Appendix 3.5-A

Human Exposure Potential Unit Concentrations

APPENDIX 3.5-A – HUMAN EXPOSURE POTENTIAL FROM CONSTITUENTS OF CONCERN AT UNIT CONCENTRATIONS

1 CONSTITUENT OF CONCERN-INDEPENDENT EQUATIONS

Calculations of parameters that are independent of elemental composition are shown below for nominal concentrations of constituents of concern (COCs). Calculations using parameters that are element- or radionuclide-specific are shown in each COC section herein.

1.1 Direct Ingestion of Groundwater

Estimated COC intake to a resident from direct ingestion of a unit concentration of COC in groundwater is as follows:

Intake, $I_W = C_w * I_D * 365$ day/yr = 1.0 Bq/L * 1.28 L/day * 365 day/yr = 466 Bq/yr

where
- I_W= Resident COC intake due to ingestion of groundwater (Bq/yr)
- C_w = COC concentration in well water (1 Bq/L)
- I_D = Adult intake of water (1.28 L/day) (EPA, 2019)

1.2 Buildup of COC in Soil

The use of impacted well water to irrigate could lead to increased COC concentrations in the surface soil and uptake in both vegetables and forage. The average daily buildup of a given COC in soil at a nominal (1.0 Bq/L) concentration in groundwater can be calculated as follows using generic irrigation parameter values from NCRP 123 (1996):

I_S = [IR (L/m^2/day) * C_{GW} (Bq/L)* IP (day/yr)]/[MD (cm) * ρ (g/cm^3)* 365 day/yr *1E4 cm^2/m^2] = 9.13 E-6 Bq/g/day

where
- I_S = Input to soil (Bq/g)
- IR = Rate of irrigation (5 L/m^2/day),
- MD = Soil mixing depth (15 cm),
- IP = Irrigation period (150 day/yr),
- ρ = Soil density (1.5 g/cm^3).

Each year of irrigation will add to the accumulation of COCs in soil. Leaching and plant uptake will remove a given COC from the soil. Over time the COC concentration in soil will increase to an equilibrium level as follows:

$C_{Seq} = I_S \lambda_S^{-1}$ = 9.13E-6 Bq/g/ d/2.70E-5/day = 3.38E-01 Bq/g

Where
- C_{Seq} = Soil concentration at equilibrium (Bq/g),
- λ_S = Soil removal constant (leaching and uptake) (i.e., the fraction of COC present that is removed per day) = 2.70E-5/day (NCRP, 1996).

Over the course of the 30-year duration of this analysis, the soil concentration will build up to:

$C_S = C_{Seq} * (1-e^{-\lambda t})$ = 3.38E-01 Bq/g $(1 - e^{-9.86E-3 * 30})$ = 8.66E-2 Bq/g, The COC concentration in soil will be used for subsequent calculations of dose and risk from eating irrigated vegetables and beef.

2 COC-DEPENDENT EQUATIONS

Equations are shown below for calculating dose and risk for a nominal concentration of COC at 1 Bq/L for radioactive constituents and 1 ug/L for non-radioactive constituents. Results may be scaled up or down depending on the measured or modeled concentration in well water.

2.1 Calculation of Potential Radiation Dose and Risk from Drinking Impacted Groundwater

Drinking impacted well water is the primary exposure pathway and can result in potential radiation dose and possible increased risk of cancer to the resident gardener as well as other toxicological effects. Doses and possible radiogenic risks for a radioactive constituent is calculated using the following equations. Systemic toxicity is addressed in Section 4.

As described in Section 1.1, for a nominal concentration of COC, intake to a resident from direct ingestion of groundwater is 466 Bq/yr

The potential dose to a resident gardener from is as follows:

$D_W = I_W * DCF_{COC,}$

where	D_W =	Dose from drinking well water (mrem/yr)
	I_W =	Resident COC intake (466 Bq/yr) and
	DCF_{COC} =	Isotopic dose conversion factor.

Using risk coefficients from Federal Guidance Report No. 13 (EPA, 1998), the thirty-year lifetime mortality risk to a resident from drinking water would calculated as follows:

$Risk = I_W * T * RCF_{COC}$,

where	I_W =	Resident COC intake (466 Bq/yr),
	RCF_f =	Isotopic mortality risk coefficient factor and
	T =	Duration of residence (30 y).

The thirty-year morbidity risk to resident from drinking water would be calculated as follows:

$Risk = I_W * T * RCF_m$,

where	I_W =	COC intake from drinking water (466 Bq/yr),
	RCF_{COCm} =	Isotopic morbidity risk coefficient factor, and
	T =	Length of consumption period (30 y).

As noted above, the risks and doses calculated based on a nominal uranium concentration of 1 Bq/L, can be prorated upward or downward linearly with concentration.

2.2 Calculation of Potential Radiation Dose and Risk to Resident from Irrigated Vegetables

An irrigated garden would subject the vegetables to both contamination from external deposition of sprayed water and from uptake of uranium from the soil. Sprayed vegetables would be likely be eaten after washing. That being the case, deposition of sprayed irrigation water or soil on the surface of the vegetables is not considered in this analysis. Vegetables grown on soil that has been irrigated over a period of 30 years could uptake some uranium. Radioactive constituent concentrations in vegetables grown on irrigated soil is given by the equation:

$C_{veg} = C_S * CF_{Veg}$

where C_{veg} = concentration of a constituent in vegetation (Bq/kg plant),
C_S = concentration of COC in soil calculated as shown in section 3.2.1.2. and
CF_{Veg} = isotopic concentration factor for plant update (Bq/kg plant per Bq/kg soil).

Because of the 30-year buildup of a constituent in soil, this isotopic concentration in vegetables would likely be the maximum.

EPA's Exposure Factor Handbook (EPA, 2011) Table ES-1 lists vegetable consumption at 53.7 kg/yr for a resident aged 40 to 49 years. It is assumed that the residents would obtain one half of their annual vegetable consumption from home-grown sources for a total consumption of 27 kg/yr. The potential dose to a resident from eating homegrown, irrigated vegetables containing a COC is shown below:

D_{Veg} = 27 kg/yr * C_{Veg} * DCF * 1 E5 mrem/Sv,
where D_{Veg} = Dose from eating vegetables (mrem/yr)
C_{veg} = Concentration in vegetables (Bq/kg plant), and
DCF = Isotopic dose conversion factor (Sv/Bq).

Elemental intake from eating vegetables, I_{Veg} in Bq/yr is equivalent to 27 kg/yr * C_{veg},. Using foodstuff risk coefficients from Federal Guidance Report No. 13 (EPA, 1998), the thirty-year lifetime mortality risk to a resident from eating vegetables irrigated with well water would be:

Risk = I_{Veg} * T * $RCF_{f,}$
where I_{Veg} = Resident COC (Bq/yr),
RCF_f = Isotopic mortality risk coefficient factor (per Bq) and
T = Length of consumption period (30 y).

Thirty-year lifetime morbidity risk to resident from eating vegetables is calculated by:

Risk = I_{Veg} * T * RCF_m ,
where I_{Veg} = COC intake,
RCF_m = Isotopic morbidity risk coefficient factor (per Bq) and
T = Length of consumption period (30 year).

2.3 Calculation of Potential Dose and Risk to Resident from Bathing with Groundwater

There is limited data on the dermal absorption of either uranium, radium or thorium. The potential for uranium, radium and thorium to be absorbed through the skin during bathing is assumed to be negligible.

2.4 Calculation of Potential Dose and Risk to Resident from Radon due to Domestic Uses of Groundwater

The use of groundwater for showering and other domestic used could lead to the inhalation of radon-222, due to the presence of radium-226 in groundwater.

Radon at a given concentration in water used domestically adds on average 1/10,000 as much to the air concentration (National Research Council, 1999) in an indoor/domestic environment. Assuming that radon-222 is in equilibrium with the radium-226 in groundwater, then groundwater with a radium-226 concentration of 1 Bq/L will on average increase the air radon-222 concentration by 1E-4 Bq/L.

The concentration of radon-222 in indoor air due to domestic groundwater use can be calculated as follows, assuming a nominal concentration of 1 Bq/L:

$C_{AIR} = 1E\text{-}4 * C_W$

where C_{Air} = Concentration of radon-222 in indoor air (Bq/L),
C_W = Concentration of radium-226 in well water (1 Bq/L).

The inhalation dose from exposure to radon is primarily due to short-lived radon daughter progeny, and so it is the amount of radon daughter exposure that is used to calculate risk and dose to people. The Working Level is the unit used to describe the quantity of radon daughter exposure.

EPA's Assessment of Risks from Radon in Homes (EPA, 2003) reports the risk due to radon daughter exposure as 5.38E-4 per Working Level Month (WLM). Further, assuming people spend 70% of their time indoors and that the equilibrium fraction between radon and its daughters is 40 percent, 1 pCi/L of radon gas results in a radon daughter exposure of 0.144 WLM/yr (EPA, 2013). Using the radon daughter exposure risk coefficient discussed above the 30-year lifetime mortality risk to a resident from using groundwater for domestic purposes would be:

$Risk = C_{AIR} * 27\ pCi/Bq * Rn_{EXP} * RFC_f * T$

where C_{AIR} = Concentration of radon-222 in indoor air (Bq/L)
Rn_{EXP} = Radon daughter exposure at nominal concentration of 1 pCi/L radon-222 (0.144 WLM/yr)
RCF_f = Mortality risk coefficient factor (5.38E-4 WLM^{-1})
T = Length of exposure period (30 y).

No morbidity risk coefficients are available for radon exposure, the morbidity risk coefficient factor for radon exposure is assumed to be 10% greater than the mortality risk coefficient. Therefore the 30-year lifetime morbidity risk to a resident using groundwater for domestic purposes would be:

$Risk = C_{AIR} * 27\ pCi/Bq * Rn_{EXP} * RFC_f * T$

where C_{AIR} = Concentration of radon-222 in indoor air (Bq/L)
Rn_{EXP} = Radon daughter exposure at nominal concentration of 1 pCi/L radon-222 (0.144 WLM/yr)
RCF_f = Morbidity risk coefficient factor (5.92E-4 WLM^{-1})
T = Length of exposure period (30 y).

The annual dose associated with exposure to a Working Level Month to a member of the general public is listed in ICRP 65 (ICRP, 1993). The potential dose to a resident from inhaling the potential radon-222 produced by domestic use of groundwater with a nominal concentration of radium-226 would be calculated as follows:

$D_{Inh} = C_{AIR} * 27\ pCi/Bq * Rn_{EXP} * DCW * T$

where C_{AIR} = Concentration of radon-222 in indoor air (Bq/L)

Rn_{EXP} = Radon daughter exposure at nominal concentration of 1 pCi/L radon-222 (0.144 WLM/yr)

DCF = WLM dose conversion factor for public (3.88E-3 Sv/WLM).

3 CARCINOGENESIS ESTIMATES

The next few sections will use the previous equations to estimate the potential dose and risk cancer from each potentially carcinogenic constituent using a nominal concentration of 1 Bq/L for radionuclides. Radiation doses are calculated on an annual basis. Risk factors are tabulated based on a potential residence duration of 30 years. The equations above are modified for a different unit concentration of 1E-3 mg/L for arsenic. No other COCs have been identified as being carcinogenic.

In the present exposure scenario, the only reasonable vector is ingestion of well water containing the COC of interest. The dose and risk are directly proportional to the COC concentration in groundwater and may be scaled upward or downward depending on the predicted groundwater concentration. As noted in section 3.1.2.3, exposure parameter values are taken from NRCP Report No. 123 (1996), *Screening Models for Releases of Radionuclides to the Atmosphere, Surface water and Ground*, and the EPA *Exposure Factors Handbook* (2019), unless otherwise noted. Due to the long half-life of each radionuclide half-life of each nuclide, calculations do not include decay corrections.

Predicted doses and cancer risks from unit intake of radionuclides in water are summarized in Table App3.5A-1.

3.1.1 Radium-226 + Radium-228

The hazardous constituent listed as radium-226 + radium-228 consists of two isotopes of radium each with specific dose conversion factors. However, the two isotopes are reported jointly and, the radiation doses are calculated using the dose conversion coefficients for radium-226 only. It is assumed that the contribution of radium-228 to the radium source term is not likely to constitute a significant fraction of because it is a decay product of thorium-232 and is not part of the uranium-238 decay series.

Dose for the combined isotopes is calculated on an annual basis and the cancer risk factors are tabulated based on a potential residence duration of 30 years.

Using the equations and parameters described above, estimated doses and cancer risks were calculated for a unit concentration (1 Bq/L) of radium-226 in well water as shown in Table App3.5A-1. The total dose of 20.2 mrem/yr was dominated by the dose from the drinking water pathway that accounted for 83 percent of the total dose. Dose from eating home-grown vegetables accounted for 17 percent or the dose and radon inhalation from domestic water use contributing less than 1 percent of the total.

Likewise, the total 30-year risk estimates for mortality and morbidity of 1.3E-04 and 1.9E-04, respectively, were also dominated by the drinking water pathway. Eating irrigated vegetables contributed to about 20 percent of the risk for both mortality and morbidity, while the risk from radon inhalation was less than 1 percent for both factors.

3.2 Thorium-230

Using the equations and parameters described above, estimated doses and cancer risks were calculated for a unit concentration (1 Bq/L) of thorium-230 in well water as shown in Table App3.5A-1. Nearly all (99.4 percent) of the total dose of 6.9 mrem/yr was dominated by the dose from the drinking water pathway. Likewise, the total 30-year risk estimates for mortality and morbidity of 2.4 E-5 and 3.7 E-5, respectively, were also dominated by the drinking water pathway.

3.2.1 Uranium

Using the equations and parameters described above, estimated doses and cancer risks were calculated for a unit concentration (1 Bq/L) of uranium in well water as shown in Table App3.5A-1. The total dose of 3.45 mrem/yr was dominated by the dose from the drinking water pathway that accounted for 98 percent of the total dose. Likewise, the total 30-year risk estimates for mortality and morbidity of 1.72 E-5 and 2.63E-5, respectively, were also dominated by the drinking water pathway.

3.3 Arsenic

With some exceptions, equations used to calculate concentrations in foodstuffs and intakes are the same for arsenic as uranium. Differences include the use of a slope factor to calculate carcinogenic risk rather than a dose conversion factor and subsequent risk factors for radiogenic risk.

3.3.1 Potential Risk to Resident from Drinking Modeled Well Water

Drinking impacted groundwater is a primary exposure pathway and can result in increased risk of cancer to the consuming resident. Arsenic intake to a resident from direct ingestion of the unit groundwater concentration is as follows:

Intake, $I_{As} = C_w * I_w * 365$ day/yr = 8E-3 mg/L * 1.28 L/day * 365 day/yr = 4.61 mg

where
- I_{As} = Resident arsenic intake (mg/yr)
- C_w = Arsenic concentration in well water (8E-3 mg/L)
- I_w = Resident intake of water (EPA, 2011)

Potential development of cancer is the main risk from chronic intake of arsenic in water. ATSDR (2007) quotes an EP-calculated oral cancer slope factor of 1.5 kg/d/mg for inorganic arsenic based on human dose-response data. So, the risk may be calculated as:

Risk = ($C_A * I_W$ * EF * T * SF) / (BW * AT) = (1E-3 * 1.28 * 365 * 30 * 1.5)/ (70 * 30 *365) = 2.7E-5.

Where
- C_{As} = Concentration of As in water (1E-3 mg/L),
- I_W = Water intake (1.28 L/day),
- EF = Exposure frequency (365 day/yr),
- T = Exposure duration (30 yr),
- SF = Slope factor (1.5 $[\text{mg/kg-day}]^{-1}$),
- BW = Body weight (70 kg), and
- AT = Average exposure days (30 yr * 365 day/yr).

3.3.2 Buildup of Arsenic in Soil Through Time

Irrigating with impacted water could lead to increased concentrations in the surface soil and uptake in both vegetables and forage. The average daily increase in arsenic concentration in soil at a modeled groundwater concentration of 1.0E-3 mg/L can be calculated as follows:

$I_S = (IR * C_{GW} * IP)/(MD * \rho * 365 \text{ day/yr} *1 \text{ E4 cm}^2 \text{ m}^{-2}) = 9.1\text{E-9 mg/g}$

Where	I_S =	Intake to soil (mg/g)
	IR =	Rate of irrigation (5 L/m^2/day),
	C_{GW} =	Arsenic concentration in water (1.0E-3 mg/L)
	MD =	Soil mixing depth (15 cm),
	IP =	Irrigation period (150 day/yr),
	ρ =	Soil density (1.5 g/cm^3).

The arsenic in soil will accumulate over time with each added year of irrigation. However, the arsenic will also be removed from the soil by leaching and uptake in plants. The concentration in the soil will increase to an equilibrium level over time as follows:

$C_{Seq} = I_S \ \lambda_S^{-1}$ = 9.1E-9 mg/g/day / 2.70E-5 d^{-1} = 3.4E-4 mg/g

Where C_{Seq} = Soil concentration at equilibrium (Bq/g),
λ_S = Soil removal constant (leaching and uptake) = 2.70E-5 per day (NCRP, 1996).

During the 30-year duration of this analysis, the arsenic concentration in soil will build up to:

$C_S = C_{Seq} * (1-e^{-\lambda t})$ = 3.4E-4 mg/g $(1 - e^{-2.72E-5 * 365 * 30})$ = 8.66E-5 mg/g,

This concentration will be used for subsequent calculations risk from ingesting irrigated vegetables.

3.3.3 Potential Risk from Ingesting Irrigated Vegetables

Spray-irrigated plants grown would be subject to contamination from both external deposition of sprayed water and from arsenic uptake from the soil. Deposition of sprayed irrigation water or soil on the surface of the vegetables is not considered in this analysis, because it is unlikely that sprayed vegetables would be eaten without washing. Vegetables grown on the soil that has been irrigated over a period of 30 years would incorporate some arsenic. Arsenic concentration in vegetables grown on irrigated soil is given by the equation:

$C_{veg} = C_{gw} * CF_{Veg}$ = 8.66E-5 mg/g * 8E-2 * 1E3 g/kg= 6.9E-3 mg/kg plant

Where	C_{veg} =	concentration of arsenic in vegetation (mg/kg plant),
	C_S =	concentration of arsenic in soil (8.66-5 mg/g),

CF_{Veg} = unitless concentration factor for arsenic (0.08 mg/kg plant per mg/Kg soil).

This should be considered a maximum plant concentration because the 30-year concentration of arsenic in the soil was used rather than an average value over that period.

The thirty-year risk to a resident from eating vegetables irrigated with well water would be as follows:

Risk = (C_{veg} * I_V * T * SF) / (BW * AT) = 1.1E-5

Where	C_{veg} =	Concentration of arsenic in vegetables (6.9E-3 mg/kg plant),
	I_V =	Vegetable intake (26.8 kg/yr),
	T =	Exposure duration (30 yr),
	SF =	Slope factor (1.5 [mg/kg-day]$^{-1}$),
	BW =	Body weight (70 kg), and
	AT =	Average exposure days (30 yr * 365 day/yr).

Table App3.5.A-2 presents the summary of cancer risks from unit concentrations of arsenic in well water.

4 SYSTEMIC TOXICITY

Estimates of intake of each hazardous constituent at the unit concentration of 1E-3 mg/L are shown in the succeeding paragraphs and summarized in Table App3.5A-3.

4.1 Arsenic

Assuming the total ingestion of arsenic by the resident gardener from direct water ingestion and ingestion of vegetables raised using groundwater for irrigation, the total daily ingestion rate for a nominal groundwater concentration of 1 E-3 mg/L would be as follows:

Direct water ingestion = 1E-3 mg/L * 1.28 L/day= 1.28E-3 mg/day

Vegetable ingestion = (6.93E-3 mg/Kg * 27 kg/yr)/365 day/yr = 5.1E-4 mg/day

Total daily ingestion of arsenic = 1.79E-3 mg/day.

Assuming a 70 kg adult, the average daily in mg/kg/day = 1.79E-3 mg/day/70 kg = 2.56E-5 mg/kg/day.

The Hazard Quotient (HQ) is the average daily intake divided by the reference dose (RfD). The RfD for arsenic for drinking water ingestion is 3.0E-4 mg/kg/day (ATSDR, 2007). Therefore, for the nominal groundwater concentration of 1E-3 mg/L, the HQ = 2.56E-5 mg/kg/day/3.0 E-4 mg/kg/day = 8.5E-02.

4.2 Boron

Boron and boron compounds have an oral RfD of 0.2 mg/kg/day (IRIS, 2007). This RfD is based on decreased fetal weight in a developmental study in rats exposed to boric acid from gestation days 0 to 20. The 0.2 mg/kg/day value is equivalent to an ATSDR-derived acute duration oral MRL.

Hence, estimated intakes of boron from a unit well-water value of 1E-3 mg/L are as follows. Direct water ingestion = 1E-3 mg/L * 1.28 L/day= 1.28E-3 mg/day. Vegetable ingestion = (8.7E-4 mg/kg * 27 Kg/yr)/365 day/yr = 6.4E-5 mg/day, which leads to total daily ingestion of boron = 1.34E-3 mg/day.

Assuming a 70 kg adult, the average daily in mg/kg/day would = 1.34E-3 mg/day/70 kg = 1.92E-5 mg/kg/day.

The Hazard Quotient (HQ) is the average daily intake divided by the reference dose. Therefore, for the nominal groundwater concentration of 1E-3 mg/L, the HQ = 1.92E-5 mg/kg/day / 0.2 mg/kg/day = 9.6E-5.

4.3 Cadmium

IRIS (2012) has established an RfD for cadmium in water of 5E-4 mg/kg/day with a health endpoint of "*significant proteinuria*." There is also an RfD for the same endpoint of 1E-3 mg/kg/day in food, which is equivalent to the chronic-duration oral exposure. For the purposes of this petition, we will use the lesser values of 5E-4 mg/kg/day .

Cadmium intake from 1E-3 mg/L water = 1E-3 mg/L * 1.28 L/day= 1.28E-3 mg/day. Ingestion of cadmium in irrigated vegetables = (4.3E-2 mg/kg * 27 kg/yr)/365 day/yr = 3.2E-3 mg/day. This leads to a total daily ingestion of cadmium = 4.48E-3 mg/day.

Assuming a 70 kg adult, the average daily in mg/kg/day = 4.48E-3 mg/day/70 kg = 6.4E-5 mg/kg/day.

The Hazard Quotient (HQ) is the average daily intake divided by the reference dose. The RfD for cadmium for tap water ingestion is 5E-4 kg/day (ATSDR, 2012). For the nominal groundwater concentration of 1E-3 mg/L, the HQ = 6.4E-5 mg/kg/day / 5E-4 mg/kg/day = 1.28E-1.

4.4 Chlorine/Chloride

EPA has established a RfD of 0.1 mg/kg/day for oral exposure to chlorine, based on the NOAEL. An estimate of potential risk based on use of water for drinking, irrigation and ingestion of irrigated garden vegetables, leads to the following results.

Direct water ingestion = 1E-3 mg/L * 1.28 L/day= 1.28E-3 mg/day plus ingestion of irrigated vegetables = (1.73 mg/Kg * 27 kg/yr)/365 day/yr = 1.3E-1 mg/day for a total daily ingestion of chloride = 1.8E-1 mg/day. Average daily intake by a 70 kg adult = 1.8E-1 mg/day/70 kg = 2.6E-3 mg/kg/day.

The RfD for chlorine water ingestion with no observed adverse effects is 0.1 mg/kg/day (IRIS, 2007). For the nominal groundwater concentration of 1E-3 mg/L, the HQ = 2.6E-3 mg/kg/day/0.1 mg/kg/day = 2.6E-2.

4.5 Fluorine

Few end points have been examined in humans following acute oral exposure to fluorides. Most available data involved exposure to lethal doses of fluoride; other examined potential targets of toxicity include the gastrointestinal tract, bone, sperm morphology, and the developing organism. A chronic-duration oral MRL of 4E-2 mg fluoride/kg/day was derived for fluoride. (ATSDR, 2003b).

Using the unit well water concentration of 1E-3 mg/L fluoride via ingestion = 1E-3 mg/L * 1.28 L/day= 1.28E-3 mg/day and fluoride ingestion via irrigated vegetables = (1.7E-3 mg/kg * 27 kg/yr)/365 day/yr = 1.3E-4 mg/day for a total daily ingestion of fluoride = 1.41E-3 mg/day.

Assuming a 70 kg adult, the average daily intake = 1.41E-3 mg/day/70 kg = 2.0E-5 mg/kg/day.

The RfD for fluorine water ingestion with an endpoint of hematopoietic effects is 4E-2 kg/day (ATSDR, 2003b). Therefore, for the nominal groundwater concentration of 1E-3 mg/L, the HQ = 2.0E-5 mg/kg/day/4E-2 mg/kg/day = 5.05E-4.

4.6 Molybdenum

Assuming the total ingestion of molybdenum by the resident gardener from direct water ingestion and ingestion of vegetables using groundwater for irrigation, the total daily ingestion rate for the nominal groundwater concentration of 1E-3 mg/L would be as follows:

Direct water ingestion = 1 E-3 mg/L * 1.28 L/day= 1.28E-3 mg/day

Vegetable ingestion = (2.86E-1 mg/Kg * 27 kg/yr)/365 day/yr = 2.1E-2 mg/day

Total daily ingestion of molybdenum = 2.24E-2 mg/day.

Assuming a 70 kg adult, the average daily intake in mg/kg/day = 2.24E-2 mg/day/70 kg = 3.2E-4 mg/kg/day

The Hazard Quotient (HQ) is the average daily intake divided by the reference dose. The molybdenum RfD for residential tap water ingestion is 5E-3 mg/kg/day (ATSDR 2017).

HQ = 3.32E-4 mg/kg/day/5.0 E-3 mg/kg/day = 6.4E-2.

Dermal absorption of molybdenum from water is considered a minor route of intake and is highly dependent on speciation. Therefore, it is not considered in this analysis.

4.7 Nitrate

Assuming the total ingestion of nitrate by the resident gardener from direct water ingestion and ingestion of vegetables raised using groundwater for irrigation, the total daily ingestion rate for a nominal groundwater concentration of 1 E-3 mg/L would be as follows:

Direct water ingestion = 1E-3 mg/L * 1.28 L/day= 1.28E-3 mg/day

Vegetable ingestion = (6.5E- mg/kg * 27 kg/yr)/365 day/yr = 4.8E-2 mg/day

Total daily ingestion of nitrate = 4.9E-2 mg/day.

Assuming a 70 kg adult, the average daily in mg/kg/day = 1.79E-3 mg/day / 70 kg = 7.0E-4 mg/kg/day.

The Hazard Quotient (HQ) is the average daily intake divided by the reference dose. The RfD for nitrate for drinking water ingestion is 4 mg/kg/day (EPA, 1992). Therefore, for the nominal groundwater concentration of 1E-3 mg/L, the HQ = 7.0E-4 / 4 mg/kg/day = 1.75E-4.

4.8 Selenium

Selenium is a naturally occurring trace element. Selenium is essential in humans and animals and is a biologically active part of a number of important proteins. Excessive intake of selenium can cause adverse health effects, but usually at doses much higher than the recommended daily allowance (RDA). Assuming the total ingestion of selenium by the resident gardener from direct water ingestion and ingestion of vegetables or beef raised using groundwater for irrigation, the total daily ingestion rate for the nominal groundwater concentration of 1E-3 mg/L would be as follows:

Direct water ingestion = 1E-3 mg/L * 1.28 L/day= 1.28E-3 mg/day

Vegetable ingestion = (8.66E-3 mg/kg * 27 kg/yr)/365 day/yr = 6.4E-4 mg/day

Total daily ingestion of selenium = 1.92E-3 mg/day

Assuming a 70 kg adult, the average daily in mg/kg/day = 1.92E-3 mg/day/70 kg = 2.74E-5 mg/kg/day.

The Hazard Quotient (HQ) is the average daily intake divided by the reference dose. The selenium RfD for residential tap water ingestion is 5E-3 mg/kg/day with dermal effects as an endpoint (EPA, 1992). Therefore, the HQ = 2.74E-4 mg/kg/day / 5.0E-3 mg/kg/day = 5.5E-03.

Dermal absorption of selenium from water is considered a minor route of intake and is highly dependent on speciation. Therefore, it is not considered in this analysis.

4.9 Vanadium

Vanadium is a naturally occurring element with an average concentration of 100 ppm. Vanadium is an essential trace element in humans and animals and is a biologically active part of a number of important proteins. Assuming the total ingestion of vanadium by the resident gardener from direct water ingestion and ingestion of vegetables or beef raised using groundwater for irrigation, the total daily ingestion rate for a nominal groundwater concentration of 1E-3 mg/L would be as follows:

Direct water ingestion = 1E-3 mg/L * 1.28 L/day= 1.28E-3 mg/day

Vegetable ingestion = (1.73E-4 mg/kg * 27 kg/yr)/365 day/yr = 1.28E-5 mg/day

Total daily ingestion of vanadium = 1.29E-3 mg/day.

Assuming a 70 kg adult, the average daily in mg/kg/day = 1.29E-3 mg/day/70 kg = 1.85E-5 mg/kg/day.

The Hazard Quotient (HQ) is the average daily intake divided by the reference dose. The oral RfD for vanadium in water is 7E-3 mg/kg/ day (EPA, 1987). Therefore, for the nominal groundwater concentration of 1E-3 mg/L, the HQ = 1.85E-5 mg/kg/day/7.0E-3 mg/kg/day = 2.64E-3.

4.10 Combined Radium-226 and Radium-228

The constituent listed as combined radium-226 and radium-228 consists of two isotopes of radium each with specific dose conversion factors.

As stated in ATSDR (1990) referring to oral consumption of radium: "*From the limited available data, it is difficult to determine if hematological effects are a concern for humans exposed to radium. No studies were located regarding hematological effects in animals after oral exposure to radium*."

Further, the reference dose for oral exposure to radium was not assessed by the IRIS program.

4.11 Thorium-230

Thorium-230 is a long-lived natural radioactive isotope. As mentioned in Section 2.2 above, it is difficult to discern whether its toxicity is attributable to its chemical or radiological characteristics. Exposure to thorium compounds in amounts large enough to pose a serious chemical health risk would be expected to pose a radiation health risk as well.

A search of the EPA's Integrated Risk Information System (IRIS, 2022) shows no entries for either thorium or thorium-230. Therefore, no hazard quotient may be calculated for this COC. Studies regarding systemic effects in humans following either acute, intermediate, or chronic duration dermal exposure to either thorium or thorium-230 are nonexistent (ATSDR, 2019). Likewise, no studies were found by ATSDR staff for any duration of exposure of cardiovascular, endocrine, gastrointestinal, hematological, hepatic, or respiratory, effects of thorium in humans.

4.12 Uranium

In addition to its three radioactive isotopes, natural uranium is chemically toxic to the kidneys. Chemical toxicity is the limiting factor and regulatory basis for soluble uranium. A reference dose (RfD) is, in general, based on the lowest observed adverse effect level (LOAEL) or the no observed adverse effect level (NOAEL). A hazard quotient is the ratio of the average daily intake to the reference dose (RfD) derived from animal or human toxicity studies. A safety factor is applied to account for the uncertainty in the studies used and depends on whether the NOAEL or LOAEL is based on human or animal data. The oral RfD for soluble uranium is 3E-3 mg/kg/day.

Assuming the total ingestion of uranium by the resident gardener from direct water ingestion and ingestion of vegetables grown using groundwater for irrigation, the total daily ingestion rate for the nominal groundwater concentration of 1E-3 mg/L would be as follows:

Direct water ingestion = 1E-3 mg/L * 1.28 L/day = 1.28E-3 mg/day

Vegetable ingestion = (1.73E-4 mg/kg * 27 kg/yr)/365 day/yr = 1.27E-5 mg/day

Total daily ingestion of uranium = 1.29E-3 mg/day.

Assuming a 70 kg adult, the average daily dose = 1.29E-3 mg/day / 70 kg = 1.84E-5 mg/kg/day.

The Hazard Quotient (HQ) is the daily dose divided by the reference dose. In this case, the HQ = 1.84E-5 mg/kg/day / 3E-3 mg/kg/day = 6.1E-3.

No studies were found regarding systemic effects in humans following either acute, intermediate, or chronic duration dermal exposure to uranium (ATSDR, 2013). Likewise, there were no studies found for any duration of exposure of cardiovascular, endocrine, gastrointestinal, hematological, hepatic, or respiratory, effects of uranium in animals.

4.13 Summary of hazard quotients from hazard constituents

As shown in Table App3.5A-3, the hazard quotients for unit concentrations of constituents in water range from 9.6E-05 for boron to 1.3E-1 for cadmium.

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Table App3.5A-1 Estimated Unit Dose and Cancer Risk from Radionuclides

Exposure Pathway	Unit Concentration in Well (Bq/L)	Calculated Dose (mrem/yr)	30-year Risk Estimate	
			Mortality	Morbidity
Combined Radium-226 + Radium-228*				
Drinking water	1.00E+00	1.67E+01	1.00E-04	1.5E-04
Eating vegetables	1.00E+00	3.33E+00	2.67E-05	3.9E-05
Radon inhalation -	1.00E+00	1.56E-01	6.28E-06	6.9E-06
Total	--	2.02E+01	1.33E-04	1.91E-04
Thorium-230				
Drinking water	1.00E+00	6.9E+00	2.3E-05	3.4E-05
Eating vegetables	1.00E+00	3.4E-02	1.5E-07	2.2E-06
Total	--	6.9E+00	2.4E-05	3.7E-05
Natural Uranium				
Drinking water	1.00E+00	3.39E+00	1.66E-05	2.5E-05
Eating vegetables	1.00E+00	1.7E-02	2.22E-07	3.4E-07
Total	--	3.41E+00	1.69E-05	2.6E-05

*Used radium-226 dose coefficient for both nuclides

Table App3.5A-2 Cancer risk from Unit Concentration of Arsenic in Well Water

Source	Intake (mg/year)	Risk
Drinking water	4.66E-01	2.74E-05
Eating vegetables	1.86E+01	1.90E-05
Total	1.91E+01	4.64E-05

mg/year - milligrams per year

Table App3.5A-3. Summary of Intakes and Predicted Hazard Quotients from Predicted Maximum Well Water Concentration for Inorganic Constituents

Constituent	RfD (mg/Kg/day)	Intake (mg/day)			Average per adult (mg/Kg/day)*	Hazard Quotient (unitless)
		Water	Vegetables	Total		
Arsenic	3.0E-04	1.3E-03	5.1E-04	1.8E-03	2.56E-05	8.5E-02
Boron	2.0E-01	1.3E-03	6.4E-05	1.3E-03	1.92E-05	9.6E-05
Cadmium	5.0E-04	1.3E-03	3.2E-03	4.5E-03	6.40E-05	1.3E-01
Chlorine	1.0E-01	1.3E-03	1.3E-01	1.8E-01	2.60E-03	2.6E-02
Fluoride	4.0E-02	1.3E-03	1.3E-04	1.4E-03	2.00E-05	5.0E-04
Molybdenum	5.0E-03	1.3E-03	2.1E-02	2.2E-02	3.20E-04	6.4E-02
Nitrate	4.0E+00	1.3E-03	4.8E-02	4.9E-02	7.00E-04	1.8E-04
Selenium	5.0E-03	1.3E-03	6.4E-04	1.9E-03	2.74E-05	5.5E-03
Uranium	3.0E-03	1.3E-03	1.3E-05	1.3E-03	1.84E-05	6.1E-03
Vanadium	7.0E-03	1.3E-03	1.3E-05	1.3E-03	1.85E-05	2.6E-03

*assumes 70 kg body weght

RfD - Reference Dose

mg/day - milligrams per day

mg/Kg/day - milligrams per kilogram per day