US EPA Superfund Radon Vapor Intrusion Preliminary Remediation Goal (RAD-VIPRG) Electronic Calculator – 15349

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ABSTRACT

Currently, there is no U.S. EPA guidance on correlating soil or groundwater levels of radon with indoor radon concentrations at Superfund sites. EPA is developing the Radon Vapor Intrusion Preliminary Remediation Goal (RAD-VIPRG) Calculator which is a spreadsheet tool that (1) lists two radon isotopes (Rn-220 and Rn-222) known to pose a potential cancer risk through the inhalation pathway; (2) provides generally recommended risk and Applicable or Relevant and Appropriate Requirements (ARAR) based preliminary remediation goals (PRG) for groundwater, soil gas (exterior to buildings and sub-slab) and indoor air for default target risk and ARAR based levels and exposure scenarios; and (3) allows calculation of site-specific PRGs based on user-defined target risk and ARAR levels and exposure scenarios. EPA developed the RAD-VIPRG calculator to help risk assessors, remedial project managers, and others involved with risk assessment and decision making at radioactively contaminated sites.

INTRODUCTION

EPA is developing the Radon Vapor Intrusion Preliminary Remediation Goal (RAD-VIPRG) Calculator which is a spreadsheet tool that (1) lists two radon isotopes (Rn-220 and Rn-222) known to pose a potential cancer risk through the inhalation pathway; (2) provides generally recommended risk and Applicable or Relevant and Appropriate Requirements (ARAR) based preliminary remediation goals (PRG) for groundwater, soil gas (exterior to buildings and sub-slab) and indoor air for default target risk and ARAR based levels and exposure scenarios; and (3) allows calculation of site-specific PRGs based on user-defined target risk and ARAR levels and exposure scenarios. The RAD-VIPRG Calculator can assist Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) remedial project managers (RPMs) and on-scene coordinators (OSCs), as well as Resource Conservation and Recovery Act (RCRA) project managers in determining whether the vapor intrusion pathway has the potential to pose an unacceptable level of risk to human health or exceed ARARs by comparing subsurface or indoor data for radon against the PRGs provided in the Calculator. The PRGs in the Calculator are not intended to be used as cleanup levels, nor are they intended to supersede existing criteria of the lead regulatory authority.

METHODS

The RAD-VIPRGs are calculated using the recommended approaches in existing guidance and are based on current understanding of the vapor intrusion pathway. For Rn-222, target indoor air concentrations are calculated according to the guidance provided in "Radiation Risk Assessment

At CERCLA Sites: Q & A" [1], the "Radionuclide Preliminary Remediation Goals (PRG)" electronic calculator [2] and the "Dose Compliance Concentrations (DCC)" electronic calculator [3].

Risk and Dose Assessment

The screening levels for groundwater and soil gas (either sub-slab gas or soil gas collected exterior to buildings) are calculated from the target indoor air concentrations using empirically-based conservative "generic" attenuation factors that reflect generally reasonable worst-case conditions as described in the EPA's draft vapor intrusion guidance [4]. The default, generic RAD-VIPRGs in this calculator are based on default exposure parameters and factors that represent Reasonable Maximum Exposure (RME) conditions for long-term/chronic exposures from either the PRG calculator when a risk based, or the DCC calculator when a dose based, ARAR exists at the site.

UMTRCA as an ARAR

The calculator also includes target levels based on the indoor radon standards of 0.002 Working Levels established under the Uranium Mill Tailings Radiation Control Act (UMTRCA) that are in 40 CFR 192.12(b)(1), which was interpreted in EPA 2014 to correspond to a concentration of 5 picocuries per liter (pCi/L) of Rn-222 or 7.5 pCi/L of Rn-220. These values are based on an indoor residential equilibrium fraction of 0.4 (40%) for Rn-222 and 0.02 (2%) for Rn-220. For the case of secular equilibrium, where the equilibrium fraction is 100%, the corresponding concentrations of Rn-222 and Rn-220 would be 2 pCi/L and 0.15 pCi/L, respectively.

Adjusting for Site-specific Data

Site-specific criteria that can be input to the calculator include exposure scenario (either residential or indoor worker), target risk or dose for radon and average in situ groundwater temperature (stabilized temperature measured during well purging prior to groundwater sampling). The RAD-VIPRG Calculator incorporates the latest slope factors and dose conversion factors in the Preliminary Remediation Goals for Radionuclides tables and will be updated as new versions of the PRG and DCC tables are released

In general, it is recommended that the user consider whether the assumptions underlying the generic conceptual model are applicable at each site, and use professional judgment to make whatever adjustments (including not considering the model at all) are appropriate. Specific factors that may result in unattenuated or enhanced transport of vapors towards a receptor, and consequently are likely to render the RAD-VIPRG screening target subsurface concentrations inappropriate, include:

- Very shallow groundwater sources (for example, depths to water less than 5 feet below foundation level);
- Shallow soil contamination vapor sources (for example, sampled at levels within a few feet of the base of the foundation)

- Buildings with significant openings to the subsurface (for example, sumps, unlined crawlspaces, earthen floors) or significant preferential pathways, either naturally-occurring or anthropogenic (not including typical utility perforations present in most buildings).

DISCUSSION

The RAD-VIPRG Calculator contains seven worksheets:

Navigation Guide: Provides information regarding the Calculator's contents and structure, including a data field dictionary (see "Navigation Guide" tab in the RAD-VIPRG Calculator) that describes each data field and any formulas used to calculate the contents of the data field.

RAD-VIPRG: Main worksheet where the user can enter the exposure scenario and risk information and select radon isotopes to calculate the screening-level values for groundwater, soil gas (sub-slab and exterior soil gas) and indoor air.

SG_IA_calc: Worksheet where the user can enter the exposure scenario and site soil gas (sub-slab and exterior soil gas) concentrations to calculate the indoor air concentrations and the resulting risk values for indoor air.

GW_IA_calc: Worksheet where the user can enter the exposure scenario and site groundwater concentrations to calculate the indoor air concentrations and the resulting risk values for indoor air.

IA_risk_calc: Worksheet where the user can enter the exposure scenario and site indoor air concentrations to calculate resulting risk values for indoor air.

ChemProps: Supporting worksheet that contains a compilation of physical and chemical properties of each radon isotope, which are used in the calculations for the RAD-VIPRG worksheet.

Version Notes: Worksheet to track the changes made in each version of the RAD-VIPRG calculator workbook.

The RAD-VIPRG Calculator allows the user to enter the exposure scenario (residential or indoor worker), target risk for carcinogens and average in situ groundwater temperature, if appropriate. Default values are provided for all these entries. For site-specific exposure scenarios, the worksheet can be unprotected to change the exposure parameters.

The Calculator uses chemical property and toxicity information to determine whether a radon isotope, if present in soil, is sufficiently volatile and toxic to pose an inhalation risk or exceed ARAR levels through vapor intrusion and whether the isotope, if present in groundwater, is sufficiently volatile and toxic to pose an inhalation risk or exceed ARAR levels through vapor intrusion at the selected cancer risk.
For a soil source, a chemical is considered sufficiently volatile and toxic to pose an inhalation risk or exceed ARAR levels through vapor intrusion if the vapor pressure (expressed in terms of vapor

concentration using the ideal gas law) of the pure component is greater than the target indoor air concentration. The soil gas attenuation factor is not considered in this comparison, although it is considered in the subsequent calculation of the target soil gas concentration.

For a groundwater source, a chemical is considered sufficiently volatile and toxic to pose an inhalation risk or exceed ARAR levels 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.

Target Indoor Air Concentration

The target breathing zone indoor air concentrations in the RAD-VIPRG Calculator are risk or ARAR-based screening levels for ambient air, and assume no radioactive decay. The risk indoor air concentrations are calculated following an approach consistent with the EPA's RAGS B [5]. The slope factors used as the basis for the calculations are from the EPA's PRG tables. Risk-based target concentrations are calculated for each radon isotope based on an adult residential exposure scenario and assume exposure of an individual for 350 days per year over a period of 26 years, while ARAR dose based assume an exposure over the year of peak dose and use dose conversion factors in the DCC calculator. The vapor concentrations in the RAD-VIPRG Calculator are given in units of picoCuries per cubic meter (pCi/m^3).

The equation for $C_{ia,inh}$, the inhalation PRG (Column P), is:

$$C_{ia,inh} = \frac{TCR}{SF_{inh} \times IFA} \qquad \text{(Eq.1)}$$

where:

$\quad$ TCR $\quad =\quad$ Target cancer risk (for example, 1.0×10^{-6})
$\quad$ SF_{inh} $\quad =\quad$ Inhalation slope factor $(pCi)^{-1}$
$\quad$ $IFA_{r-adj} =\quad$ Inhalation fraction for age-adjusted receptor (m^3/day)

The inhalation fraction for age-adjusted residents is calculated as follows:

$$IFA_{r-adj} = \left(EF_{r-c} \times ED_{r-c} \times \frac{ET_{r-c}}{24} \times IRA_{r-c}\right) + \left(EF_{r-a} \times ED_{r-a} \times \frac{ET_{r-a}}{24} \times IRA_{r-a}\right) \quad \text{(Eq. 2)}$$

Where:

$\quad$ EF_{r-c} $\quad =\quad$ Exposure frequency for the resident child
$\quad$ EF_{r-a} $\quad =\quad$ Exposure frequency for the resident adult
$\quad$ ED_{r-c} $\quad =\quad$ Exposure duration for the resident child
$\quad$ ED_{r-a} $\quad =\quad$ Exposure duration for the resident adult
$\quad$ ET_{r-c} $\quad =\quad$ Exposure time for the resident child

ET_{r-a} = Exposure time for the resident adult
IRA_{r-c} = Inhalation rate of air for the resident child
IRA_{r-a} = Inhalation rate of air for the resident adult

The inhalation fraction for indoor workers is calculated as follows:

$$IFA_c = \left(EF_c \times ED_c \times \frac{ET_c}{24} \times IRA_c \right) \qquad \text{(Eq. 3)}$$

Where:

EF_c = Exposure frequency for the indoor worker
ED_c = Exposure duration for the indoor worker
ET_c = Exposure time for the indoor worker
IRA_c = Inhalation rate for the indoor worker

The equation for $C_{ia,ee}$, the external exposure PRG (Column Q), is:

$$C_{ia,ee} = \frac{TCR \times \left(\frac{365 days}{year} \right) \times \left(\frac{24 hours}{day} \right)}{SF_{ee} \times EF \times ED \times ET \times GSF_a} \qquad \text{(Eq. 4)}$$

Where:

TCR = Target cancer risk (for example, 1.0×10^{-6})
SF_{ee} = Inhalation slope factor $(pCi)^{-1}$
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
ET = Exposure time (hours/day)
GSF_a = Gamma shielding factor (unitless)

The equation for C_{ia}, the ambient air PRG based on both inhalation and submersion external exposure (Column R) is:

$$C_{ia} = \frac{1}{\left(\frac{1}{C_{ia,inh}} \right) + \left(\frac{1}{C_{ia,ee}} \right)} \qquad \text{(Eq. 5)}$$

Target Sub-Slab and Exterior Soil Gas Concentration Corresponding to Target Indoor Air Concentration (Column G)

The target soil gas concentration corresponding to an isotope's target indoor air concentration at the selected target cancer risk is calculated by dividing the indoor air concentration by the generic attenuation factor of 0.1.

$$C_{soil-gas} = \frac{C_{target,ia}}{AF_{ss}} \qquad \text{(Eq. 6)}$$

where:

$C_{soil\text{-}gas}$ =	Target soil gas concentration [$\mu g/m^3$]	
AF_{ss} =	Attenuation factor (ratio of indoor air concentration to sub-slab or soil gas concentration; default value is 0.1)	

Target Groundwater Concentration Corresponding to Target Indoor Air Concentration (Column H)

The target groundwater concentration corresponding to an isotope'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 so that:

$$C_{gw} = \frac{C_{target,ia}}{HLC \times AF_{gw} \times \left(\frac{1000\,L}{m^3}\right)} \qquad \text{(Eq. 7)}$$

where:

C_{gw} =	Target groundwater concentration (micrograms per liter [pCi/L])	
$C_{target,ia}$ =	Target indoor air concentration (pCi/m^3)	
AF_{gw} =	Attenuation factor (ratio of indoor air concentration to groundwater concentration; the default value is 0.001)	
HLC =	Dimensionless Henry's Law Constant at the specified groundwater temperature [(milligrams per liter (mg/L) – vapor)/(mg/L – H_2O)]	

The following equation can be used to calculate the Henry's Law Constant at a groundwater temperature of 25 degrees Celsius:

$$H'25 = \frac{Hc25 \times \left(\frac{1000\,L}{m^3}\right)}{R \times (298.15\,K)} \qquad \text{(Eq. 8)}$$

where:

$H'25$ =	Dimensionless Henry's Law Constant at 25 degrees Celsius	
$Hc25$ =	Henry's Law Constant at 25 degrees Celsius (atm-m^3 per mole)	
R =	Universal gas constant (0.082057 L-atm/mol-degrees Kelvin)	

6

For groundwater temperatures other than 25 degrees Celsius, the following equation is used to calculate Henry's Law Constant:

$$H'T_{gw} = Hc25 \times exp\left[\left(\frac{DH_{v,b}}{RC}\right) \times \frac{\left(1-\frac{T_{gw}}{T_{crit}}\right)}{\left(1-\frac{T_{boil}}{T_{crit}}\right)}\right]^n \times \left[\left(\frac{1}{T_{gw}}\right) - \left(\frac{1}{298.15\,K}\right)\right] \qquad \text{(Eq. 9)}$$

where:

H'T$_{gw}$	=	Dimensionless Henry's Law Constant at the groundwater temperature
Hc25	=	Henry's Law Constant at 25 degrees Celsius (atm-m^3 per mole)
DH$_{v,b}$	=	Enthalpy of vaporization at the normal boiling point (cal/mol)
RC	=	Universal gas constant (1.9872 cal/mol-K)
T$_{gw}$	=	Groundwater temperature (degrees Kelvin)
T$_{crit}$	=	Critical temperature (degrees Kelvin)
T$_{boil}$	=	Normal boiling point (degrees Kelvin)
n	=	If (T$_{boil}$/T$_{crit}$ < 0.57), n = 0.3
		If (T$_{boil}$/T$_{crit}$ > 0.71), n = 0.41
		If (0.57 < T$_{boil}$/T$_{crit}$ ≤ 0.71), n = (0.74 x T$_{boil}$/T$_{crit}$ - 0.116)

The temperature assumed for each isotope is listed as the temperature for groundwater vapor concentration. For informational purposes, the calculated groundwater target concentration is compared with the ARAR for the isotope.

CONCLUSIONS

The RAD-VIPRG Calculator will facilitate the risk assessment process and remediation of Superfund remedial sites with potential indoor radon issues from radium or thorium contamination in soil or groundwater.

REFERENCES

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