most cases, this results from not understanding the intended use of the RVISLs. In order to prevent misuse of the RVISLs, the following should be avoided:

- Applying RVISL levels to a site without adequately developing a conceptual site model that identifies relevant exposure pathways and exposure scenarios.
- Use of RVISL levels as cleanup levels without verifying numbers with a health physicist/risk assessor.
- Use of outdated RVISL levels tables that have been superseded by more recent publications.
- Not considering the effects from the presence of multiple isotopes.
- Not considering the individual model limitations as described in section 2.1.

3.4 When Radon Measurement is Preferred

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, risk, or dose targets.

4. Radon Vapor Intrusion Screening Level Equations

This section presents the screening level equations for human exposure to contaminated air. The equations and technical discussion are aimed at developing compliance levels for risk-based and dose-based RVISLs. The following text presents the land use equations and their exposure routes. Table 1 (section 7 of the User's Guide) presents the definitions of the variables and their default values. The default values are selected to represent the reasonably maximum exposed (RME) individual and generally represent the upper bounds of exposure. The default values and exposure models are consistent with the Chemical Vapor Intrusion Screening Level (VISL) calculator if the same pathways are addressed (e.g., inhalation) and are analogous if pathways are similar (e.g., external exposure). This calculator and the [VISL](#) both follow the recommendations in the [OSWER Directive](#) concerning use of exposure parameters from the [2011 Exposure Factors Handbook](#). Any alternative values or assumptions used in remedy evaluation or selection on a CERCLA site should be presented with supporting rationale in Administrative Records.

4.1 Air Screening Level Equations

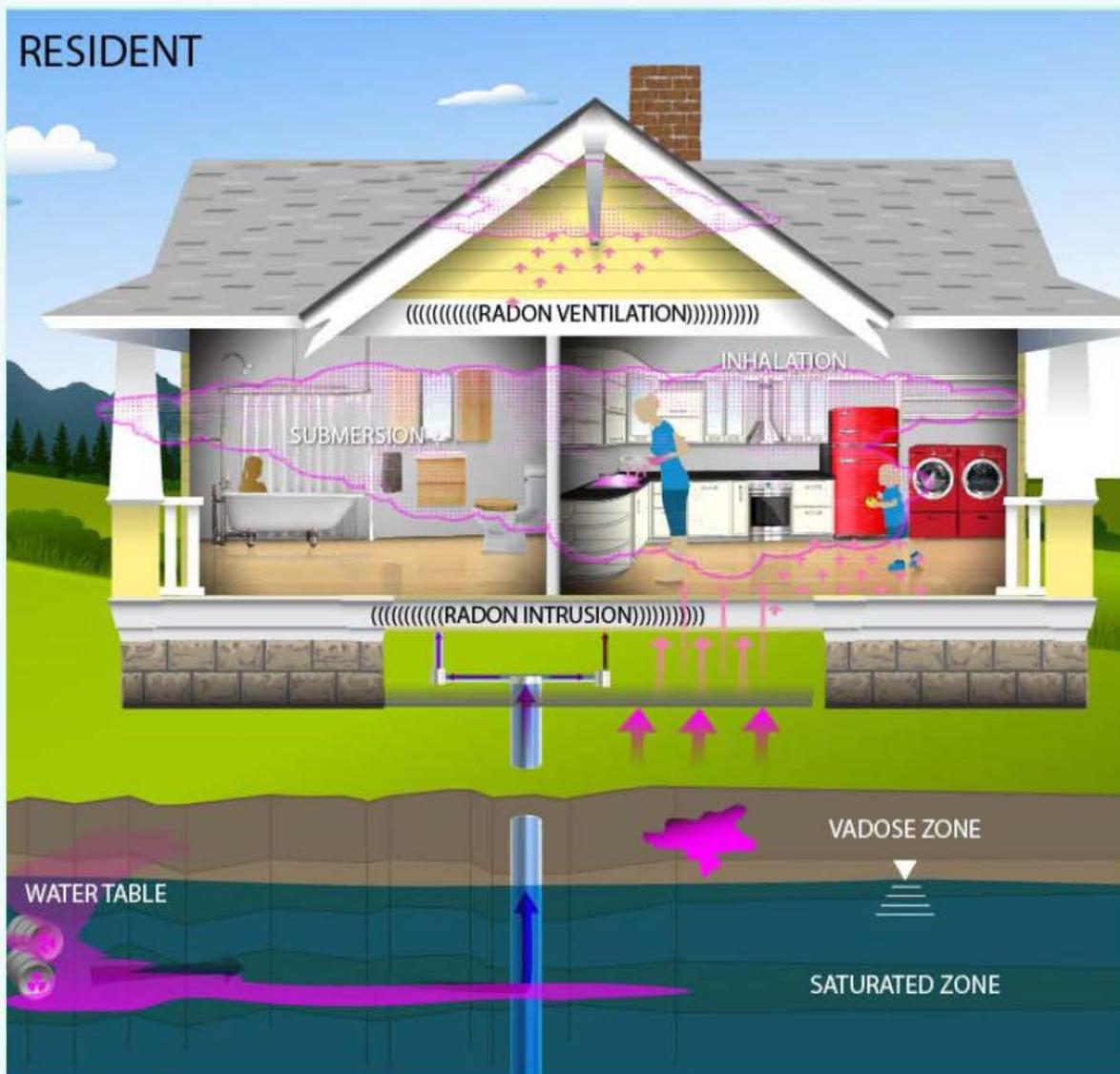
The user can select working level-based, risk-based or dose-based screening level type and either a resident or worker exposure scenario. The conversions to WLs based on the risk-based and dose-based RVISLs is also presented in the following sections.

4.1.1 Resident Air

This receptor spends all of the day at home. The resident is assumed to be exposed to contaminants via the

following pathways: inhalation of ambient air and external radiation from contaminants in ambient air. To take into account the different inhalation rates for children and adults, age-adjusted intake equations were developed to account for changes in intake as the receptor ages.

Graphical Representation



Working Level-Based Vapor Intrusion Screening Level Equation

This is the risk-based equation for determining the protective resident air concentration.

Inhalation

Radon - 222

$$C_{\text{res-ia-inh}} \left(\frac{\text{pCi}}{\text{L}} \right) = \left(\frac{\text{TWL}}{\left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{100 \text{ pCi}}{\text{L}} \right)} \right)} \right)$$

Radon - 220

$$C_{\text{res-ia-inh}} \left(\frac{\text{pCi}}{\text{L}} \right) = \left(\frac{\text{TWL}}{\left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{7.5 \text{ pCi}}{\text{L}} \right)} \right)} \right)$$

Radon - 219

$$C_{\text{res-ia-inh}} \left(\frac{\text{pCi}}{\text{L}} \right) = \left(\frac{\text{TWL}}{\left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{162 \text{ pCi}}{\text{L}} \right)} \right)} \right)$$

Risk-Based Vapor Intrusion Screening Level Equations

These are the risk-based equations for determining the protective resident air concentrations.

Inhalation

$$C_{\text{res-ia-inh-risk}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{\text{TR}}{\text{SF}_{\text{I}} \left(\frac{\text{risk/pCi}}{\text{pCi}} \right) \times \text{IFA}_{\text{res-adj}} \left(161,000 \text{ m}^3 \right)}$$

where:

$$\text{IFA}_{\text{res-adj-risk}} \left(161,000 \text{ m}^3 \right) = \left(\left(\text{EF}_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{res-c}} (6 \text{ years}) \times \text{ET}_{\text{res-c}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_{\text{res-c}} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \right) + \left(\text{EF}_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{res-a}} (20 \text{ years}) \times \text{ET}_{\text{res-a}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_{\text{res-a}} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \right) \right)$$

Submersion

$$C_{\text{res-ia-sub-risk}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{\text{TR}}{\text{SF}_{\text{sub}} \left(\frac{\text{risk/year}}{\text{pCi/m}^3} \right) \times \text{EF}_{\text{res}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times \text{ED}_{\text{res}} (26 \text{ years}) \times \text{ET}_{\text{res}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{GSF}_a (1.0)}$$

Total

$$C_{\text{res-ia-tot-risk}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\frac{1}{C_{\text{inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right)} + \frac{1}{C_{\text{sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right)}}$$

where:

$$C_{\text{inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\left(\sum_{i=1}^n \left[\frac{1}{\left(\frac{C_{\text{res-ia-inh-risk}} \left(\frac{\text{pCi}}{\text{m}^3} \right)_i}{A_{\text{eq}}} \right)} \right] \right)}$$

and:

$$C_{\text{sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\left(\sum_{i=1}^n \left[\frac{1}{\left(\frac{C_{\text{res-ia-sub-risk}} \left(\frac{\text{pCi}}{\text{m}^3} \right)_i}{A_{\text{eq}}} \right)} \right] \right)}$$

where:

n = the number of progeny in the decay series

Inhalation Working Level Conversions

Radon - 222

$$C_{\text{res-ia-inh-wl}} (\text{WL}) = C_{\text{res-ia-inh-risk}} \left(\frac{\text{pCi}}{\text{L}} \right) \times \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{100 \text{ pCi}}{\text{L}} \right)} \right)$$

Radon - 220

$$C_{\text{res-ia-inh-wl}} (\text{WL}) = C_{\text{res-ia-inh-risk}} \left(\frac{\text{pCi}}{\text{L}} \right) \times \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{7.5 \text{ pCi}}{\text{L}} \right)} \right)$$

Radon - 219

$$C_{\text{res-ia-inh-wl}} (\text{WL}) = C_{\text{res-ia-inh-risk}} \left(\frac{\text{pCi}}{\text{L}} \right) \times \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{162 \text{ pCi}}{\text{L}} \right)} \right)$$

Dose-Based Vapor Intrusion Screening Level Equations

These are the dose-based equations for determining the protective resident air concentrations.

Inhalation

$$C_{\text{res-ia-inh-dose}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{\text{TDL} \left(\frac{\text{mrem}}{\text{year}} \right)}{\text{DCF}_i \left(\frac{\text{mrem}}{\text{pCi}} \right) \times \text{IFA}_{\text{res-adj}} \left(\frac{6,195 \text{ m}^3}{\text{year}} \right)}$$

where:

$$\text{IFA}_{\text{res-adj-dose}} \left(\frac{6,195 \text{ m}^3}{\text{year}} \right) = \left(\left(\text{EF}_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \text{ET}_{\text{res-c}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_{\text{res-c}} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \times \text{AAF}_{\text{res-c}}(0.23) \right) + \left(\text{EF}_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \text{ET}_{\text{res-a}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_{\text{res-a}} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \times \text{AAF}_{\text{res-a}}(0.77) \right) \right)$$

where:

$$\text{AAF}_{\text{res-c}}(0.23) = \left(\frac{\text{ED}_{\text{res-c}}(6 \text{ years})}{\text{ED}_{\text{res}}(26 \text{ years})} \right) \text{ and } \text{AAF}_{\text{res-a}}(0.77) = \left(\frac{\text{ED}_{\text{res-a}}(20 \text{ years})}{\text{ED}_{\text{res}}(26 \text{ years})} \right)$$

Submersion

$$C_{\text{res-ia-sub-dose}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{\text{TDL} \left(\frac{\text{mrem}}{\text{year}} \right)}{\text{DCF}_{\text{sub}} \left(\frac{\text{mrem/year}}{\text{pCi/m}^3} \right) \times \text{EF}_{\text{res}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times \text{ET}_{\text{res}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{GSF}_a(1.0)}$$

Total

$$C_{\text{res-ia-tot-dose}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\frac{1}{C_{\text{inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right)} + \frac{1}{C_{\text{sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right)}}$$

where:

$$C_{\text{inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\left(\sum_{i=1}^n \frac{1}{\left(\frac{C_{\text{res-ia-inh-dose}} \left(\frac{\text{pCi}}{\text{m}^3} \right)_i}{A_{\text{eq}}} \right)} \right)}$$

and:

$$C_{\text{sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\left(\sum_{i=1}^n \frac{1}{\left(\frac{C_{\text{res-ia-sub-dose}} \left(\frac{\text{pCi}}{\text{m}^3} \right)_i}{A_{\text{eq}}} \right)} \right)}$$

where:

n = the number of progeny in the decay series

Inhalation Working Level Conversions

Radon - 222

$$C_{\text{res-ia-inh-wl}}(\text{WL}) = C_{\text{res-ia-inh-dose}} \left(\frac{\text{pCi}}{\text{L}} \right) \times \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{100 \text{ pCi}}{\text{L}} \right)} \right)$$

Radon - 220

$$C_{\text{res-ia-inh-wl}}^{\text{(WL)}} = C_{\text{res-ia-inh-dose}} \left(\frac{\text{pCi}}{\text{L}} \right) \times \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{7.5 \text{ pCi}}{\text{L}} \right)} \right)$$

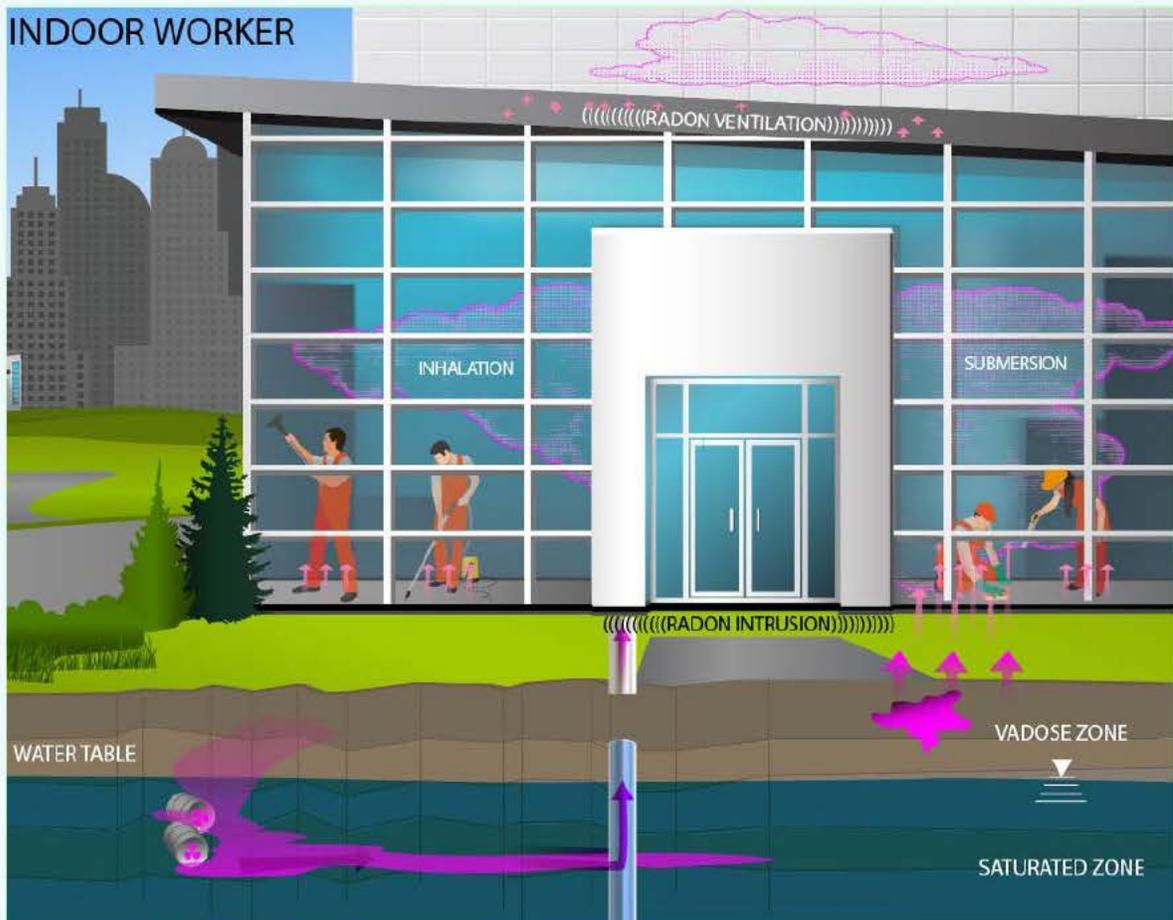
Radon - 219

$$C_{\text{res-ia-inh-wl}}^{\text{(WL)}} = C_{\text{res-ia-inh-dose}} \left(\frac{\text{pCi}}{\text{L}} \right) \times \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{162 \text{ pCi}}{\text{L}} \right)} \right)$$

4.1.2 Worker Air

This long-term receptor is a full time employee working on-site who spends 8 hours of the workday indoors. The indoor worker is assumed to be exposed to contaminants via the following pathways: inhalation of ambient air and external radiation from contaminants in ambient air.

Graphical Representation



Working Level-Based Vapor Intrusion Screening Level Equation

This is the risk-based equation for determining the protective industrial air concentration.

Inhalation

Radon - 222

$$C_{w-ia-inh} \left(\frac{\text{pCi}}{\text{L}} \right) = \left(\frac{\text{TWL}}{\left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{100 \text{ pCi}}{\text{L}} \right)} \right)} \right)$$

Radon - 220

$$C_{w-ia-inh} \left(\frac{\text{pCi}}{\text{L}} \right) = \left(\frac{\text{TWL}}{\left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{7.5 \text{ pCi}}{\text{L}} \right)} \right)} \right)$$

Radon - 219

$$C_{w-ia-inh} \left(\frac{\text{pCi}}{\text{L}} \right) = \left(\frac{\text{TWL}}{\left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{162 \text{ pCi}}{\text{L}} \right)} \right)} \right)$$

Risk-Based Vapor Intrusion Screening Level Equations

These are the risk-based equations for determining the protective industrial air concentrations.

Inhalation

$$C_{w-ia-inh-risk} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{\text{TR}}{\text{SF}_i \left(\frac{\text{risk}}{\text{pCi}} \right) \times \text{EF}_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \text{ED}_w (25 \text{ years}) \times \text{ET}_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IR}_{A_w} \left(\frac{60 \text{ m}^3}{\text{day}} \right)}$$

Submersion

$$C_{w-ia-sub-risk} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{\text{TR}}{\text{SF}_{sub} \left(\frac{\text{risk/year}}{\text{pCi/m}^3} \right) \times \text{EF}_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times \text{ED}_w (25 \text{ years}) \times \text{ET}_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{GSF}_a (1.0)}$$

Total

$$C_{w-ia-tot-risk} \left(\frac{pCi}{m^3} \right) = \frac{1}{\frac{1}{C_{inh} \left(\frac{pCi}{m^3} \right)} + \frac{1}{C_{sub} \left(\frac{pCi}{m^3} \right)}}$$

where:

$$C_{inh} \left(\frac{pCi}{m^3} \right) = \frac{1}{\left(\sum_{i=1}^n \frac{1}{\left(\frac{C_{w-ia-inh-risk} \left(\frac{pCi}{m^3} \right)_i}{A_{eq}} \right)} \right)}$$

and:

$$C_{sub} \left(\frac{pCi}{m^3} \right) = \frac{1}{\left(\sum_{i=1}^n \frac{1}{\left(\frac{C_{w-ia-sub-risk} \left(\frac{pCi}{m^3} \right)_i}{A_{eq}} \right)} \right)}$$

where:

n = the number of progeny in the decay series

Inhalation Working Level Conversions

Radon - 222

$$C_{w-ia-inh-wl}^{(WL)} = C_{w-ia-inh-risk} \left(\frac{pCi}{L} \right) \times \left(\frac{F_{eq} \times 1 WL}{\left(\frac{100 pCi}{L} \right)} \right)$$

Radon - 220

$$C_{w-ia-inh-wl}^{(WL)} = C_{w-ia-inh-risk} \left(\frac{pCi}{L} \right) \times \left(\frac{F_{eq} \times 1 WL}{\left(\frac{7.5 pCi}{L} \right)} \right)$$

Radon - 219

$$C_{w-ia-inh-wl}^{(WL)} = C_{w-ia-inh-risk} \left(\frac{pCi}{L} \right) \times \left(\frac{F_{eq} \times 1 WL}{\left(\frac{162 pCi}{L} \right)} \right)$$

Dose-Based Vapor Intrusion Screening Level Equations

These are the dose-based equations for determining the protective industrial air concentrations.

Inhalation

$$C_{w-ia-inh-dose} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{\text{TDL} \left(\frac{\text{mrem}}{\text{year}} \right)}{\text{DCF}_i \left(\frac{\text{mrem}}{\text{pCi}} \right) \times \text{EF}_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \text{ET}_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IR}_{A_w} \left(\frac{60 \text{ m}^3}{\text{day}} \right)}$$

Submersion

$$C_{w-ia-sub-dose} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{\text{TDL} \left(\frac{\text{mrem}}{\text{year}} \right)}{\text{DCF}_{\text{sub}} \left(\frac{\text{mrem}/\text{year}}{\text{pCi}/\text{m}^3} \right) \times \text{EF}_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times \text{ET}_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{GSF}_a (1.0)}$$

Total

$$C_{w-ia-tot-dose} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\frac{1}{C_{inh} \left(\frac{\text{pCi}}{\text{m}^3} \right)} + \frac{1}{C_{sub} \left(\frac{\text{pCi}}{\text{m}^3} \right)}}$$

where:

$$C_{inh} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\sum_{i=1}^n \left(\frac{C_{w-ia-inh-dose} \left(\frac{\text{pCi}}{\text{m}^3} \right)_i}{A_{eq}} \right)}$$

and:

$$C_{sub} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\sum_{i=1}^n \left(\frac{C_{w-ia-sub-dose} \left(\frac{\text{pCi}}{\text{m}^3} \right)_i}{A_{eq}} \right)}$$

where:

n = the number of progeny in the decay series

Inhalation Working Level Conversions

Radon - 222

$$C_{w-ia-inh-wl}^{(WL)} = C_{w-ia-inh-dose} \left(\frac{\text{pCi}}{\text{L}} \right) \times \left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{100 \text{ pCi}}{\text{L}} \right)} \right)$$

Radon - 220

$$C_{w-ia-inh-wl}^{(WL)} = C_{w-ia-inh-dose} \left(\frac{\text{pCi}}{\text{L}} \right) \times \left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{7.5 \text{ pCi}}{\text{L}} \right)} \right)$$

$$C_{w-ia-inh-wl}^{(WL)} = C_{w-ia-inh-dose} \left(\frac{pCi}{L} \right) \times \left(\frac{F_{eq} \times 1 WL}{\left(\frac{162 pCi}{L} \right)} \right)$$

4.2 Groundwater Screening Level Equation

This equation is used to determine the groundwater concentration protective of exposure to indoor air. The equation uses a groundwater attenuation factor and H' . For a groundwater source, a chemical is considered sufficiently volatile and toxic to pose an inhalation risk through vapor intrusion if the vapor concentration (calculated using the chemical's Henry's Law Constant at the groundwater temperature) corresponding to the chemical's solubility limit in water is greater than the target indoor air concentration. The groundwater attenuation factor is not considered in this comparison, although it is considered in the subsequent calculation of the target groundwater concentration. The target groundwater concentration corresponding to a chemical's target indoor air concentration is calculated by dividing the target indoor air concentration by an attenuation factor of 0.001 and then converting the vapor concentration to an equivalent groundwater concentration, assuming equilibrium between the aqueous and vapor phases at the water table. The equilibrium partitioning is assumed to obey Henry's Law.

The groundwater attenuation factor and the soil gas attenuation factors are never combined in this calculator.

$$C_{gw,Target} \left(\frac{pCi}{L} \right) = \frac{C_{i,a,Target} \left(\frac{pCi}{m^3} \right)}{AF_{gw} \times \left(1000 \frac{L}{m^3} \right) \times H'}$$

4.3 Soil Gas Screening Level Equation

This equation is used to determine the soil gas concentration protective of exposure to indoor air. The soil gas attenuation factor used in the calculations is 0.03, which is the generic attenuation factor used for sub-slab gas in the 2002 draft vapor intrusion guidance. This attenuation factor is used for all soil gas data, as additional information collected after development of the 2002 draft vapor intrusion guidance (U.S. EPA 2002b) suggests that external soil gas samples need to be evaluated as conservatively as sub-slab gas samples (U.S. EPA 2010).

The groundwater attenuation factor and the soil gas attenuation factors are never combined in this calculator.

$$C_{sg,Target} \left(\frac{pCi}{m^3} \right) = \frac{C_{i,a,Target} \left(\frac{pCi}{m^3} \right)}{AF_{ss}}$$

4.4 Vapor Intrusion Screening Level Supporting Equations

Chemicals must be sufficiently volatile and toxic to pose inhalation risk via vapor intrusion from soil and groundwater sources. This is determined by calculating the chemical's pure phase vapor concentration and the groundwater vapor concentration. The soil gas vapor concentration and the groundwater vapor concentration must be greater than the air screening level to determine a VISL. No equations are necessary for radon as they would be for other chemicals.

- **Pure Phase Vapor Pressure**

Radon and Thoron are considered sufficiently volatile and toxic to pose inhalation and external exposure risk via vapor intrusion from a soil source.

- **Groundwater Vapor Concentration**

Radon and Thoron are considered sufficiently volatile and toxic to pose inhalation and external exposure risk via vapor intrusion from a groundwater source.

5. Predicting WL, ELCR, and Annual Dose from Indoor Air Concentration

This section presents the equations used to calculate the indoor air concentration, cancer risk, and dose from the user-provided soil gas and/or groundwater concentration. The equations and technical discussion are aimed at developing compliance levels for risk-based and dose-based RVISLs. The following text presents the land use equations and their exposure routes. Table 1 (section 7 of the User's Guide) presents the definitions of the variables and their default values. The default values are selected to represent the reasonably maximum exposed (RME) individual and generally represent the upper bounds of exposure. The default values and exposure models are consistent with the Chemical Vapor Intrusion Screening Level (VISL) calculator if the same pathways are addressed (e.g., inhalation) and are analogous if pathways are similar (e.g., external exposure). This calculator and the [VISL](#) both follow the recommendations in the [OSWER Directive](#) concerning use of exposure parameters from the [2011 Exposure Factors Handbook](#). Any alternative values or assumptions used in remedy evaluation or selection on a CERCLA site should be presented with supporting rationale in Administrative Records.

5.1 WL, ELCR, and Annual Dose from Indoor Air Concentrations

This section presents the equations to calculate working levels from radon concentrations in air. Also presented, are the equations to calculate excess lifetime cancer risk (ELCR) and annual dose based on chronic daily intakes (CDI) from radon and progeny concentrations in air.

5.1.1 WL Calculation

These are the equations for calculating WLs for each of the Rn-222, Rn-220, and Rn-219.

Radon - 222

$$WL = C_{i,a} \left(\frac{\text{pCi}}{\text{L}} \right) \times \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{100 \text{ pCi}}{\text{L}} \right)} \right)$$

Radon - 220

$$WL = C_{i,a} \left(\frac{\text{pCi}}{\text{L}} \right) \times \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{7.5 \text{ pCi}}{\text{L}} \right)} \right)$$

Radon - 219

$$WL = C_{i,a} \left(\frac{\text{pCi}}{\text{L}} \right) \times \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{162 \text{ pCi}}{\text{L}} \right)} \right)$$

5.1.2 ELCR Calculation

These are the equations for calculating ELCR and CDIs.

5.1.2.1 ELCR

$$ELCR_{\text{tot}} = ELCR_{\text{inh}} + ELCR_{\text{sub}}$$

where:

$$ELCR_{\text{inh}} = \sum_{i=1}^n \left(\text{CDI}(\text{pCi}) \times \text{SF}_i \left(\frac{\text{risk}}{\text{pCi}} \right) \times A_{\text{eq}} \right)_i$$

and:

$$ELCR_{\text{sub}} = \sum_{i=1}^n \left(\text{CDI} \left(\frac{\text{pCi-year}}{\text{m}^3} \right) \times \text{SF}_{\text{sub}} \left(\frac{\text{risk/year}}{\text{pCi/m}^3} \right) \times A_{\text{eq}} \right)_i$$

where:

i = the number of progeny in the decay series

5.1.2.2 Resident Air CDIs

Inhalation

$$\text{CDI}_{\text{res-ia-inh-risk}} (\text{pCi}) = C_{i,a} \left(\frac{\text{pCi}}{\text{m}^3} \right) \times \text{IFA}_{\text{res-adj}} (161,000 \text{ m}^3)$$

where:

$$\text{IFA}_{\text{res-adj-risk}} (161,000 \text{ m}^3) = \left[\left(\text{EF}_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{res-c}} (6 \text{ years}) \times \text{ET}_{\text{res-c}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_{\text{res-c}} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \right) + \left(\text{EF}_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{res-a}} (20 \text{ years}) \times \text{ET}_{\text{res-a}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_{\text{res-a}} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \right) \right]$$

Submersion

$$\text{CDI}_{\text{res-ia-sub-risk}} \left(\frac{\text{pCi-year}}{\text{m}^3} \right) = C_{i,a} \left(\frac{\text{pCi}}{\text{m}^3} \right) \times \text{EF}_{\text{res}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times \text{ED}_{\text{res}} (26 \text{ years}) \times \text{ET}_{\text{res}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{SF}_a (1.0)$$

5.1.2.3 Worker Air CDIs

Inhalation

$$\text{CDI}_{\text{wia-inh-risk}} (\text{pCi}) = C_{i,a} \left(\frac{\text{pCi}}{\text{m}^3} \right) \times \text{EF}_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \text{ED}_w (25 \text{ years}) \times \text{ET}_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_w \left(\frac{60 \text{ m}^3}{\text{day}} \right)$$

Submersion

$$CDI_{w-ia-sub-risk} \left(\frac{pCi\text{-year}}{m^3} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ yr}}{365 \text{ day}} \right) \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

5.1.3 Annual Dose Calculation

These are the equations for calculating annual dose and CDIs.

5.1.3.1 Annual Dose

$$Dose_{tot} \left(\frac{mrem}{\text{year}} \right) = Dose_{inh} \left(\frac{mrem}{\text{year}} \right) + Dose_{sub} \left(\frac{mrem}{\text{year}} \right)$$

where:

$$Dose_{inh} \left(\frac{mrem}{\text{year}} \right) = \sum_{i=1}^n \left(CDI \left(\frac{pCi}{\text{year}} \right) \times DCF_i \left(\frac{mrem}{pCi} \right) \times A_{eq} \right)_i$$

and:

$$Dose_{sub} \left(\frac{mrem}{\text{year}} \right) = \sum_{i=1}^n \left(CDI \left(\frac{pCi}{m^3} \right) \times DCF_{sub} \left(\frac{mrem/\text{year}}{pCi/m^3} \right) \times A_{eq} \right)_i$$

where:

i = the number of progeny in the decay series

5.1.3.2 Resident Air CDIs

Inhalation

$$CDI_{res-ia-inh-dose} \left(\frac{pCi}{\text{year}} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times IFA_{res-adj} \left(\frac{6,195 m^3}{\text{year}} \right)$$

where:

$$IFA_{res-adj-dose} \left(\frac{6,195 m^3}{\text{year}} \right) = \left(\left(EF_{res-c} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ET_{res-c} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-c} \left(\frac{10 m^3}{\text{day}} \right) \times AAF_{res-c} (0.23) \right) + \left(EF_{res-a} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ET_{res-a} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-a} \left(\frac{20 m^3}{\text{day}} \right) \times AAF_{res-a} (0.77) \right) \right)$$

where:

$$AAF_{res-c} (0.23) = \left(\frac{ED_{res-c} (6 \text{ years})}{ED_{res} (26 \text{ years})} \right) \text{ and } AAF_{res-a} (0.77) = \left(\frac{ED_{res-a} (20 \text{ years})}{ED_{res} (26 \text{ years})} \right)$$

Submersion

$$CDI_{res-ia-sub-dose} \left(\frac{pCi}{m^3} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times EF_{res} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ET_{res} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

5.1.3.3 Worker Air CDIs

Inhalation

$$CDI_{w-ia-inh-dose} \left(\frac{pCi}{\text{year}} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_w \left(\frac{60 m^3}{\text{day}} \right)$$

Submersion

$$CDI_{w-ia-sub-dose} \left(\frac{pCi}{m^3} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

5.2 Indoor Air Concentration from Groundwater Concentration Equation

This section presents the equation used to calculate the indoor air concentration from the user-provided groundwater concentration.

$$C_{i,a} \left(\frac{\text{pCi}}{\text{m}^3} \right) = C_{gw} \left(\frac{\text{pCi}}{\text{L}} \right) \times AF_{gw} \times \left(1000 \frac{\text{L}}{\text{m}^3} \right) \times H'_{gw}$$

5.3 Indoor Air Concentration from Soil Gas Concentration Equation

This section presents the equation used to calculate the indoor air concentration from the user-provided soil gas concentration.

$$C_{i,a} \left(\frac{\text{pCi}}{\text{m}^3} \right) = C_{sg} \left(\frac{\text{pCi}}{\text{m}^3} \right) \times AF_{ss}$$

6. Modifications of Standard Equation Inputs

The following sections describe the process to change specific standard equation inputs.

6.1 Modifications of Groundwater Temperatures

Users are given the option to change groundwater-soil system temperature from the default of 25°C to a site-specific value. Since the unitless Henry's Law Constant (H') is derived based on the partial pressure of a gas in equilibrium with a liquid and the equilibrium changes when temperature changes, H' is changed to reflect the equilibrium at the given temperature. The equation below illustrates how H' is derived when groundwater temperature is changed. An EPA Fact Sheet describing the process can be found at <https://www.epa.gov/vaporintrusion/fact-sheet-correcting-henrys-law-constant-temperature>.

The following equations are used to calculate Henry's Law Constant at various groundwater temperatures:

- **To Determine Henry's Law Constant at a Groundwater Temperature other than 25 Degrees Celsius**

$$C_{sv} \left(\frac{\text{pCi}}{\text{cm}^3\text{-v}} \right) = H'_{TS} \times C_w \left(\frac{\text{pCi}}{\text{cm}^3\text{-v}} \right)$$

$$H' = \left(\frac{\exp \left[- \frac{\Delta H_{v,w} \left(\frac{\text{cal}}{\text{mol}} \right)}{R_c (1.9872 \text{ cal/mol}\cdot\text{K})} \times \left(\frac{1}{T_w (\text{K})} - \frac{1}{T_R (298.15 \text{ K})} \right) \right] \times \text{HLC} \left(\text{atm}\cdot\text{m}^3/\text{mol} \right)}{R \left(8.205\text{E-}05 \text{ atm}\cdot\text{m}^3/\text{mol}\cdot\text{K} \right) \times T_w (\text{K})} \right)$$

where:

$$T_w (\text{K}) = T_w (^\circ\text{C}) + 273.15$$

and:

$$\Delta H_{v,w} \left(\frac{\text{cal}}{\text{mol}} \right) = \Delta H_{v,b} \left(\frac{\text{cal}}{\text{mol}} \right) \times \left[\frac{1 - T_w (\text{K})/T_c (\text{K})}{1 - T_b (\text{K})/T_c (\text{K})} \right]^\eta$$

where:

$$\text{IF } \left(\frac{T_b}{T_c} \right) < 0.57, \text{ then: } \eta = 0.3;$$

$$\text{IF } \left(\frac{T_b}{T_c} \right) > 0.71, \text{ then: } \eta = 0.41;$$

$$\text{IF } 0.57 < \left(\frac{T_b}{T_c} \right) \leq 0.71, \text{ then: } \eta = \left(0.74 \times \left(\frac{T_b}{T_c} \right) - 0.116 \right)$$

- **To Determine Henry's Law Constant at a Groundwater Temperature of 25 Degrees Celsius**

$$H_{25} = \frac{\text{HLC} \left(\text{atm}\cdot\text{m}^3/\text{mol}\cdot\text{K} \right) \times \left(1000 \text{ L}/\text{m}^3 \right)}{R \left(8.205\text{E-}05 \text{ L}\cdot\text{atm}/\text{mol}\cdot\text{K} \right) \times T (298.15 \text{ K})}$$

6.2 Air Exchange Rates and Inhalation Fractional Equilibrium Factor (F_{eq})

The indoor air concentration of radon and progeny is dependent upon the air exchange rate within a given volume. The air exchange rate, otherwise known as air changes per hour (ACH), is defined as the ratio of airflow to the total volume of air. As an example, an ACH value of 0.18 would mean that eighteen percent of a given volume of air is exchanged per hour. The air exchange rate is related to an important parameter known as the inhalation fractional equilibrium factor (F_{eq}) for estimating the level of detriment from radon inhalation. F_{eq} has been researched for radon and thoron in various dwellings for many years (Chen & Harley, 2018 Parts I and II). The F_{eq} is a unitless measurement of the disequilibrium associated with the decay of radon and its subsequent progeny. The F_{eq} is useful for calculating the internal dose from radon, since most of the dose received is not from the radon parent itself but rather the alpha energies emitted from its progeny. The total progeny alpha energy emitted at any air exchange rate is divided by the total progeny alpha energy emitted at a state of equilibrium where no air exchanges are taking place within a given volume

of air. At equilibrium, the value of the F_{eq} is equal to one; however, a F_{eq} of one is seldom measured due to conditions described in Section 2.1 and deposition on surfaces. As the air exchange rate in a given volume increases, the fractional equilibrium factor decreases. The F_{eq} is only used in the working level (WL) conversions presented in Sections 2.4, 4.1.2, and 4.2.2. A more detailed explanation of the F_{eq} derivation is presented in [ORNL 2020](#).

6.3 Air Exchange Rates and Activity Equilibrium Factor (A_{eq})

The activity equilibrium factor (A_{eq}) is defined as the ratio of progeny to parent activity concentrations at a given air exchange rate. For a straight decay chain, at zero air exchanges, the (A_{eq}) is equal to one and decreases as the air exchange rate increases. An A_{eq} of one, however, is seldom measured due to conditions described in Section 2.1 and deposition on surfaces. The activity equilibrium factor is utilized in the RVISL air equations to calculate risk and dose for inhalation and submersion. The initial risks and doses (analogous to PRGs) assume that the radon decay chain members are in equilibrium with each other without any air exchanges present. Therefore, the activity equilibrium factors modify the initial risks and doses for inhalation and submersion by accounting for the disequilibrium between radon and its progeny due to decay and air exchanges that are present. A default value of 0.18 air exchanges per hour was selected for the resident land use, and a default value of 0.6 air exchanges per hour for the industrial worker land use was selected from the "Update for Chapter 19 of the Exposure Factors Handbook" (U.S. EPA, 2018) for resident (Table 19-25) and commercial (Table 19-30) buildings using the tenth percentile values. This means 90% of structures would have a higher air exchange rate and thus a lower level of progeny, which would result in less risk, dose, and WL. Users that may want to determine the air exchange rate for a particular building to justify changing the default should refer to section 6.4 of the User Guide. A more detailed explanation of the A_{eq} derivation is presented in [ORNL 2020](#).

6.4 Measurement of Air Exchange Rates

The ACH can be a building-specific measurement, to provide a more accurate air contamination exposure assessment. The ACH is the exchange rate of indoor air with outdoor air, an important determinant for entry of outdoor air contaminants and for removal of indoor-emitted air contaminants. There is no EPA guidance on recommended methods for determining ACH. Breen (2014) presents an overview and critical analysis of the scientific literature on empirical and physical air exchange rate models for residential and commercial buildings, which are feasible for exposure assessments. Models are included for the three types of airflows that can occur across building envelopes: leakage, natural ventilation, and mechanical ventilation. The paper provides guidance for selecting the preferable air exchange rate model based on available data, desired temporal resolution, types of airflows, and types of buildings included in the exposure assessment. The US EPA [Indoor Air Quality website](#) also provides information on HVAC use in buildings. There are also more detailed papers on particular air exchange measurement approaches (i.e., by placing tubes that emit and collect perfluorocarbon tracers throughout a building) (Breen 2014). Guidance on placement of the tubes can be found in "[Research Operating Procedure 10 for Placement of PFT Emitters and Collection Tubes in DEARS](#)" (Thornburg, 2015).

6.5 Modification of Attenuation Factors

The default attenuation factors can be substituted for site-specific attenuation factors if underlying site

conditions are known. [EPA 2012](#) presents site-specific attenuation factors for sub-slab soil gas, groundwater, and crawlspaces for chemicals. The attenuation factors are summarized in the following table. The defaults used in the RVISL calculator are highlighted. The defaults are based on the 95th percentile and are appropriate for adjusting an RME scenario. The 50th percentile values would be more appropriate for a central tendency exposure scenario where a large amount of sampling data is available to reduce uncertainty in calculating the exposure concentration or defining nature and extent of the source term.

Subslab Soil Gas Attenuation Factors		
Residence Type	Median (50 th percentile)	95 th Percentile
All residences	3E-03 (0.003)	3E-02 (0.03)*
Residences with basements	3E-03 (0.003)	3E-02 (0.03)
Residences with slab-on-grade	3E-03 (0.003)	1E-02 (0.01)
Groundwater Attenuation Factors		
Scenario	Median (50 th percentile)	95 th Percentile
All soil types and water depths	7E-05 (0.00007)	1E-03 (0.001)*
Fine soil type	5E-05 (0.00005)	5E-04 (0.0005)
Coarse soil type	1E-04 (0.0001)	1E-03 (0.001)
Very coarse soil type	2E-04 (0.0002)	4E-03 (0.004)
Depth to water < 1.5 m	6E-04 (0.0006)	7E-03 (0.007)
Depth to water 1.5-3 m	1E-04 (0.0001)	2E-03 (0.002)
Depth to water 3-5 m	4E-05 (0.00004)	2E-03 (0.002)
Depth to water > 5 m	5E-05 (0.00005)	6E-04 (0.0006)
Exterior Soil Gas Attenuation Factors		
Scenario	Median (50 th percentile)	95 th Percentile

All residences	4E-03 (0.004)	3E-01 (0.3)
Crawlspace Attenuation Factor		
Scenario	Median (50th percentile)	95th Percentile
All residences	4E-01 (0.4)	9E-01 (0.9)

*These are the VISL and RVISL defaults.

7. Recommended Default Exposure Parameters

Table 1 presents the definitions of the variables and their default values. The default values are selected to represent the reasonably maximum exposed (RME) individual and generally represent the upper bounds of exposure. The RVISL default values and exposure models are consistent with the chemical [VISL](#) calculator. The VISL and RVISL calculator default values are consistent where the same pathways are addressed. This calculator follows the recommendations in the [OSWER Directive](#) concerning use of exposure parameters from the [2011 Exposure Factors Handbook](#). Any alternative values or assumptions used in remedy evaluation or selection on a CERCLA site should be presented with supporting rationale in Administrative Records.

Table 1. Recommended Default Exposure Parameters

Radon Vapor Intrusion Levels			
Symbol ▼	Definition (units) ▼	Default ▼	Reference ▼
$C_{gw, Target}$	Target Groundwater Screening Level (pCi/L)	Isotope-Specific	Determined in this calculator
$C_{res-ia-inh}$	Resident Air Inhalation (WL)	Isotope-specific	Determined in this calculator
$C_{res-ia-inh-dose}$	Resident Air Inhalation (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{res-ia-inh-risk}$	Resident Air Inhalation (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{res-ia-inh-wl}$	Resident Air Inhalation (pCi/L) Conversion to Working Level (WL)	Isotope-specific	Determined in this calculator

$C_{res-ia-sub-dose}$	Resident Air Submersion (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{res-ia-sub-risk}$	Resident Air Submersion (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{res-ia-tot-dose}$	Resident Air Total (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{res-ia-tot-risk}$	Resident Air Total (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{sg, Target}$	Target Soil Gas Screening Level (pCi/m ³)	Isotope-Specific	Determined in this calculator
$C_{w-ia-inh}$	Worker Air Inhalation (WL)	Isotope-specific	Determined in this calculator
$C_{w-ia-inh-dose}$	Worker Air Inhalation (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-inh-risk}$	Worker Air Inhalation (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-inh-wl}$	Worker Air Inhalation (pCi/m ³) Conversion Working Level (WL)	Isotope-specific	Determined in this calculator
$C_{w-ia-sub-dose}$	Worker Air Submersion (pCi-year/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-sub-risk}$	Worker Air Submersion (pCi-year/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-tot-dose}$	Worker Air Total (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-tot-risk}$	Worker Air Total (pCi/m ³)	Isotope-specific	Determined in this calculator

Radon Chronic Daily Intakes

--	--	--	--

Symbol ▼	Definition (units) ↗	Default ↗	Reference ↗
$CDI_{res-ia-sub-dose}$	Resident Air Submersion (pCi/m ³)	Isotope-specific	Determined in this calculator
$CDI_{res-ia-sub-risk}$	Resident Air Submersion (pCi-year/m ³)	Isotope-specific	Determined in this calculator
$CDI_{w-ia-inh-dose}$	Worker Air Inhalation (pCi/year)	Isotope-specific	Determined in this calculator
$CDI_{w-ia-inh-risk}$	Worker Air Inhalation (pCi)	Isotope-specific	Determined in this calculator
$CDI_{w-ia-sub-dose}$	Worker Air Submersion (pCi/m ³)	Isotope-specific	Determined in this calculator
$CDI_{w-ia-sub-risk}$	Worker Air Submersion (pCi-year/m ³)	Isotope-specific	Determined in this calculator
$CDI_{res-ia-inh-dose}$	Resident Air Inhalation (pCi/year)	Isotope-specific	Determined in this calculator
$CDI_{res-ia-inh-risk}$	Resident Air Inhalation (pCi)	Isotope-specific	Determined in this calculator
WL	Indoor Air Working Level Concentration	Isotope-specific	Determined in this calculator

Toxicity Values

Symbol ▼	Definition (units) ↗	Default ↗	Reference ↗
SF_i	Slope Factor - inhalation (risk/pCi)	Isotope-specific	ORNL 2014 and ORNL 2017
DCF_i	Dose Conversion Factor - inhalation (mrem/pCi)	Isotope-specific	ORNL 2014 and ORNL 2017
DCF_{sub}	Dose Conversion Factor - submersion (mrem/year per pCi/cm ³). For use in this tool, ORNL 2014 units were converted to risk/year per pCi/m ³ .	Isotope-specific	ORNL 2014
	Slope Factor - submersion		

SF_{sub}	(risk/year per pCi/cm). For use in this tool, ORNL 2014 units were converted to risk/year per pCi/m ³ .	Isotope-specific	ORNL 2014
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Miscellaneous Variables

Symbol ▼	Definition (units) 🗨	Default 🗨	Reference 🗨
AF_{gw}	Attenuation Factor Groundwater (unitless)	0.001	U.S. EPA 2014b
AF_{ss}	Attenuation Factor Sub-Slab (unitless)	0.03	U.S. EPA 2014b
CDI	Chronic Daily Intake	Isotope-Specific	Determined in this calculator
CF_{WL}	Working Level Conversion Fraction (L/pCi)	Isotope-Specific	Based on ACH selection.
C_{gw}	Groundwater Concentration (pCi/L)	Isotope-Specific	Determined in this calculator or Entered by user
$C_{i,a}^{Target}$	Target Indoor Air Concentration (pCi/m ³)	Isotope-Specific	Determined in this calculator or Entered by user
C_{sg}	Soil Gas Concentration (pCi/m ³)	Isotope-Specific	Determined in this calculator or Entered by user
C_{vp}	Pure Phase Vapor Concentration	Isotope-Specific	Determined in this calculator
ELCR	Excess Lifetime Cancer Risk	Isotope-Specific	Determined in this calculator
F_{eq}	Radon Equilibrium Factor	Isotope-Specific	ORNL 2020
GSF_a	Gamma Shielding Factor - Air (unitless)	1	Developed for Radon VISL Calculator
H^T_{gw}	Dimensionless Henry's Law Constant for Groundwater Temperatures other than 25°Celsius	Isotope-Specific	See Radon-specific Parameters

LEL	Lower Explosive Limit (% by volume)	Radon is an inert gas and the LEL is not of concern as it would be for chemicals.	See Radon-specific Parameters
MW	Molecular Weight (g/mole)	Isotope-Specific	See Radon-specific Parameters
n	<p>If $(T_{\text{boil}}/T_{\text{crit}} < 0.57)$</p> <p>If $(T_{\text{boil}}/T_{\text{crit}} > 0.71)$</p> <p>If $(0.57 < T_{\text{boil}}/T_{\text{crit}} \leq 0.71)$</p>	<p>$n = 0.3$</p> <p>$n = 0.41$</p> <p>$n = (0.74 \times T_{\text{boil}}/T_{\text{crit}} - 0.116)$</p>	<p>U.S. EPA Fact Sheet:</p> <p>Unitless exponent values used to determine $H_{v,gw}$</p>
R	Universal Gas Constant (L-atm/mole-degrees K)	0.082057	U.S. EPA Fact Sheet
RC	Universal Gas Constant (cal/mole-degree K)	1.9872	U.S. EPA Fact Sheet
S	Water Solubility Limit (mg/L)	Isotope-Specific	See Radon-specific Parameters
T	Absolute Temperature (Kelvin)	298.15	Equivalent to 25°Celsius
T_b	Normal Boiling Point (Kelvin)	Isotope-Specific	See Radon-specific Parameters
T_c	Critical Temperatures (Kelvin)	Isotope-Specific	See Radon-specific Parameters
TCR	Target Cancer Risk	1×10^{-6}	Selected by user
TDL	Target Dose Limit	1	Selected by user
T_{gw}	Groundwater Temperatures (Kelvin)	Site-specific	User-provided
TWL	Target Working Level	(unitless)	Selected by user
$H_{v,b}$	Enthalpy of vaporization at the normal boiling point (cal/mol)	Isotope-Specific	See Radon-specific Parameters
$H_{v,gw}$	Enthalpy of vaporization at temperature of groundwater(cal/mol)	Isotope-Specific	Determined in this calculator

ACH	Air Exchanges per Hour	0.18 resident; 0.6 industrial	U.S. EPA 2018 Table 19-25 and Table 19-30
A_{eq}	Activity Equilibrium Factor	Isotope-Specific	ORNL 2020
H'	Dimensionless Henry's Law Constant at 25°Celsius (unitless)	Isotope-Specific	See Radon-specific Parameters
HLC	Henry's Law Constant at 25°Celsius (atm·m ³ per mole)	Isotope-Specific	See Radon-specific Parameters
$HLC-T_{gw}$	Henry's Law Constant for Groundwater Temperatures other than 25°Celsius (atm·m ³ per mole)	Isotope-Specific	See Radon-specific Parameters

Exposure Frequency, Exposure Duration, and Exposure Time Variables

Symbol ▼	Definition (units) ⚙	Default ⚙	Reference ⚙
AAF_{res-a}	Resident Age Adjustment Factor - adult (unitless)	0.77	Determined in this calculator
AAF_{res-c}	Resident Age Adjustment Factor - child (unitless)	0.23	Determined in this calculator
ED_{res}	Resident Exposure Duration (year)	26	U.S. EPA 2011, Table 16-108; 90th percentile for current residence time.
ED_{res-a}	Resident Exposure Duration - adult (year)	20	ED_{res} (26 years) - ED_{res-c} (6 years)
ED_{res-c}	Resident Exposure Duration - child (year)	6	U.S. EPA 1991 (pg. 15)
ED_w	Worker Exposure Duration - (year)	25	U.S. EPA 1991 (pg. 15)
EF_{res}	Resident Exposure Frequency (days/year)	350	U.S. EPA 1991 (pg. 15)

EF_{res-a}	Resident Exposure Frequency - adult (days/year)	350	U.S. EPA 1991 (pg. 15)
EF_{res-c}	Resident Exposure Frequency - child (days/year)	350	U.S. EPA 1991 (pg. 15)
EF_w	Worker Exposure Frequency (days/year)	250	U.S. EPA 1991 (pg. 15)
ET_{res}	Resident Air Exposure Time (hours/day)	24	The whole day
ET_{res-a}	Resident Air Exposure Time - adult (hours/day)	24	The whole day
ET_{res-c}	Resident Air Exposure Time - child (hours/day)	24	The whole day
ET_w	Worker Air Exposure Time (hours/day)	8	The work day
$IFA_{res-adj-dose}$	Resident Age-Adjusted Inhalation Fraction (m^3)	6,195 (m^3 /year)	Calculated using the age-adjusted intake factors equation.
$IFA_{res-adj-risk}$	Resident Age-Adjusted Inhalation Fraction (m^3)	161,100 (m^3)	Calculated using the age-adjusted intake factors equation.
IRA_{res-a}	Resident Inhalation Rate - adult (m^3 /day)	20	U.S. EPA 1991 (pg. 15)
IRA_{res-c}	Resident Inhalation Rate - child (m^3 /day)	10	U.S. EPA 1991 (pg. 15)
IRA_w	Worker Inhalation Rate (m^3 /day; based on a rate of 2.5 m^3 /hour for 24 hours)	60	U.S. EPA 1997b (pg. 5-11)

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Summary

I am a Senior Risk Analyst at the United States Nuclear Regulatory Commission in Rockville, MD. I am responsible for review of dose and performance assessment models prepared by licensees and the United States Department of Energy for a number of complex decommissioning sites; waste-incident-to-reprocessing facilities; and low-level waste disposal facilities. I have served as the lead technical reviewer on a number of complex decommissioning projects including the West Valley Demonstration Project in West Valley, New York; the AAR Manufacturing site in Livonia, Michigan; and the Beltsville Agricultural and Research Center in Beltsville, Maryland. I have also served as a lead technical reviewer helping to facilitate closure of large, underground high-level waste tanks located at the Idaho National Laboratory in Idaho Falls, Idaho, and the Savannah River Site near Aiken, South Carolina. I was also a key member of the technical review teams for the Saltstone Disposal Facility at the Savannah River Site, and Hanford Single-Shell Tanks in Hanford, Washington. I assessed the risk of pre-Part 61 regulation low-level waste disposals at the request of Washington Department of Health for the U.S. Ecology's low-level waste disposal facility located in Hanford, Washington. As a senior risk analyst, I have also worked on development of guidance related to review of performance assessments prepared for low-level-waste disposal and dose modeling prepared to support complex site decommissioning. I have also prepared course materials and conducted training related to radioactive waste disposal and performance assessment reviews both nationally and internationally.

Experience

Senior Risk Analyst

U.S. Nuclear Regulatory Commission

Jun 2005 - Present (15 years 5 months +)

- Provides consultative reviews of performance assessments for waste-incident-to-reprocessing facilities (e.g., high-level waste tank closures at Idaho National Laboratory and Savannah River Site).
- Monitors DOE disposal actions related to waste-incident-to-reprocessing to assess compliance with performance objectives for low-level-waste disposal.
- Prepares independent models to assess risk of residual radioactivity in soils and buildings; and near-surface disposal of radioactive waste.
- Participates in public meetings and technical exchanges with decommissioning licensees and U.S. Department of Energy.
- Prepares guidance and conducts training related to reviews of low-level-waste disposal performance assessments and decommissioning dose modeling.
- Participates in international activities to develop guidance and conduct training related to decommissioning (e.g., NEA's Expert Group on Legacy Management) and low-level waste disposal (e.g., IAEA's Human Intrusion in the Context of Disposal of Radioactive Waste). Conducted dose modeling and contaminant fate and transport modeling training focused on uranium recovery sites in South America.
- Dose analyst on the reactor protective measures team in the Emergency Response Organization.

Senior Engineer

Bechtel Savannah River Site

May 2001 - May 2004 (3 years 1 month)

- Constructed groundwater models to assess risk and evaluate remedial alternatives for contaminated groundwater and source areas under the CERCLA program.
- Participated in Core Team meetings with state and federal regulators.
- Prepared groundwater monitoring plans.
- Evaluated groundwater monitoring data.
- Prepared dose assessments for decommissioning sites.
- Conducted technical training.

Education



Clemson University

Master of Science (MS), Environmental Systems Engineering

1996 - 1998

Course work included:

Environmental Engineering

Air Pollution

Health Physics/Radiation Protection

Radiation Detection and Instrumentation

Environmental Risk Assessment

Groundwater Modeling

Contaminant Fate and Transport

Environmental Chemistry

Advanced Engineering Mathematics

Geostatistics

Environmental Law



College of Charleston

Bachelor's Degree, Mathematics

Double Major in Mathematics (BS) and Political Science (BA)

Course work included:

Calculus I, II, III

Differential Equations

Advanced Calculus I and II

Linear Algebra

Modern Algebra

Discrete Structures

Form Logic and Logic Theory

Computer Programming

Judicial Process

Constitutional Law

International Law

Criminal Justice

Civil Liberties

Physics

Chemistry

Spanish

Licenses & Certifications

 **Regression Analysis** - Statistics.com

 **ANOVA and Regression** - Statistics.com

 **Predictive Analytics** - Statistics.com

 **Predictive Analytics 2 - Neural Nets and Regression** - The Institute for Statistics Education at Statistics.com

 **Predictive Analytics 3 - Dimension Reduction, Clustering, and Association Rules** - The Institute for Statistics Education at Statistics.com

Skills

Radioactive Waste Management • Groundwater Modeling • Groundwater Remediation • Probabilistic Models • Risk Assessment • Nuclear Decommissioning • Environmental Engineering • Remediation • Radiological Surveys

Honors & Awards

 **Team Special Act Award** - United States Nuclear Regulatory Commission
2006, 2007, 2020

 **Performance Award** - United States Nuclear Regulatory Commission
1999, 2000, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019

 **Time Off Award** - United States Nuclear Regulatory Commission
2005, 2008, 2019

 **Group Award** - United States Nuclear Regulatory Commission
2009, 2009, 2010, 2014, and 2018

 **Employee of the Quarter Award** - Office of Federal State Material and Environmental Management Programs
Sep 2011

Peer Reviewer Conflict of Interest Certification

Peer Review: **Draft Radon Vapor Intrusion Screening Level Calculator (RIVSL)**

A conflict of interest or lack of impartiality exists when the proposed peer reviewer personally (or the peer reviewer's immediate family), or his or her employer, has financial interests that may be affected by the results of the peer review; or may provide an unfair competitive advantage to the peer reviewer (or employer); or if the peer reviewer's objectivity in performing the peer review may be impaired due to other factors. When the Peer Reviewer knows that a reasonable person with knowledge of the facts may question the peer reviewer'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 RIVSL calculator (and associated webpages) under peer review, 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 peer review, or any reason that your impartiality in the matter might be questioned? No Yes
- Have you had any previous involvement with the RIVSL 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 peer review, 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 peer review? 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 peer review:

(a) Peer Reviewer 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 Peer Reviewer has disclosed all such relevant information to EMS or to EPA.

(b) Peer Reviewer agrees that if an actual, apparent, or potential personal or organizational conflict of interest is identified during performance of this peer review, he/she immediately will make a full disclosure in writing to EMS. This disclosure shall include a description of actions that Peer Reviewer (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. Peer Reviewer shall continue performance until notified by EMS of any contrary action to be taken.


Signature

10/9/2020
Date

Check here if any explanation is attached

Cynthia Barr
Printed Name

USNRC
Affiliation/Organization

Charge Questions (Barr):

A. Homepage and Overall Website

1. Is the website clearly organized, described, easy to navigate, and generally “user friendly” and appropriate for the target audience? If not, what do you recommend?

Yes the web site is clearly organized, easy to navigate and user friendly.

2. Have the objectives of the RVISL calculator, as stated in the documentation, been met? If not, what do you recommend?

I am unsure what the “objectives” of RVISL calculator are. However, the RIVSL appears to do the following as explained in the User’s Manual:

This tool provides screening level concentrations of radon for groundwater, soil gas (sub-slab and exterior), and indoor air to assist Agency staff with making a radon vapor intrusion screening level (RVISL) determination based on limited, initial data. In addition to calculating screening levels, 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.

Several comments are provided in the pdf files of the User’s Manual and other documentation that if incorporated I think would provide increased transparency and support for the methodology.

3. Do you recommend any modifications to the Homepage graphic?

Yes, several comments were made on the homepage graphic (see file RVISL Home Page and FAQs csb comments.pdf)

4. Do you have any other recommendations to improve the usability of the website?

See comments in pdf files.

B. User’s Guide

1. Does the User’s Guide adequately explain the concepts addressed by the calculator and its limitations?

Additional detail could be provided. See comments in file RVISL User’s Guide csb.pdf.

Additionally, it would help to provide screen shots of the forms and the output with simple examples of how to use the calculator.

2. Are the assumptions clear and reasonable? If not, what do you recommend?

Yes, the assumptions are generally clear and reasonable.

3. Are the sources and citations appropriate, and do they represent the current state of knowledge? If not, what do you recommend?

Additional detail and supporting information could be provided (e.g., support for risk-significant assumptions and parameters and information on dosimetry). See comments in the file RVISL User's Guide csb.pdf.

C. Frequent Questions

1. Are the 11 questions clearly worded? If not, what do you recommend?

Please see comments on RVISL Home Page and FAQs csb comments.pdf file.

2. Are the 11 responses clear, concise, and accurate? If not, what do you recommend?

Please see comments on RVISL Home Page and FAQs csb comments.pdf file.

3. Are there other helpful questions and answers that should be added? If yes, please list the questions.

Yes, include a basic question and answer on how the screening levels are calculated based on default assumptions and parameters. A table of alternative approaches to using the calculator on the main page or in the User's Manual would be helpful. Describe where the generic screening levels are located (it looks like this information is not yet available on the web site, see empty page when you click on the "generic tables" link although that would be helpful).

D. Calculator

1. Are the results clearly explained and presented? If not, what do you recommend?

See comment above on User's Manual. It would help to provide screen shots of inputs and outputs from the calculator.

2. Are the results appropriately described and qualified (to the extent that they may be relied upon and defended)? If not, what do you recommend?

Additional detail could be provided as noted in the file RVISL User's Guide csb.pdf.

3. Do the results provide defensible explanation of how they were derived, or are they the result of a "black box?" Do you recommend anything different?

Additional detail could be provided as noted in the file RVISL User's Guide csb.pdf.

4. RVISL calculation of the equilibrium level (F_{eq}) of radon progeny that would be present in indoor air is based on air exchange rate. Should other mechanisms (seasonal atmospheric changes, building construction, surface plating, aerosol sizes, regional geology, air flow) be incorporated in the calculation?

As noted in comment, insufficient information is provided to determine the conservatism or reasonableness of the default values. The capability to adjust the parameter with sufficient support (in addition to adjusting the air exchange rate) would be beneficial

particularly if additional credit could be taken to alleviate potential conservatisms using the current approach.

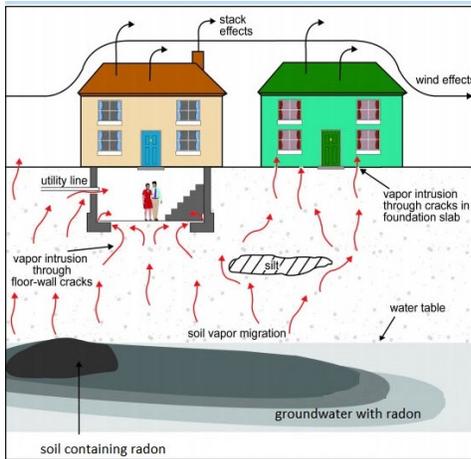
5. Is there anything else you recommend for the calculator to improve it for its stated purpose?

See comments provided in the file RVISL User's Guide csb.pdf

- E. Anything Else?

Is there anything else you would recommend to improve the RVISL calculator's utility, accuracy, completeness, or supportability?

Additional information on any benchmarking, verification, and validation studies, including supporting data, would also increase confidence in the results.



1
 2 **Figure caption:** This figure depicts the migration of radon in soil gas from contaminated soil and groundwater
 3 into buildings. Radon in soil gas is shown to enter buildings through cracks in the foundation and openings for
 4 utility lines. Atmospheric conditions and building ventilation are shown to influence radon soil gas intrusion.

5 Welcome

6 Welcome to the "Radon Vapor Intrusion Screening Level (RVISL) Calculator Home Page for
 7 Radionuclide Contaminants at Superfund Sites". This website was developed with DOE's Oak
 8 Ridge National Laboratory (ORNL) under an Interagency Agreement with the U.S. Environmental
 9 Protection Agency (EPA). The RVISL website is now the generally recommended source of radon
 10 screening levels for all EPA regions. The RVISL calculator output provides comparison values and
 11 risk and dose estimates for residential and commercial/industrial exposures to radon in soil gas,
 12 air, and groundwater. Note that for Comprehensive Environmental Response, Compensation, and
 13 Liability Act (CERCLA) remedial actions, dose assessment is generally done only to show
 14 compliance with a dose-based Applicable or Relevant and Appropriate Requirement (ARAR). In
 15 addition, the calculator presents the option to compare the indoor air concentration, entered by
 16 the user or derived from groundwater or soil gas activities, to state standards or Uranium Mill
 17 Tailings Radiation Control Act (UMTRCA) standards, which also may be potential ARARs. The
 18 unified use of the RVISLs to screen radon at Superfund sites promotes national consistency. The
 19 RVISL uses the same database of toxicity values, chemical parameters, and inhalation exposure
 20 equations as the [Preliminary Remediation Goals \(PRGs\)](#) for Radionuclide Contaminants at
 21 Superfund Sites calculator. The RVISL calculator provides default parameters that can be
 22 modified to reflect site-specific risks. To ensure proper use of the calculator, please review
 23 the [What's New](#), [User's Guide](#), and [Frequently Asked Questions](#) links. The EPA has prepared a [fact](#)
 24 [sheet](#) for the general public that describes RVISL uses, RVISL calculator operation, and land uses
 25 available for assessment. Additionally, this [fact sheet](#) describes the RVISL content in greater detail
 26 for EPA staff. Below is a general description of screening levels for radon. If the calculator is used
 27 with non-default inputs in a decision on a Superfund site, it is recommended that the inputs be
 28 clearly identified and justified by the user.

29 The RVISL calculator provides updated guidance for developing screening levels (SLs) or
 30 preliminary remediation goals (PRGs) for indoor radon-222, radon-220, and radon-219 that are

31 risk- or dose-based and for showing compliance with the UMTRCA indoor radon standards for
32 radon-222 and radon-220. The RVISL, therefore, supersedes the risk assessment approach in
33 Preliminary Remediation Goals for Radionuclides in Buildings ([BPRG](#)) electronic calculator, the
34 dose assessment approach in ARAR Dose Compliance Concentrations Goals for Radionuclides in
35 Buildings ([BDCC](#)) electronic calculator, and Q17 of the guidance document "[Radiation Risk
36 Assessment At CERCLA Sites: Q & A](#)" issued on May 2014. Computer codes such as the RVISL,
37 which were developed to predict potential human exposure from radon concentrations in indoor
38 air, are based on simplified equations and assumptions and are highly imprecise for an individual
39 house or structure. EPA would recommend, where possible, Regions use measurements of radon
40 indoors rather than rely on the transport portions of the RVISL. In particular, testing of
41 groundwater or soil gas is not required to demonstrate compliance with RVISL WL, pCi/L, risk, or
42 dose targets.

43 Users should note that since background radon levels are typically outside the risk range, the
44 RVISL calculator is likely to be used primarily for ARAR compliance. For example, the UMTRCA
45 indoor radon standards 40 CFR 192.12(b)(1) and 192.41(b) were identified as likely Federal ARARs
46 for Rn-222 and Rn-220 in Attachment A of the EPA guidance document "Establishment of Cleanup
47 Levels for CERCLA Sites with Radioactive Contamination." There are some state standards
48 expressed in pCi/l or mrem/yr that, if more stringent than the UMTRCA standards, may be
49 selected as ARARs.

50 **Introduction**

51 Superfund sites are addressed under the authority of the Comprehensive Environmental
52 Response, Compensation, and Liability Act (CERCLA) of 1980, which was amended by the 1986
53 Superfund Amendments and Reauthorization Act. The purpose of this website is to provide a
54 screening level calculation tool to assist risk assessors, remedial project managers, and others
55 involved with risk assessment and decision-making at CERCLA sites in developing or refining
56 screening levels.

57 Rn-222 is commonly referred to radon because of its parent radium-226. Rn-220 is commonly
58 called thoron because of its parent thorium. Rn-219 is commonly called actinon because of its
59 parent actinium. Click the decay chain link to see the decay series for [Rn-222](#), [Rn-220](#), and [Rn-219](#).
60 The metal groups in these images are based on [Los Alamos National Laboratory](#) literature. See
61 section 2.2 of the User's Guide to learn what progeny are evaluated in this web calculator. More
62 details about the decay chains can be found in the EPA's [Decay Chain](#) Tool.

63 This tool is based on the [Technical Guide for Assessing and Mitigating the Vapor Intrusion
64 Pathway from Subsurface Vapor Sources to Indoor Air \(June 2015\)](#). Vapor intrusion occurs when
65 there is a migration of vapor-forming chemicals or radon from any subsurface source into an
66 overlying building. Recognition of soil vapor intrusion to buildings and other enclosed spaces
67 occurred in the 1980s with concerns over radon intrusion. Subsequently, there was an increasing
68 awareness that anthropogenic chemicals (e.g., petroleum hydrocarbons and chlorinated

69 solvents) in soil, groundwater, and sewers and drainlines could also pose threats to indoor air
70 quality via the vapor intrusion pathway.

71 The RVISL calculator results were previously verified. The documentation from these may be seen
72 on the [Internal Verification](#) and [External Verification](#) pages. The RVISL calculator was also
73 previously peer reviewed, and the documentation of the review may be seen [here](#).

74 Chemicals are not addressed on this website. For chemical vapor intrusion, please go to [EPA's](#)
75 [Vapor Intrusion Screening Level Calculator](#).

76 Note: No consideration is given to ecological effects in the values presented in this calculator.

77 **Frequently Asked Questions**

78 **This page presents many questions asked by site users and the applicable responses. Please**
79 **search this page for answers to your questions prior to contacting technical support staff.**
80 **Researching the questions and answers posted here will greatly reduce the time it takes for**
81 **you to solve many problems that arise from calculating and using this SL site.**

82 1. [What are RVISLs? How are they used?](#)

83 RVISLs are preliminary remediation goal concentrations for groundwater, soil gas (sub-
84 slab and exterior), and indoor air to assist Agency staff with making a vapor intrusion
85 determination based on limited, initial data.

86 2. [How can I change attenuation factors?](#)

87 To change the attenuation factors, run the [calculator](#); the main page has editable cells
88 with the default factors presented.

89 The screening levels for groundwater and soil gas (either sub-slab gas or soil gas
90 collected exterior to buildings) are calculated from the target indoor air concentrations
91 using empirically-based conservative "generic" attenuation factors that reflect
92 generally reasonable worst-case conditions, as described in the EPA's vapor intrusion
93 guidance.

94 A critical assumption for this generic model is that site-specific subsurface
95 characteristics will tend to reduce or attenuate soil gas concentrations as vapors
96 migrate upward from the source and into overlying structures. Specific factors that may
97 result in relatively unattenuated or enhanced transport of vapors into a building
98 include the following:

- 99 ○ Significant openings to the subsurface that facilitate soil gas entry into the building
100 (e.g., sumps, unlined crawl spaces, earthen floors) other than typical utility
101 penetrations.

- 102 ○ Very shallow groundwater sources (e.g., depths to water less than five feet below
103 foundation level)
- 104 ○ Significant routes for preferential, subsurface vapor migration whether naturally
105 occurring (e.g., fractured bedrock) or anthropogenic.

106 The factors listed above may negate the appropriate application of the recommended
107 attenuation factors and the sub-slab, groundwater, and soil gas VISLs for purposes of
108 identifying sites or buildings unlikely to pose a health concern through the vapor
109 intrusion pathway. On the other hand, further evaluation of the vapor intrusion
110 pathway is still appropriate when the sub-slab, groundwater, and soil gas VISLs are
111 exceeded for samples from a building or site where these specific factors are present.

112 Vapor source types that typically make the use of the recommended attenuation
113 factors and health-based VISLs for groundwater and soil gas inappropriate include:

- 114 ○ Those originating in landfills where methane is generated in sufficient quantities to
115 induce advective transport in the vadose zone.
- 116 ○ Those originating in commercial or industrial settings where vapor-forming chemicals
117 can be released within an enclosed space and the density of the chemicals' vapor may
118 result in significant advective transport of the vapors downward through cracks and
119 openings in floors and into the vadose zone.
- 120 ○ Leaking vapors from pressurized gas transmission lines.

121 In each case, the diffusive transport of vapors may be overridden by advective
122 transport, and the vapors may be transported in the vadose zone several hundred feet
123 from the source of contamination with little attenuation in concentration. In general,
124 EPA recommends considering whether the assumptions underlying the generic
125 conceptual model are attained at a given site. If they are not attained, then EPA
126 recommends that the medium-specific VISLs not be relied upon as a line of evidence for
127 identifying sites or buildings unlikely to pose a health concern through the vapor
128 intrusion pathway. Where the assumptions regarding the subsurface attenuation
129 factors do not or may not apply, EPA generally recommends collecting indoor air
130 samples.

131 3. **Why can't I calculate RVISLs for bulk soil samples?**
132 Consistent with the 2015 OSWER Technical Guide for Assessing and Mitigating the Vapor
133 Intrusion Pathway from Subsurface Vapor Sources, "bulk soil (as opposed to soil gas)
134 sampling and analysis is not currently recommended for estimating the potential for
135 vapor intrusion to pose unacceptable human health risk in indoor air, because of the
136 potential for vapor loss due to volatilization during soil sampling, preservation, and
137 analysis. In addition, there are uncertainties associated with soil partitioning
138 calculations."

139 4. **How can I access the "forward calculator" function?**
140 In addition to calculating screening levels, the [calculator](#) allows the user to input data
141 collected from their site. This data is used to model the indoor air concentration,
142 calculate a chronic daily intake, and present cancer risk. On the [calculator](#) main page,
143 select "Yes" under the section titled "**Predict indoor air concentrations and risk from
144 measured media concentrations?**". A choice will be presented for the user to select
145 between air, soil gas, and groundwater data. "Site-specific" mode is automatically
146 activated, and the user will be prompted to enter their site data.

147 5. **How can I adjust groundwater temperatures?**
148 The main page of the [calculator](#) has a cell where the temperature can be changed from
149 the default of 25 °C.

150 Users are given the option to change the groundwater-soil system temperature from
151 the default of 25°C to a site-specific value. Since the unitless Henry's Law Constant (H')
152 is derived based on the partial pressure of a gas in equilibrium with a liquid and the
153 equilibrium changes when temperature changes, H' is changed to reflect the
154 equilibrium at the given temperature. The equation below illustrates how H' is derived
155 when groundwater temperature is changed. An EPA Fact Sheet describing the process
156 can be found at [https://www.epa.gov/vaporintrusion/fact-sheet-correcting-henrys-law-
157 constant-temperature](https://www.epa.gov/vaporintrusion/fact-sheet-correcting-henrys-law-constant-temperature).

158 6. **How are the results converted to a mass basis?**
159 Appendix B of the [Soil Screening Guidance for Radionuclides Technical Background
160 Document](#) presents a formula for converting PRGs in pCi/g to mg/kg and also a formula
161 for converting pCi/L to mg/L. The equation is reproduced here with similar conversions
162 for mg/m³ and mg/cm².

$$C_{i,a} \text{ (mg/L)} = 2.8 \times 10^{-15} \left(\frac{\text{mg} \cdot \text{mole}}{\text{pCi} \cdot \text{g} \cdot \text{year}} \right) \times A_w \left(\frac{\text{g}}{\text{mole}} \right) \times T_{1/2} \text{ (years)} \times C_{gw} \text{ (pCi/L)}$$

and:

$$C_{i,a} \text{ (mg/m}^3\text{)} = 2.8 \times 10^{-15} \left(\frac{\text{mg} \cdot \text{mole}}{\text{pCi} \cdot \text{g} \cdot \text{year}} \right) \times A_w \left(\frac{\text{g}}{\text{mole}} \right) \times T_{1/2} \text{ (years)} \times C_{sg} \text{ (pCi/m}^3\text{)}$$

where:

A_w is the radionuclide atomic weight and $T_{1/2}$ is the radionuclide half-life.

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165 The derivation of the 2.8×10^{-12} conversion is presented below.

$$2.8 \times 10^{-15} \left(\frac{\text{mg} \cdot \text{mole}}{\text{pCi} \cdot \text{g} \cdot \text{year}} \right) = \left(\frac{1 \times 10^{-12} \text{ Ci}}{\text{pCi}} \right) \times \left(\frac{3.7 \times 10^{10} \text{ nt/s}}{\text{Ci}} \right) \times \left(\frac{31,536,000 \text{ s}}{\text{year}} \right) \times \frac{1}{0.693} \times \left(\frac{\text{atoms}}{\text{nt}} \right) \times \left(\frac{1 \text{ mole}}{6.023 \times 10^{23} \text{ atoms}} \right) \times \left(\frac{1000 \text{ mg}}{\text{g}} \right)$$

where:

nt = nuclear transformations (decays)

$$A \left(\frac{\text{nt}}{\text{year}} \right) = \frac{N \text{ (number of atoms)}}{T_{1/2} \text{ (years)}} \times 0.693 \left(\frac{\text{nt}}{\text{atom}} \right)$$

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167

168 Combination of the derivation of the conversions with the isotope-specific half life and
169 atomic weight is presented here.

$$C_{i,a} \text{ (mg/L)} = C_{gw} \text{ (pCi/L)} \times \left(\frac{1 \times 10^{-12} \text{ Ci}}{\text{pCi}} \right) \times \left(\frac{3.7 \times 10^{10} \text{ nt/s}}{\text{Ci}} \right) \times \left(\frac{31,536,000 \text{ s}}{\text{year}} \right) \times \frac{1}{0.693} \times \left(\frac{\text{atoms}}{\text{nt}} \right) \times \left(\frac{1 \text{ mole}}{6.023 \times 10^{23} \text{ atoms}} \right) \times \left(\frac{1000 \text{ mg}}{\text{g}} \right) \times A_w \left(\frac{\text{g}}{\text{mole}} \right) \times T_{1/2} \text{ (years)}$$

and

$$C_{i,a} \text{ (mg/m}^3\text{)} = C_{sg} \text{ (pCi/m}^3\text{)} \times \left(\frac{1 \times 10^{-12} \text{ Ci}}{\text{pCi}} \right) \times \left(\frac{3.7 \times 10^{10} \text{ nt/s}}{\text{Ci}} \right) \times \left(\frac{31,536,000 \text{ s}}{\text{year}} \right) \times \frac{1}{0.693} \times \left(\frac{\text{atoms}}{\text{nt}} \right) \times \left(\frac{1 \text{ mole}}{6.023 \times 10^{23} \text{ atoms}} \right) \times \left(\frac{1000 \text{ mg}}{\text{g}} \right) \times A_w \left(\frac{\text{g}}{\text{mole}} \right) \times T_{1/2} \text{ (years)}$$

where:

A_w is the radionuclide atomic weight and $T_{1/2}$ is the radionuclide half-life.

nt = nuclear transformations (decays)

$$A \left(\frac{\text{nt}}{\text{year}} \right) = \frac{N \text{ (number of atoms)}}{T_{1/2} \text{ (years)}} \times 0.693 \left(\frac{\text{nt}}{\text{atom}} \right)$$

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7. How were the UMTRCA working level (WL) standards converted to pCi/L?

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This table depicts the three steps to convert the UMTRCA WL standard to pCi/L. For more discussion on WLs, see the [User's Guide](#) Section 2.8.

Assuming Radon Equilibrium Factor (F_{eq}) = 1		
Rn-222	Rn-220	Rn-219
1 WL = 100 pCi/L	1 WL = 7.5 pCi/L	1 WL = 162 pCi/L
1 WL = 100,000 pCi/m ³	1 WL = 7,500 pCi/m ³	1 WL = 162,000 pCi/m ³
1 WL = 3.7 Bq/L	1 WL = 0.2775 Bq/L	1 WL = 5.994 Bq/L
1 WL = 3,700 Bq/m ³	1 WL = 277.5 Bq/m ³	1 WL = 5,994 Bq/m ³
Assuming Radon Equilibrium Factor (F_{eq}) = 0.4 for Rn-222 and 0.02 for Rn-220		
Rn-222	Rn-220	Rn-219
1 WL = 250 pCi/L	1 WL = 375 pCi/L	Unable to provide conversion due to missing F_{eq} from Federal Guidance for Rn-219.
1 WL = 250,000 pCi/m ³	1 WL = 375,000 pCi/m ³	
1 WL = 9.25 Bq/L	1 WL = 13.875 Bq/L	
1 WL = 9,250 Bq/m ³	1 WL = 13,875 Bq/m ³	
Standardized to 0.02 Working Levels (WL)		
Rn-222	Rn-220	Rn-219
0.02 WL = 5 pCi/L	0.02 WL = 7.5 pCi/L	Unable to provide conversion due to missing F_{eq} from Federal Guidance for Rn-219.
0.02 WL = 5,000 pCi/m ³	0.02 WL = 7,500 pCi/m ³	
0.02 WL = 0.185 Bq/L	0.02 WL = 0.2775 Bq/L	

0.02 WL = 185 Bq/m ³	0.02 WL = 277.5 Bq/m ³	
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177 **Working Level Conversion References**

- 178 ○ David Allen. [Dose Conversion Factors for Radon WLM](#). Centers for Disease Control (CDC),
179 June 2018.
- 180 ○ Health Physics Society (HPS). [Ask the Experts: Environmental and Background
181 Radiation - Radon, May 2017.](#)

182 **8. When do I use risk-based versus dose-based versus WL screening level types?**

183 The RVISL calculator is likely to be used primarily for ARAR compliance. For example,
184 the UMTRCA indoor radon standards 40 CFR 192.12(b)(1) and 192.41(b) were identified
185 as likely Federal ARARs for Rn-222 and Rn-220 in Attachment A of the EPA guidance
186 document "Establishment of Cleanup Levels for CERCLA Sites with Radioactive
187 Contamination." There are some state standards that may be expressed in pCi/l or
188 mrem/yr that if more stringent than the UMTRCA standards may be selected as ARARs.
189 Background levels of indoor radon will typically exceed the risk range, and it would
190 generally not be expected that remediation levels for indoor radon would be risk-based
191 or based on background. The risk portions of the RVISL can still be used to provide risk
192 estimates for the ARAR-based remediation levels.

193 **9. When should modelling instead of measurements be used for indoor radon?**

194 Computer codes such as the RVISL, which were developed to predict radon
195 concentrations in indoor air for potential human exposure based on simplified
196 equations and assumptions, are highly imprecise for an individual house or structure.
197 EPA would recommend, where possible, Regions use measurements of radon indoors
198 rather than rely on the transport portions of the RVISL. In particular, testing of
199 groundwater or soil gas is not required to demonstrate compliance with RVISL WL,
200 pCi/L, risk, or dose targets.

201 **10. Why do the Superfund RVISL calculator risk results for 4 pCi/L of Rn-222 in air differ
202 from the reported ORIA health risks for the same activity?**

203 The RVISL calculator risk results for 4 pCi/L of Rn-222 in air differ from the reported
204 ORIA health risks for the same activity for several reasons. The first reason for a
205 difference in the risk results is that the RVISL calculator uses risk coefficients based on
206 morbidity (getting cancer) from inhalation and submersion exposure routes, while the
207 ORIA tables are based on mortality (death) from inhalation-induced lung cancer only.
208 The ORIA [Health Risk of Radon](#) web page reports that for smokers and never-smokers,
209 the mortality risk from lung cancer of 4 pCi/L of Rn-222 is 62 out of 1,000 people and 7
210 out of 1,000 people, respectively, or 6.2×10^{-2} and 7×10^{-3} . Given in the scientific notation
211 format used in the RVISL, this relates to a lung cancer mortality risk of 6.2E-02 and 7E-
212 03, respectively. The RVISL residential risk results for a combination of smokers and

213 never-smokers to 4 pCi/L of Rn-222 in air is 8.39E-02, which rounds to 8.4×10^{-2} .
 214 Additionally, the ORIA risk estimates are based on an average population study, where
 215 the individual's exposure parameters are not considered, while the RVISL results are
 216 based on a reasonably maximum exposed (RME) individual. The individual exposure
 217 parameters considered in Superfund assessments include dwelling air exchange rate,
 218 inhalation rates, exposure duration, and resident time indoors.

219 For more information on different methods for making radon inhalation cancer risk
 220 estimates see section 2.3.1 of the User Guide.

221 **11. I noticed the VISL and RVISL use the same attenuation factors. Are the VISL default**
 222 **attenuation factors appropriate for use in the RVISL calculator?**

223 The default VISL attenuation factors are also used in the RVISL. In fact, radon intrusion
 224 studies were the foundation for recognition that chemical vapors also intrude into
 225 buildings and enclosed spaces from soil and groundwater sources ([EPA 1995](#)). It was
 226 also observed that vapor intrusion mitigation remedies suppress both chemical and
 227 radon gasses and that monitoring radon intrusion is a viable surrogate for predicting
 228 chemical intrusion susceptibility in buildings ([EPA 2015](#)). Many studies reported in [EPA](#)
 229 [2012a](#), demonstrate strong correlation between radon and chemical sub-slab soil gas
 230 attenuation factors calculated when the radon and chemicals are uniformly collocated.

231 The default attenuation factors can be substituted for site-specific attenuation factors if
 232 underlying site conditions are known. [EPA 2012b](#) presents site-specific attenuation
 233 factors for sub-slab soil gas, groundwater, and crawlspaces for chemicals. The
 234 attenuation factors are summarized in the following table. The defaults used in the VISL
 235 and RVISL calculators are highlighted. The defaults are based on the 95th percentile and
 236 are appropriate for adjusting an RME scenario. The 50th percentile values would be more
 237 appropriate for a central tendency exposure scenario where a large amount of
 238 sampling data is available to reduce uncertainty in calculating the exposure
 239 concentration or defining nature and extent of the source term.

Subslab Soil Gas Attenuation Factors		
Residence Type	Median (50 th percentile)	95 th Percentile
All residences	3E-03 (0.003)	3E-02 (0.03)*
Residences with basements	3E-03 (0.003)	3E-02 (0.03)
Residences with slab-on-grade	3E-03 (0.003)	1E-02 (0.01)

Groundwater Attenuation Factors		
Scenario	Median (50 th percentile)	95 th Percentile
All soil types and water depths	7E-05 (0.00007)	1E-03 (0.001)*
Fine soil type	5E-05 (0.00005)	5E-04 (0.0005)
Coarse soil type	1E-04 (0.0001)	1E-03 (0.001)
Very coarse soil type	2E-04 (0.0002)	4E-03 (0.004)
Depth to water < 1.5 m	6E-04 (0.0006)	7E-03 (0.007)
Depth to water 1.5-3 m	1E-04 (0.0001)	2E-03 (0.002)
Depth to water 3-5 m	4E-05 (0.00004)	2E-03 (0.002)
Depth to water > 5 m	5E-05 (0.00005)	6E-04 (0.0006)
Exterior Soil Gas Attenuation Factors		
Scenario	Median (50 th percentile)	95 th Percentile
All residences	4E-03 (0.004)	3E-01 (0.3)
Crawlspace Attenuation Factor		
Scenario	Median (50 th percentile)	95 th Percentile
All residences	4E-01 (0.4)	9E-01 (0.9)

*These are the VISL and RVISL defaults.

[CONTACT US](#)

Draft Radon VISL User's Guide (April 2020)

[PDF of User 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 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](#).

This tool provides screening level concentrations of radon for groundwater, soil gas (sub-slab and exterior), and indoor air to assist Agency staff with making a radon vapor intrusion screening level (RVISL) determination based on limited, initial data. In addition to calculating screening levels, 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. Note that for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial actions, dose assessment is generally done only to show compliance with a dose based Applicable or Relevant and Appropriate Requirement (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.

The RVISL calculator provides updated guidance developing screening levels (SLs) 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. The RVISL therefore supersedes the risk assessment approach in Preliminary Remediation Goals for

Radon Vapor Intrusion Screening Levels (RVISL)

- [Home Page](#)
- [User's Guide](#)
- [What's New](#)
- [Frequent Questions](#)
- [Equations](#)
- [RVISL Calculator](#)
- [Generic Tables](#)

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.

[Open All Sections](#) | [Close All Sections](#)

Disclaimer

This guidance sets forth a recommended, but not mandatory, approach based upon currently available information with respect to risk and dose assessment for response actions at CERCLA sites. This document does not establish binding rules. Alternative approaches for risk assessment may be found to be more appropriate at specific sites (e.g., where site circumstances do not match the underlying assumptions, conditions, and models of the guidance). The decision whether to use an alternative approach and a description of any such approach should be documented for such sites. Accordingly, comments questioning the use of the approaches recommended in this guidance at individual CERCLA sites should be considered and an explanation provided for the selected approach.

It should also be noted that the radon vapor intrusion screening levels (RVISLs) produced by this calculator are based upon human health risk and do not address potential ecological risk. Some sites in sensitive ecological settings may also need to be evaluated for potential ecological risk. EPA's guidance "[Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessment](#)" contains an eight step process for using benchmarks for ecological effects in the remedy selection process.

The RVISL calculator provides updated guidance developing screening levels (SLs) 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. 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.

1. Understanding the RVISL Website

1.1 General Considerations

Radon is an inert, cancer-causing, radioactive gas at room temperature and these criteria used to determine if a chemical is suitable for vapor intrusion analysis will be ignored for this calculator.

- To determine vapor intrusion of a chemical, the chemical must first meet the criteria for volatility, which is either a Vapor Pressure > 1 mm Hg or a Henry's Law Constant > 1×10^{-5} atm-m³/mole.
- A chemical must be sufficiently volatile and toxic to pose inhalation or external exposure risk

via vapor intrusion from soil source.

- Third, the chemical must be sufficiently volatile and toxic to pose inhalation or external exposure risk via vapor intrusion from groundwater.
- The chemical must contain either a reference concentration (RfC) or an inhalation unit risk (IUR) for a VISL to be calculated.

While radon is suitable for the vapor intrusion models used for chemicals, this language is not suitable for radon. Radon has inhalation and external exposure (submersion) risk coefficients (slope factors) and dose coefficients. Additionally, all radionuclides are considered Group A carcinogens by the EPA.

The concentration ratios between radon and its progeny indoors (i.e., the indoor F_{eq}) is very much influenced by ventilation, exhalation, solid-particle concentration, and surface deposition of radon progeny (Chen & Harley, 2018). Exhalation, solid-particle concentration, and surface deposition were omitted in this study, for simplification. Air quality was also neglected, and it was assumed that actinon, thoron, radon, and subsequent progeny were uniformly distributed over the air volume.

The medium-specific RVISLs for health protection are developed considering a generic conceptual model for vapor intrusion consisting of:

- a source of vapors underneath the building(s) either in the vadose zone or in the uppermost, continuous zone of groundwater, separations between walls and foundation slabs, cracks in foundations;
- vapor migration via diffusion upwards through unsaturated soils from these sources toward the ground surface and overlying buildings; and
- buildings with poured concrete foundations (e.g., basement or slab-on-grade foundations) that are susceptible to soil gas entry.

A critical assumption for this generic model is that site-specific subsurface characteristics will tend to reduce or attenuate soil gas concentrations as vapors migrate upward from the source and into overlying structures. The RVISL relies on default attenuation factors developed from measured VI data; however, **some site-specific characteristics may result in relatively unattenuated or enhanced transport of vapors into a building.** These factors include:

- significant openings to the subsurface that facilitate soil gas entry into the building (e.g., sumps, unlined crawl spaces, earthen floors) other than typical utility penetrations;
- very shallow groundwater sources (e.g., depths to water less than five feet below foundation level); and
- significant routes for preferential, subsurface vapor migration whether naturally occurring (e.g., fractured bedrock) or anthropogenic routes: (e.g., abandoned underground utilities, gravel, highly permeable soil under foundation).

These specific factors may render the use of the recommended attenuation factors and the sub-slab, groundwater, and soil gas RVISLs inappropriate for purposes of

Identifying sites or buildings unlikely to pose a health concern through the vapor intrusion pathway. On the other hand, further evaluation of the vapor intrusion pathway is still appropriate when the sub-slab, groundwater, and soil gas RVISLs are exceeded for samples from a building or site where these specific factors are present.

In addition, certain vapor sources, listed below, invalidate the recommended attenuation factors and screening levels used the RVISL:

- those originating in landfills where radon is generated in sufficient quantities to induce advective transport in the vadose zone and
- those originating in commercial or industrial settings where radon can be released within an enclosed space and the density of the radon vapor may result in significant advective transport of the vapors downward through cracks and openings in floors and into the vadose zone.

In each case, the diffusive transport of vapors may be overridden by advective transport, and the vapors may be transported in the vadose zone several hundred feet from the source of contamination with little attenuation in concentration.

The previously mentioned assumptions and warnings involving attenuation factors are for generic chemicals and do generally apply to radon; however, there are additional considerations for radon entry dynamics. It is recommended that users of this calculator consider all these factors and the ones that are listed below. The concentration of radon in a building depends on:

1. Source of radon and its strength
2. Transport of radon
 - Pathways
 - Soil - high soil porosity or utility trenches, etc.
 - Building Shell - joints, cracks, earthen areas, utility penetrations, etc. in the foundation
 - Driving forces that pull or push radon towards the building and inside the building.
 - air pressure differences
 - diffusion
 - emanation
 - well water
 - environmental effects (e.g., frost or saturated upper soil horizon, rain, pavement around buildings can "cap" the soil)
3. Ventilation rate of building

Radon concentration are influenced by the complex interaction of:

1. Local geology
2. Soil
 - Parent isotope content
 - Moisture content

- Temperature difference
- Permeability
- Water table fluctuation
- 3. Climate and meteorological factors
 - Season
 - Barometric pressure changes
 - Precipitation (e.g. rate, amount)
 - Wind speed and direction
 - Snow cover or soil saturation
 - Temperature inversions
- 4. Building characteristics
 - Pressure differences
 - Heating systems
 - Ventilation
 - Water source
 - Building materials
- 5. Occupant Activities
 - Window opening
 - Fireplace and wood stove use

1.2 RVISL Outputs

This calculator only offers one output option, whereas other EPA risk and dose calculators offer three options.

- Assumes secular equilibrium throughout chain (no decay)
- Does not assume secular equilibrium, provide results for progeny throughout chain
- Does not assume secular equilibrium, provides results for selected isotopes only

The RVISL output is based on an equilibrium relationship of the three parent isotopes to their progeny. In the case of [Rn-222](#), this means the progeny prior to Pb-210; for [Rn-220](#) and [Rn-219](#), all progeny are included. This equilibrium relationship, which is based on air exchange rates within the structure, is dubbed the activity equilibrium fraction (A_{eq}) and is discussed in greater detail in section 4.3.

The calculator output is organized by radon parent. Each radon parent has its own output section. The first row for each radon parent section is a total of the progeny and parent fractional contribution. Radon-219 is first followed by radon-220 and Rn-222.

$$RVISL_{tot} = \frac{1}{\left(\sum_{i=1}^n \frac{1}{RVISL_{route\ i}} \right)}$$

where:

n = total number of exposure routes;

and:

$$RVISL_{route} = \frac{1}{\left(\sum_{i=1}^n \frac{1}{\left(\frac{RVISL}{A_{eq}} \right)_i} \right)}$$

where:

n = number of short-lived progeny in the decay series;

RVISL = RVISL for isotope in decay chain;

A_{eq} = activity equilibrium factor for isotope.

The RVISL calculator gives the user the option to select either a risk or a dose-based calculation. The risk and dose-based outputs are given in pCi, unless the user elects Bq.

The RVISL calculator has an option to include the results in working levels (WLs) for comparison to the UMTRCA standards in addition to results based on volume (pCi/m³ or pCi/L). The calculator gives the contribution of each short-lived isotope (parent and progeny) to the total RVISL. When WLs are included in the output, only the parent activity is converted to a WL, and the total RVISL value derived for the whole chain is not used for the WL conversion despite the WL value being displayed in the top row for the chain. For more information on the short-lived progeny included in each RVISL calculation and WL conversions, see section 1.8.

1.3 Slope Factors (SFs) and Dose Conversion Factors (DCFs)

EPA classifies all radionuclides as Group A carcinogens ("carcinogenic to humans"). Group A classification is used only when there is sufficient evidence from epidemiologic studies to support a causal association between exposure to the agents and cancer. The following sections discuss the sources of inhalation and external exposure via submersion in gas cloud SFs and DCFs used in this calculator.

1.3.1 Inhalation

The [Radon Cancer Risk Coefficients and Age-Specific Effective Dose Coefficients](#) report from Oak Ridge National Laboratory lists inhalation cancer slope factors (SFs) (risk coefficients for total cancer morbidity) and dose coefficients (DCFs) for radionuclides in conventional units of picocuries (pCi). Inhalation SFs and DCFs are central estimates in a linear model of the age-averaged, lifetime attributable radiation cancer incidence (fatal and nonfatal cancer) risk or dose per unit of activity inhaled, expressed as risk/pCi or mrem/pCi, respectively.

The inhalation SFs and DCFs from the [Radon Cancer Risk Coefficients and Age-Specific Effective Dose Coefficients](#) report differ from the inhalation values presented in [Health Effects Assessment Summary Tables \(HEAST\)](#). The inhalation SFs and DCFs used in this calculator were calculated using ORNL's DCAL software in the manner of Federal Guidance Reports (FGR) 12 and 13. The coefficients tabulated here are for inhalation of individual radionuclides without accompanying progeny but include the contribution to dose of ingrowth of radioactive progeny in the body following intake of a parent radionuclide. This approach allows the user to derive effective dose estimates or cancer risk estimates for any known or hypothetical combination of radon and its short-lived progeny in air. This is essential for the fractional activity equilibrium factors derived in this calculator based on air exchange rates (see sections 4.2 and 4.3.). Using SFs and DCFs calculated with the methods from HEAST and with the fractional activity equilibrium models in this calculator would result in overestimation of risk and dose.

An alternative approach for assessing cancer risk associated with radon in homes is to use models that express radiogenic lung cancer risk as a function of past exposure, such as those recommended in the National Research Council's report of the sixth Biological Effects of Ionizing Radiation (BEIR VI) report (1999) and the World Health Organization (WHO) Handbook (2009). The BEIR VI models and those described in the WHO Handbook do not require dose calculations and were derived by data analysis of epidemiological studies of lung cancer associated with exposure to radon. No recommendation is made here as to which approach is to be preferred for other purposes. The SFs derived in the ORNL report are used here to allow for more direct comparisons with the associated DCFs.

The ORNL Radon report does not include inhalation risk or dose coefficients for Rn-219, because the short half-life creates a large uncertainty in the distribution of decays in the body. That large uncertainty is one reason why the International Commission on Radiological Protection (ICRP) generally does not provide inhalation or ingestion dose coefficients for such short-lived radionuclides.

EPA currently provides guidance on inhalation risk assessment in [RAGS Part F](#) (Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual, Part F, Supplemental Guidance for Inhalation Risk Assessment); however, this guidance only addresses chemicals. The development of inhalation slope factors for radionuclides differs from the guidance presented in RAGS Part F for development of inhalation unit risk (IUR) values for chemicals.

1.3.2 Submersion

The external exposure SFs and DCFs used in this calculator are taken from Calculation of Slope Factors and Dose Coefficients (ORNL 2014). The external SFs and DCFs were calculated using ORNL's DCAL software in the manner of Federal Guidance Report 12 and 13 and differ from the values presented in [HEAST](#). External exposure SFs and DCFs are central estimates of lifetime attributable radiation cancer incidence risk for each year of exposure to external radiation from photon-emitting radionuclides distributed uniformly in a gas cloud and

are expressed as risk/yr per pCi/m³ air or mrem/year per pCi/m³ air. When combined with site-specific media concentration data and appropriate exposure assumptions, SFs can be used to estimate lifetime cancer risks, and DCFs can be used to estimate annual dose to members of the general population due to radionuclide exposures

1.4 Radon-specific Parameters

Several radon-specific parameters are needed for development of the RVISLs.

1. Half-life, lambda (λ), atomic number, and atomic weight are taken from [ICRP 107](#).

Isotope	Half-life (year)	λ (year ⁻¹)	Atomic Number	Atomic Weight
Rn-219	1.26E-07	5.52E+06	86	219.009
Rn-220	1.76E-06	3.93E+05	86	220.011
Rn-222	1.05E-02	6.62E+01	86	222.018

2. Vapor Pressure (VP) (mmHg at 25°C) is taken from Table 11 - Vapor Pressure - Inorganic Compounds of the online version of Yaws' Critical Property Data for Chemical Engineers and Chemists, 2014. The value stated in the source is 12,620 mmHg at 25°C. The value is taken from a [plot](#) of the Antoine Equation $\log P = A - (B/(T+C))$.
3. Density (ρ) (g Rn/cm³ at 0 °C) is taken from CRC Handbook of Chemistry and Physics 67th Edition, pg. B-122. The value stated in the source is 9.73 g/L (No temperature is given but thought to be based on 0 °C). Density is used to calculate the water solubility, below. Converting to the required units is as follows:

$$\left(9.73 \times 10^{-3} \frac{\text{g}}{\text{cm}^3}\right) = \left(\left(9.73 \frac{\text{g}}{\text{L}}\right) \times \left(1 \frac{\text{L}}{1000 \text{ cm}^3}\right)\right)$$

4. Water Solubility (S) (mg/L at 25°C) is taken from CRC Handbook of Chemistry and Physics 67th Edition, pg. B-122. The value stated in the source is 22.4 cm³Rn/100 cm³ H₂O at 25°C. Converting to the required units is as follows, assuming 1cm³ = 1 mL:

$$\left(2220 \frac{\text{mg Rn gas}}{\text{L H}_2\text{O}}\right) = \left(\left(22.4 \frac{\text{cm}^3 \text{ Rn}}{100 \text{ cm}^3 \text{ H}_2\text{O}}\right) \times \left(1000 \frac{\text{mL H}_2\text{O}}{1 \text{ L H}_2\text{O}}\right) \times \left(1 \frac{\text{L gas}}{1000 \text{ mL gas}}\right) \times \left(1 \frac{\text{mol}}{22.4 \text{ L gas}}\right) \times \left(222.018 \frac{\text{g Rn}}{\text{mol}}\right) \times \left(1000 \frac{\text{mg H}_2\text{O}}{\text{g}}\right)\right)$$

5. Henry's Law Constant (HLC) (atm-m³/mole at 25°C) is taken from [Atmos. Chem. Phys., 15, 2015](#), pg. 4418. The value of 9.3E-05 mol/m³Pa at 25°C is selected as the largest of six values presented. Converting to the required units is as follows:

$$\left(0.106 \text{ atm}\cdot\text{m}^3/\text{mol}\right) = \left(\left(\frac{1}{9.3\times 10^{-5} \text{ mol}/\text{m}^3\text{Pa}}\right) \times \left(\frac{1 \text{ atm}}{101325 \text{ Pa}}\right)\right)$$

6. Unitless Henry's Law Constant (H') (unitless at 25°C). The value is derived from $0.106 \text{ atm}\cdot\text{m}^3/\text{mol} / 0.02446 = 4.34$. The conversion factor, 0.02446 is calculated by multiplying the universal gas constant, $8.0257338\text{E-}05 \text{ atm}\cdot\text{m}^3/\text{mol K}$, by the temperature 298.16 K.
7. Critical Temperature (T_c) (K) is taken from CRC Handbook of Chemistry and Physics online version. The value reported is 104 °C, which is 377.15 K.
8. Boiling Point (T_b) (K) is taken from CRC Handbook of Chemistry and Physics online version. The value reported is -67.7 °C, which is 211.45 K.
9. Lower Explosive Limit (LEL) (% by volume). Radon is an inert gas and the LEL is not of concern as it would be for chemicals.
10. Enthalpy of vaporization at the normal boiling point (cal/mol) is taken from Yaw's Thermophysical Properties of Chemicals and Hydrocarbons [Table 63](#). Enthalpy of Vaporization at Boiling Point - Inorganic Compounds (Electronic Edition). The reported value is 18.098 kJ/mol. Converting to the required units is as follows:

$$\left(4326 \text{ cal}/\text{mol}\right) = \left(\left(18.098 \text{ kJ}/\text{mol}\right) \times \left(1000 \text{ J}/\text{kJ}\right) \times \left(1 \text{ cal}/4.184 \text{ J}\right)\right)$$

1.5 Understanding Risk Output on the RVISL Website

The RVISL [calculator](#) provides an option to select risk output. In the calculator, select "yes" if risk output is desired. Selecting risk output requires the calculator to be run in "Site Specific" mode. The risk values presented on this site are radionuclide-specific values for Radon contaminants in air that may warrant further investigation or site cleanup.

1.5.1 General Considerations for the Risk Output

This portion of the risk assessment process is generally referred to as "Risk Characterization". This step incorporates the outcome of the exposure and toxicity assessments to calculate the risk resulting from potential exposure to radionuclides via the pathways and routes of exposure determined appropriate for the source area. Risk is calculated in this tool using the following equation.

The basic equation for calculating excess lifetime cancer risk is:

$$\text{Risk} = \text{CDI} \times \text{SF} \times A_{\text{eq}}$$

where:

Risk = a unitless probability of an individual developing cancer over a lifetime;

CDI = chronic daily intake or dose [pCi or pCi-year/m³]

SF = slope factor, expressed in [risk/pCi or risk/year per pCi/m³]

A_{eq} = Activity Equilibrium Factor of individual isotope (See Section 4.3)

The risk results are color coded to identify risk ranges and potential radionuclides of concern. The colors and the associated risk ranges are presented in the table below.

Excess Lifetime Cancer Risk			
Risk Range	Risk < 0.000001	Risk > 0.000001	Risk > 0.0001
Color Code	No shading	Yellow	Red

1.5.2 One-Hit Rule

The linear risk equation, listed above, is valid only at low risk levels (below estimated risks of 0.01). For sites where radiological exposure might be high (estimated risks above 0.01), an alternate calculation should be used. The one-hit equation, which is consistent with the linear low-dose model, should be used instead ([RAGS, part A, ch. 8](#)). The results presented on the preliminary remediation goal (PRG) calculator use this rule. In the following instances, the one-hit rule is used independently in the risk output tables:

- Risk from a single exposure route for a single radionuclide.
- Summation of single radionuclide risk (without one-hit rule applied to single radionuclide results) for multiple exposure routes (right of each row).
- Summation of risk (without one-hit rule applied to single radionuclide results) from a single exposure route for multiple radionuclides (bottom of each column).
- Summation of total risk (without one-hit rule applied to single radionuclide results or summations listed above) from multiple radionuclides across multiple exposure routes (bottom right hand cell).

1.6 Understanding Dose Output on the RVISL Website

This portion of the risk assessment process is generally referred to as "Dose Characterization". This step incorporates the outcome of the exposure and toxicity assessments to calculate the dose resulting from potential exposure to radionuclides via the pathways and routes of exposure determined appropriate for the source area. Dose is calculated in this tool using the following equation:

$$\text{Dose} = \text{CDI} \times \text{DCF} \times A_{\text{eq}}$$

where:

Dose = The energy absorbed from radiation by a person (mrem/year)

CDI = Chronic Daily Intake or Dose [pCi/year or pCi/m³]

DCF = Dose Conversion Factor [mrem/pCi or mrem/year per pCi/m³]

A_{eq} = Activity Equilibrium Factor of individual isotope

1.7 Comparison to State and UMTRCA Standards

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 that may be potential ARARs. The state standards are likely only for Rn-222. A preset value of 4 pCi/L of air is given, as it is the most common pCi/L value used in state standards. For the UMTRCA comparison option, a preset value of 0.02 working levels (WL) is given for Rn-222 and Rn-220. Alternative values can be entered for either of these standards on the first page of the calculator. For more information on evaluation of radon working levels, see section 1.8.

1.8 Understanding Working Levels (WL)

The term Working Level (WL) refers to the activity of the progeny present in air from a specific radon parent (i.e., radon, thoron, or actinon). Specifically, WLs do not include the contribution from the parent. According to the EPA's code of federal regulations [40 CFR 192.11](#), "a working level (WL) means any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of alpha particles with a total energy of 130 billion electron volts." In the case of [Rn-222](#), this means the progeny prior to Pb-210; for [Rn-220](#) and [Rn-219](#), all progeny are included. U.S. EPA 1989 ([RAGS Part A](#)), the National Institute of Occupational Safety and Health (NIOSH) ([Dose Conversion Factors for Radon WLM](#)), the National Council on Radiation Protection and Measurements (NCRP) [Report No.97](#), and The Department of Energy ([DOE-STD-1121-2008](#)) agree with the definition and/or offer equivalent values in units of pCi/L. At 100% equilibrium, one WL is equal to 100pCi/L of Rn-222, 7.5 pCi/L of Rn-220, and 162 pCi/L of Rn-219. While this is a significant difference in the gas concentrations, by definition of the working level, the decay products will ultimately emit the same amount of alpha energy. This, however, does not lead to the same lung dose. This is caused largely by the difference in the half-lives of the decay products. Since Rn-220 products have longer half-lives, the body has longer to transport the activity from one compartment to another and thus deliver dose to different areas of the lung. Since the working level is an air concentration, it is analogous to an exposure rate. To describe exposure, the unit working level month (WLM) is also used. A WLM is the exposure equivalent to breathing one WL for 170 hours (one working month). The NRC in [CFR 20.1003](#) and NIOSH in [Dose Conversion Factors for Radon WLM](#) identify the individual progeny that are included as "short-lived" daughters. Some of the extremely short-lived daughters are explicitly excluded in WL calculations because they would represent a very small number of atoms inhaled and add computational time without gaining significant precision gains. For this calculator, all short-lived progeny are considered for completeness because of modern computing advances. See details in sections 4.2 and 4.3 of

this user's guide to see how the inhalation fractional equilibrium (F_{eq}) and activity equilibrium factor (A_{eq}) values were calculated for short-lived progeny.

"Properties and behaviour of radon and thoron and their decay products in the air" (J. Porstendorfer, Journal of Aerosol Science, Vol 25:2, March 1994, pg 219-263) further supports the WL definition and conversion to pCi/L and offers insight on the consideration of radon daughter aerosols formation and deposition on surfaces. "Measurement of Equilibrium Factor ' F_{eq} ' between Radon and its Progeny and Thoron and its Progeny in the Indoor Atmosphere Using Nuclear Track Detectors" (R. Ramola, Indoor and Built Environment, Vol12:351-355, 2003) discusses the air exchange rate impact on radon progeny plating on surfaces and impacting the measured equilibrium in air. These papers present many of the difficulties in predicting and measuring F_{eq} values due to seasonal atmospheric changes, building construction, surface plating, aerosol sizes, regional geology, air flow, etc. The F_{eq} is important to establish for determining compliance with WL ARARs, such as the UMTRCA standards described in section 1.7 of this user's guide. Previous EPA guidance on complying with the UMTRCA standard as an ARAR at CERCLA sites assumed a F_{eq} of 0.4 (40%) for Rn-222 and 0.02 (2%) for Rn-220. These F_{eq} values, which when applied to the 0.02 WL ARAR equate to 5 pCi/L of Rn-222 or 7.5 pCi/L of Rn-220, were to be used to demonstrate compliance with the UMTRCA standard. Rn-219 does not have an UMTRCA standard. EPA's new guidance for ARAR compliance is to use this calculator with either default or site/building-specific air exchange rates to determine radon/thoron levels that comply with the 0.02 WL ARAR.

For more information on evaluation of radon working levels, see question 17 in the [Radiation Risk Assessment At CERCLA Sites: Q&A](#) and question 7 in the [Frequent Questions](#) page on this site. Note that the RVISL calculator provides updated guidance developing screening levels (SLs) or preliminary remediation goals (PRGs) for showing compliance with the UMTRCA indoor radon standards for radon-222 and radon-220. The RVISL therefore supersedes the approach for determining WL in question 17 of the guidance document "Radiation Risk Assessment At CERCLA Sites: Q & A" issued on May 2014.

The following equation demonstrates the conversion of the default Rn-222 RVISL in pCi/L to a WL while correcting for the F_{eq} differences between the conversion and calculated values. The F_{eq} in the conversion assumes 100% equilibrium ($F_{eq}=1$), and the F_{eq} for the RVISL is calculated based on the air exchange rate used.

$$\text{RVISL}_{\text{Rn-222}}^{\text{WL}} \left(2.39 \times 10^{-5} \text{ WL} \right) = \text{RVISL}_{\text{Rn-222}}^{\text{pCi}} \left(\frac{2.72 \times 10^{-3} \text{ pCi}}{\text{L}} \right) \times \left(\frac{F_{eq} (0.88) \times 1 \text{ WL}}{\left(\frac{100 \text{ pCi}}{\text{L}} \right)} \right)$$

1.9 Problems Predicting the Activity of Radium, Thorium and Actinium based on Radon, Thoron, and Actinon RVISLs

Ra-226, Th-232, and Ac-227 are the namesakes and the long-lived near chain member sources of Rn-222, Rn-220, and Rn-219, respectively. In an ideal setting, the amount of solid

source is directly related to the amount of gas product via the fractional decay of the parent. Ra-226 and Th-232 have a straight decay chain to Rn-222 and Rn-220, respectively. Ac-227 decay to Rn-219 is a branched decay chain; 98.6% of Ac-227 decays to Rn-219. Predicting the amount of radon gas available for vapor intrusion in the natural environment, however, is not an ideal setting. Several factors make it impossible for this calculator to confidently predict suitable default radon, thoron, and actinon target indoor air concentrations from subsurface (soil and groundwater) radium, thorium, and actinium concentrations. The IAEA has published Technical Report Series No. 474, [Measurement and Calculation of Radon Releases from NORM Residues](#), that addresses many of these difficulties.

The newly formed radon atom must first escape from the ore material to the interstitial space between grains. This emanation happens when the recoil energy is sufficient for the radon atom to break from the ore grains. Once in the interstitial space, the radon must be able to be transported to the surface via diffusion and advective flow. Depending on the distance to the surface and media properties, the relatively short-lived radon may decay before exhalation to the atmosphere. Most recoiling atoms do not make it out of the ore material into the interstitial space and, because of the very small diffusion coefficient through dense minerals, even less atoms are likely to be exhaled to the atmosphere.

Detailed modeling of the subsurface environment may be possible to estimate the amount of a solid source that results in gaseous exhalation. One such model is the NORM And Legacy Site Assessment ([NORMALYSA](#)) software. This software is able to simulate transport from a source medium through clean cover layers to the surface. The [User's Manual](#) details how NORMALYSA employs emanation, diffusion, and exhalation to predict radon air concentrations. Chapters 2 and 4 of [TRS No. 474](#) present details on emanation coefficient determination that may be useful for site-specific analysis.

2. Radon Vapor Intrusion Screening Level Equations

This section presents the screening levels for human exposure to contaminated air. The equations and technical discussion are aimed at developing compliance levels for risk-based and dose-based RVISLs. The following text presents the land use equations and their exposure routes. Table 1 (section 5 of the User's Guide) presents the definitions of the variables and their default values. The default values are selected to represent the reasonably maximum exposed (RME) individual and generally represent the upper bounds of exposure. The default values and exposure models are consistent with the Chemical Vapor Intrusion Screening Level (VISL) calculator if the same pathways are addressed (e.g., inhalation) and are analogous if pathways are similar (e.g., external exposure). This calculator and the [VISL](#) both follow the recommendations in the [OSWER Directive](#) concerning use of exposure parameters from the [2011 Exposure Factors Handbook](#). Any alternative values or assumptions used in remedy evaluation or selection on a CERCLA site should be presented with supporting rationale in Administrative Records.

2.1 Air Screening Level Equations

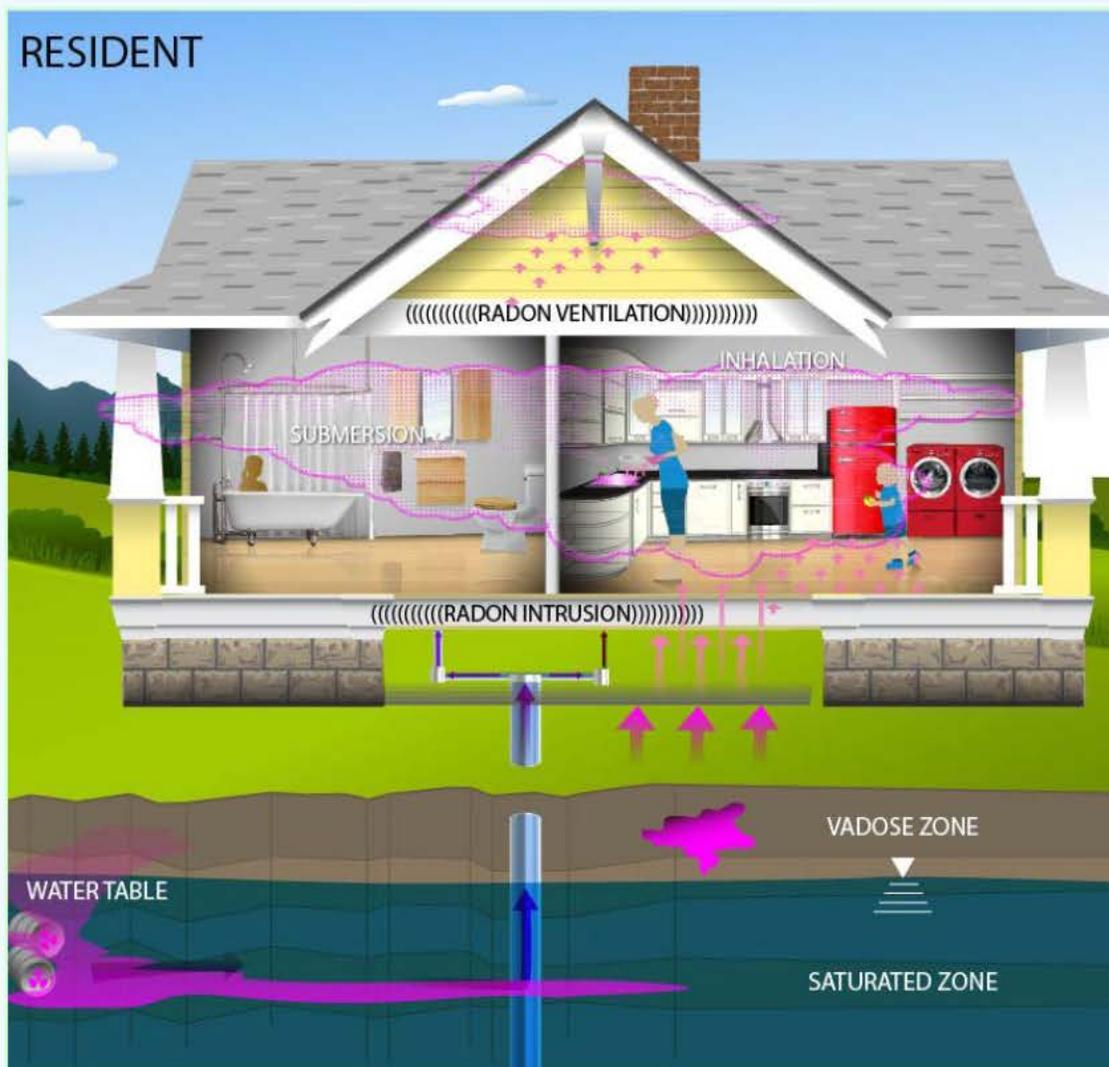
The user can select risk-based or dose-based equations and either a resident or worker receptor. The

RVISL conversion to working levels (WLs) is also presented in the following sections.

2.1.1 Resident Air

This receptor spends all of the day at home. The resident is assumed to be exposed to contaminants via the following pathways: inhalation of ambient air and external radiation from contaminants in ambient air. To take into account the different inhalation rates for children and adults, age-adjusted intake equations were developed to account for changes in intake as the receptor ages.

Graphical Representation



Risk-Based Vapor Intrusion Screening Level Equations

These are the risk-based equations for determining the protective resident air concentrations.

Inhalation

$$C_{\text{res-ia-inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{\text{TR}}{\text{SF}_i \left(\frac{\text{risk}}{\text{pCi}} \right) \times \text{IFA}_{\text{res-adj}} (161,000 \text{ m}^3)}$$

where:

$$\text{IFA}_{\text{res-adj}} (161,000 \text{ m}^3) = \left(\left(\text{EF}_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{res-c}} (6 \text{ years}) \times \text{ET}_{\text{res-c}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_{\text{res-c}} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \right) + \left(\text{EF}_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{res-a}} (20 \text{ years}) \times \text{ET}_{\text{res-a}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_{\text{res-a}} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \right) \right)$$

Submersion

$$C_{\text{res-ia-sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{\text{TR}}{\text{SF}_{\text{sub}} \left(\frac{\text{risk/year}}{\text{pCi/m}^3} \right) \times \text{EF}_{\text{res}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times \text{ED}_{\text{res}} (26 \text{ years}) \times \text{ET}_{\text{res}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{GSF}_a (1.0)}$$

Total

$$C_{\text{res-ia-tot}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\frac{1}{C_{\text{inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right)} + \frac{1}{C_{\text{sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right)}}$$

$$\text{where: } C_{\text{inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\left(\sum_{i=1}^n \frac{1}{\left(\frac{C_{\text{res-ia-inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right)}{A_{\text{eq}}} \right)} \right)} \quad \text{and: } C_{\text{sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\left(\sum_{i=1}^n \frac{1}{\left(\frac{C_{\text{res-ia-sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right)}{A_{\text{eq}}} \right)} \right)}$$

where:

n = the number of progeny in the decay series

Total Working Level Conversion

$$C_{\text{res-ia-tot-wl}} (\text{WL}) = C_{\text{res-ia-tot}} \left(\frac{\text{pCi}}{\text{L}} \right) \times \text{CF}_{\text{WL}}$$

where:

$$\text{CF}_{\text{WL}} (\text{Rn-222}) = \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{100 \text{ pCi}}{\text{L}} \right)} \right);$$

$$\text{CF}_{\text{WL}} (\text{Rn-220}) = \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{7.5 \text{ pCi}}{\text{L}} \right)} \right);$$

$$\text{CF}_{\text{WL}} (\text{Rn-219}) = \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{162 \text{ pCi}}{\text{L}} \right)} \right)$$

where:

F_{eq} = radon equilibrium factor for the given parent.

Dose-Based Vapor Intrusion Screening Level Equations

These are the dose-based equations for determining the protective resident air concentrations.

Inhalation

$$C_{\text{res-ia-inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{DL \left(\frac{\text{mrem}}{\text{year}} \right)}{DCF_i \left(\frac{\text{mrem}}{\text{pCi}} \right) \times IFA_{\text{res-adj}} \left(\frac{6,195 \text{ m}^3}{\text{year}} \right)}$$

where:

$$IFA_{\text{res-adj}} \left(\frac{6,195 \text{ m}^3}{\text{year}} \right) = \left(\left(EF_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ET_{\text{res-c}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{res-c}} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \times AAF_{\text{res-c}} (0.23) \right) + \left(EF_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ET_{\text{res-a}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{res-a}} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \times AAF_{\text{res-a}} (0.77) \right) \right)$$

where:

$$AAF_{\text{res-c}} (0.23) = \left(\frac{ED_{\text{res-c}} (6 \text{ years})}{ED_{\text{res}} (26 \text{ years})} \right) \text{ and } AAF_{\text{res-a}} (0.77) = \left(\frac{ED_{\text{res-a}} (20 \text{ years})}{ED_{\text{res}} (26 \text{ years})} \right)$$

Submersion

$$C_{\text{res-ia-sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{DL \left(\frac{\text{mrem}}{\text{year}} \right)}{DCF_{\text{sub}} \left(\frac{\text{mrem/year}}{\text{pCi/m}^3} \right) \times EF_{\text{res}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ET_{\text{res}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)}$$

Total

$$C_{\text{res-ia-tot}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\frac{1}{C_{\text{inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right)} + \frac{1}{C_{\text{sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right)}}$$

$$\text{where: } C_{\text{inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\left(\sum_{i=1}^n \frac{1}{\left(\frac{C_{\text{res-ia-inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right)_i}{A_{\text{eq}}} \right)} \right)} \text{ and: } C_{\text{sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\left(\sum_{i=1}^n \frac{1}{\left(\frac{C_{\text{res-ia-sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right)_i}{A_{\text{eq}}} \right)} \right)}$$

where:

n = the number of progeny in the decay series

Total Working Level Conversion

$$C_{\text{res-ia-tot-wl}}(\text{WL}) = C_{\text{res-ia-tot}} \left(\frac{\text{pCi}}{\text{L}} \right) \times CF_{\text{WL}}$$

where:

$$CF_{\text{WL}}(\text{Rn-222}) = \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{100 \text{ pCi}}{\text{L}} \right)} \right);$$

$$CF_{\text{WL}}(\text{Rn-220}) = \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{7.5 \text{ pCi}}{\text{L}} \right)} \right);$$

$$CF_{\text{WL}}(\text{Rn-219}) = \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{162 \text{ pCi}}{\text{L}} \right)} \right)$$

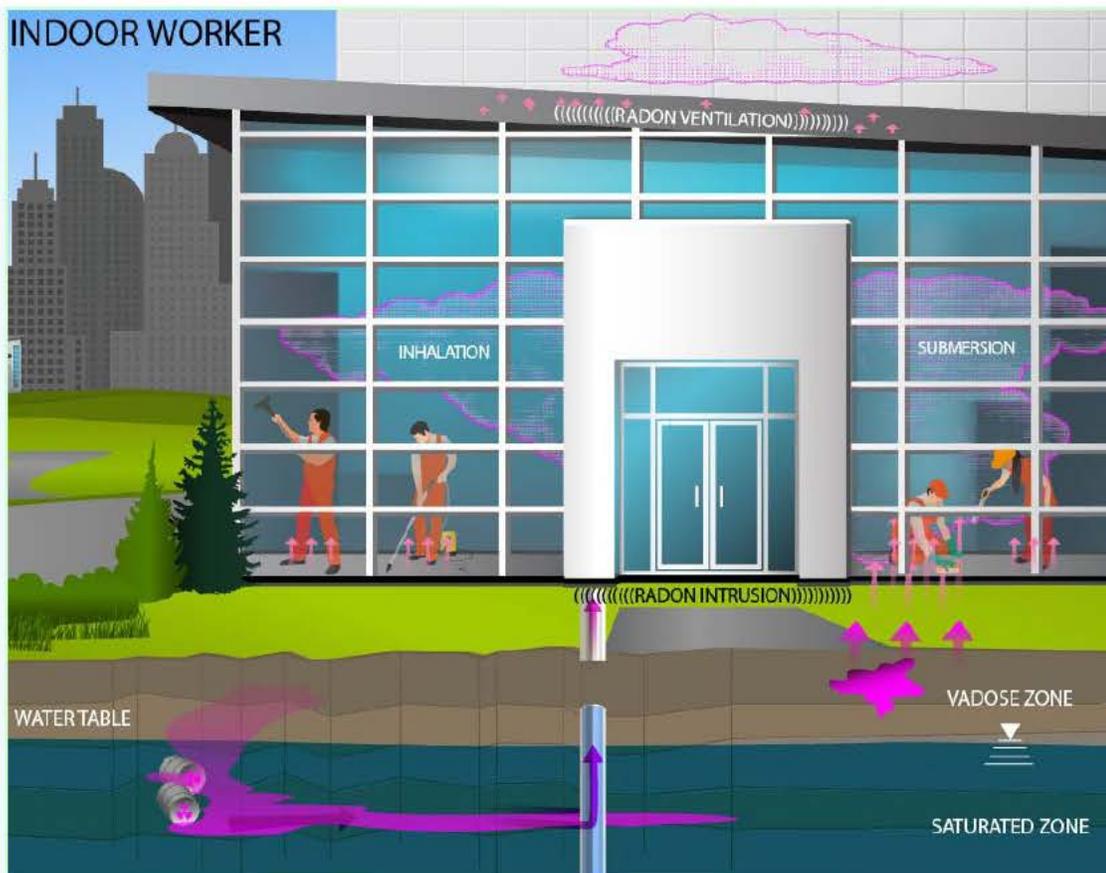
where:

F_{eq} = radon equilibrium factor for the given parent.

2.1.2 Worker Air

This long-term receptor is a full time employee working on-site who spends 8 hours of the workday indoors. The indoor worker is assumed to be exposed to contaminants via the following pathways: inhalation of ambient air and external radiation from contaminants in ambient air.

Graphical Representation



Risk-Based Vapor Intrusion Screening Level Equations

These are the risk-based equations for determining the protective industrial air concentrations.

Inhalation

$$C_{w-ia-inh} \left(\frac{pCi}{m^3} \right) = \frac{TR}{SF_i \left(\frac{risk}{pCi} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_w \left(\frac{60 \text{ m}^3}{\text{day}} \right)}$$

Submersion

$$C_{w-ia-sub} \left(\frac{pCi}{m^3} \right) = \frac{TR}{SF_{sub} \left(\frac{risk/year}{pCi/m^3} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)}$$

Total

$$C_{w-ia-tot} \left(\frac{pCi}{m^3} \right) = \frac{1}{\frac{1}{C_{inh} \left(\frac{pCi}{m^3} \right)} + \frac{1}{C_{sub} \left(\frac{pCi}{m^3} \right)}}$$

$$\text{where: } C_{inh} \left(\frac{pCi}{m^3} \right) = \frac{1}{\left[\sum_{i=1}^n \left(\frac{1}{\left(\frac{C_{w-ia-inh} \left(\frac{pCi}{m^3} \right)}{A_{eq}} \right)} \right)_i \right]} \quad \text{and: } C_{sub} \left(\frac{pCi}{m^3} \right) = \frac{1}{\left[\sum_{i=1}^n \left(\frac{1}{\left(\frac{C_{w-ia-sub} \left(\frac{pCi}{m^3} \right)}{A_{eq}} \right)} \right)_i \right]}$$

where:

n = the number of progeny in the decay series

Total Working Level Conversion

$$C_{w-ia-tot-wl}^{(W\text{L})} = C_{w-ia-tot} \left(\frac{\text{pCi}}{\text{L}} \right) \times CF_{WL}$$

where:

$$CF_{WL}^{(\text{Rn-222})} = \left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{100 \text{ pCi}}{\text{L}} \right)} \right);$$

$$CF_{WL}^{(\text{Rn-220})} = \left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{7.5 \text{ pCi}}{\text{L}} \right)} \right);$$

$$CF_{WL}^{(\text{Rn-219})} = \left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{162 \text{ pCi}}{\text{L}} \right)} \right)$$

where:

F_{eq} = radon equilibrium factor for the given parent.

Dose-Based Vapor Intrusion Screening Level Equations

These are the dose-based equations for determining the protective industrial air concentrations.

Inhalation

$$C_{w-ia-inh} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{DL \left(\frac{\text{mrem}}{\text{year}} \right)}{DCF_i \left(\frac{\text{mrem}}{\text{pCi}} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_w \left(\frac{60 \text{ m}^3}{\text{day}} \right)}$$

Submersion

$$C_{w-ia-sub} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{DL \left(\frac{\text{mrem}}{\text{year}} \right)}{DCF_{sub} \left(\frac{\text{mrem/year}}{\text{pCi/m}^3} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)}$$

Total

$$C_{w-ia-tot} \left(\frac{pCi}{m^3} \right) = \frac{1}{\frac{1}{C_{inh} \left(\frac{pCi}{m^3} \right)} + \frac{1}{C_{sub} \left(\frac{pCi}{m^3} \right)}}$$

$$\text{where: } C_{inh} \left(\frac{pCi}{m^3} \right) = \frac{1}{\sum_{i=1}^n \left(\frac{C_{w-ia-inh} \left(\frac{pCi}{m^3} \right)_i}{A_{eq}} \right)} \quad \text{and: } C_{sub} \left(\frac{pCi}{m^3} \right) = \frac{1}{\sum_{i=1}^n \left(\frac{C_{w-ia-sub} \left(\frac{pCi}{m^3} \right)_i}{A_{eq}} \right)}$$

where:

n = the number of progeny in the decay series

Total Working Level Conversion

$$C_{w-ia-tot-wl}^{(W\text{L})} = C_{w-ia-tot} \left(\frac{pCi}{L} \right) \times CF_{WL}$$

where:

$$CF_{WL}^{(Rn-222)} = \left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{100 \text{ pCi}}{L} \right)} \right);$$

$$CF_{WL}^{(Rn-220)} = \left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{7.5 \text{ pCi}}{L} \right)} \right);$$

$$CF_{WL}^{(Rn-219)} = \left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{162 \text{ pCi}}{L} \right)} \right)$$

where:

F_{eq} = radon equilibrium factor for the given parent.

2.2 Groundwater Screening Level Equation

This equation is used to determine the groundwater concentration protective of exposure to indoor air. The equation uses a groundwater attenuation factor and H'. For a groundwater source, a chemical is considered sufficiently volatile and toxic to pose an inhalation risk through vapor intrusion if the vapor concentration (calculated using the chemical's Henry's Law Constant at the groundwater temperature) corresponding to the chemical's solubility limit in water is greater than the target indoor air concentration. The groundwater attenuation factor is not considered in this comparison, although it is considered in the subsequent calculation of the target groundwater concentration. The target groundwater concentration corresponding to a chemical's target indoor air concentration is calculated by dividing the target indoor air concentration by an attenuation factor of 0.001 and then converting the vapor concentration to

an equivalent groundwater concentration, assuming equilibrium between the aqueous and vapor phases at the water table. The equilibrium partitioning is assumed to obey Henry's Law.

The groundwater attenuation factor and the soil gas attenuation factors are never combined in this calculator.

$$C_{\text{gw},\text{Target}} \left(\frac{\text{pCi}}{\text{L}} \right) = \frac{C_{\text{i,a},\text{target}} \left(\frac{\text{pCi}}{\text{m}^3} \right)}{AF_{\text{gw}} \times \left(1000 \frac{\text{L}}{\text{m}^3} \right) \times H'}$$

2.3 Soil Gas Screening Level Equation

This equation is used to determine the soil gas concentration protective of exposure to indoor air. The soil gas attenuation factor used in the calculations is 0.03, which is the generic attenuation factor used for sub-slab gas in the 2002 draft vapor intrusion guidance. This attenuation factor is used for all soil gas data, as additional information collected after development of the 2002 draft vapor intrusion guidance (EPA 2002) suggests that external soil gas samples need to be evaluated as conservatively as sub-slab gas samples (EPA 2010).

The groundwater attenuation factor and the soil gas attenuation factors are never combined in this calculator.

$$C_{\text{sg},\text{Target}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{C_{\text{i,a},\text{Target}} \left(\frac{\text{pCi}}{\text{m}^3} \right)}{AF_{\text{ss}}}$$

2.4 Vapor Intrusion Screening Level Supporting Equations

Chemicals must be sufficiently volatile and toxic to pose inhalation risk via vapor intrusion from soil and groundwater sources. This is determined by calculating the chemicals pure phase vapor concentration and the groundwater vapor concentration. The soil gas vapor concentration and the groundwater vapor concentration must be greater than the air screening level to determine a VISL. No equations are necessary for radon as they would be for other chemicals.

- **Pure Phase Vapor Pressure**

Radon and Thoron are considered sufficiently volatile and toxic to pose inhalation and external exposure risk via vapor intrusion from a soil source.

- **Groundwater Vapor Concentration**

Radon and Thoron are considered sufficiently volatile and toxic to pose inhalation and external exposure risk via vapor intrusion from a groundwater source.

3. Indoor Air Concentration, Cancer Risk, and Dose Calculation Equations

This section presents the equations used to calculate the indoor air concentration, cancer risk, and dose from the user-provided soil gas and/or groundwater concentration. The equations and technical discussion are aimed at developing compliance levels for risk-based and dose-based RVISLs. The following text presents the land use equations and their exposure routes. Table 1 (section 5 of the User's Guide) presents the definitions of the variables and their default values. The default values are selected to represent the reasonably maximum exposed (RME) individual and generally represent the upper bounds of exposure. The default values and exposure models are consistent with the Chemical Vapor Intrusion Screening Level (VISL) calculator if the same pathways are addressed (e.g., inhalation) and are analogous if pathways are similar (e.g., external exposure). This calculator and the [VISL](#) both follow the recommendations in the [OSWER Directive](#) concerning use of exposure parameters from the [2011 Exposure Factors Handbook](#). Any alternative values or assumptions used in remedy evaluation or selection on a CERCLA site should be presented with supporting rationale in Administrative Records.

3.1 Indoor Air Concentration Derived from Soil Gas Concentration Equation

This section presents the equation used to calculate the indoor air concentration from the user-provided soil gas concentration.

$$C_{i,a} \left(\frac{\text{pCi}}{\text{m}^3} \right) = C_{\text{s-gas}} \left(\frac{\text{pCi}}{\text{m}^3} \right) \times AF_{\text{ss}}$$

3.2 Indoor Air Concentration Derived from Groundwater Concentration Equation

This section presents the equation used to calculate the indoor air concentration from the user-provided groundwater concentration.

$$C_{i,a} \left(\frac{\text{pCi}}{\text{m}^3} \right) = C_{\text{water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times AF_{\text{gw}} \times \left(1000 \frac{\text{L}}{\text{m}^3} \right) \times H'_{\text{gw}}$$

3.3 Calculation of Cancer Risk and Dose from Indoor Air Concentrations

This section presents the chronic daily intake equations used to calculate the cancer risk and dose from indoor air concentrations.

3.3.1 Risk-Based CDI Equations

3.3.1.1 Excess Lifetime Cancer Risk

$$ELCR_{tot} = ELCR_{inh} + ELCR_{sub}$$

where:

$$ELCR_{inh} = \sum_{i=1}^n \left(CDI(pCi) \times SF_i \left(\frac{risk}{pCi} \right) \times A_{eq} \right)_i$$

and:

$$ELCR_{sub} = \sum_{i=1}^n \left(CDI \left(\frac{pCi \cdot year}{m^3} \right) \times SF_{sub} \left(\frac{risk/year}{pCi/m^3} \right) \times A_{eq} \right)_i$$

where:

i = the number of progeny in the decay series

3.3.1.2 Resident Air

Inhalation

$$CDI_{res-ia-rad-inh} (pCi) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times IFA_{res-adj} (161,000 m^3)$$

where:

$$IFA_{res-adj} (161,000 m^3) = \left(\left(EF_{res-c} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-c} (6 \text{ years}) \times ET_{res-c} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-c} \left(\frac{10 m^3}{\text{day}} \right) \right) + \left(EF_{res-a} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-a} (20 \text{ years}) \times ET_{res-a} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-a} \left(\frac{20 m^3}{\text{day}} \right) \right) \right)$$

Submersion

$$CDI_{res-ia-rad-sub-nodecay} \left(\frac{pCi \cdot year}{m^3} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times EF_{res} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{res} (26 \text{ years}) \times ET_{res} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

3.3.1.2 Worker Air

Inhalation

$$CDI_{w-ia-rad-inh} (pCi) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_w \left(\frac{60 m^3}{\text{day}} \right)$$

Submersion

$$CDI_{w-ia-rad-sub} \left(\frac{pCi \cdot year}{m^3} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ yr}}{365 \text{ day}} \right) \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

3.3.2 Dose-Based CDI Equations

3.3.2.1 Annual Dose

$$Dose_{tot} \left(\frac{mrem}{year} \right) = Dose_{inh} \left(\frac{mrem}{year} \right) + Dose_{sub} \left(\frac{mrem}{year} \right)$$

where:

$$Dose_{inh} \left(\frac{mrem}{year} \right) = \sum_{i=1}^n \left(CDI \left(\frac{pCi}{year} \right) \times DCF_i \left(\frac{mrem}{pCi} \right) \times A_{eq} \right)_i$$

and:

$$Dose_{sub} \left(\frac{mrem}{year} \right) = \sum_{i=1}^n \left(CDI \left(\frac{pCi}{m^3} \right) \times DCF_{sub} \left(\frac{mrem/year}{pCi/m^3} \right) \times A_{eq} \right)_i$$

where:

i = the number of progeny in the decay series

3.3.2.2 Resident Air

Inhalation

$$CDI_{res-ia-inh} \left(\frac{pCi}{year} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times IFA_{res-adj} \left(\frac{6,195 m^3}{year} \right)$$

where:

$$IFA_{res-adj} \left(\frac{6,195 m^3}{year} \right) = \left(\left(EF_{res-c} \left(\frac{350 \text{ days}}{year} \right) \times ET_{res-c} \left(\frac{24 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-c} \left(\frac{10 m^3}{day} \right) \times AAF_{res-c} (0.23) \right) + \left(EF_{res-a} \left(\frac{350 \text{ days}}{year} \right) \times ET_{res-a} \left(\frac{24 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-a} \left(\frac{20 m^3}{day} \right) \times AAF_{res-a} (0.77) \right) \right)$$

where:

$$AAF_{res-c} (0.23) = \left(\frac{ED_{res-c} (6 \text{ years})}{ED_{res} (26 \text{ years})} \right) \text{ and: } AAF_{res-a} (0.77) = \left(\frac{ED_{res-a} (20 \text{ years})}{ED_{res} (26 \text{ years})} \right)$$

Submersion

$$CDI_{res-ia-sub} \left(\frac{pCi}{m^3} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times EF_{res} \left(\frac{350 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ET_{res} \left(\frac{24 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

3.3.2.2 Worker Air

Inhalation

$$CDI_{w-ia-inh} \left(\frac{pCi}{year} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times EF_w \left(\frac{250 \text{ days}}{year} \right) \times ET_w \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_w \left(\frac{60 m^3}{day} \right)$$

Submersion

$$CDI_{w-ia-sub} \left(\frac{pCi}{m^3} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times EF_w \left(\frac{250 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ET_w \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

4. Modifications of Standard Equations

These are the conversions for modifying standard equations.

4.1 Modifications of Groundwater Temperatures

The following equations are used to calculate Henry's Law Constant at various groundwater temperatures:

- **To Determine Henry's Law Constant at a Groundwater Temperature other than 25 Degrees Celsius**

$$C_{sv} \left(\frac{\text{pCi}}{\text{cm}^3\text{-v}} \right) = H'_{TS} \times C_w \left(\frac{\text{pCi}}{\text{cm}^3\text{-v}} \right)$$

$$H' = \frac{\exp \left[- \frac{\Delta H_{v,w} \left(\frac{\text{cal}}{\text{mol}} \right)}{R_c \left(1.9872 \text{ cal/mol}\cdot^{\circ}\text{K} \right)} \times \left(\frac{1}{T_w \left(^{\circ}\text{K} \right)} - \frac{1}{T_R \left(298.15 \text{ }^{\circ}\text{K} \right)} \right) \right] \times \text{HLC} \left(\text{atm}\cdot\text{m}^3/\text{mol} \right)}{R \left(8.205\text{E-}05 \text{ atm}\cdot\text{m}^3/\text{mol}\cdot^{\circ}\text{K} \right) \times T_w \left(^{\circ}\text{K} \right)}$$

where:

$$T_w \left(^{\circ}\text{K} \right) = T_w \left(^{\circ}\text{C} \right) + 273.15$$

and:

$$\Delta H_{v,w} \left(\frac{\text{cal}}{\text{mol}} \right) = \Delta H_{v,b} \left(\frac{\text{cal}}{\text{mol}} \right) \times \left[\frac{1 - T_w \left(^{\circ}\text{K} \right) / T_c \left(^{\circ}\text{K} \right)}{1 - T_b \left(^{\circ}\text{K} \right) / T_c \left(^{\circ}\text{K} \right)} \right]^{\eta}$$

where:

$$\text{IF } \left(\frac{T_b}{T_c} \right) < 0.57, \text{ then: } \eta = 0.3;$$

$$\text{IF } \left(\frac{T_b}{T_c} \right) > 0.71, \text{ then: } \eta = 0.41;$$

$$\text{IF } 0.57 < \left(\frac{T_b}{T_c} \right) \leq 0.71, \text{ then: } \eta = \left(0.74 \times \left(\frac{T_b}{T_c} \right) - 0.116 \right)$$

- **To Determine Henry's Law Constant at a Groundwater Temperature of 25 Degrees Celsius**

$$H_{25} = \frac{\text{HLC} \left(\text{atm}\cdot\text{m}^3/\text{mol}\cdot\text{K} \right) \times \left(1000 \text{ L}/\text{m}^3 \right)}{R \left(8.205\text{E-}05 \text{ L}\cdot\text{atm}/\text{mol}\cdot\text{K} \right) \times T \left(298.15 \text{ K} \right)}$$

4.2 Air Exchange Rates and Inhalation Fractional Equilibrium Factor (F_{eq})

The indoor air concentration of radon and progeny is dependent upon the air exchange rate within a given volume. The air exchange rate, otherwise known as air changes per hour (ACH),

is defined as the ratio of airflow to the total volume of air. As an example, an ACH value of 0.18 would mean that eighteen percent of a given volume of air is exchanged per hour. The air exchange rate is related to an important parameter known as the inhalation fractional equilibrium factor (F_{eq}) for estimating the level of detriment from radon inhalation. F_{eq} has been researched for radon and thoron in various dwellings for many years (Chen & Harley, 2018 Parts I and II). The F_{eq} is a unitless measurement of the disequilibrium associated with the decay of radon and its subsequent progeny. The F_{eq} is useful for calculating the internal dose from radon, since most of the dose received is not from the radon parent itself but rather the alpha energies emitted from its progeny. The total progeny alpha energy emitted at any air exchange rate is divided by the total progeny alpha energy emitted at a state of equilibrium where no air exchanges are taking place within a given volume of air. At equilibrium, the value of the F_{eq} is equal to one; however, a F_{eq} of one is seldom measured due to conditions described in Section 1.1 and deposition on surfaces. As the air exchange rate in a given volume increases, the fractional equilibrium factor decreases. The F_{eq} is only used in the working level (WL) conversions presented in Sections 1.8, 2.1, and 2.2. A more detailed explanation of the F_{eq} derivation is presented in [ORNL 2019](#).

4.3 Air Exchange Rates and Activity Equilibrium Factor (A_{eq})

The activity equilibrium factor (A_{eq}) is defined as the ratio of progeny to parent activity concentrations at a given air exchange rate. For a straight decay chain, at zero air exchanges, the (A_{eq}) is equal to one and decrease as the air exchange rate increases. However, an A_{eq} of one is seldom measured due to conditions described in Section 1.1 and deposition on surfaces. The activity equilibrium factor is utilized in the RVISL air equations to calculate risk and dose for inhalation and submersion. The initial risks and doses (analogous to PRGs) assume that the radon decay chain members are in equilibrium with each other without any air exchanges present. Therefore, the activity equilibrium factors modify the initial risks and doses for inhalation and submersion by accounting for the disequilibrium between radon and its progeny due to decay and air exchanges that are present. A default value of 0.18 air exchanges per hour was selected for the resident land use, and a default value of 0.6 air exchanges per hour for the industrial worker land use was selected from the "Update for Chapter 19 of the Exposure Factors Handbook" (EPA, 2018) for resident (Table 19-25) and commercial (Table 19-30) buildings using the tenth percentile values, which means 90% of structures would have a higher air exchange rate and thus a lower level of progeny which would result in less risk, dose, and WL. Users that may want to determine the air exchange rate for a particular building to justify changing the default should refer to section 4.4 of the User Guide. A more detailed explanation of the A_{eq} derivation is presented in [ORNL 2019](#).

4.4 Measurement of Air Exchange Rates

The ACH can be a building-specific measurement, to provide a more accurate air contamination exposure assessment. The ACH is the exchange rate of indoor air with outdoor air, an important determinant for entry of outdoor air contaminants and for removal of indoor-emitted air contaminants. There is no EPA guidance on recommended methods for determining ACH. Breen (2014) presents an overview and critical analysis of the scientific

literature on empirical and physical air exchange rate models for residential and commercial buildings, which are feasible for exposure assessments. Models are included for the three types of airflows that can occur across building envelopes: leakage, natural ventilation, and mechanical ventilation. The paper provides guidance for selecting the preferable air exchange rate model based on available data, desired temporal resolution, types of airflows, and types of buildings included in the exposure assessment. The US EPA [Indoor Air Quality website](#) also provides information on HVAC use in buildings. There are also more detailed papers on particular air exchange measurement approaches (i.e., by placing tubes that emit and collect perfluorocarbon tracers throughout a building). The measurement of air exchange rates can be done by placing tubes that emit and collect perfluorocarbon tracers throughout a building ([CDC, 2018](#)). Guidance on placement of the tubes can be found in "[Research Operating Procedure 10 for Placement of PFT Emitters and Collection Tubes in DEARS](#)" (Thornburg, 2005).

5. Recommended Default Exposure Parameters

Table 1 presents the definitions of the variables and their default values. The default values are selected to represent the reasonably maximum exposed (RME) individual and generally represent the upper bounds of exposure. The RVISL default values and exposure models are consistent with the chemical [VISL](#) calculator. The VISL and RVISL calculator default values are consistent where the same pathways are addressed. This calculator follows the recommendations in the [OSWER Directive](#) concerning use of exposure parameters from the [2011 Exposure Factors Handbook](#). Any alternative values or assumptions used in remedy evaluation or selection on a CERCLA site should be presented with supporting rationale in Administrative Records.

Table 1. Recommended Default Exposure Parameters

Symbol	Definition (units)	Default	Reference
VISLs			
$C_{res-ia-inh-decay}$	Resident Air Inhalation with Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{res-ia-sub-decay}$	Resident Air Submersion with Half-Life Decay (pCi-year/m ³)	Isotope-specific	Determined in this calculator
$C_{res-ia-tot-decay}$	Resident Air Total with Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{res-ia-inh-nodecay}$	Resident Air Inhalation without Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{res-ia-sub-}$	Resident Air Submersion without Half-	Isotope-specific	Determined in this

$C_{res-ia-tot-nodecay}$	Resident Air Total without Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-inh-decay}$	Worker Air Inhalation with Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-sub-decay}$	Worker Air Submersion with Half-Life Decay (pCi-year/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-tot-decay}$	Worker Air Total with Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-inh-nodecay}$	Worker Air Inhalation without Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-sub-nodecay}$	Worker Air Submersion without Half-Life Decay (pCi-year/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-tot-nodecay}$	Worker Air Total without Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
C_{gw}	Groundwater Screening Level (pCi/L)	Isotope-Specific	Determined in this calculator
C_{sg}	Soil Gas Screening Level (pCi/m ³)	Isotope-Specific	Determined in this calculator
CDIs			
$CDI_{res-ia-inh-decay}$	Resident Air Inhalation with Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$CDI_{res-ia-sub-decay}$	Resident Air Submersion with Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$CDI_{res-ia-inh-nodecay}$	Resident Air Inhalation without Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$CDI_{res-ia-sub-nodecay}$	Resident Air Submersion without Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$nodecay$	Life Decay (pCi-year/m ³)		calculator

$CDI_{w-ia-inh-decay}$	Worker Air Inhalation with Half-Life Decay (pCi/m^3)	Isotope-specific	Determined in this calculator
$CDI_{w-ia-sub-decay}$	Worker Air Submersion with Half-Life Decay (pCi/m^3)	Isotope-specific	Determined in this calculator
$CDI_{w-ia-inh-nodecay}$	Worker Air Inhalation without Half-Life Decay (pCi/m^3)	Isotope-specific	Determined in this calculator
$CDI_{w-ia-sub-nodecay}$	Worker Air Submersion without Half-Life Decay (pCi/m^3)	Isotope-specific	Determined in this calculator
Toxicity Values			
SF_i	Slope Factor - inhalation (risk/pCi)	Isotope-specific	ORNL 2014
SF_{sub}	Slope Factor - submersion (risk/year per pCi/cm^3): For use in this tool, ORNL 2014c units were converted to (risk/year per pCi/m^3)	Isotope-specific	ORNL 2014
DCF_i	Dose Conversion Factor - inhalation (mrem/pCi)	Isotope-specific	ORNL 2014
DCF_{sub}	Dose Conversion Factor - submersion (mrem/year per pCi/cm^3): For use in this tool, ORNL 2014c units were converted to (risk/year per pCi/m^3)	Isotope-specific	ORNL 2014
Miscellaneous Variables			
TCR	Target Cancer Risk	1×10^{-6}	Selected by user
ACH	Air Exchanges per Hour	0.18 resident; 0.6 industrial	EPA 2018 Table 19-25 and Table 19-30
F_{eq}	Radon Equilibrium Factor	Isotope-Specific	ORNL 2019
A_{eq}	Activity Equilibrium Factor	Isotope-Specific	ORNL 2019
ELCR	Excess Lifetime Cancer Risk	Isotope-Specific	Determined in this calculator

CDI	Chronic Daily Intake	Isotope-Specific	Determined in this calculator
$H_{v,b}$	Enthalpy of vaporization at the normal boiling point (cal/mol)	Isotope-Specific	See Radon-specific Parameters
$H_{v,gw}$	Enthalpy of vaporization at temperature of groundwater(cal/mol)	Isotope-Specific	Determined in this calculator
H'	Dimensionless Henry's Law Constant at 2 5°Celsius (unitless)	Isotope-Specific	See Radon-specific Parameters
HLC	Henry's Law Constant at 2 5°Celsius (atm-m ³ per mole)	Isotope-Specific	See Radon-specific Parameters
$H'T_{gw}$	Dimensionless Henry's Law Constant for Groundwater Temperatures other than 2 5°Celsius	Isotope-Specific	See Radon-specific Parameters
$HLCT_{gw}$	Henry's Law Constant for Groundwater Temperatures other than 2 5°Celsius (atm-m ³ per mole)	Isotope-Specific	See Radon-specific Parameters
T	Absolute Temperature (Kelvin)	298.15	Equivalent to 2 5°Celsius
T_{gw}	Groundwater Temperatures (Kelvin)	Site-specific	User-provided
T_c	Critical Temperatures (Kelvin)	Isotope-Specific	See Radon-specific Parameters
T_b	Normal Boiling Point (Kelvin)	Isotope-Specific	See Radon-specific Parameters
n	If ($T_{boil}/T_{crit} < 0.57$) If ($T_{boil}/T_{crit} > 0.71$) If ($0.57 < T_{boil}/T_{crit} \leq 0.71$)	$n = 0.3$ $n = 0.41$ $n = (0.74 \times T_{boil}/T_{crit} - 0.116)$	U.S. EPA Fact Sheet : Unitless exponent values used to determine $H_{v,gw}$
S	Water Solubility Limit (mg/L)	Isotope-Specific	See Radon-specific Parameters

R	Universal Gas Constant (L-atm/mole-degrees K)	0.082057	U.S. EPA Fact Sheet
RC	Universal Gas Constant (cal/mole-degree K)	1.9872	U.S. EPA Fact Sheet
MW	Molecular Weight (g/mole)	Isotope-Specific	See Radon-specific Parameters
AF _{ss}	Attenuation Factor Sub-Slab (unitless)	0.03	U.S. EPA 2014
AF _{gw}	Attenuation Factor Groundwater (unitless)	0.001	U.S. EPA 2014
LEL	Lower Explosive Limit (% by volume)	Radon is an inert gas and the LEL is not of concern as it would be for chemicals.	See Radon-specific Parameters
C _{vp}	Pure Phase Vapor Concentration	Isotope-Specific	Determined in this calculator
C _{gw}	Target Groundwater Concentration (pCi/L)	Isotope-Specific	Determined in this calculator or Entered by user
C _{sg}	Target Soil Gas Concentration (pCi/m ³)	Isotope-Specific	Determined in this calculator or Entered by user
C _{i,a} ^{Target}	Target Indoor Air Concentration (pCi/m ³)	Isotope-Specific	Determined in this calculator or Entered by user
GSF _a	Gamma Shielding Factor - Air (unitless)	1	Developed for Radon VISL Calculator

Exposure Frequency, Exposure Duration, and Exposure Time Variables

Resident Exposure Frequency

[U.S. EPA 1991a \(pg.](#)

EF_{res}	(days/year)	350	15)
EF_{res-c}	Resident Exposure Frequency - child (days/year)	350	U.S. EPA 1991a (pg. 15)
EF_{res-a}	Resident Exposure Frequency - adult (days/year)	350	U.S. EPA 1991a (pg. 15)
EF_w	Worker Exposure Frequency (days/year)	250	U.S. EPA 1991a (pg. 15)
ED_{res}	Resident Exposure Duration (year)	26	EPA 2011, Table 16-108; 90th percentile for current residence time.
ED_{res-c}	Resident Exposure Duration - child (year)	6	U.S. EPA 1991a (pg. 15)
ED_{res-a}	Resident Exposure Duration - adult (year)	20	ED_{res} (26 years) - ED_{res-c} (6 years)
ED_w	Worker Exposure Duration - (year)	25	U.S. EPA 1991a (pg. 15)
ET_{res}	Resident Air Exposure Time (hours/day)	24	The whole day
ET_{res-c}	Resident Air Exposure Time - child (hours/day)	24	The whole day
ET_{res-a}	Resident Air Exposure Time - adult (hours/day)	24	The whole day
ET_w	Worker Air Exposure Time (hours/day)	8	The work day
IRA_{res-c}	Resident Inhalation Rate - child (m^3/day)	10	U.S. EPA 1991a (pg. 15)
IRA_{res-a}	Resident Inhalation Rate - adult (m^3/day)	20	U.S. EPA 1991a (pg. 15)
	Resident Age-Adjusted Inhalation		Calculated using the

IFA _{res}	Fraction (m ³)	161,100	age-adjusted intake factors equation.
IRA _w	Worker Inhalation Rate (m ³ /day; based on a rate of 2.5 m ³ /hour for 24 hours)	60	U.S. EPA 1997a (pg. 5-11)

6. References

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WHO. 2009. World Health Organization handbook on indoor radon: a public health perspective.

Ryan Schierman

Formerly with:

Wyoming Department of Environmental Quality

Uranium Recovery Program

RYAN S. SCHIERMAN

EXPERIENCE

Wyoming Dept. of Environmental Quality Cheyenne WY July 2015- September 2020

Uranium Recovery Program Manager ENNR13

- Obtained a partial Agreement with the Nuclear Regulatory Commission (NRC) to become the 38th Agreement State. Wyoming's Agreement was the first partial Agreement with the NRC for material solely at uranium recovery operations.
- Completed Agreement with the NRC in 3.5 years, 2 years sooner than projected and 2.5 million dollars under budget.
- Represented Wyoming's interest on a national level as a representative of Organization of Agreement States and the Conference of Radiation Control Program Directors (CRCPD).
- Developed a fee structure to collect an annual budget of 1.6 million dollars.
- Interacted with Wyoming legislative staff to pass statutory provisions for the program. Including developing NRC compatible regulations that were only applicable to uranium recovery.
- Interacted with Wyoming's Governor Staff on a wide variety of issues ranging from Wyoming's NRC Agreement to Interim Storage of Spent Nuclear Fuel.
- Managed the Uranium Recovery Program which consisted of 6 professional staff with broad technical backgrounds ranging from Health Physics to Geochemistry.
- Provided expertise and oversight for the licensing and compliance of the States 14 Uranium Recovery Source Material Licensees.
- Oversaw an efficiency review of the Department of Environmental Quality (DEQ) Land Quality Division using Lean Six Sigma principles and developed an implementation plan for the recommendations.

Uranium One, Americas Casper, WY June 2014 – July 2015

Environmental Health and Safety Manager/Radiation Safety Officer

- Oversaw and managed the Environmental Safety and Health Department at the mine site which consisted of 7 individuals.
- Responsible for the occupational safety of employees at the mine site.
- Ensured Uranium One was in compliance with NRC, The Department of Transportation (DOT), and Wyoming DEQ requirements.
- Assisted in the development of a Root Cause Analysis that analyzed upset conditions that lead to pressurization of a drum of yellowcake. The information found from the Root Cause analysis provided additional information to the NRC. The information bolstered previous understandings of what was causing drum pressurization across the industry and assisted in the prevention of such pressurizations industry wide.
- Evaluated cleanup of historical contamination to ensure that it met regulatory requirements and met an acceptable risk threshold.

Uranerz Energy Corporation Casper, WY May 2013 – June 2014

Radiation Safety Officer

- Developed the Radiation Safety Program, including the NRC and DOT training, the radiation work permit program, the bioassay program, dose assessment procedures, standard operating procedures, and establishing routine inspection requirements.
- Developed cleanup standards for the site using radiological computer code (RESRAD).
- Established administrative action levels for spill cleanup at the site.

- Utilized, operated, and maintained instrumentation necessary to meet requirements for contamination control.

Environmental Monitoring Laboratory Pocatello, ID Sept 2011 – May 2013

Research Assistant

- Researched potential of honey as an environmental monitor of cesium deposition following Japan's Fukushima Daiichi accident.
- Utilized, operated, and maintained 4 high purity germanium, 2 gas flow proportional, and 2 liquid scintillation detectors to analyze environmental media samples.
- Collaborated with Idaho's Department of Environmental Quality on the collection and analysis of air, water, and soil samples.

Denison Mines Blanding, UT Jan 2011-July 2011

Environmental Technician

- Project lead in instituting company safety practices during groundwater nitrate plum exploration
- Assisted in regulatory compliance by sampling over 80 wells on site on a routine basis, and collection other environmental samples such as surface water, vegetation, soil, and air.

UMETCO Minerals Corporation Gas Hills, WY April 2004-Aug 2005 (summers)

Radiation Tech

- Assisted in implementation of the decommissioning plan by conducting gamma surveys of repository cover material, collecting and preparing soil samples for analysis, and performing the necessary contamination surveys of equipment for public access.

EDUCATION

- *Idaho State University* Pocatello, ID May 2013
Masters in Health Physics
(NRC Fellow)
- *Brigham Young University* Provo, UT Dec. 2010
Bachelor of Science in Environmental Science

Certification and Associations

- Passed the American Board of Health Physics (ABHP) CHP Part I Exam in 2018 and will seat for Part II in 2020
- Certified Uranium Recovery Inspector and Program Manager (NRC IMC 1248 App H & I)
- Nuclear Regulatory Fellow at Idaho State University
- Member of the Health Physics Society since 2011
- Member of the Organization of Agreement States since 2015
- Member of the Conference of Radiation Control Program Directors since 2015

Training

- Multi -Agency Radiation Survey and Site Investigation Manual (MARSSIM)
- Health Physics for Uranium Recovery
- Root Cause Analysis
- Characterization and Planning for Decommissioning
- Transportation of Radioactive Material
- Visual Sampling Plan
- MILDOS Area
- RESRAD
- Advanced Health Physics
- Environmental Monitoring
- Environmental Risk Assessment
- Inspection and Licensing Procedures

Peer Reviewer Conflict of Interest Certification

Peer Review: **Draft Radon Vapor Intrusion Screening Level Calculator (RIVSL)**

A conflict of interest or lack of impartiality exists when the proposed peer reviewer personally (or the peer reviewer's immediate family), or his or her employer, has financial interests that may be affected by the results of the peer review; or may provide an unfair competitive advantage to the peer reviewer (or employer); or if the peer reviewer's objectivity in performing the peer review may be impaired due to other factors. When the Peer Reviewer knows that a reasonable person with knowledge of the facts may question the peer reviewer'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 RIVSL calculator (and associated webpages) under peer review, 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 peer review, or any reason that your impartiality in the matter might be questioned? No Yes
- Have you had any previous involvement with the RIVSL 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 peer review, 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 peer review? 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 peer review:

(a) Peer Reviewer 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 Peer Reviewer has disclosed all such relevant information to EMS or to EPA.

(b) Peer Reviewer agrees that if an actual, apparent, or potential personal or organizational conflict of interest is identified during performance of this peer review, he/she immediately will make a full disclosure in writing to EMS. This disclosure shall include a description of actions that Peer Reviewer (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. Peer Reviewer shall continue performance until notified by EMS of any contrary action to be taken.



Signature

10-14-2020
Date

Check here if any explanation is attached

Ryan Schierman
Printed Name

NA
Affiliation/Organization

Charge Questions (Schierman):

- A. Homepage and Overall Website
1. Is the website clearly organized, described, easy to navigate, and generally “user friendly” and appropriate for the target audience? If not, what do you recommend?
 - On the homepage the reviewer would include the purpose of the screening tool. The user’s guide, under the disclaimer has an appropriate statement that could be included in the homepage:

“ Purpose of this guidance is to provide a radon vapor intrusion screening level (RVISL) calculation tool to assist risk assessors, remedial project managers, and others involved with risk assessment and decision-making at CERCLA sites in developing RVISLs or preliminary remediation goals 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.”
 - The limitations of the calculator, as discussed under “Potential Problems and Limitations” as well as assumptions made by the calculator, should be more clearly identified as a bullet on the home page. The bullet could be listed as “Assumptions and Limitations.” The reviewer understand that under the first paragraph of the user’s guide it states to read disclaimer first however, to prevent misuse of the calculator identifying the limitations and assumptions up front may deter misuse.
 - Additionally, it should be stressed on the home page that the recommendation contained in Section 3.4 “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, risk, or dose targets.”
 - On the original homepage the reviewer recommends as done in other sections in the user’s guide a clarifying statement that screening levels are synonymous with preliminary remediation goals.
 2. Have the objectives of the RVISL calculator, as stated in the documentation, been met? If not, what do you recommend?
 - The objectives for the RVISL calculator, as stated in the user’s guide have been met as described. One item that may be prudent to discuss more in depth is the current shortfall and the need for the RVISL calculator. Discussing how the calculator closes this shortfall would be beneficial.
 3. Do you recommend any modifications to the Homepage graphic?
 - Developers may want to consider changing the graphic to state that the soil contains radium instead of radon. Radon is not attached to the soil particle. It is a nuance and may not be worth changing.

- The Graphical representation under Radon Vapor Intrusion Screening Level Equations/Air Screening Level Equations/Residential Air and Workers Air is misleading. Representing sources of radon as drums of waste may lead to misconceptions on sources of radon. I prefer the homepage graphic depiction of the source as solely soil containing radon (radium) or just a radiation symbol.

4. Do you have any other recommendations to improve the usability of the website?

- On the homepage the “Welcome” and “Introduction” seem to be a little verbose and could be consolidated into one section.
- Generic Tables Bullet is not functional

B. User’s Guide

1. Does the User’s Guide adequately explain the concepts addressed by the calculator and its limitations?

- The reviewer agrees that the guide adequately explained the concepts addressed by the calculator. The reviewer would recommend adding a bullet under “Radon Vapor Intrusion Screening Levels (RVISL) table” stating “Assumptions and Limitations” All assumptions and limitations should be clearly documented under this bullet.

2. Are the assumptions clear and reasonable? If not, what do you recommend?

- See response to B. User’s guide question 1.

3. Are the sources and citations appropriate, and do they represent the current state of knowledge? If not, what do you recommend?

- Additional resources for the author to consider:
 1. ICRP, 2014. Radiological Protection against Radon Exposure. ICRP Publication 126. Ann. ICRP 43(3)
 2. ICRP, 2017. Occupational Intakes of Radionuclides Part 3. ICRP Publication 137. Ann. ICRP 46 (3/4)

“While ICRP Publication 137 does not specifically address public exposures, it is intended that this same dose coefficient applies to exposures in homes.

3. NCRP Report 97. Measurement of Radon and Radon Daughters in Air.
4. NCRP Report 160. Ionizing Radiation Exposure of the Population of the United States. 2009. *Radon Equilibrium factors*.

C. Frequent Questions

1. Are the 11 questions clearly worded? If not, what do you recommend?

- The questions are clearly worded, I have no further recommendations.

2. Are the 11 responses clear, concise, and accurate? If not, what do you recommend?

- I found no issues with the responses and they appeared to be accurate.

3. Are there other helpful questions and answers that should be added? If yes, please list the questions.
 - I would add the following question.

Can I change a radon equilibrium factor or activity equilibrium factor to site specific data?.

With an exchange rate of zero the radon equilibrium fraction is 1 to 1 or 100%. NCRP and other organizations have proposed other equilibrium factors. While I understand the equilibrium factor can be modified using air exchanges, the reviewer believes it would be good to clarify in the frequent question section how equilibrium can be changed.

D. Calculator

1. Are the results clearly explained and presented? If not, what do you recommend?
 - When selecting the target dose (mrem/yr) under the dose-based screening level type the default is 1 mrem. I am unsure where the 1 mrem/year comes from. In the supporting document *Analysis of what Radiation Dose Limit is Protective of Human Health at CERCLA Sites (Including Review of Dose Limits in NRC Decommissioning Rule)* it states EPA has considered cancer risk from radiation in a number of different contexts, and has consistently concluded that levels of 15 mrem/yr. EDE (which equates to approximately a 3×10^{-4} cancer risk) or less are protective and achievable. Why not set the default to 15 mrem/yr?
2. Are the results appropriately described and qualified (to the extent that they may be relied upon and defended)? If not, what do you recommend?
 - From the limited testing of the calculator, the results correspond with the equations described in the user's guide. The question of whether they may be relied upon or defended is harder to answer. The calculator purpose from the reviewer's understanding is to assist risk assessors, remedial project managers, and others to make decision at CERCLA sites in developing screening levels or preliminary remediation goals. As stated in the user's guide "Predicting the amount of radon gas available for vapor intrusion in the natural environment, is not an ideal setting. Several factors make it impossible for this calculator to confidently predict suitable target indoor air concentrations from sources in soil and groundwater." The reviewer agrees with the language in the user's guide and there are such variabilities that make it hard for the calculator to be defensible. With measurement however, the results become much more defensible.
3. Do the results provide defensible explanation of how they were derived, or are they the result of a "black box?" Do you recommend anything different?
 - I think the user's guide adequately describes how the equations were derived.
4. RVISL calculation of the equilibrium level (F_{eq}) of radon progeny that would be present in indoor air is based on air exchange rate. Should other mechanisms (seasonal

atmospheric changes, building construction, surface plating, aerosol sizes, regional geology, air flow) be incorporated in the calculation?

- Ultimately, there are many factors that influence radon concentrations indoors. Incorporating the above items may improve the estimate, however it would also introduce more uncertainty in the estimate. The answer to the question is whether the calculator as presented provides a conservative estimate of the radon air concentrations. As EPA implements the calculator and sets screening levels, it will be interesting to compare actual measurements with what was predicted to understand if more variables are needed in the calculation.

5. Is there anything else you recommend for the calculator to improve it for its stated purpose?

E. Anything Else?

Is there anything else you would recommend to improve the RVISL calculator's utility, accuracy, completeness, or supportability?

- I think it is important to note that the calculator is a tool to assist decision making at CERCLA sites in developing screening levels. It is not a regulatory requirement or the only way to set screening levels. While the calculator is helpful, as stated by EPA in the documentation where possible regions should use measurements of radon indoors rather than rely on the transport portions of the calculator. Testing of groundwater or soil gas is not required to demonstrate compliance with RVISL, working levels, risk, or dose targets.
- The calculator is to be used at CERCLA sites. However, the user's guide and the calculator frequently refer back to UMTRCA applicable or relevant and appropriate requirements (ARAR). The reviewer understands that a few UMTRCA sites are also listed as CERCLA sites. Is the utility of the calculator comparing UMTRCA ARAR only for these UMTRCA sites listed as CERCLA? Outside of UMTRCA, is there utility in comparing it back to these standards? Is it the intent of the developers that the calculator would be used outside of CERCLA facilities? These are items to consider that are not clear upon review of the calculator and the accompanying documentation.

Carl Spreng

Retired: Colorado Department of Public Health
and Environment

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
Master of Science – Geology
Post-graduate courses:
Geohydrology
Geophysics

Brigham Young University (1975)
Brigham Young University (1978)

University of Colorado
Colorado School of Mines

Peer Reviewer Conflict of Interest Certification

Peer Review: **Draft Radon Vapor Intrusion Screening Level Calculator (RIVSL)**

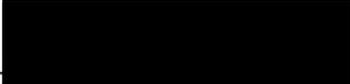
A conflict of interest or lack of impartiality exists when the proposed peer reviewer personally (or the peer reviewer's immediate family), or his or her employer, has financial interests that may be affected by the results of the peer review; or may provide an unfair competitive advantage to the peer reviewer (or employer); or if the peer reviewer's objectivity in performing the peer review may be impaired due to other factors. When the Peer Reviewer knows that a reasonable person with knowledge of the facts may question the peer reviewer'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 RIVSL calculator (and associated webpages) under peer review, 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 peer review, or any reason that your impartiality in the matter might be questioned? No Yes
- Have you had any previous involvement with the RIVSL 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 peer review, 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 peer review? 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 peer review:

- Peer Reviewer 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 Peer Reviewer has disclosed all such relevant information to EMS or to EPA.
- Peer Reviewer agrees that if an actual, apparent, or potential personal or organizational conflict of interest is identified during performance of this peer review, he/she immediately will make a full disclosure in writing to EMS. This disclosure shall include a description of actions that Peer Reviewer (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. Peer Reviewer shall continue performance until notified by EMS of any contrary action to be taken.


Signature _____ Date 9/23/2020

Check here if any explanation is attached

Carl Spreng
Printed Name

CO Dept. of Public Health & Environment (retired)
Affiliation/Organization

Charge Questions (Spreng):

A. Homepage and Overall Website

1. Is the website clearly organized, described, easy to navigate, and generally “user friendly” and appropriate for the target audience? If not, what do you recommend?

The website is clearly organized; it progresses from topic to topic generally in a logical sequence. The instructions and descriptions necessarily vary in detail, which likely matches the range of knowledge among the target audience(s).

2. Have the objectives of the RVISL calculator, as stated in the documentation, been met? If not, what do you recommend?

The calculator was created to develop PRGs or SLs that “predict potential human exposure from radon concentrations in indoor air”. It meets those objectives.

3. Do you recommend any modifications to the Homepage graphic?

The graphic adequately portrays the various vapor transport concepts. The source – the “soil containing radon” blob – looks like it may have been copied from a chemical spill figure.

4. Do you have any other recommendations to improve the usability of the website?

No. The instructions and information seem to fit the range of potential users. Links to the references cited also improve the usability of the website.

B. User’s Guide

1. Does the User’s Guide adequately explain the concepts addressed by the calculator and its limitations?

Yes, the concepts are fully and clearly explained. The Guide describes uncertainties, assumptions and defaults, and the inherent problems with predicting air concentrations from subsurface sources. It also explains that it does not establish binding rules.

2. Are the assumptions clear and reasonable? If not, what do you recommend?

The assumptions are generally reasonable and clearly worded. Suggested revisions are shown in an attached file in the text edit/comment mode of Adobe Acrobat.

3. Are the sources and citations appropriate, and do they represent the current state of knowledge? If not, what do you recommend?

The sources and citations are appropriate and seem to be up to date. The only additional reference that I suggested was in Section 1.7 where it might be worth mentioning that EPA participates in the radon industry-led ANSI/AARST voluntary consensus-based standards (VCS) process: <https://standards.aarst.org/>

“EPA Guidance on the Use of Voluntary Consensus Standards for State Indoor Radon Grant Recipients.” https://www.epa.gov/sites/production/files/2019-08/documents/august_2019_sirg_vcs_program_guidance_epa402-b19-080.pdf

I have also noted in several places where links to documents do not open.

C. Frequent Questions

1. Are the 11 questions clearly worded? If not, what do you recommend?
The questions are generally clearly worded. Suggested revisions are shown in an attached file in the text edit/comment mode of Adobe Acrobat.
2. Are the 11 responses clear, concise, and accurate? If not, what do you recommend?
The responses are generally clearly worded and accurate. Suggested revisions are shown in an attached file in the text edit/comment mode of Adobe Acrobat.
3. Are there other helpful questions and answers that should be added? If yes, please list the questions.
The list of questions/answers seems adequate.

D. Calculator

1. Are the results clearly explained and presented? If not, what do you recommend?
The calculator results are clearly displayed. A minor comment: The “time stamp” at the bottom of the output spreadsheet is Eastern Time. If the time is necessary for complete documentation of calculator runs, that should probably be noted.
2. Are the results appropriately described and qualified (to the extent that they may be relied upon and defended)? If not, what do you recommend?
Yes, the results are appropriately described and qualified. The Home Page and User’s Guide describe uncertainties and assumptions.
3. Do the results provide defensible explanation of how they were derived, or are they the result of a “black box?” Do you recommend anything different?
The best test of a calculator that tries to replicate natural phenomenon is whether it consistently produces reasonable results. Several “test runs” with various input parameters seem to produce reasonable results.
4. RVISL calculation of the equilibrium level (F_{eq}) of radon progeny that would be present in indoor air is based on air exchange rate. Should other mechanisms (seasonal atmospheric changes, building construction, surface plating, aerosol sizes, regional geology, air flow) be incorporated in the calculation?
Section 1.1 states that several factors affecting the indoor F_{eq} were omitted for “simplification”. It is assumed that the “other mechanisms” may also be minor enough that they, too, could be ignored. Section 1.8 mentions research that provides data on

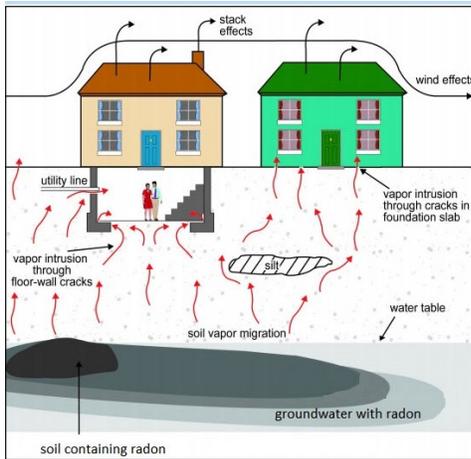
some of these mechanisms, but this research demonstrates how difficult it is to predict F_{eq} values because of them. It is also assumed that additional research may someday allow the effects of some of these “other mechanisms” to be included in the calculator.

5. Is there anything else you recommend for the calculator to improve it for its stated purpose?

No - no additional recommendations beyond those in the comments in the attached files.

- E. Anything else? Is there anything else you would recommend to improve the RVISL calculator’s utility, accuracy, completeness, or supportability?

No - no additional recommendations beyond those in the comments in the attached files.



1

2 **Figure caption:** This figure depicts the migration of radon in soil gas from contaminated soil and groundwater
 3 into buildings. Radon in soil gas is shown to enter buildings through cracks in the foundation and openings for
 4 utility lines. Atmospheric conditions and building ventilation are shown to influence radon soil gas intrusion.

5 Welcome

6 Welcome to the "Radon Vapor Intrusion Screening Level (RVISL) Calculator Home Page for
 7 Radionuclide Contaminants at Superfund Sites". This website was developed with DOE's Oak
 8 Ridge National Laboratory (ORNL) under an Interagency Agreement with the U.S. Environmental
 9 Protection Agency (EPA). The RVISL website is now the generally recommended source of radon
 10 screening levels for all EPA regions. The RVISL calculator output provides comparison values and
 11 risk and dose estimates for residential and commercial/industrial exposures to radon in soil gas,
 12 air, and groundwater. Note that for Comprehensive Environmental Response, Compensation, and
 13 Liability Act (CERCLA) remedial actions, dose assessment is generally done only to show
 14 compliance with a dose-based Applicable or Relevant and Appropriate Requirement (ARAR). In
 15 addition, the calculator presents the option to compare the indoor air concentration, entered by
 16 the user or derived from groundwater or soil gas activities, to state standards or Uranium Mill
 17 Tailings Radiation Control Act (UMTRCA) standards, which also may be potential ARARs. The
 18 unified use of the RVISLs to screen radon at Superfund sites promotes national consistency. The
 19 RVISL uses the same database of toxicity values, chemical parameters, and inhalation exposure
 20 equations as the [Preliminary Remediation Goals \(PRGs\)](#) for Radionuclide Contaminants at
 21 Superfund Sites calculator. The RVISL calculator provides default parameters that can be
 22 modified to reflect site-specific risks. To ensure proper use of the calculator, please review
 23 the [What's New](#), [User's Guide](#), and [Frequently Asked Questions](#) links. The EPA has prepared a [fact](#)
 24 [sheet](#) for the general public that describes RVISL uses, RVISL calculator operation, and land uses
 25 available for assessment. Additionally, this [fact sheet](#) describes the RVISL content in greater detail
 26 for EPA staff. Below is a general description of screening levels for radon. If the calculator is used
 27 with non-default inputs in a decision on a Superfund site, it is recommended that the inputs be
 28 clearly identified and justified by the user.

29 The RVISL calculator provides updated guidance for developing screening levels (SLs) or
 30 preliminary remediation goals (PRGs) for indoor radon-222, radon-220, and radon-219 that are

31 risk- or dose-based and for showing compliance with the UMTRCA indoor radon standards for
32 radon-222 and radon-220. The RVISL, therefore, supersedes the risk assessment approach in
33 Preliminary Remediation Goals for Radionuclides in Buildings ([BPRG](#)) electronic calculator, the
34 dose assessment approach in ARAR Dose Compliance Concentrations Goals for Radionuclides in
35 Buildings ([BDCC](#)) electronic calculator, and Q17 of the guidance document "[Radiation Risk
36 Assessment At CERCLA Sites: Q & A](#)" issued on May 2014. Computer codes such as the RVISL,
37 which were developed to predict potential human exposure from radon concentrations in indoor
38 air, are based on simplified equations and assumptions and are highly imprecise for an individual
39 house or structure. EPA would recommend, where possible, Regions use measurements of radon
40 indoors rather than rely on the transport portions of the RVISL. In particular, testing of
41 groundwater or soil gas is not required to demonstrate compliance with RVISL WL, pCi/L, risk, or
42 dose targets.

43 Users should note that since background radon levels are typically outside the risk range, the
44 RVISL calculator is likely to be used primarily for ARAR compliance. For example, the UMTRCA
45 indoor radon standards 40 CFR 192.12(b)(1) and 192.41(b) were identified as likely Federal ARARs
46 for Rn-222 and Rn-220 in Attachment A of the EPA guidance document "Establishment of Cleanup
47 Levels for CERCLA Sites with Radioactive Contamination." There are some state standards
48 expressed in pCi/l or mrem/yr that, if more stringent than the UMTRCA standards, may be
49 selected as ARARs.

50 **Introduction**

51 Superfund sites are addressed under the authority of the Comprehensive Environmental
52 Response, Compensation, and Liability Act (CERCLA) of 1980, which was amended by the 1986
53 Superfund Amendments and Reauthorization Act. The purpose of this website is to provide a
54 screening level calculation tool to assist risk assessors, remedial project managers, and others
55 involved with risk assessment and decision-making at CERCLA sites in developing or refining
56 screening levels.

57 Rn-222 is commonly referred to radon because of its parent radium-226. Rn-220 is commonly
58 called thoron because of its parent thorium. Rn-219 is commonly called actinon because of its
59 parent actinium. Click the decay chain link to see the decay series for [Rn-222](#), [Rn-220](#), and [Rn-219](#).
60 The metal groups in these images are based on [Los Alamos National Laboratory](#) literature. See
61 section 2.2 of the User's Guide to learn what progeny are evaluated in this web calculator. More
62 details about the decay chains can be found in the EPA's [Decay Chain](#) Tool.

63 This tool is based on the [Technical Guide for Assessing and Mitigating the Vapor Intrusion
64 Pathway from Subsurface Vapor Sources to Indoor Air \(June 2015\)](#). Vapor intrusion occurs when
65 there is a migration of vapor-forming chemicals or radon from any subsurface source into an
66 overlying building. Recognition of soil vapor intrusion to buildings and other enclosed spaces
67 occurred in the 1980s with concerns over radon intrusion. Subsequently, there was an increasing
68 awareness that anthropogenic chemicals (e.g., petroleum hydrocarbons and chlorinated

69 solvents) in soil, groundwater, and sewers and drainlines could also pose threats to indoor air
70 quality via the vapor intrusion pathway.

71 The RVISL calculator results were previously verified. The documentation from these may be seen
72 on the [Internal Verification](#) and [External Verification](#) pages. The RVISL calculator was also
73 previously peer reviewed, and the documentation of the review may be seen [here](#).

74 Chemicals are not addressed on this website. For chemical vapor intrusion, please go to [EPA's](#)
75 [Vapor Intrusion Screening Level Calculator](#).

76 Note: No consideration is given to ecological effects in the values presented in this calculator.

77 **Frequently Asked Questions**

78 **This page presents many questions asked by site users and the applicable responses. Please**
79 **search this page for answers to your questions prior to contacting technical support staff.**
80 **Researching the questions and answers posted here will greatly reduce the time it takes for**
81 **you to solve many problems that arise from calculating and using this SL site.**

82 1. [What are RVISLs? How are they used?](#)

83 RVISLs are preliminary remediation goal concentrations for groundwater, soil gas (sub-
84 slab and exterior), and indoor air to assist Agency staff with making a vapor intrusion
85 determination based on limited, initial data.

86 2. [How can I change attenuation factors?](#)

87 To change the attenuation factors, run the [calculator](#); the main page has editable cells
88 with the default factors presented.

89 The screening levels for groundwater and soil gas (either sub-slab gas or soil gas
90 collected exterior to buildings) are calculated from the target indoor air concentrations
91 using empirically-based conservative "generic" attenuation factors that reflect
92 generally reasonable worst-case conditions, as described in the EPA's vapor intrusion
93 guidance.

94 A critical assumption for this generic model is that site-specific subsurface
95 characteristics will tend to reduce or attenuate soil gas concentrations as vapors
96 migrate upward from the source and into overlying structures. Specific factors that may
97 result in relatively unattenuated or enhanced transport of vapors into a building
98 include the following:

- 99 ○ Significant openings to the subsurface that facilitate soil gas entry into the building
100 (e.g., sumps, unlined crawl spaces, earthen floors) other than typical utility
101 penetrations.

- 102 ○ Very shallow groundwater sources (e.g., depths to water less than five feet below
103 foundation level)
- 104 ○ Significant routes for preferential, subsurface vapor migration whether naturally
105 occurring (e.g., fractured bedrock) or anthropogenic.

106 The factors listed above may negate the appropriate application of the recommended
107 attenuation factors and the sub-slab, groundwater, and soil gas VISLs for purposes of
108 identifying sites or buildings unlikely to pose a health concern through the vapor
109 intrusion pathway. On the other hand, further evaluation of the vapor intrusion
110 pathway is still appropriate when the sub-slab, groundwater, and soil gas VISLs are
111 exceeded for samples from a building or site where these specific factors are present.

112 Vapor source types that typically make the use of the recommended attenuation
113 factors and health-based VISLs for groundwater and soil gas inappropriate include:

- 114 ○ Those originating in landfills where methane is generated in sufficient quantities to
115 induce advective transport in the vadose zone.
- 116 ○ Those originating in commercial or industrial settings where vapor-forming chemicals
117 can be released within an enclosed space and the density of the chemicals' vapor may
118 result in significant advective transport of the vapors downward through cracks and
119 openings in floors and into the vadose zone.
- 120 ○ Leaking vapors from pressurized gas transmission lines.

121 In each case, the diffusive transport of vapors may be overridden by advective
122 transport, and the vapors may be transported in the vadose zone several hundred feet
123 from the source of contamination with little attenuation in concentration. In general,
124 EPA recommends considering whether the assumptions underlying the generic
125 conceptual model are attained at a given site. If they are not attained, then EPA
126 recommends that the medium-specific VISLs not be relied upon as a line of evidence for
127 identifying sites or buildings unlikely to pose a health concern through the vapor
128 intrusion pathway. Where the assumptions regarding the subsurface attenuation
129 factors do not or may not apply, EPA generally recommends collecting indoor air
130 samples.

131 3. **Why can't I calculate RVISLs for bulk soil samples?**
132 Consistent with the 2015 OSWER Technical Guide for Assessing and Mitigating the Vapor
133 Intrusion Pathway from Subsurface Vapor Sources, "bulk soil (as opposed to soil gas)
134 sampling and analysis is not currently recommended for estimating the potential for
135 vapor intrusion to pose unacceptable human health risk in indoor air, because of the
136 potential for vapor loss due to volatilization during soil sampling, preservation, and
137 analysis. In addition, there are uncertainties associated with soil partitioning
138 calculations."

139 4. **How can I access the "forward calculator" function?**
140 In addition to calculating screening levels, the [calculator](#) allows the user to input data
141 collected from their site. This data is used to model the indoor air concentration,
142 calculate a chronic daily intake, and present cancer risk. On the [calculator](#) main page,
143 select "Yes" under the section titled "**Predict indoor air concentrations and risk from
144 measured media concentrations?**". A choice will be presented for the user to select
145 between air, soil gas, and groundwater data. "Site-specific" mode is automatically
146 activated, and the user will be prompted to enter their site data.

147 5. **How can I adjust groundwater temperatures?**
148 The main page of the [calculator](#) has a cell where the temperature can be changed from
149 the default of 25 °C.
150 Users are given the option to change the groundwater-soil system temperature from
151 the default of 25°C to a site-specific value. Since the unitless Henry's Law Constant (H')
152 is derived based on the partial pressure of a gas in equilibrium with a liquid and the
153 equilibrium changes when temperature changes, H' is changed to reflect the
154 equilibrium at the given temperature. The equation below illustrates how H' is derived
155 when groundwater temperature is changed. An EPA Fact Sheet describing the process
156 can be found at [https://www.epa.gov/vaporintrusion/fact-sheet-correcting-henrys-law-
157 constant-temperature](https://www.epa.gov/vaporintrusion/fact-sheet-correcting-henrys-law-constant-temperature).

158 6. **How are the results converted to a mass basis?**
159 Appendix B of the [Soil Screening Guidance for Radionuclides Technical Background
160 Document](#) presents a formula for converting PRGs in pCi/g to mg/kg and also a formula
161 for converting pCi/L to mg/L. The equation is reproduced here with similar conversions
162 for mg/m³ and mg/cm².

$$C_{i,a} \text{ (mg/L)} = 2.8 \times 10^{-15} \left(\frac{\text{mg} \cdot \text{mole}}{\text{pCi} \cdot \text{g} \cdot \text{year}} \right) \times A_w \left(\frac{\text{g}}{\text{mole}} \right) \times T_{1/2} \text{ (years)} \times C_{gw} \text{ (pCi/L)}$$

and:

$$C_{i,a} \text{ (mg/m}^3\text{)} = 2.8 \times 10^{-15} \left(\frac{\text{mg} \cdot \text{mole}}{\text{pCi} \cdot \text{g} \cdot \text{year}} \right) \times A_w \left(\frac{\text{g}}{\text{mole}} \right) \times T_{1/2} \text{ (years)} \times C_{sg} \text{ (pCi/m}^3\text{)}$$

where:

A_w is the radionuclide atomic weight and $T_{1/2}$ is the radionuclide half-life.

163
164

165 The derivation of the 2.8×10^{-12} conversion is presented below.

$$2.8 \times 10^{-15} \left(\frac{\text{mg} \cdot \text{mole}}{\text{pCi} \cdot \text{g} \cdot \text{year}} \right) = \left(\frac{1 \times 10^{-12} \text{ Ci}}{\text{pCi}} \right) \times \left(\frac{3.7 \times 10^{10} \text{ nt/s}}{\text{Ci}} \right) \times \left(\frac{31,536,000 \text{ s}}{\text{year}} \right) \times \frac{1}{0.693} \times \left(\frac{\text{atoms}}{\text{nt}} \right) \times \left(\frac{1 \text{ mole}}{6.023 \times 10^{23} \text{ atoms}} \right) \times \left(\frac{1000 \text{ mg}}{\text{g}} \right)$$

where:

nt = nuclear transformations (decays)

$$A \left(\frac{\text{nt}}{\text{year}} \right) = \frac{N \text{ (number of atoms)}}{T_{1/2} \text{ (years)}} \times 0.693 \left(\frac{\text{nt}}{\text{atom}} \right)$$

166
167

168 Combination of the derivation of the conversions with the isotope-specific half life and
169 atomic weight is presented here.

$$C_{i,a} \text{ (mg/L)} = C_{gw} \text{ (pCi/L)} \times \left(\frac{1 \times 10^{-12} \text{ Ci}}{\text{pCi}} \right) \times \left(\frac{3.7 \times 10^{10} \text{ nt/s}}{\text{Ci}} \right) \times \left(\frac{31,536,000 \text{ s}}{\text{year}} \right) \times \frac{1}{0.693} \times \left(\frac{\text{atoms}}{\text{nt}} \right) \times \left(\frac{1 \text{ mole}}{6.023 \times 10^{23} \text{ atoms}} \right) \times \left(\frac{1000 \text{ mg}}{\text{g}} \right) \times A_w \left(\frac{\text{g}}{\text{mole}} \right) \times T_{1/2} \text{ (years)}$$

and

$$C_{i,a} \text{ (mg/m}^3\text{)} = C_{sg} \text{ (pCi/m}^3\text{)} \times \left(\frac{1 \times 10^{-12} \text{ Ci}}{\text{pCi}} \right) \times \left(\frac{3.7 \times 10^{10} \text{ nt/s}}{\text{Ci}} \right) \times \left(\frac{31,536,000 \text{ s}}{\text{year}} \right) \times \frac{1}{0.693} \times \left(\frac{\text{atoms}}{\text{nt}} \right) \times \left(\frac{1 \text{ mole}}{6.023 \times 10^{23} \text{ atoms}} \right) \times \left(\frac{1000 \text{ mg}}{\text{g}} \right) \times A_w \left(\frac{\text{g}}{\text{mole}} \right) \times T_{1/2} \text{ (years)}$$

where:

A_w is the radionuclide atomic weight and $T_{1/2}$ is the radionuclide half-life.

nt = nuclear transformations (decays)

$$A \left(\frac{\text{nt}}{\text{year}} \right) = \frac{N \text{ (number of atoms)}}{T_{1/2} \text{ (years)}} \times 0.693 \left(\frac{\text{nt}}{\text{atom}} \right)$$

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7. How were the UMTRCA working level (WL) standards converted to pCi/L?

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This table depicts the three steps to convert the UMTRCA WL standard to pCi/L. For more discussion on WLs, see the [User's Guide](#) Section 2.8.

Assuming Radon Equilibrium Factor (F_{eq}) = 1		
Rn-222	Rn-220	Rn-219
1 WL = 100 pCi/L	1 WL = 7.5 pCi/L	1 WL = 162 pCi/L
1 WL = 100,000 pCi/m ³	1 WL = 7,500 pCi/m ³	1 WL = 162,000 pCi/m ³
1 WL = 3.7 Bq/L	1 WL = 0.2775 Bq/L	1 WL = 5.994 Bq/L
1 WL = 3,700 Bq/m ³	1 WL = 277.5 Bq/m ³	1 WL = 5,994 Bq/m ³
Assuming Radon Equilibrium Factor (F_{eq}) = 0.4 for Rn-222 and 0.02 for Rn-220		
Rn-222	Rn-220	Rn-219
1 WL = 250 pCi/L	1 WL = 375 pCi/L	Unable to provide conversion due to missing F_{eq} from Federal Guidance for Rn-219.
1 WL = 250,000 pCi/m ³	1 WL = 375,000 pCi/m ³	
1 WL = 9.25 Bq/L	1 WL = 13.875 Bq/L	
1 WL = 9,250 Bq/m ³	1 WL = 13,875 Bq/m ³	
Standardized to 0.02 Working Levels (WL)		
Rn-222	Rn-220	Rn-219
0.02 WL = 5 pCi/L	0.02 WL = 7.5 pCi/L	Unable to provide conversion due to missing F_{eq} from Federal Guidance for Rn-219.
0.02 WL = 5,000 pCi/m ³	0.02 WL = 7,500 pCi/m ³	
0.02 WL = 0.185 Bq/L	0.02 WL = 0.2775 Bq/L	

0.02 WL = 185 Bq/m ³	0.02 WL = 277.5 Bq/m ³	
---------------------------------	-----------------------------------	--

177 **Working Level Conversion References**

- 178 ○ David Allen. [Dose Conversion Factors for Radon WLM](#). Centers for Disease Control (CDC),
 179 June 2018.
- 180 ○ Health Physics Society (HPS). [Ask the Experts: Environmental and Background
 181 Radiation - Radon, May 2017.](#)

182 **8. When do I use risk-based versus dose-based versus WL screening level types?**

183 The RVISL calculator is likely to be used primarily for ARAR compliance. For example,
 184 the UMTRCA indoor radon standards 40 CFR 192.12(b)(1) and 192.41(b) were identified
 185 as likely Federal ARARs for Rn-222 and Rn-220 in Attachment A of the EPA guidance
 186 document "Establishment of Cleanup Levels for CERCLA Sites with Radioactive
 187 Contamination." There are some state standards that may be expressed in pCi/l or
 188 mrem/yr that if more stringent than the UMTRCA standards may be selected as ARARs.
 189 Background levels of indoor radon will typically exceed the risk range, and it would
 190 generally not be expected that remediation levels for indoor radon would be risk-based
 191 or based on background. The risk portions of the RVISL can still be used to provide risk
 192 estimates for the ARAR-based remediation levels.

193 **9. When should modelling instead of measurements be used for indoor radon?**

194 Computer codes such as the RVISL, which were developed to predict radon
 195 concentrations in indoor air for potential human exposure based on simplified
 196 equations and assumptions, are highly imprecise for an individual house or structure.
 197 EPA would recommend, where possible, Regions use measurements of radon indoors
 198 rather than rely on the transport portions of the RVISL. In particular, testing of
 199 groundwater or soil gas is not required to demonstrate compliance with RVISL WL,
 200 pCi/L, risk, or dose targets.

201 **10. Why do the Superfund RVISL calculator risk results for 4 pCi/L of Rn-222 in air differ
 202 from the reported ORIA health risks for the same activity?**

203 The RVISL calculator risk results for 4 pCi/L of Rn-222 in air differ from the reported
 204 ORIA health risks for the same activity for several reasons. The first reason for a
 205 difference in the risk results is that the RVISL calculator uses risk coefficients based on
 206 morbidity (getting cancer) from inhalation and submersion exposure routes, while the
 207 ORIA tables are based on mortality (death) from inhalation-induced lung cancer only.
 208 The ORIA [Health Risk of Radon](#) web page reports that for smokers and never-smokers,
 209 the mortality risk from lung cancer of 4 pCi/L of Rn-222 is 62 out of 1,000 people and 7
 210 out of 1,000 people, respectively, or 6.2×10^{-2} and 7×10^{-3} . Given in the scientific notation
 211 format used in the RVISL, this relates to a lung cancer mortality risk of 6.2E-02 and 7E-
 212 03, respectively. The RVISL residential risk results for a combination of smokers and

213 never-smokers to 4 pCi/L of Rn-222 in air is 8.39E-02, which rounds to 8.4×10^{-2} .
 214 Additionally, the ORIA risk estimates are based on an average population study, where
 215 the individual's exposure parameters are not considered, while the RVISL results are
 216 based on a reasonably maximum exposed (RME) individual. The individual exposure
 217 parameters considered in Superfund assessments include dwelling air exchange rate,
 218 inhalation rates, exposure duration, and resident time indoors.

219 For more information on different methods for making radon inhalation cancer risk
 220 estimates see section 2.3.1 of the User Guide.

221 **11. I noticed the VISL and RVISL use the same attenuation factors. Are the VISL default**
 222 **attenuation factors appropriate for use in the RVISL calculator?**

223 The default VISL attenuation factors are also used in the RVISL. In fact, radon intrusion
 224 studies were the foundation for recognition that chemical vapors also intrude into
 225 buildings and enclosed spaces from soil and groundwater sources ([EPA 1995](#)). It was
 226 also observed that vapor intrusion mitigation remedies suppress both chemical and
 227 radon gasses and that monitoring radon intrusion is a viable surrogate for predicting
 228 chemical intrusion susceptibility in buildings ([EPA 2015](#)). Many studies reported in [EPA](#)
 229 [2012a](#), demonstrate strong correlation between radon and chemical sub-slab soil gas
 230 attenuation factors calculated when the radon and chemicals are uniformly collocated.

231 The default attenuation factors can be substituted for site-specific attenuation factors if
 232 underlying site conditions are known. [EPA 2012b](#) presents site-specific attenuation
 233 factors for sub-slab soil gas, groundwater, and crawlspaces for chemicals. The
 234 attenuation factors are summarized in the following table. The defaults used in the VISL
 235 and RVISL calculators are highlighted. The defaults are based on the 95th percentile and
 236 are appropriate for adjusting an RME scenario. The 50th percentile values would be more
 237 appropriate for a central tendency exposure scenario where a large amount of
 238 sampling data is available to reduce uncertainty in calculating the exposure
 239 concentration or defining nature and extent of the source term.

Subslab Soil Gas Attenuation Factors		
Residence Type	Median (50 th percentile)	95 th Percentile
All residences	3E-03 (0.003)	3E-02 (0.03)*
Residences with basements	3E-03 (0.003)	3E-02 (0.03)
Residences with slab-on-grade	3E-03 (0.003)	1E-02 (0.01)

Groundwater Attenuation Factors		
Scenario	Median (50 th percentile)	95 th Percentile
All soil types and water depths	7E-05 (0.00007)	1E-03 (0.001)*
Fine soil type	5E-05 (0.00005)	5E-04 (0.0005)
Coarse soil type	1E-04 (0.0001)	1E-03 (0.001)
Very coarse soil type	2E-04 (0.0002)	4E-03 (0.004)
Depth to water < 1.5 m	6E-04 (0.0006)	7E-03 (0.007)
Depth to water 1.5-3 m	1E-04 (0.0001)	2E-03 (0.002)
Depth to water 3-5 m	4E-05 (0.00004)	2E-03 (0.002)
Depth to water > 5 m	5E-05 (0.00005)	6E-04 (0.0006)
Exterior Soil Gas Attenuation Factors		
Scenario	Median (50 th percentile)	95 th Percentile
All residences	4E-03 (0.004)	3E-01 (0.3)
Crawlspace Attenuation Factor		
Scenario	Median (50 th percentile)	95 th Percentile
All residences	4E-01 (0.4)	9E-01 (0.9)

*These are the VISL and RVISL defaults.

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Draft Radon VISL User's Guide (April 2020)

[PDF of User 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 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](#).

This tool provides screening level concentrations of radon for groundwater, soil gas (sub-slab and exterior), and indoor air to assist Agency staff with making a radon vapor intrusion screening level (RVISL) determination based on limited, initial data. In addition to calculating screening levels, 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. Note that for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial actions, dose assessment is generally done only to show compliance with a dose based Applicable or Relevant and Appropriate Requirement (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.

The RVISL calculator provides updated guidance developing screening levels (SLs) 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. The RVISL therefore supersedes the risk assessment approach in Preliminary Remediation Goals for

Radon Vapor Intrusion Screening Levels (RVISL)

- [Home Page](#)
- [User's Guide](#)
- [What's New](#)
- [Frequent Questions](#)
- [Equations](#)
- [RVISL Calculator](#)
- [Generic Tables](#)

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.

[Open All Sections](#) | [Close All Sections](#)

Disclaimer

This guidance sets forth a recommended, but not mandatory, approach based upon currently available information with respect to risk and dose assessment for response actions at CERCLA sites. This document does not establish binding rules. Alternative approaches for risk assessment may be found to be more appropriate at specific sites (e.g., where site circumstances do not match the underlying assumptions, conditions, and models of the guidance). The decision whether to use an alternative approach and a description of any such approach should be documented for such sites. Accordingly, comments questioning the use of the approaches recommended in this guidance at individual CERCLA sites should be considered and an explanation provided for the selected approach.

It should also be noted that the radon vapor intrusion screening levels (RVISLs) produced by this calculator are based upon human health risk and do not address potential ecological risk. Some sites in sensitive ecological settings may also need to be evaluated for potential ecological risk. EPA's guidance "[Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessment](#)" contains an eight step process for using benchmarks for ecological effects in the remedy selection process.

The RVISL calculator provides updated guidance developing screening levels (SLs) 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. 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.

1. Understanding the RVISL Website

1.1 General Considerations

Radon is an inert, cancer-causing, radioactive gas at room temperature and these criteria used to determine if a chemical is suitable for vapor intrusion analysis will be ignored for this calculator.

- To determine vapor intrusion of a chemical, the chemical must first meet the criteria for volatility, which is either a Vapor Pressure > 1 mm Hg or a Henry's Law Constant > 1×10^{-5} atm-m³/mole.
- A chemical must be sufficiently volatile and toxic to pose inhalation or external exposure risk

via vapor intrusion from soil source.

- Third, the chemical must be sufficiently volatile and toxic to pose inhalation or external exposure risk via vapor intrusion from groundwater.
- The chemical must contain either a reference concentration (RfC) or an inhalation unit risk (IUR) for a VISL to be calculated.

While radon is suitable for the vapor intrusion models used for chemicals, this language is not suitable for radon. Radon has inhalation and external exposure (submersion) risk coefficients (slope factors) and dose coefficients. Additionally, all radionuclides are considered Group A carcinogens by the EPA.

The concentration ratios between radon and its progeny indoors (i.e., the indoor F_{eq}) is very much influenced by ventilation, exhalation, solid-particle concentration, and surface deposition of radon progeny (Chen & Harley, 2018). Exhalation, solid-particle concentration, and surface deposition were omitted in this study, for simplification. Air quality was also neglected, and it was assumed that actinon, thoron, radon, and subsequent progeny were uniformly distributed over the air volume.

The medium-specific RVISLs for health protection are developed considering a generic conceptual model for vapor intrusion consisting of:

- a source of vapors underneath the building(s) either in the vadose zone or in the uppermost, continuous zone of groundwater, separations between walls and foundation slabs, cracks in foundations;
- vapor migration via diffusion upwards through unsaturated soils from these sources toward the ground surface and overlying buildings; and
- buildings with poured concrete foundations (e.g., basement or slab-on-grade foundations) that are susceptible to soil gas entry.

A critical assumption for this generic model is that site-specific subsurface characteristics will tend to reduce or attenuate soil gas concentrations as vapors migrate upward from the source and into overlying structures. The RVISL relies on default attenuation factors developed from measured VI data; however, **some site-specific characteristics may result in relatively unattenuated or enhanced transport of vapors into a building.** These factors include:

- significant openings to the subsurface that facilitate soil gas entry into the building (e.g., sumps, unlined crawl spaces, earthen floors) other than typical utility penetrations;
- very shallow groundwater sources (e.g., depths to water less than five feet below foundation level); and
- significant routes for preferential, subsurface vapor migration whether naturally occurring (e.g., fractured bedrock) or anthropogenic routes: (e.g., abandoned underground utilities, gravel, highly permeable soil under foundation).

These specific factors may render the use of the recommended attenuation factors and the sub-slab, groundwater, and soil gas RVISLs inappropriate for purposes of

Identifying sites or buildings unlikely to pose a health concern through the vapor intrusion pathway. On the other hand, further evaluation of the vapor intrusion pathway is still appropriate when the sub-slab, groundwater, and soil gas RVISLs are exceeded for samples from a building or site where these specific factors are present.

In addition, certain vapor sources, listed below, invalidate the recommended attenuation factors and screening levels used the RVISL:

- those originating in landfills where radon is generated in sufficient quantities to induce advective transport in the vadose zone and
- those originating in commercial or industrial settings where radon can be released within an enclosed space and the density of the radon vapor may result in significant advective transport of the vapors downward through cracks and openings in floors and into the vadose zone.

In each case, the diffusive transport of vapors may be overridden by advective transport, and the vapors may be transported in the vadose zone several hundred feet from the source of contamination with little attenuation in concentration.

The previously mentioned assumptions and warnings involving attenuation factors are for generic chemicals and do generally apply to radon; however, there are additional considerations for radon entry dynamics. It is recommended that users of this calculator consider all these factors and the ones that are listed below. The concentration of radon in a building depends on:

1. Source of radon and its strength
2. Transport of radon
 - Pathways
 - Soil - high soil porosity or utility trenches, etc.
 - Building Shell - joints, cracks, earthen areas, utility penetrations, etc. in the foundation
 - Driving forces that pull or push radon towards the building and inside the building.
 - air pressure differences
 - diffusion
 - emanation
 - well water
 - environmental effects (e.g., frost or saturated upper soil horizon, rain, pavement around buildings can "cap" the soil)
3. Ventilation rate of building

Radon concentration are influenced by the complex interaction of:

1. Local geology
2. Soil
 - Parent isotope content
 - Moisture content

- Temperature difference
- Permeability
- Water table fluctuation
- 3. Climate and meteorological factors
 - Season
 - Barometric pressure changes
 - Precipitation (e.g. rate, amount)
 - Wind speed and direction
 - Snow cover or soil saturation
 - Temperature inversions
- 4. Building characteristics
 - Pressure differences
 - Heating systems
 - Ventilation
 - Water source
 - Building materials
- 5. Occupant Activities
 - Window opening
 - Fireplace and wood stove use

1.2 RVISL Outputs

This calculator only offers one output option, whereas other EPA risk and dose calculators offer three options.

- Assumes secular equilibrium throughout chain (no decay)
- Does not assume secular equilibrium, provide results for progeny throughout chain
- Does not assume secular equilibrium, provides results for selected isotopes only

The RVISL output is based on an equilibrium relationship of the three parent isotopes to their progeny. In the case of [Rn-222](#), this means the progeny prior to Pb-210; for [Rn-220](#) and [Rn-219](#), all progeny are included. This equilibrium relationship, which is based on air exchange rates within the structure, is dubbed the activity equilibrium fraction (A_{eq}) and is discussed in greater detail in section 4.3.

The calculator output is organized by radon parent. Each radon parent has its own output section. The first row for each radon parent section is a total of the progeny and parent fractional contribution. Radon-219 is first followed by radon-220 and Rn-222.

$$RVISL_{tot} = \frac{1}{\left(\sum_{i=1}^n \frac{1}{RVISL_{route\ i}} \right)}$$

where:

n = total number of exposure routes;

and:

$$RVISL_{route} = \frac{1}{\left(\sum_{i=1}^n \frac{1}{\left(\frac{RVISL}{A_{eq}} \right)_i} \right)}$$

where:

n = number of short-lived progeny in the decay series;

RVISL = RVISL for isotope in decay chain;

A_{eq} = activity equilibrium factor for isotope.

The RVISL calculator gives the user the option to select either a risk or a dose-based calculation. The risk and dose-based outputs are given in pCi, unless the user elects Bq.

The RVISL calculator has an option to include the results in working levels (WLs) for comparison to the UMTRCA standards in addition to results based on volume (pCi/m³ or pCi/L). The calculator gives the contribution of each short-lived isotope (parent and progeny) to the total RVISL. When WLs are included in the output, only the parent activity is converted to a WL, and the total RVISL value derived for the whole chain is not used for the WL conversion despite the WL value being displayed in the top row for the chain. For more information on the short-lived progeny included in each RVISL calculation and WL conversions, see section 1.8.

1.3 Slope Factors (SFs) and Dose Conversion Factors (DCFs)

EPA classifies all radionuclides as Group A carcinogens ("carcinogenic to humans"). Group A classification is used only when there is sufficient evidence from epidemiologic studies to support a causal association between exposure to the agents and cancer. The following sections discuss the sources of inhalation and external exposure via submersion in gas cloud SFs and DCFs used in this calculator.

1.3.1 Inhalation

The [Radon Cancer Risk Coefficients and Age-Specific Effective Dose Coefficients](#) report from Oak Ridge National Laboratory lists inhalation cancer slope factors (SFs) (risk coefficients for total cancer morbidity) and dose coefficients (DCFs) for radionuclides in conventional units of picocuries (pCi). Inhalation SFs and DCFs are central estimates in a linear model of the age-averaged, lifetime attributable radiation cancer incidence (fatal and nonfatal cancer) risk or dose per unit of activity inhaled, expressed as risk/pCi or mrem/pCi, respectively.

The inhalation SFs and DCFs from the [Radon Cancer Risk Coefficients and Age-Specific Effective Dose Coefficients](#) report differ from the inhalation values presented in [Health Effects Assessment Summary Tables \(HEAST\)](#). The inhalation SFs and DCFs used in this calculator were calculated using ORNL's DCAL software in the manner of Federal Guidance Reports (FGR) 12 and 13. The coefficients tabulated here are for inhalation of individual radionuclides without accompanying progeny but include the contribution to dose of ingrowth of radioactive progeny in the body following intake of a parent radionuclide. This approach allows the user to derive effective dose estimates or cancer risk estimates for any known or hypothetical combination of radon and its short-lived progeny in air. This is essential for the fractional activity equilibrium factors derived in this calculator based on air exchange rates (see sections 4.2 and 4.3.). Using SFs and DCFs calculated with the methods from HEAST and with the fractional activity equilibrium models in this calculator would result in overestimation of risk and dose.

An alternative approach for assessing cancer risk associated with radon in homes is to use models that express radiogenic lung cancer risk as a function of past exposure, such as those recommended in the National Research Council's report of the sixth Biological Effects of Ionizing Radiation (BEIR VI) report (1999) and the World Health Organization (WHO) Handbook (2009). The BEIR VI models and those described in the WHO Handbook do not require dose calculations and were derived by data analysis of epidemiological studies of lung cancer associated with exposure to radon. No recommendation is made here as to which approach is to be preferred for other purposes. The SFs derived in the ORNL report are used here to allow for more direct comparisons with the associated DCFs.

The ORNL Radon report does not include inhalation risk or dose coefficients for Rn-219, because the short half-life creates a large uncertainty in the distribution of decays in the body. That large uncertainty is one reason why the International Commission on Radiological Protection (ICRP) generally does not provide inhalation or ingestion dose coefficients for such short-lived radionuclides.

EPA currently provides guidance on inhalation risk assessment in [RAGS Part F](#) (Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual, Part F, Supplemental Guidance for Inhalation Risk Assessment); however, this guidance only addresses chemicals. The development of inhalation slope factors for radionuclides differs from the guidance presented in RAGS Part F for development of inhalation unit risk (IUR) values for chemicals.

1.3.2 Submersion

The external exposure SFs and DCFs used in this calculator are taken from Calculation of Slope Factors and Dose Coefficients (ORNL 2014). The external SFs and DCFs were calculated using ORNL's DCAL software in the manner of Federal Guidance Report 12 and 13 and differ from the values presented in [HEAST](#). External exposure SFs and DCFs are central estimates of lifetime attributable radiation cancer incidence risk for each year of exposure to external radiation from photon-emitting radionuclides distributed uniformly in a gas cloud and

are expressed as risk/yr per pCi/m³ air or mrem/year per pCi/m³ air. When combined with site-specific media concentration data and appropriate exposure assumptions, SFs can be used to estimate lifetime cancer risks, and DCFs can be used to estimate annual dose to members of the general population due to radionuclide exposures

1.4 Radon-specific Parameters

Several radon-specific parameters are needed for development of the RVISLs.

1. Half-life, lambda (λ), atomic number, and atomic weight are taken from [ICRP 107](#).

Isotope	Half-life (year)	λ (year ⁻¹)	Atomic Number	Atomic Weight
Rn-219	1.26E-07	5.52E+06	86	219.009
Rn-220	1.76E-06	3.93E+05	86	220.011
Rn-222	1.05E-02	6.62E+01	86	222.018

2. Vapor Pressure (VP) (mmHg at 25°C) is taken from Table 11 - Vapor Pressure - Inorganic Compounds of the online version of Yaws' Critical Property Data for Chemical Engineers and Chemists, 2014. The value stated in the source is 12,620 mmHg at 25°C. The value is taken from a [plot](#) of the Antoine Equation $\log P = A - (B/(T+C))$.
3. Density (ρ) (g Rn/cm³ at 0 °C) is taken from CRC Handbook of Chemistry and Physics 67th Edition, pg. B-122. The value stated in the source is 9.73 g/L (No temperature is given but thought to be based on 0 °C). Density is used to calculate the water solubility, below. Converting to the required units is as follows:

$$\left(9.73 \times 10^{-3} \frac{\text{g}}{\text{cm}^3}\right) = \left(\left(9.73 \frac{\text{g}}{\text{L}}\right) \times \left(1 \frac{\text{L}}{1000 \text{ cm}^3}\right)\right)$$

4. Water Solubility (S) (mg/L at 25°C) is taken from CRC Handbook of Chemistry and Physics 67th Edition, pg. B-122. The value stated in the source is 22.4 cm³Rn/100 cm³ H₂O at 25°C. Converting to the required units is as follows, assuming 1cm³ = 1 mL:

$$\left(2220 \frac{\text{mg Rn gas}}{\text{L H}_2\text{O}}\right) = \left(\left(22.4 \frac{\text{cm}^3 \text{ Rn}}{100 \text{ cm}^3 \text{ H}_2\text{O}}\right) \times \left(1000 \frac{\text{mL H}_2\text{O}}{1 \text{ L H}_2\text{O}}\right) \times \left(1 \frac{\text{L gas}}{1000 \text{ mL gas}}\right) \times \left(1 \frac{\text{mol}}{22.4 \text{ L gas}}\right) \times \left(222.018 \frac{\text{g Rn}}{\text{mol}}\right) \times \left(1000 \frac{\text{mg H}_2\text{O}}{\text{g}}\right)\right)$$

5. Henry's Law Constant (HLC) (atm-m³/mole at 25°C) is taken from [Atmos. Chem. Phys., 15, 2015](#), pg. 4418. The value of 9.3E-05 mol/m³Pa at 25°C is selected as the largest of six values presented. Converting to the required units is as follows:

$$\left(0.106 \text{ atm}\cdot\text{m}^3/\text{mol}\right) = \left(\left(\frac{1}{9.3\times 10^{-5} \text{ mol}/\text{m}^3\text{Pa}}\right) \times \left(\frac{1 \text{ atm}}{101325 \text{ Pa}}\right)\right)$$

6. Unitless Henry's Law Constant (H') (unitless at 25°C). The value is derived from $0.106 \text{ atm}\cdot\text{m}^3/\text{mol} / 0.02446 = 4.34$. The conversion factor, 0.02446 is calculated by multiplying the universal gas constant, $8.0257338\text{E-}05 \text{ atm}\cdot\text{m}^3/\text{mol K}$, by the temperature 298.16 K.
7. Critical Temperature (T_c) (K) is taken from CRC Handbook of Chemistry and Physics online version. The value reported is 104 °C, which is 377.15 K.
8. Boiling Point (T_b) (K) is taken from CRC Handbook of Chemistry and Physics online version. The value reported is -67.7 °C, which is 211.45 K.
9. Lower Explosive Limit (LEL) (% by volume). Radon is an inert gas and the LEL is not of concern as it would be for chemicals.
10. Enthalpy of vaporization at the normal boiling point (cal/mol) is taken from Yaw's Thermophysical Properties of Chemicals and Hydrocarbons [Table 63](#). Enthalpy of Vaporization at Boiling Point - Inorganic Compounds (Electronic Edition). The reported value is 18.098 kJ/mol. Converting to the required units is as follows:

$$\left(4326 \text{ cal}/\text{mol}\right) = \left(\left(18.098 \text{ kJ}/\text{mol}\right) \times \left(1000 \text{ J}/\text{kJ}\right) \times \left(1 \text{ cal}/4.184 \text{ J}\right)\right)$$

1.5 Understanding Risk Output on the RVISL Website

The RVISL [calculator](#) provides an option to select risk output. In the calculator, select "yes" if risk output is desired. Selecting risk output requires the calculator to be run in "Site Specific" mode. The risk values presented on this site are radionuclide-specific values for Radon contaminants in air that may warrant further investigation or site cleanup.

1.5.1 General Considerations for the Risk Output

This portion of the risk assessment process is generally referred to as "Risk Characterization". This step incorporates the outcome of the exposure and toxicity assessments to calculate the risk resulting from potential exposure to radionuclides via the pathways and routes of exposure determined appropriate for the source area. Risk is calculated in this tool using the following equation.

The basic equation for calculating excess lifetime cancer risk is:

$$\text{Risk} = \text{CDI} \times \text{SF} \times A_{\text{eq}}$$

where:

Risk = a unitless probability of an individual developing cancer over a lifetime;

CDI = chronic daily intake or dose [pCi or pCi-year/m³]

SF = slope factor, expressed in [risk/pCi or risk/year per pCi/m³]

A_{eq} = Activity Equilibrium Factor of individual isotope (See Section 4.3)

The risk results are color coded to identify risk ranges and potential radionuclides of concern. The colors and the associated risk ranges are presented in the table below.

Excess Lifetime Cancer Risk			
Risk Range	Risk < 0.000001	Risk > 0.000001	Risk > 0.0001
Color Code	No shading	Yellow	Red

1.5.2 One-Hit Rule

The linear risk equation, listed above, is valid only at low risk levels (below estimated risks of 0.01). For sites where radiological exposure might be high (estimated risks above 0.01), an alternate calculation should be used. The one-hit equation, which is consistent with the linear low-dose model, should be used instead ([RAGS, part A, ch. 8](#)). The results presented on the preliminary remediation goal (PRG) calculator use this rule. In the following instances, the one-hit rule is used independently in the risk output tables:

- Risk from a single exposure route for a single radionuclide.
- Summation of single radionuclide risk (without one-hit rule applied to single radionuclide results) for multiple exposure routes (right of each row).
- Summation of risk (without one-hit rule applied to single radionuclide results) from a single exposure route for multiple radionuclides (bottom of each column).
- Summation of total risk (without one-hit rule applied to single radionuclide results or summations listed above) from multiple radionuclides across multiple exposure routes (bottom right hand cell).

1.6 Understanding Dose Output on the RVISL Website

This portion of the risk assessment process is generally referred to as "Dose Characterization". This step incorporates the outcome of the exposure and toxicity assessments to calculate the dose resulting from potential exposure to radionuclides via the pathways and routes of exposure determined appropriate for the source area. Dose is calculated in this tool using the following equation:

$$\text{Dose} = \text{CDI} \times \text{DCF} \times A_{\text{eq}}$$

where:

Dose = The energy absorbed from radiation by a person (mrem/year)

CDI = Chronic Daily Intake or Dose [pCi/year or pCi/m³]

DCF = Dose Conversion Factor [mrem/pCi or mrem/year per pCi/m³]

A_{eq} = Activity Equilibrium Factor of individual isotope

1.7 Comparison to State and UMTRCA Standards

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 that may be potential ARARs. The state standards are likely only for Rn-222. A preset value of 4 pCi/L of air is given, as it is the most common pCi/L value used in state standards. For the UMTRCA comparison option, a preset value of 0.02 working levels (WL) is given for Rn-222 and Rn-220. Alternative values can be entered for either of these standards on the first page of the calculator. For more information on evaluation of radon working levels, see section 1.8.

1.8 Understanding Working Levels (WL)

The term Working Level (WL) refers to the activity of the progeny present in air from a specific radon parent (i.e., radon, thoron, or actinon). Specifically, WLs do not include the contribution from the parent. According to the EPA's code of federal regulations [40 CFR 192.11](#), "a working level (WL) means any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of alpha particles with a total energy of 130 billion electron volts." In the case of [Rn-222](#), this means the progeny prior to Pb-210; for [Rn-220](#) and [Rn-219](#), all progeny are included. U.S. EPA 1989 ([RAGS Part A](#)), the National Institute of Occupational Safety and Health (NIOSH) ([Dose Conversion Factors for Radon WLM](#)), the National Council on Radiation Protection and Measurements (NCRP) [Report No.97](#), and The Department of Energy ([DOE-STD-1121-2008](#)) agree with the definition and/or offer equivalent values in units of pCi/L. At 100% equilibrium, one WL is equal to 100pCi/L of Rn-222, 7.5 pCi/L of Rn-220, and 162 pCi/L of Rn-219. While this is a significant difference in the gas concentrations, by definition of the working level, the decay products will ultimately emit the same amount of alpha energy. This, however, does not lead to the same lung dose. This is caused largely by the difference in the half-lives of the decay products. Since Rn-220 products have longer half-lives, the body has longer to transport the activity from one compartment to another and thus deliver dose to different areas of the lung. Since the working level is an air concentration, it is analogous to an exposure rate. To describe exposure, the unit working level month (WLM) is also used. A WLM is the exposure equivalent to breathing one WL for 170 hours (one working month). The NRC in [CFR 20.1003](#) and NIOSH in [Dose Conversion Factors for Radon WLM](#) identify the individual progeny that are included as "short-lived" daughters. Some of the extremely short-lived daughters are explicitly excluded in WL calculations because they would represent a very small number of atoms inhaled and add computational time without gaining significant precision gains. For this calculator, all short-lived progeny are considered for completeness because of modern computing advances. See details in sections 4.2 and 4.3 of

this user's guide to see how the inhalation fractional equilibrium (F_{eq}) and activity equilibrium factor (A_{eq}) values were calculated for short-lived progeny.

"Properties and behaviour of radon and thoron and their decay products in the air" (J. Porstendorfer, Journal of Aerosol Science, Vol 25:2, March 1994, pg 219-263) further supports the WL definition and conversion to pCi/L and offers insight on the consideration of radon daughter aerosols formation and deposition on surfaces. "Measurement of Equilibrium Factor ' F_{eq} ' between Radon and its Progeny and Thoron and its Progeny in the Indoor Atmosphere Using Nuclear Track Detectors" (R. Ramola, Indoor and Built Environment, Vol12:351-355, 2003) discusses the air exchange rate impact on radon progeny plating on surfaces and impacting the measured equilibrium in air. These papers present many of the difficulties in predicting and measuring F_{eq} values due to seasonal atmospheric changes, building construction, surface plating, aerosol sizes, regional geology, air flow, etc. The F_{eq} is important to establish for determining compliance with WL ARARs, such as the UMTRCA standards described in section 1.7 of this user's guide. Previous EPA guidance on complying with the UMTRCA standard as an ARAR at CERCLA sites assumed a F_{eq} of 0.4 (40%) for Rn-222 and 0.02 (2%) for Rn-220. These F_{eq} values, which when applied to the 0.02 WL ARAR equate to 5 pCi/L of Rn-222 or 7.5 pCi/L of Rn-220, were to be used to demonstrate compliance with the UMTRCA standard. Rn-219 does not have an UMTRCA standard. EPA's new guidance for ARAR compliance is to use this calculator with either default or site/building-specific air exchange rates to determine radon/thoron levels that comply with the 0.02 WL ARAR.

For more information on evaluation of radon working levels, see question 17 in the [Radiation Risk Assessment At CERCLA Sites: Q&A](#) and question 7 in the [Frequent Questions](#) page on this site. Note that the RVISL calculator provides updated guidance developing screening levels (SLs) or preliminary remediation goals (PRGs) for showing compliance with the UMTRCA indoor radon standards for radon-222 and radon-220. The RVISL therefore supersedes the approach for determining WL in question 17 of the guidance document "Radiation Risk Assessment At CERCLA Sites: Q & A" issued on May 2014.

The following equation demonstrates the conversion of the default Rn-222 RVISL in pCi/L to a WL while correcting for the F_{eq} differences between the conversion and calculated values. The F_{eq} in the conversion assumes 100% equilibrium ($F_{eq}=1$), and the F_{eq} for the RVISL is calculated based on the air exchange rate used.

$$\text{RVISL}_{\text{Rn-222}}^{\text{WL}} \left(2.39 \times 10^{-5} \text{ WL} \right) = \text{RVISL}_{\text{Rn-222}}^{\text{pCi}} \left(\frac{2.72 \times 10^{-3} \text{ pCi}}{\text{L}} \right) \times \left(\frac{F_{eq} (0.88) \times 1 \text{ WL}}{\left(\frac{100 \text{ pCi}}{\text{L}} \right)} \right)$$

1.9 Problems Predicting the Activity of Radium, Thorium and Actinium based on Radon, Thoron, and Actinon RVISLs

Ra-226, Th-232, and Ac-227 are the namesakes and the long-lived near chain member sources of Rn-222, Rn-220, and Rn-219, respectively. In an ideal setting, the amount of solid

source is directly related to the amount of gas product via the fractional decay of the parent. Ra-226 and Th-232 have a straight decay chain to Rn-222 and Rn-220, respectively. Ac-227 decay to Rn-219 is a branched decay chain; 98.6% of Ac-227 decays to Rn-219. Predicting the amount of radon gas available for vapor intrusion in the natural environment, however, is not an ideal setting. Several factors make it impossible for this calculator to confidently predict suitable default radon, thoron, and actinon target indoor air concentrations from subsurface (soil and groundwater) radium, thorium, and actinium concentrations. The IAEA has published Technical Report Series No. 474, [Measurement and Calculation of Radon Releases from NORM Residues](#), that addresses many of these difficulties.

The newly formed radon atom must first escape from the ore material to the interstitial space between grains. This emanation happens when the recoil energy is sufficient for the radon atom to break from the ore grains. Once in the interstitial space, the radon must be able to be transported to the surface via diffusion and advective flow. Depending on the distance to the surface and media properties, the relatively short-lived radon may decay before exhalation to the atmosphere. Most recoiling atoms do not make it out of the ore material into the interstitial space and, because of the very small diffusion coefficient through dense minerals, even less atoms are likely to be exhaled to the atmosphere.

Detailed modeling of the subsurface environment may be possible to estimate the amount of a solid source that results in gaseous exhalation. One such model is the NORM And Legacy Site Assessment ([NORMALYSA](#)) software. This software is able to simulate transport from a source medium through clean cover layers to the surface. The [User's Manual](#) details how NORMALYSA employs emanation, diffusion, and exhalation to predict radon air concentrations. Chapters 2 and 4 of [TRS No. 474](#) present details on emanation coefficient determination that may be useful for site-specific analysis.

2. Radon Vapor Intrusion Screening Level Equations

This section presents the screening levels for human exposure to contaminated air. The equations and technical discussion are aimed at developing compliance levels for risk-based and dose-based RVISLs. The following text presents the land use equations and their exposure routes. Table 1 (section 5 of the User's Guide) presents the definitions of the variables and their default values. The default values are selected to represent the reasonably maximum exposed (RME) individual and generally represent the upper bounds of exposure. The default values and exposure models are consistent with the Chemical Vapor Intrusion Screening Level (VISL) calculator if the same pathways are addressed (e.g., inhalation) and are analogous if pathways are similar (e.g., external exposure). This calculator and the [VISL](#) both follow the recommendations in the [OSWER Directive](#) concerning use of exposure parameters from the [2011 Exposure Factors Handbook](#). Any alternative values or assumptions used in remedy evaluation or selection on a CERCLA site should be presented with supporting rationale in Administrative Records.

2.1 Air Screening Level Equations

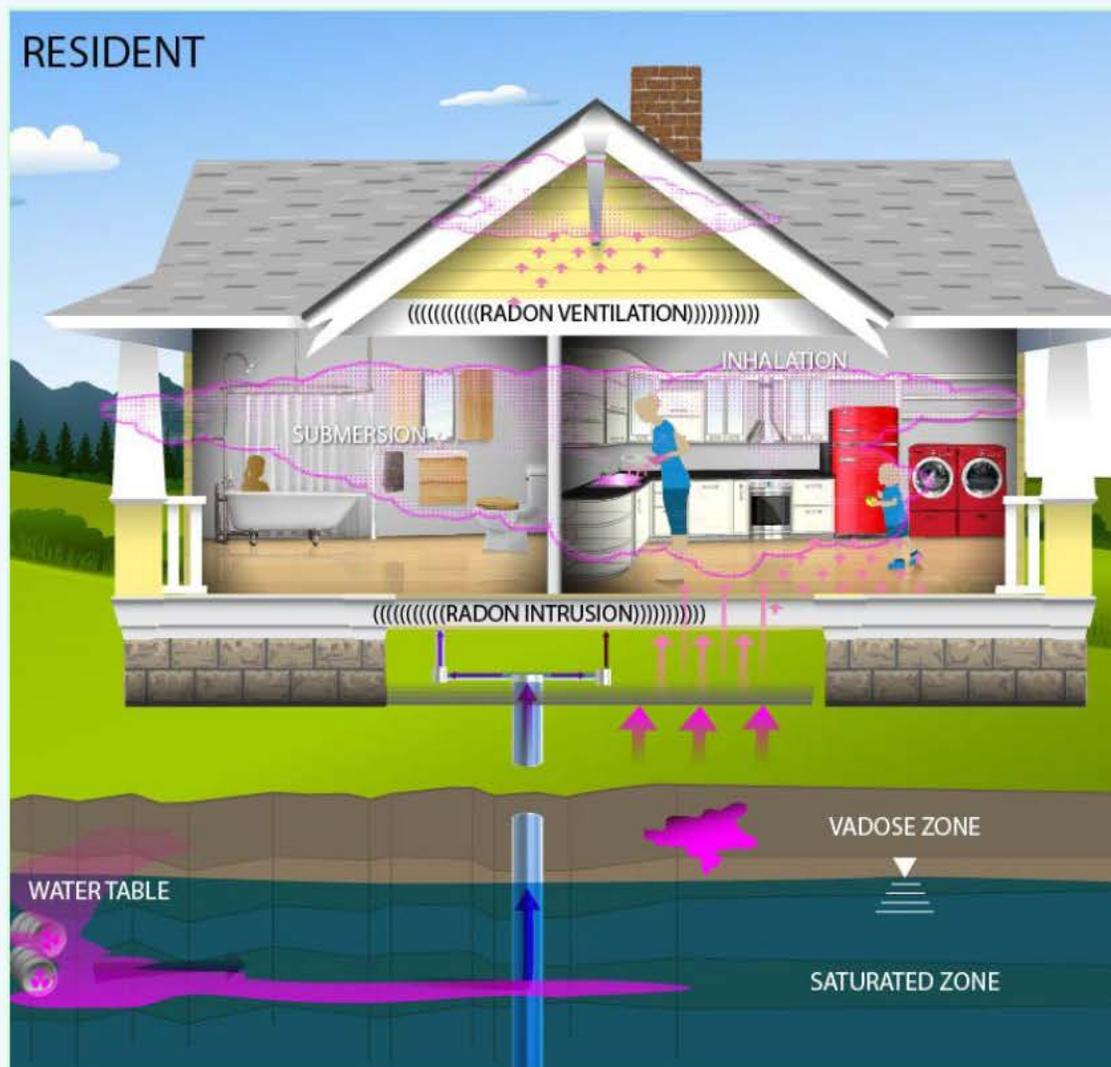
The user can select risk-based or dose-based equations and either a resident or worker receptor. The

RVISL conversion to working levels (WLs) is also presented in the following sections.

2.1.1 Resident Air

This receptor spends all of the day at home. The resident is assumed to be exposed to contaminants via the following pathways: inhalation of ambient air and external radiation from contaminants in ambient air. To take into account the different inhalation rates for children and adults, age-adjusted intake equations were developed to account for changes in intake as the receptor ages.

Graphical Representation



Risk-Based Vapor Intrusion Screening Level Equations

These are the risk-based equations for determining the protective resident air concentrations.

Inhalation

$$C_{\text{res-ia-inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{\text{TR}}{\text{SF}_i \left(\frac{\text{risk}}{\text{pCi}} \right) \times \text{IFA}_{\text{res-adj}} (161,000 \text{ m}^3)}$$

where:

$$\text{IFA}_{\text{res-adj}} (161,000 \text{ m}^3) = \left(\left(\text{EF}_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{res-c}} (6 \text{ years}) \times \text{ET}_{\text{res-c}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_{\text{res-c}} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \right) + \left(\text{EF}_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{res-a}} (20 \text{ years}) \times \text{ET}_{\text{res-a}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_{\text{res-a}} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \right) \right)$$

Submersion

$$C_{\text{res-ia-sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{\text{TR}}{\text{SF}_{\text{sub}} \left(\frac{\text{risk/year}}{\text{pCi/m}^3} \right) \times \text{EF}_{\text{res}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times \text{ED}_{\text{res}} (26 \text{ years}) \times \text{ET}_{\text{res}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{GSF}_a (1.0)}$$

Total

$$C_{\text{res-ia-tot}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\frac{1}{C_{\text{inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right)} + \frac{1}{C_{\text{sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right)}}$$

$$\text{where: } C_{\text{inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\left(\sum_{i=1}^n \frac{1}{\left(\frac{C_{\text{res-ia-inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right)}{A_{\text{eq}}} \right)} \right)} \quad \text{and: } C_{\text{sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\left(\sum_{i=1}^n \frac{1}{\left(\frac{C_{\text{res-ia-sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right)}{A_{\text{eq}}} \right)} \right)}$$

where:

n = the number of progeny in the decay series

Total Working Level Conversion

$$C_{\text{res-ia-tot-wl}} (\text{WL}) = C_{\text{res-ia-tot}} \left(\frac{\text{pCi}}{\text{L}} \right) \times \text{CF}_{\text{WL}}$$

where:

$$\text{CF}_{\text{WL}} (\text{Rn-222}) = \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{100 \text{ pCi}}{\text{L}} \right)} \right);$$

$$\text{CF}_{\text{WL}} (\text{Rn-220}) = \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{7.5 \text{ pCi}}{\text{L}} \right)} \right);$$

$$\text{CF}_{\text{WL}} (\text{Rn-219}) = \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{162 \text{ pCi}}{\text{L}} \right)} \right)$$

where:

F_{eq} = radon equilibrium factor for the given parent.

Dose-Based Vapor Intrusion Screening Level Equations

These are the dose-based equations for determining the protective resident air concentrations.

Inhalation

$$C_{\text{res-ia-inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{DL \left(\frac{\text{mrem}}{\text{year}} \right)}{DCF_i \left(\frac{\text{mrem}}{\text{pCi}} \right) \times IFA_{\text{res-adj}} \left(\frac{6,195 \text{ m}^3}{\text{year}} \right)}$$

where:

$$IFA_{\text{res-adj}} \left(\frac{6,195 \text{ m}^3}{\text{year}} \right) = \left(\left(EF_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ET_{\text{res-c}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{res-c}} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \times AAF_{\text{res-c}} (0.23) \right) + \left(EF_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ET_{\text{res-a}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{res-a}} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \times AAF_{\text{res-a}} (0.77) \right) \right)$$

where:

$$AAF_{\text{res-c}} (0.23) = \left(\frac{ED_{\text{res-c}} (6 \text{ years})}{ED_{\text{res}} (26 \text{ years})} \right) \text{ and } AAF_{\text{res-a}} (0.77) = \left(\frac{ED_{\text{res-a}} (20 \text{ years})}{ED_{\text{res}} (26 \text{ years})} \right)$$

Submersion

$$C_{\text{res-ia-sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{DL \left(\frac{\text{mrem}}{\text{year}} \right)}{DCF_{\text{sub}} \left(\frac{\text{mrem/year}}{\text{pCi/m}^3} \right) \times EF_{\text{res}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ET_{\text{res}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)}$$

Total

$$C_{\text{res-ia-tot}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\frac{1}{C_{\text{inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right)} + \frac{1}{C_{\text{sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right)}}$$

$$\text{where: } C_{\text{inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\left(\sum_{i=1}^n \frac{1}{\left(\frac{C_{\text{res-ia-inh}} \left(\frac{\text{pCi}}{\text{m}^3} \right)_i}{A_{\text{eq}}} \right)} \right)} \text{ and: } C_{\text{sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{1}{\left(\sum_{i=1}^n \frac{1}{\left(\frac{C_{\text{res-ia-sub}} \left(\frac{\text{pCi}}{\text{m}^3} \right)_i}{A_{\text{eq}}} \right)} \right)}$$

where:

n = the number of progeny in the decay series

Total Working Level Conversion

$$C_{\text{res-ia-tot-wl}}(\text{WL}) = C_{\text{res-ia-tot}} \left(\frac{\text{pCi}}{\text{L}} \right) \times CF_{\text{WL}}$$

where:

$$CF_{\text{WL}}(\text{Rn-222}) = \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{100 \text{ pCi}}{\text{L}} \right)} \right);$$

$$CF_{\text{WL}}(\text{Rn-220}) = \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{7.5 \text{ pCi}}{\text{L}} \right)} \right);$$

$$CF_{\text{WL}}(\text{Rn-219}) = \left(\frac{F_{\text{eq}} \times 1 \text{ WL}}{\left(\frac{162 \text{ pCi}}{\text{L}} \right)} \right)$$

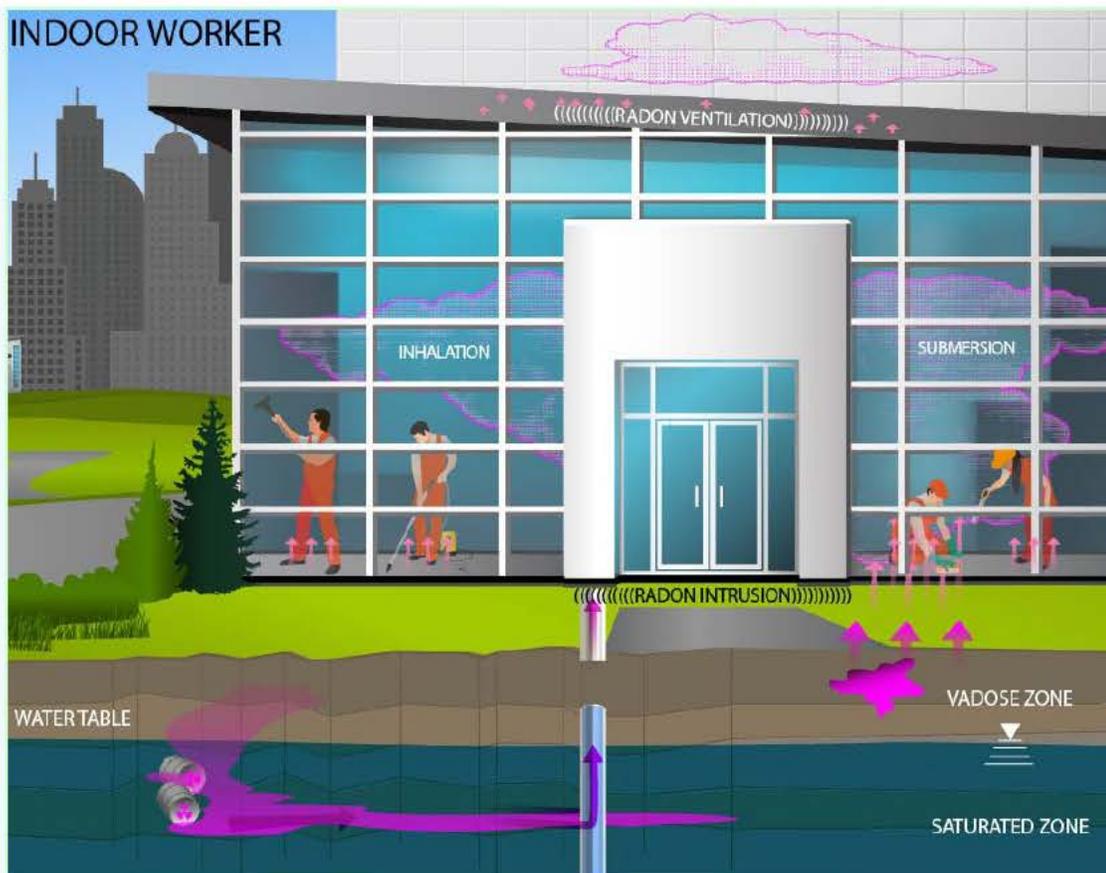
where:

F_{eq} = radon equilibrium factor for the given parent.

2.1.2 Worker Air

This long-term receptor is a full time employee working on-site who spends 8 hours of the workday indoors. The indoor worker is assumed to be exposed to contaminants via the following pathways: inhalation of ambient air and external radiation from contaminants in ambient air.

Graphical Representation



Risk-Based Vapor Intrusion Screening Level Equations

These are the risk-based equations for determining the protective industrial air concentrations.

Inhalation

$$C_{w-ia-inh} \left(\frac{pCi}{m^3} \right) = \frac{TR}{SF_i \left(\frac{risk}{pCi} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_w \left(\frac{60 \text{ m}^3}{\text{day}} \right)}$$

Submersion

$$C_{w-ia-sub} \left(\frac{pCi}{m^3} \right) = \frac{TR}{SF_{sub} \left(\frac{risk/year}{pCi \cdot m^3} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)}$$

Total

$$C_{w-ia-tot} \left(\frac{pCi}{m^3} \right) = \frac{1}{\frac{1}{C_{inh} \left(\frac{pCi}{m^3} \right)} + \frac{1}{C_{sub} \left(\frac{pCi}{m^3} \right)}}$$

$$\text{where: } C_{inh} \left(\frac{pCi}{m^3} \right) = \frac{1}{\left[\sum_{i=1}^n \left(\frac{1}{\left(\frac{C_{w-ia-inh} \left(\frac{pCi}{m^3} \right)}{A_{eq}} \right)} \right)_i \right]} \quad \text{and: } C_{sub} \left(\frac{pCi}{m^3} \right) = \frac{1}{\left[\sum_{i=1}^n \left(\frac{1}{\left(\frac{C_{w-ia-sub} \left(\frac{pCi}{m^3} \right)}{A_{eq}} \right)} \right)_i \right]}$$

where:

n = the number of progeny in the decay series

Total Working Level Conversion

$$C_{w-ia-tot-wl}^{(W\text{L})} = C_{w-ia-tot} \left(\frac{\text{pCi}}{\text{L}} \right) \times CF_{WL}$$

where:

$$CF_{WL}^{(\text{Rn-222})} = \left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{100 \text{ pCi}}{\text{L}} \right)} \right);$$

$$CF_{WL}^{(\text{Rn-220})} = \left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{7.5 \text{ pCi}}{\text{L}} \right)} \right);$$

$$CF_{WL}^{(\text{Rn-219})} = \left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{162 \text{ pCi}}{\text{L}} \right)} \right)$$

where:

F_{eq} = radon equilibrium factor for the given parent.

Dose-Based Vapor Intrusion Screening Level Equations

These are the dose-based equations for determining the protective industrial air concentrations.

Inhalation

$$C_{w-ia-inh} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{DL \left(\frac{\text{mrem}}{\text{year}} \right)}{DCF_i \left(\frac{\text{mrem}}{\text{pCi}} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_w \left(\frac{60 \text{ m}^3}{\text{day}} \right)}$$

Submersion

$$C_{w-ia-sub} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{DL \left(\frac{\text{mrem}}{\text{year}} \right)}{DCF_{sub} \left(\frac{\text{mrem/year}}{\text{pCi/m}^3} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)}$$

Total

$$C_{w-ia-tot} \left(\frac{pCi}{m^3} \right) = \frac{1}{\frac{1}{C_{inh} \left(\frac{pCi}{m^3} \right)} + \frac{1}{C_{sub} \left(\frac{pCi}{m^3} \right)}}$$

$$\text{where: } C_{inh} \left(\frac{pCi}{m^3} \right) = \frac{1}{\sum_{i=1}^n \left(\frac{C_{w-ia-inh} \left(\frac{pCi}{m^3} \right)_i}{A_{eq}} \right)} \quad \text{and: } C_{sub} \left(\frac{pCi}{m^3} \right) = \frac{1}{\sum_{i=1}^n \left(\frac{C_{w-ia-sub} \left(\frac{pCi}{m^3} \right)_i}{A_{eq}} \right)}$$

where:

n = the number of progeny in the decay series

Total Working Level Conversion

$$C_{w-ia-tot-wl}^{(W\text{L})} = C_{w-ia-tot} \left(\frac{pCi}{L} \right) \times CF_{WL}$$

where:

$$CF_{WL}^{(Rn-222)} = \left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{100 \text{ pCi}}{L} \right)} \right);$$

$$CF_{WL}^{(Rn-220)} = \left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{7.5 \text{ pCi}}{L} \right)} \right);$$

$$CF_{WL}^{(Rn-219)} = \left(\frac{F_{eq} \times 1 \text{ WL}}{\left(\frac{162 \text{ pCi}}{L} \right)} \right)$$

where:

F_{eq} = radon equilibrium factor for the given parent.

2.2 Groundwater Screening Level Equation

This equation is used to determine the groundwater concentration protective of exposure to indoor air. The equation uses a groundwater attenuation factor and H' . For a groundwater source, a chemical is considered sufficiently volatile and toxic to pose an inhalation risk through vapor intrusion if the vapor concentration (calculated using the chemical's Henry's Law Constant at the groundwater temperature) corresponding to the chemical's solubility limit in water is greater than the target indoor air concentration. The groundwater attenuation factor is not considered in this comparison, although it is considered in the subsequent calculation of the target groundwater concentration. The target groundwater concentration corresponding to a chemical's target indoor air concentration is calculated by dividing the target indoor air concentration by an attenuation factor of 0.001 and then converting the vapor concentration to

an equivalent groundwater concentration, assuming equilibrium between the aqueous and vapor phases at the water table. The equilibrium partitioning is assumed to obey Henry's Law.

The groundwater attenuation factor and the soil gas attenuation factors are never combined in this calculator.

$$C_{\text{gw},\text{Target}} \left(\frac{\text{pCi}}{\text{L}} \right) = \frac{C_{\text{i,a},\text{target}} \left(\frac{\text{pCi}}{\text{m}^3} \right)}{\text{AF}_{\text{gw}} \times \left(1000 \frac{\text{L}}{\text{m}^3} \right) \times H'}$$

2.3 Soil Gas Screening Level Equation

This equation is used to determine the soil gas concentration protective of exposure to indoor air. The soil gas attenuation factor used in the calculations is 0.03, which is the generic attenuation factor used for sub-slab gas in the 2002 draft vapor intrusion guidance. This attenuation factor is used for all soil gas data, as additional information collected after development of the 2002 draft vapor intrusion guidance (EPA 2002) suggests that external soil gas samples need to be evaluated as conservatively as sub-slab gas samples (EPA 2010).

The groundwater attenuation factor and the soil gas attenuation factors are never combined in this calculator.

$$C_{\text{sg},\text{Target}} \left(\frac{\text{pCi}}{\text{m}^3} \right) = \frac{C_{\text{i,a},\text{Target}} \left(\frac{\text{pCi}}{\text{m}^3} \right)}{\text{AF}_{\text{ss}}}$$

2.4 Vapor Intrusion Screening Level Supporting Equations

Chemicals must be sufficiently volatile and toxic to pose inhalation risk via vapor intrusion from soil and groundwater sources. This is determined by calculating the chemicals pure phase vapor concentration and the groundwater vapor concentration. The soil gas vapor concentration and the groundwater vapor concentration must be greater than the air screening level to determine a VISL. No equations are necessary for radon as they would be for other chemicals.

- **Pure Phase Vapor Pressure**

Radon and Thoron are considered sufficiently volatile and toxic to pose inhalation and external exposure risk via vapor intrusion from a soil source.

- **Groundwater Vapor Concentration**

Radon and Thoron are considered sufficiently volatile and toxic to pose inhalation and external exposure risk via vapor intrusion from a groundwater source.

3. Indoor Air Concentration, Cancer Risk, and Dose Calculation Equations

This section presents the equations used to calculate the indoor air concentration, cancer risk, and dose from the user-provided soil gas and/or groundwater concentration. The equations and technical discussion are aimed at developing compliance levels for risk-based and dose-based RVISLs. The following text presents the land use equations and their exposure routes. Table 1 (section 5 of the User's Guide) presents the definitions of the variables and their default values. The default values are selected to represent the reasonably maximum exposed (RME) individual and generally represent the upper bounds of exposure. The default values and exposure models are consistent with the Chemical Vapor Intrusion Screening Level (VISL) calculator if the same pathways are addressed (e.g., inhalation) and are analogous if pathways are similar (e.g., external exposure). This calculator and the [VISL](#) both follow the recommendations in the [OSWER Directive](#) concerning use of exposure parameters from the [2011 Exposure Factors Handbook](#). Any alternative values or assumptions used in remedy evaluation or selection on a CERCLA site should be presented with supporting rationale in Administrative Records.

3.1 Indoor Air Concentration Derived from Soil Gas Concentration Equation

This section presents the equation used to calculate the indoor air concentration from the user-provided soil gas concentration.

$$C_{i,a} \left(\frac{\text{pCi}}{\text{m}^3} \right) = C_{\text{s-gas}} \left(\frac{\text{pCi}}{\text{m}^3} \right) \times AF_{\text{ss}}$$

3.2 Indoor Air Concentration Derived from Groundwater Concentration Equation

This section presents the equation used to calculate the indoor air concentration from the user-provided groundwater concentration.

$$C_{i,a} \left(\frac{\text{pCi}}{\text{m}^3} \right) = C_{\text{water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times AF_{\text{gw}} \times \left(1000 \frac{\text{L}}{\text{m}^3} \right) \times H'_{\text{gw}}$$

3.3 Calculation of Cancer Risk and Dose from Indoor Air Concentrations

This section presents the chronic daily intake equations used to calculate the cancer risk and dose from indoor air concentrations.

3.3.1 Risk-Based CDI Equations

3.3.1.1 Excess Lifetime Cancer Risk

$$ELCR_{tot} = ELCR_{inh} + ELCR_{sub}$$

where:

$$ELCR_{inh} = \sum_{i=1}^n \left(CDI(pCi) \times SF_i \left(\frac{risk}{pCi} \right) \times A_{eq} \right)_i$$

and:

$$ELCR_{sub} = \sum_{i=1}^n \left(CDI \left(\frac{pCi \cdot year}{m^3} \right) \times SF_{sub} \left(\frac{risk/year}{pCi/m^3} \right) \times A_{eq} \right)_i$$

where:

i = the number of progeny in the decay series

3.3.1.2 Resident Air

Inhalation

$$CDI_{res-ia-rad-inh} (pCi) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times IFA_{res-adj} (161,000 m^3)$$

where:

$$IFA_{res-adj} (161,000 m^3) = \left(\left(EF_{res-c} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-c} (6 \text{ years}) \times ET_{res-c} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-c} \left(\frac{10 m^3}{\text{day}} \right) \right) + \left(EF_{res-a} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-a} (20 \text{ years}) \times ET_{res-a} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-a} \left(\frac{20 m^3}{\text{day}} \right) \right) \right)$$

Submersion

$$CDI_{res-ia-rad-sub-nodecay} \left(\frac{pCi \cdot year}{m^3} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times EF_{res} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{res} (26 \text{ years}) \times ET_{res} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

3.3.1.2 Worker Air

Inhalation

$$CDI_{w-ia-rad-inh} (pCi) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_w \left(\frac{60 m^3}{\text{day}} \right)$$

Submersion

$$CDI_{w-ia-rad-sub} \left(\frac{pCi \cdot year}{m^3} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ yr}}{365 \text{ day}} \right) \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

3.3.2 Dose-Based CDI Equations

3.3.2.1 Annual Dose

$$Dose_{tot} \left(\frac{mrem}{year} \right) = Dose_{inh} \left(\frac{mrem}{year} \right) + Dose_{sub} \left(\frac{mrem}{year} \right)$$

where:

$$Dose_{inh} \left(\frac{mrem}{year} \right) = \sum_{i=1}^n \left(CDI \left(\frac{pCi}{year} \right) \times DCF_i \left(\frac{mrem}{pCi} \right) \times A_{eq} \right)_i$$

and:

$$Dose_{sub} \left(\frac{mrem}{year} \right) = \sum_{i=1}^n \left(CDI \left(\frac{pCi}{m^3} \right) \times DCF_{sub} \left(\frac{mrem/year}{pCi/m^3} \right) \times A_{eq} \right)_i$$

where:

i = the number of progeny in the decay series

3.3.2.2 Resident Air

Inhalation

$$CDI_{res-ia-inh} \left(\frac{pCi}{year} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times IFA_{res-adj} \left(\frac{6,195 m^3}{year} \right)$$

where:

$$IFA_{res-adj} \left(\frac{6,195 m^3}{year} \right) = \left(\left(EF_{res-c} \left(\frac{350 \text{ days}}{year} \right) \times ET_{res-c} \left(\frac{24 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-c} \left(\frac{10 m^3}{day} \right) \times AAF_{res-c} (0.23) \right) + \left(EF_{res-a} \left(\frac{350 \text{ days}}{year} \right) \times ET_{res-a} \left(\frac{24 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-a} \left(\frac{20 m^3}{day} \right) \times AAF_{res-a} (0.77) \right) \right)$$

where:

$$AAF_{res-c} (0.23) = \left(\frac{ED_{res-c} (6 \text{ years})}{ED_{res} (26 \text{ years})} \right) \text{ and: } AAF_{res-a} (0.77) = \left(\frac{ED_{res-a} (20 \text{ years})}{ED_{res} (26 \text{ years})} \right)$$

Submersion

$$CDI_{res-ia-sub} \left(\frac{pCi}{m^3} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times EF_{res} \left(\frac{350 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ET_{res} \left(\frac{24 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

3.3.2.2 Worker Air

Inhalation

$$CDI_{w-ia-inh} \left(\frac{pCi}{year} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times EF_w \left(\frac{250 \text{ days}}{year} \right) \times ET_w \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_w \left(\frac{60 m^3}{day} \right)$$

Submersion

$$CDI_{w-ia-sub} \left(\frac{pCi}{m^3} \right) = C_{i,a} \left(\frac{pCi}{m^3} \right) \times EF_w \left(\frac{250 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ET_w \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

4. Modifications of Standard Equations

These are the conversions for modifying standard equations.

4.1 Modifications of Groundwater Temperatures

The following equations are used to calculate Henry's Law Constant at various groundwater temperatures:

- **To Determine Henry's Law Constant at a Groundwater Temperature other than 25 Degrees Celsius**

$$C_{sv} \left(\frac{\text{pCi}}{\text{cm}^3\text{-v}} \right) = H'_{TS} \times C_w \left(\frac{\text{pCi}}{\text{cm}^3\text{-v}} \right)$$

$$H' = \frac{\exp \left[- \frac{\Delta H_{v,w} \left(\frac{\text{cal}}{\text{mol}} \right)}{R_c \left(1.9872 \text{ cal/mol}\cdot^{\circ}\text{K} \right)} \times \left(\frac{1}{T_w \left(^{\circ}\text{K} \right)} - \frac{1}{T_R \left(298.15 \text{ }^{\circ}\text{K} \right)} \right) \right] \times \text{HLC} \left(\text{atm}\cdot\text{m}^3/\text{mol} \right)}{R \left(8.205\text{E-}05 \text{ atm}\cdot\text{m}^3/\text{mol}\cdot^{\circ}\text{K} \right) \times T_w \left(^{\circ}\text{K} \right)}$$

where:

$$T_w \left(^{\circ}\text{K} \right) = T_w \left(^{\circ}\text{C} \right) + 273.15$$

and:

$$\Delta H_{v,w} \left(\frac{\text{cal}}{\text{mol}} \right) = \Delta H_{v,b} \left(\frac{\text{cal}}{\text{mol}} \right) \times \left[\frac{1 - T_w \left(^{\circ}\text{K} \right) / T_c \left(^{\circ}\text{K} \right)}{1 - T_b \left(^{\circ}\text{K} \right) / T_c \left(^{\circ}\text{K} \right)} \right]^{\eta}$$

where:

$$\text{IF } \left(\frac{T_b}{T_c} \right) < 0.57, \text{ then: } \eta = 0.3;$$

$$\text{IF } \left(\frac{T_b}{T_c} \right) > 0.71, \text{ then: } \eta = 0.41;$$

$$\text{IF } 0.57 < \left(\frac{T_b}{T_c} \right) \leq 0.71, \text{ then: } \eta = \left(0.74 \times \left(\frac{T_b}{T_c} \right) - 0.116 \right)$$

- **To Determine Henry's Law Constant at a Groundwater Temperature of 25 Degrees Celsius**

$$H_{25} = \frac{\text{HLC} \left(\text{atm}\cdot\text{m}^3/\text{mol}\cdot\text{K} \right) \times \left(1000 \text{ L}/\text{m}^3 \right)}{R \left(8.205\text{E-}05 \text{ L}\cdot\text{atm}/\text{mol}\cdot\text{K} \right) \times T \left(298.15 \text{ K} \right)}$$

4.2 Air Exchange Rates and Inhalation Fractional Equilibrium Factor (F_{eq})

The indoor air concentration of radon and progeny is dependent upon the air exchange rate within a given volume. The air exchange rate, otherwise known as air changes per hour (ACH),

is defined as the ratio of airflow to the total volume of air. As an example, an ACH value of 0.18 would mean that eighteen percent of a given volume of air is exchanged per hour. The air exchange rate is related to an important parameter known as the inhalation fractional equilibrium factor (F_{eq}) for estimating the level of detriment from radon inhalation. F_{eq} has been researched for radon and thoron in various dwellings for many years (Chen & Harley, 2018 Parts I and II). The F_{eq} is a unitless measurement of the disequilibrium associated with the decay of radon and its subsequent progeny. The F_{eq} is useful for calculating the internal dose from radon, since most of the dose received is not from the radon parent itself but rather the alpha energies emitted from its progeny. The total progeny alpha energy emitted at any air exchange rate is divided by the total progeny alpha energy emitted at a state of equilibrium where no air exchanges are taking place within a given volume of air. At equilibrium, the value of the F_{eq} is equal to one; however, a F_{eq} of one is seldom measured due to conditions described in Section 1.1 and deposition on surfaces. As the air exchange rate in a given volume increases, the fractional equilibrium factor decreases. The F_{eq} is only used in the working level (WL) conversions presented in Sections 1.8, 2.1, and 2.2. A more detailed explanation of the F_{eq} derivation is presented in [ORNL 2019](#).

4.3 Air Exchange Rates and Activity Equilibrium Factor (A_{eq})

The activity equilibrium factor (A_{eq}) is defined as the ratio of progeny to parent activity concentrations at a given air exchange rate. For a straight decay chain, at zero air exchanges, the (A_{eq}) is equal to one and decrease as the air exchange rate increases. However, an A_{eq} of one is seldom measured due to conditions described in Section 1.1 and deposition on surfaces. The activity equilibrium factor is utilized in the RVISL air equations to calculate risk and dose for inhalation and submersion. The initial risks and doses (analogous to PRGs) assume that the radon decay chain members are in equilibrium with each other without any air exchanges present. Therefore, the activity equilibrium factors modify the initial risks and doses for inhalation and submersion by accounting for the disequilibrium between radon and its progeny due to decay and air exchanges that are present. A default value of 0.18 air exchanges per hour was selected for the resident land use, and a default value of 0.6 air exchanges per hour for the industrial worker land use was selected from the "Update for Chapter 19 of the Exposure Factors Handbook" (EPA, 2018) for resident (Table 19-25) and commercial (Table 19-30) buildings using the tenth percentile values, which means 90% of structures would have a higher air exchange rate and thus a lower level of progeny which would result in less risk, dose, and WL. Users that may want to determine the air exchange rate for a particular building to justify changing the default should refer to section 4.4 of the User Guide. A more detailed explanation of the A_{eq} derivation is presented in [ORNL 2019](#).

4.4 Measurement of Air Exchange Rates

The ACH can be a building-specific measurement, to provide a more accurate air contamination exposure assessment. The ACH is the exchange rate of indoor air with outdoor air, an important determinant for entry of outdoor air contaminants and for removal of indoor-emitted air contaminants. There is no EPA guidance on recommended methods for determining ACH. Breen (2014) presents an overview and critical analysis of the scientific

literature on empirical and physical air exchange rate models for residential and commercial buildings, which are feasible for exposure assessments. Models are included for the three types of airflows that can occur across building envelopes: leakage, natural ventilation, and mechanical ventilation. The paper provides guidance for selecting the preferable air exchange rate model based on available data, desired temporal resolution, types of airflows, and types of buildings included in the exposure assessment. The US EPA [Indoor Air Quality website](#) also provides information on HVAC use in buildings. There are also more detailed papers on particular air exchange measurement approaches (i.e., by placing tubes that emit and collect perfluorocarbon tracers throughout a building). The measurement of air exchange rates can be done by placing tubes that emit and collect perfluorocarbon tracers throughout a building ([CDC, 2018](#)). Guidance on placement of the tubes can be found in "[Research Operating Procedure 10 for Placement of PFT Emitters and Collection Tubes in DEARS](#)" (Thornburg, 2005).

5. Recommended Default Exposure Parameters

Table 1 presents the definitions of the variables and their default values. The default values are selected to represent the reasonably maximum exposed (RME) individual and generally represent the upper bounds of exposure. The RVISL default values and exposure models are consistent with the chemical [VISL](#) calculator. The VISL and RVISL calculator default values are consistent where the same pathways are addressed. This calculator follows the recommendations in the [OSWER Directive](#) concerning use of exposure parameters from the [2011 Exposure Factors Handbook](#). Any alternative values or assumptions used in remedy evaluation or selection on a CERCLA site should be presented with supporting rationale in Administrative Records.

Table 1. Recommended Default Exposure Parameters

Symbol	Definition (units)	Default	Reference
VISLs			
$C_{res-ia-inh-decay}$	Resident Air Inhalation with Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{res-ia-sub-decay}$	Resident Air Submersion with Half-Life Decay (pCi-year/m ³)	Isotope-specific	Determined in this calculator
$C_{res-ia-tot-decay}$	Resident Air Total with Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{res-ia-inh-nodecay}$	Resident Air Inhalation without Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{res-ia-sub-}$	Resident Air Submersion without Half-	Isotope-specific	Determined in this

$C_{res-ia-tot-nodecay}$	Resident Air Total without Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-inh-decay}$	Worker Air Inhalation with Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-sub-decay}$	Worker Air Submersion with Half-Life Decay (pCi-year/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-tot-decay}$	Worker Air Total with Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-inh-nodecay}$	Worker Air Inhalation without Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-sub-nodecay}$	Worker Air Submersion without Half-Life Decay (pCi-year/m ³)	Isotope-specific	Determined in this calculator
$C_{w-ia-tot-nodecay}$	Worker Air Total without Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
C_{gw}	Groundwater Screening Level (pCi/L)	Isotope-Specific	Determined in this calculator
C_{sg}	Soil Gas Screening Level (pCi/m ³)	Isotope-Specific	Determined in this calculator
CDIs			
$CDI_{res-ia-inh-decay}$	Resident Air Inhalation with Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$CDI_{res-ia-sub-decay}$	Resident Air Submersion with Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$CDI_{res-ia-inh-nodecay}$	Resident Air Inhalation without Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator
$CDI_{res-ia-sub-nodecay}$	Resident Air Submersion without Half-Life Decay (pCi/m ³)	Isotope-specific	Determined in this calculator

$CDI_{w-ia-inh-decay}$	Worker Air Inhalation with Half-Life Decay (pCi/m^3)	Isotope-specific	Determined in this calculator
$CDI_{w-ia-sub-decay}$	Worker Air Submersion with Half-Life Decay (pCi/m^3)	Isotope-specific	Determined in this calculator
$CDI_{w-ia-inh-nodecay}$	Worker Air Inhalation without Half-Life Decay (pCi/m^3)	Isotope-specific	Determined in this calculator
$CDI_{w-ia-sub-nodecay}$	Worker Air Submersion without Half-Life Decay (pCi/m^3)	Isotope-specific	Determined in this calculator
Toxicity Values			
SF_i	Slope Factor - inhalation (risk/pCi)	Isotope-specific	ORNL 2014
SF_{sub}	Slope Factor - submersion (risk/year per pCi/cm^3): For use in this tool, ORNL 2014c units were converted to (risk/year per pCi/m^3)	Isotope-specific	ORNL 2014
DCF_i	Dose Conversion Factor - inhalation (mrem/pCi)	Isotope-specific	ORNL 2014
DCF_{sub}	Dose Conversion Factor - submersion (mrem/year per pCi/cm^3): For use in this tool, ORNL 2014c units were converted to (risk/year per pCi/m^3)	Isotope-specific	ORNL 2014
Miscellaneous Variables			
TCR	Target Cancer Risk	1×10^{-6}	Selected by user
ACH	Air Exchanges per Hour	0.18 resident; 0.6 industrial	EPA 2018 Table 19-25 and Table 19-30
F_{eq}	Radon Equilibrium Factor	Isotope-Specific	ORNL 2019
A_{eq}	Activity Equilibrium Factor	Isotope-Specific	ORNL 2019
ELCR	Excess Lifetime Cancer Risk	Isotope-Specific	Determined in this calculator

CDI	Chronic Daily Intake	Isotope-Specific	Determined in this calculator
$H_{v,b}$	Enthalpy of vaporization at the normal boiling point (cal/mol)	Isotope-Specific	See Radon-specific Parameters
$H_{v,gw}$	Enthalpy of vaporization at temperature of groundwater(cal/mol)	Isotope-Specific	Determined in this calculator
H'	Dimensionless Henry's Law Constant at 2 5°Celsius (unitless)	Isotope-Specific	See Radon-specific Parameters
HLC	Henry's Law Constant at 2 5°Celsius (atm-m ³ per mole)	Isotope-Specific	See Radon-specific Parameters
$H'T_{gw}$	Dimensionless Henry's Law Constant for Groundwater Temperatures other than 2 5°Celsius	Isotope-Specific	See Radon-specific Parameters
$HLCT_{gw}$	Henry's Law Constant for Groundwater Temperatures other than 2 5°Celsius (atm-m ³ per mole)	Isotope-Specific	See Radon-specific Parameters
T	Absolute Temperature (Kelvin)	298.15	Equivalent to 2 5°Celsius
T_{gw}	Groundwater Temperatures (Kelvin)	Site-specific	User-provided
T_c	Critical Temperatures (Kelvin)	Isotope-Specific	See Radon-specific Parameters
T_b	Normal Boiling Point (Kelvin)	Isotope-Specific	See Radon-specific Parameters
n	If ($T_{boil}/T_{crit} < 0.57$) If ($T_{boil}/T_{crit} > 0.71$) If ($0.57 < T_{boil}/T_{crit} \leq 0.71$)	$n = 0.3$ $n = 0.41$ $n = (0.74 \times T_{boil}/T_{crit} - 0.116)$	U.S. EPA Fact Sheet : Unitless exponent values used to determine $H_{v,gw}$
S	Water Solubility Limit (mg/L)	Isotope-Specific	See Radon-specific Parameters

R	Universal Gas Constant (L-atm/mole-degrees K)	0.082057	U.S. EPA Fact Sheet
RC	Universal Gas Constant (cal/mole-degree K)	1.9872	U.S. EPA Fact Sheet
MW	Molecular Weight (g/mole)	Isotope-Specific	See Radon-specific Parameters
AF _{ss}	Attenuation Factor Sub-Slab (unitless)	0.03	U.S. EPA 2014
AF _{gw}	Attenuation Factor Groundwater (unitless)	0.001	U.S. EPA 2014
LEL	Lower Explosive Limit (% by volume)	Radon is an inert gas and the LEL is not of concern as it would be for chemicals.	See Radon-specific Parameters
C _{vp}	Pure Phase Vapor Concentration	Isotope-Specific	Determined in this calculator
C _{gw}	Target Groundwater Concentration (pCi/L)	Isotope-Specific	Determined in this calculator or Entered by user
C _{sg}	Target Soil Gas Concentration (pCi/m ³)	Isotope-Specific	Determined in this calculator or Entered by user
C _{i,a} ^{Target}	Target Indoor Air Concentration (pCi/m ³)	Isotope-Specific	Determined in this calculator or Entered by user
GSF _a	Gamma Shielding Factor - Air (unitless)	1	Developed for Radon VISL Calculator

Exposure Frequency, Exposure Duration, and Exposure Time Variables

Resident Exposure Frequency

[U.S. EPA 1991a \(pg.](#)

EF_{res}	(days/year)	350	15)
EF_{res-c}	Resident Exposure Frequency - child (days/year)	350	U.S. EPA 1991a (pg. 15)
EF_{res-a}	Resident Exposure Frequency - adult (days/year)	350	U.S. EPA 1991a (pg. 15)
EF_w	Worker Exposure Frequency (days/year)	250	U.S. EPA 1991a (pg. 15)
ED_{res}	Resident Exposure Duration (year)	26	EPA 2011, Table 16-108; 90th percentile for current residence time.
ED_{res-c}	Resident Exposure Duration - child (year)	6	U.S. EPA 1991a (pg. 15)
ED_{res-a}	Resident Exposure Duration - adult (year)	20	ED_{res} (26 years) - ED_{res-c} (6 years)
ED_w	Worker Exposure Duration - (year)	25	U.S. EPA 1991a (pg. 15)
ET_{res}	Resident Air Exposure Time (hours/day)	24	The whole day
ET_{res-c}	Resident Air Exposure Time - child (hours/day)	24	The whole day
ET_{res-a}	Resident Air Exposure Time - adult (hours/day)	24	The whole day
ET_w	Worker Air Exposure Time (hours/day)	8	The work day
IRA_{res-c}	Resident Inhalation Rate - child (m^3/day)	10	U.S. EPA 1991a (pg. 15)
IRA_{res-a}	Resident Inhalation Rate - adult (m^3/day)	20	U.S. EPA 1991a (pg. 15)
	Resident Age-Adjusted Inhalation		Calculated using the

IFA_{res}	Fraction (m^3)	161,100	age-adjusted intake factors equation.
IRA_w	Worker Inhalation Rate (m^3/day ; based on a rate of $2.5 m^3/hour$ for 24 hours)	60	U.S. EPA 1997a (pg. 5-11)

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Matthew Williams

Michigan Department of Great Lakes, Energy
and the Environment

Matthew Williams

*Volatilization to the Indoor Air Specialist
Michigan Department of Great Lakes, Energy and the Environment (EGLE)*

EDUCATION

1993 Bachelor of Science - Majors in Geology and Earth Science
Central Michigan University, Mt. Pleasant, Michigan

EXPERIENCE

September 2008 – Present

Interstate Technology & Regulatory Council (ITRC)

Member and Team Co-Lead

- Led and participated on multiple state-led coalitions on the development of documents and training including Vapor Intrusion, Petroleum Vapor Intrusion, and Vapor Intrusion Mitigation

June 1998 – Present

Department of Great Lakes, Energy and the Environment (EGLE)

Program Specialist (since 2001)

- Statewide expert for the volatilization to the indoor air pathway (VIAP);
- Develops Remediation and Redevelopment Division (RRD) policies, guidance, and training for staff and the regulated community associated with the VIAP;
- Experienced in using vapor intrusion models for the development of site-specific criteria;
- Developed EGLE's vapor intrusion and direct volatilization to indoor air calculator;
- Proposes new techniques, investigative procedures, and policies associated with the VIAP;
- Plans and coordinates training and outreach for staff and the regulated community;
- Review, design, and propose mitigation systems and scopes of work designed to prevent unaccepted exposures for the VIAP;
- Serve as the technical consultant and liaison for the VIAP with industry and other governmental agencies;
- Recommend methods for bringing violations or potential unacceptable health risks into compliance with applicable state and federal laws;
- Assist in the drafting of administrative rules; and
- Leads and participates on multiple national and statewide teams as a national expert on multiple topics associated with the VIAP on behalf of EGLE.

Project Manager Duties

- Evaluated the nature and extent of environmental issues and determines probable causes and ways to reduce the potential health risks;
- Prepared reports and letters for environmental regulatory violations that explain and describe required the required corrective action; and
- Identify and discuss ways for parties to bring sources of pollution into compliance with applicable state and federal laws including Part 201 and Part 213 of the NREPA, CERCLA, and RCRA.

June 1993 – May 1998

Consulting firms (DLZ, STS Consultants, and Dahl)

Duties:

- Performed Phase I and Phase II Environmental Site Assessments in conformance with ASTM guidelines;
- Performed hydrogeological investigations using various field investigative techniques;
- Performed geophysical investigations across the nation; and
- Prepared Risk-Based Corrective Action and Groundwater Monitoring Reports.

References Available Upon Request

Peer Reviewer Conflict of Interest Certification

Peer Review: **Draft Radon Vapor Intrusion Screening Level Calculator (RIVSL)**

A conflict of interest or lack of impartiality exists when the proposed peer reviewer personally (or the peer reviewer's immediate family), or his or her employer, has financial interests that may be affected by the results of the peer review; or may provide an unfair competitive advantage to the peer reviewer (or employer); or if the peer reviewer's objectivity in performing the peer review may be impaired due to other factors. When the Peer Reviewer knows that a reasonable person with knowledge of the facts may question the peer reviewer'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 RIVSL calculator (and associated webpages) under peer review, 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 peer review, or any reason that your impartiality in the matter might be questioned? No Yes
- Have you had any previous involvement with the RIVSL 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 peer review, 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 peer review? 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 peer review:

(a) Peer Reviewer 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 Peer Reviewer has disclosed all such relevant information to EMS or to EPA.

(b) Peer Reviewer agrees that if an actual, apparent, or potential personal or organizational conflict of interest is identified during performance of this peer review, he/she immediately will make a full disclosure in writing to EMS. This disclosure shall include a description of actions that Peer Reviewer (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. Peer Reviewer shall continue performance until notified by EMS of any contrary action to be taken.

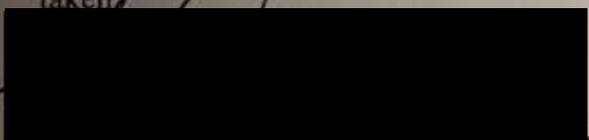
Signature

Date

Check here if any explanation is attached

Printed Name

Affiliation/Organization


10/8/2020

MATTHEW A. WILLIAMS
Michigan Environment, Great Lakes and Energy

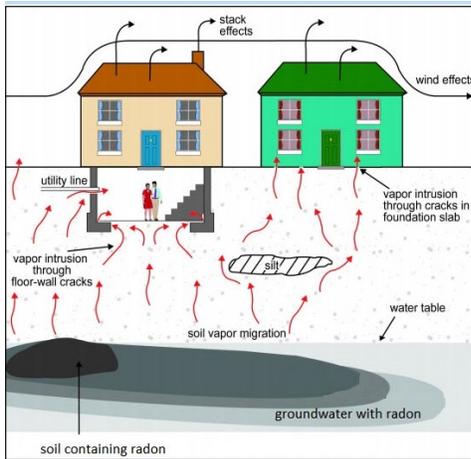
MATRIX OF PEER REVIEW COMMENTS Radon Vapor Intrusion Screening Level Calculator

Commenter	Charge Question No.	Section (Use dropdown arrow for each cell)	Line No. (Home Page and FAQs only)	Section No. (User's Guide only)	Table No. (If applicable)	Other Descriptor	Comment	EPA Resolution
Williams	A1	Overview	2	Welcome		General Comment	My background is in chemical vapor intrusion (PVI and CVI) and naturally occurring radon. From a user with that background, and the fact that the green box takes a person to the chemical VISL page, it took several times reading the title and then the introduction to sort out that the radon that being discussed is from radionuclide contamination and not naturally occurring radon or from chemical vapor intrusion, especially as the figure you are using is the exact same figure that was generated for chemical vapor intrusion and the links take you to the VISL vs the RVISL. I would recommend making the title more specific and/or adding some type of call-out box so that when someone hits the homepage that it is clearer what type of vapor intrusion they are dealing with.	
Williams	A1	Overview	2	Figure		Figure	Recommend that a figure for RVISL be different than what is used for the chemical VISL similar to the figures in the user guide	
Williams	A1	Overview	2	Figure		Figure	Figure did not appear correctly on the website and only was observable on the supplied PDF	
Williams	A1	Overview	2	Figure		Figure	This figure is typically associated with chemical vapor intrusion. I would recommend that you change the language so that it states: This figure depicts the migration of radon from radionuclide contaminants in soil gas from contaminated soil and groundwater into buildings. Radon in soil gas from radionuclide contaminants is shown to enter buildings through cracks in the foundation and openings for utility lines similar to other forms of contamination. Atmospheric conditions and building ventilation are shown to influence radon soil gas intrusion.	
Williams	A1	Overview	2	Figure		Figure	Recommend that you do not start with the figure. Move the figure down.	
Williams	A1	Overview	20-23	Figure			the Preliminary Remediation Goals link takes you to the right page but the "What's New", "User's Guide", "Frequently Asked Questions" and "Fact Sheet" links do not.	
Williams	A1	Overview		Call out box		Green callout box	All links in the green box titled "Radon Vapor Intrusion Screening Levels (RVISL)" actually takes you to the EPA's VISL (https://www.epa.gov/vaporintrusion/vapor-intrusion-screening-level-calculator) and not the radon-VISL page	
	A1		6-28				<p>Recommend the first paragraph be broken apart as follows for clarity:</p> <p>Welcome to the "Radon Vapor Intrusion Screening Level (RVISL) Calculator Home Page for Radionuclide Contaminants at Superfund Sites". This website was developed with DOE's Oak Ridge National Laboratory (ORNL) under an Interagency Agreement with the U.S. Environmental Protection Agency (EPA).</p> <p>The RVISL website is now the generally recommended source of radon screening levels for all 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 unified use of the RVISLs to screen radon at Superfund sites promotes national consistency. The RVISL uses the same database of toxicity values, chemical parameters, and inhalation exposure equations as the Preliminary Remediation Goals (PRGs) for Radionuclide Contaminants at Superfund Sites calculator.</p> <p>Note that for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial actions, dose assessment is generally done only to show compliance with a dose-based Applicable or Relevant and Appropriate Requirement (ARAR).</p> <p>The RVISL calculator provides default parameters that can be modified to reflect site-specific risks. 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. If the calculator is used with non-default inputs in a decision on a Superfund site, it is recommended that the inputs be clearly identified and justified by the user.</p> <p>To ensure proper use of the calculator, please review the What's New, User's Guide, and Frequently Asked Questions links.</p> <p>The EPA has prepared a fact sheet for the general public that describes RVISL uses, RVISL calculator operation, and land uses available for assessment. Additionally, this fact sheet describes the RVISL content in greater detail for EPA staff.</p>	
Williams		Overview	29-49				Recommend the 2nd and 3rd paragraph be moved from the Welcome and into the introduction	
Williams							Note similar to "Note that for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial actions, dose assessment is generally done only to show compliance with a dose-based Applicable or Relevant and Appropriate Requirement (ARAR)." should be in a call out box.	
Williams	A1	Overview		Call out box		Green callout box	Recommend that the first paragraph be broken apart to make it easier to read	

Commenter	Charge Question No.	Section (Use dropdown arrow for each cell)	Line No. (Home Page and FAQs only)	Section No. (User's Guide only)	Table No. (If applicable)	Other Descriptor	Comment	EPA Resolution
Williams	A1	Overview				Homepage and Overall Website	<p><u>Is the website clearly organized, described, easy to navigate, and generally "user friendly" and appropriate for the target audience?</u> The welcome section provides good information but it needs to be simplified with similar topics moved together. When the website is final the links will make it easy to navigate and user friendly, but they currently are not pointing to the right documents. The info contained is appropriate, but it is hard to absorb as some of the thoughts are broken apart.</p> <p>Also there needs to be some care as the document uses a lot of the information in the VISL for the RVISL and it sometimes is not clear that the concepts and science used in the development of the RVISLs is based in part on the work and concepts utilized in the VISL. It is also not clear if the RVISL will be completely different than the VISL or if it will be incorporated into it</p> <p><u>If not, what do you recommend?</u> Breaking apart some of the longer paragraphs and keeping some of the similar info and thoughts together. Also providing some basic information on the information that is being applied from the VISL in a unique chapter that describes vapor intrusion in general and then how radon vapor intrusion is similar.</p>	
Williams	A2	Overview				Homepage and Overall Website	<p><u>Have the objectives of the RVISL calculator, as stated in the documentation, been met?</u> The objectives should be more clearly and simply stated so it is hard to understand if they have been met.</p> <p><u>If not, what do you recommend?</u> Clearly state what the objective is. It appears that besides the calculator that there is another goal to provide updated guidance on how to develop screening values. There might be others.</p>	
Williams	A2	Overview	10			Homepage and Overall Website	"The RVISL calculator provides updated guidance for developing screening levels (SLs) or preliminary remediation goals (PRGs)" is technically not correct. The website is providing the updated guidance and the calc is providing calculated cleanup values.	
Williams	A3	Overview				Homepage and Overall Website	<p><u>Do you recommend any modifications to the Homepage graphic?</u> Understanding that that CVI and PVI behaves similarly to radon VI, it might be more appropriate to develop a specific graphic for RVI or instead of using it as a RVI graphic use the graphic as a more general representation of VI in general. would recommend using the graphic on Page 14 and 18 of the UseGguide or a similar one/color scheme.</p>	
Williams	A4	Overview				Homepage and Overall Website	<p><u>Do you have any other recommendations to improve the usability of the website?</u> I think as radon is using a lot of the similar concepts of VI and that web page that there is some additions to that web page that point a user to the radon VI web page.</p>	
Williams	B1	User's Guide				User's Guide	<p><u>Does the User's Guide adequately explain the concepts addressed by the calculator and its limitations?</u> No. If it does, the chapter titles do not make it clear on where a person would go to even find it. The chapter section titles (e.g., 1. Understanding the RVISL Website and 2. Radon Vapor Intrusion Screening Level Equations) do not point to where the information can be found for a user. It does discuss how radon concentration are influenced but it does not appear to describe how the calculator addresses it.</p>	
Williams	B2	User's Guide				User's Guide	<p><u>Are the assumptions clear and reasonable? If not, what do you recommend?</u> The assumptions should be provided under a single section of the report.</p>	
Williams	B3	User's Guide				User's Guide	<p><u>Are the sources and citations appropriate, and do they represent the current state of knowledge?</u> Based on my understanding of the VISL the references seem applicable.</p>	
Williams	C1	FAQs	87			Frequent Questions	<p><u>Are the 11 questions clearly worded? If not, what do you recommend?</u> Q2 - Doesn't really tell the user how "To change the attenuation factors." There is a lot of info here that is not related to the specific question. Recommend that the question is answered with additional detail and the rest is removed or moved to a different FAQ if the developer feels that it is important.</p>	
Williams	C1	FAQs	147			Frequent Questions	<p><u>Are the 11 questions clearly worded? If not, what do you recommend?</u> Q5 - The first paragraph answers the question. The second paragraph should be moved to a unique FAQ</p>	
Williams	C2	FAQs	87 and 147			Frequent Questions	<p><u>Are the 11 responses clear, concise, and accurate? If not, what do you recommend?</u> The recommendations are provided under charge question C1</p>	
Williams	C3	FAQs	87 and 147			Frequent Questions	<p><u>Are there other helpful questions and answers that should be added? If yes, please list the questions.</u> Recommendations include breaking questions Q2 and Q5 into 2 different questions.</p>	
Williams	D1					Calculator	<p><u>Are the results clearly explained and presented? If not, what do you recommend?</u> Link to the calculator did not go to the RVISL and therefore no comments can be provided</p>	
Williams	D2					Calculator	<p><u>Are the results appropriately described and qualified (to the extent that they may be relied upon and defended)? If not, what do you recommend?</u> Link to the calculator did not go to the RVISL and therefore no comments can be provided</p>	

Commenter	Charge Question No.	Section (Use dropdown arrow for each cell)	Line No. (Home Page and FAQs only)	Section No. (User's Guide only)	Table No. (If applicable)	Other Descriptor	Comment	EPA Resolution
Williams	D3					Calculator	<u>Do the results provide defensible explanation of how they were derived, or are they the result of a "black box?" Do you recommend anything different?</u> Link to the calculator did not go to the RVISL and therefore no comments can be provided	
Williams	D4					Calculator	<u>RVISL calculation of the equilibrium level (F_{eq}) of radon progeny that would be present in indoor air is based on air exchange rate. Should other mechanisms (seasonal atmospheric changes, building construction, surface plating, aerosol sizes, regional geology, air flow) be incorporated in the calculation?</u> Link to the calculator did not go to the RVISL and therefore no comments can be provided	
Williams	A1	Overview	57-62	Introduction		Homepage and Overall Website	This paragraph seems out of place.	
Williams	A1	Overview	59	Introduction		Homepage and Overall Website	The "chain link in the "Click the decay chain link" should be a link to where you want the user to go.	
Williams	A1	Overview	57-62	Introduction		Homepage and Overall Website	"Click the decay chain link to see the decay series for Rn-222, Rn-220, and Rn-219. The metal groups in these images are based on Los Alamos National Laboratory literature. See section 2.2 of the User's Guide to learn what progeny are evaluated in this web calculator. More details about the decay chains can be found in the EPA's Decay Chain Tool." This is an example where there appears to be the same though separated by a different one. "Click the decay chain link to see the decay series for Rn-222, Rn-220, and Rn-219." AND "More details about the decay chains can be found in the EPA's Decay Chain Tool." is the same thought and could be combined and the other sentence "See section 2.2 of the User's Guide to learn what progeny are evaluated in this web calculator." can be moved to the end.	
Williams	A1		71-73	Introduction		Homepage and Overall	Links go to the wrong page	
Williams	C1	FAQs	82	1		Question 1	It should be made clear that this	
Williams	B2	User's Guide		Introduction			It should be made clear that the RVISL calculator doesn't provide the updated guidance, the user guide does.	
Williams	B2	User's Guide		Introduction			What the RVISL supersedes is an important concept that should be moved to a callout box to provide added emphasis	
Williams	B2	User's Guide		Introduction			I would break the following into a callout box to emphasize: "Note that for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial actions, dose assessment is generally done only to show compliance with adose based Applicable or Relevant and Appropriate Requirement (ARAR)."	
Williams	B2	User's Guide		Introduction			This seems to be pretty important and should be called out or emphasized by making only this statement bold: "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.	
Williams	B2	User's Guide		Introduction			There should be some description and overview of each section that is in the user's guide	
Williams	B2	User's Guide		1.1			This section identifies specific factors that may render the use of the values inappropriate, but it should also provide direction on what to do and that the values should not be used.	
Williams	B2	User's Guide		1.1			It would seem that the concentration of radon (in vapor though not specific) in a building also depends on the distance of the vapor source to the building.	
Williams	B2	User's Guide		1.3			This statement is important and should be moved to the beginning of the document as well "EPA classifies all radionuclides as Group A carcinogens ("carcinogenic to humans"). Group A classification is used only when there is sufficient evidence from epidemiologic studies to support a causal association between exposure to the agents and cancer. The following sections discuss the sources of inhalation and external exposure via submersion in gas cloud SFs and DCFs used in this cal..."	
Williams	B2	User's Guide		1.5.2			Is the "One-Hit Rule" a specific rule or just a "concept" Further explanation is warranted.	
Williams	B2	User's Guide		2			Section 2. Radon Vapor Intrusion Screening Level Equations states: This section presents the screening levels for human exposure to contaminated air. This is not correct. This section provides the equations that are used in the RVISL (but also in combination with Sections 3 and 4 as well. The equations and technical discussion are aimed at developing compliance levels for risk-based and dose-based RVISLs.	
Williams	B2	User's Guide		2.1.1			It appears that the "graphical representation" is aligned with a conceptual site model. Conceptual site model is the term that is used in the VISL and in discussion VI it should be	
Williams	B2	User's Guide		2.1.1			Recommended to use this graphic as part of the overview along with the figure in 2.1.2	
Williams	B2	User's Guide		2.1.2			It appears that the "graphical representation" is aligned with a conceptual site model. Conceptual site model is the term that is used in the VISL and in discussion VI it should be	
Williams	B2	User's Guide		2.1.2			Recommended to use this graphic as part of the overview along with the figure in 2.1.1	
Williams	B2	User's Guide		2			Sections 2, 3, 4 are all equations and should be placed in a single chapter for ease of discussion	
Williams	B2	User's Guide		3			Sections 2 3 4 are all equations and should be placed in a single chapter for ease of discussion	

Commenter	Charge Question No.	Section (Use dropdown arrow for each cell)	Line No. (Home Page and FAQs only)	Section No. (User's Guide only)	Table No. (If applicable)	Other Descriptor	Comment	EPA Resolution
Williams	B2	User's Guide		4			Sections 2, 3, 4 are all equations and should be placed in a single chapter for ease of discussion	
Williams	B2	User's Guide		4.2			Air Exchange Rates is described differently then what is presented in EPA's VISL documentation and should be alligned with that definition	
Williams	B2	User's Guide		4.2			Inhalation Fractional Equilibrium Factor is unique to radon and it should be emphasized that it is different then chemical VI and how it impacts the calculated results	
Williams	B2	User's Guide		4.4			The collection of ACH should also be descrbed to the user it the calc will allow an inputed value and where it place it	
Williams	B2	User's Guide	General Comment				There should be some screen shots of the actual input screen with a description of what inputs are placed in each section.	
Williams	B2	User's Guide		5			Some of the input values are not specifically input paramters so a more generic term would be appropraite	



1
 2 **Figure caption:** This figure depicts the migration of radon in soil gas from contaminated soil and groundwater
 3 into buildings. Radon in soil gas is shown to enter buildings through cracks in the foundation and openings for
 4 utility lines. Atmospheric conditions and building ventilation are shown to influence radon soil gas intrusion.

5

Welcome

6 Welcome to the "Radon Vapor Intrusion Screening Level (RVISL) Calculator Home Page for
 7 Radionuclide Contaminants at Superfund Sites". This website was developed with DOE's Oak
 8 Ridge National Laboratory (ORNL) under an Interagency Agreement with the U.S. Environmental
 9 Protection Agency (EPA). The RVISL website is now the generally recommended source of radon
 10 screening levels for all EPA regions. The RVISL calculator output provides comparison values and
 11 risk and dose estimates for residential and commercial/industrial exposures to radon in soil gas,
 12 air, and groundwater. Note that for Comprehensive Environmental Response, Compensation, and
 13 Liability Act (CERCLA) remedial actions, dose assessment is generally done only to show
 14 compliance with a dose-based Applicable or Relevant and Appropriate Requirement (ARAR). In
 15 addition, the calculator presents the option to compare the indoor air concentration, entered by
 16 the user or derived from groundwater or soil gas activities, to state standards or Uranium Mill
 17 Tailings Radiation Control Act (UMTRCA) standards, which also may be potential ARARs. The
 18 unified use of the RVISLs to screen radon at Superfund sites promotes national consistency. The
 19 RVISL uses the same database of toxicity values, chemical parameters, and inhalation exposure
 20 equations as the [Preliminary Remediation Goals \(PRGs\)](#) for Radionuclide Contaminants at
 21 Superfund Sites calculator. The RVISL calculator provides default parameters that can be
 22 modified to reflect site-specific risks. To ensure proper use of the calculator, please review
 23 the [What's New](#), [User's Guide](#), and [Frequently Asked Questions](#) links. The EPA has prepared a [fact](#)
 24 [sheet](#) for the general public that describes RVISL uses, RVISL calculator operation, and land uses
 25 available for assessment. Additionally, this [fact sheet](#) describes the RVISL content in greater detail
 26 for EPA staff. Below is a general description of screening levels for radon. If the calculator is used
 27 with non-default inputs in a decision on a Superfund site, it is recommended that the inputs be
 28 clearly identified and justified by the user.

29 The RVISL calculator provides updated guidance for developing screening levels (SLs) or
 30 preliminary remediation goals (PRGs) for indoor radon-222, radon-220, and radon-219 that are

31 risk- or dose-based and for showing compliance with the UMTRCA indoor radon standards for
32 radon-222 and radon-220. The RVISL, therefore, supersedes the risk assessment approach in
33 Preliminary Remediation Goals for Radionuclides in Buildings ([BPRG](#)) electronic calculator, the
34 dose assessment approach in ARAR Dose Compliance Concentrations Goals for Radionuclides in
35 Buildings ([BDCC](#)) electronic calculator, and Q17 of the guidance document "[Radiation Risk
36 Assessment At CERCLA Sites: Q & A](#)" issued on May 2014. Computer codes such as the RVISL,
37 which were developed to predict potential human exposure from radon concentrations in indoor
38 air, are based on simplified equations and assumptions and are highly imprecise for an individual
39 house or structure. EPA would recommend, where possible, Regions use measurements of radon
40 indoors rather than rely on the transport portions of the RVISL. In particular, testing of
41 groundwater or soil gas is not required to demonstrate compliance with RVISL WL, pCi/L, risk, or
42 dose targets.

43 Users should note that since background radon levels are typically outside the risk range, the
44 RVISL calculator is likely to be used primarily for ARAR compliance. For example, the UMTRCA
45 indoor radon standards 40 CFR 192.12(b)(1) and 192.41(b) were identified as likely Federal ARARs
46 for Rn-222 and Rn-220 in Attachment A of the EPA guidance document "Establishment of Cleanup
47 Levels for CERCLA Sites with Radioactive Contamination." There are some state standards
48 expressed in pCi/l or mrem/yr that, if more stringent than the UMTRCA standards, may be
49 selected as ARARs.

50 **Introduction**

51 Superfund sites are addressed under the authority of the Comprehensive Environmental
52 Response, Compensation, and Liability Act (CERCLA) of 1980, which was amended by the 1986
53 Superfund Amendments and Reauthorization Act. The purpose of this website is to provide a
54 screening level calculation tool to assist risk assessors, remedial project managers, and others
55 involved with risk assessment and decision-making at CERCLA sites in developing or refining
56 screening levels.

57 Rn-222 is commonly referred to radon because of its parent radium-226. Rn-220 is commonly
58 called thoron because of its parent thorium. Rn-219 is commonly called actinon because of its
59 parent actinium. Click the decay chain link to see the decay series for [Rn-222](#), [Rn-220](#), and [Rn-219](#).
60 The metal groups in these images are based on [Los Alamos National Laboratory](#) literature. See
61 section 2.2 of the User's Guide to learn what progeny are evaluated in this web calculator. More
62 details about the decay chains can be found in the EPA's [Decay Chain](#) Tool.

63 This tool is based on the [Technical Guide for Assessing and Mitigating the Vapor Intrusion
64 Pathway from Subsurface Vapor Sources to Indoor Air \(June 2015\)](#). Vapor intrusion occurs when
65 there is a migration of vapor-forming chemicals or radon from any subsurface source into an
66 overlying building. Recognition of soil vapor intrusion to buildings and other enclosed spaces
67 occurred in the 1980s with concerns over radon intrusion. Subsequently, there was an increasing
68 awareness that anthropogenic chemicals (e.g., petroleum hydrocarbons and chlorinated

69 solvents) in soil, groundwater, and sewers and drainlines could also pose threats to indoor air
70 quality via the vapor intrusion pathway.

71 The RVISL calculator results were previously verified. The documentation from these may be seen
72 on the [Internal Verification](#) and [External Verification](#) pages. The RVISL calculator was also
73 previously peer reviewed, and the documentation of the review may be seen [here](#).

74 Chemicals are not addressed on this website. For chemical vapor intrusion, please go to [EPA's](#)
75 [Vapor Intrusion Screening Level Calculator](#).

76 Note: No consideration is given to ecological effects in the values presented in this calculator.

77 **Frequently Asked Questions**

78 **This page presents many questions asked by site users and the applicable responses. Please**
79 **search this page for answers to your questions prior to contacting technical support staff.**
80 **Researching the questions and answers posted here will greatly reduce the time it takes for**
81 **you to solve many problems that arise from calculating and using this SL site.**

82 1. [What are RVISLs? How are they used?](#)

83 RVISLs are preliminary remediation goal concentrations for groundwater, soil gas (sub-
84 slab and exterior), and indoor air to assist Agency staff with making a vapor intrusion
85 determination based on limited, initial data.

86 2. [How can I change attenuation factors?](#)

87 To change the attenuation factors, run the [calculator](#); the main page has editable cells
88 with the default factors presented.

89 The screening levels for groundwater and soil gas (either sub-slab gas or soil gas
90 collected exterior to buildings) are calculated from the target indoor air concentrations
91 using empirically-based conservative "generic" attenuation factors that reflect
92 generally reasonable worst-case conditions, as described in the EPA's vapor intrusion
93 guidance.

94 A critical assumption for this generic model is that site-specific subsurface
95 characteristics will tend to reduce or attenuate soil gas concentrations as vapors
96 migrate upward from the source and into overlying structures. Specific factors that may
97 result in relatively unattenuated or enhanced transport of vapors into a building
98 include the following:

- 99 ○ Significant openings to the subsurface that facilitate soil gas entry into the building
100 (e.g., sumps, unlined crawl spaces, earthen floors) other than typical utility
101 penetrations.

- 102 ○ Very shallow groundwater sources (e.g., depths to water less than five feet below
103 foundation level)
- 104 ○ Significant routes for preferential, subsurface vapor migration whether naturally
105 occurring (e.g., fractured bedrock) or anthropogenic.

106 The factors listed above may negate the appropriate application of the recommended
107 attenuation factors and the sub-slab, groundwater, and soil gas VISLs for purposes of
108 identifying sites or buildings unlikely to pose a health concern through the vapor
109 intrusion pathway. On the other hand, further evaluation of the vapor intrusion
110 pathway is still appropriate when the sub-slab, groundwater, and soil gas VISLs are
111 exceeded for samples from a building or site where these specific factors are present.

112 Vapor source types that typically make the use of the recommended attenuation
113 factors and health-based VISLs for groundwater and soil gas inappropriate include:

- 114 ○ Those originating in landfills where methane is generated in sufficient quantities to
115 induce advective transport in the vadose zone.
- 116 ○ Those originating in commercial or industrial settings where vapor-forming chemicals
117 can be released within an enclosed space and the density of the chemicals' vapor may
118 result in significant advective transport of the vapors downward through cracks and
119 openings in floors and into the vadose zone.
- 120 ○ Leaking vapors from pressurized gas transmission lines.

121 In each case, the diffusive transport of vapors may be overridden by advective
122 transport, and the vapors may be transported in the vadose zone several hundred feet
123 from the source of contamination with little attenuation in concentration. In general,
124 EPA recommends considering whether the assumptions underlying the generic
125 conceptual model are attained at a given site. If they are not attained, then EPA
126 recommends that the medium-specific VISLs not be relied upon as a line of evidence for
127 identifying sites or buildings unlikely to pose a health concern through the vapor
128 intrusion pathway. Where the assumptions regarding the subsurface attenuation
129 factors do not or may not apply, EPA generally recommends collecting indoor air
130 samples.

131 3. **Why can't I calculate RVISLs for bulk soil samples?**
132 Consistent with the 2015 OSWER Technical Guide for Assessing and Mitigating the Vapor
133 Intrusion Pathway from Subsurface Vapor Sources, "bulk soil (as opposed to soil gas)
134 sampling and analysis is not currently recommended for estimating the potential for
135 vapor intrusion to pose unacceptable human health risk in indoor air, because of the
136 potential for vapor loss due to volatilization during soil sampling, preservation, and
137 analysis. In addition, there are uncertainties associated with soil partitioning
138 calculations."

139 4. **How can I access the "forward calculator" function?**
140 In addition to calculating screening levels, the [calculator](#) allows the user to input data
141 collected from their site. This data is used to model the indoor air concentration,
142 calculate a chronic daily intake, and present cancer risk. On the [calculator](#) main page,
143 select "Yes" under the section titled "**Predict indoor air concentrations and risk from
144 measured media concentrations?**". A choice will be presented for the user to select
145 between air, soil gas, and groundwater data. "Site-specific" mode is automatically
146 activated, and the user will be prompted to enter their site data.

147 5. **How can I adjust groundwater temperatures?**
148 The main page of the [calculator](#) has a cell where the temperature can be changed from
149 the default of 25 °C.

150 Users are given the option to change the groundwater-soil system temperature from
151 the default of 25°C to a site-specific value. Since the unitless Henry's Law Constant (H')
152 is derived based on the partial pressure of a gas in equilibrium with a liquid and the
153 equilibrium changes when temperature changes, H' is changed to reflect the
154 equilibrium at the given temperature. The equation below illustrates how H' is derived
155 when groundwater temperature is changed. An EPA Fact Sheet describing the process
156 can be found at [https://www.epa.gov/vaporintrusion/fact-sheet-correcting-henrys-law-
157 constant-temperature](https://www.epa.gov/vaporintrusion/fact-sheet-correcting-henrys-law-constant-temperature).

158 6. **How are the results converted to a mass basis?**
159 Appendix B of the [Soil Screening Guidance for Radionuclides Technical Background
160 Document](#) presents a formula for converting PRGs in pCi/g to mg/kg and also a formula
161 for converting pCi/L to mg/L. The equation is reproduced here with similar conversions
162 for mg/m³ and mg/cm².

$$C_{i,a} \text{ (mg/L)} = 2.8 \times 10^{-15} \left(\frac{\text{mg} \cdot \text{mole}}{\text{pCi} \cdot \text{g} \cdot \text{year}} \right) \times A_w \left(\frac{\text{g}}{\text{mole}} \right) \times T_{1/2} \text{ (years)} \times C_{gw} \text{ (pCi/L)}$$

and:

$$C_{i,a} \text{ (mg/m}^3\text{)} = 2.8 \times 10^{-15} \left(\frac{\text{mg} \cdot \text{mole}}{\text{pCi} \cdot \text{g} \cdot \text{year}} \right) \times A_w \left(\frac{\text{g}}{\text{mole}} \right) \times T_{1/2} \text{ (years)} \times C_{sg} \text{ (pCi/m}^3\text{)}$$

where:

A_w is the radionuclide atomic weight and $T_{1/2}$ is the radionuclide half-life.

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165 The derivation of the 2.8×10^{-12} conversion is presented below.

$$2.8 \times 10^{-15} \left(\frac{\text{mg} \cdot \text{mole}}{\text{pCi} \cdot \text{g} \cdot \text{year}} \right) = \left(\frac{1 \times 10^{-12} \text{ Ci}}{\text{pCi}} \right) \times \left(\frac{3.7 \times 10^{10} \text{ nt/s}}{\text{Ci}} \right) \times \left(\frac{31,536,000 \text{ s}}{\text{year}} \right) \times \frac{1}{0.693} \times \left(\frac{\text{atoms}}{\text{nt}} \right) \times \left(\frac{1 \text{ mole}}{6.023 \times 10^{23} \text{ atoms}} \right) \times \left(\frac{1000 \text{ mg}}{\text{g}} \right)$$

where:

nt = nuclear transformations (decays)

$$A \left(\frac{\text{nt}}{\text{year}} \right) = \frac{N \text{ (number of atoms)}}{T_{1/2} \text{ (years)}} \times 0.693 \left(\frac{\text{nt}}{\text{atom}} \right)$$

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168 Combination of the derivation of the conversions with the isotope-specific half life and
169 atomic weight is presented here.

$$C_{i,a} \text{ (mg/L)} = C_{gw} \text{ (pCi/L)} \times \left(\frac{1 \times 10^{-12} \text{ Ci}}{\text{pCi}} \right) \times \left(\frac{3.7 \times 10^{10} \text{ nt/s}}{\text{Ci}} \right) \times \left(\frac{31,536,000 \text{ s}}{\text{year}} \right) \times \frac{1}{0.693} \times \left(\frac{\text{atoms}}{\text{nt}} \right) \times \left(\frac{1 \text{ mole}}{6.023 \times 10^{23} \text{ atoms}} \right) \times \left(\frac{1000 \text{ mg}}{\text{g}} \right) \times A_w \left(\frac{\text{g}}{\text{mole}} \right) \times T_{1/2} \text{ (years)}$$

and

$$C_{i,a} \text{ (mg/m}^3\text{)} = C_{sg} \text{ (pCi/m}^3\text{)} \times \left(\frac{1 \times 10^{-12} \text{ Ci}}{\text{pCi}} \right) \times \left(\frac{3.7 \times 10^{10} \text{ nt/s}}{\text{Ci}} \right) \times \left(\frac{31,536,000 \text{ s}}{\text{year}} \right) \times \frac{1}{0.693} \times \left(\frac{\text{atoms}}{\text{nt}} \right) \times \left(\frac{1 \text{ mole}}{6.023 \times 10^{23} \text{ atoms}} \right) \times \left(\frac{1000 \text{ mg}}{\text{g}} \right) \times A_w \left(\frac{\text{g}}{\text{mole}} \right) \times T_{1/2} \text{ (years)}$$

where:

A_w is the radionuclide atomic weight and $T_{1/2}$ is the radionuclide half-life.

nt = nuclear transformations (decays)

$$A \left(\frac{\text{nt}}{\text{year}} \right) = \frac{N \text{ (number of atoms)}}{T_{1/2} \text{ (years)}} \times 0.693 \left(\frac{\text{nt}}{\text{atom}} \right)$$

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7. How were the UMTRCA working level (WL) standards converted to pCi/L?

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This table depicts the three steps to convert the UMTRCA WL standard to pCi/L. For more discussion on WLs, see the [User's Guide](#) Section 2.8.

Assuming Radon Equilibrium Factor (F_{eq}) = 1		
Rn-222	Rn-220	Rn-219
1 WL = 100 pCi/L	1 WL = 7.5 pCi/L	1 WL = 162 pCi/L
1 WL = 100,000 pCi/m ³	1 WL = 7,500 pCi/m ³	1 WL = 162,000 pCi/m ³
1 WL = 3.7 Bq/L	1 WL = 0.2775 Bq/L	1 WL = 5.994 Bq/L
1 WL = 3,700 Bq/m ³	1 WL = 277.5 Bq/m ³	1 WL = 5,994 Bq/m ³
Assuming Radon Equilibrium Factor (F_{eq}) = 0.4 for Rn-222 and 0.02 for Rn-220		
Rn-222	Rn-220	Rn-219
1 WL = 250 pCi/L	1 WL = 375 pCi/L	Unable to provide conversion due to missing F_{eq} from Federal Guidance for Rn-219.
1 WL = 250,000 pCi/m ³	1 WL = 375,000 pCi/m ³	
1 WL = 9.25 Bq/L	1 WL = 13.875 Bq/L	
1 WL = 9,250 Bq/m ³	1 WL = 13,875 Bq/m ³	
Standardized to 0.02 Working Levels (WL)		
Rn-222	Rn-220	Rn-219
0.02 WL = 5 pCi/L	0.02 WL = 7.5 pCi/L	Unable to provide conversion due to missing F_{eq} from Federal Guidance for Rn-219.
0.02 WL = 5,000 pCi/m ³	0.02 WL = 7,500 pCi/m ³	
0.02 WL = 0.185 Bq/L	0.02 WL = 0.2775 Bq/L	

0.02 WL = 185 Bq/m ³	0.02 WL = 277.5 Bq/m ³	
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177 **Working Level Conversion References**

- 178 ○ David Allen. [Dose Conversion Factors for Radon WLM](#). Centers for Disease Control (CDC),
 179 June 2018.
- 180 ○ Health Physics Society (HPS). [Ask the Experts: Environmental and Background
 181 Radiation - Radon, May 2017.](#)

182 **8. When do I use risk-based versus dose-based versus WL screening level types?**

183 The RVISL calculator is likely to be used primarily for ARAR compliance. For example,
 184 the UMTRCA indoor radon standards 40 CFR 192.12(b)(1) and 192.41(b) were identified
 185 as likely Federal ARARs for Rn-222 and Rn-220 in Attachment A of the EPA guidance
 186 document "Establishment of Cleanup Levels for CERCLA Sites with Radioactive
 187 Contamination." There are some state standards that may be expressed in pCi/l or
 188 mrem/yr that if more stringent than the UMTRCA standards may be selected as ARARs.
 189 Background levels of indoor radon will typically exceed the risk range, and it would
 190 generally not be expected that remediation levels for indoor radon would be risk-based
 191 or based on background. The risk portions of the RVISL can still be used to provide risk
 192 estimates for the ARAR-based remediation levels.

193 **9. When should modelling instead of measurements be used for indoor radon?**

194 Computer codes such as the RVISL, which were developed to predict radon
 195 concentrations in indoor air for potential human exposure based on simplified
 196 equations and assumptions, are highly imprecise for an individual house or structure.
 197 EPA would recommend, where possible, Regions use measurements of radon indoors
 198 rather than rely on the transport portions of the RVISL. In particular, testing of
 199 groundwater or soil gas is not required to demonstrate compliance with RVISL WL,
 200 pCi/L, risk, or dose targets.

201 **10. Why do the Superfund RVISL calculator risk results for 4 pCi/L of Rn-222 in air differ
 202 from the reported ORIA health risks for the same activity?**

203 The RVISL calculator risk results for 4 pCi/L of Rn-222 in air differ from the reported
 204 ORIA health risks for the same activity for several reasons. The first reason for a
 205 difference in the risk results is that the RVISL calculator uses risk coefficients based on
 206 morbidity (getting cancer) from inhalation and submersion exposure routes, while the
 207 ORIA tables are based on mortality (death) from inhalation-induced lung cancer only.
 208 The ORIA [Health Risk of Radon](#) web page reports that for smokers and never-smokers,
 209 the mortality risk from lung cancer of 4 pCi/L of Rn-222 is 62 out of 1,000 people and 7
 210 out of 1,000 people, respectively, or 6.2×10^{-2} and 7×10^{-3} . Given in the scientific notation
 211 format used in the RVISL, this relates to a lung cancer mortality risk of 6.2E-02 and 7E-
 212 03, respectively. The RVISL residential risk results for a combination of smokers and

213 never-smokers to 4 pCi/L of Rn-222 in air is 8.39E-02, which rounds to 8.4×10^{-2} .
 214 Additionally, the ORIA risk estimates are based on an average population study, where
 215 the individual's exposure parameters are not considered, while the RVISL results are
 216 based on a reasonably maximum exposed (RME) individual. The individual exposure
 217 parameters considered in Superfund assessments include dwelling air exchange rate,
 218 inhalation rates, exposure duration, and resident time indoors.

219 For more information on different methods for making radon inhalation cancer risk
 220 estimates see section 2.3.1 of the User Guide.

221 **11. I noticed the VISL and RVISL use the same attenuation factors. Are the VISL default**
 222 **attenuation factors appropriate for use in the RVISL calculator?**

223 The default VISL attenuation factors are also used in the RVISL. In fact, radon intrusion
 224 studies were the foundation for recognition that chemical vapors also intrude into
 225 buildings and enclosed spaces from soil and groundwater sources ([EPA 1995](#)). It was
 226 also observed that vapor intrusion mitigation remedies suppress both chemical and
 227 radon gasses and that monitoring radon intrusion is a viable surrogate for predicting
 228 chemical intrusion susceptibility in buildings ([EPA 2015](#)). Many studies reported in [EPA](#)
 229 [2012a](#), demonstrate strong correlation between radon and chemical sub-slab soil gas
 230 attenuation factors calculated when the radon and chemicals are uniformly collocated.

231 The default attenuation factors can be substituted for site-specific attenuation factors if
 232 underlying site conditions are known. [EPA 2012b](#) presents site-specific attenuation
 233 factors for sub-slab soil gas, groundwater, and crawlspaces for chemicals. The
 234 attenuation factors are summarized in the following table. The defaults used in the VISL
 235 and RVISL calculators are highlighted. The defaults are based on the 95th percentile and
 236 are appropriate for adjusting an RME scenario. The 50th percentile values would be more
 237 appropriate for a central tendency exposure scenario where a large amount of
 238 sampling data is available to reduce uncertainty in calculating the exposure
 239 concentration or defining nature and extent of the source term.

Subslab Soil Gas Attenuation Factors		
Residence Type	Median (50 th percentile)	95 th Percentile
All residences	3E-03 (0.003)	3E-02 (0.03)*
Residences with basements	3E-03 (0.003)	3E-02 (0.03)
Residences with slab-on-grade	3E-03 (0.003)	1E-02 (0.01)

Groundwater Attenuation Factors		
Scenario	Median (50th percentile)	95th Percentile
All soil types and water depths	7E-05 (0.00007)	1E-03 (0.001)*
Fine soil type	5E-05 (0.00005)	5E-04 (0.0005)
Coarse soil type	1E-04 (0.0001)	1E-03 (0.001)
Very coarse soil type	2E-04 (0.0002)	4E-03 (0.004)
Depth to water < 1.5 m	6E-04 (0.0006)	7E-03 (0.007)
Depth to water 1.5-3 m	1E-04 (0.0001)	2E-03 (0.002)
Depth to water 3-5 m	4E-05 (0.00004)	2E-03 (0.002)
Depth to water > 5 m	5E-05 (0.00005)	6E-04 (0.0006)
Exterior Soil Gas Attenuation Factors		
Scenario	Median (50th percentile)	95th Percentile
All residences	4E-03 (0.004)	3E-01 (0.3)
Crawlspace Attenuation Factor		
Scenario	Median (50th percentile)	95th Percentile
All residences	4E-01 (0.4)	9E-01 (0.9)

*These are the VISL and RVISL defaults.